Support Structures for Offshore Wind Turbines

Design Standards

Design Optimisation

by

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Agenda

- ***Introduction***
- ***How offshore wind farms affect support structure design***
- ***Mono-pile – Tripods – Gravity – Bucket; pro et contra***
- ***Onshore moving Offshore: requirements and increased reliability***
- ***Fatigue Design of Offshore Wind Turbine Structures***
- ***Design Rules and Standards***


DNV Global Wind Energy
Creates Confidence
... in the Wind Industry

- *DNV Global Wind Energy located in Denmark*
- *Network with DNV offices: UK, Germany, Spain, US, the Netherlands, Taiwan and India*
- *Wind turbine type certification, wind farm project certification, State of the art rules for off-shore windturbine structures*
- *25 persons expecting expansion to 75 within 5 years*
- *Technical co-operation with Risø Research Laboratory*

DNV history of Offshore Wind Farms - Denmark

DENMARK

Vindeby, 5 MW,
Installation Year: 1991
SEAS/Bonus

Tunø Knob, 5 MW,
Installation Year: 1995
Elsam/Vestas

Middelgrunden 40 MW.
Installation Year: 2000
SEAS and Bonus

Samsø, 25 MW
Installation Year: 2002
Hydro Soil Services
Project Certification.

Frederikshavn, 4 prototype WT
Installation Year: 2002/2003
Elsam

Horns Rev, 160 MW
Installation Year: 2002/2003
Elsam/Eltra

Rødsand, 165 MW
Installation Year: 2002/2003
Energi E2/SEAS

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DNV history of Offshore Wind Farms - Germany

GERMANY

Wilhelmshaven, 4.5 MW
Installation Year: 2004
Enercon/Bladt Industries

Borkum West, 60 MW
Installation Year: 2004
Prokon Nord

SKY 2000 – 150 MW
Installation Year: 2004
EON

Butendiek, 240 MW
Installation Year: 2005
Offshore Bürgerwindpark Butendiek

Arkona Becken Südost

AWE (EON)

Adlergrund

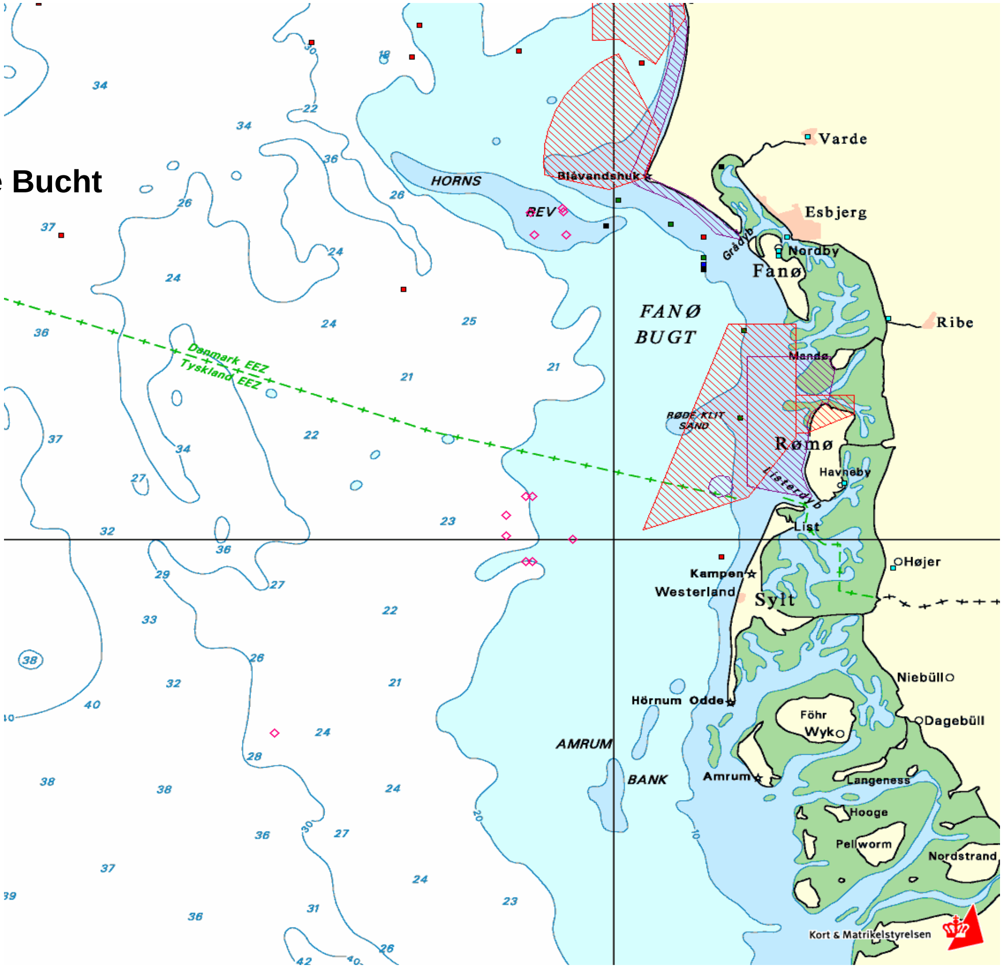
Umweltkontor

Pommersche Bucht

Winkra

North Sea

WSD



DNV history of Offshore Wind Farms – UK

UK

North Hoyle, 60 MW
Installation Year: 2003
Vestas Celtic Ltd

Kentish Flats, 90 MW
Installation Year: 2004
GREP

Rhyl Flat, 60 MW
Installation Year: 2005
National Wind Power

Barrow Offshore Wind Farm, 110 MW
Installation Year: 2005
Vestas Celtic Wind Technology Ltd.

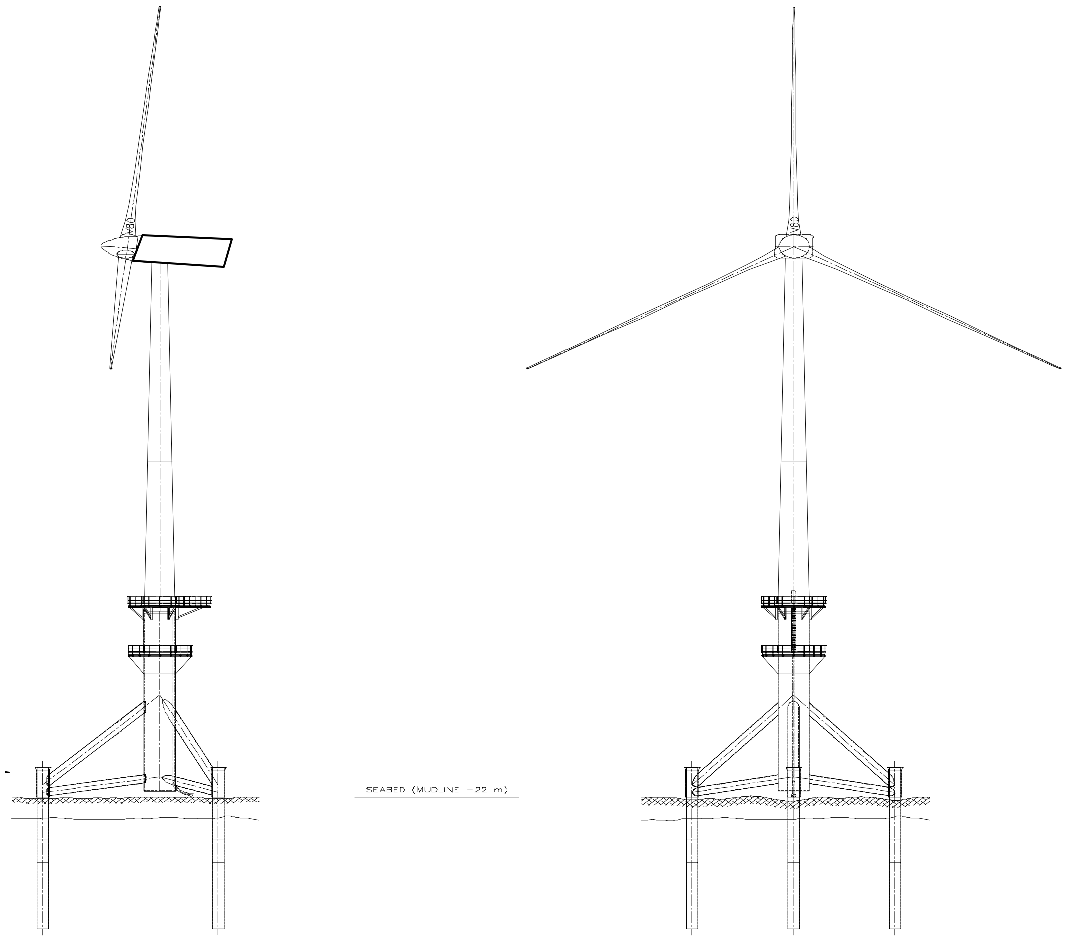
Teeside Offshore Wind Farm, 110 MW
Installation Year: 2006
LPC.

Lynn + Inner Dowsing, 250 MW
Installation Year: 2004
AMEC.

NETHERLANDS

Egmond an Zee, 100 MW
Installation year: 2004
BCE

Site Specific Integrated Structural System



Site specific, e.g.:

- Wave height
- Water depth
- Tide and Current
- Soil Conditions
- Wind+Wave Loads
- Optimised project specific support structure design

How offshore wind farms affect support structure design

Support Structures reaches 30-40 % of the total investment. This has the following impact:

- **Design**

  - Differentiated foundation types and or sizes

  - Further offshore i.e. harsh environment yielding high requirements to strength

  - Large water depth resulting in significant dynamic influence of foundation to the WT

  - High requirements to installation phase as critical when far out to sea

  - Simple and robust solutions in favor to high-tech non-proven solutions.

- **Insurance – Investors**

  - Requirements to reliable investments, thus independent project certification

- **Critical issues during project**

  - e.g. procurement of steel, sea transport, installation vessels, installation

Onshore moving Offshore: requirements and increased reliability

- Large investments
- Requirements from insurance companies to have a system for evaluating the quality and reliability
- Certification type of system – run by 3. party

Certification System comprises:

Design Verification (Site Specific)

Manufacturing survey (all important parts in WT and the support structure)

Installation survey

In service inspection

Cross engineering expertise what can it bring

Key areas of know-how for design of offshore WT support structures:

- Geotechnical modeling and analysis
- Aerodynamic modeling and analysis
- Hydrodynamic modeling and analysis
- Structural modeling and analysis
- Practical issues such as procurement, manufacturing and installation
- Cost evaluation
- Combination of the above
- Project Management

Important to have a team of engineers who covers the above when designing offshore wind turbine structures.

Criteria driving design

Criteria driving the design ?

* Installation (e.g. availability, harsh environment, etc)

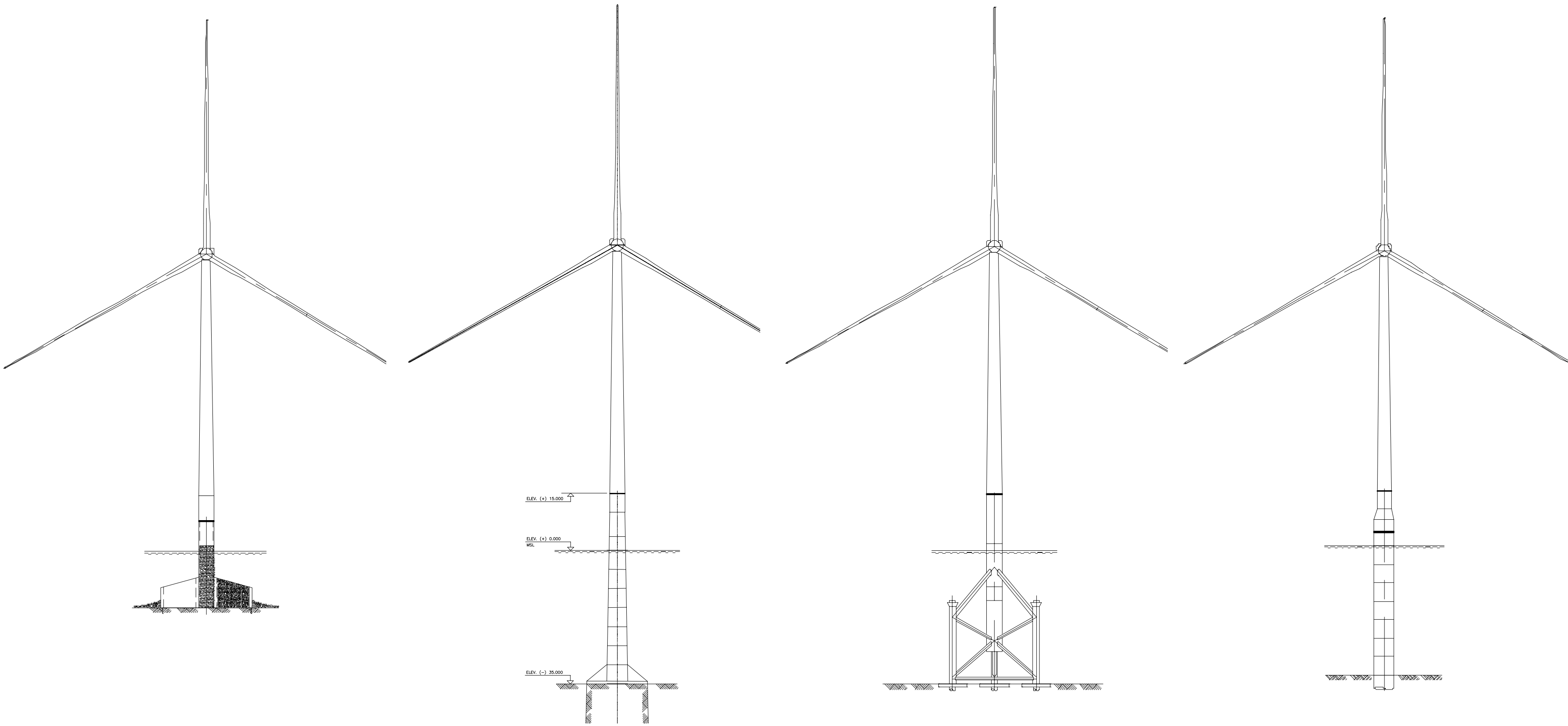
* Flexibility (e.g. requirements to WT)

* Environment (e.g. waves, current, soil etc.)

* Manufacturing (e.g. local facilities)

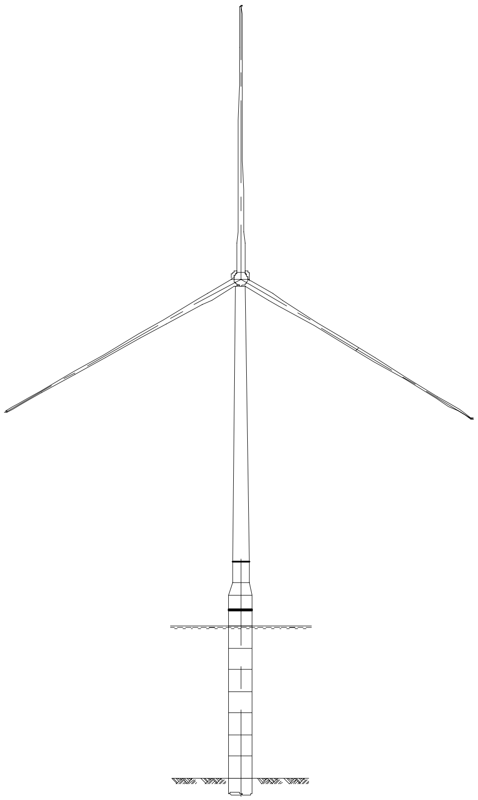
* Requirements to decommissioning

Commonly used concepts for support structures



Gravity Base   Suction Bucket   Tripod   Mono Pile

Commonly used concepts for support structures



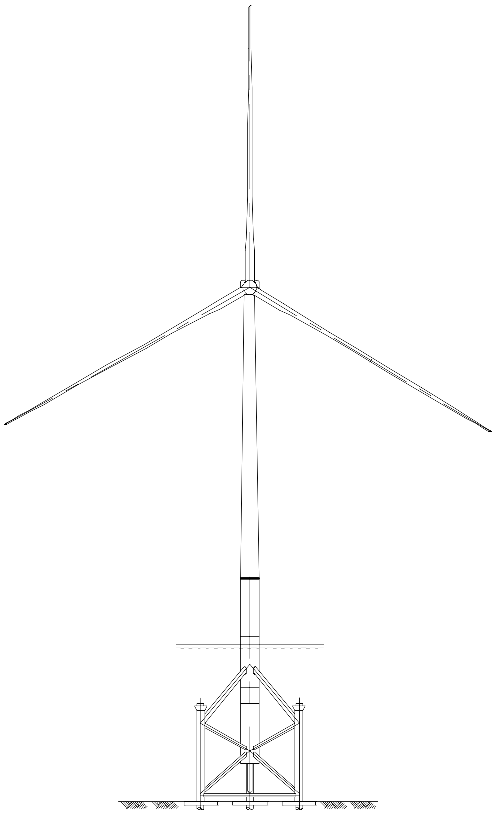
Mono Pile

<u>Mono Pile</u>

Simplicity in fabrication and installation

Becomes flexible at large water depth (~25 m), where adequate pile diameters (> 5m) result in significantly increased installation cost.

Commonly used concepts for support structures



Tripod

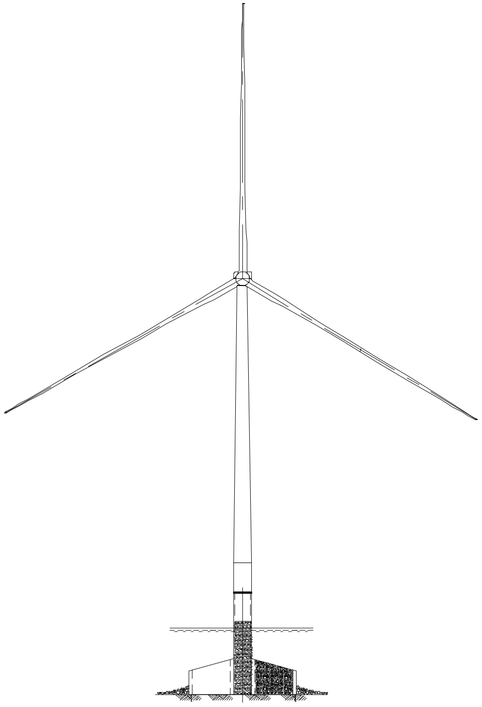
Tripod

Economical structural solution (steel weight/capacity ratio)

Well known technology for manufacturing and installation

More costly in fabrication than Mono Pile

Commonly used concepts for support structures



Gravity

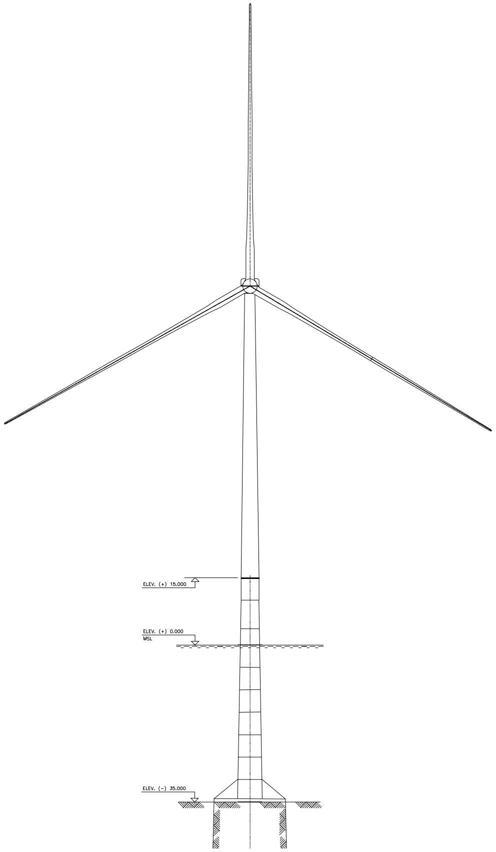
Gravity Base

Possible to float out – decrease cost of crane vessel

Fabrication/material is low cost (by use of concrete).

Not competitive at larger water depth

Commonly used concepts for support structures



Bucket

<u>Bucket</u>

‘Smart’ Gravity base concept

Fabrication/material cost comparable to that of Mono pile

Non proven technology at larger water depth

Decommissioning relatively simple process

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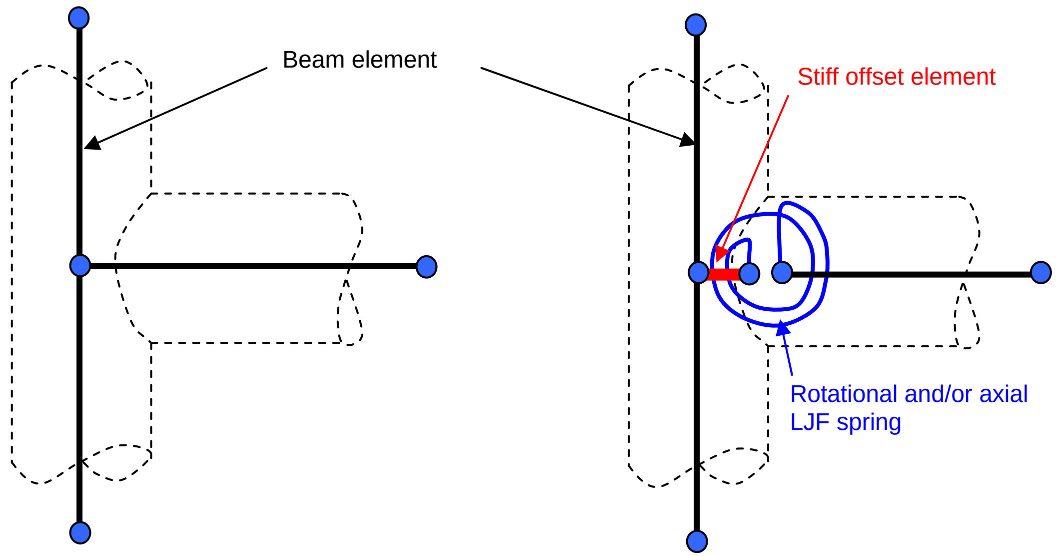
Fatigue Design of Offshore WT Structures

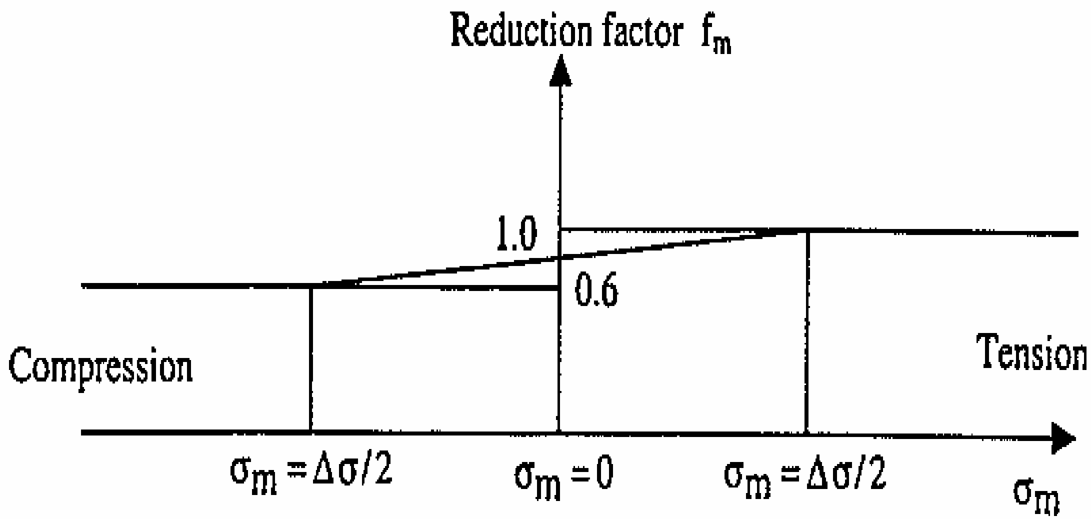
In order for offshore wind turbines and their support structures to be economically feasible, optimisation of the design, including the fatigue design needs to be carried out.

Local Joint Flexibility (LJF)



Influence from mean stress on fatigue life

Non-welded and welded structural details (plate structures)



Standards and Codes – Offshore Wind Turbines

Currently no national nor international Standard/Codes covering Offshore Wind Turbines as an integrated System:

- **IEC WT01** covers wind turbine (foundation not covered/optional)
- **IS0 19902** covers offshore fixed structures (wind turbines not covered)
- **Danish Recommendation for Offshore Wind Turbines**, December 2001 (offhore support structure design not covered specifically)

DNV Rules for Offshore Wind Turbines

Content of DNV Rules

- Design principles
- Safety levels
- Site conditions
- Loads
- Structural design
- Materials
- Corrosion
- Manufacturing
- Transport
- Installation
- Maintenance
- Decommissioning

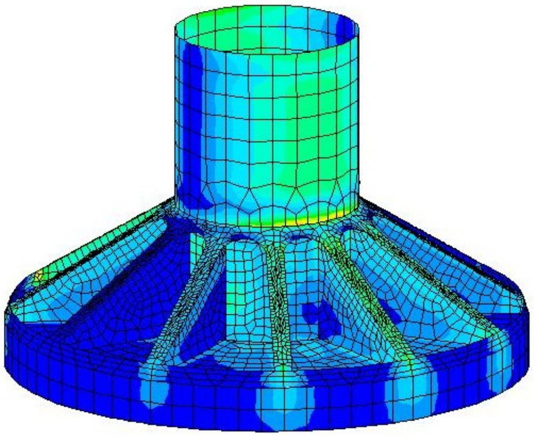
‘Life cycle approach’

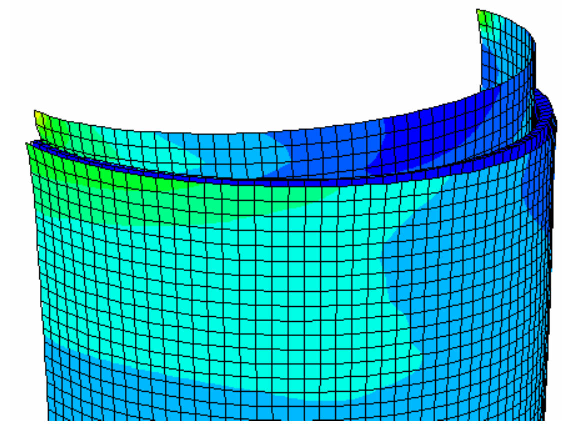
DNV Rules for Offshore Wind Turbines

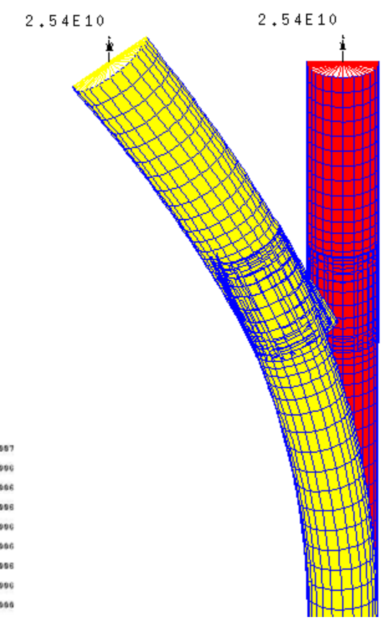
Special new topics covered by the DNV Rules

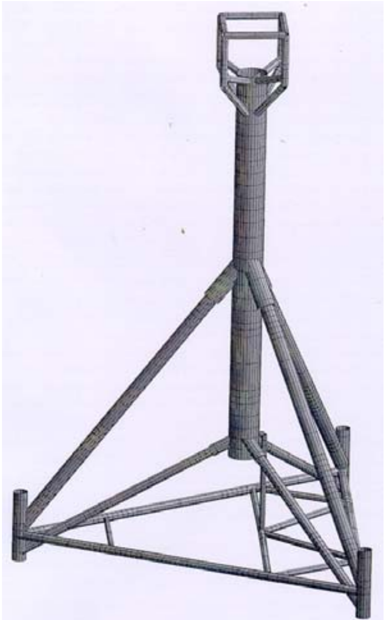
- Minimum soil investigations
- Determination of design waves
- Combined loads (wind-waves and wind-ice)
- State-of-the-art fatigue design of tubular joints
- Grouted connections in mono-piles
- Grouted connections - pile to jacket sleeve
- Composite design - steel tubular in concrete shaft
- Suction bucket foundation

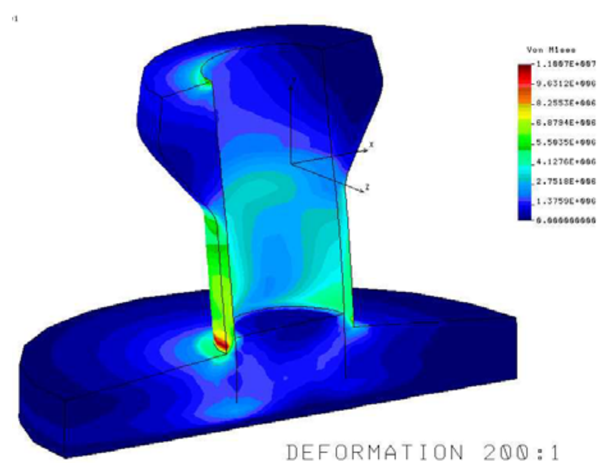
DNV Rules for Offshore Wind Turbines – Support Structures











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