LANDBASEREDE VINDMØLLETÅRNE

- KUN HIMLEN ER EN BEGRÆNSNING

Martin Jespersen, Rambøll

Dansk Ståldag 8. November 2018

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WIND TURBINE TOWERS

Martin Jespersen

- Chief Consultant, Ramboll Energy, Towers & Telecom
- MSc., Civil Engineering, Technical University of Denmark

  MSc. Thesis: "Guyed Wind Turbine Towers for Onshore Applications"
- Employed at Rambøll since 2007.
- Member ECCS Technical Committee no. 16 "Wind Energy Support Structures"

Field of work:

- Design of towers for wind turbines
- Design of towers and masts for telecom and broadcast
- Design of towers for overhead transmission

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DESIGNING WIND TURBINE TOWERS - A TRULY MULTIDISCIPLINARY TASK

- Load generation
- Structural design
- Patents
- Transport
- Installation
- Site civils
- Interfaces to other disciplines
- Blade clearance
- Foundations
- Internals, H&S
- Standardized products
- Maintenance
- Reliability
- Supply-chain
- Local content, taxation
- Local infrastructure
- Labour costs
- Aesthetics
- Etc…

BUSINESS CASE CAN ONLY BE DERIVED AND BENCHMARKED FROM THE ENTIRE VALUE-CHAIN OF A SPECIFIC PROJECT!

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WIND TURBINE TOWERS – WHY LARGER HUB HEIGHT?

Large hub heights > 120m

- **Political, market or other incentives promoting development of wind power in areas which do not exhibit ideal conditions, larger hub height can be a solution:**
  - **Wind resource can be higher (increased power production)**
  - **Reduced turbulence and variation in wind profile (in areas with forest or other obstacles)**
- **Rated power and rotors for onshore wind is continuously increased:**
  - **~4.5-4.8MW and rotor diameter 150-160m (5.000 households)**

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CONVENTIONAL TOWERS FOR ONSHORE WIND TURBINES

Construction of wind turbine steel towers for onshore with height of more than 110m is increasingly problematic

- Steel weights becomes very big
- It is difficult to transport sections with a diameter larger than 4.5m
- Foundation forces become extremely large
- Erection with cranes can be difficult and costly

OVERVIEW OF ALTERNATIVE WIND TURBINE TOWER CONCEPTS

Steel

Segmented towers

Lattice towers (angle bar, cold formed profiles, etc.)

Jacket hybrid towers

Guyed/cable stayed towers

…

Other materials

Segmented concrete towers

Steel/concrete hybrids

In-situ cast concrete towers

Wooden towers

…

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OVERVIEW OF ALTERNATIVE WIND TURBINE TOWER CONCEPTS

- Equipping with internals at site
- Working temperatures?
- Grout/dry joints
- Local content
- Scalable production
- Moulds
- Transport
- Site work
- Transition to RNA

Other materials

Segmented concrete towers

Steel/concrete hybrids

In-situ cast concrete towers

Wooden towers

…

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OVERVIEW OF ALTERNATIVE WIND TURBINE TOWER CONCEPTS

Technical concept review performed by Ramboll

- As a full concrete tower…
- …but employing industry standard steel tower affecting:
  - Site work
  - Internals

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…

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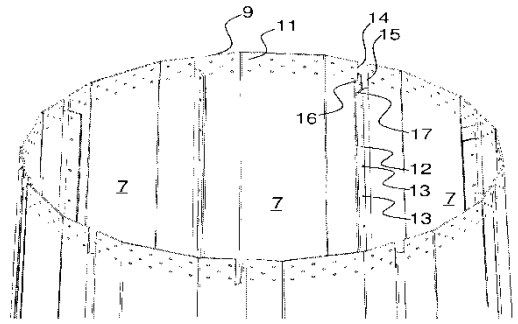
…

- Tubular section made from bolted shell segments
- The sections are then bolted together to form a tower
- In part equipping with internals at site
- Transportable
- Bolts

Assembly and installation of bolted steel shell tower sections



Layout of tower section, patent illustration

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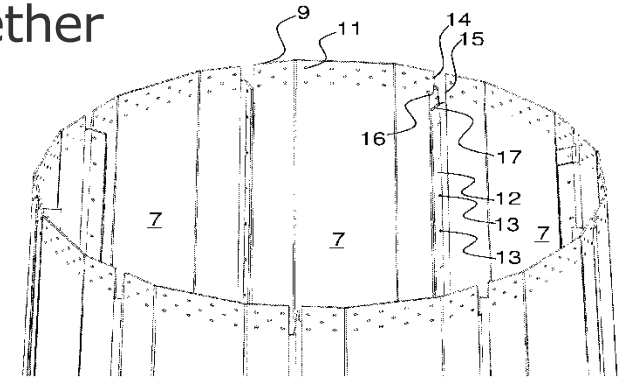
BOLTED STEEL SHELL (BSS) TOWER (SEGMENTED TOWER)

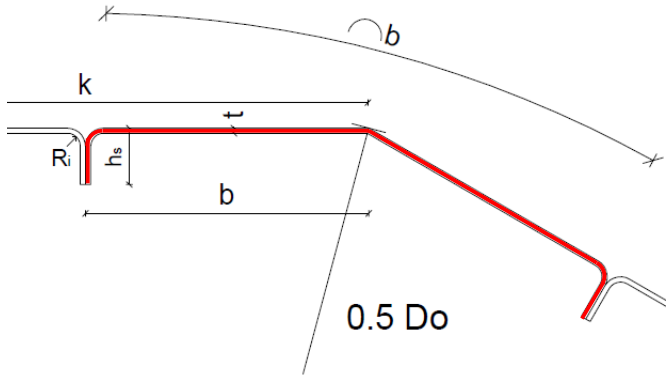
- Novel idea by Andreasen Towers A/S, and further developed together with Siemens Wind Power A/S with assistance from Ramboll. More than 200 towers supplied in Europe with Siemens turbines and hub heights of up to 142m.
- Each tubular section is constructed of shell segments bolted together
- The sections are bolted together using lap joints

Bolted steel shell tower installed with wind turbine from Siemens Wind Power A/S at Stamåsen wind farm

Assembly and installation of bolted steel shell tower sections



Layout of bolted steel shell tower section, patent illustration



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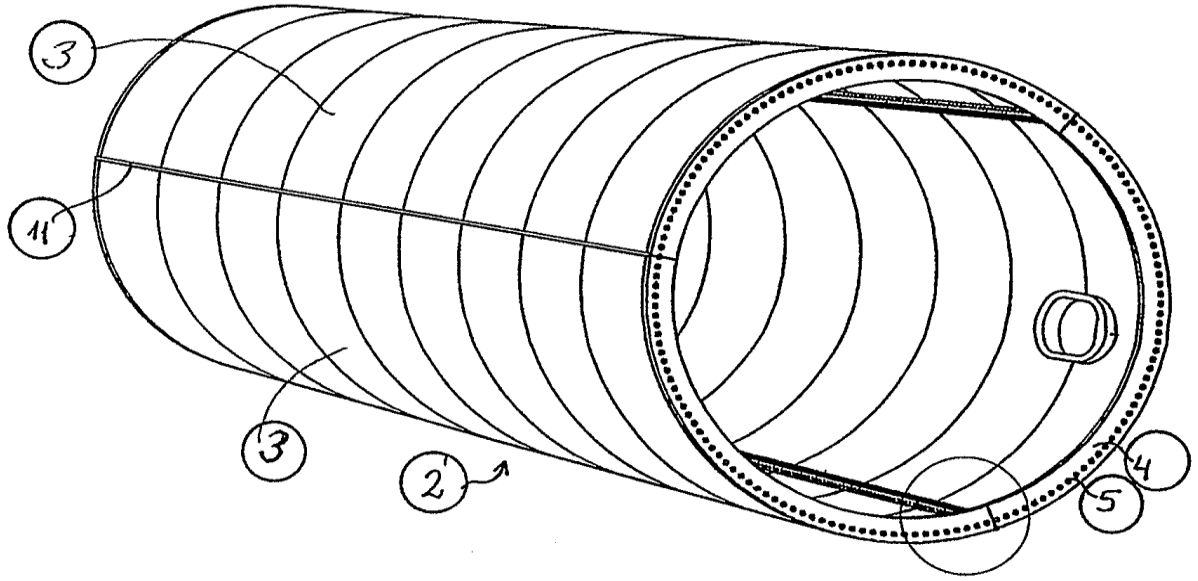
VESTAS LARGE DIAMETER STEEL TOWER - LDST (SEGMENTED TOWER)

- Each tubular section is made from 3 can-section segments bolted together longitudinally at site
- The sections are bolted together using flange joints
- No transition piece



Vestas Large Diameter Steel Tower (LDST), Sketch from patent

- Patented 2003
- First prototype 2005
- Second prototype 2013
- Commercial release 2014

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OVERVIEW OF ALTERNATIVE WIND TURBINE TOWER CONCEPTS

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Segmented towers

Lattice towers (angle bar, cold formed profiles, etc.)

Jacket hybrid towers

Guyed/cable stayed towers

…

- Simple production: Cut, punch and surface treatment
- Smaller foundations
- Transportable
- Sizes of angle bars
- Many bolts
- Friction surfaces
- Secondary bracing
- Site work/time
- Maintenance bolts?
- Transition piece
- Visual impact?

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OVERVIEW OF ALTERNATIVE WIND TURBINE TOWER CONCEPTS

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Guyed/cable stayed towers

…

- Fewer elements (compared to lattice)
- Upper industry standard tubular tower
- Smaller foundations
- Transportable
- Less bolts
- Site work/time
- Maintenance
- Transition piece
- Visual impact?

K-Jacket conceptual design by Peter Kelemen and Ramboll for Salzgitter AG Illustration by Peter Kelemen

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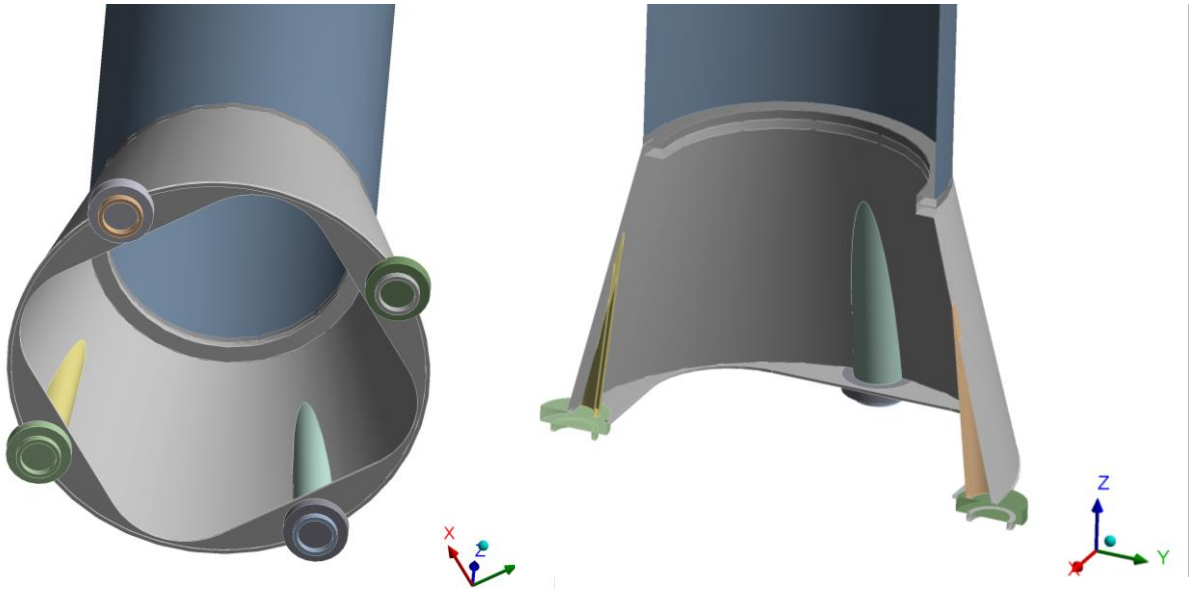
ONSHORE K-JACKET HYBRID TOWER

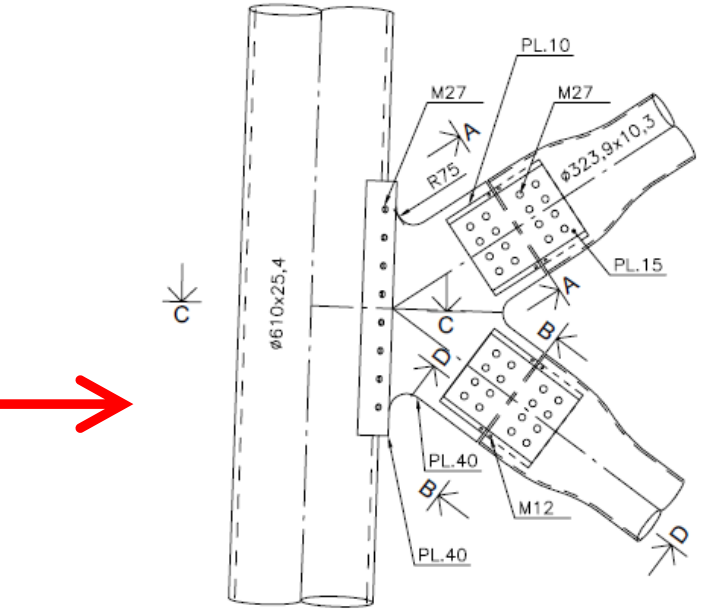
- Ramboll has assisted Salzgitter AG with the development of conceptual design
- Industrial rate production with HFI tubes
- “Bucket” TP for transition between cylindrical tower and K-Jacket
- Internals, evacuation procedures, etc.?
- Maintenance of bolts?

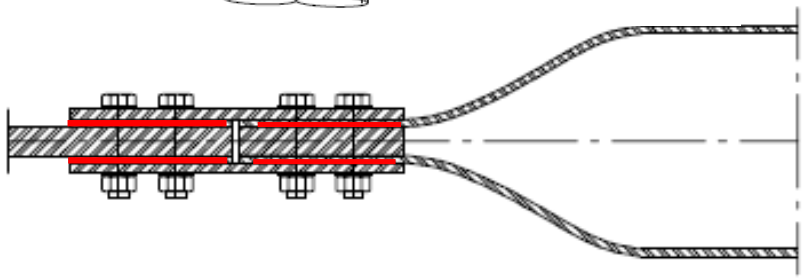


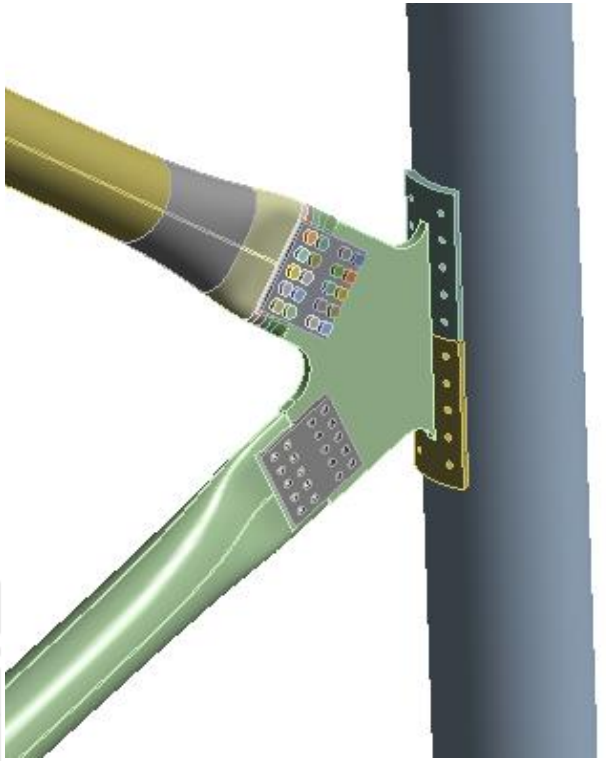
K-JACKET BRACINGS WITH INNOVATIVE JOINT CONCEPT DEVELOPED BY RAMBOLL

- Squeezed tubular joints offers minimum of fabrication and simple assembly with good tolerances.

Squeezed bracing joint in telecom tower, Romania







OVERVIEW OF ALTERNATIVE WIND TURBINE TOWER CONCEPTS

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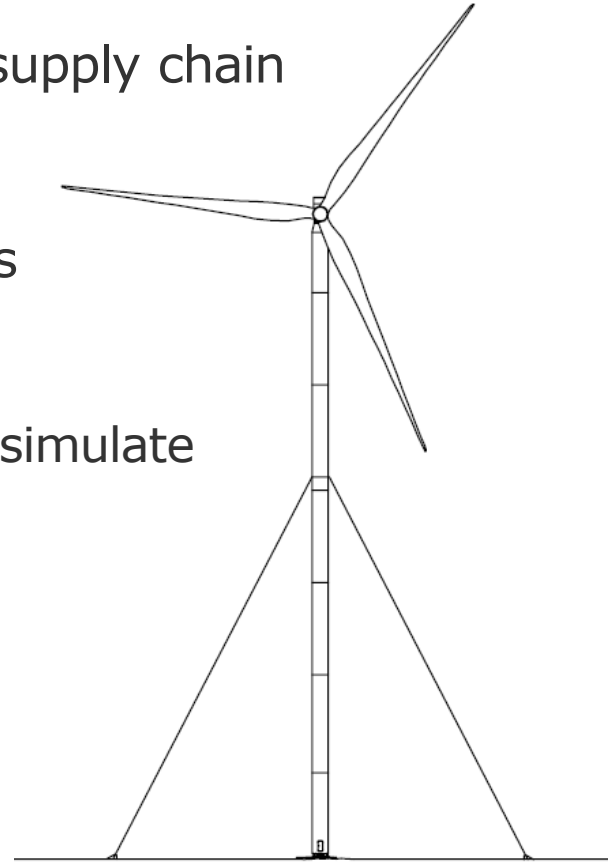
Jacket hybrid towers

Guyed/cable stayed towers

…

- Scaling law
- Close to conventional supply chain
- Smaller foundations
- Transportable elements
- Reduced visual impact
- High end-knowledge to simulate and design
- Maintenance (guys)



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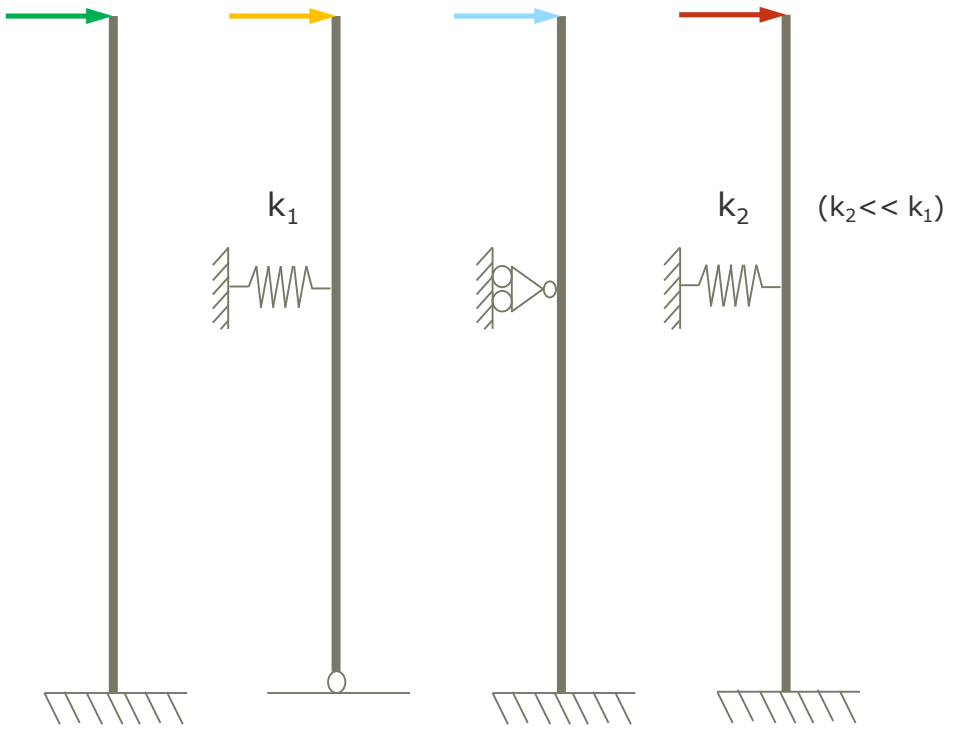
GUYED WIND TURBINE TOWER STATIC MODEL



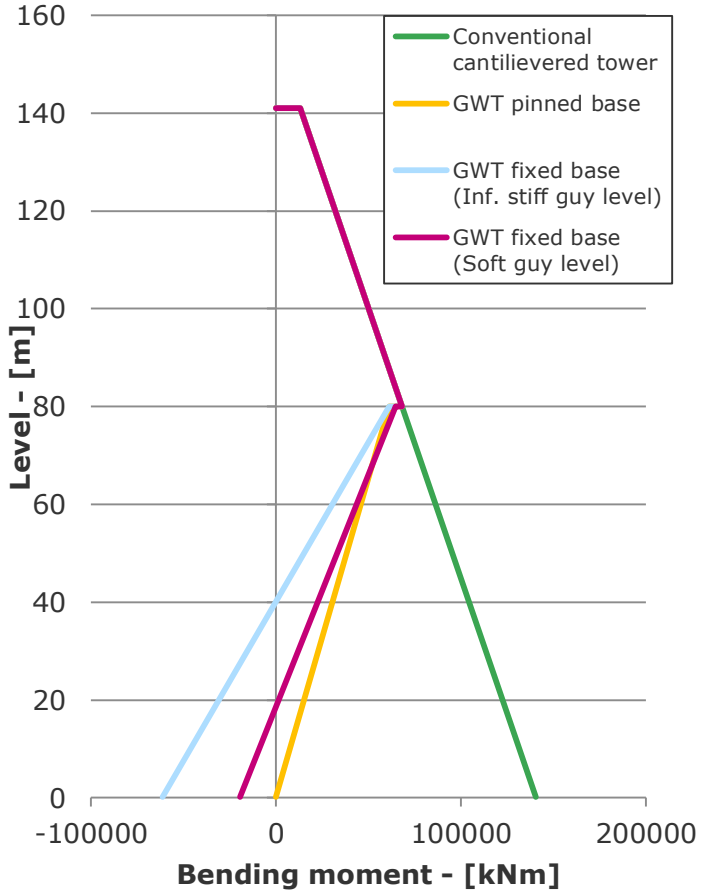


Figure: Bending moment distribution for different base detail concepts

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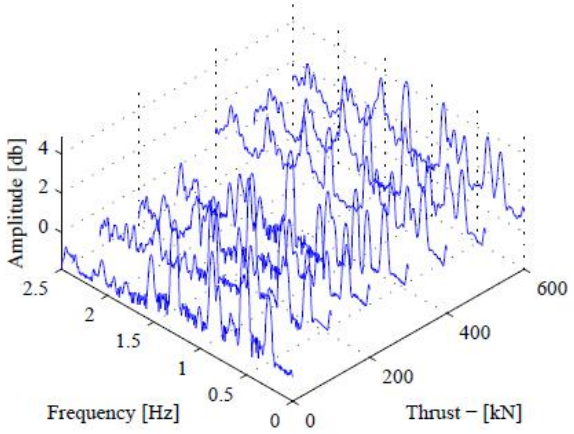
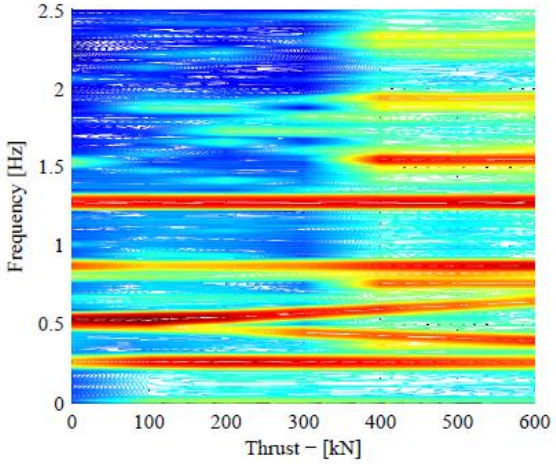
GUYED WIND TURBINE TOWER - DEVELOPED BY RAMBOLL

- Ramboll has performed rigorous design studies and analysis of guyed wind turbine towers in the frequency and time domain, also in cooperation with experts from DTU Wind, since 2013
- Leveraging Ramboll's +70years experience from guyed structures in telecommunication industry



(a) *Sample response spectrum from effect parameter study on thrust.*

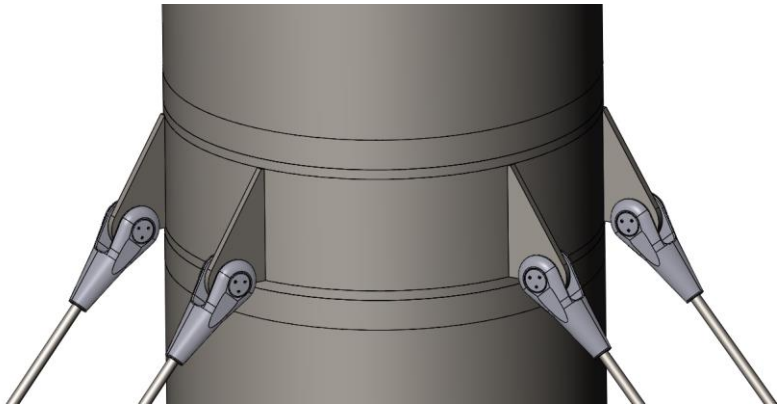


(b) *Sample contour plot based on response spectrum in Figure 18a from effect parameter study.*

Figure 18: *Example of representation of high frequency content in response spectrum by a contour plot*

GUYED WIND TURBINE TOWER – DEVELOPED BY RAMBOLL

Figure: Guy attachment in tower



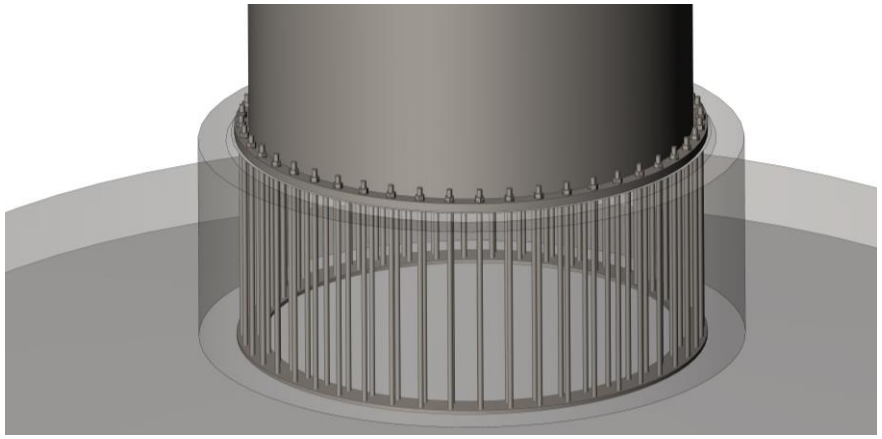


Figure: Tower at foundation base

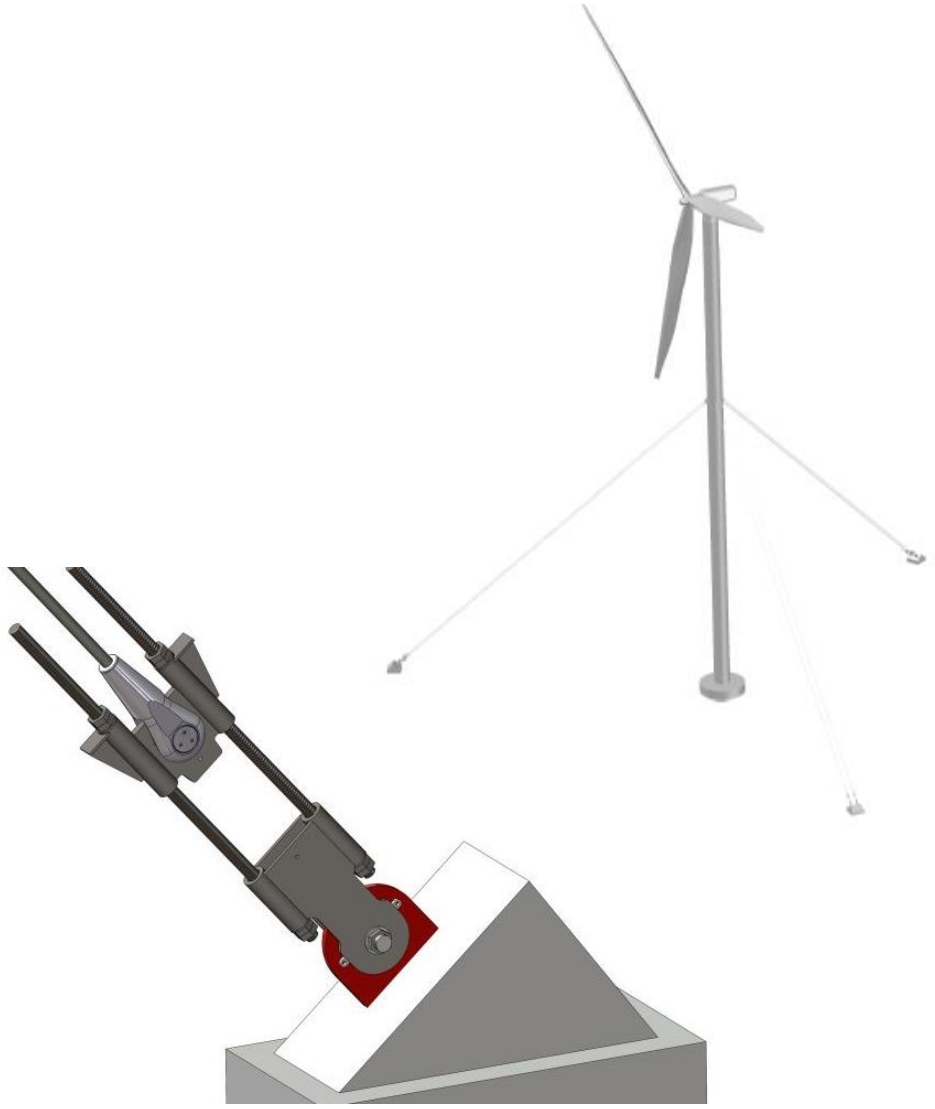


Figure: Guy attachment at foundation

GUYED WIND TURBINE TOWER – DEVELOPED BY RAMBOLL

Visualization of wind park with guyed wind turbine tower developed by Ramboll

VESTAS CABLE STAYED TOWER (GUYED TOWER)

2017 Vestas Cable stayed tower, *3D visualization*

First commercial/R&D project announced in 2018

2017 Vestas prototype tower, Østerild, DK

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GUYED WIND TURBINE TOWERS - OTHERS

MERVENTO 3.6-118 (Finland) IIA

- Prototype erected March 2012
- 128m HH – 118m rotor diameter
- Direct-Drive topology
- On-shore and "offshore"

Vergnet GEV HP 1MW (France) IIIA

- Prototype erected
- 2 Bladed
- 70m hub height – 62m rotor diameter
- Build-in nacelle erecting system

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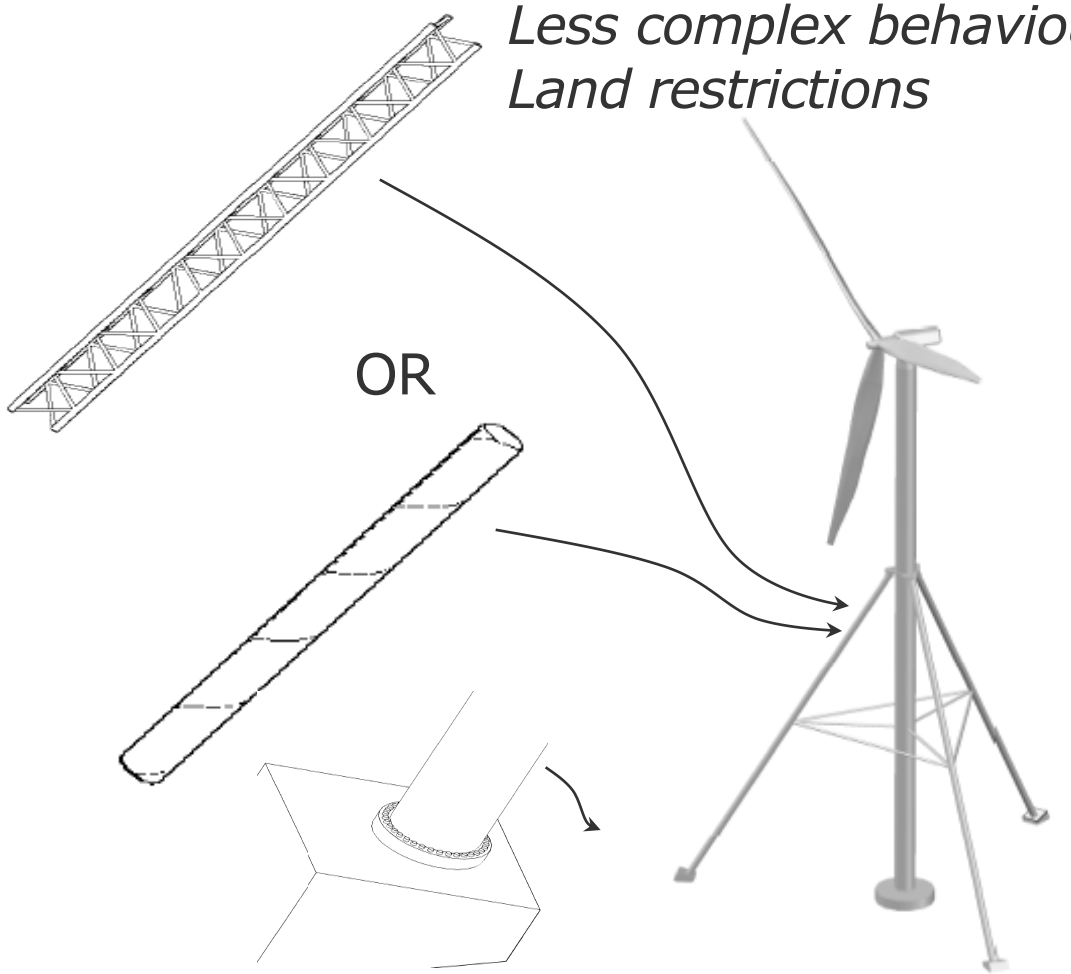
LATEST RAMBOLL CONCEPT: STRUTTED WIND TURBINE TOWER (STWT)

Still the most attractive

Guyed wind turbine tower developed by Ramboll

Less complex behaviour
Land restrictions



Strutted wind turbine tower developed by Ramboll

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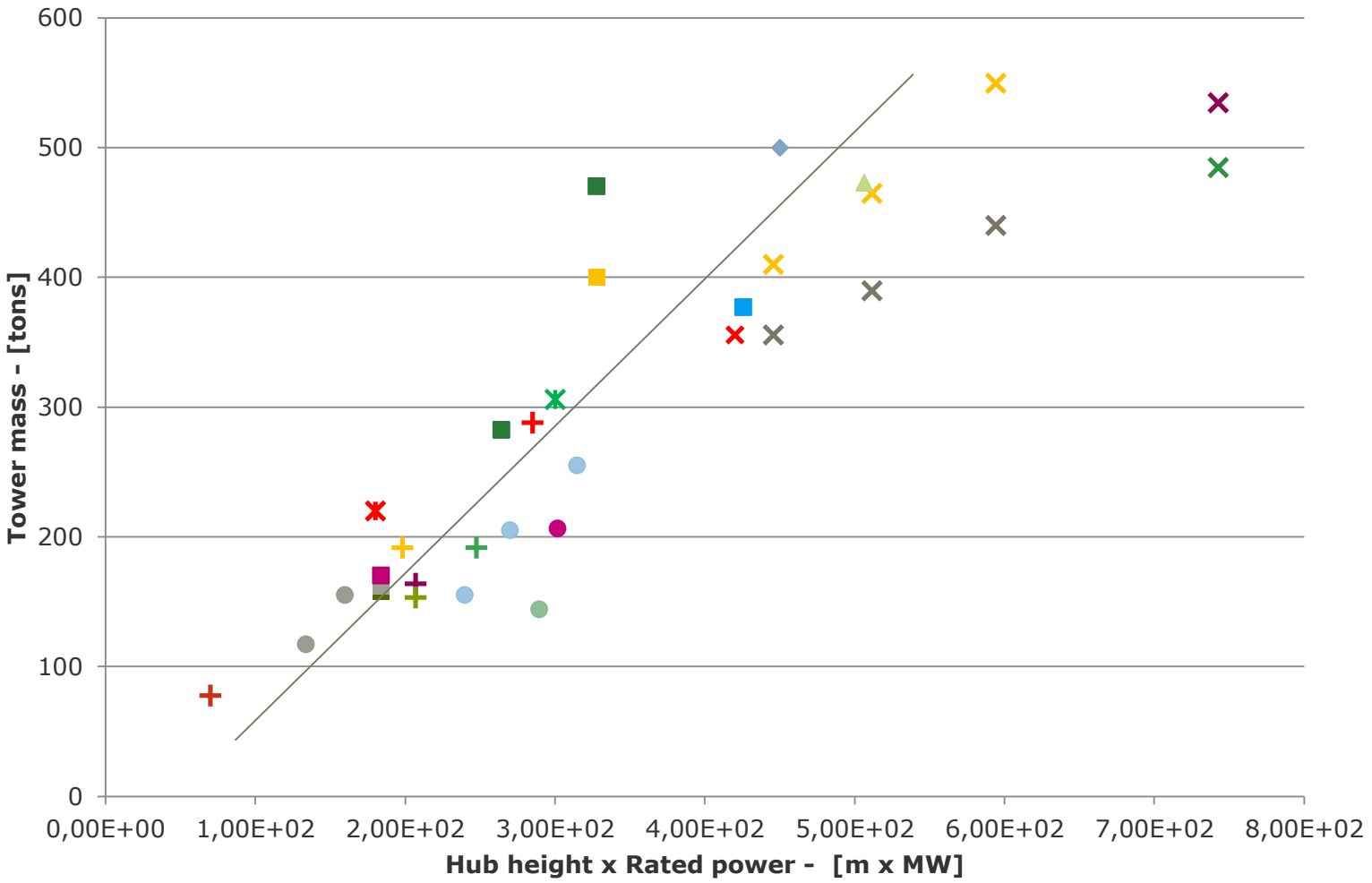
GUYED/STRUTTED WIND TURBINE TOWER – DEVELOPED BY RAMBOLL

Visualization of wind park with strutted wind turbine tower developed by Ramboll

COMPARISON OF GUYED WIND TURBINE TO AVAILABLE DATA



Ramboll GWT (STIFF)
Ramboll GWT (SOFT)
Ramboll GWT (STIFF)
Ramboll GWT (SOFT)
Ramboll STWT (SOFT)
Ramboll K-Jacket

TOWER MASS IS NOT THE ONLY COST DRIVER!

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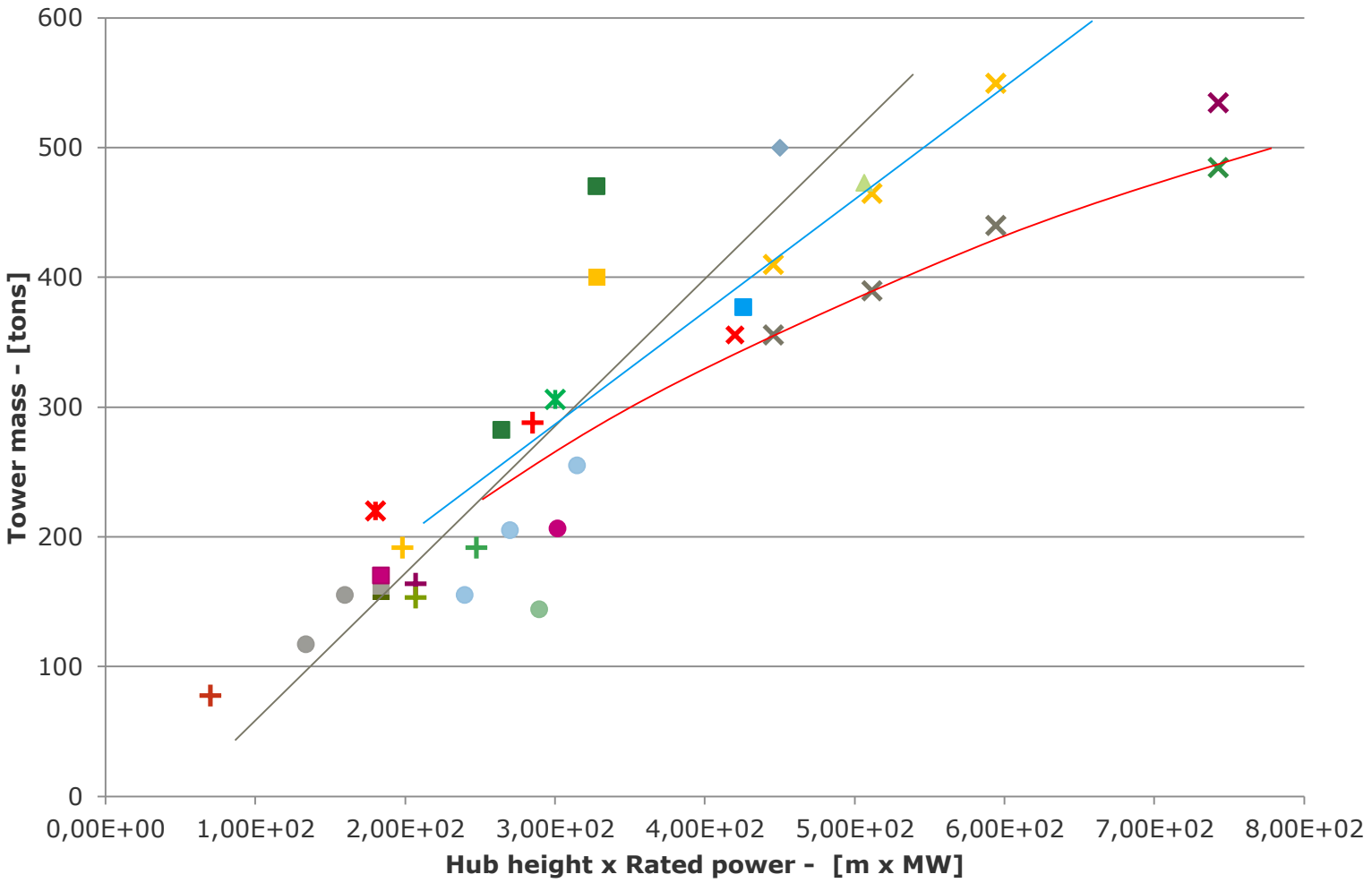
COMPARISON OF GUYED WIND TURBINE TO AVAILABLE DATA



Ramboll GWT (STIFF)
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Ramboll K-Jacket

TOWER MASS IS NOT THE ONLY COST DRIVER!

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SPØRGSMÅL?

Martin Jespersen, Rambøll Energi, Towers & Telecom
mtxj@ramboll.com
http://www.ramboll.com/wind