Structural degradation of a large composite wind turbine blade in a full-scale fatigue test

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Background

Motivations:

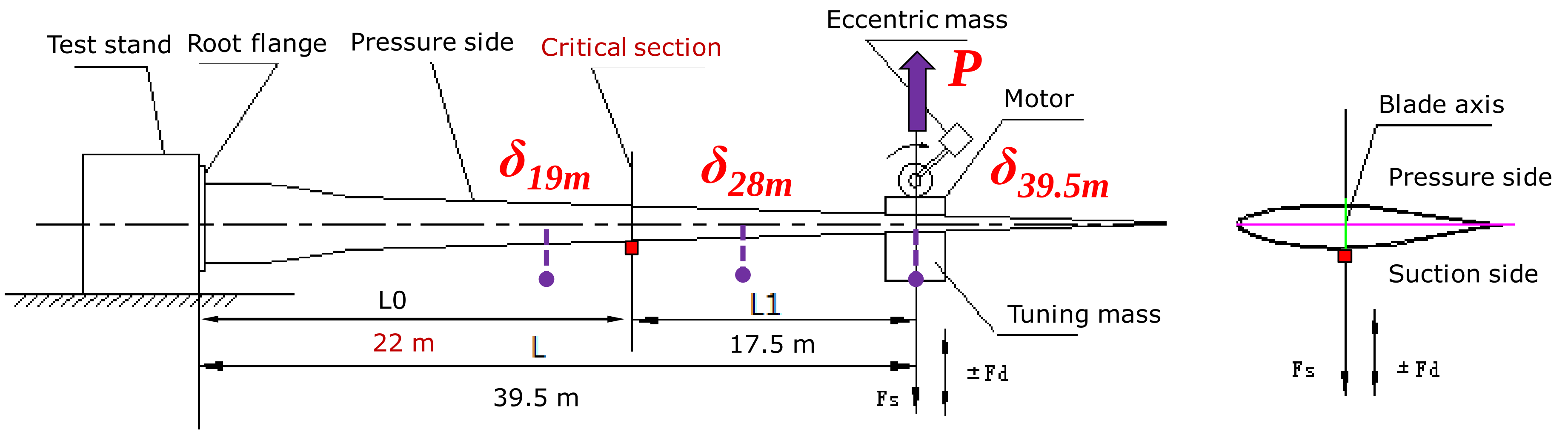
- Wind turbine blades sustain a high number of loading cycles up to a magnitude of 1,000 million during their 20-25 years' service lives.
- Substantial studies have been carried out at a coupon level to characterize fatigue degradation of **materials** particularly of UD composites.
- No much experimental study on fatigue degradation of **rotor blades** at a full-scale structural level.

Problems:

- Do structural properties of rotor blades at a full structural scale degrade in a similar manner to what has been observed in material tests at a coupon level?
- What might be particular concerns one should take into account when predicting fatigue response of rotor blades?

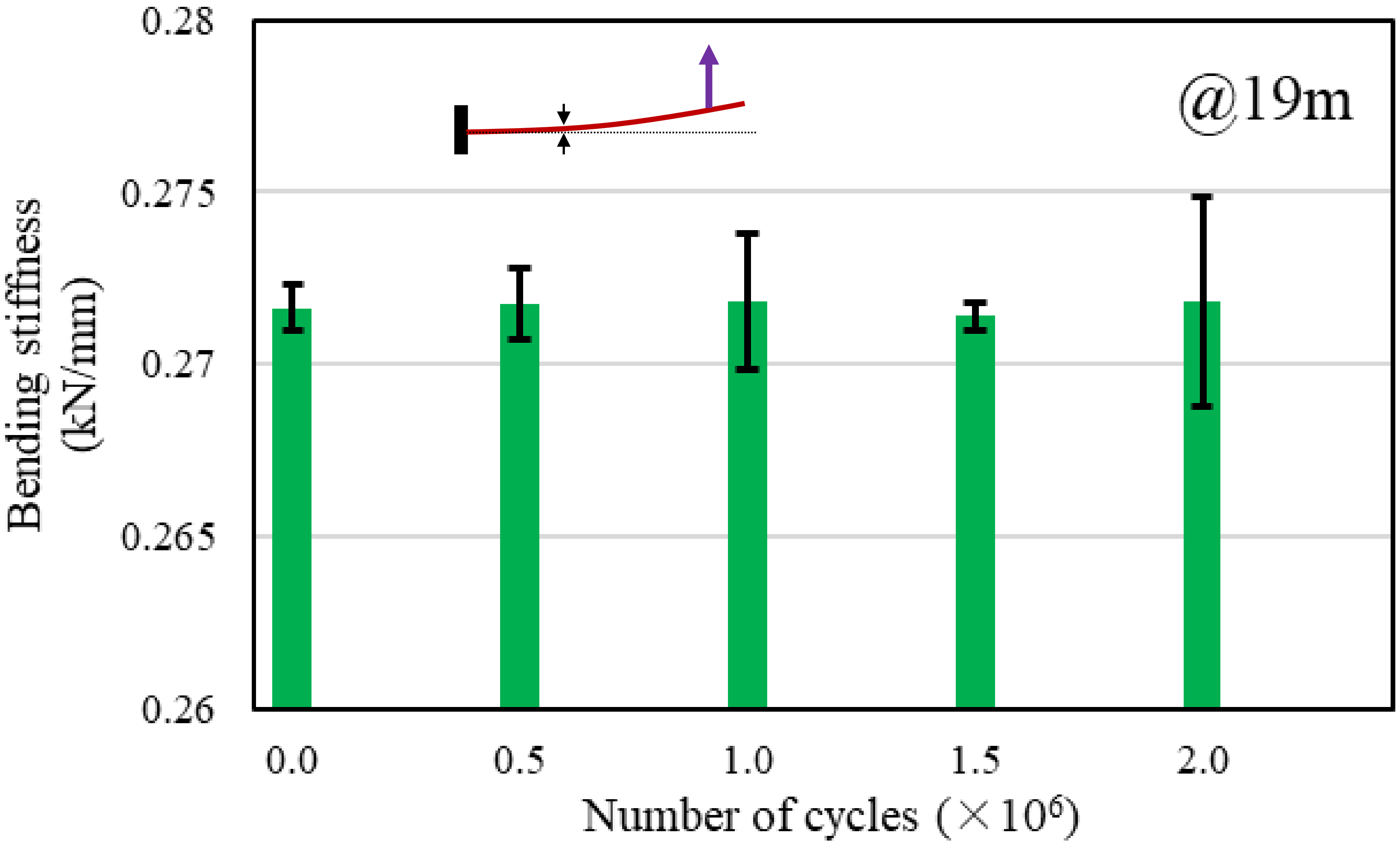
Test setup and measurements

- The blade: 47m, glassfiber/epoxy composites, 2MW, IEC IIA.
- Test standard: IEC 61400-23 (ed. 2014)
- Controlling parameter: -1100 με @22m SS, ***2.0 M cycles with 1st mode***.

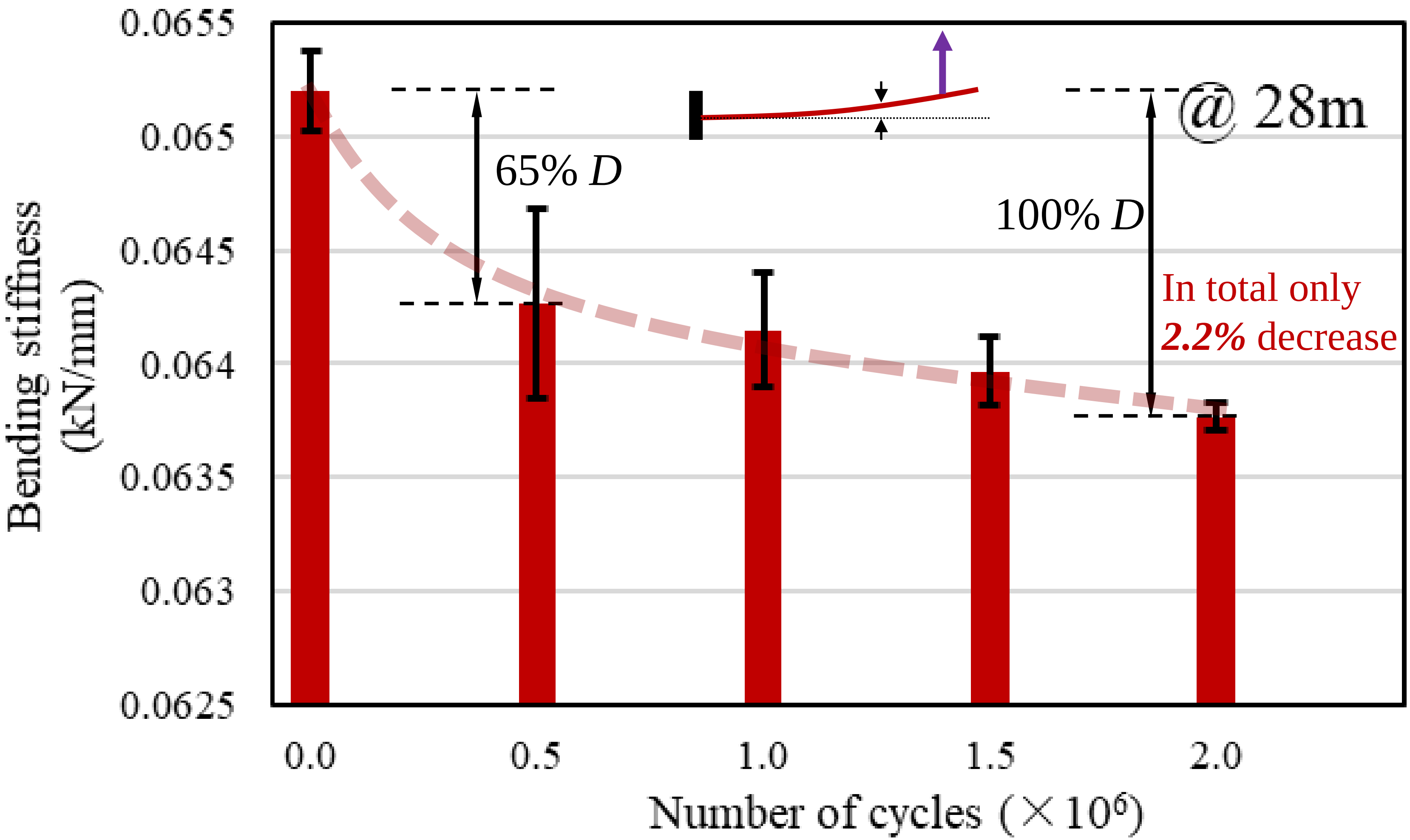


- Strain: ½ bridge SG along SC with temp. compensation.
- ***Bending stiffness (P/δ_i):*** Disp. @19m, 28m and 39.5m with *P* @39.5 m.
- ***Natural frequencies*** and ***damping ratios***: 2 flap-wise, 2 edge-wise modes and 1 torsional mode.

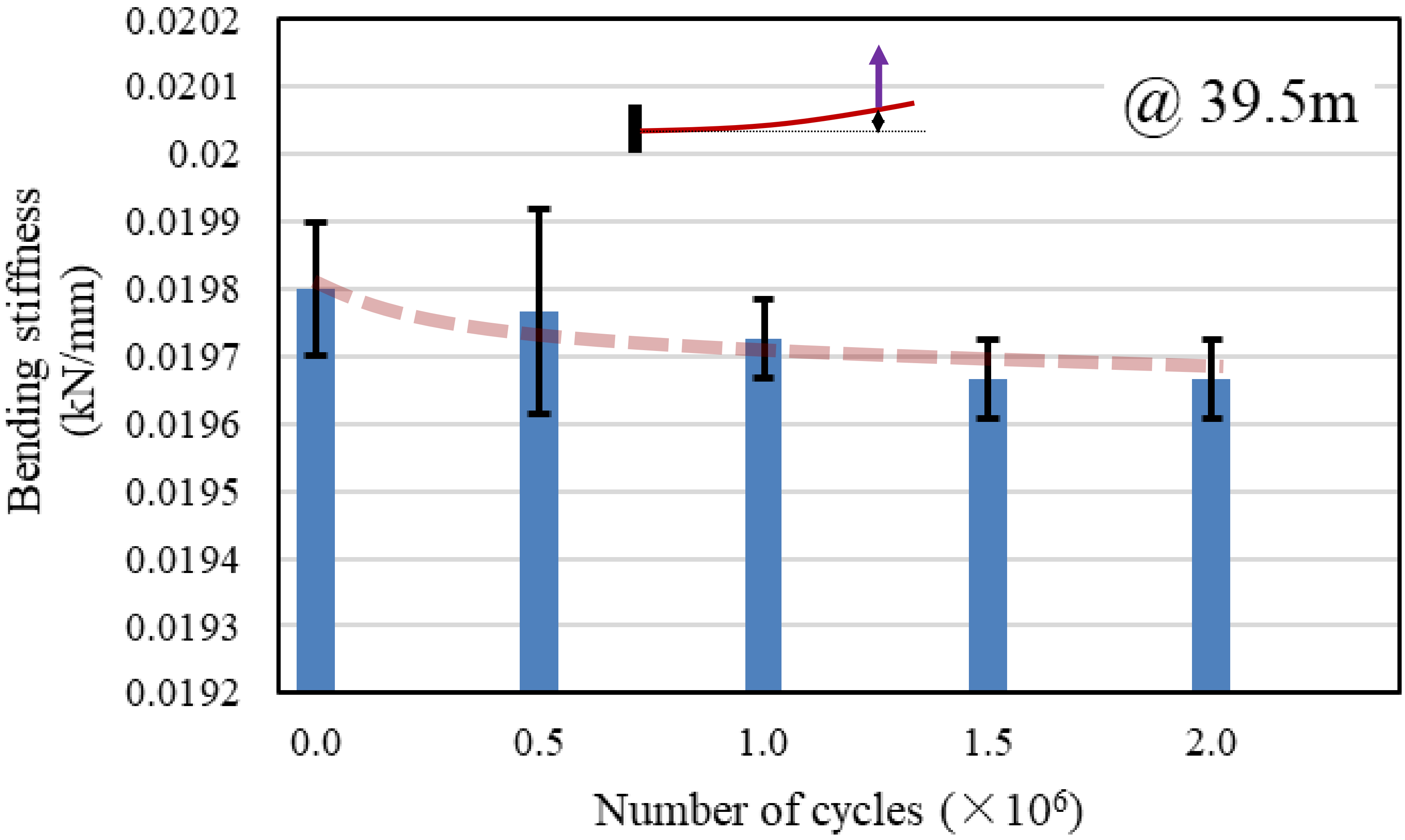
Stiffness degradation @ 19m



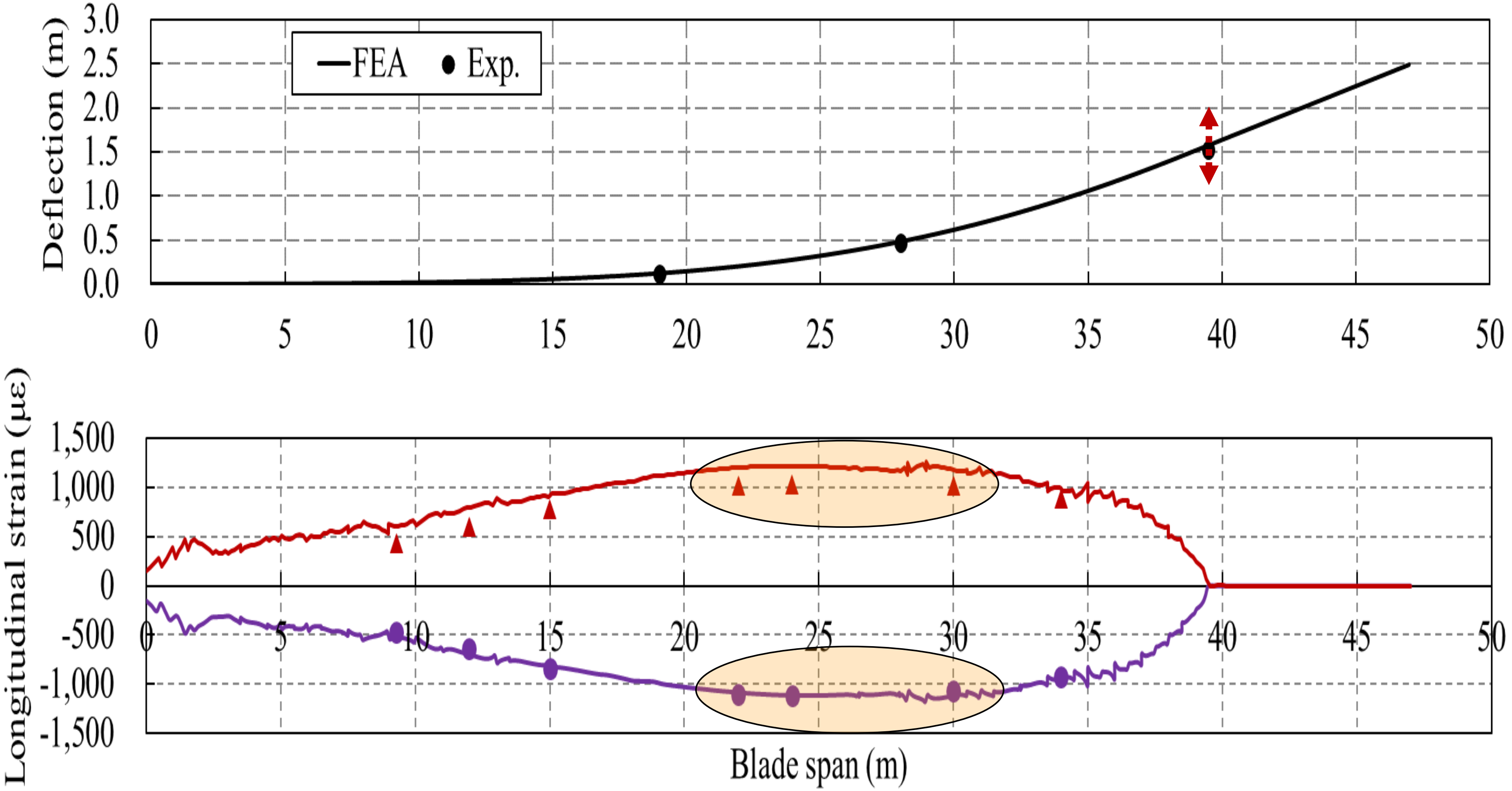
Stiffness degradation @ 28m



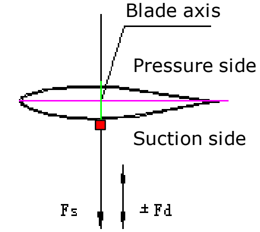
Stiffness degradation @ 39.5m



Highly-strained region



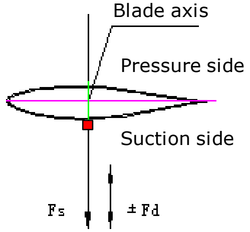
Changes of structural dynamics

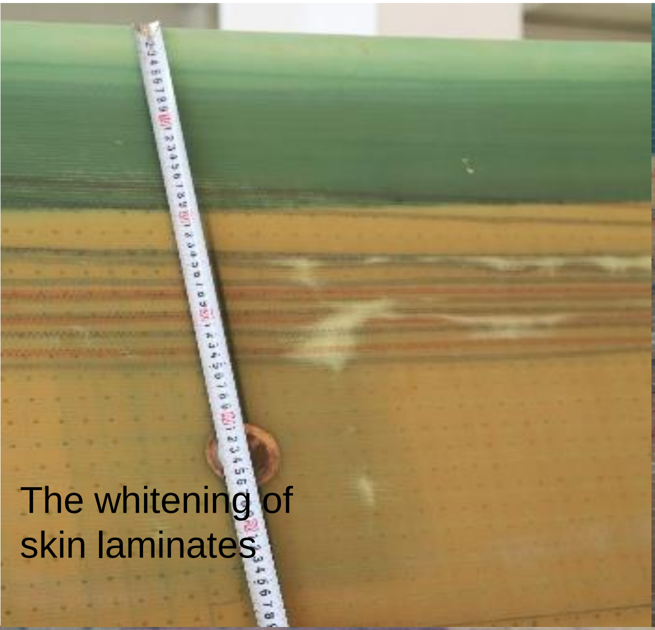


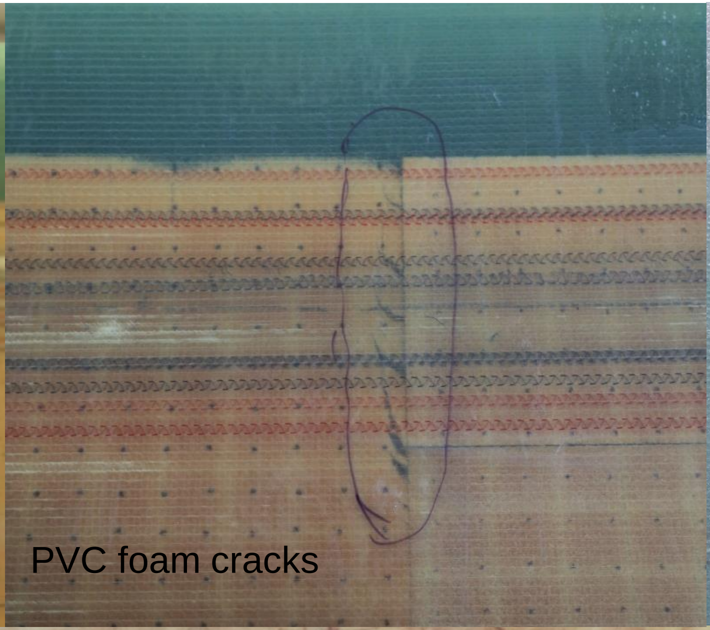
	Modes of Vibration	**Pre-fatigue (0.0 cycle)**	**Post-fatigue (2.0 m cycles)**	Change (%)
Natural frequency (Hz) (5 times average)	1st flapwise bending	0.663	0.660	-0.45
	1st edgewise bending	1.227	1.220	-0.57
	2nd flapwise bending	2.102	2.106	0.19
	2nd edgewise bending	4.076	4.082	0.15
	1st torsion	8.781	8.802	0.24
Damping ratio (%) (5 times average)	**1st flapwise bending**	0.167	0.204	**22.16**
	1st edgewise bending	0.153	0.166	8.50
	2nd flapwise bending	0.295	0.357	**20.90**
	2nd edgewise bending	0.080	0.089	11.25
	1st torsion	0.084	0.122	**45.24**

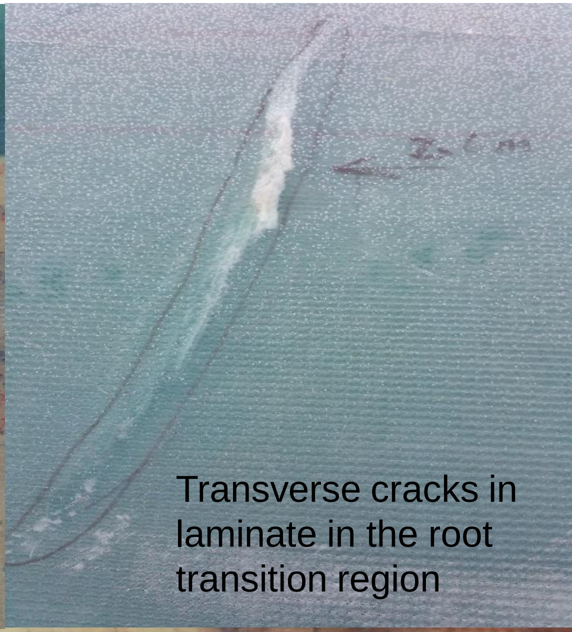
Presumption: Fatigue damages in biaxial skin laminates and core materials led to the increased energy dissipation.

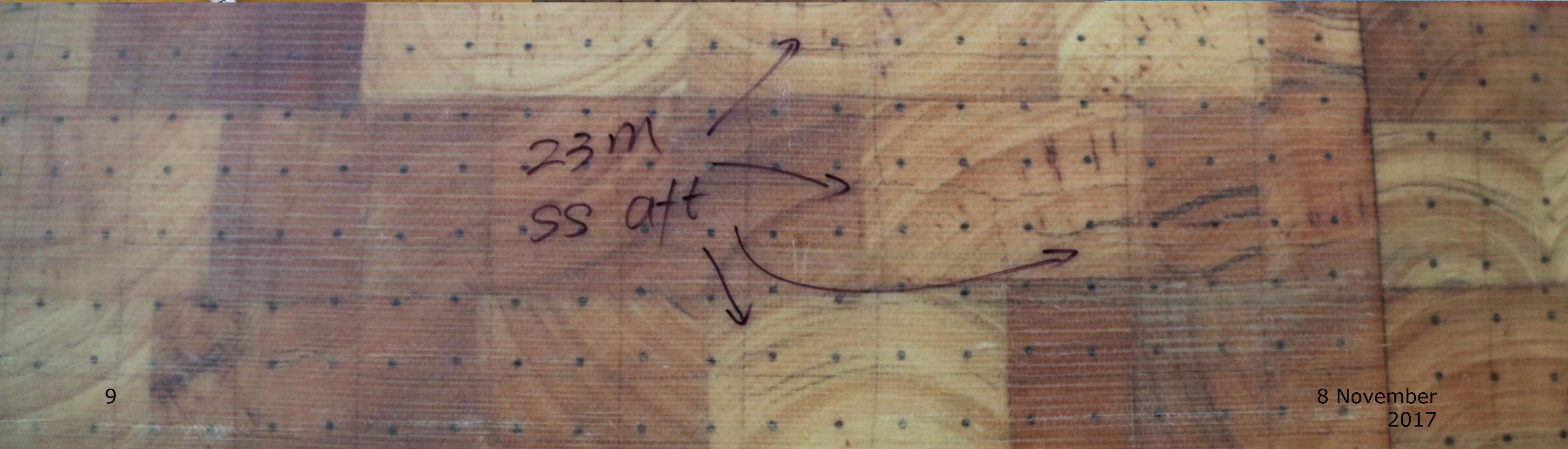
Post-fatigue examination




The whitening of skin laminates


PVC foam cracks


Transverse cracks in laminate in the root transition region



Preliminary findings

- A full-scale blade shows a ***stiffness degradation pattern similar to*** composite materials as the flap-wise bending stiffness is controlled by fatigue properties of UD composites.
- The changes of natural frequencies due to fatigue are negligible ***(<1%)***. However, ***the changes of damping ratios are significant*** and they might be ***more practical metrics*** to indicate the overall fatigue damage.
- Significant increase of the damping ratio in ***torsional mode*** might be due to fatigue damage in ***angle-fiber composites*** and ***sandwich core materials*** used in the blade shells.
- The existence of potentially ***critical cracks in local laminates*** cannot be reflected by the changes of global structural properties.

Future study of interest

The fact: Rotor blades are ***delicate combinations of different materials*** primarily ***glued and bolted*** together to sustain ***complex wind loads*** for 20 to 25 years.

Materials used in a blade: *fibers, resin, sandwich cores, adhesives, metals, etc.*

- *Fatigue properties of **different constituent materials**.*
- ***The weakest link** due to material, structural and geometric **discontinuities**.*
- ***Multi-axial** stresses under complex load combinations.*
- *Possibilities of using **different degradation trends** in different materials as **diagnostic information** for SHM.*

Natural lights illuminate the interior of a large blade which is not painted, allowing a beautiful visualization of discontinuities filled with epoxy resin and adhesive paste.