Wind turbine design factors for long-term management

13/02/19

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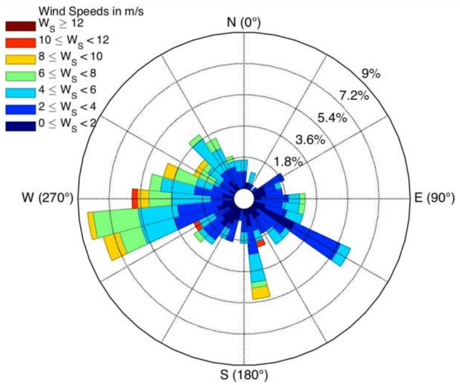
Offshore Renewable Energy

Agenda

- What is long term management?
- The design process and long term management
- Benefits and requirement for long term management
- Need for SHM and NDT

- Case Studies:
  - Reactive: Manufacturing defects
  - Life: Monopile Fatigue Life
  - Operation: Turbine uprating
  - Optimisation: Closing the Design Loop

What is long term management?



- Environment / Weather
- Operating regime
- Turbine Design
- Substructure Design
- …

Design

Validate and Manage

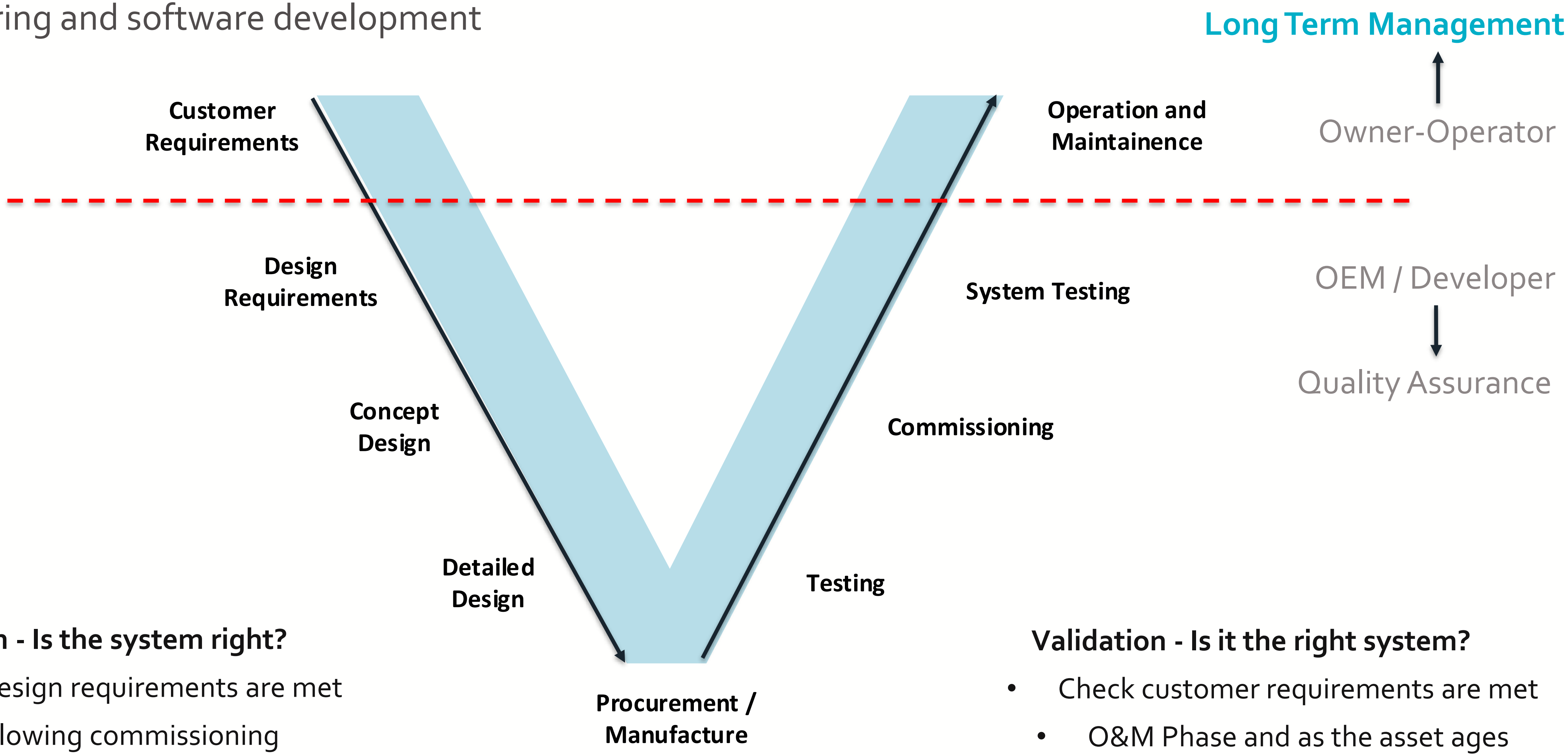
Reality

- Storms
- Control changes
- Corrosion / Degradation
- Unexpected events
- …

Comparison of design vs. reality and managing discrepancies

The design process and long term management

- V&V – common quality assurance approach used in engineering and software development



Verification - Is the system right?

- Check design requirements are met
  - Following commissioning

Validation - Is it the right system?

- Check customer requirements are met
  - O&M Phase and as the asset ages

Benefits / requirement of long term management

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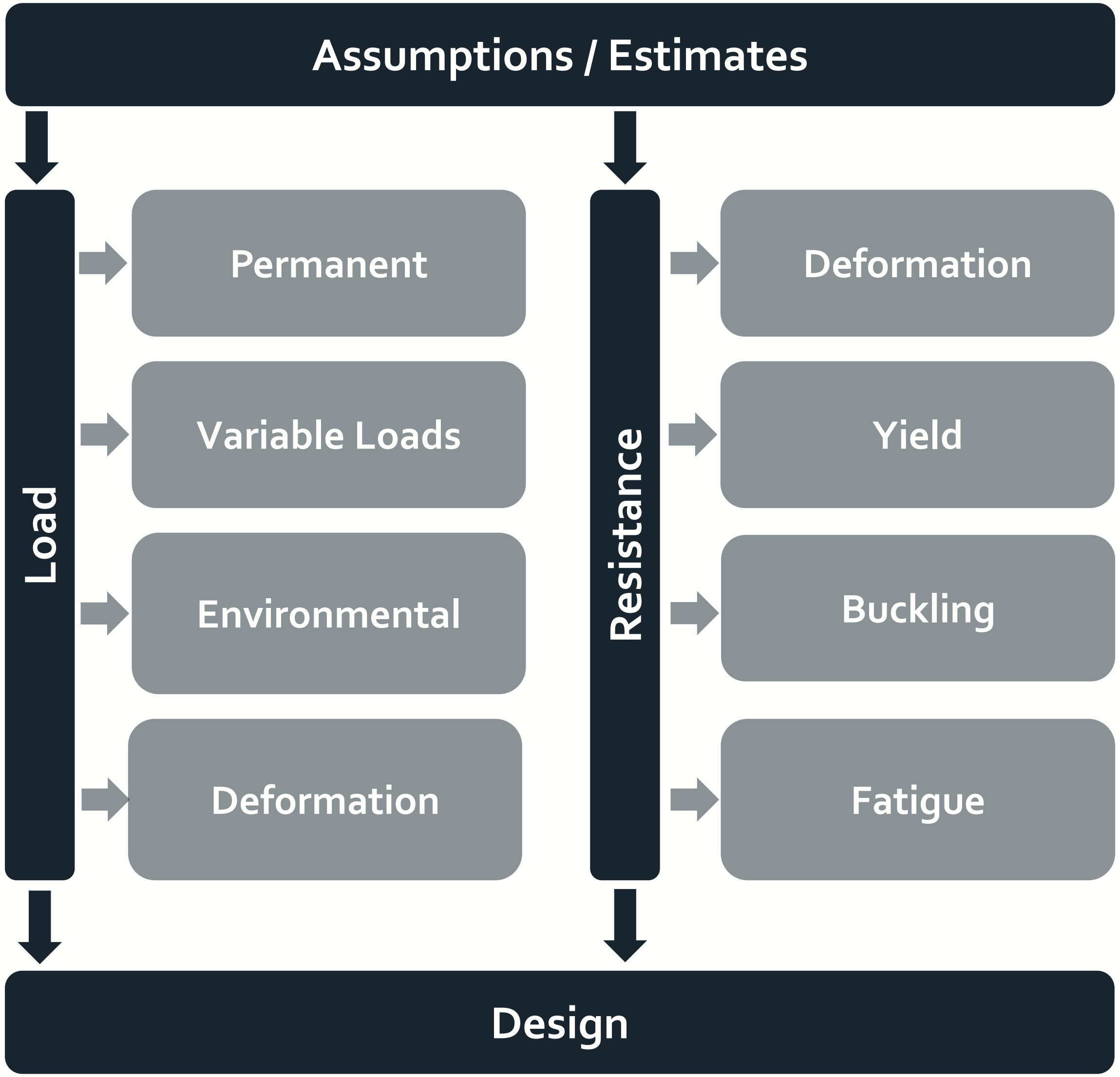
Legislation	• Mandatory inspections required in some countries
Financial	• Assurances required by financial organisations • Requirement for insurer
Operations	• Strategic operational decisions made based on the impact on the asset
Integrity	• Assess remaining life and possible life extension
Reactive	• Fundamental design / manufacturing issues requiring action • Unexpected reactive actions required
Design Optimisation	• Uncertainty drives conservatism in design and therefore increases cost • Learning from through life management could help optimise future design

The need for NDT and SHM

- Many variables in wind turbine design
- Assumptions and estimates made during design
- Typical offshore structure design by LRFD (Load Resistance Factored Design) method
    - DNVGL-ST-0126 – Support Structures for Wind Turbines

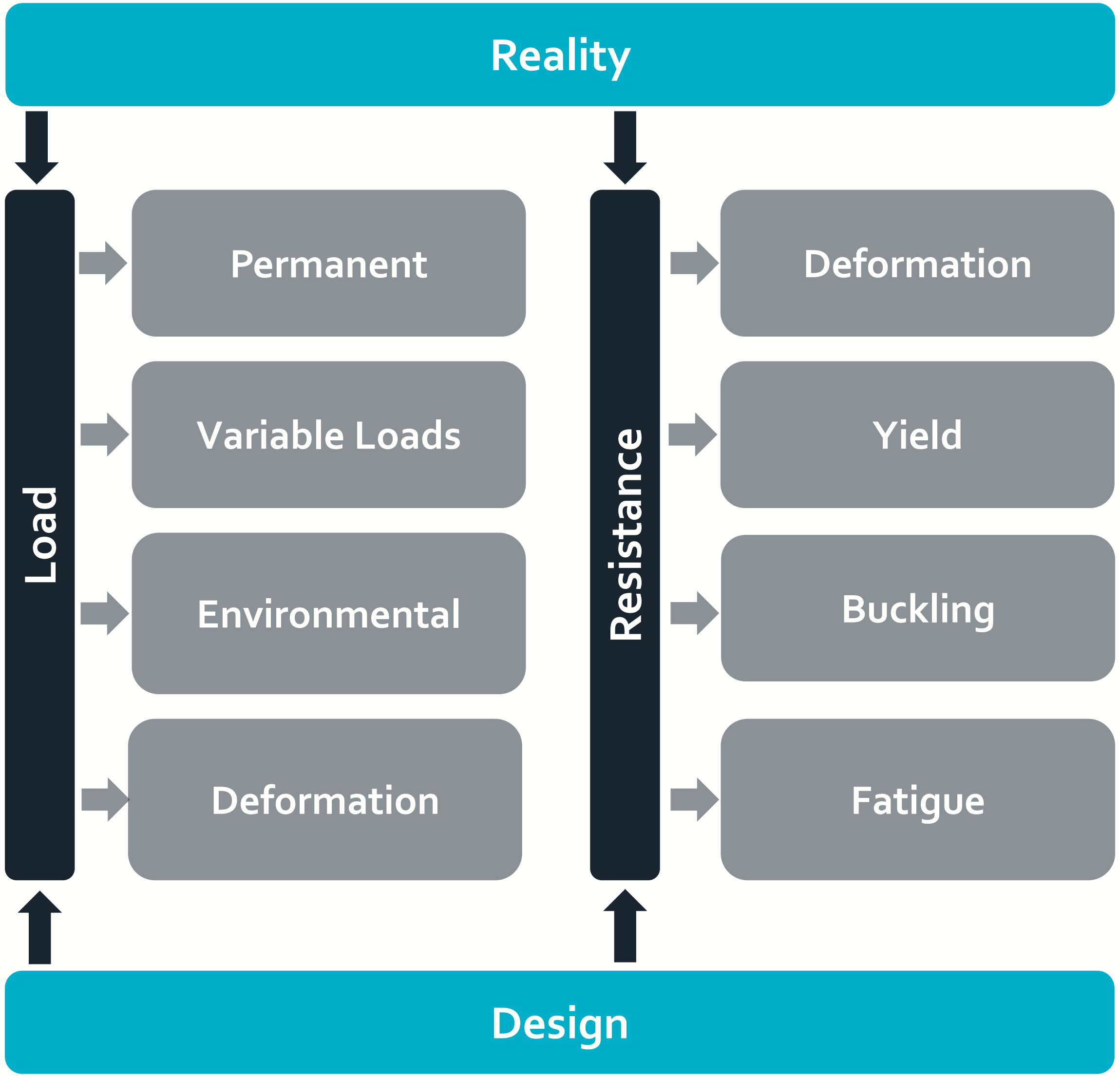


The need for NDT and SHM

- Once asset is operational through life management (reality vs. design) can be carried out

- For example:
    - Are the permanent loads such as weight within the assumed design envelope?
    - Are the variables loads during operation within the limits of those used in design?
    - Does the system during operation provide the yield strength required?
    - Will the fatigue resistance of the component be acceptable?

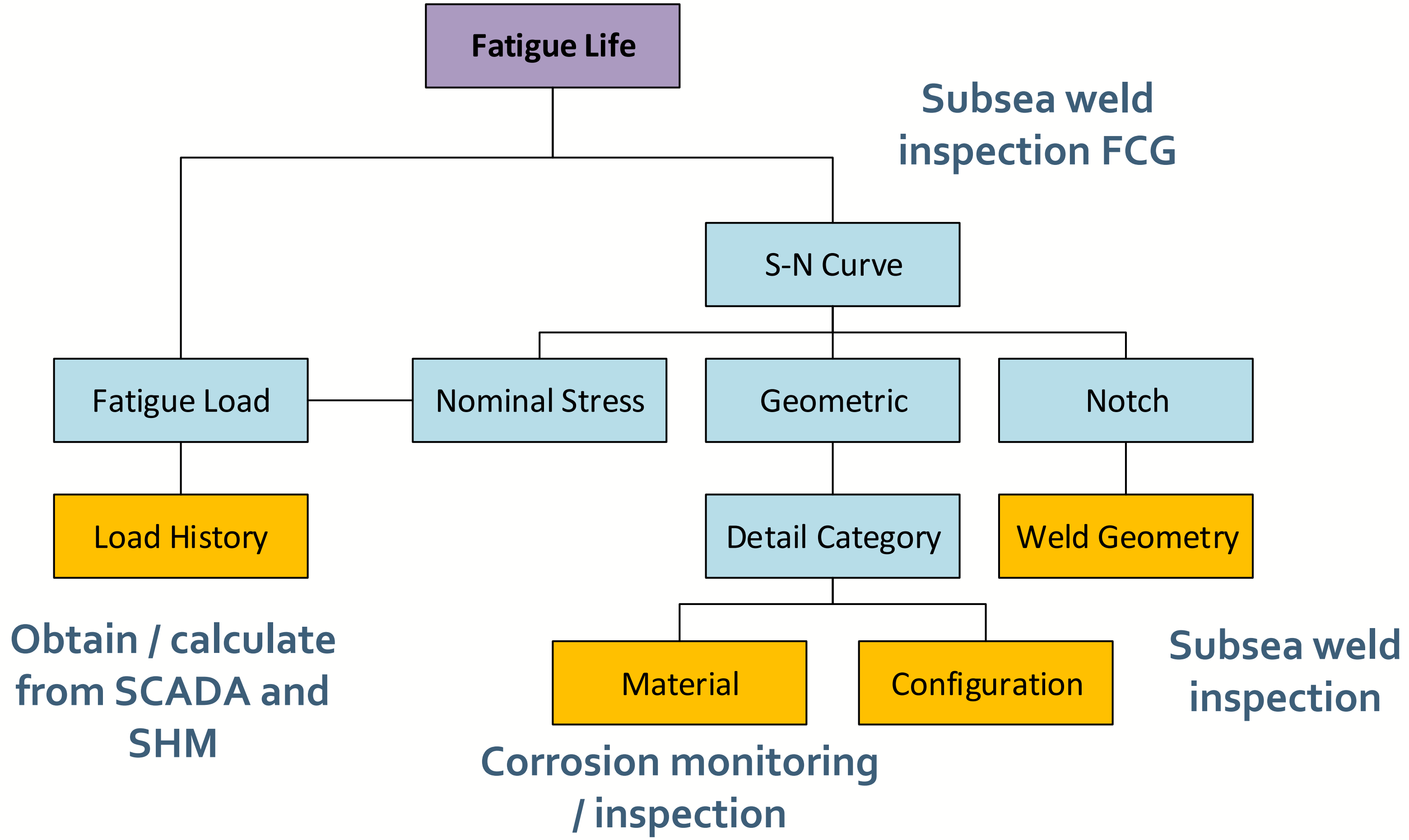
- **To validate the system, measurement of real behaviour is needed → SHM & NDT enable this**

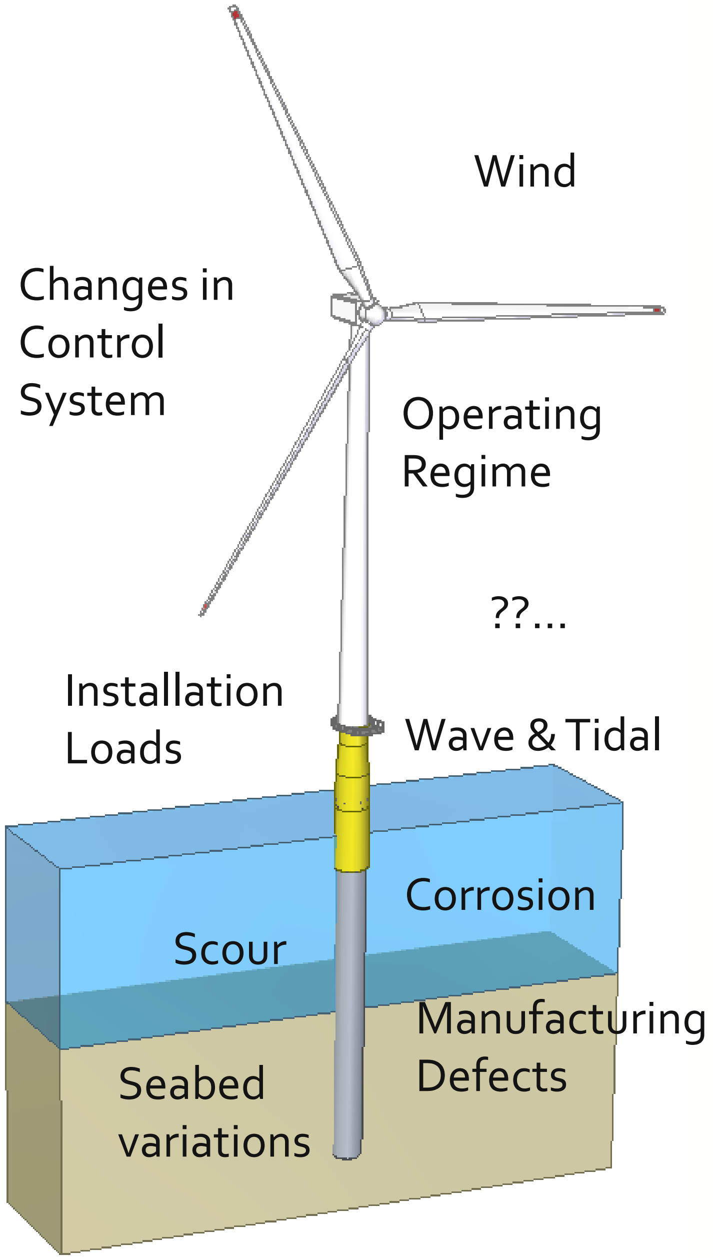


Case Study – Monopile Fatigue

Monopiles are fatigue driven.

Evaluation of remaining life for integrity management or life extension





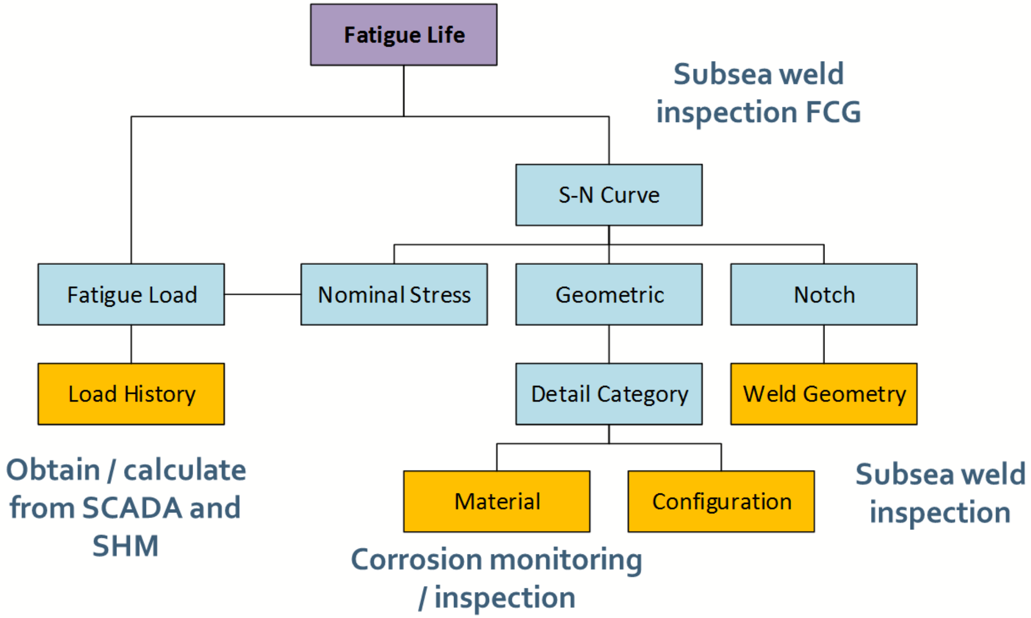
Case Study – Manufacturing Defects

Manufacturing quality concessions on foundation welded joints. Assets commissioned with known defects.

Evaluation of risk required for strategic decisions on operation and remediation options

Inspection and monitoring schedule developed:

- Load:
  - Monitor strains on foundation
  - Estimate of bending moment
  - Compare with design
- Resistance:
  - Assets with severe defects diver inspected annually
  - Acoustic sensors fitted to detect crack growth on high risk assets



Assets continue to operate safely. Cost of complete remediation avoided. Safety justified by evaluating reality against design.

Case Study – Turbine Uprating

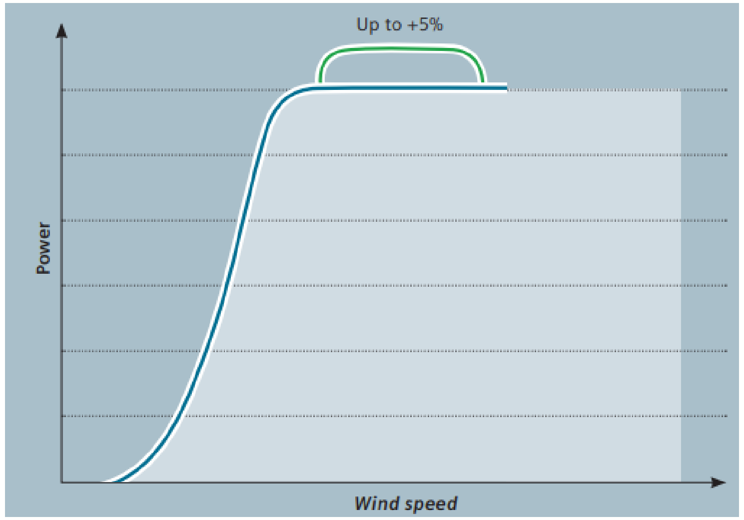
Turbine OEM offers opportunity to uprate the turbine up to 4% AEP, however the substructures have already been designed

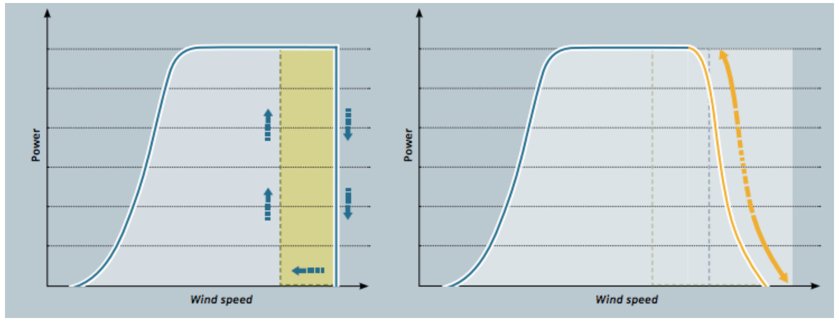
Evaluation of change in control and loading required to ensure integrity is not compromised

Phased introduction of new control system and monitoring on low number of turbines:

- Logging of SCADA and environmental data
- Monitoring of corresponding tower loads through strain gauging
- Run turbine across entire operating range and capture data
- Analysis carried out to evaluate real load vs. design forecast

Loads compared with design specification to ensure they are within the substructure limits → justification of maintained integrity





https://www.siemens.com/content/dam/internet/siemens-com/global/market-specific-solutions/wind/brochures/infographic-power-boost-functionality.pdf

Case Study – Design Optimisation

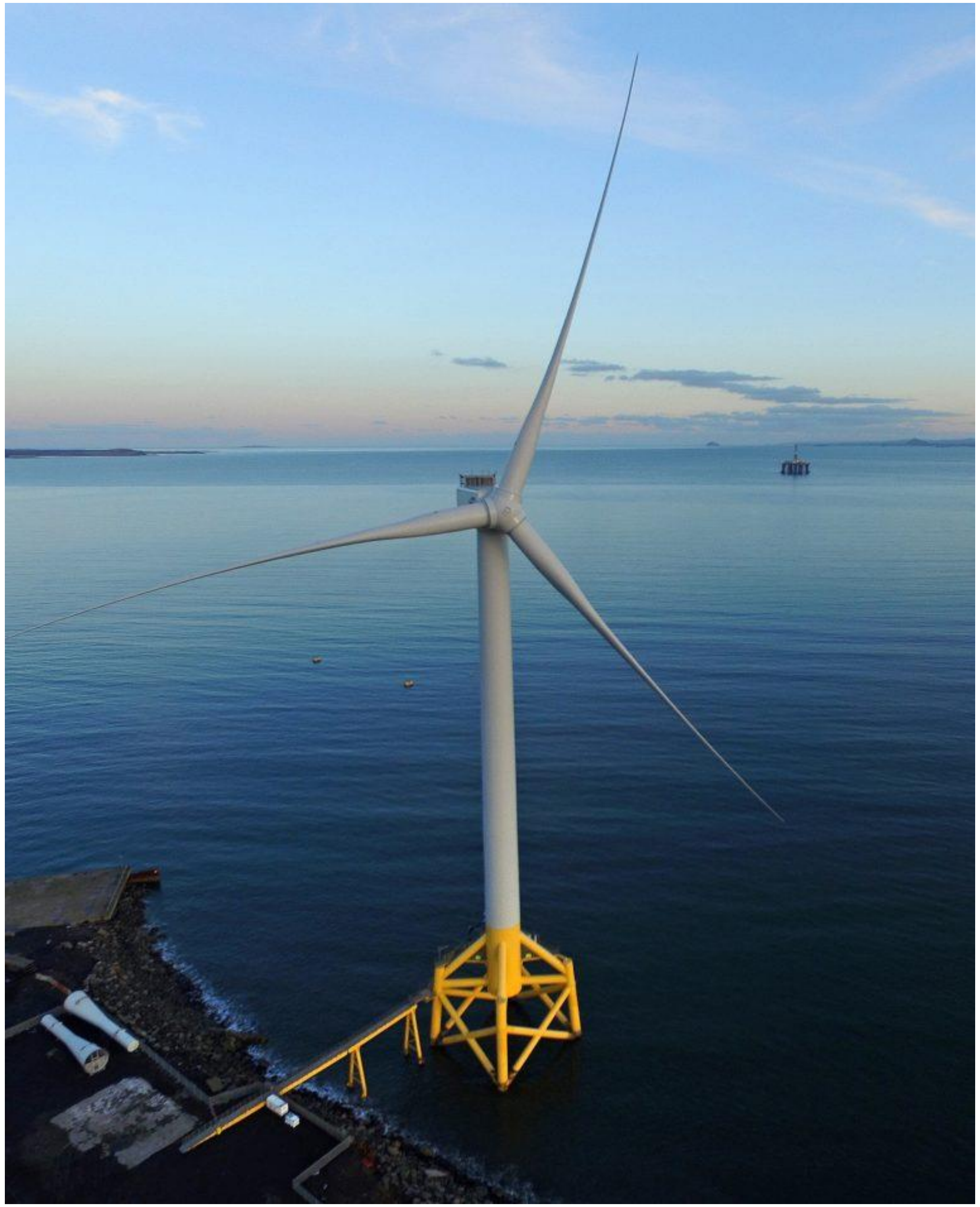
Levenmouth Demonstration Turbine has a jacket structure designed by Ramboll .

Desire to close the design loop by validating design against real performance

Introduction a suite of SHM systems onto the turbine structure including:

- Strain gauging across the jacket, tower, blades
- Accelerometers across tower
- Bolt tension sensors
- LIDAR… and other

Gathered data to be used to validate original design models and perform optimisation



Case Study – Grouted Connection Failure

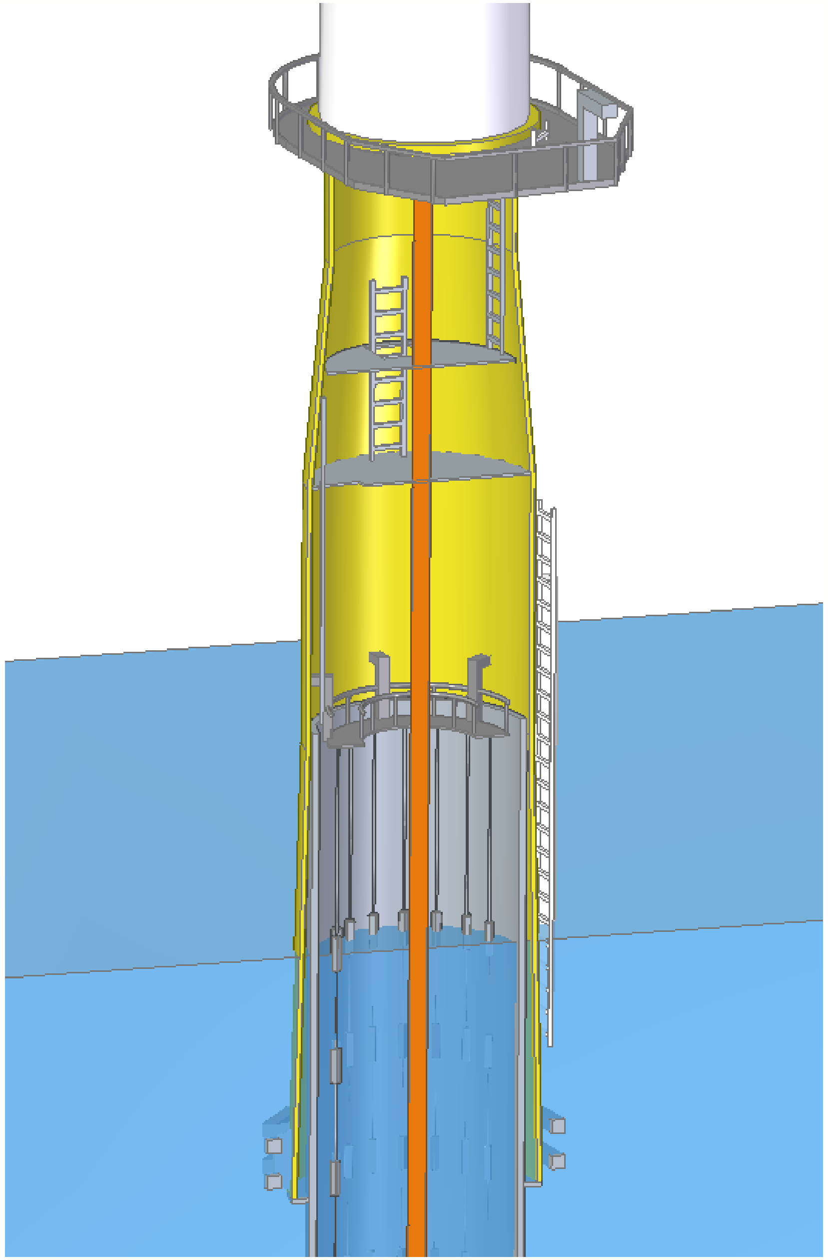
Optimistic assumptions in early foundation design resulted in common failure of grouted connections between TP and MP

Inspection of assets required to determine the condition and integrity of grouted connections

Use of ROV equipped with ultrasonic inspection sensor to inspect the integrity of the grouted joint, through the steel structure

- Sensor could be deployed either outside of inside the pile
- Marine growth removal will be required
- Interpretation of sensor data required

Enables check of grout interface integrity and drive the need for remediation. Design standards revised to incorporate failure learnings and mitigate grouted connection failures for future designs



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