Definition of a Foundation Monitoring Strategy Based on Criticality

Session 5.6 H2020 Project: ROMEO

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Balancing CAPEX and OPEX can only be achieved with a lifecycle view

Maintenance strategy needs to be developed from detailed design on - to cut LCOE.
### Periodic Inspection of OFW Support Structures (DNV)

<table>
<thead>
<tr>
<th>Component</th>
<th>Inspection Interval</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifting Appliances</td>
<td>&lt; 1 year</td>
<td></td>
</tr>
<tr>
<td>Bolt Pre-tension</td>
<td>&lt; 1 year</td>
<td></td>
</tr>
<tr>
<td>Grouted Connections/Grout Seal</td>
<td>&lt; 1 year</td>
<td>Usually sufficient to inspect limited number of structures (as long as inspected behaviour is similar).</td>
</tr>
<tr>
<td>Upper part of Ladders</td>
<td>&lt; 1 year</td>
<td></td>
</tr>
<tr>
<td>Upper part of J-Tubes</td>
<td>&lt; 1 year</td>
<td></td>
</tr>
<tr>
<td>Fatigue Cracks</td>
<td></td>
<td>Depends on design fatigue factor (DFF). Reliable inspection (eddy current or magnetic particle inspection) has to be carried out.</td>
</tr>
<tr>
<td>Dents and Deformations</td>
<td>&lt; 5 years</td>
<td>Inspection should clarify the structural condition above water.</td>
</tr>
<tr>
<td>Marine Growth</td>
<td>&lt; 1 year</td>
<td>Is there marine growth that has to be removed to comply with the design assumptions?</td>
</tr>
<tr>
<td>Access Platforms</td>
<td>&lt; 1 year</td>
<td></td>
</tr>
<tr>
<td>Upper part of Fenders</td>
<td>&lt; 1 year</td>
<td></td>
</tr>
<tr>
<td>Lower part of Ladders</td>
<td>&lt; 5 years</td>
<td>(more frequent inspection during first five years)</td>
</tr>
<tr>
<td>Lower part of Fenders</td>
<td>&lt; 5 years</td>
<td>(more frequent inspection during first five years)</td>
</tr>
<tr>
<td>Corrosion Protection</td>
<td>&lt; 1 year (above water)</td>
<td>Anodes and coating have to be checked. Visual inspection below water may be carried out by ROV.</td>
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<tr>
<td></td>
<td>&lt; 5 years (below water)</td>
<td></td>
</tr>
<tr>
<td>Dents, Deformations, Damage, Debris</td>
<td>&lt; 5 years</td>
<td>Inspection should clarify the structural condition below water. Visual inspection may be carried out by ROV.</td>
</tr>
<tr>
<td>Fatigue Cracks</td>
<td></td>
<td>Inspection Interval = Calculated fatigue life ( \gamma_m \cdot 3.0 ). Reliable inspection has to be carried out.</td>
</tr>
<tr>
<td>Lower part of J-Tubes</td>
<td>&lt; 5 years</td>
<td>Check for damages. (more frequent inspection during first five years)</td>
</tr>
<tr>
<td>Scour and Scour Protection</td>
<td>&lt; 5 years</td>
<td>Check scour protection and possible scour development. (more frequent inspection during first five years)</td>
</tr>
</tbody>
</table>
Industry 4.0 entering Offshore Wind

What is the economic value of condition based maintenance?

✓ reduce OPEX: 10-40%
✓ reduce downtime: 50%
✓ lower CAPEX: 3-5%

From: McKinsey Global Institute report, The Internet of Things: Mapping the value beyond the hype

Source: McKinsey Global Institute report, The Internet of Things: Mapping the value beyond the hype
Statement:

There are sufficient technological solutions. It is about mastering the process.
Failure Modes and Effect Analysis

Customised FMECA focused on those mechanisms that take sufficient time before a failure materialises. Hence allow sufficient time to react and plan for maintenance mobilization / failure prevention or mitigation.

Conclusions

1) More than 60 failure modes have been investigated related to substructures
2) For almost half of them, a value creating potential for the use of monitoring systems was identified
Assess potential for monitoring for high criticality items
Virtual sensing
Optimal Sensor Placement Analysis

Approach

1) Analysis of current sensor set up through Modal Assurance Criterion
2) Definition of possible sensor placement locations
3) Optimisation of the sensor layout by adding/removing sensors. Sensor elimination technique – max. accepted coupling is 25%.

Average displacement modulus at OSS and WTG
Virtual sensing
Optimal Sensor Placement Analysis

Current OSS CMS:
- Sensors not located in areas where highest displacements are expected.
- Approx. 60% of coupling between 2nd and 5th mode.
- Too many DOFs leading to coupling.

Optimised variant of OSS CMS:
- Disregarding 9 DOFs lead to better results with addition of 1x ACC at roof deck.
- Coupling is reduced to a max. of 17.5%.
Virtual sensing
Optimal Sensor Placement Analysis

Current WTG CMS:
- Approx. 25% correlation between 1st and 3rd mode shape – just at the acceptable limit.
- Others pairs with a maximum 10% correlation.

Optimised variant of WTG CMS:
- Slight improvements with 4x acc. sensors.
- Coupling is reduced to a max. of 17.5%.
Summary

1. Always start with Failure Mode and Criticality Analysis
2. Define purpose and objectives of monitoring based on highest criticalities
3. Develop failure mechanisms and match with currently existing monitoring technology
4. Assess capabilities of virtual sensing.
5. Assess capabilities of direct monitoring
7. Develop monitoring concept for entire wind farm based on parameter variation

- Purpose driven monitoring system
- With cost effective sensor layout
- Condition based maintenance enabled
Thanks for your attention.

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