Wind Turbine Monitoring of an Operational Wind Farm in Ireland

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SEAI National Energy Research Development and Demonstration (RD&D) Funding Programme

The SEAI National Energy Research Development and Demonstration (RD&D) Funding Programme invests in innovative energy RD&D projects which contributes to Ireland's transition to a clean and secure energy future

Relevant RD&D Sustainable Energy Authority of Ireland (SEAI) Funded Projects:

Remote and autonomous inspection and maintenance of onshore and offshore wind turbines (REMOTE-WIND)

This representation has been funded by the Sustainable Energy Authority of Ireland under the SEAI Research, Development & Demonstration Funding Programme, Grant number 21/RDD/613

A comprehensive decision support tool for end-of-life wind turbines of Ireland; Lifetime Extension, Decommissioning, Repowering, Repurposing [WindLEDeRR]

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Wind Farm in Ireland

- Bord Na Móna (BNM) facilitated and collaborated with the implementation of aspects of the WindLEDeRR and REMOTE-WIND projects
- Bellacorick Wind Farm, County Mayo, Ireland
- Originally a demonstration project, part funded through European Commission under the VALOREN programme (Council Regulation (EEC) No. 3301/86)
- Owned and operated by Bord Na Móna
- Began operation in 1992, 21 Wind Turbines
  - 20 turbines: Nordtank NTK300/31, tip height 46.5m, tower 31m
  - 1 turbine: Nordtank NTK450/37, tip height 53.5m, tower 35m
- First commercial Grid Scale Wind Farm in Ireland, and longest in operation
- Bellacorick Wind Farm site will be decommissioned and repowered as part of planning application for Oweninny Phase 3 Wind Farm awaiting planning decision
- Fitting that a demonstration project is used to demonstrate novel / experiential testing methods (but of a practical nature) to determine Wind Turbine Remaining Useful Life and Condition Assessment

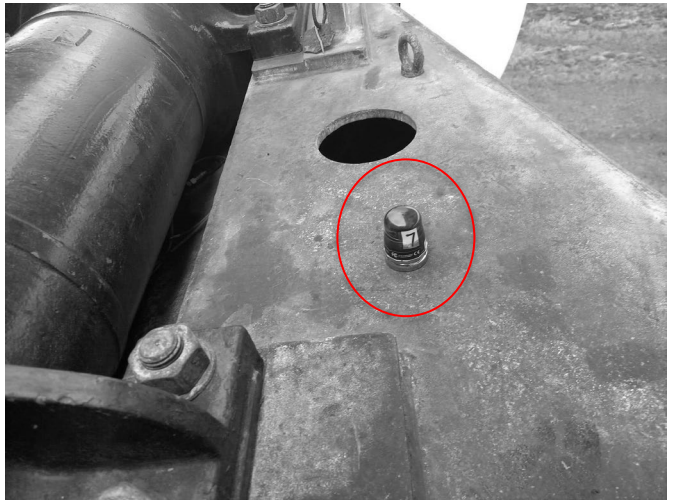
REMOTE-WIND: Laser Doppler Vibrometry (SWIR-LDV)

- Full-Scale Demonstration of Laser Doppler Vibrometry (SWIR-LDV)
- Optical method for non-contact analysis of vibrational velocity and displacement of vibrating structures
- measures doppler frequency shift by focusing laser light on object of interest eg wind turbine



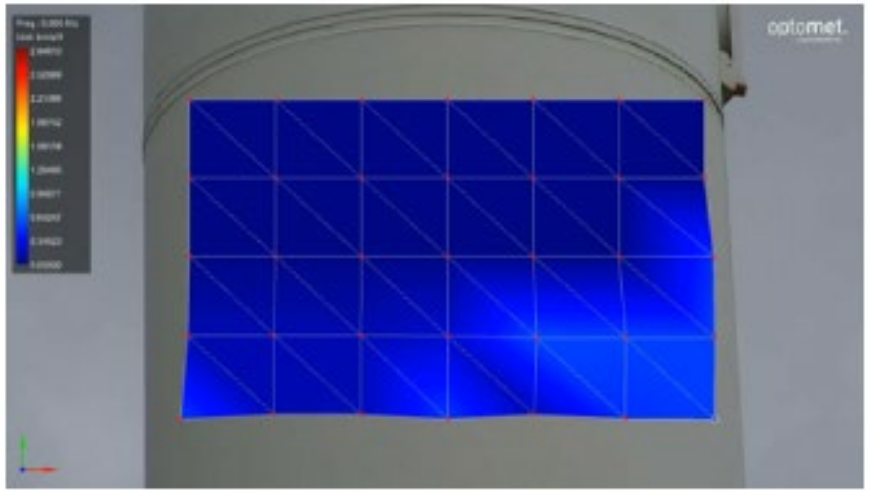

REMOTE-WIND: Laser Doppler Vibrometry (SWIR-LDV)

- Comparison of LDV with data from wireless accelerometers installed within tower:
  - Close to tower bottom
  - Mid Tower
  - Close to tower top
  - Nacelle (to monitor maximum acceleration levels, no more than ~0.15-0.20g)
- Wireless accelerometers installed 90 degrees apart at each height to measure values along 2 axes
- Values of structure natural frequency measured by LDV compared with data from wireless accelerometers
- Natural frequency is proportional to square root of stiffness, and stiffness is connected to potential degradation of material (steel) / interconnection with foundation
- Testing of multiple WTGs would permit the determination of natural frequencies, and outliers may be indicative of structural issue for further investigation

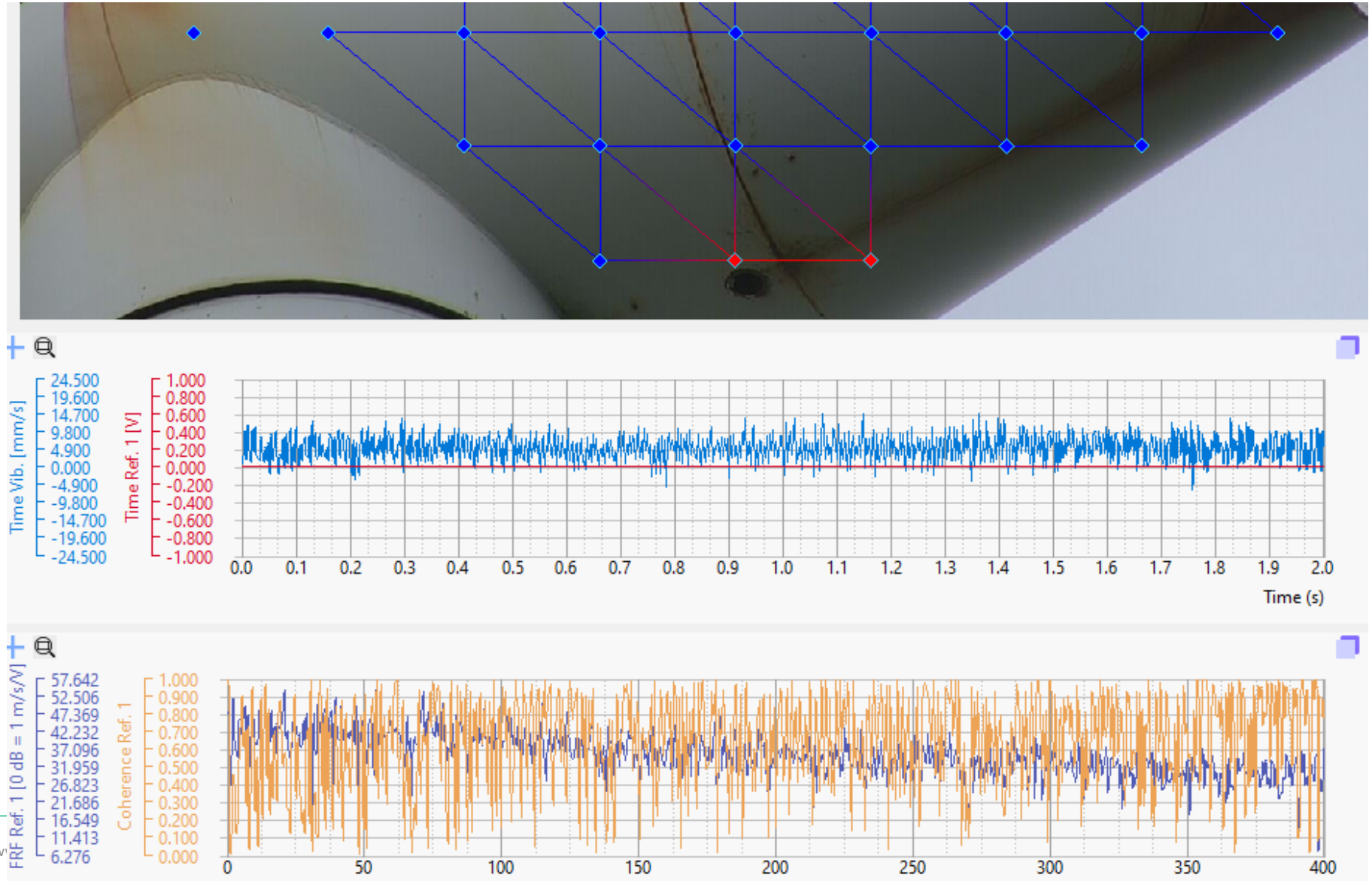


REMOTE-WIND: Laser Doppler Vibrometry (SWIR-LDV)

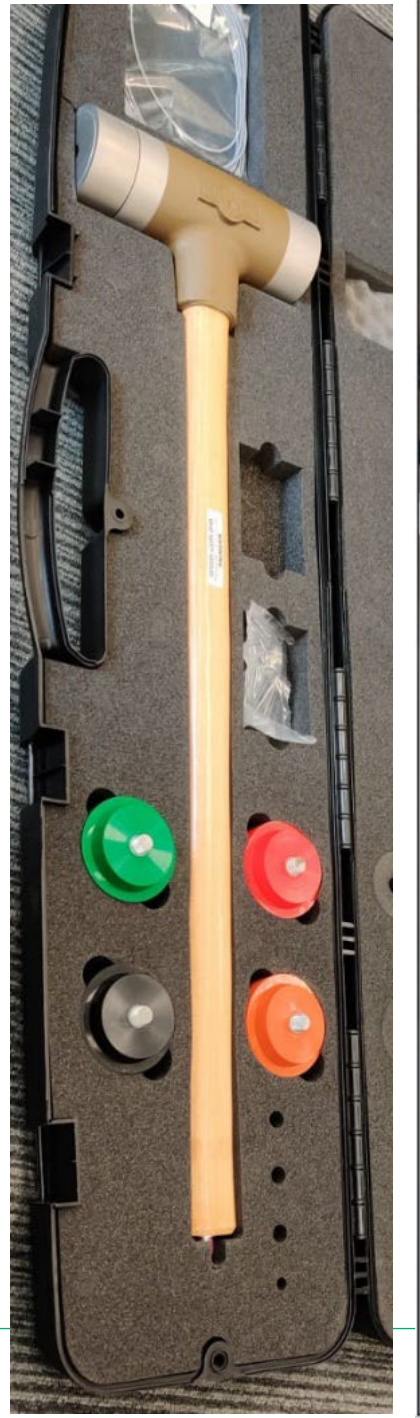
- Wind Turbine shut down and rotor locked
- 2 Vibration test cases:
  - Vibration induced by ambient wind
  - Vibration induced by impulse hammers
    - Load cell connected, different hammer ‘heads’ of different hardness to ‘excite’ various bands of frequency of structure in effort to identify eigenfrequency
- Initial results indicate good agreement between LDV and accelerometers for determining natural frequency
- Potential Advantages of LDV approach:
  - Rapid (multiple WTG testing possible on site per day); 10min max per grid of laser acquisition points (sequential measurement)
  - Non Contact
  - No working at height
- Practical challenges
  - LDV is sensitive to vibration and atmospheric conditions
    - LDV installed in van to shelter from wind and potential rain
  - Power supply (however achievable using WTG power supply)
  - Solid ground and tripod of known frequency required
  - line of sight required, range (~100m multipoint, ~200m single point)
  - Initial cost of device

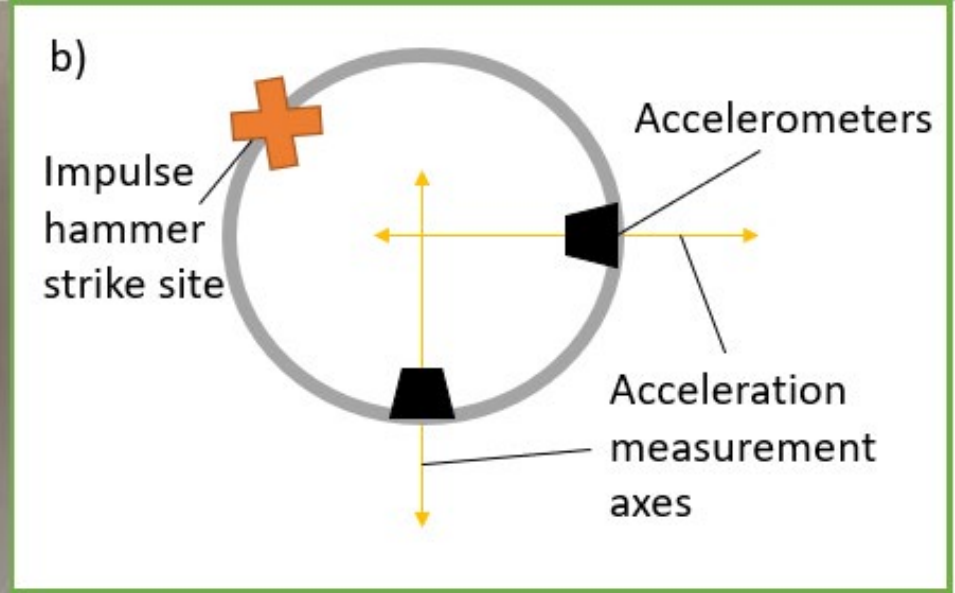


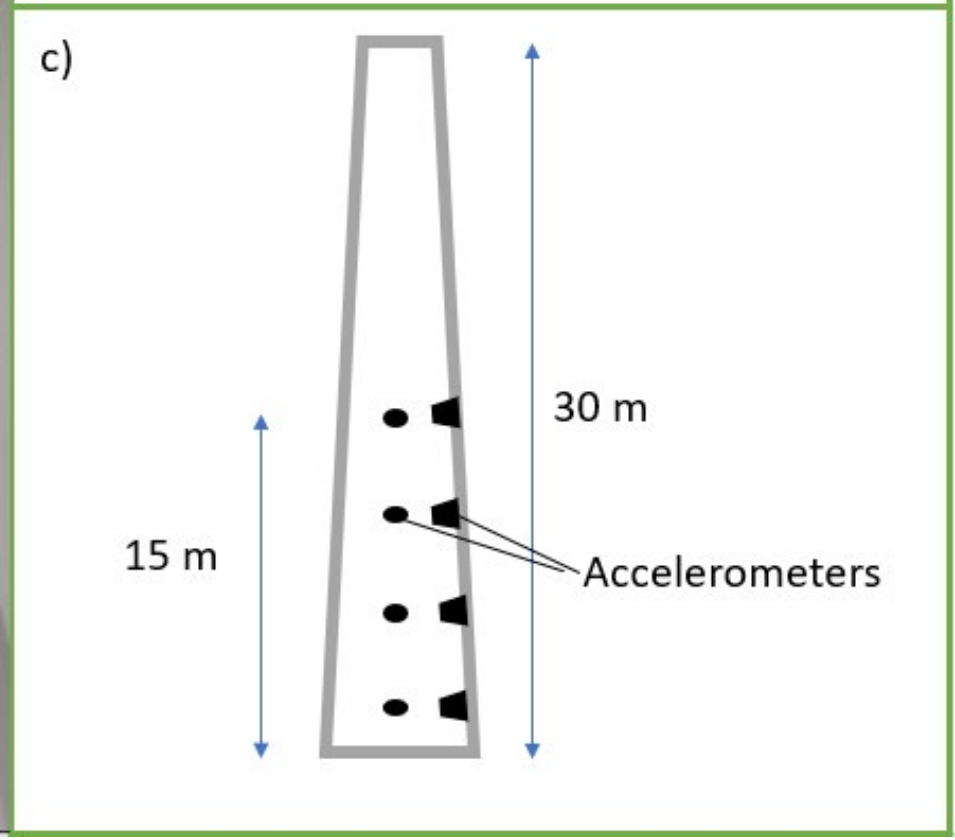
Responses from LDV



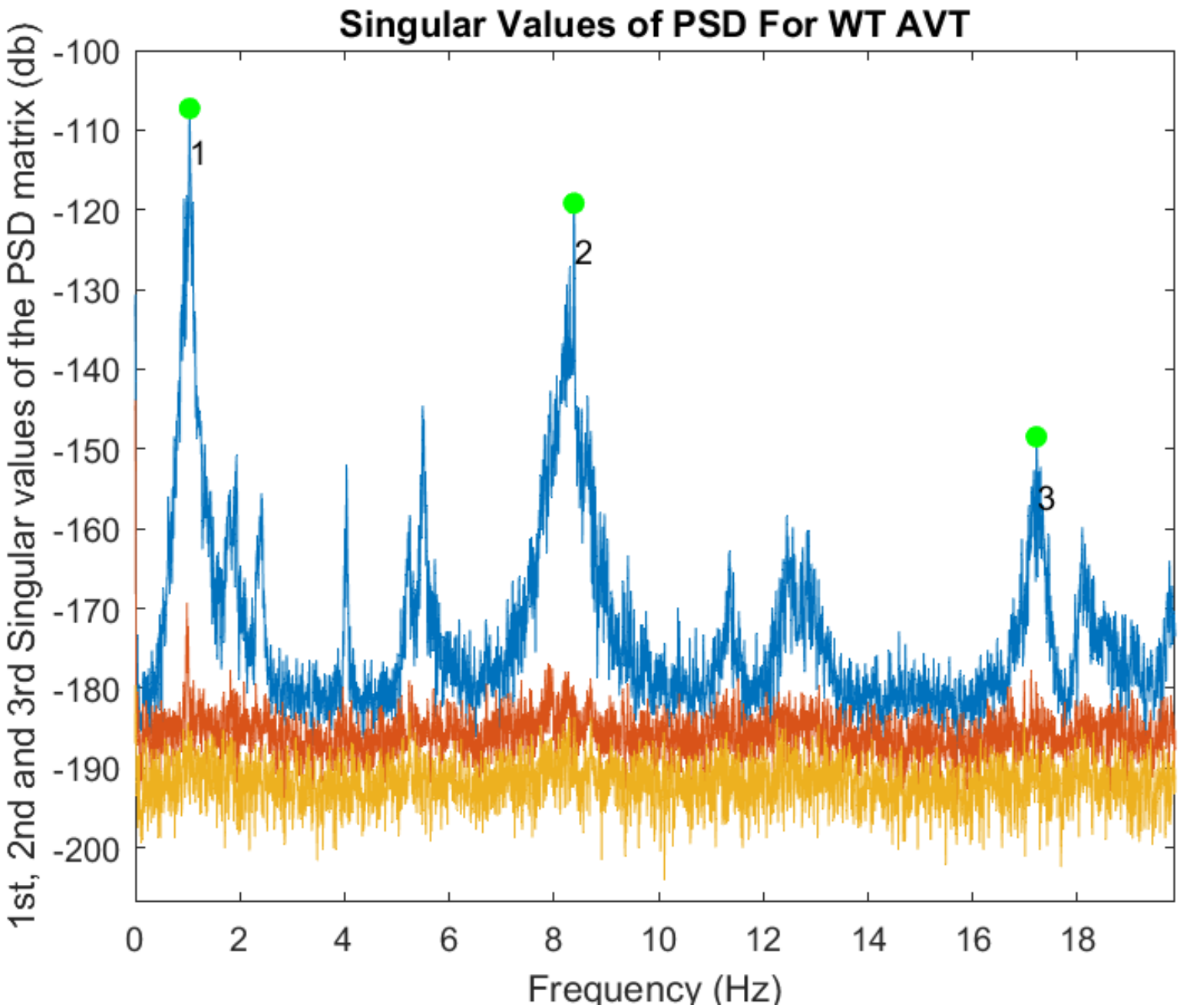
Wireless Accelerometers





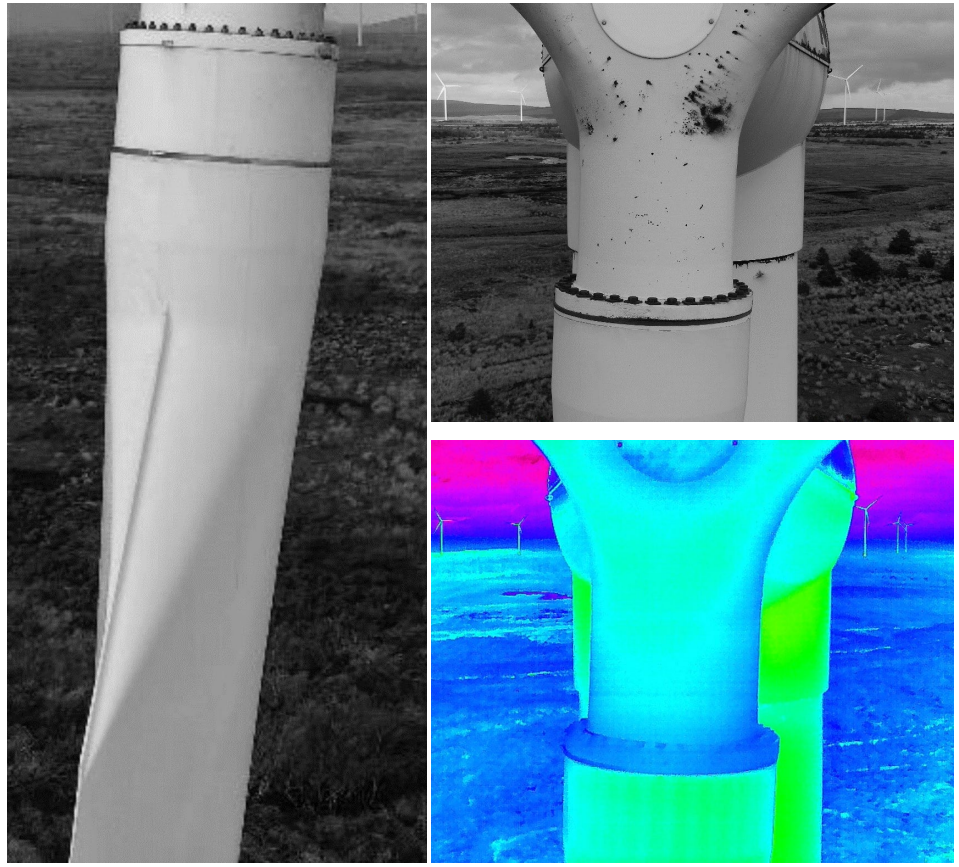


Frequency Responses



REMOTE-WIND: Drone based Blade Inspection + Thermal Imaging

- 20 MP Zoom Camera
- Radiometric Thermal Camera and Laser Rangefinder
- Aim of Drone Inspection was to determine condition of blade
  - Leading Edge
  - Blade Surface
  - Trailing Edge
  - Thermal Imagery to investigate potential for water ingress
- Images indicate overall very good condition for >30 year old blades
  - No cracks
  - Superficial features only
  - Low leading edge erosion
  - No evidence of water ingress
- Advantages: no working at height, rapid, objective measurements



WindLEDeRR + REMOTE-WIND: Foundation Inspection + Monitoring

- Why assess condition of foundation?
  - Determine quality of concrete on site after long operational period (since 1992)
  - Determine condition of steel reinforcement (‘rebar’) in the concrete foundation
  - Undertake inspections to aid the determination of Remaining Useful Life
  - Health and Safety
  - Foundation is a fundamental part of the overall wind turbine structure (foundation – tower interaction), however concealed from view
  - Confirm As-Built Foundation Design and Dimensions matches that on Design Drawings (sometimes not available for very old assets!)

- What can impact foundation condition?
  - Potential cracking of concrete, due to site loading conditions, or foundation degradation
  - Environmental conditions: Peatland environment can have slightly acidic properties
  - Hidden defects / voids in concrete that could potentially have been in-situ from time of construction

WindLEDeRR + REMOTE-WIND: Foundation Inspection + Monitoring

- What to assess? Assessments such as:
  - Concrete condition:
    - Visual defects on surface of concrete
    - Cement Content: minimum cement content required for durability: for example, current ISEN206 requires a minimum Cement Content for an Exposure Class (extracted via 'breakout' of area of concrete)
    - Compressive Strength: if strength of cores is below that required by current ISEN206 standard, this may then require a follow on structural assessment
  - Reinforcement type and condition:
    - Visual inspection
    - Confirm rebar type and diameter, and compare to detailed design drawings (where available)
    - Reinforcement Corrosion Assessment:
    - Half Cell Potential: Half-cell potential testing measures the corrosion voltage (Potential Difference) from the surface of the concrete to exposed rebar
    - Resistivity: Proceq Resipod attempts to induce an electrical field (send electrical current) between 2 outer probes
    - Low current flow measurement is indicative of low likelihood of corrosion, as this indicate higher resistivity in concrete. This means lower likelihood of water ingress as water and salts would conduct electricity
  - cover calibration:
    - Compare level of concrete cover to that required by current standards
  - Material / Chemical analysis: a variety of tests are required, such as:
    - Carbonation penetration: pH of 9 and above indicates low carbonation and by extension low penetration of air (CO2) into voids in concrete, which would impact durability of reinforcement
    - Chloride penetration: high chloride concentration in concrete may aggressively attack reinforcement and therefore reduce structural integrity of foundation. Require chloride levels of 0.4% of mass of cement.

WindLEDeRR + REMOTE-WIND: Foundation Inspection + Monitoring

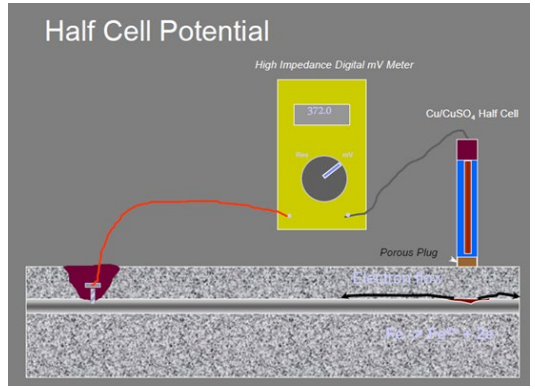
- Site Preparation: Wind Turbine Shut Down and Isolated

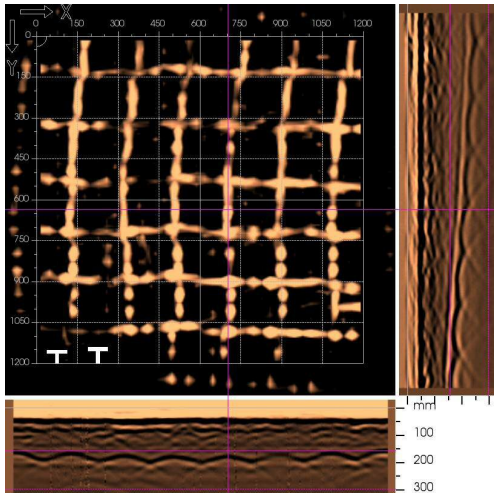


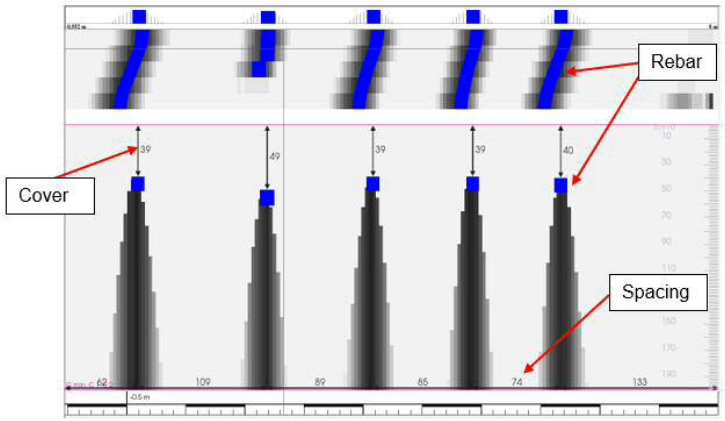


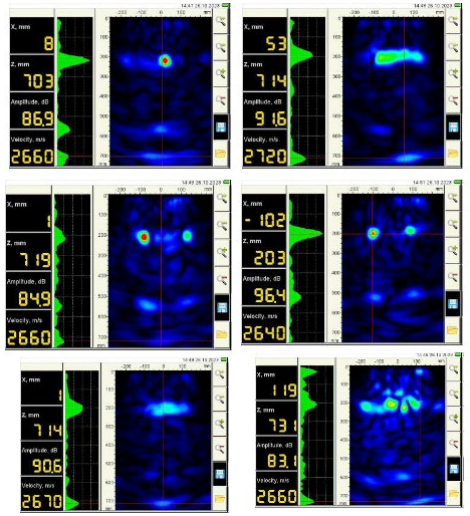

WindLEDeRR + REMOTE-WIND: Foundation Inspection + Monitoring

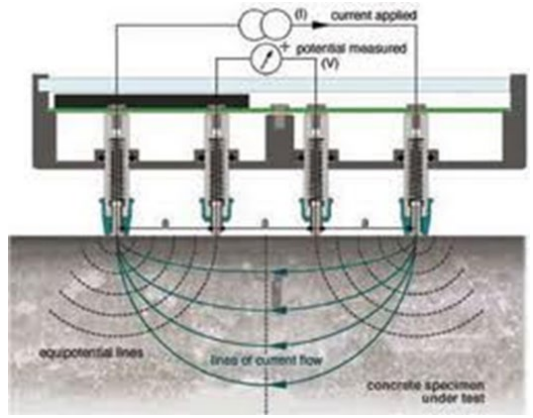
- NDT: GPR systems used to find
  - buried services
  - Reinforcement position
- NDT: Concrete detector:
  - rebar localisation
  - depth measurement
  - size estimation
- NDT: Ultrasonic Tomography
  - depth measurement
  - Concrete integrity (voids)
- NDT: Reinforcement Corrosion Assessment:
  - Half Cell Potential
  - Resistivity











WindLEDeRR + REMOTE-WIND: Foundation Inspection + Monitoring

- No Carbonation
  - At both breakout depth and surface, indicated by pink colour
- Low Chlorination
  - Drill into concrete, 3 small holes, collect dust from holes, and send for Lab analysis
  - Low chloride 0.02% measured, very good result (ie natural chlorides), below 0.4% chloride by mass of cement represents a low corrosion risk
- Visual Inspection indicated rebar in excellent condition
- High level of concrete cover exceeding current minimum requirements
- 100mm diameter Concrete cores and ‘breakout’ samples sent for testing to test
  - Compressive Strength
  - Cement Content

WindLEDeRR + REMOTE-WIND: Foundation Inspection + Monitoring

- REMOTE-WIND initiative to install vibrating wire strain gauges
- strain gauges measure foundation strain variation at foundation rebar over time
- Could not install strain gauges on rebar at edge of tower, due to density of rebar and also potential requirement for welding
- Strain Gauges surveyed, one N-S and one E-W
- After installation of strain gauges, breakout reinstatement using correct structural grouts with appropriate properties (eg N/mm2 strength) to grout manufacturer instructions, and also ensures strain gauges do not move post installation
- Data logger installed at base of tower with 2 new gauges

Míle Buíochas / Thank You

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