# Introduction to offshore wind turbines (OWTs)

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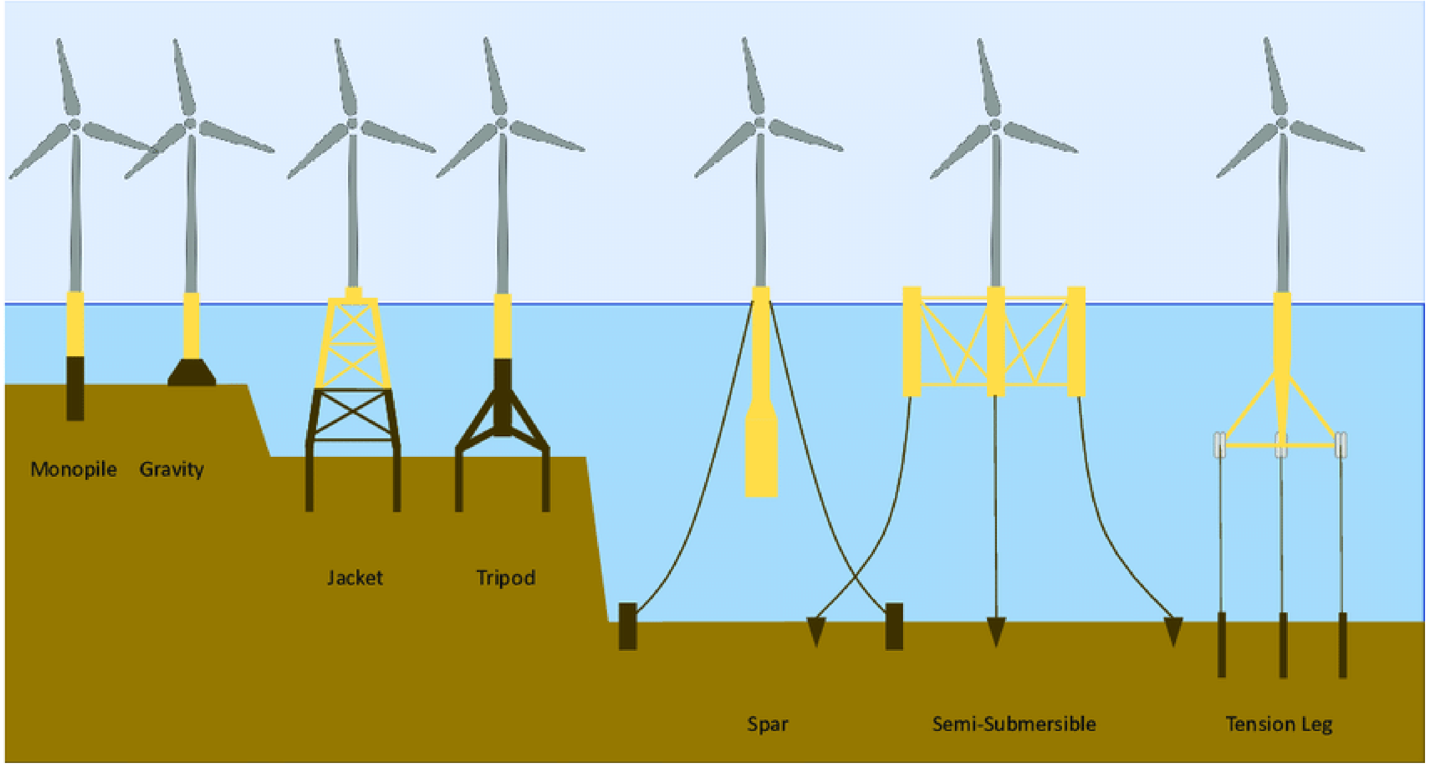
# Outline

1. Support structure configurations
2. Analysis and design elements of OWTs
3. Offshore wind farms: from planning to operation

# 1. Support structure configurations

- Fixed OWTs
- Floating OWTs

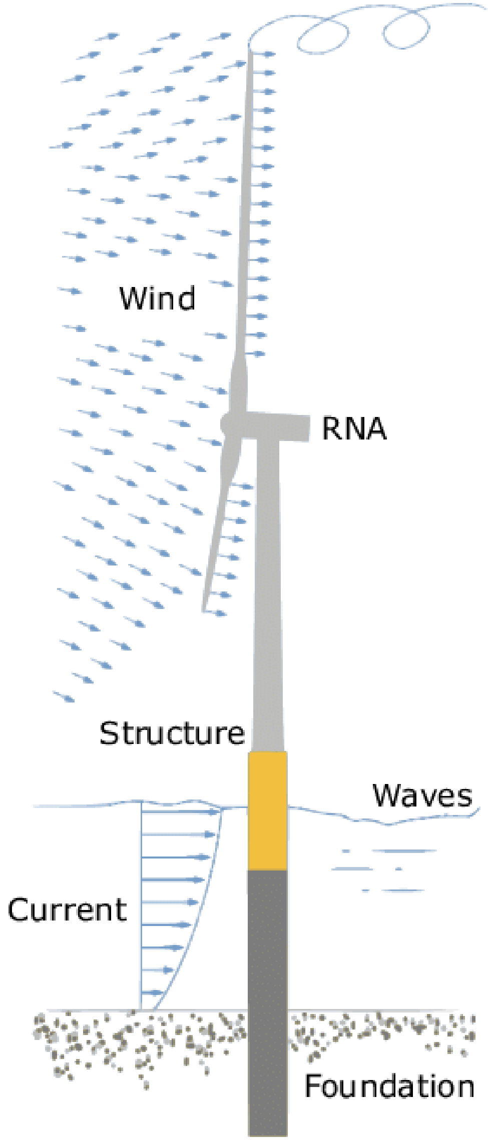



- Issues:

  Metocean, Fabrication, Transport, Installation, Soils, Moorings, Tower and Turbine Specification

- Environmental forces: wind, waves and currents

# 1.1 Fixed OWTs: Monopile




Water depth: 50 m and going up

Supporting structure pile diameter: 10 m and going up

Foundation: tradeoff as stiff soil increases natural frequency but hinders drivability, care for scour

Example from the Veja Mate offshore wind farm in the North Sea 130 km north of Germany: length 82.2 m, diameter 7.8 m, for water depth ~40 m

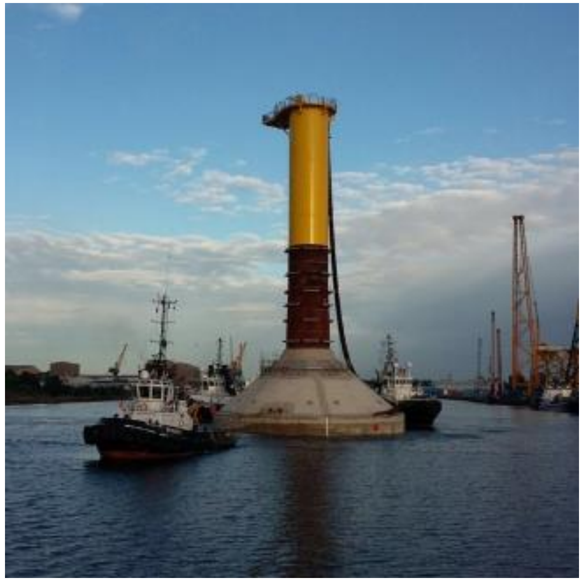
# 1.1 Fixed OWTs: Gravity Base

Water depth: 40 m and going up

Produced in land and self-floating transport to location

Foundation: risk of liquefaction induced by cyclic loads, care for scour

Example from the Blyth offshore wind demonstration project in the North Sea off the Scotland coast: height 60 m, base diameter 31 m, for water depth ~40 m



# 1.1 Fixed OWTs: Jacket

Water depth: 50 m and going up

Produced in land and transported to location by barges

Foundation: fatigue performance for combined hydrodynamic and aerodynamic loads

Example from the TPC offshore wind farm 8 km off the west coast of Taiwan: height 55-62 m, anchored to the seabed by four pin piles of 3.1 m diameter each.

# 1.1 Fixed OWTs: Tripod

Water depth: 50 m and going up

Produced in land and transported to location by barges

Foundation: stiffer and cheaper than jacket

Performance: less resonant with waves

Example from the Germany
Global Tech I offshore wind farm.
Each tripod foundation weighs 900 T,
stands 60 m high and takes around
four months to produce.

# 1.2 Floating OWTs: Spar-Buoy

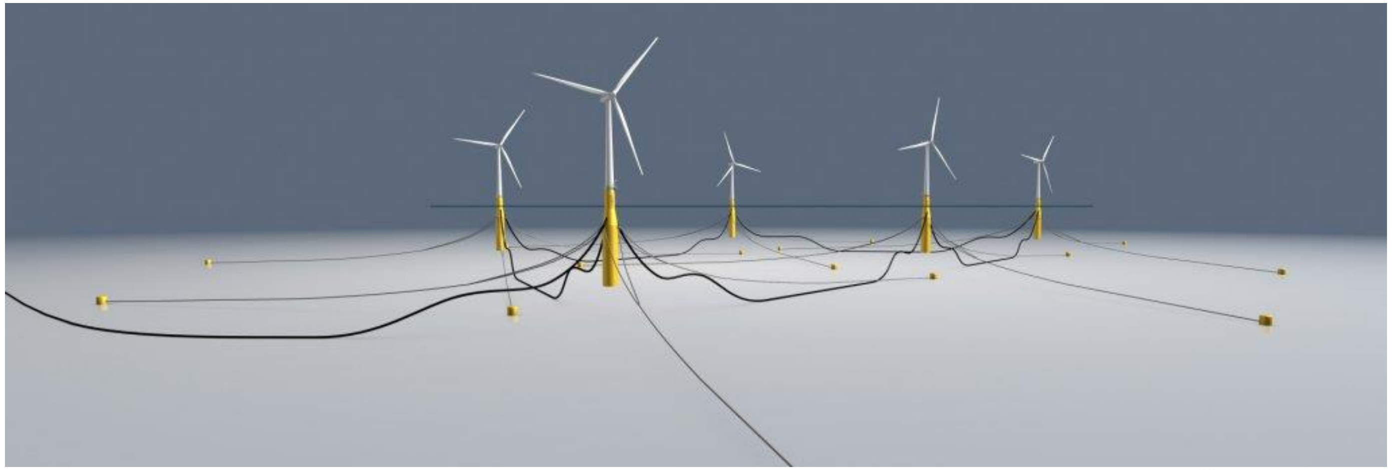
Example (www.equinor.com): The 30 MW Hywind Scotland wind farm in the North Sea, which comprises five 6 MW turbines.

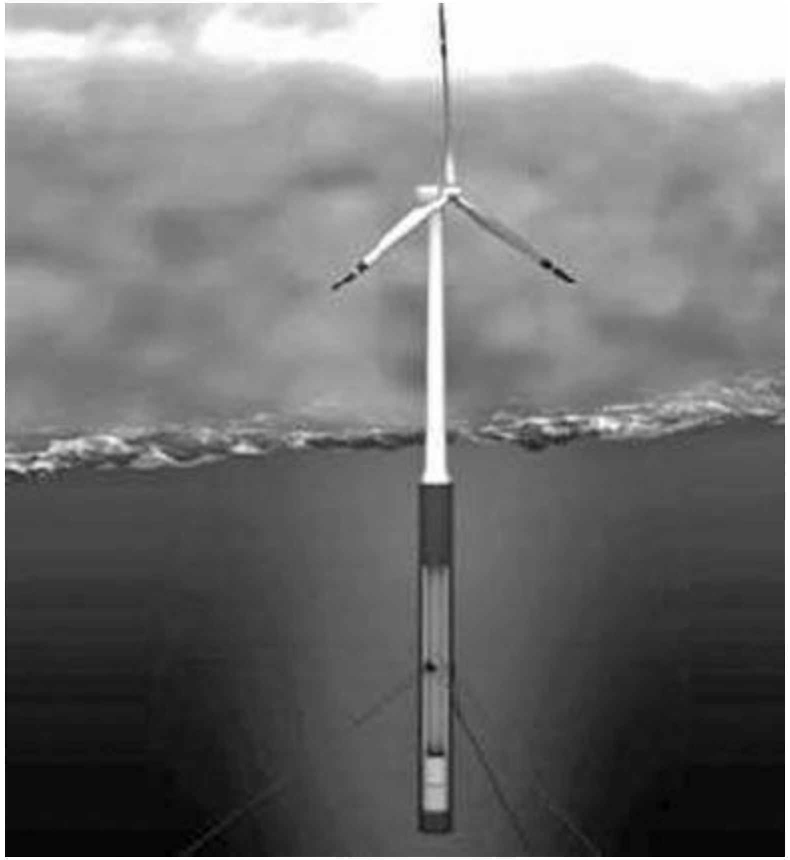
The rotor diameter is 154 m and the overall height is 253 m.

The pilot farm covers around 4 $km^2$ in water depths between 95-130 m.

The average wind speed is 10 m/s and the average wave height is 1.8 m.

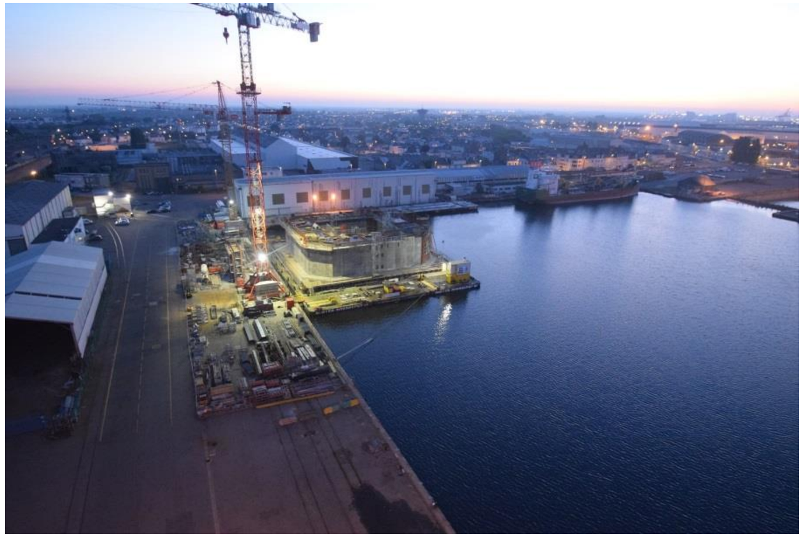
The export cable length to shore is 30 km.





# 1.2 Floating OWTs: Barge

Example (www.bw-ideol.com): Floatgen is a 2 MW floating wind turbine demonstrator installed 12 miles off the coast of Le Croisic, France, at water depth of 33 m. The patented Damping Pool ® floating foundation: hull edge dimensions 36×36 m, draught 7.5 m, 6 synthetic fiber (nylon) mooring lines.

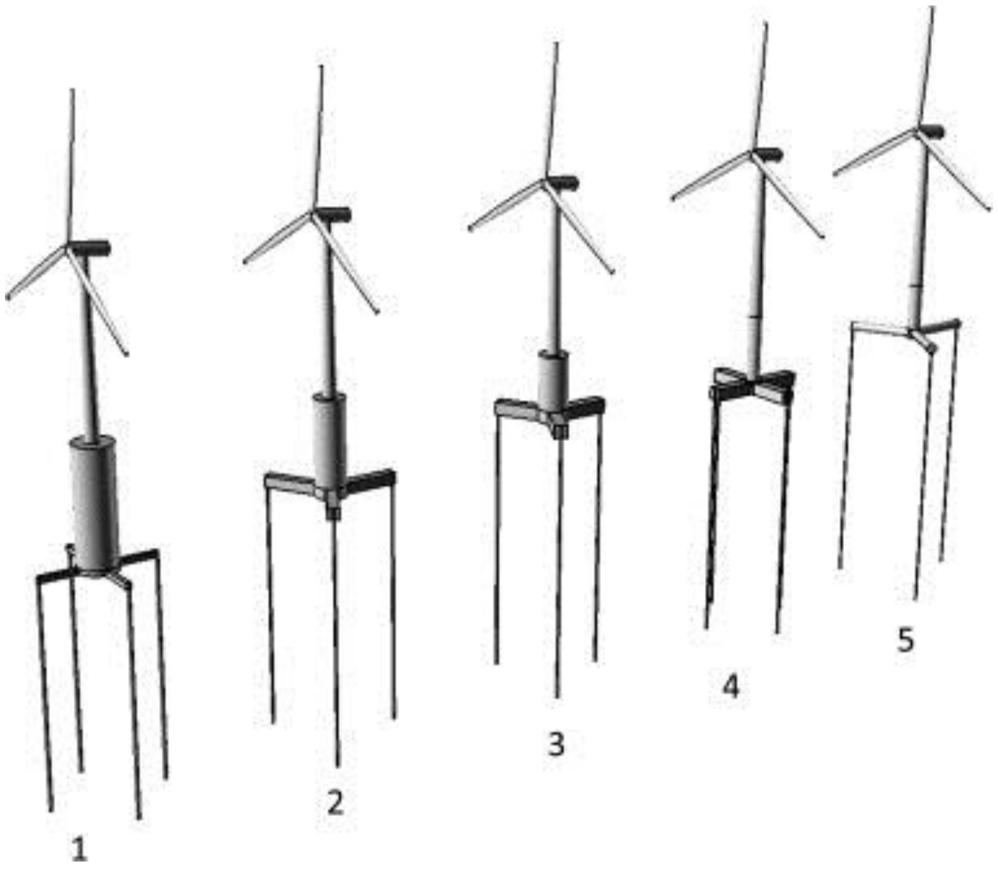


# 1.2 Floating OWTs: Semi-Submersible

Example (www.edp.com): The WindFloat Atlantic wind farm is located 20 km off the coast of Portugal, at Viana do Castelo, at water depth of 100 m, and 3 OWTs. Each floating structure – measuring 30 m high and with a 50 m distance between its columns – supports a large wind turbine of 8.4 MW production capacity.

# 1.2 Floating OWTs: Tension-Leg

Several concepts; no field examples.




# 2. Analysis and design elements of OWTs

Additional issues for **fixed OWTs** with respect to onshore ones:

- Loads (pressure and forces) due to waves and currents
- Foundation scour due to the action of waves and currents

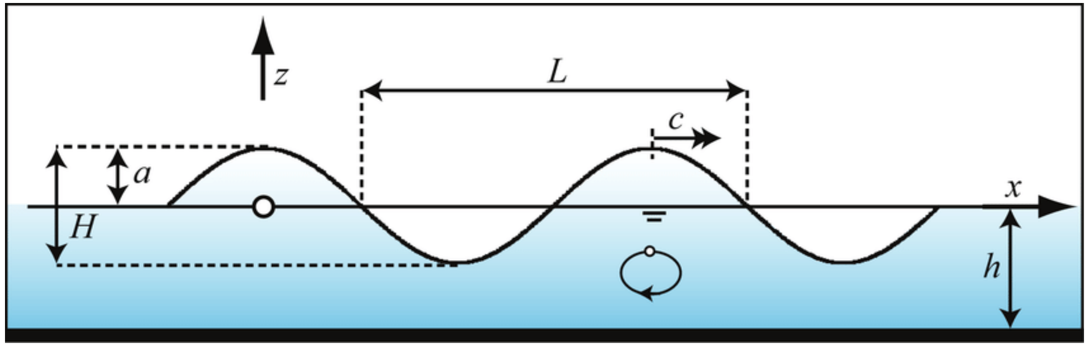
Additional issues for **floating OWTs** with respect to onshore ones:

- Loads (pressure and forces) due to waves and currents
- Mooring forces
- Six-degree of freedom motion

# 2. Analysis and design elements of OWTs

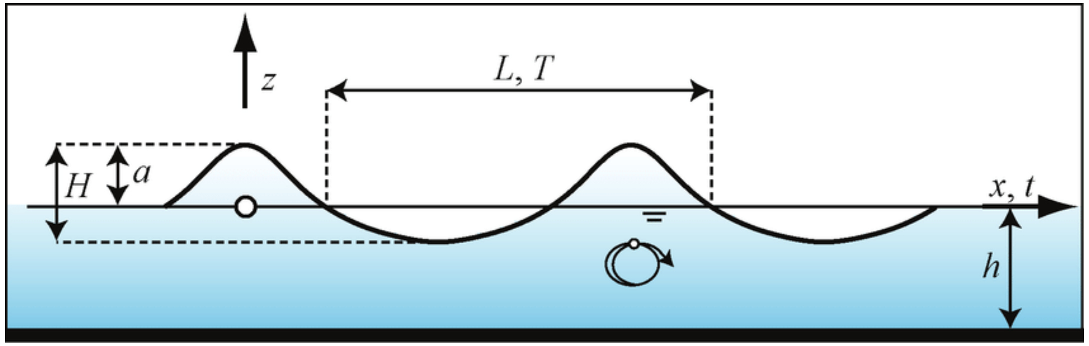
Wave parameters:

- ***H***: wave height
- ***L***: wavelength
- ***T***: wave period




Regular (monochromatic) linear waves


Irregular waves

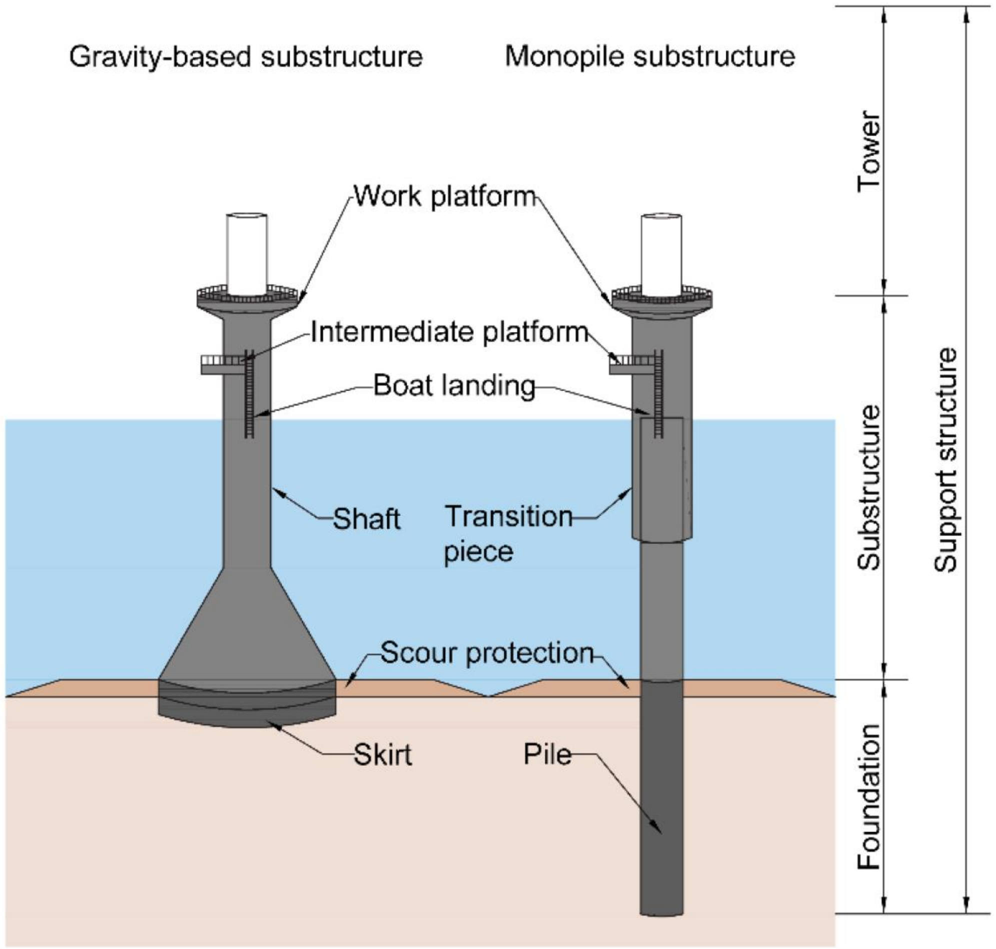



Regular (monochromatic) nonlinear waves

# 2. Analysis and design elements of OWTs

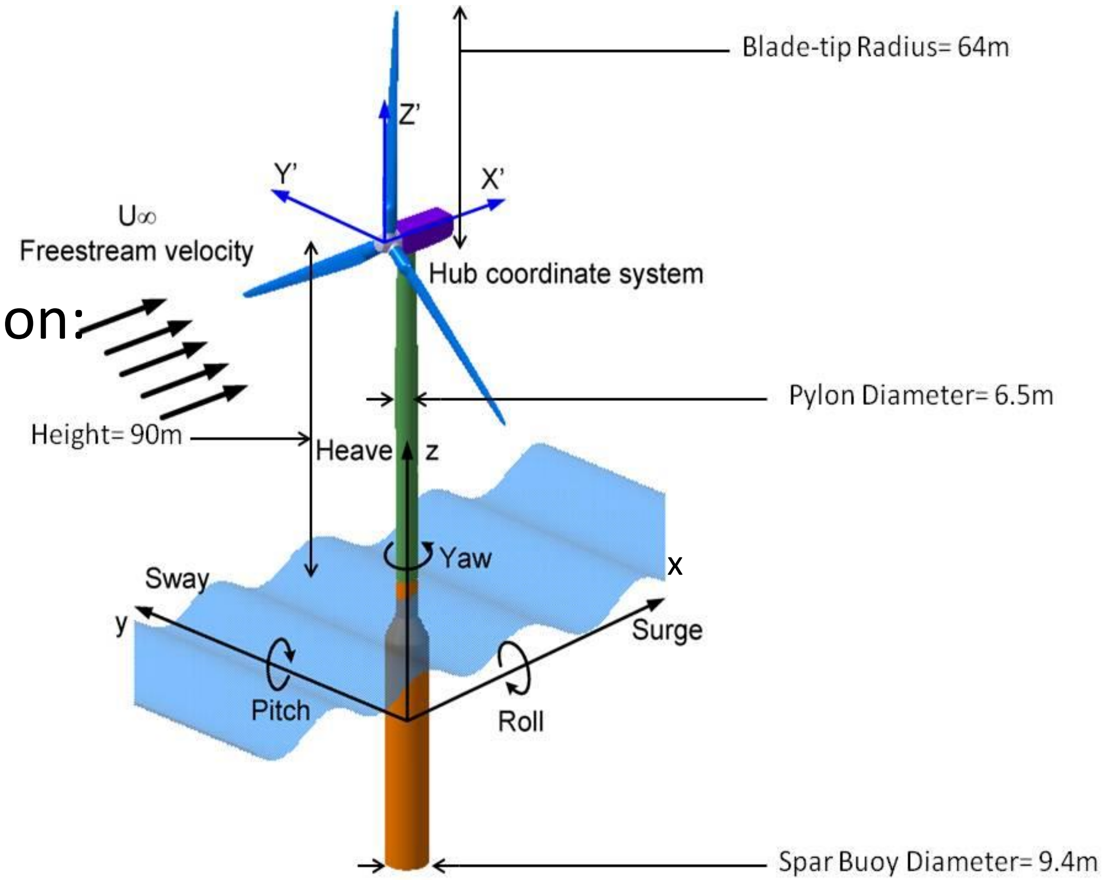
Forces induced by waves and currents depend on:

- *D*: typical horizontal cross-sectional dimension of support structure
- *H*: wave height
- *L*: wavelength
- *U*: current velocity



# 2. Analysis and design elements of OWTs

- Six-degree of freedom motion:
  - Linear motions: surge, heave, sway
  - Rotational motions: pitch, roll, yaw
- Forces induced by waves and currents depend on:
  - *D*: typical horizontal cross-sectional dimension of support structure
  - *H*: wave height
  - *L*: wavelength
  - *U*: current velocity
- Mooring forces should also be accounted for.



# 2. Analysis and design elements of OWTs

Equations of motion of floatng OWTs:

$$\sum_{k=1}^{6}\left( (M_{jk}+A_{jk})\frac{d^2\zeta_k}{dt^2}+B_{jk}\frac{d\zeta_k}{dt}+C_{jk}\zeta_k \right)=F_j$$

where $\zeta_k$ ($k$=1,2,…6) are the OWT motions w.r.t. the equilibrium position, $M_{jk}$, $A_{jk}$, $B_{jk}$ and $C_{jk}$ are the mass, added mass, damping, and restoring (including mooring) forcing terms, respectively, of the "*j*" degree-of-freedom due to unit motion of the "*k*" degree-of-freedom, and $F_J$ are the external applied forces due to wind, waves, and/or currents.

# 3. Offshore wind farms: from planning to operation

Every project is divided into three phases:

- Planning (2-4 years)

  Site selection and feasibility; Environmental impact assessment;

  Approvals, licenses and permits
- Construction (1-2 years)

  Planning; Manufacturing; Deployment; Installation;

  Managerial and financial issues
- Operation (25 years plus M&D)

  Maintenance; Environmental monitoring; Decommissioning

# 3. Offshore wind farms: Planning

Three key selection factors for offshore wind farm locations:

- Available wind energy
- Electric grid connectivity
- Installation site conditions

Data that should be considered can be divided into two groups:

- Restricted areas in the vicinity of the potential offshore wind farm
- Environmental/technical/financial/social parameters in the region of the potential offshore wind farm

# 3. Offshore wind farms: Planning

In the first group, all relevant restrictions, either natural or anthropogenic, should be identified that prohibit the use or proximity of a particular region to the potential offshore wind farm. Such regions are:

- Harbour entrances and navigation routes
- Areas with environmental restrictions
- Oil and gas extraction
- Military exercise areas
- Underwater cables
- Marine archaeology sites
- Landscape and seascape as public heritage

# 3. Offshore wind farms: Planning

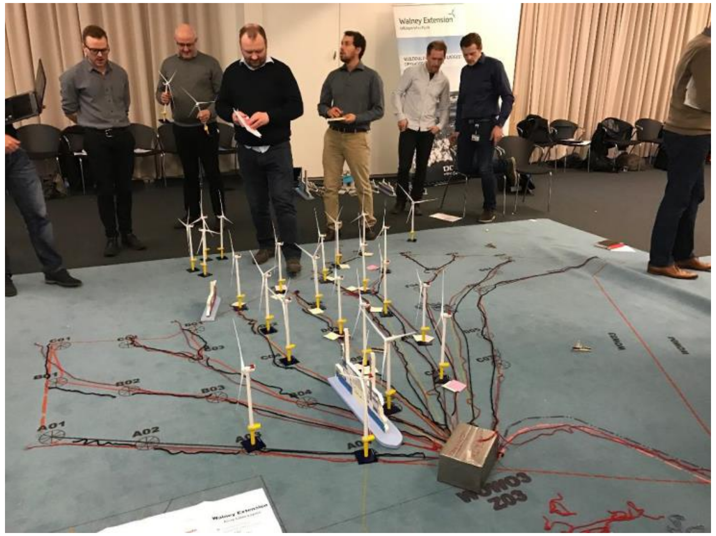
The second group includes all the environmental/technical/financial/social constraints/parameters that should be evaluated regarding the suitability of a location for the construction of an offshore wind farm:

| | | | |
|---|---|---|---|
| Marine mammals | Wind energy resource | Investment costs | Social acceptability |
| Fish and shellfish | Water depth | Energy production capacity | Visual impacts |
| Birds and bats | Distance to shore | Realization time | Safety |
| Aquaculture | Seabed geology | CO2 emissions avoidance | Leisure and tourism |
| Disposal Sites | Cables and pipelines | Shipping and navigation | Archaeology |
| Commercial and sport fisheries | Onshore and offshore substations | Size of available sea area | Acoustic noise |

# 3. Offshore wind farms: Construction

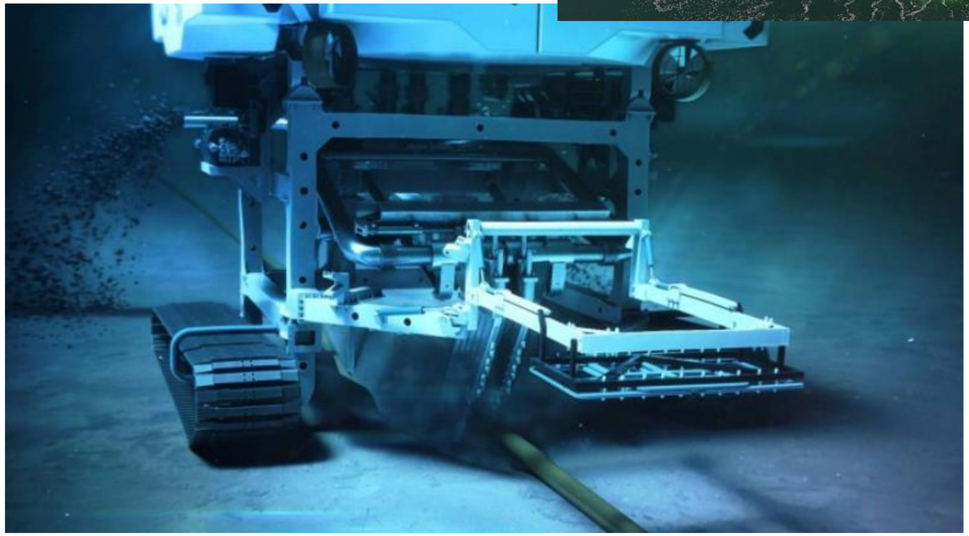
The most important aspects of the construction phase are:

- Construction planning
- Geotechnical and geophysical surveys
- Onshore and offshore substation installation
- Onshore/intertidal cable installation



# 3. Offshore wind farms: Construction

- Onshore manufacturing of support structures
- Transport and installation of support structures
- Transport and installation of towers, nacelles and rotors
- Offshore cable installation



# 3. Offshore wind farms: Operation

The most important aspects of the operation phase are:

- Electricity production
- Inspections: foundations, structure integrity, corrosion, blades, cables , etc.
- Maintenance: turbines, bird guano, health & safety monitoring/management, etc.
- Decommissioning: recycle

# Outlook

Today, 8 MW turbines are in operation.

A 14 MW turbine has been introduced; the GE Haliade-X offshore turbine features a 14 MW, 13 MW or 12 MW capacity, a 220-meter rotor, and a 107-meter blade.