OFFSHORE WIND TURBINE INSTALLATION - SAFELY PUSHING THE BOUNDARIES

18 OCT 2018, SCHIEDAM

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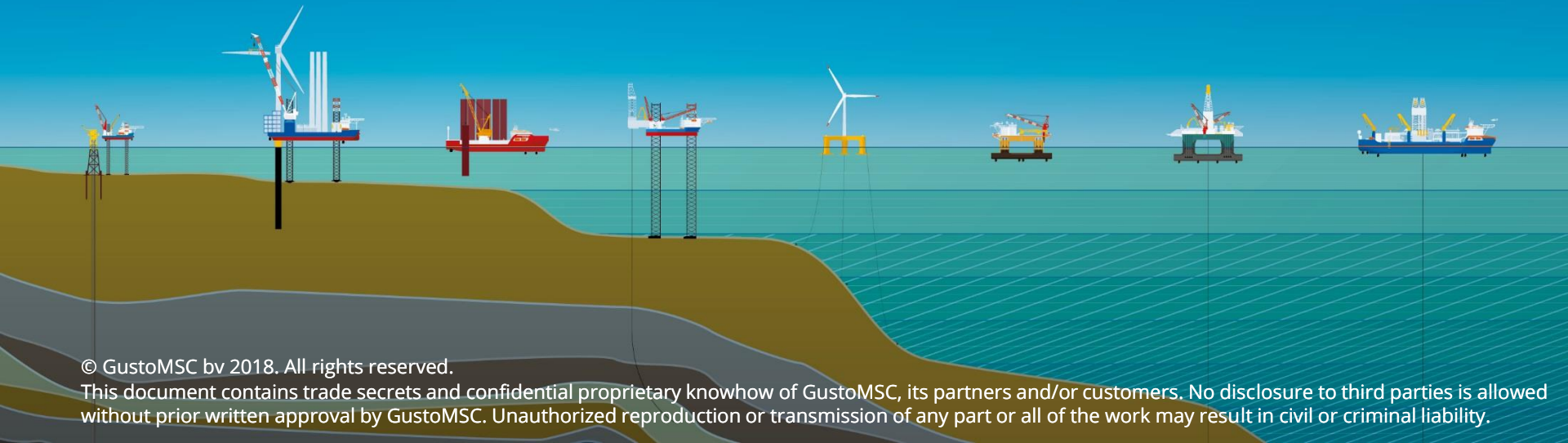


OVERVIEW

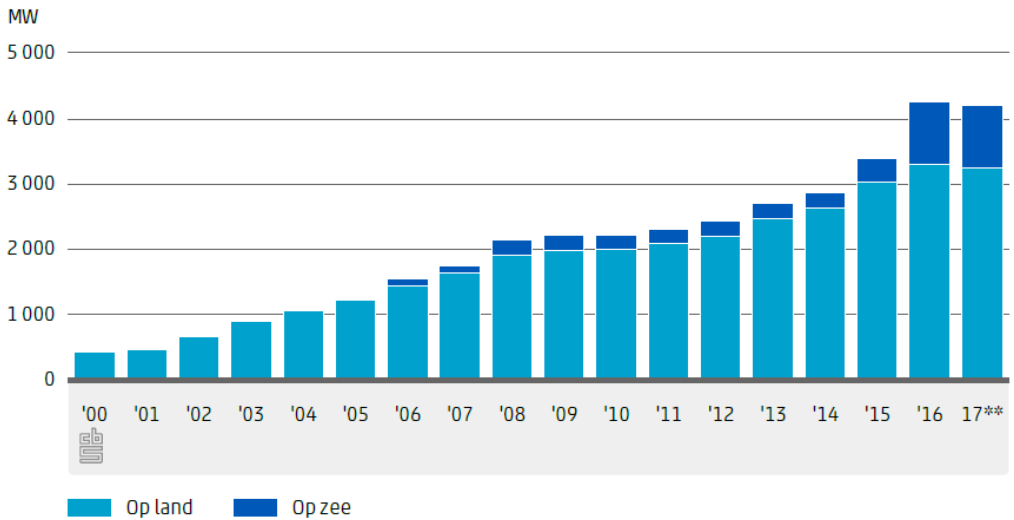
Introduction
- Market development
- Wind Turbine Installation
- WTI jack-up sizing challenges
- Why push the limits?

Industry knowledge gaps
- Information flow
- Soil interaction
- Increased dynamics

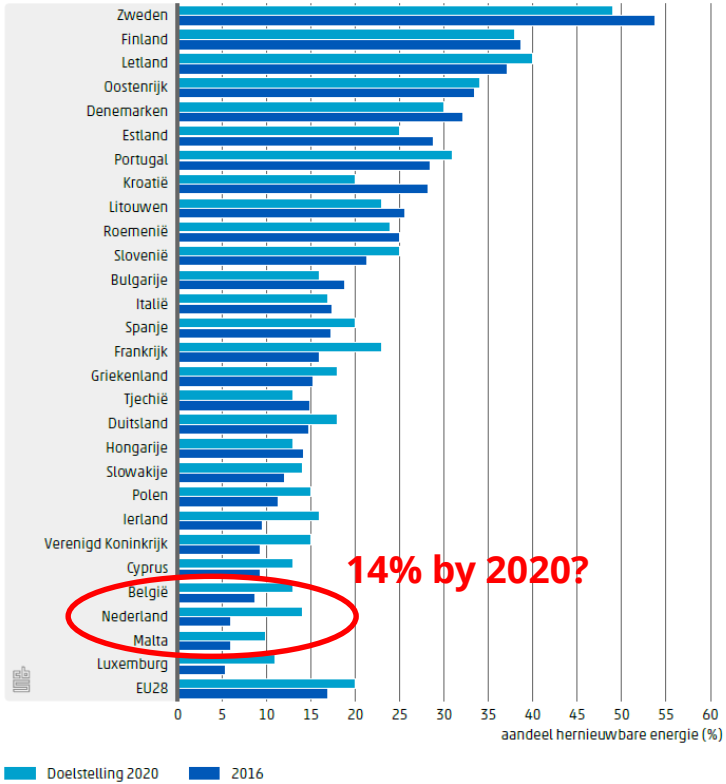
Pushing the boundaries safely

MARKET

4.0.1 Opgesteld vermogen windenergie



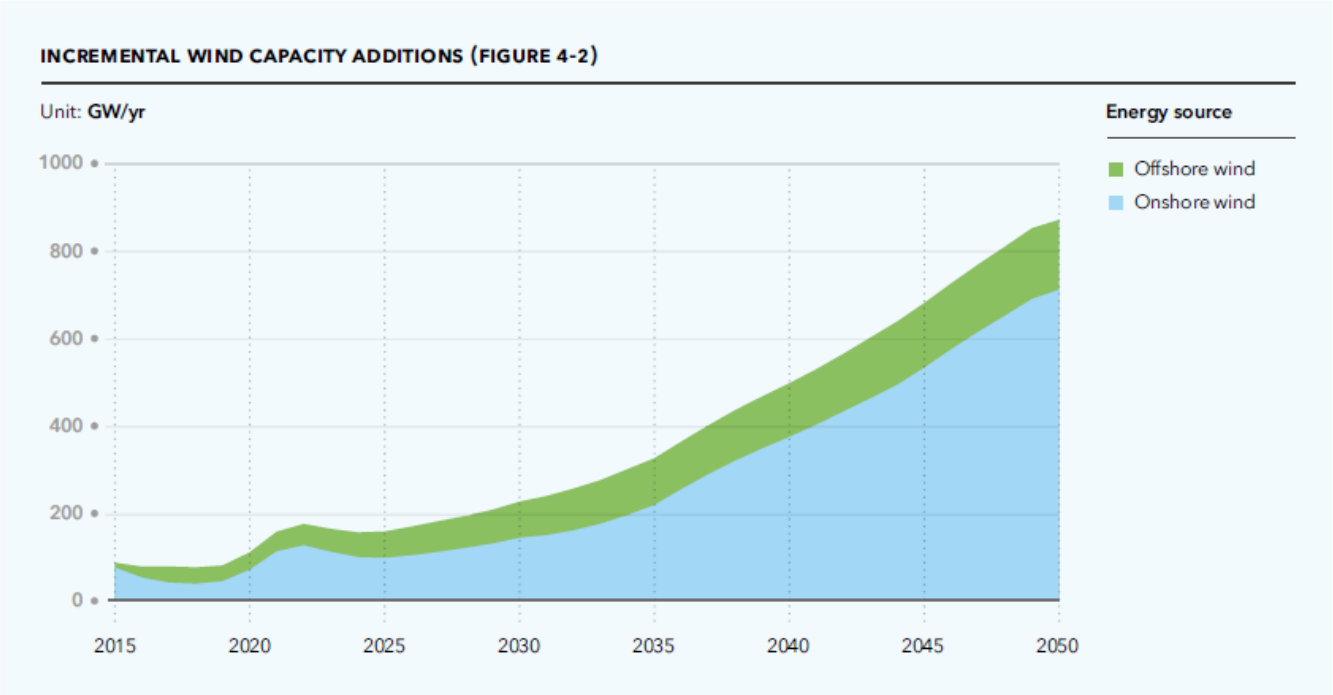
2.5.1 Aandeel hernieuwbare energie in bruto energetisch eindverbruik



Bron: CBS voor Nederland, Eurostat (2017a) voor andere landen.

Source: CBS – Hernieuwbare energie in Nederland 2017

MARKET - WORLD WIDE POTENTIAL?

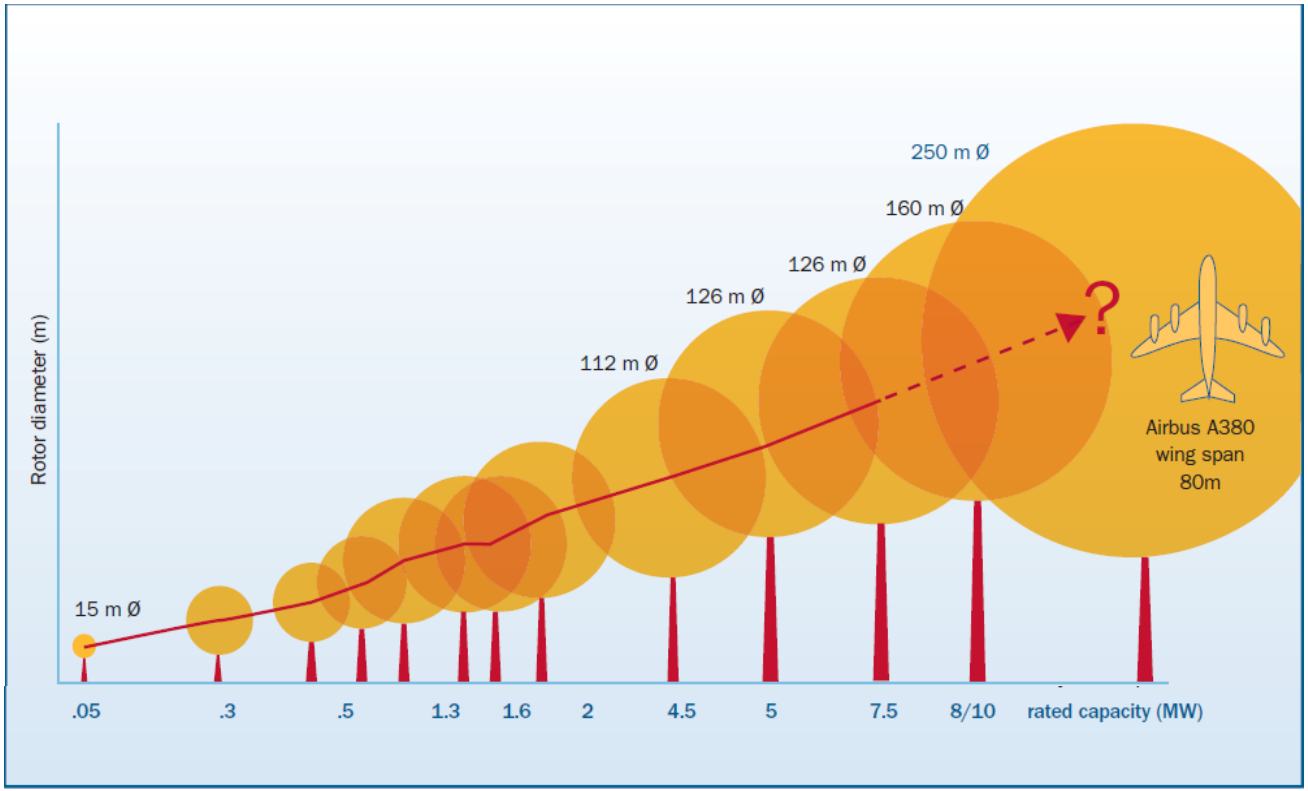


Source: DNV GL_ Energy Transition Outlook 2017

Question:

How to get those MW's up and running...

...safely and efficiently?



Source: GEAI (modified)

FOUNDATION INSTALLATION

FOUNDATION INSTALLATION

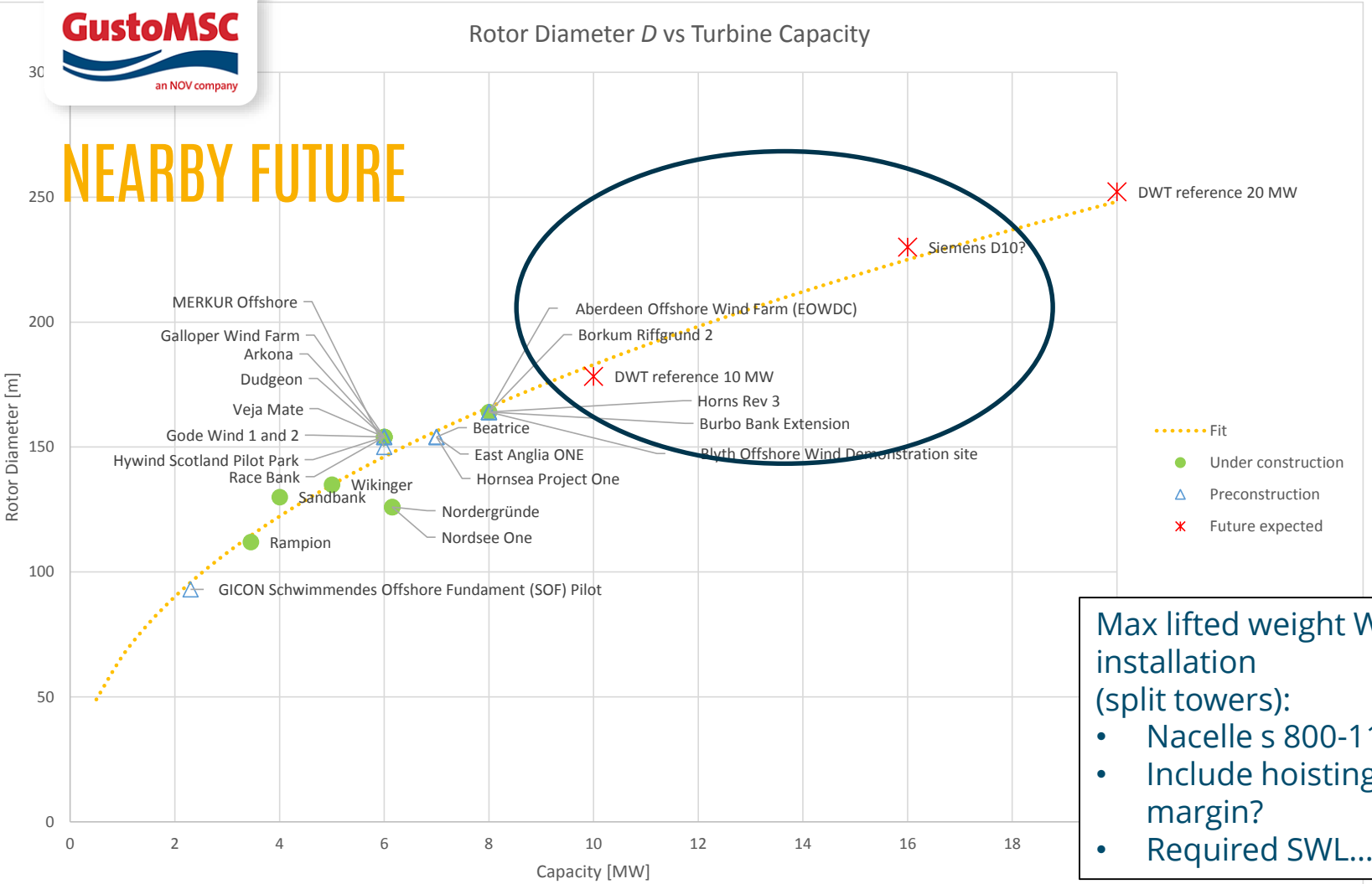
TRANSITION PIECE INSTALLATION

TURBINE INSTALLATION

The table must be stable…

Especially when mating bolted flanges at 100+ m above SWL

NEARBY FUTURE



Max lifted weight WTG installation
(split towers):

- Nacelle s 800-1100 t?
- Include hoisting gear, margin?
- Required SWL…?

TURBINES ARE GETTING LARGER

Installation bottleneck?
Higher mass to be lifted → Larger cranes needed

Larger crane → Larger Jack-Up needed. Cost still in proportion?

Higher hub heights → Longer crane. Stiffness? Dynamics?

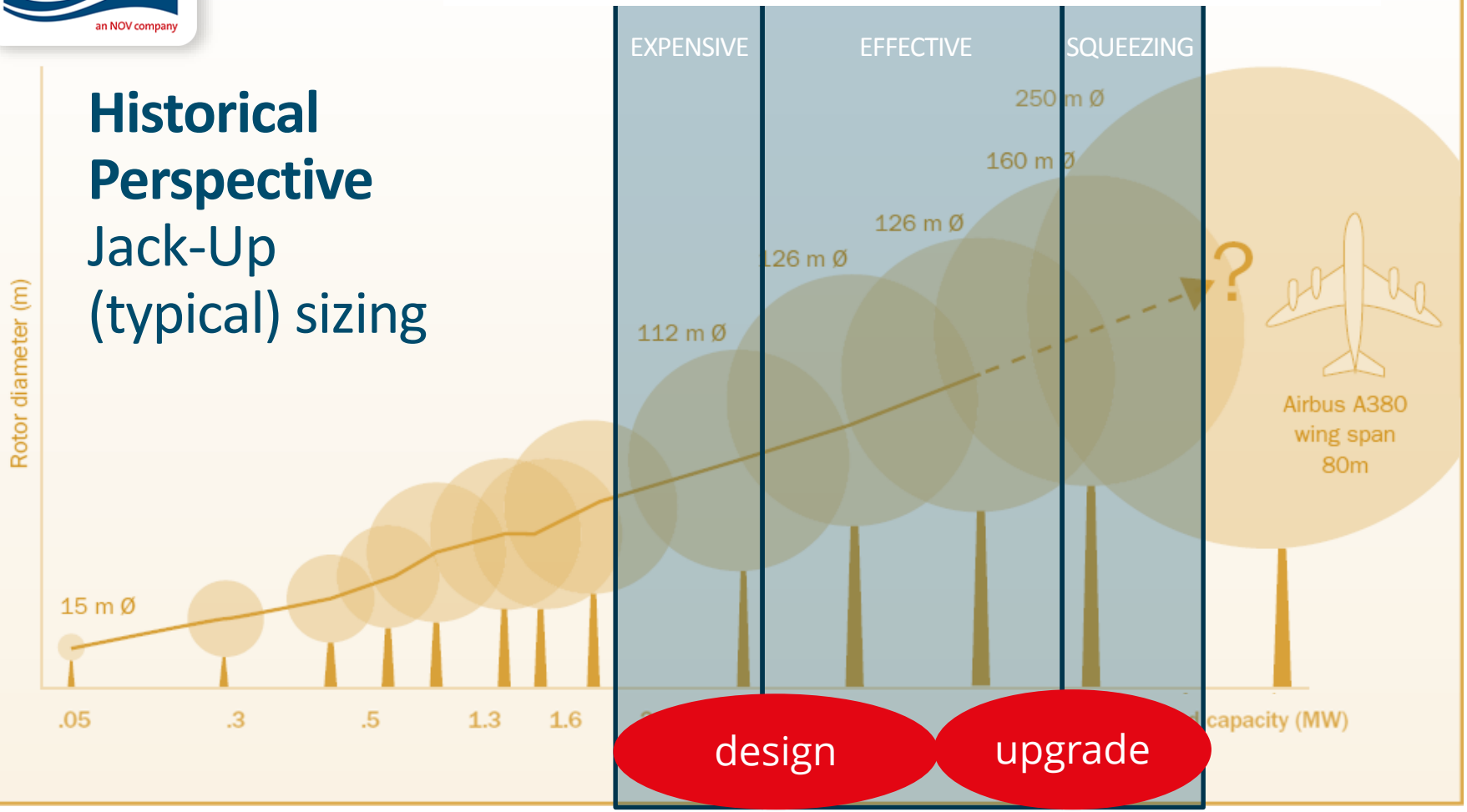
Fewer turbines per field: 400 MW wind farm? 100 x 4 MW vs 40 x 10 MW

Can we predict a reasonable horizon? Investment for 20 years?

GustoMSC
an NOV company

NG-9000C (trendsetter)

Historical Perspective
Jack-Up
(typical) sizing



Source: GEAI (modified)

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Fewer turbines per field: 400 MW wind farm? 100 x 4 MW vs 40 x 10 MW

Can we predict a reasonable horizon? Investment for 20 years?

Can we stretch current solutions?

Extremely long boom:

- Maneuvering in harbor
- Boom flexibility, tuggering
- Extra boom weight = extra overturning
- Transit sea state (boom strength + fatigue)

Can we stay efficient enough?

Or do we go back in time? LCOE?

Note: Ingenious solution, but for harsh remote sites different solutions are required

Current Lifting Height:

- Typical 6-8 MW
- Hub height approx. ±115 m +SWL
- Required hook height:
  ±150 m +SWL
  Reasonable airgap 15 m
- Typical hull depth 10 m

Consequence:

Long crane boom required for 6-8 MW.

Next generation WTG: **Extremely** long boom required.

PRELOADING - CRANE OPS

Larger crane?

Jack-up OK?

How about the soil?

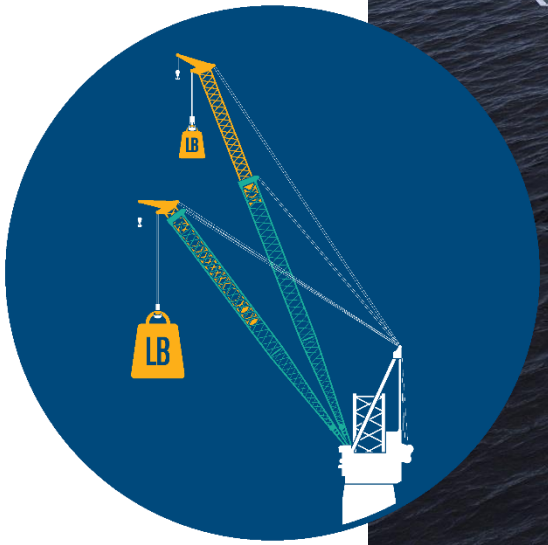
FOUNDATION INTEGRITY

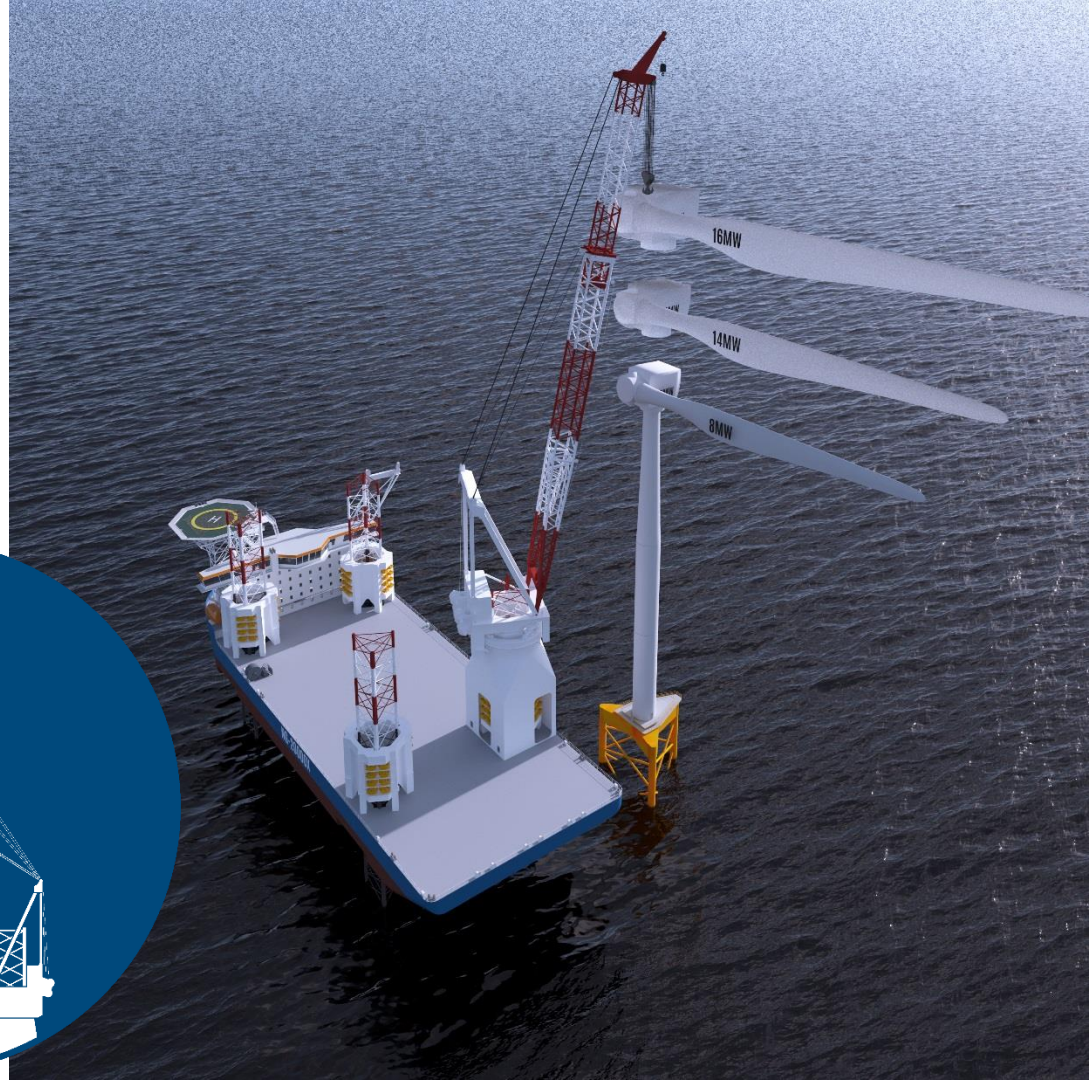
EXTENDED HEIGHT + WEIGHT

Telescopic boom, proven platform, truss legs
Solid

Sufficient beam
Safe

Sufficient preload
Stable



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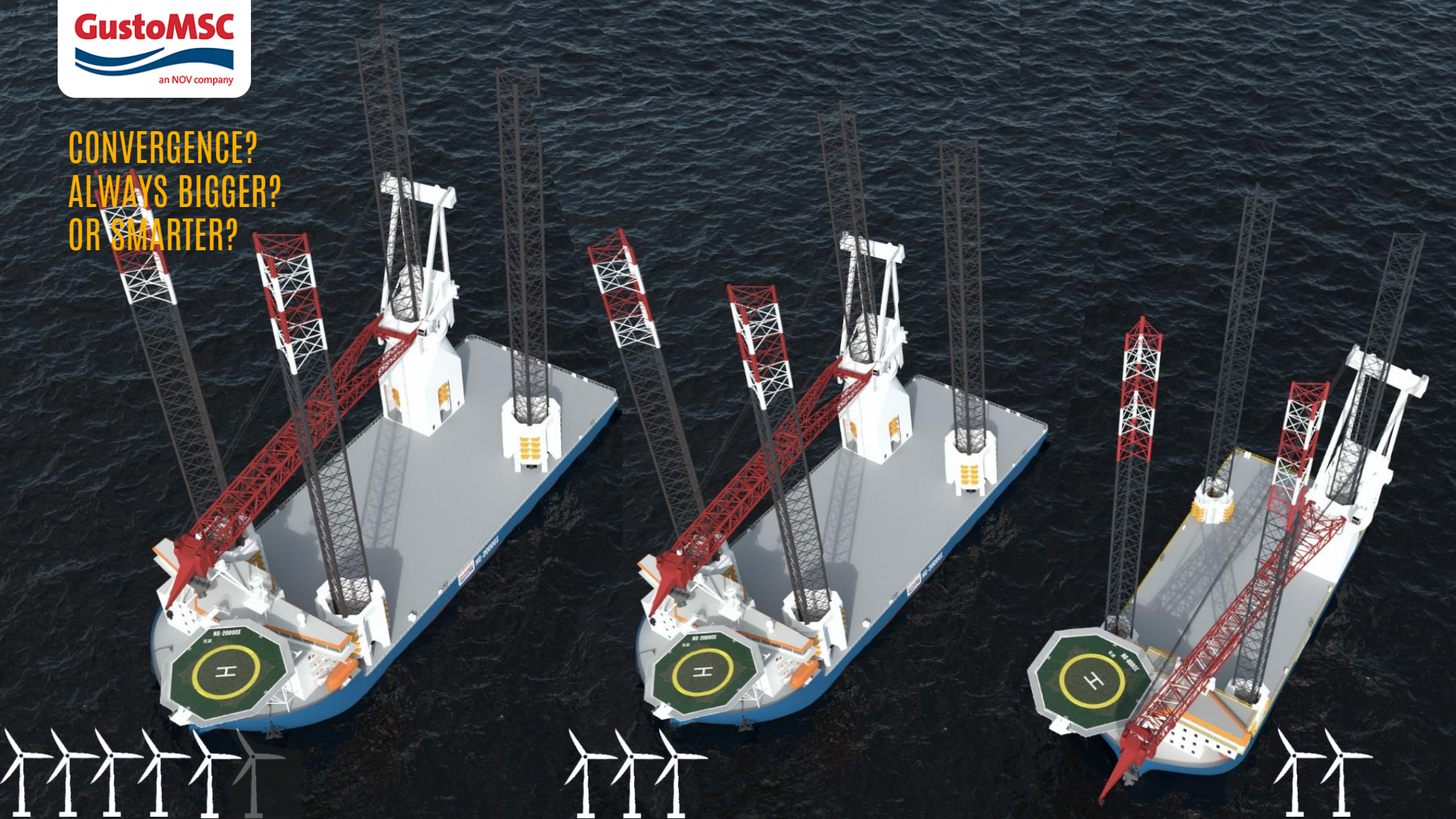
CONVERGENCE?
ALWAYS BIGGER?
OR SMARTER?



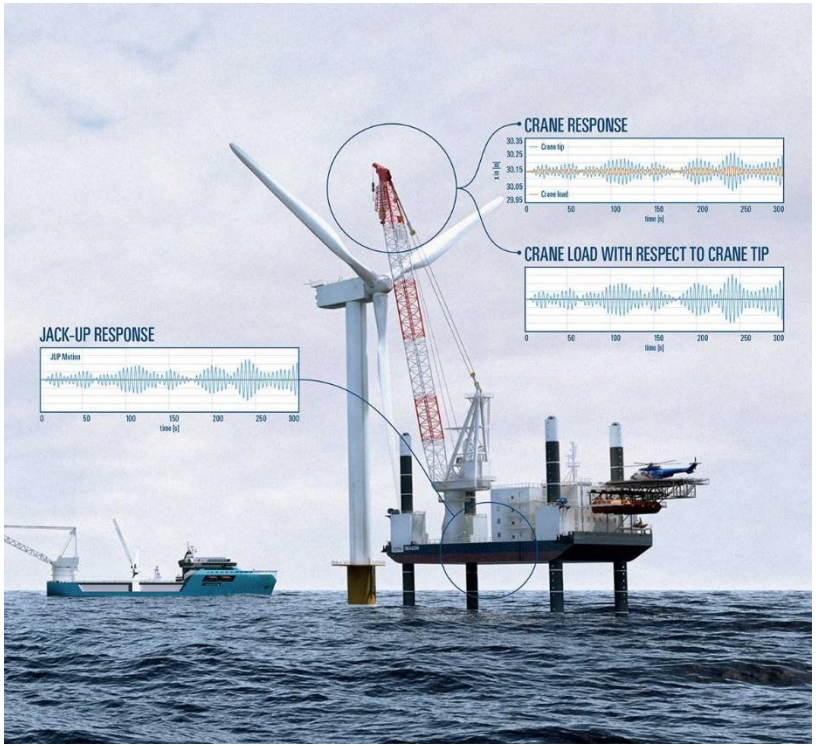
WHY PUSH THE LIMITS

Bigger is not always better

Stretching current solutions, developing improvements
By in depth knowledge of technical and key operational challenges

To achieve more efficiency at equal or better safety

PUSHING THE LIMITS - TRADITIONAL ENGINEERING METHODS

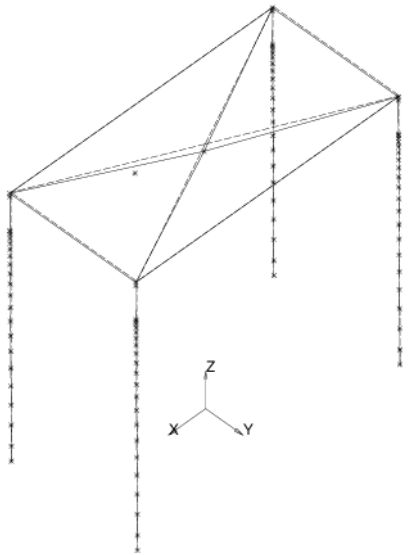


A successful wind turbine installation starts with a well designed jack-up that provides a solid and stable basis for the required operations.

Operational boundaries can only be optimized based on a thorough understanding of the jack-up and crane response in an offshore environment.

To provide the required insight into the workability of jack-ups, GustoMSC has developed a portfolio of engineering tools, which allow a thorough yet fast assessment of the motions and internal loads for any given unit and its crane.

ENGINEERING TOOLS - EQUIVALENT JACK-UP MODELS



GustoMSC has developed (and continuously improves) the software it uses to assess the behavior of a jack-up on site.

Equivalent jack-up models are used to assess the (dynamic) response of the jack-up for different conditions:

- Leg-bottom impact
- Jacking and preloading
- Operational
- Survival
- Accidental (earthquake)

These comprehensive models vary greatly in complexity depending on the:

- Structural model
- Wave kinematics (e.g. higher order waves in time domain simulations)
- Soil-structure interaction (e.g. kinematic hardening)
- Workings of the jacking and fixation system

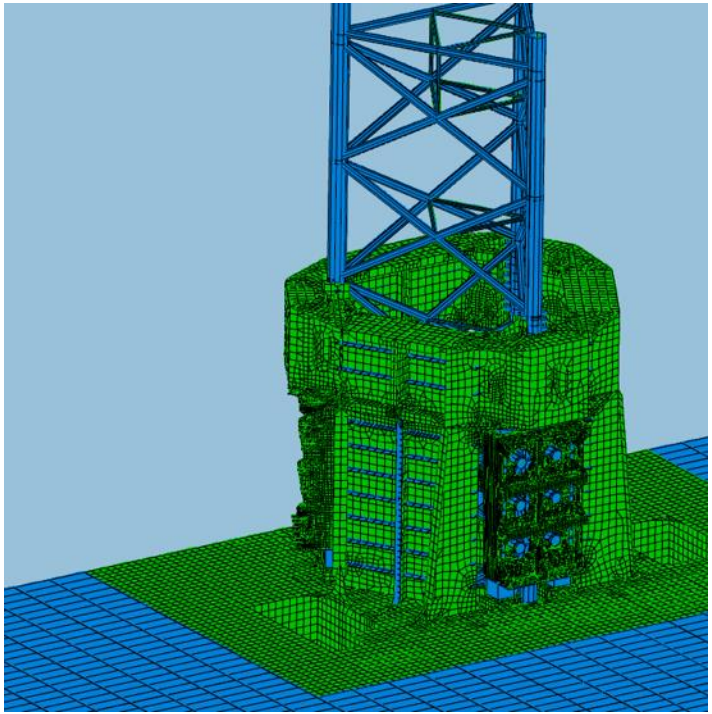
ENGINEERING TOOLS - DETAILED JACK-UP MODELS

Detailed structural models are used to verify structural adequacy of the leg, hull and interface based on the (internal) loads provided by the detailed model.

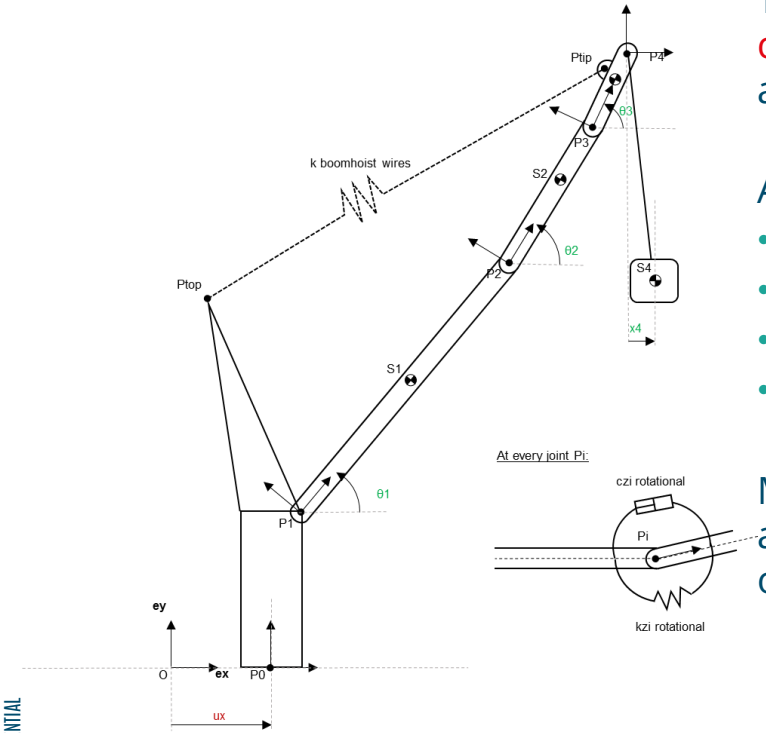
These detailed models are time consuming to create and solve compared to the equivalent models.

A practical approach to evaluating the adequacy of the jack-up is to identify the critical load cases using the equivalent models, while using the detailed model for the final verification.

A similar approach may be applied to cranes: In addition to detailed models used to verify design cases, an equivalent crane model is useful to evaluate the (dynamic) response of the total system.



ENGINEERING TOOLS - EQUIVALENT CRANE MODEL



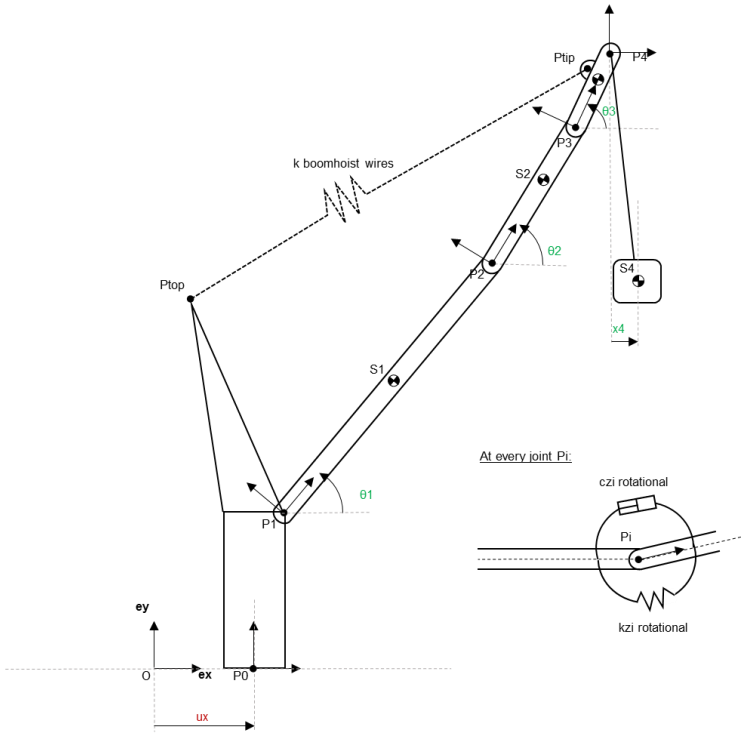
The rationale is to go for the simplest model that accurately captures the response of a crane on a jack up, based (as much as possible) on first principles.

Advantages:

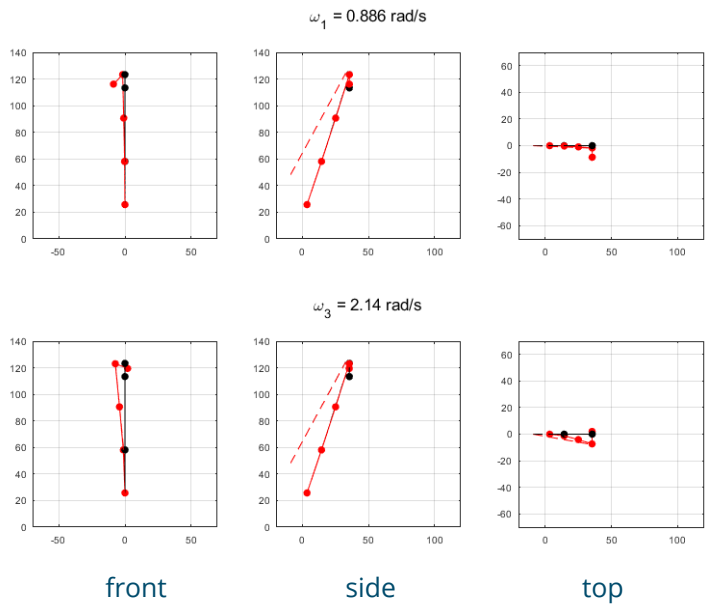
- Easy to modify the crane model
- Easy to combine with the jack-up models
- Easy (and fast) calculation of the relevant eigenmodes
- Easy (and fast) calculation of the response

Making possible fast pre- and post processing of the vast amount of cases that are required for the purpose of optimizing a crane design or its workability on a particular site.

CRANE DYNAMICS - MODAL ANALYSIS



10 m sling length, no load in hook



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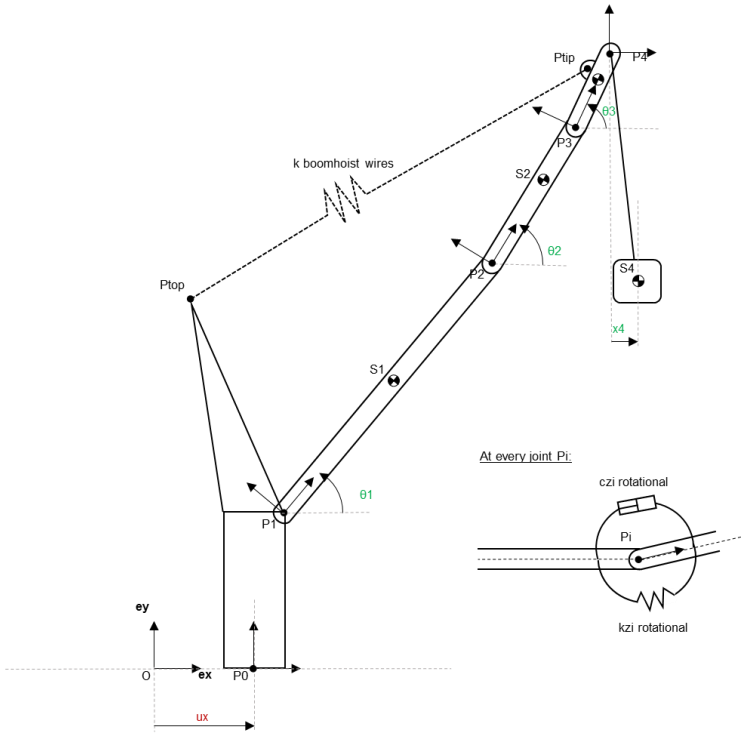
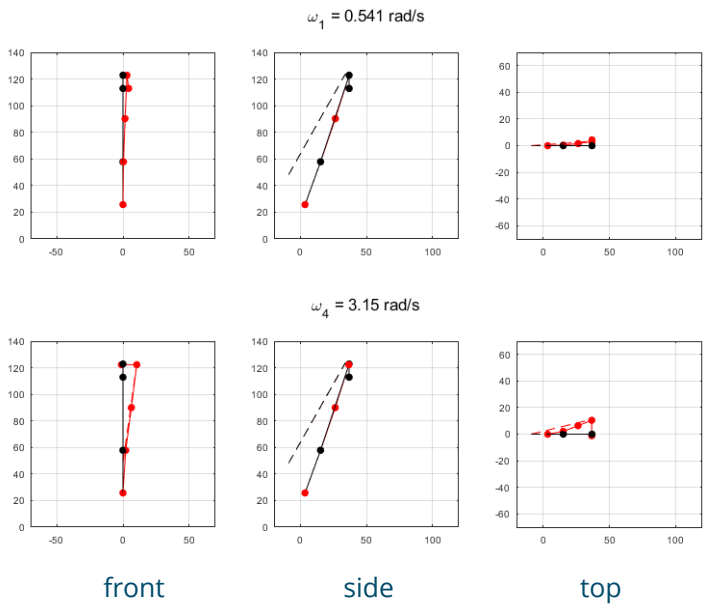
CRANE DYNAMICS - MODAL ANALYSIS



10 m sling length, 400t load in hook



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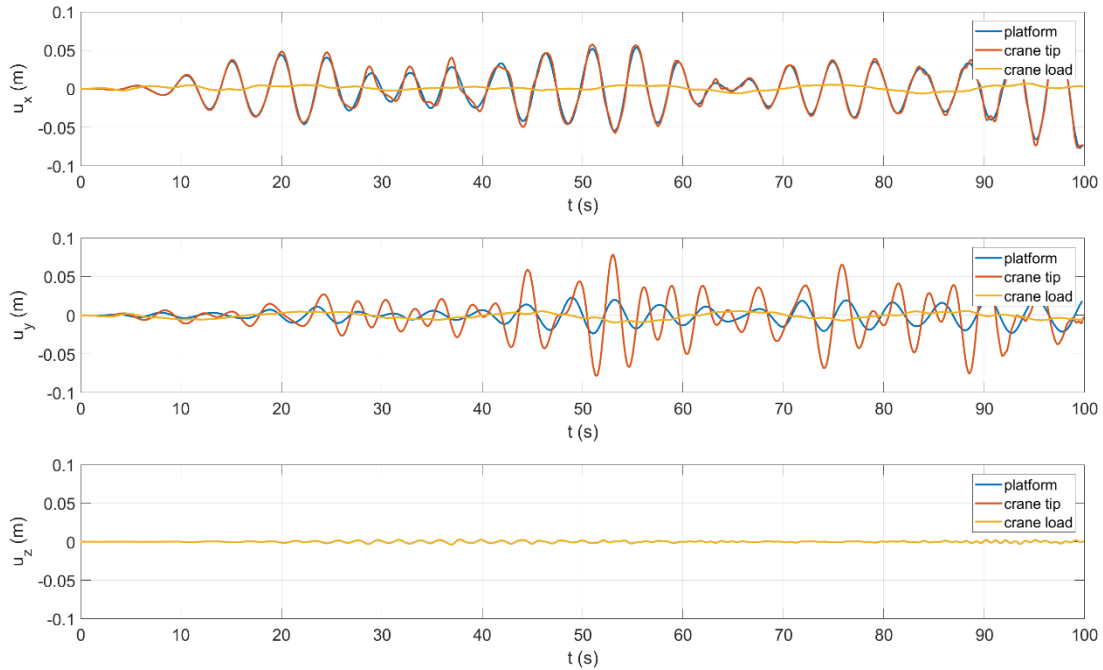
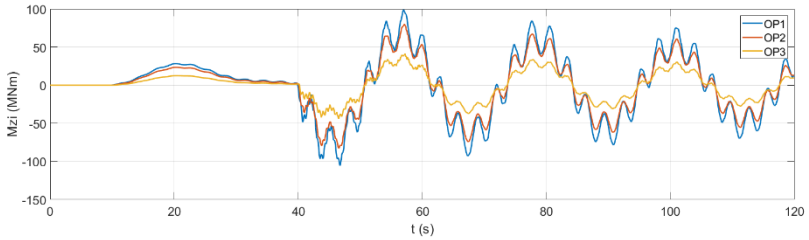
CRANE DYNAMICS - TIME DOMAIN SIMULATIONS

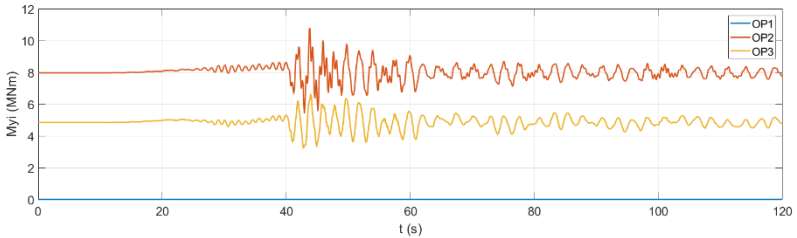
Time domain simulations

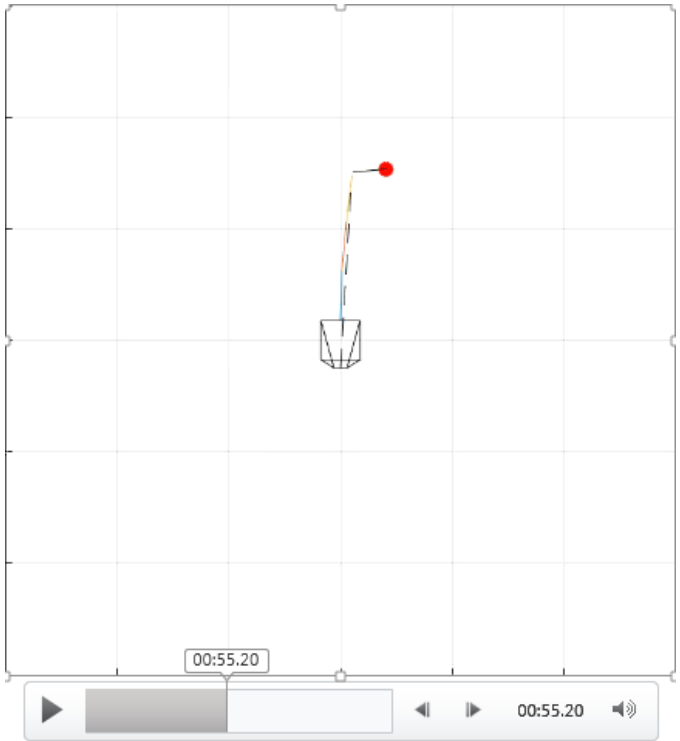
- NG-9000C
- 18,000t elevated weight
- 40 m airgap
- Hs = 2.5 m
- Tp = 5 s
- crane on PS AFT
- boom angle = 75 deg.
- slew angle = 90 deg.
- main hoist load = 800 t
- sling length = 80 m



CRANE DYNAMICS - EMERGENCY SLEW STOP TEST







IDENTIFYING ROOM FOR IMPROVEMENT

CONSIDER THE FOLLOWING SITUATIONS

"I just want to know if I can commence the operations in this particular situation. What am I to do with this 100 page report full of figures and tables from GustoMSC?" Asks the operator.

"Yes, I'll figure out the answer." says the engineer to the operator. "Let me think about it and write a report containing my advice. I'll come back to you in two weeks."

The jacking engineer tries to make out what preload was achieved preload as the crane operator slews the foundation overboard, resulting in an increase of the loads on the crane leg increase: "Was it 8900 t or was it 8800 t for the leg closest to the crane? The handwriting of that guy from the night shift is so difficult to read."

"Hey," exclaims the marine warranty surveyor looking over the shoulder of the jacking engineer during preloading operations, "the preload shown on the jacking system console does not match the preload covered in the site specific assessment report."

IDENTIFYING ROOM FOR IMPROVEMENT

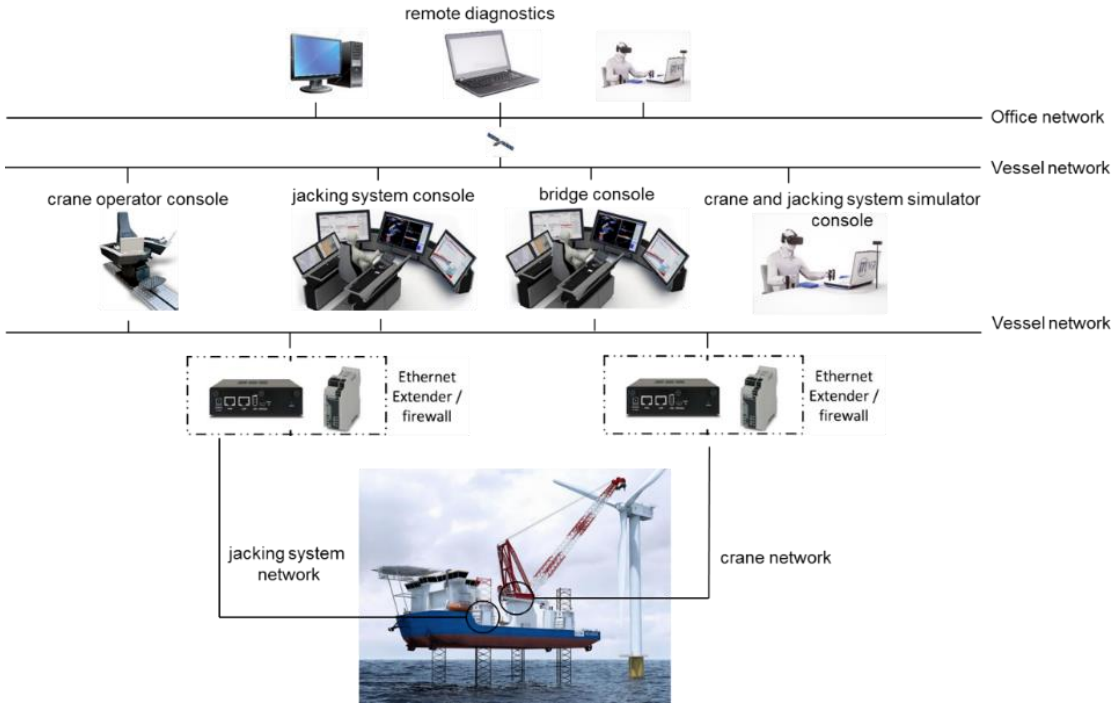
CONSIDER THE FOLLOWING SITUATIONS

The jacking engineer, after preloading operations, equalizes the loads on the legs and shuts off the hydraulic power units and exclaims: "I'm off to doing something else, my work here is done."

The crane operator chooses a different travel path for the foundation with a weight at the limit of the crane capacity. He is sure that as long as he respects the crane SWL curve on his display everything is safe.

PUSHING THE LIMITS - THE DIGITAL TRANSFORMATION

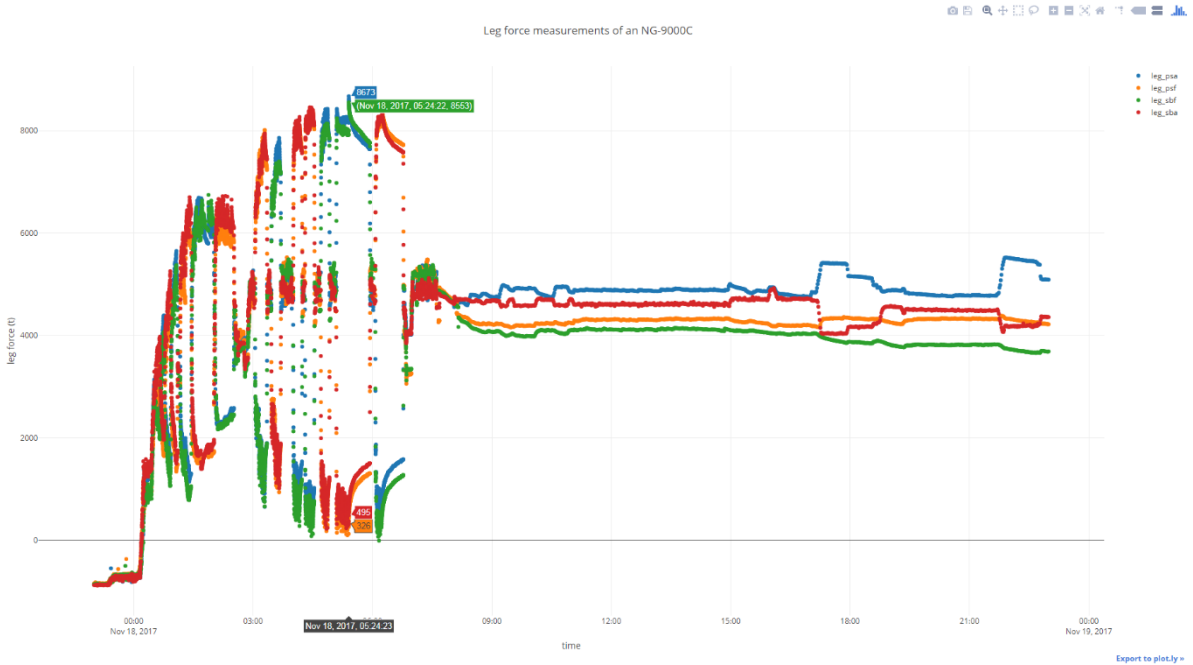
Through connecting the different system networks and by translating the data into practical real-time guidance for the operators the safety and performance of the units may be increased



USER FRIENDLY ACCESS TO KEY SYSTEM DATA

EXAMPLE: IMPROVING THE FLOW OF INFORMATION BETWEEN OPERATORS AND ENGINEERS

Provide interactive dashboards to access actual and historical system data (e.g. jacking system loads)

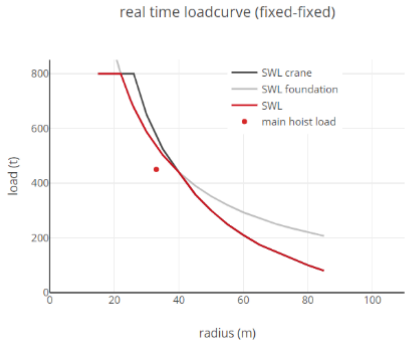


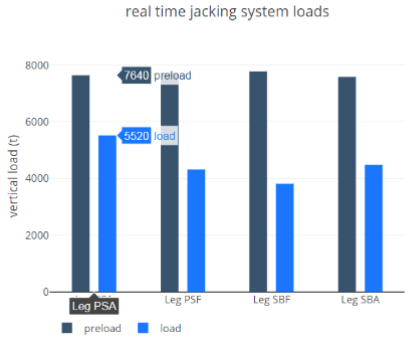
AUTOMATED GUIDANCE DURING OPERATIONS

EXAMPLE: IMPROVE OPERATOR AWARENESS ON ACTUAL UTILIZATIONS DURING LIFTING OPERATIONS

The crane driver should be aware of the governing limits, this includes the limit imposed by the jack-up foundation.

The jacking engineer should have clear insight on the load and the established foundation capacity (preload).





AUTOMATED GUIDANCE DURING LIFTING OPERATIONS

KEY BENEFITS:

- Providing automated guidance to the operators enhances the safety during lifting operations and allows the operators to focus on their primary tasks.
- Reliable knowledge of the utilizations allows the operator to unlock the full potential of the wind turbine installation vessel (GustoMSC's PRETORQUE method).

This significantly increases the maximum crane size that may sensibly be installed on a unit without compromising safety
(see example upgrade of NG-9000 with 900 t to a 1500 t crane)

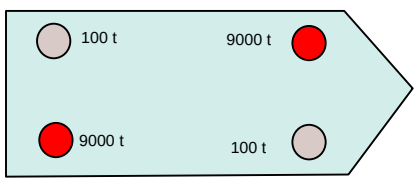
PRETORQUE

The rationale is to reduce the load on the leg nearest to the crane (PS AFT) before lifting operations, therefore increasing the margin of safety for the foundation stability during lifting operations.

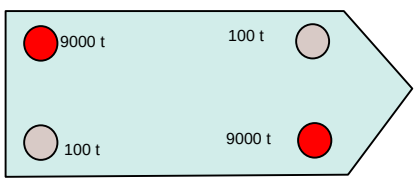
Example of modest PreTorque:

Example:
4000 t vs 4550 t

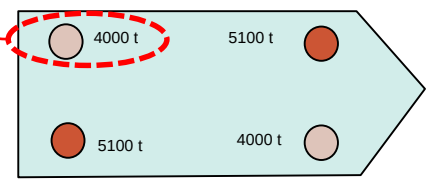
Preload legs 2 and 4



Preload legs 1 and 3

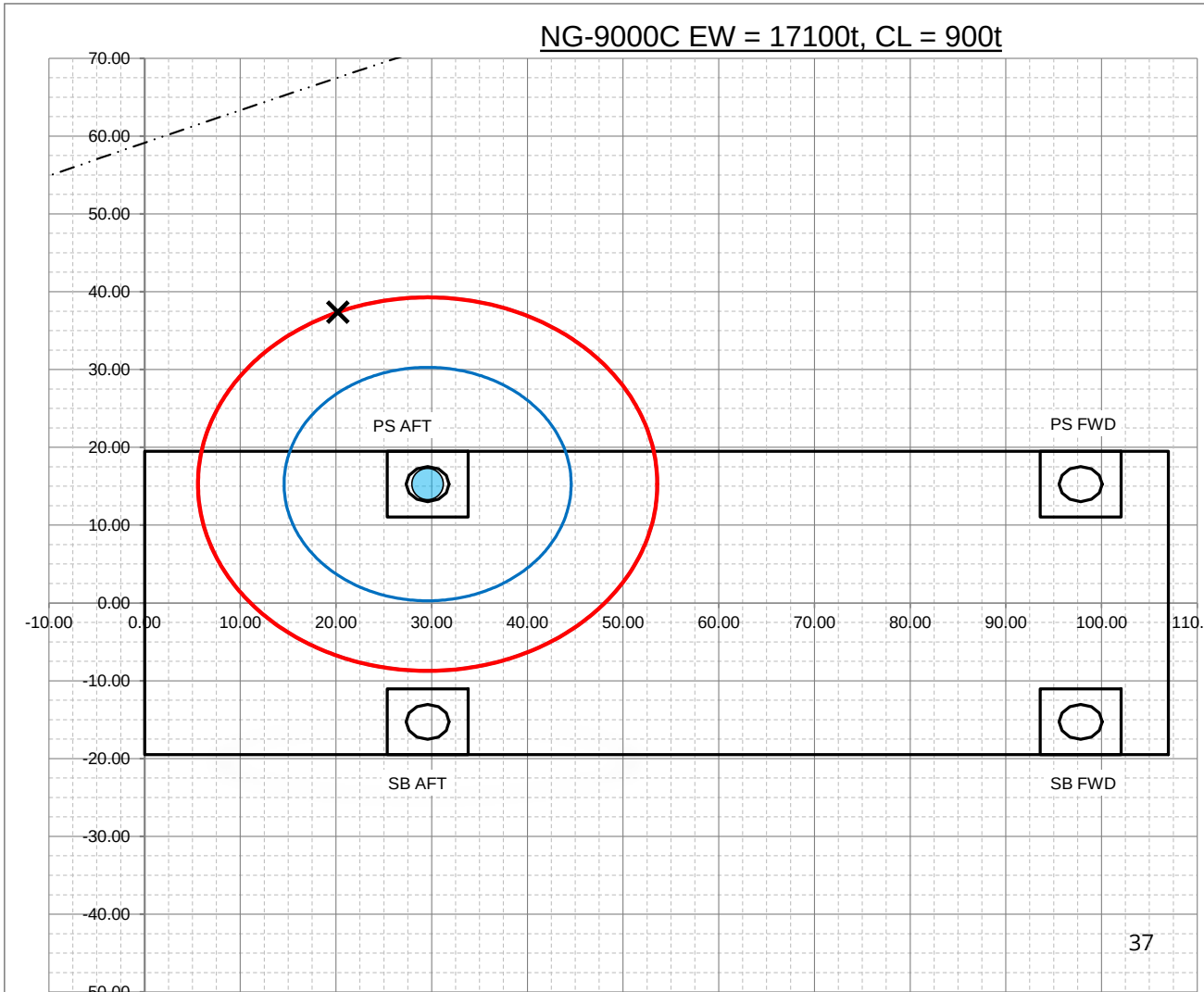


PARTIALLY equalize



PRETORQUE

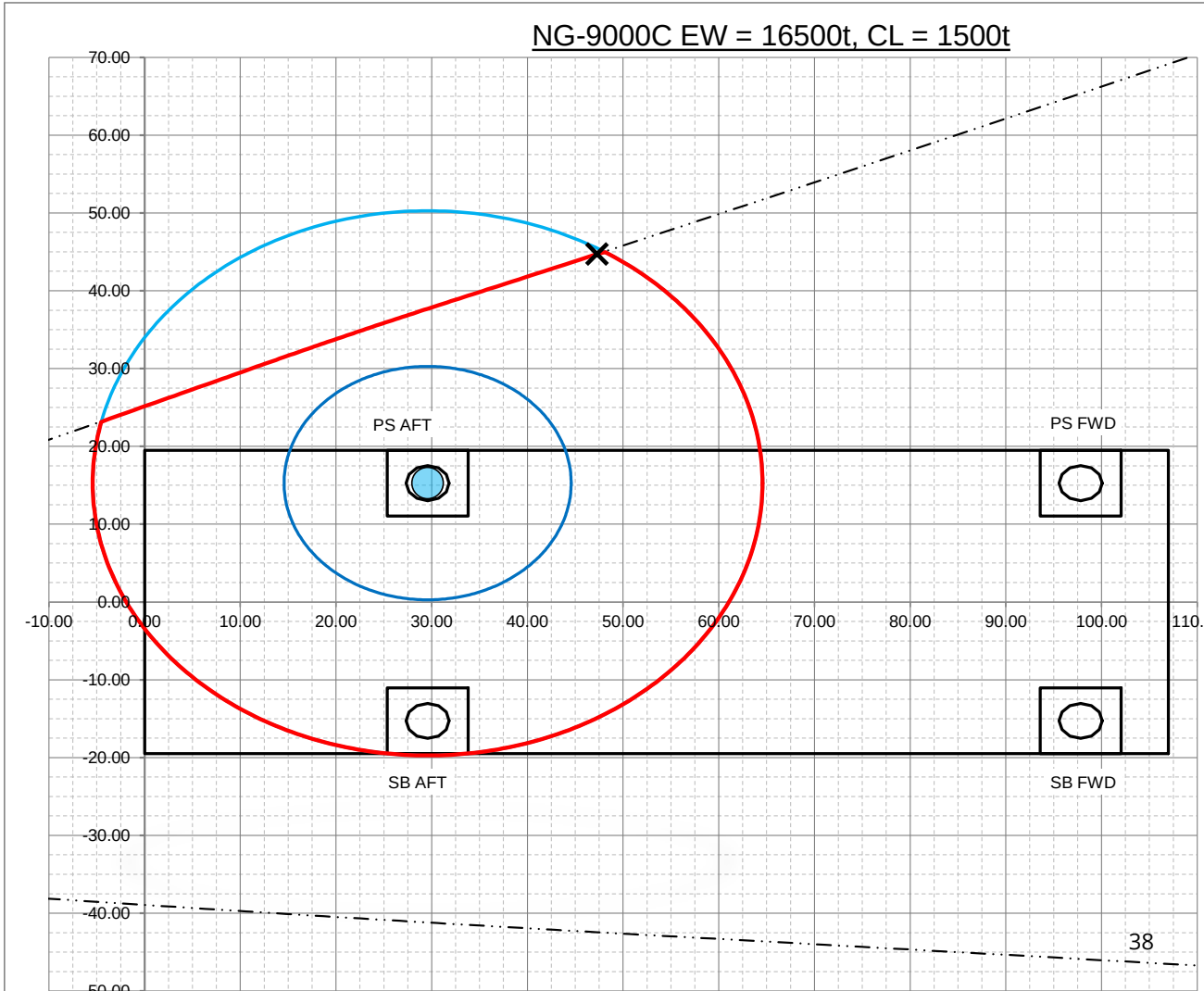
Safe:
NG-9000C with
Crane 900 t x 24 m,
safety 0.9,
(original design)



PRETORQUE

Safe:
NG-9000C with
Crane 900 t x 24 m,
safety 0.9,
(original design)

Unsafe:
NG-9000C with
Crane 1500 t x 35m,
safety 0.9

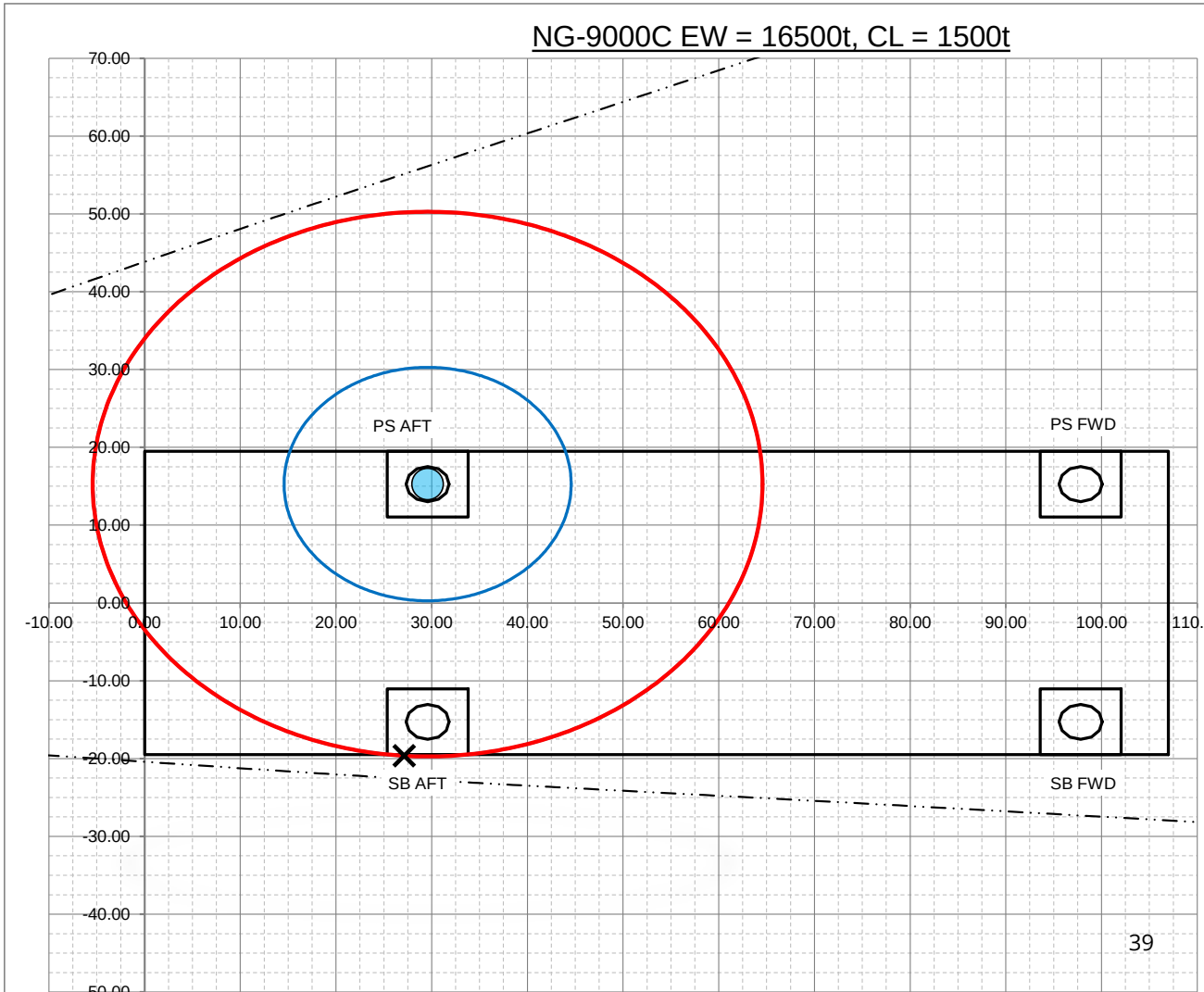


PRETORQUE

Safe:
NG-9000C with
Crane 900 t x 24 m,
safety 0.9,
(original design)

Unsafe:
NG-9000C with
Crane 1500 t x 35m,
safety 0.9,

Safe:
NG-9000C with
Crane 1500 t x 35m,
safety 0.9,
With **PreTorque**



SAFELY PUSHING THE BOUNDARIES

CONCLUSION

GustoMSC aims to achieve more efficiency for the wind turbine installation units at equal or better safety by developing smart solutions using in depth knowledge of technical and operational challenges.

To achieve this goal we continuously improve our in-house developed software that allows us to efficiently perform analyses for the wind turbine installation vessels, while various new ways are explored to provide key operational guidance to operators in real-time.

THANK YOU FOR YOUR KIND ATTENTION