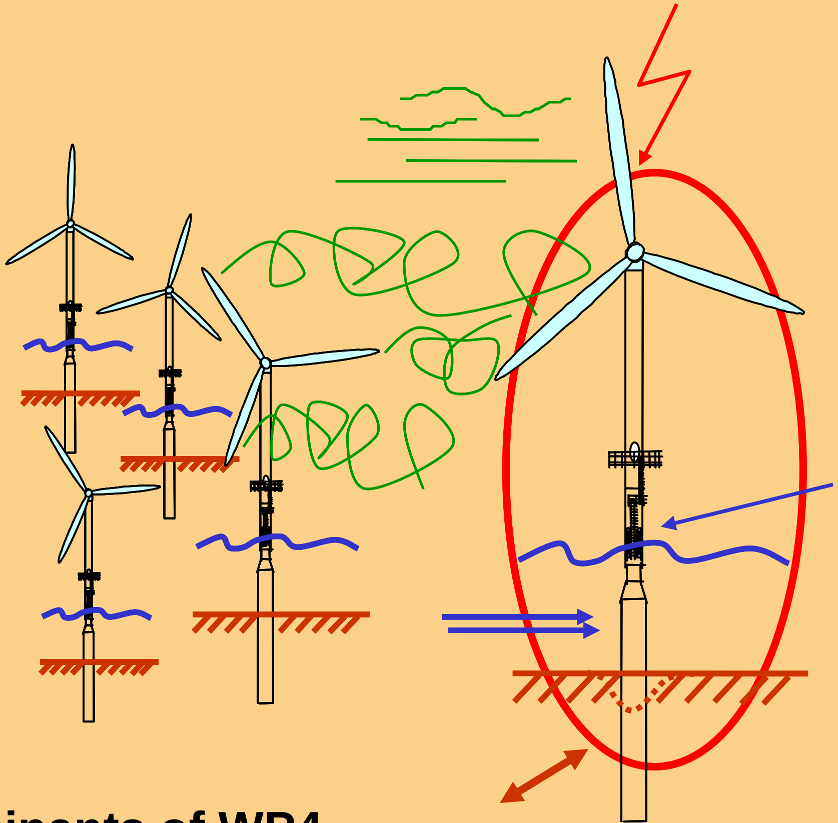
UpWind

WP 4 Offshore Support Structures



Martin Kühn, et al.
Endowed Chair of Wind Energy
University of Stuttgart

Thanks to the co-authors from the 9 participants of WP4

Universität Stuttgart

RAMBØLL

RISØ

GARRAD HASSAN

SIXTH FRAMEWORK PROGRAMME

TU Delft
Delft University of Technology

Germanischer Lloyd

DONG energy

GE Wind Energy

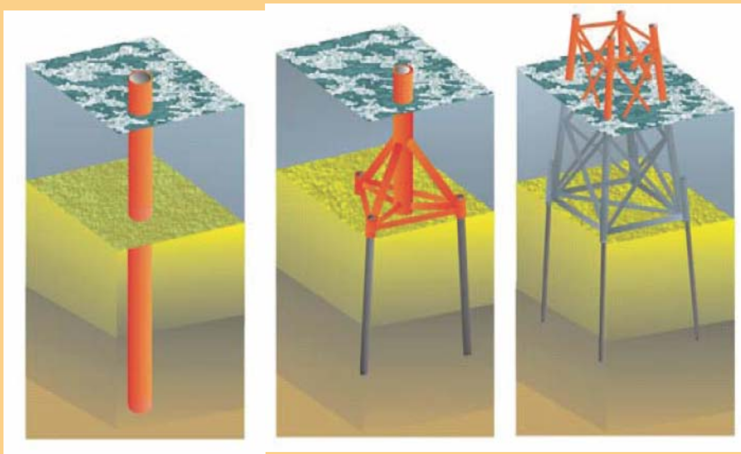
Overview

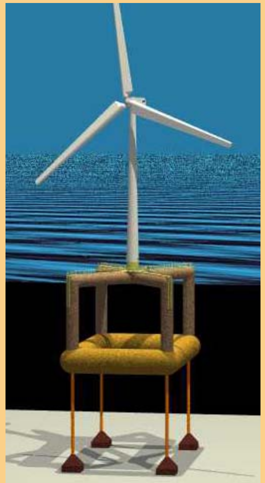
Introduction – Design Issues

WP4 - Objectives & Participants

First year results

Conclusions





Design Issues (1): Large Water Depths & Large Turbines

Large water depth and remote sites require very large turbines

Increase of hydro*__dynamic__* loading

- **softer designs attract wave excitation**

New support structure concepts required

- **limited viability of classic monopile**
- **braced and floating structures**

Proposed solutions

- **integrated design of rotor-nacelle-assembly and support structure**
- **load mitigation by smart turbine control**

[Courtesy of *REpower, Mammoet Van OOrd*]

Design Issues (2): Mismatch of Variable Site Conditions and Series Production

Distinctly different design requirements

- support structure: => site-specific from scratch
- rotor-nacelle-assembly: => Type Class + final design check

Impact of site conditions

- Dutch Q7 project:
  30% difference in foundations loads
- Kentish Flats:
  30 different monopile designs

Proposed solutions

- optimisation for large numbers
  and local site conditions
- compensation by turbine control

Design Issues (3):
Design Methods & Standards

Current industrial design tools
- (mainly) monopile / GBS model
- relatively simple hydrodynamics
- no detailed foundation models

Design methods
- distinct experience and methods in wind energy and offshore oil & gas

Standardisation
- little experience with new offshore standards

Onshore prototype Multibrid Tripod

Proposed solutions
- innovative design methods e.g. design tools, wave modelling
- update standards e.g. IEC 61400-3 ed. 2

Objectives WP 4:
Offshore Support Structures

- Innovative, cost-efficient support structures
- Integrated designs of support structure
  and turbine machinery

Particular emphasis on:

- large wind turbines
- deep-water solutions
- designs insensitive to site conditions
- cost reduction through series production

=> Enable the large-scale implementation of offshore wind farms across the EU and other markets

WP 4: Complementary Partnership

Partner	Particular contribution
UStutt	integrated design, enhanced design methods
DUT	innovative support structures
GH	WT control, floating designs
Rambøll	design for series production, offshore oil & gas experience
Risø	enhanced design methods
GL Wind	standards & certification, offshore oil & gas experience
GE	offshore turbine experience
Dong	offshore wind farm experience
Shell	offshore wind farm experience

WP 4: Tasks and Activities

WP 4.1 Integration of support structure and turbine design

- **develop integrated design and employ WT control for**
    - **mitigation of aerodynamic and hydrodynamic loading**
    - **compensation of site and structural variability**

WP 4.2 Support structure concepts for deep-water sites

- **innovative bottom-mounted structures, e.g. truss-type**
- **very soft structures: monopile or braced-type**
- **floating structures**

=> impose new WT requirements

WP 4.3 Enhancement of design methods and standards

- **design tools & methods: e.g. structural reliability methods, large number of similar designs, floating design**
- **support 1st revision of IEC 61400-3 (Offshore Wind Turbine Standard)**

Example from Task 4.1: Levels of Different Load Reduction Concepts

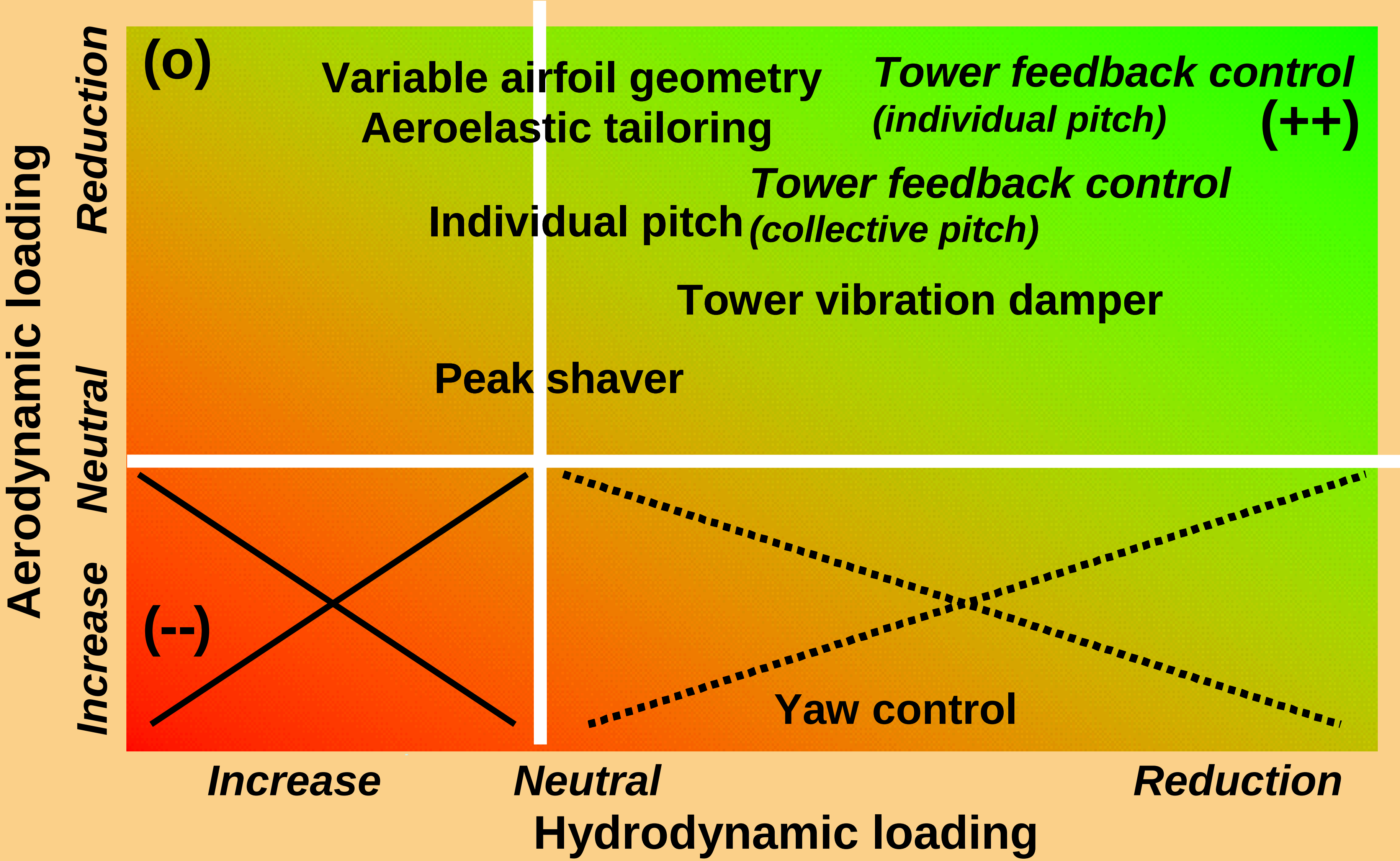
OWT design conditions/bases:
- **high design aerodynamic damping**
- **reduced hydrodynamic sensitivity**
- **allow steady operation at 1P resonance**

Operational control:
- **adjustment of operational parameters acc. to short-term statistics (wind conditions, actual sea state, wind-wave misalignment, etc.)**

Dynamic control:
- **response feedback control of *fatigue loads***

response feedback control of *extreme loads* (event triggered)

Prospects of Load Mitigation Concepts

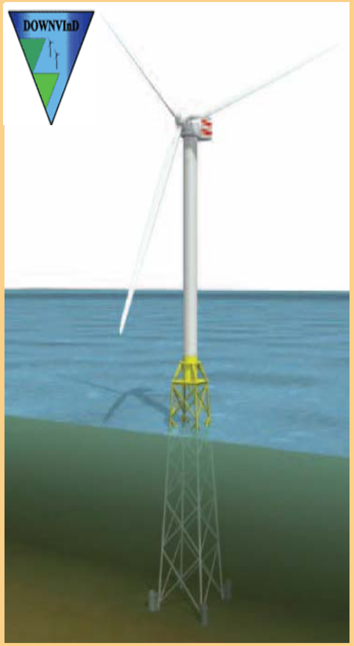


Load Mitigation for Particular Support Types

Monopile

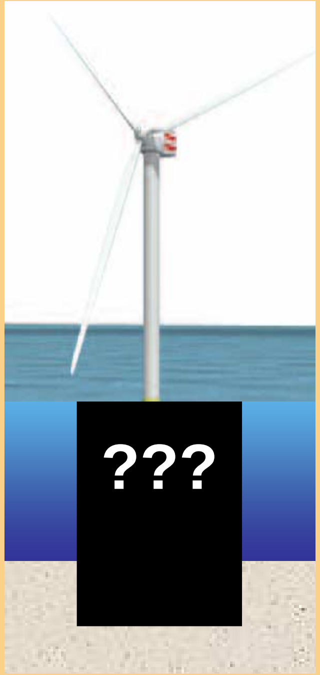
- low stiffness
- large diameter
- 1P excitation

Jacket



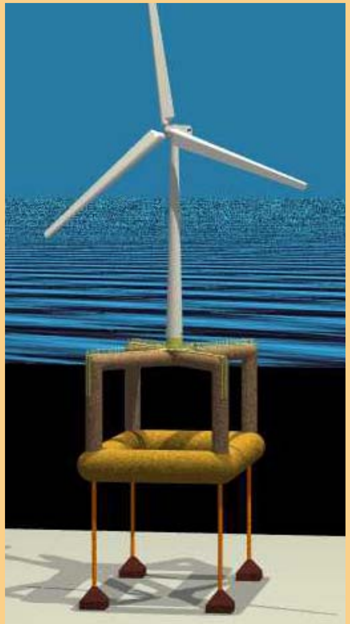
- tubular joints
- torsion
- 3P excitation

Compliant



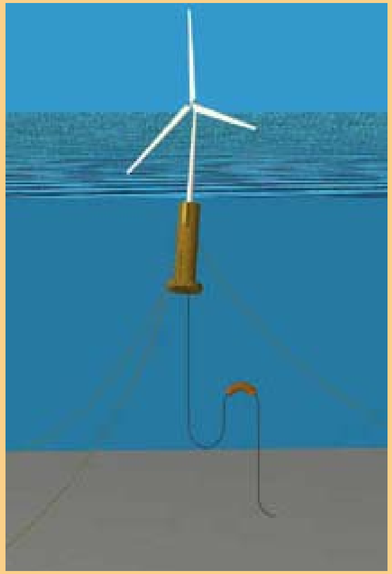
- wave excitation
- top deflection
- P-δ effects

Tension Leg Platform



- translational motions
- mooring loads

Floating Spar



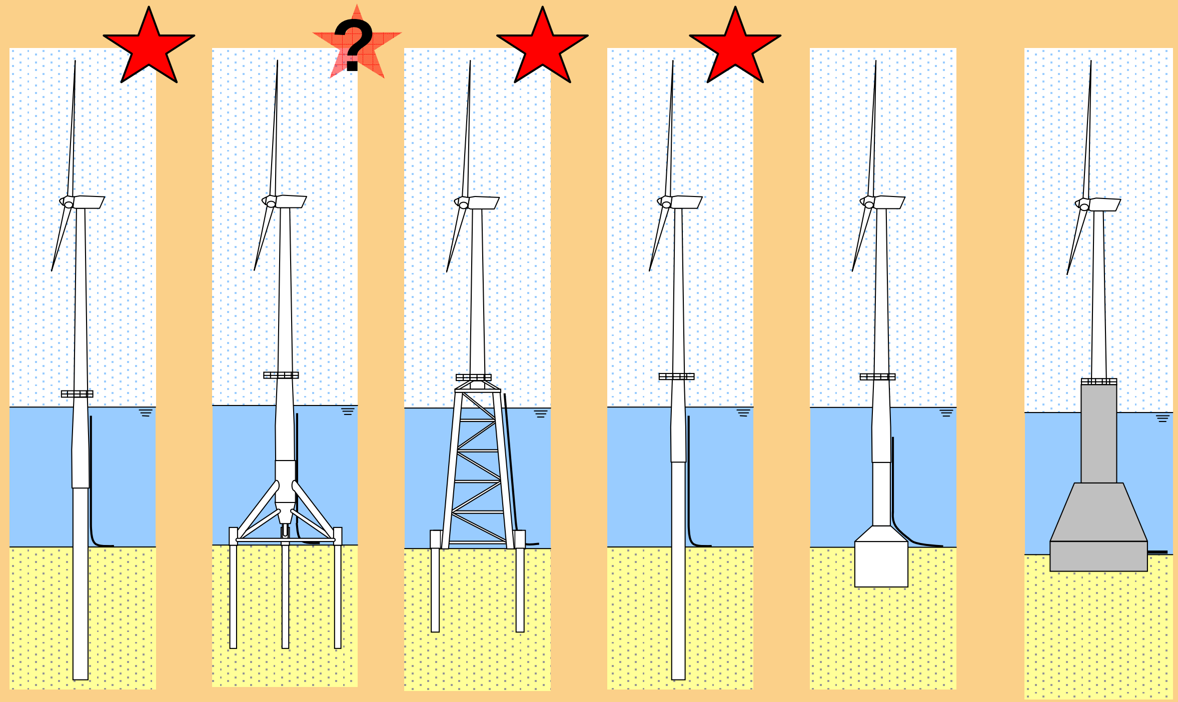
- angular motion
- mooring loads

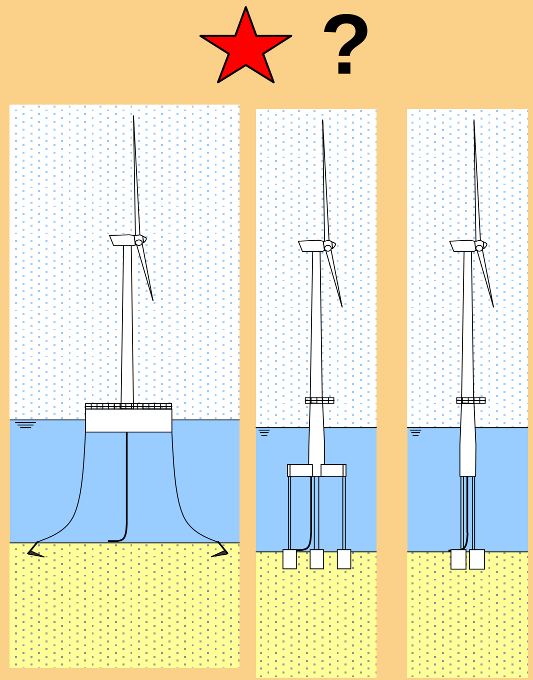
Different design drivers

=> different load mitigation concepts

UpWind

Example from Task 4.2: Offshore Support Structures: Fixed & Floating





Particular interest in WP4

- **Monopile (classic as well as compliant)**
- **Jacket (Tripod)**
- **Floating**

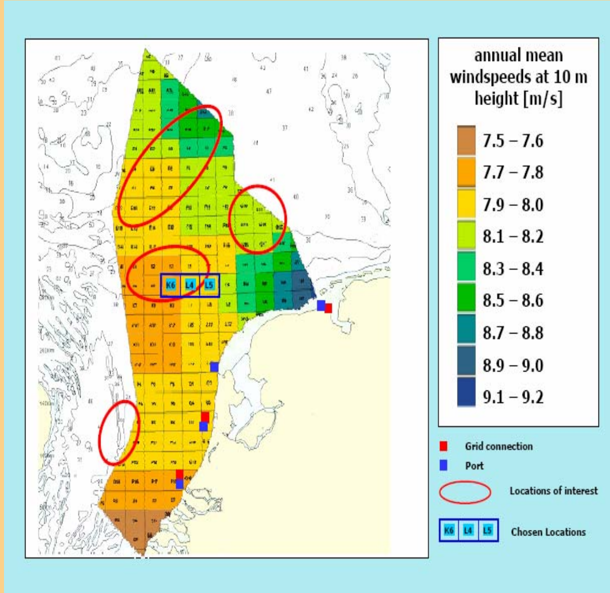
Reference Site
& Review of Design & Installation Issues

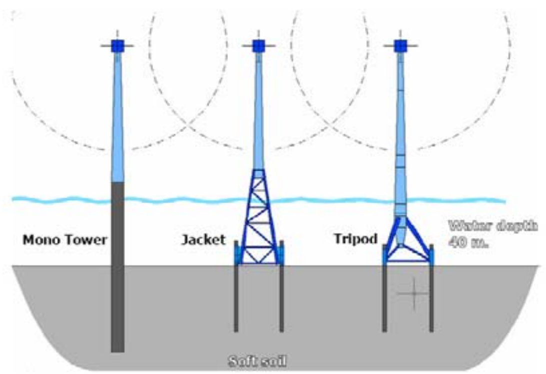
Data for reference site and turbine
- 5MW wind turbine
- soil profiles
- met–ocean data

Review of design & installation issues
=> Support structure evaluation matrix
- score list
- 6 main aspects, 20 sub-aspects
- 9 concepts at 4 water depths

Design of deep-water support structure concepts
- monopile, tripod, jacket (soft-stiff, soft-soft)

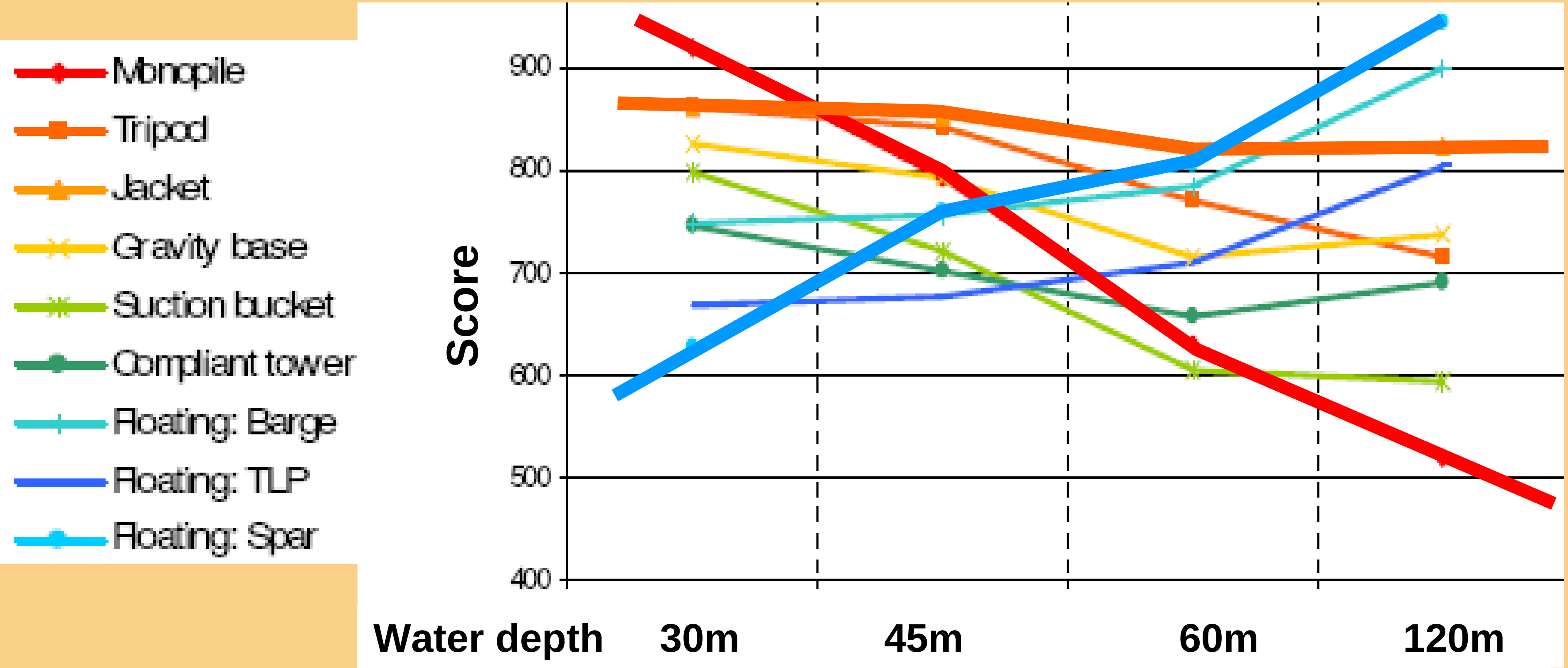
=> Design during 2nd year





Support Structure Evaluation: Average Results w.r.t. to 20 sub-aspects

Superior designs: Monopile …..Jacket….. Floating spar



Current designs (< 20 m): Monopile, (GBS)

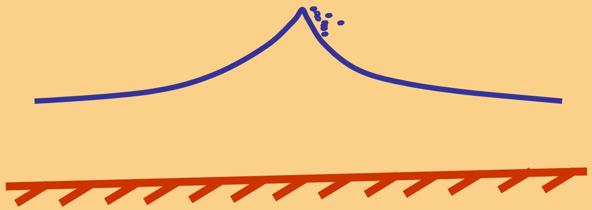
Current design: First Jacket

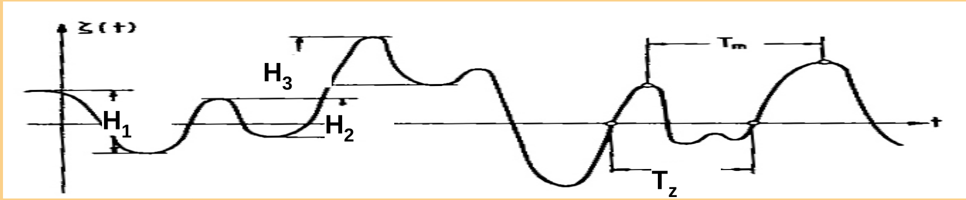
UpWind

Example from Task 4.3: Review of Modeling Approaches for Irregular, Non-linear Waves

Traditional approaches are incompatible !

non-linear, regular waves	linear, irregular sea state
=> quasi-static analysis	=> dynamic analysis





Irregular, non-linear waves are relevant for

- shallow water locations (below 20 m water depth)
- possibly only for some extreme load cases at larger depth

Preferred methods for WP4 purposes

1. irregular Airy waves with Wheeler stretching
2. irregular Airy waves with New Wave and Wheeler stretching

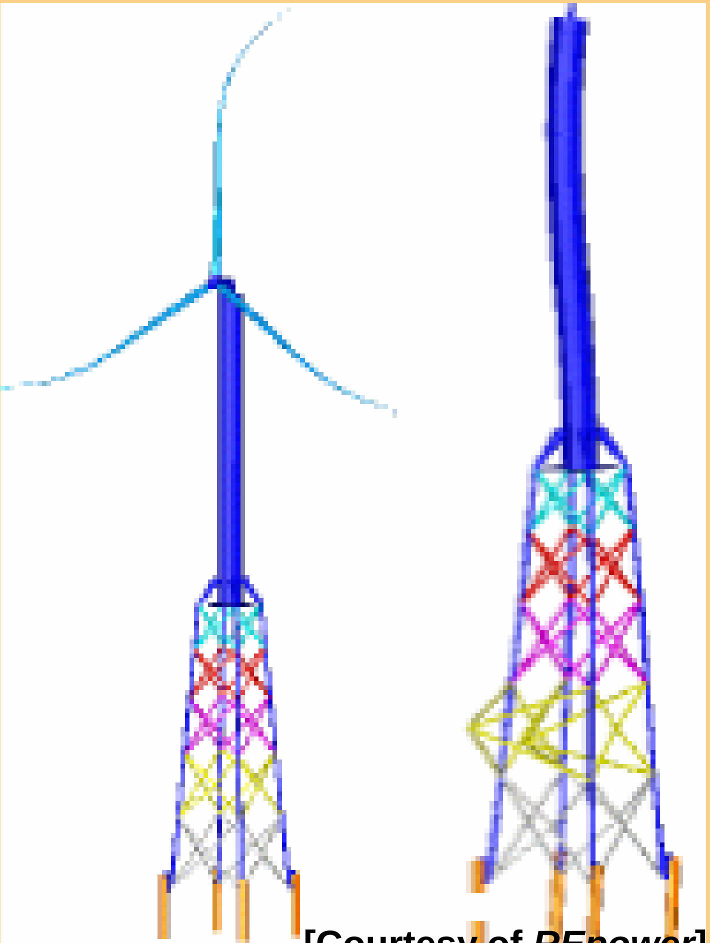
- sufficiently complex to provide the needed accuracy
- well established within the traditional offshore community
  => suitable for design purposes

Example from Task 4.3: Design Tool for Multi-Member Structures (under development)

Current industrial design tools
- (mainly) monopile / GBS model
- relatively simple hydrodynamics
- no non-linear foundation models

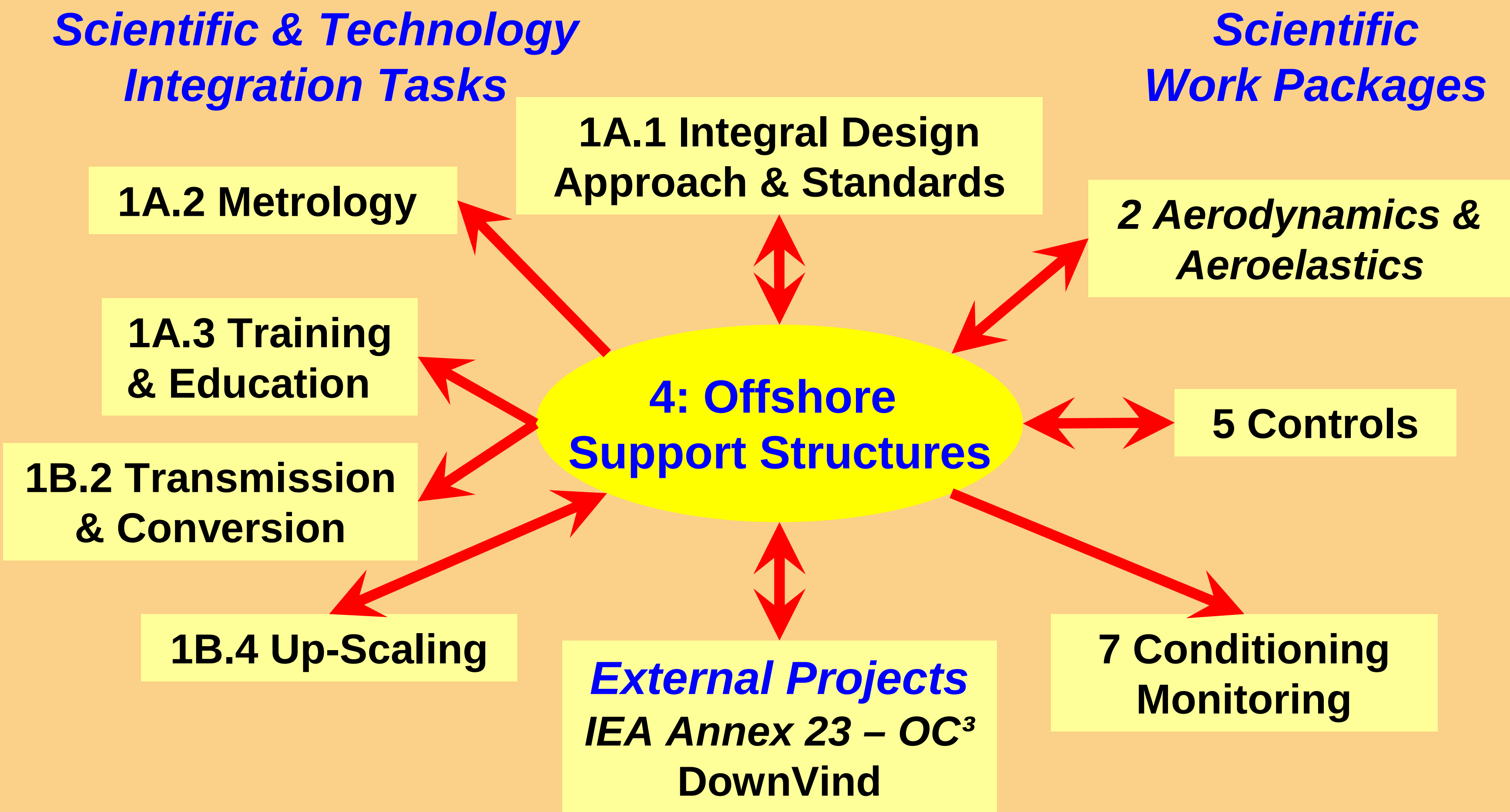
Complex dynamics of braced structures
- e.g. interaction between rotor modes and local supports structure modes
- time series approach for hot spots analysis required

Goals
- coupling of Flex5 code with FE code
- further development of Bladed code



[Courtesy of *REpower*]

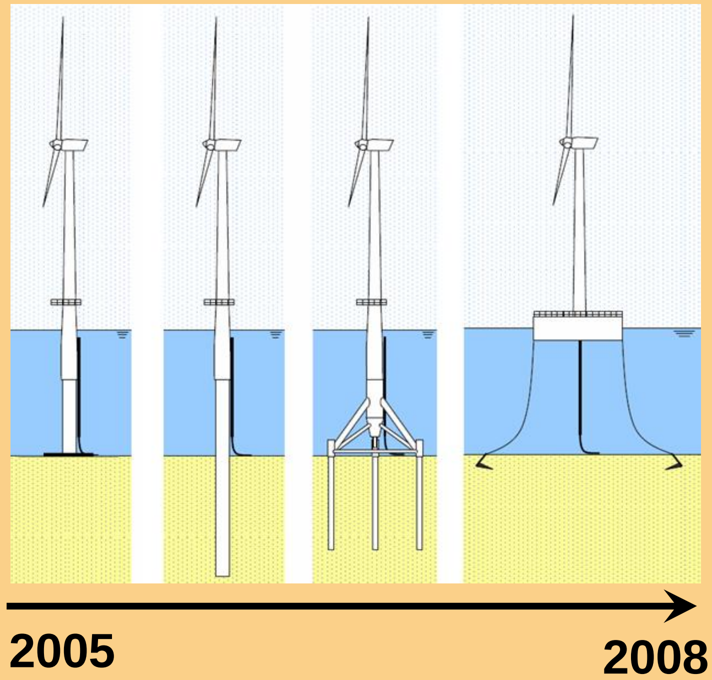
Cooperation within Integrated Project UpWind



Exchange with IEA Wind Annex 23 – Offshore Wind Energy

"Offshore Code Comparison Collaboration" (OC³)

- first international benchmark of offshore wind design tools
- coordinated by National Renewable Energy Laboratory (NREL)
- several WP4 participants involved

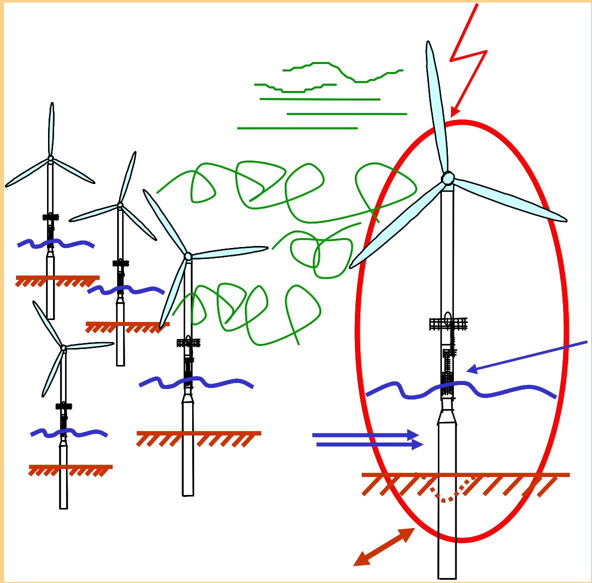


NREL is associated partner in WP4

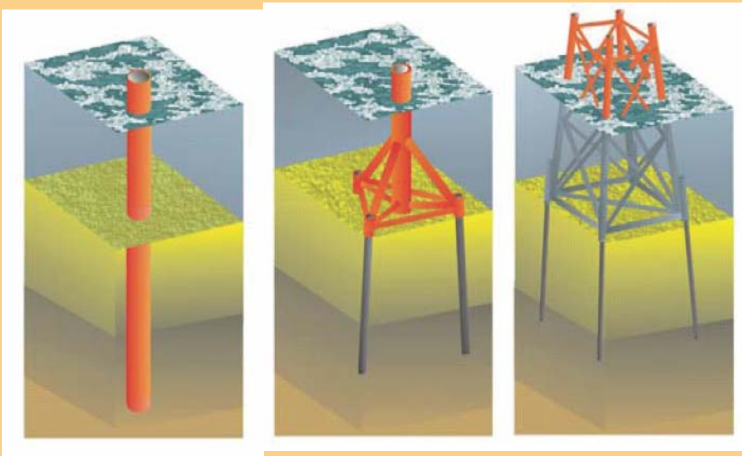
- active participation
- special interest in floating

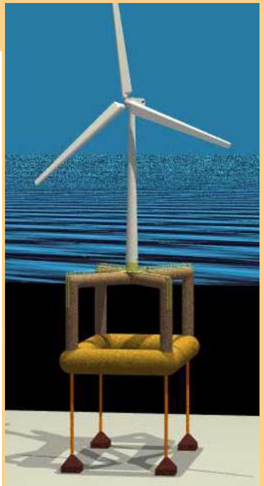
Conclusions on WP4

Cost reduction through integrated design



Cost reduction through design methods & standards





Cost reduction through site-insensitivity & series production

=> Enable the large-scale implementation of offshore wind farms across the EU and other markets

Further information

UpWind web site

www.upwind.eu

UpWind Project Coordinator

Peter Hjuler Jensen
RISØ National Laboratory, Denmark, www.risoe.dk

WP4 Work Package Leader

Martin Kühn

University of Stuttgart, Germany

www.uni-stuttgart.de/windenergie