

# Definition of a Foundation Monitoring Strategy Based on Criticality

Session 5.6 H2020 Project: ROMEO

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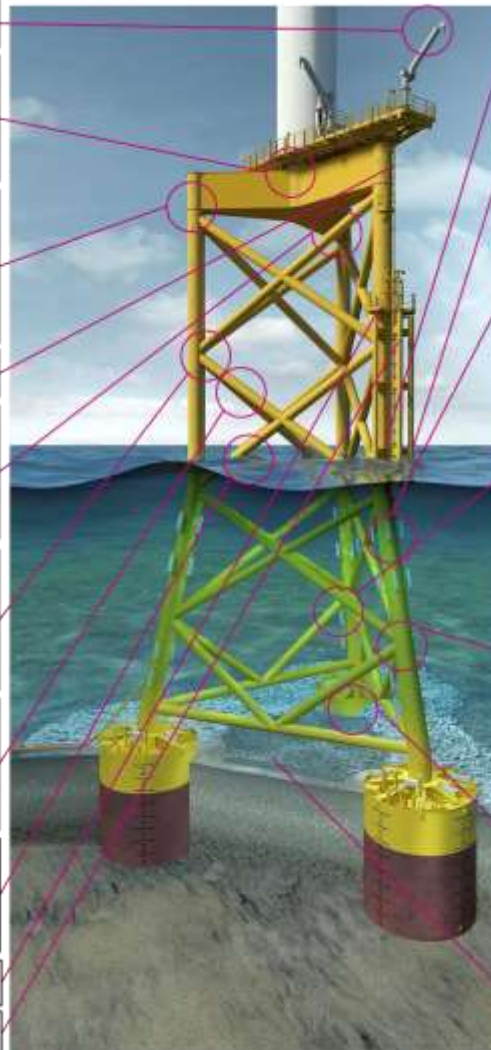






# Balancing CAPEX and OPEX can only be achieved with a lifecycle view



Maintenance strategy needs to be developed from detailed design on - to cut LCOE.

Check for damages.	Inspection Interval: < 1 year	<b>Lifting appliances</b>
Check for damages at bolted connections. Check bolt pre-tension.	Inspection Interval: < 1 year	<b>Bolt pre-tension</b> 
Inspect grout seal for cracks and loss of grout (top and bottom of connections). Usually sufficient to inspect limited number of structures (as long as inspected behaviour is similar).	Inspection Interval: < 1 year	<b>Grouted Connections/ Grout Seal</b> 
Check for damages.	Inspection Interval: < 1 year	<b>Upper part of Ladders</b>
Check for damages.	Inspection Interval: < 1 year	<b>Upper part of J-Tubes</b> 
Inspection Interval = Calculated fatigue life * DFF/3.0 Reliable inspection (eddy current or magnetic particle inspection) has to be carried out.	Inspection Interval: Depends on design fatigue factor (DFF)	<b>Fatigue Cracks</b> 
Inspection should clarify the structural condition above water.	Inspection Interval: < 1 year	<b>Dents and Deformations</b> 
Is there marine growth that has to be removed to comply with the design assumptions?	Inspection Interval: < 1 year	<b>Marine Growth</b> 
Check for damages.	Inspection Interval: < 1 year	<b>Access Platforms</b>
Check for damages.	Inspection Interval: < 1 year	<b>Upper part of Fenders</b>



<b>Lower part of Ladders</b>	Inspection Interval: < 5 years	(more frequent inspection during first five years)
<b>Lower part of Fenders</b>	Inspection Interval: < 5 years	(more frequent inspection during first five years)
<b>Corrosion Protection</b> 	Inspection Interval: < 1 year (above water) < 5 years (below water)	Anodes and coating have to be checked. Visual inspection below water may be carried out by ROV
<b>Dents, Deformations, Damages and Debris</b> 	Inspection Interval: < 5 years	Inspection should clarify the structural condition below water. Visual inspection may be carried out by ROV
<b>Fatigue Cracks</b> 	Inspection Interval: Depends on material factor ( $\gamma_m$ )	Inspection Interval = Calculated fatigue life * $\gamma_m^2/1.25^2$ Reliable inspection has to be carried out.
<b>Lower part of J-Tubes</b> 	Inspection Interval: < 5 years	Check for damages. (more frequent inspection during first five years)
<b>Scour and Scour Protection</b>	Inspection Interval: < 5 years	Check scour protection and possible scour development (more frequent inspection during first five years)

Periodic Inspection OFW Support Structures (DNV)

# 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

A background image showing several wind turbines on a coastal plain at sunset. The sun is low on the horizon, casting a warm orange glow across the sky and reflecting on the water in the foreground. The turbines are silhouetted against the bright sky.

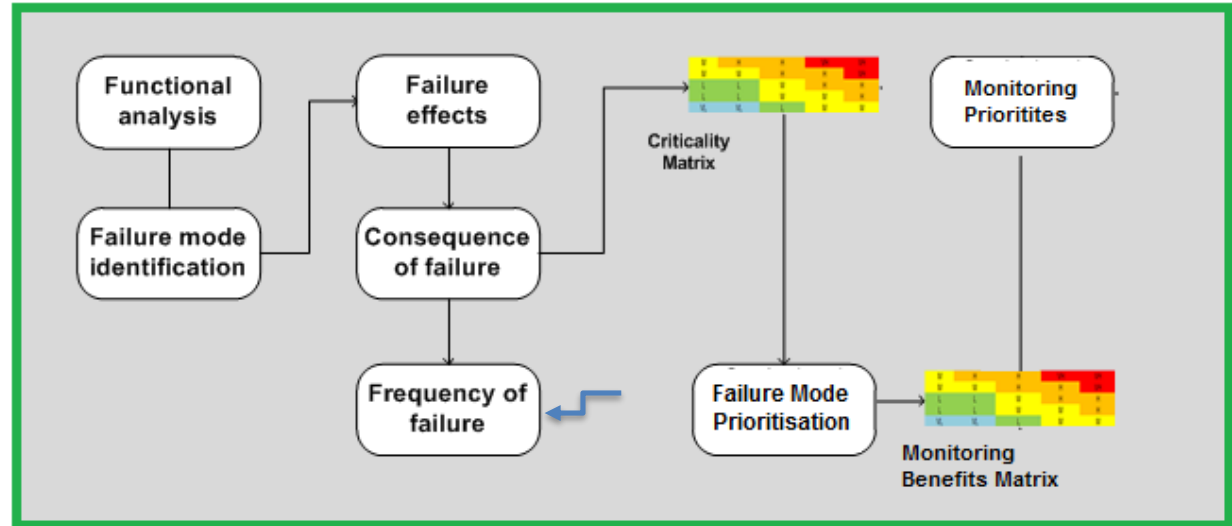
Statement:

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.

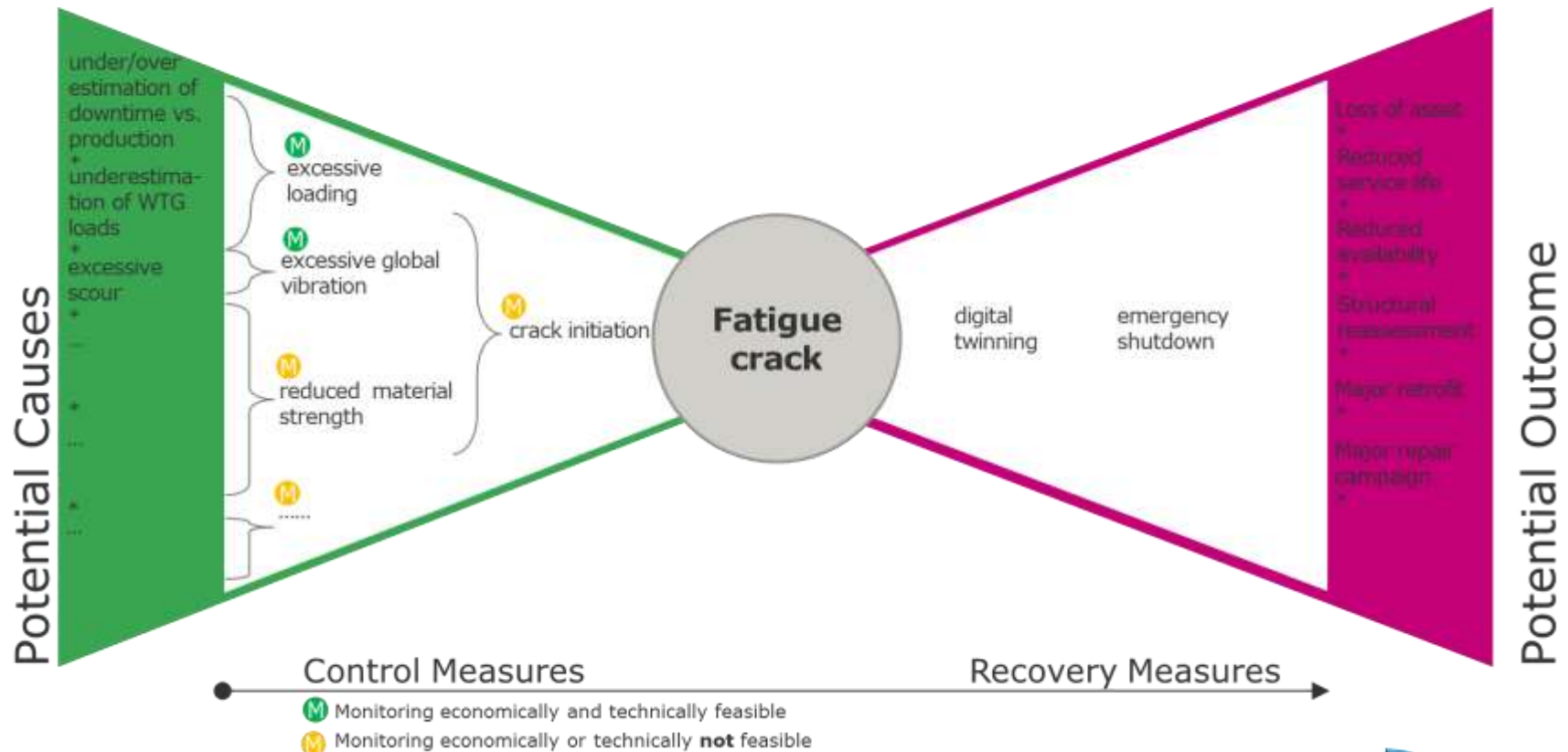


## Conclusions

- 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

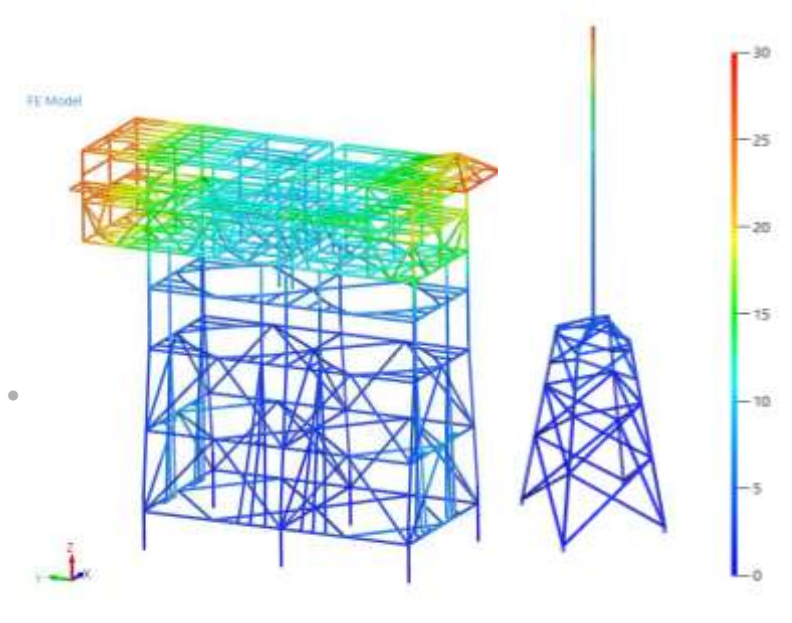


# Assess potential for monitoring for high criticality items



# Virtual sensing

## Optimal Sensor Placement Analysis



*Average displacement modulus at OSS and WTG*

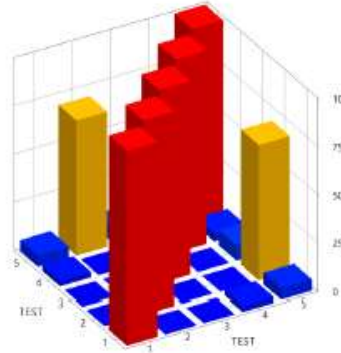
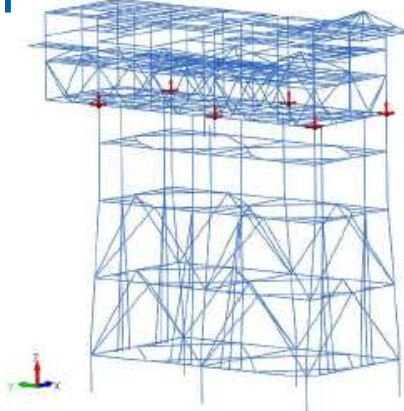
### Approach

- 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%.



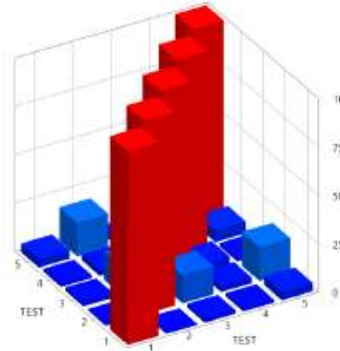
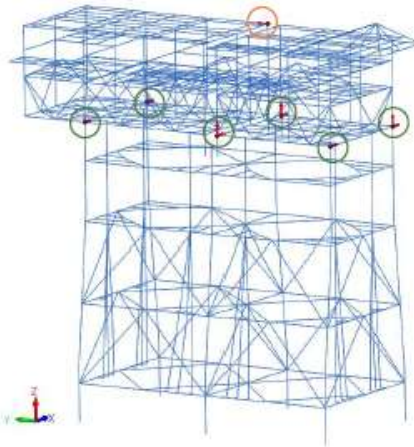
# Virtual sensing

## Optimal Sensor Placement Analysis



### Current OSS CMS:

- Sensors not located in areas where highest displacements are expected.
- Approx. 60% of coupling between 2<sup>nd</sup> and 5<sup>th</sup> mode.
- Too many DOFs leading to coupling.

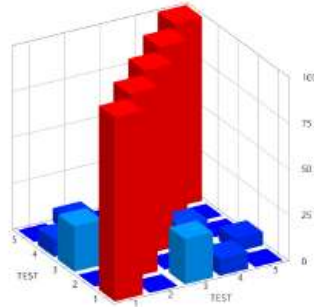
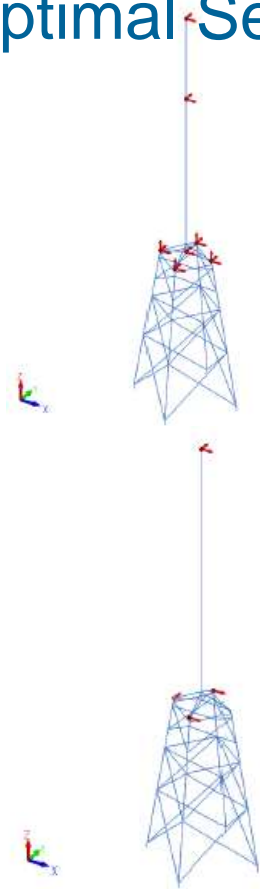


### Optimised variant of OSS CMS:

- Disregarding 9 DOFs lead to better results with addition of 1x ACC at roof deck.
- Coupling is reduced to a max. of 17.5%.

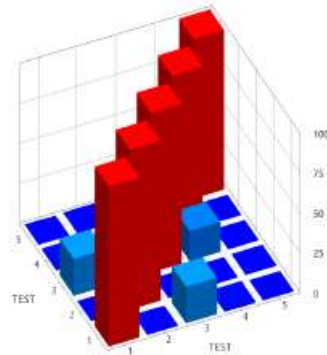
# Virtual sensing

## Optimal Sensor Placement Analysis



### Current WTG CMS:

- Approx. 25% correlation between 1<sup>st</sup> and 3<sup>rd</sup> 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
  6. Benchmark solutions economically and technically.
  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

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Thanks for your attention.

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