OFFSHORE WIND TURBINE FOUNDATIONS

Christophe PEYRARD
EDF R&D - LNHE
Laboratoire d’Hydraulique St Venant
WIND RESOURCE IN EUROPE

From the *European Wind Atlas*. Copyright © 1989 by Risø National Laboratory, Denmark
OFFSHORE WIND ENERGY

From DNV
OBJECTIVES OF THE PRESENTATION

- **Offshore Wind Energy**
  - Development / General context
  - Bottom fixed context in France
  - Floating context in France

- **Bottom fixed / Floating foundations**
  - Engineering
  - Construction
  - Installation

- **Technical aspects and challenges**
OFFSHORE WIND CONTEXT
OFFSHORE WIND - HISTORY

- 1st offshore wind turbine installed in Sweden in 1991 (Nogersund; 220kW Wind World W2500; Ø 25 m).
- 1st offshore wind farm in Denmark in 1992 (off Vindeby; 11 x 450 kW Bonus B35/450). Water depth: 2 - 4 m; gravity foundation; 3km from shore.
- Until 2001, various developments off Denmark, Sweden and Netherlands (turbines P< 1MW).
- Denmark started to develop large offshore wind farms:
  - Horns Rev I (2002): 160 MW; 80 x Vestas V80-2MW
  - Nysted (2003): 166 MW; 72 x Siemens SWT 2.3MW turbines
- Since 2003, the UK then Germany and Belgium have launched large offshore wind projects...
OFFSHORE WIND DEVELOPMENT

**OWF Capacity**

- 1990-1996: 4 MW
- 1996-2000: 8 MW
- 2000-2004: 42 MW
- 2004-2008: 54 MW
- 2008-2012: 81 MW

**Number of WTGs per OWF**

- 1990-1996: 9
- 1996-2000: 12
- 2000-2004: 20
- 2004-2008: 20
- 2008-2012: 26

**Average Water Depth of OWF**

- 1990-1996: 2.0m
- 1996-2000: 4.7m
- 2000-2004: 7.9m
- 2004-2008: 14.3m
- 2008-2012: 22.0m

**Key Markets**

- Only activity in the Netherlands and Denmark.
- Netherlands and Swedish activity. Emergence of UK market.
- Huge growth in Danish and UK markets.
- Netherlands, UK and Sweden largest markets. Emergence of Asian wind farms.
TURBINES SIZE EVOLUTION

EVOLUTION OF THE TURBINE DIAMETER
Diameter in meters

- **Onshore**
- **Offshore**

- **Altamont Pass, CA**
  Kenetech 33-300 kW
  33m rotor

- **Buffalo Ridge, MN**
  Z-750 kW
  46m rotor

- **Altamont Pass, CA**
  Kenetech 56-100 kW
  17m rotor

- **Borkum West, Germany**
  Areva 5 MW
  115m rotor

- **Hagerman, ID**
  GE 1.5 MW
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- **Osterild, Denmark**
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- **Ellern, Germany**
  Enercon 7.5 MW
  127m rotor

- **Siemens 1X MW 205m rotor**

- **Vestas 8MW 164m rotor**

- **Energy Park Five, Scotland**
  Samsung 7MW 171m rotor

83.5 m SSP Blade for Samsung S7.0-171 (Denmark)

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EUROPEAN OFFSHORE WIND TARGET 2020

NREAP 2020: 43 GW
EWEA estimate (mid-2014); 23.5 GW in 2020

Source: BTM Consult - A Part of Navigant

Unit: GW

NREAP: National Renewable Energy Action Plan

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OFFSHORE WIND DEVELOPMENT - MAIN STEPS

**Origination**
- Initial screening of potential sites
- Preliminary evaluation of seabed and wind conditions
- Securing of project and property rights
- Application for permission

**Development**
- Wind Assessment/Ground Survey
- Environmental Impact Assessment (EIA)
- Technical planning
- Securing of grid connection
- Receiving of construction permit

**Construction**
- Component contracts signed
- Installation of foundations and wind turbines
- Connection to onshore grid
- Commissioning and start of operation

**Operation**
- Hands-on and pro-active operation
- Regular check and maintenance of technical equipment
- Repairs, overhauls and upgrades
- At end of lifetime: decommissioning or repowering
OFFSHORE WIND FOUNDATIONS
BOTTOM FIXED FOUNDATIONS
DEFINITION

- **Civil Engineering definition**
  - Under ground part of the structure
  - Soil-structure boundary
  - Soil mechanics / Geotechnical field
  - Definition used by some French utilities

- **Offshore wind field definition**
  - “Under tower” part of the structure
  - Soil-structure and water-structure boundaries
  - Soil mechanics and Fluid Mechanics
  - Definition generally adopted in UK, Germany and many foreign utilities
OWT foundations main types:
- Monopile
- Tripod
- Jacket
- Gravity Based Foundation (GBF or GBS)

Usually, the choice of the structure depends on the water depth and the sea bed (rock, sand...)
- Monopile typically until 20/30m
- Tripod typically until 30/40m
- Jacket typically until 50/60m
- GBS typically until 30/50m
FLOATING FOUNDATIONS
SPAR: HYWIND (2009)

- 800 ml mooring lines
- Turbine Siemens SWT 2.3MW
- Water depth: 220 m

Hywind Demo – in operation since 2009

**Main Data**
- Wind turbine: 2.3 MW
- Turbine weight: 138 tonnes
- Draft: 100 m
- Displacement: 5300 m³
- Diameter at water line: 6 m
- Water depths: 120-700 metres

**Characteristics**
- Full scale demo
- Based on a slender buoy concept
- Steel tower and substructure
- Dynamic pitch regulation
- Assembled at inshore site in sheltered waters
- Towed upright to field
- Designed for extreme North Sea conditions
SEMI-SUB : WINDFLOAT (2011)

Phase 1 – Demonstration
- Capacity: 2MW WindFloat prototype
- Location: Aguçadoura, grid connected
- ~6 km of coast, 40 - 50 m water depth
- Turbine: 2MW offshore wind turbine
- Test period: 24+ months

Phase 2 - Pre-commercial
- Capacity: ~27MW (~5 WindFloat units)
- Location: Portuguese Pilot Zone
- Turbine: Likely Vestas and other, Multi MW

Core focus of DemoWFloot
JAPANESE PROJECTS: SEMI-SUB AND SPAR (2013)

Fukushima (Mitsui/Hitachi)

- Design for use with a 2MW turbine
- Width 58 m
- Total column length 32 m of which 16 m will be submerged
- Hub height 60 m

GOTO OWT (Toda/Hitachi)

Full Scale:
- 2MW downwind turbine with 80m rotor diameter
- Total spar length 172m
- Total weight incl. Turbine 3,400 t
- Steel with pre-stressed concrete
- Steel chain mooring, 3 points, catenary, attached to drag anchors

Image Source: Kyoto University
## JAPANESE PROJECTS : SEA ANGEL (2015)

Fukushima 7 MW (MHI)  
=  
Bigest Offshore Wind turbine installed

<table>
<thead>
<tr>
<th>Items</th>
<th>Scopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine</td>
<td>• Verification of 7MW hydraulic turbine.</td>
</tr>
<tr>
<td>Floating</td>
<td>• Development of V-shape semi-sub floating.</td>
</tr>
<tr>
<td></td>
<td>• Development of the reduction of floating motion by turbine control and O&amp;M program.</td>
</tr>
<tr>
<td>Mooring</td>
<td>• 8 pieces catenary.</td>
</tr>
</tbody>
</table>

- Rotor diameter: 164m  
- Hub height: 105m (ASL)  
- Height of the floater: 32m

Installed summer 2015

FUKUSHIMA-FORWARD Project
ADVANCED SPAR 5 MW (2016)

- Last part of Fukushima forward project
  - 5MW Turbine
    - Hitachi
    - Downwind type
  - Advanced-spar concept
    - Japan Marine United
    - Low draft solution (30m)
    - Large sections (50m)

Japan is still working on prototypes
OFFSHORE WIND IN FRANCE
FRANCE

- **2004**: 1st Call for Tender “Centrales Eoliennes en mer”. 1 site awarded: Côte d’Albâtre (Velettes – Enertrag 105 MW with Areva). NIMBY issues... Cancelled.

- **2011**: 1st Round (Call for Tender) - 3 GW - 5 sites (Le Tréport - Fécamp - Courseulles - St Brieuc et St Nazaire). 4 sites awarded 1.9 GW. Construction: 2019-2020.

1st ROUND – RESULTS

- Fécamp: 498 MW
- Courseulles-sur-mer: 450 MW
- Saint-Brieuc: 500 MW
- Saint-Nazaire: 480 MW

Consortium “Ailes Marines SAS”
- 70% Iberdrola – 30% Eole-RES

Consortium “Eolien Maritime France”
- 60% EDF EN – 40% Dong Energy

Dieppe – Le Tréport: 750 MW

Total: 1.9 GW
2nd ROUND – RESULTS

Dieppe – Le Tréport
496 MW

Iles d’Yeu et de Noirmoutier
496 MW

Société “Les Eoliennes en mer de Dieppe-Le Tréport”

Société “Les Eoliennes en mer de Vendée”

Total 1 GW
INDUSTRIAL SIZE PROJECTS

- **Ambition**: 3 GW of Offshore Wind by 2020
  - 6 sites on the Atlantic coast
  - Water depth: 20m-40m
  - Distance to shore: 10/20 km

- **Large wind farms**
  - Typical installed power: 500 MW
  - Turbine: 5MW to 8 MW
    - Diameter ~ 150 m
  - 70 to 100 turbines / farm
COUT DE L’ÉLECTRICITÉ

TYPICAL ONSHORE & OFFSHORE WIND COST BREAKDOWN
Capital cost breakdown (top) & share of capital in levelized cost of electricity (bottom)

CAPEX = Capital Expenditure
OPEX = Operational Expenditure
CoE = Cost of Electricity

\[ CoE = \frac{CAPEX + OPEX}{PRODUCTION} \]

Réduire le coût de l’électricité pour être compétitif lorsque les subventions étatiques s’arrêteront

Un enjeu majeur!
PRINCIPAUX RISQUES LIÉS À LA CONSTRUCTION

Résultat du sondage (2012-2013) sur les principaux risques en phase construction, vus par les développeurs de projets en Europe (Utilities) :

- Cable installation : 53.8%
- Turbine installation in difficult weather conditions : 46.2%
- Lead times: making sure the project does not overspend its budget due to poor time management : 38.5%
- Foundation installation : 30.8%
- The use of installation vessels : 30.8%
- Health and safety of the workers : 30.8%
- Wind turbine installation : 21.3%
- Using heavy lifting equipment offshore : 7.7%

Vision RWE :

Cable installation remains the top challenge for the majority of Europe’s largest utilities. The cost of cable repair and the complexity of the cable installation procedure (especially in deeper water, further from the shore) could be the reason for this fact.
FRENCH FLOATING PROJECTS
ADEME “AAP” : APRIL 2016

4 sites selected on the French coasts for precommercial farms
20/30 MW by project (3-6 turbines)
Consortiums (Turbine/Floater/Utility)

1 Atlantic site

3 Mediterranean sites
2 PROJECTS ALREADY AWARDED

- **Ile de Groix (Atlantic) – 24 MW**
  - EOLFI
  - General Electric (ex-Alstom) / 6MW turbine
  - DCNS

- **Gruissan (Languedoc) – 24 MW**
  - Quadran
  - Senvion / 6 MW turbine
  - IDEOL

- **Demonstrator project**
  - IDEOL 2MW
  - Under construction by Bouygues TP
  - SEMREV 2017

--- Will be the first Offshore Wind turbine in France!
BOTTOM FIXED
/
FLOATING FOUNDATIONS
BOTTOM FIXED FOUNDATIONS
BOTTOM FIXED FOUNDATION
DESIGN METHODOLOGY

- **Aerodynamic forces**
  - Coming from the turbine
  - Provided by the turbine manufacturer

- **Hydrodynamic forces**
  - Current
  - Waves

- **Soil response**
  - Depending on the sea bed type
  - Depending on the foundation type

- **Transition piece**
  - Link between sub-structure and Turbine/Mast system
  - Boundary between hydrodynamic design and aerodynamic design
BOTTOM FIXED FOUNDATION

TYPE OF FOUNDATIONS 1/3

- OWT foundations main types:
  - Monopile
  - Tripod
  - Jacket
  - Gravity Based Foundation (GBF or GBS)

- Usually, the choice of the structure depends on the water depth and the sea bed (rock, sand...)
  - Monopile typically until 20/30m
  - Tripod typically until 30/40m
  - Jacket typically until 50/60m
  - GBS typically until 30/50m
Repartition of OWT foundations

- End 2012 figures
- Monopile is the most used foundation type
  - Denmark
  - Germany
  - UK
- GBF is significant
- Tripod/Tripile is not common
COMPLEX DESIGN…
BOTTOM FIXED FOUNDATION
HYDRODYNAMIC MODELS - FORCES

- Hydrodynamic loads model - Standards
  - Semi-Empirical approach (Morison formula)
  - Thin bodies approximation

\[
F = C_M \cdot \rho \pi \frac{D^2}{4} \dot{U}(t) + \frac{1}{2} \rho \cdot C_D \cdot D \cdot \dot{U} \cdot |U|
\]

Perfect fluid approx.

Viscous effect

Coefficients + Kinematics

Hydrodynamic Force
BASIN TESTS
HYDRODYNAMIC FORCES EVALUATION – MODEL CALIBRATION

- Froude scaling
  - Inertia forces conserved
  - Reynolds similitude lost
  - State of the art of the O&G industry

- Typical scale
  - Between 1/20th and 1/50th
  - Water depth: 40m => 1m to 2m
  - Structure diameter: 7m => 15 to 40 cm
  - ECN, Oceanide, IFREMER…
MONOPILE PILING

- Hydro-hammer or vibro-driving devices are used.
- Noise impact on sea mammals: key issue!
- Multi-Hammer are used when diameter > 7.5 m
SCOUR PROTECTION

Horseshoe and Wake Vortices around a Cylindrical Element

CROSS-SECTION

Deltarès

Offshore Windpark Egmond aan Zee – scour protection

Teesside – Kyowa Filter Bags – MSS Engineering
JACKET

- Jacket: steel lattice structure (welded pipes Ø 0.5 – 1.5m) from Oil & Gas industry. ~ 1000tons (> 1km welding!).
- Structure suitable for deep water (< 50-60 m) with heavy turbines (> 5 MW). Small leg monopiles are driven in the seabed (Ø 1 – 2.5m).
- 1st offshore wind installation: demonstration site Beatrice in Scotland in 2006 (2 x REpower 5 MW – 45 m water depth).

Advantages

- Lightweight and stiff structure
- Better global load transmission compared to monopiles
- Large variations in water depth can be covered through cantilevering piles or modifying the geometry
- No scour protection required
- Structural redundancy
- Low soil dependency
- Good response to wave loads. Little sensitivity to large waves and limited dynamic amplifications of loads due to high stiffness
- Limited storage area compared to GBF
- Faster fabrication compared to GBFs (serial production)
- Better quality control
- Easy decommissioning

Disadvantages

- Complexity of fabrication
- Large number of joints required compared to other latticed structures
- Logistical issues due to the templates (pre-piling case)
- Complex connection to transition pieces
- High manufacturing lead-times
- No standardized design that leads to long certification processes
TRIPOD INSTALLATION (ALPHA VENTUS)

Tripods being welded

Tripod up-ended for shipping

Tripods arriving at Wilhelmshaven port

Heavy-lift crane ship on site

Tripod foundation lowered to seabed

Installation complete
# VARIOUS GBS CONCEPTS

<table>
<thead>
<tr>
<th>Type</th>
<th>Features</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-Buoyant (“Floating”)</td>
<td>GBS can be floated out and towed to the offshore site using standard tugs. At the site, GBS is filled with ballast.</td>
<td>Gravitas</td>
</tr>
<tr>
<td>Auxiliary Buoyancy (“Semi-floating”)</td>
<td>Special transport vessel required for buoyancy support. This concept helps reduce concrete volume. Additional ballasting at site.</td>
<td>Strabag</td>
</tr>
<tr>
<td>Crane Lowered</td>
<td>GBS cannot float. A heavy lift crane vessel is required. A large transportation barge + heavy crane vessel can also be used. Possible additional ballasting at site.</td>
<td>Rambiz-DEME</td>
</tr>
</tbody>
</table>
TURBINE INSTALLATION
TURBINE INSTALLATION
TURBINE INSTALLATION
INSTALLATION – HEAVY OFFSHORE VESSELS
FLOATING FOUNDATIONS TECHNOLOGIES
FLOATING FOUNDATION

WHY?

- 0-60m: Bottom Fixed Foundations
- 60-500m: Too deep for Fixed
- >500m: Floating
FLOATING FOUNDATION
WHY?

- Going to deeper waters
  - Bottom fixed foundation: maximum ~ 50-60 m water depth (structure size, installation vessel: crane, Jack Up...).

- European Areas
  - Offshore Norway, Scotland, Ireland
  - Mediterranean Sea

- Technology from Oil & Gas offshore.

- Installation should require less specific vessels

- Possibility to assemble both turbine and platform onshore (port) and tow them out on site.

- Challenges
  - Platform motions
  - Moorings
  - Dynamic electric cable
  - Further from shore means higher winds but also higher sea states
Hywind-demo
WindFloat 1
Fukushima Forward
GOTO OWT

Fukushima Forward
Pre-commercial farms
EXAMPLES OF FLOATING PROJECTS...
STABILITY
OVERVIEW

- Stability consists of comparing
  - Heeling moment due to wind
  - Restoring forces due to buoyancy

- Wind heeling moment
  - Rotor thrust
  - Point of application

- Buoyancy restoring moment
  - Position of center of buoyancy B
  - Position of center of gravity G
  - Water plane area

K=Baseline (keel)
B=Buoyancy
G=Lightweight+Deadweight
M=Metacenter
GZ=Righting Lever
STABILITY
OVERVIEW

- Hydrostatic stiffness

\[ K_H = \rho V g \left( KB - KG + \frac{I}{V} \right) \]
STABILITY APPLICATION

- SPAR SOLUTION

\[ K_H = \rho V g \left( KB - KG + \frac{I}{V} \right) \]

KB-KG=GB  Low contribution

Stability from the distance between Center of Gravity and Center of buoyancy
STABILITY APPLICATION

- BARGE SOLUTION

\[ K_H = \rho V_g \left( K_B - K_G + \frac{I}{V} \right) \]

\[ KB - KG = GB < 0 \quad \text{High contribution} \]

\[ \text{Stability from the size of the water plane area} \]
STABILITY APPLICATION

- TLP SOLUTION

$$K_H = \rho V g \left( K_B - K_G + \frac{I}{V} \right)$$

Unstable

Strong Tensions

Stability from the tendons

KB-KG=GB Contribution
STABILITY
ADDITIONAL CASES

- In addition, you need to consider
  
  - Damaged cases, when the floater is partially flooded
  
  - Towing and installation phases

Flooded compartment
Generally, 4 types of floaters are considered:

- BARGE
- SPAR
- TLP
- SEMI-SUB
FLOATING PLATEFORMS
DESIGN PROCESS

- **Metocean study**

- **Stability**
  - Plateform counterbalance wind heeling moment

- **Motions**
  - Maximum motions & accelerations to insure system resistance
  - Maximum motions for power performance

- **Station-Keeping**
  - Insure IAC security
  - Avoid drift

- **Installation**
  - Is the plateform easy to build / install / maintain
MOTIONS AND ACCELERATIONS ANALYSIS

OVERVIEW

- Floating offshore wind plateforms motions due to
  - Wind: stochastic phenomenon
  - Waves: irregular sea states
  - Current
  - Platform / Structure natural modes

  ➡️ Non-linear moorings
  ➡️ Non-linear forces

- Need to perform a numerical analysis
  - Aerodynamic models
  - Hydrodynamic models
  - Structural models

  ➡️ Keep in mind: 
  ~10,000 load cases
Hydrodynamic models used in most of the FOWT projects

- Potential flow + no viscosity
  - Irrotational
  - No drag forces
- Linear hypothesis
  - Small waves
  - Small motions

Differences between bottom fixed and floating

- Need for buoyancy/stability leads to « Large » structures
  - Thin bodies hypothesis not fully respected
- Structure experiences significant motions
  - Need to model waves – motions interactions
- Wave-Structure interaction

Diffraction / Radiation approach
### MOTIONS AND ACCELERATIONS ANALYSIS

**MODELLING APPROACH – HYDRODYNAMICS - POTENTIAL FLOW**

- **Numerical tools**
  - Comercial
    - WAMIT
    - DIODORE
    - HYDROSTAR
    - AQWA
  - Non-commercial
    - NEMOH (Free - Open Source – Ecole Centrale Nantes)

- **Outputs**
  - Added mass
  - Radiation Damping
  - Hydrodynamic forces
  - Hydrostatic stiffness

**Equation Of Motion**

\[
(M + M_A(\omega))\ddot{x} + (D + B(\omega))\dot{x} + (K + K_H)x = F_e
\]

6 degrees of freedom equation
MOTIONS AND ACCELERATIONS ANALYSIS
MODELLING APPROACH – FREQUENCY DOMAIN MODELLING

\[
(M + M_A(\omega))\ddot{x} + (D + B(\omega))\dot{x} + (K + K_H)x = F_e
\]

Pitch - 180°

Amplitude of motion (°)

\[ M\dddot{x} + Kx = 0 \]

Natural period peak

High pulsation

Low pulsation

Period (s)

Mass

Damping

Stiffness
MOTIONS AND ACCELERATIONS ANALYSIS
AERO/HYDRO COUPLING – DAMPING

- Aerodynamic Damping: WINFLO project
  - Influence on motions
  - Control strategy

Pitch decay test

Aero + Hydro
Hydro Only
STATION KEEPING ANALYSIS

TYPE OF MOORING SYSTEM

- **Catenary lines**
  - Weight
  - Large Mooring radius
    - Several times water depth
    - \(~ 400 \text{ m} – 800 \text{ m}\)
    - Farm application?
  - Used for the 5 multi MW FOWT projects

- **TLP**
  - Tension
  - Low Mooring radius
    - \(~ 50 \text{ m}\)
    - Good for farm application

- **Taut or semi-taut lines**
  - Intermediate solution
  - Generally with synthetic rope
All FOWT projects use mainly time domain approach to design their system
- Motion and acceleration analysis
- Mooring sizing

Some numerical tools from Oil&Gas and Onshore wind have been adapted and coupled
- Orcaflex / No aerodynamic module
- Deeplines Wind
- Bladed
- FAST (free & OpenSource) / No dynamic mooring

Keep in mind that another software is often necessary to solve the Diffraction/Radiation problem
BASIN TESTS
FULL SYSTEM SCALING

- **Froude scaling**
  - Well adapted for wave-structure interaction
  - Aerodynamics very sensitive to Reynolds number
  - Hard (impossible) to scale
    - Geometry
    - Thrust
    - Rotor speed and wind velocity

- **Typical scale**
  - Between 1/20th and 1/50th
  - Water depth: 100m => 2m to 5m
  - Catenary lines ~ 600m => 10m to 30m
BASIN TESTS
OTHER STRATEGIES FOR FULL SYSTEM MODELLING

- Need for full system behavior assessment
  - Froude scaling / Reynolds scaling
  - Multi-MW prototypes Expensive & time consuming

- Software In the Loop (SIL)
  - Froude scaling for the mast, floater and mooring
  - Fan on top of mast, driven by an aerodynamic software
    Experimental validation of hydrodynamic behavior

- Wind Tunnel tests
  - Reynolds scaling
  - Hexapod
    Experimental validation of aerodynamic loads under wave induced motions

- CFD
  - Global system modelling
  - High CPU cost
INSTALLATION
INSTALLATION - SEMISUBMERSIBLE

Tow from Setúbal to Agucadoura (~400 km) using the same vessel that was used for the mooring installation.

In Operation since December 2011.
NEXT STEP FOR FLOATING - HYWIND SCOTLAND

“Roadmap” Hywind-Statoil

2001

Concept  Model test  Full-scale  Pilot Park, 3-6 turbines  Large Parks, 500-1000MW

2008

2009

2015-2018 Hywind II

2025 ?


<table>
<thead>
<tr>
<th>Hywind Scotland</th>
<th>Installed capacity (5 WTGs)</th>
<th>30 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (sea level)</td>
<td>~4 km²</td>
</tr>
<tr>
<td></td>
<td>Water depth</td>
<td>95-120 m</td>
</tr>
<tr>
<td></td>
<td>Average wind speed (@100 m)</td>
<td>10.1 m/s</td>
</tr>
<tr>
<td></td>
<td>Mean waves, Hs</td>
<td>1.8 m</td>
</tr>
<tr>
<td></td>
<td>Offshore export cable length</td>
<td>Ca. 30 km</td>
</tr>
<tr>
<td></td>
<td>Onshore cable length</td>
<td>Ca. 2-3 km</td>
</tr>
<tr>
<td></td>
<td>Transmission voltage</td>
<td>33 kV</td>
</tr>
<tr>
<td></td>
<td>Mooring</td>
<td>Pre-laid chains</td>
</tr>
<tr>
<td></td>
<td>Anchor</td>
<td>Suction</td>
</tr>
</tbody>
</table>

Winner of Scottish Floating Offshore Wind Call for Tender (2013)

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SOME CHALLENGES FOR OFFSHORE WIND
**TURBINE SIZE AND CONTROLLER**

**EVOLUTION OF THE TURBINE DIAMETER**

Diameter in meters

<table>
<thead>
<tr>
<th>Year</th>
<th>Onshore</th>
<th>Offshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td></td>
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<tr>
<td>1990</td>
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<td>1995</td>
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**83.5 m SSP Blade for Samsung S7.0-171 (Denmark)**

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**Wind induced motion damping**

**Fatigue reduction**

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**Onshore controller**

**Floating adaptation**
FLOATING WIND
STILL AT A R&D STAGE

- **Need for stability**
  - Reduce turbine thrust
  - Increase turbine tolerance to tilt
  - Innovative floater solution

- **Flexible system design**
  - Mooring lines length
  - Mooring lines materials
  - Export cable / Offset of the FOWT

- **Projects technical de-risking**
  - Global behavior of a complex system
    - Basin test strategy?
    - CFD?
HYDRODYNAMIC LOADS
BETTER ESTIMATION FOR BETTER DESIGN

- Ringing loads observed on Gravity Based Foundations
  - Ringing is a high order hydrodynamic phenomenon
  - Induces very high loads ↔ Design for Extrem storms

- TLP structures can also experience ringing loads
  - Example: Heidrun Tension Leg Plateform
  - Impact on tendons design

High peak load, 11 times the standard deviation

Development of fully nonlinear hydrodynamic models (Potential flow / Navier-Stokes)

High CPU cost/High research cost
HYDRODYNAMIC LOADS
BETTER ESTIMATION FOR BETTER DESIGN

- Breaking waves
  - When steepness increase until a level of about 14%
  - Impact loads
  - Complex fluid mechanics problem

Needs for experimental work

Or CFD (VoF, SPH methods…)

Test EOL30 : bottom slope 5% - $d_{	ext{atmos}} = 0.8 \text{ m} - T = 2.4 \text{ s} - H_{	ext{atmos}} = 0.288 \text{ m}$

Test EOL107 : bottom slope 2.5% - $d_{	ext{atmos}} = 1.0 \text{ m} - T = 1.6 \text{ s} - H_{	ext{atmos}} = 0.280 \text{ m}$
SCOURING

- Sediment convection by fluid
  - Waves
  - Currents

- Scouring issues
  - Can be very critical
  - Modelling
  - Protection

Loss of stability for the foundation
Stiffness – Natural frequencies
Very high number of load cases to design an OWT
- ~ 20000 DLCs
- Fatigue + Extreme events
- Standards and Guidelines : IEC, DVN, GL, ABS…

Due to the number of parameters
- Wind
  - Direction / Intensity / Turbulence
- Wave
  - Direction / Height / Period / Spectrum
- Turbine
  - Start up / Shut down / Grid loss
- …

Design strategy
- Response based design ?
- Fatigue assessment
PROJECT ACCEPTABILITY
CRITICAL ISSUE IN THE DEVELOPMENT

- YYY
  - XXX
THANK YOU