An approach in using guided waves for ice detection on wind turbines

Siavash Shoja, Viktor Berbyuk, Anders Boström

Department of Applied Mechanics
Division of Dynamics
Chalmers University of Technology

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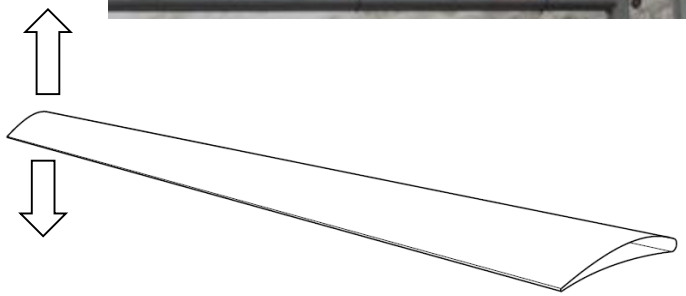
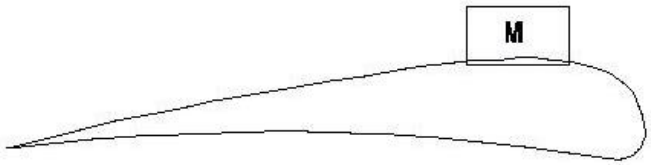
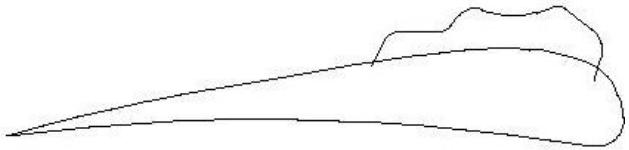
Background

- Wind turbines operating in cold regions face ice accumulation on the blades.

- Icing conditions on wind turbine causes:
  - Increased loads on the blades
  - Reduced aerodynamic efficiency
  - Undesired vibrations and turbulence
  - Safety issues





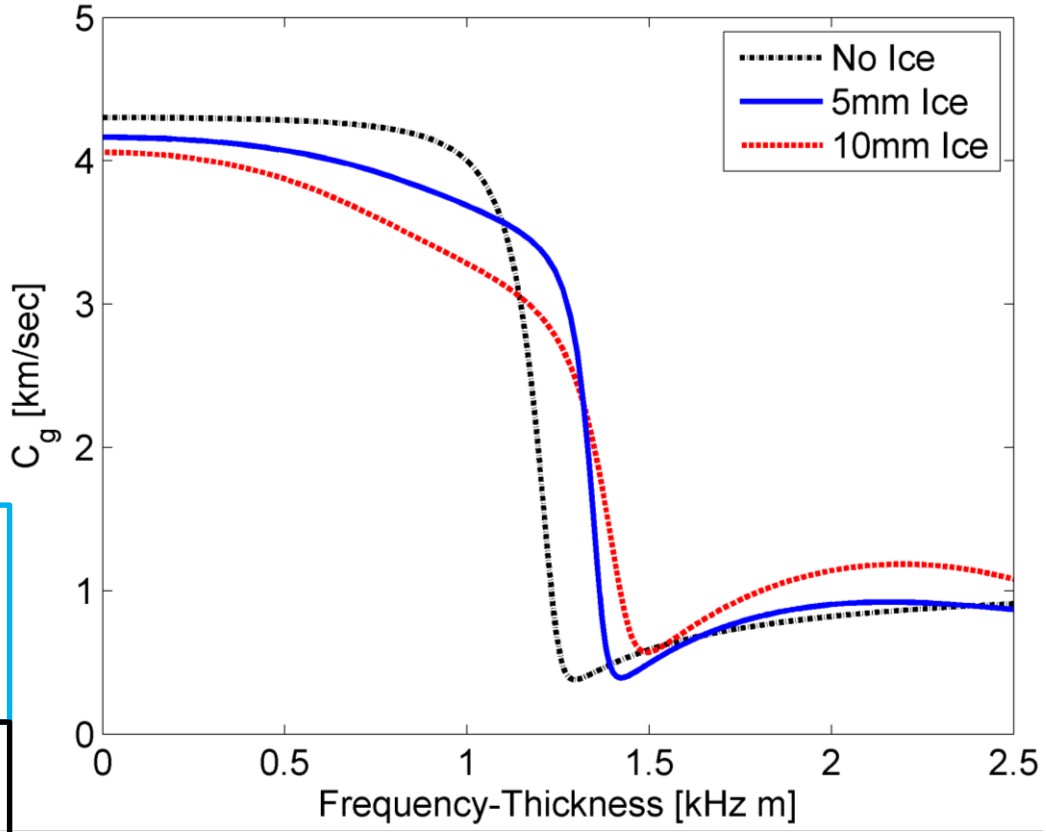


Project description

- The aim of the project is to develop a method for early detection of ice using ultrasonic guided waves in the turbine blades.
- Current results are based on experiments which are done in a cold climate lab at Chalmers University of Technology.
- A computational model will be developed based on experimental measurements for further study.
- A virtual prototype of an ice detection system on wind turbine blades base on guided wave propagation shall be introduced at the end of the project.

Mathematical Calculations

$$\rho^{(n)}\ddot{u}_i = C^{(n)}_{ijkl}\frac{\partial^2 u_l}{\partial x_j\,\partial x_k} \qquad n = (1,2)$$



x_1

x_3

$$\sigma_{31}^{(1)} = \sigma_{33}^{(1)} = 0 \qquad (1)$$

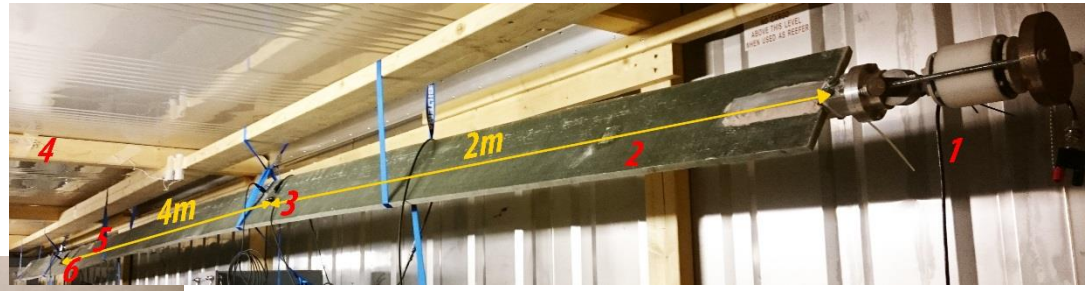
$$u_1^{(1)} = u_1^{(2)} \qquad \sigma_{31}^{(1)} = \sigma_{31}^{(2)}$$

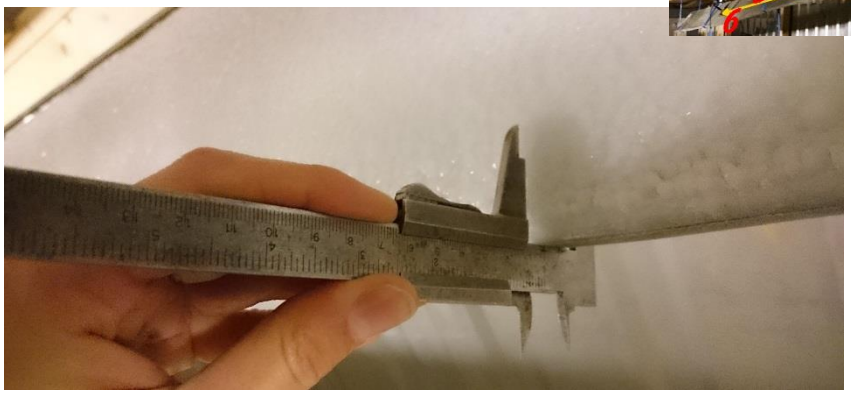
$$\sigma_{33}^{(1)} = \sigma_{33}^{(2)} \qquad u_3^{(1)} = u_3^{(2)} \qquad (2)$$

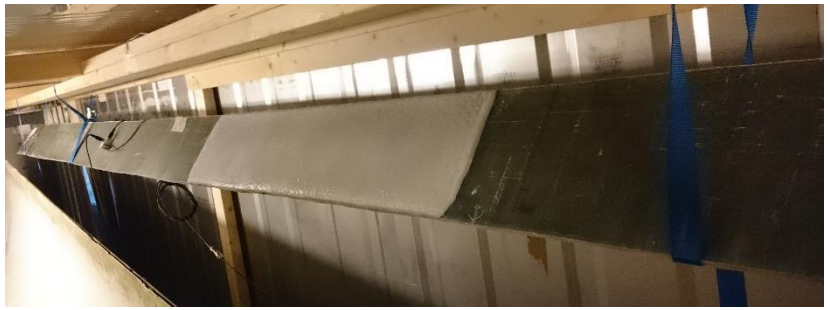
$$\sigma_{31}^{(2)} = \sigma_{33}^{(2)} = 0$$

Primary Experiments

Temperature: −12°C
Ice: Mixed glaze and rime
Ice Thickness: 3 mm to 9 mm
Excitation: Windowed sine wave with 5kHz center frequency

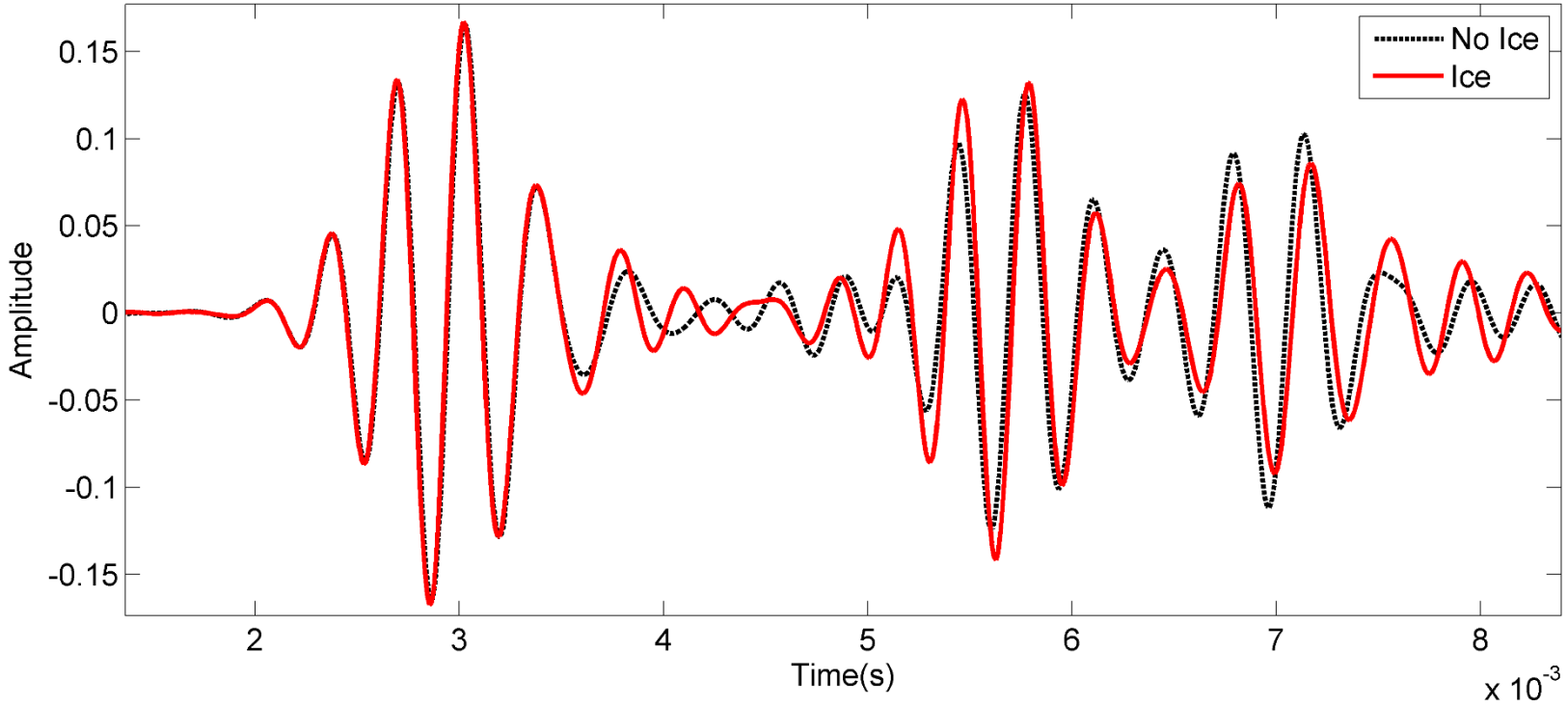






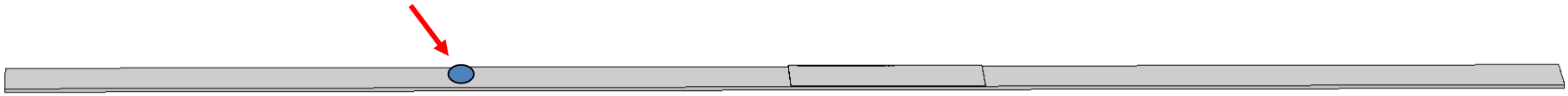
Berbyuk V et. al. 2013. Towards early ice detection on wind turbine blades using acoustic waves.

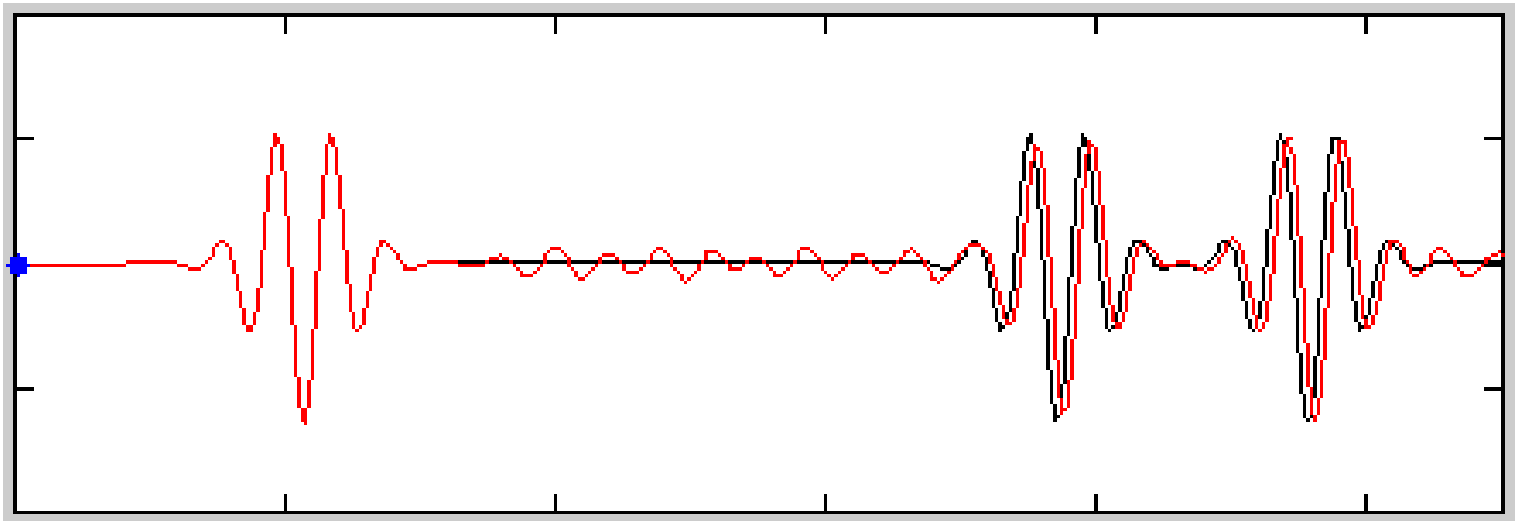
Experimental Results



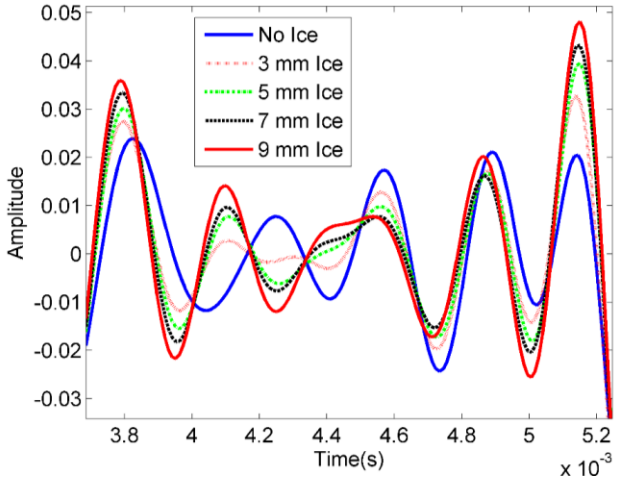
What is happening?

Excistance of a layer of ice changes the group velocity of the guided wave and creates reflections.

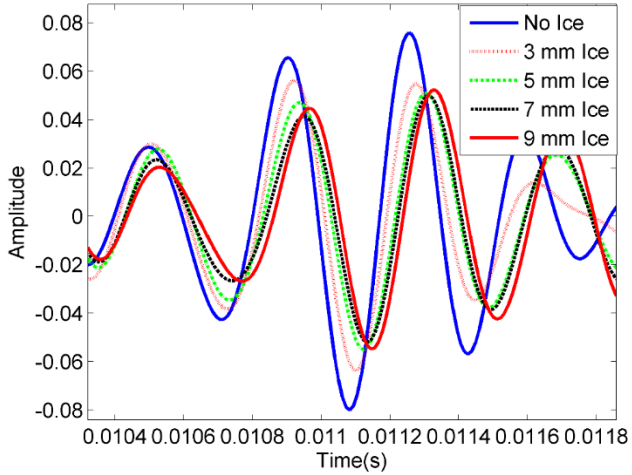




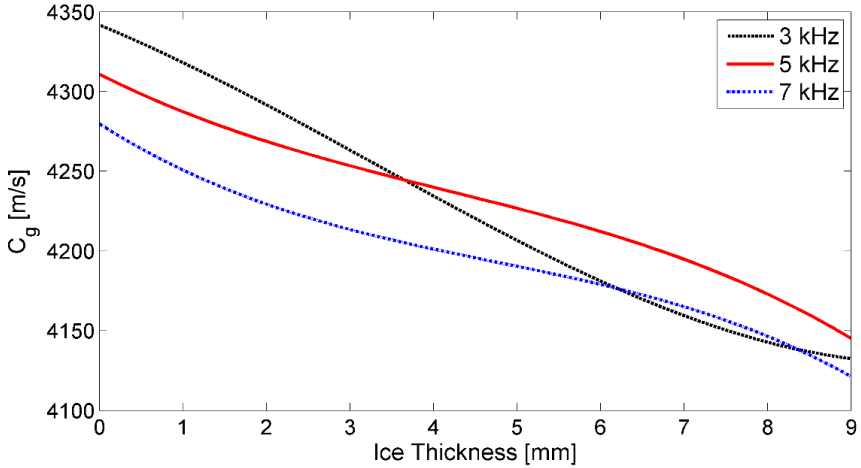
Effect of ice thickness



Comparing the amplitude of reflections



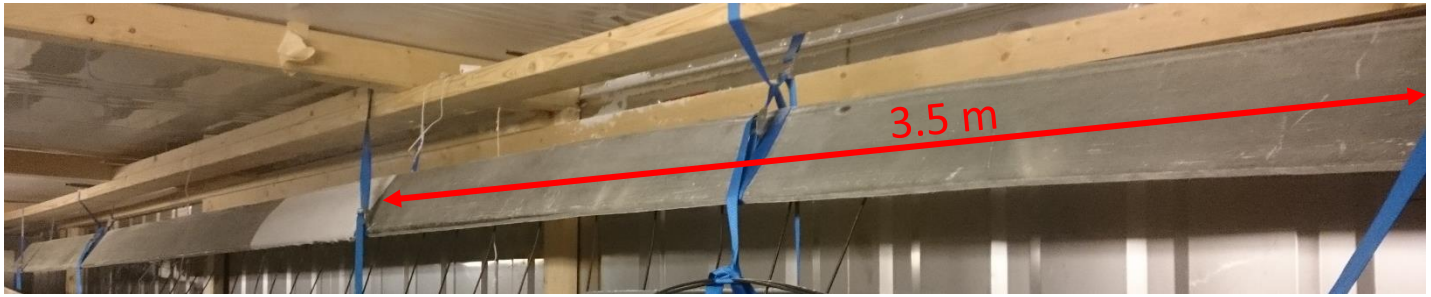
Comparing the phase of the signal



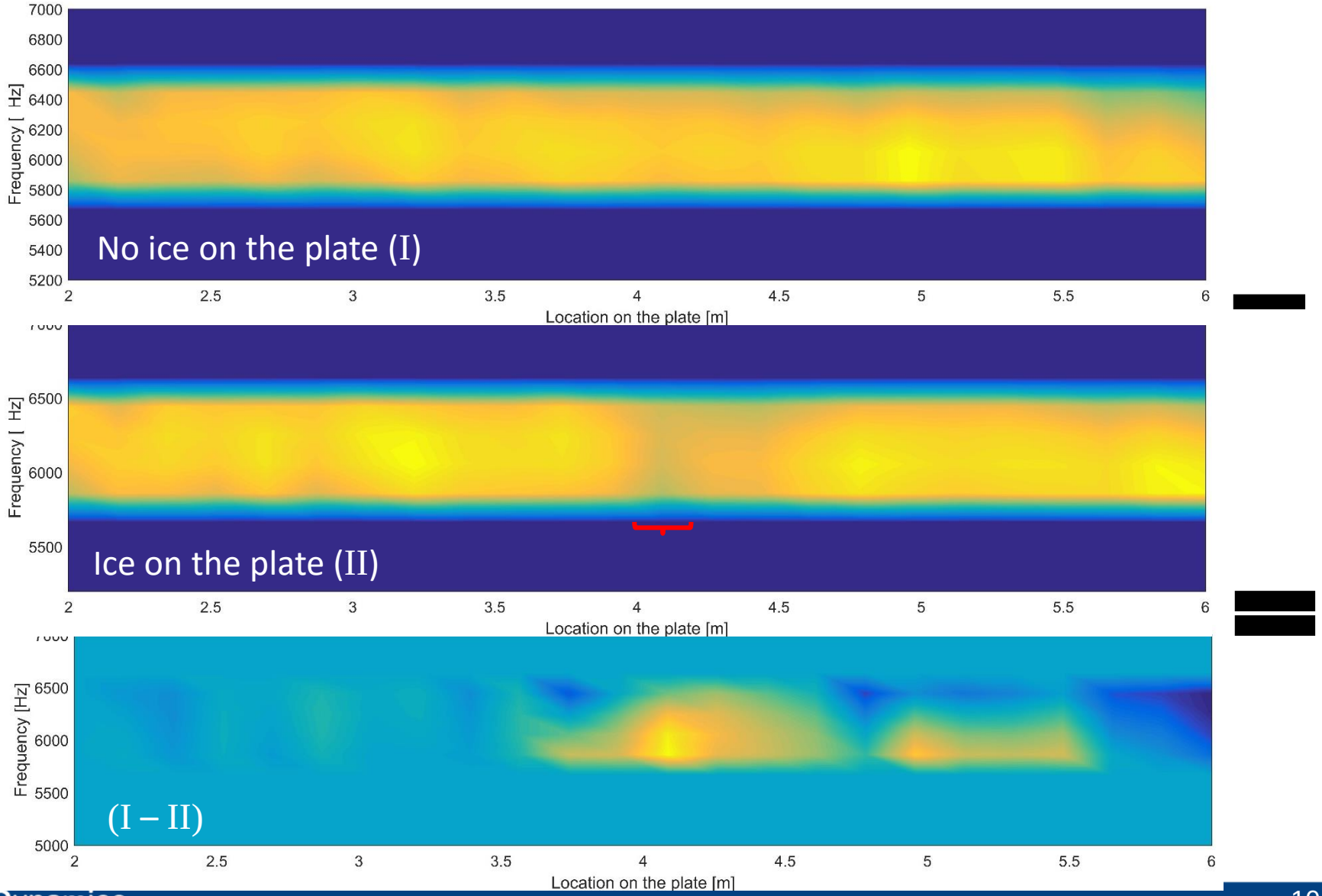
Shoja, S. et al. INVESTIGATING THE APPLICATION OF GUIDED WAVE PROPAGATION FOR ICE DETECTION ON COMPOSITE MATERIALS. *International Conference on Engineering Vibration, Ljubljana, 2015*

Multichannel test set-up

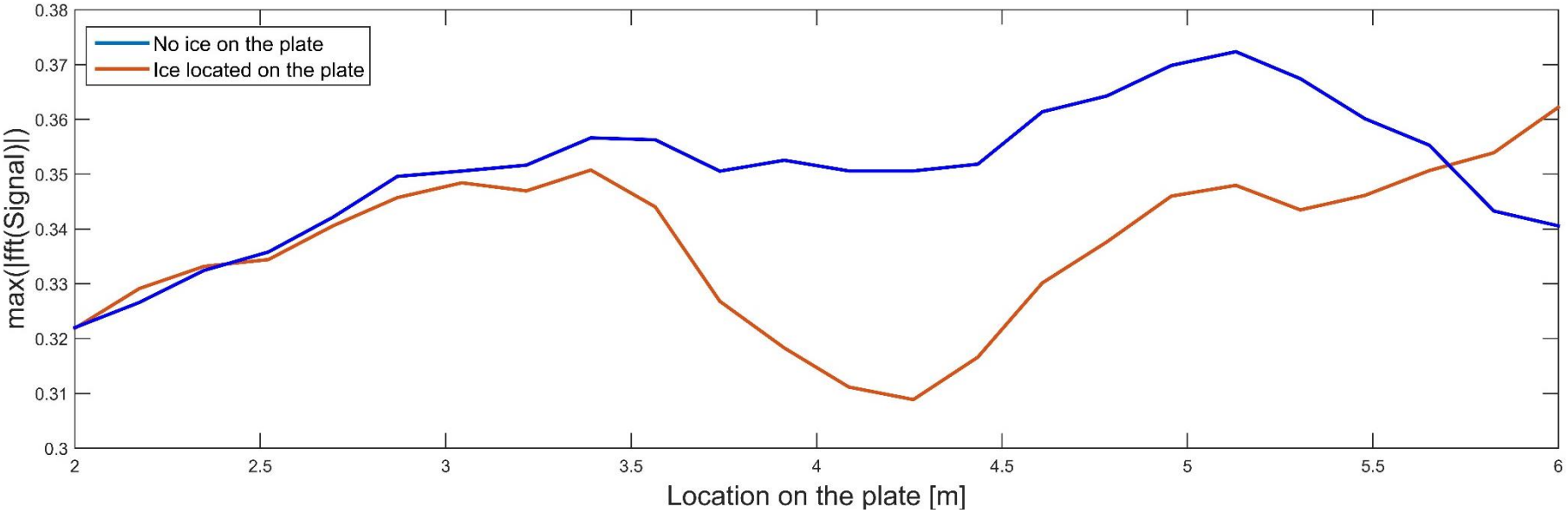
Temperature: −24°C
Ice: Mixed glaze and rime
Ice Thickness: 10±1 mm (≈ 1.5 kg mass) located at 3.5m to 4.25m
Excitation: Windowed and continuous sine wave with 3 kHz to 7 kHz center frequencies
Ice and accelerometers were located on opposite sides of the plate



FFT Approach in Multichannel Method



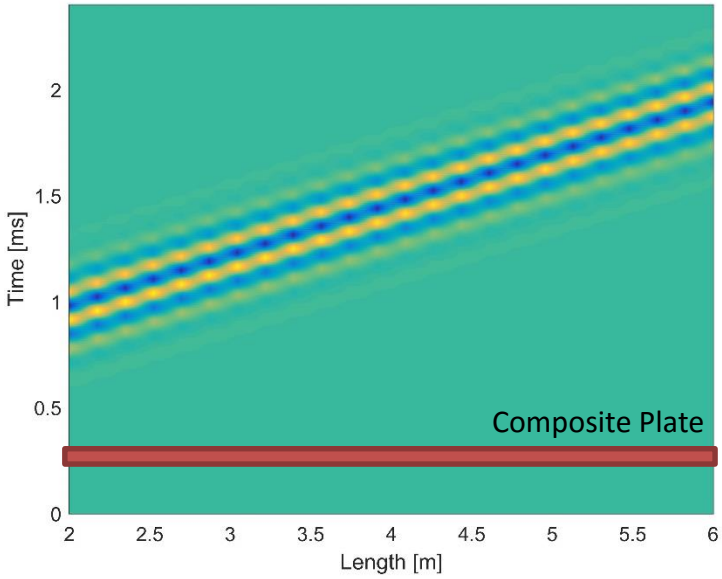
Pick values of the FFT Approach

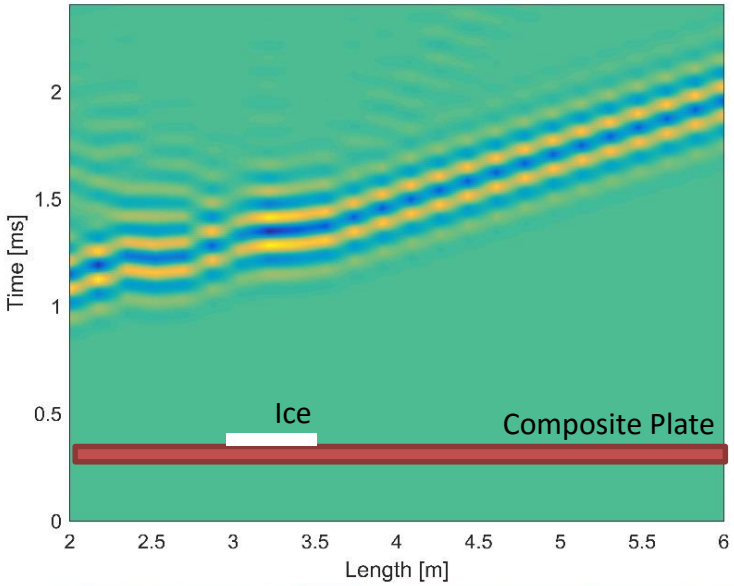


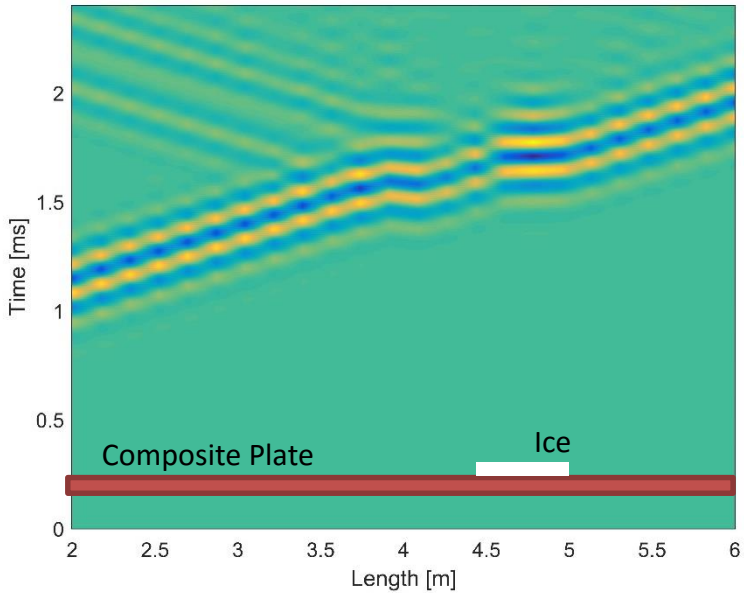
Computational Model for a Virtual Protoype of an Ice Detection System

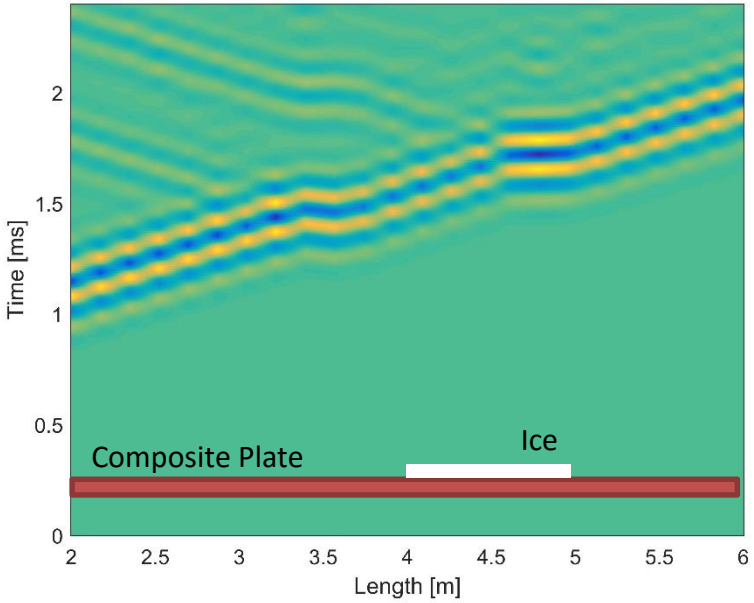
- To optimize the location and number of the sensors, the excitation frequency and creating a database for a statistical model a computational model is needed.
- Two 2D and 3D transient FE models are developed.
- Models are calibrated by optimizing the material properties using experimental measurements (On-going).

Computational Results

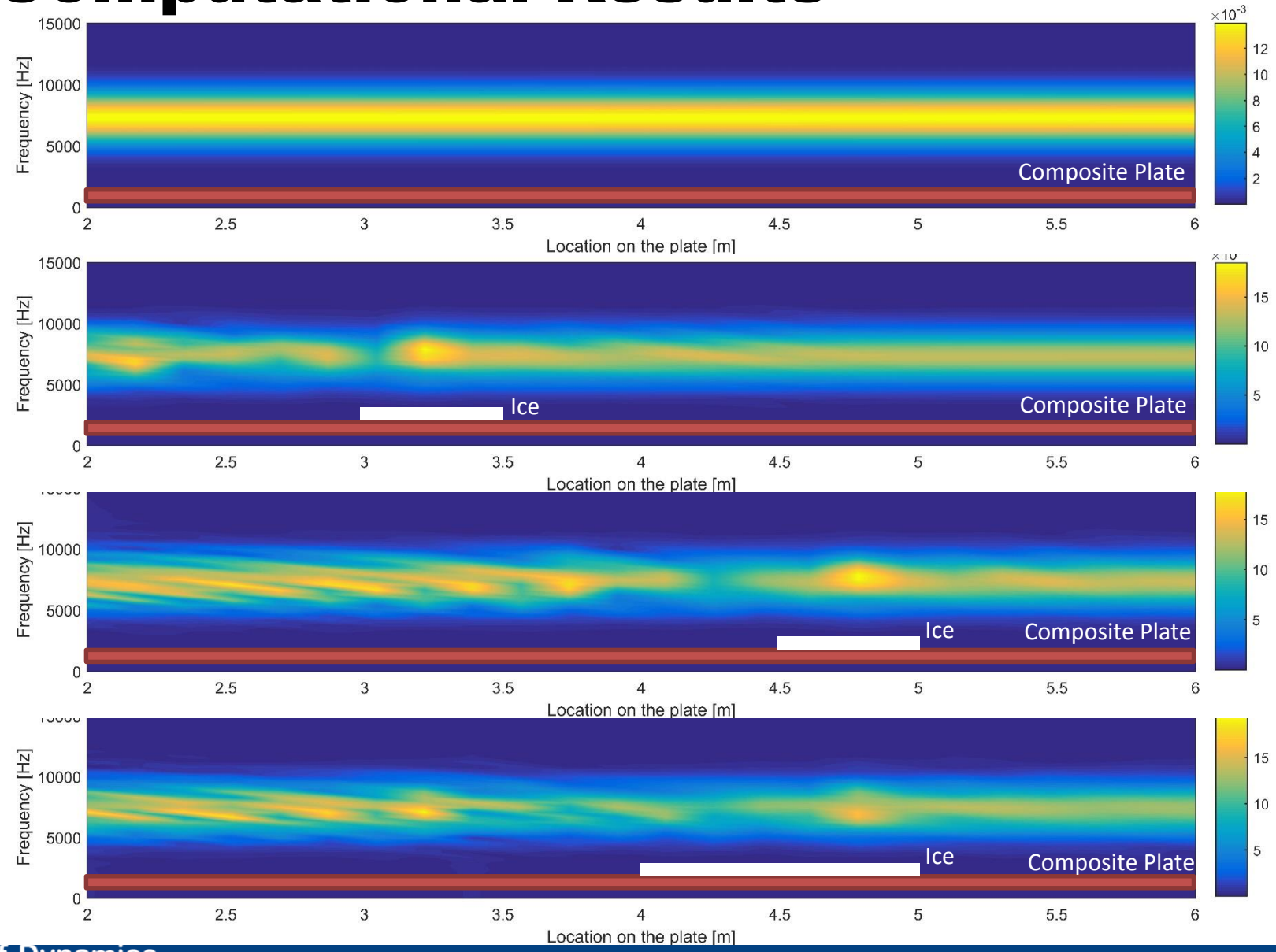








Computational Results



Further Work

- Investigating the effect of low temperature on composite structures. (SPIE Conference, Las Vegas, March 2016)

- Parameter identification of properties of the material and model calibration using guided waves.

- New experimental work for ice detection on an actual turbine blade (made by Vestas) using higher frequency.

Multifunctionality

- ***De-icing:*** Ultrasonic guided waves can be used to De-ice the wind turbine blades. By choosing an optimum wave mode and frequency, ultrasonic guided waves can induce delaminating transverse shear stress at the interface between the ice layer and the substrate structure *{Yun, 2008}, {Overmeyer, 2013}, {Habibi, 2015}.*

- ***Structural Health Monitoring:*** Ultrasonic guided waves can be used in order to accurately detect damage in critical areas of the wind turbine structure {Hameed, 2009}.

Conclusion

1. Is it possible to detect a patch of ice on a wind turbine blade using guided waves?
   - *Yes*
2. How is it possible to detect the thickness of the accumulated ice in guided wave application?
   - *By measuring the group velocity of the wave*
3. How is it possible to detect the location and length of the accumulated ice using guided waves?
   - *By calculating and comparing the Fourier Transform of the respond signal.*
4. Why is it important to have a computational model?
   - *For optimization and collecting a database with lower cost.*
5. Does the detection system has the potential of having other applications like De-icing and SHM?
   - *Yes*

Acknowledgement

This project is part of a PhD project “Ice detection for smart de-icing of wind turbines” and it funded by Swedish Energy Agency (Dnr 2013-001475, project 37286-1).

We are looking for industrial and academic partnership for implementation of application of guided waves for ice detection on wind turbines.

Thank You!

Contacts:
Siavash.shoja@chalmers.se
Viktor.Berbyuk@chalmers.se
Anders.bostrom@chalmers.se