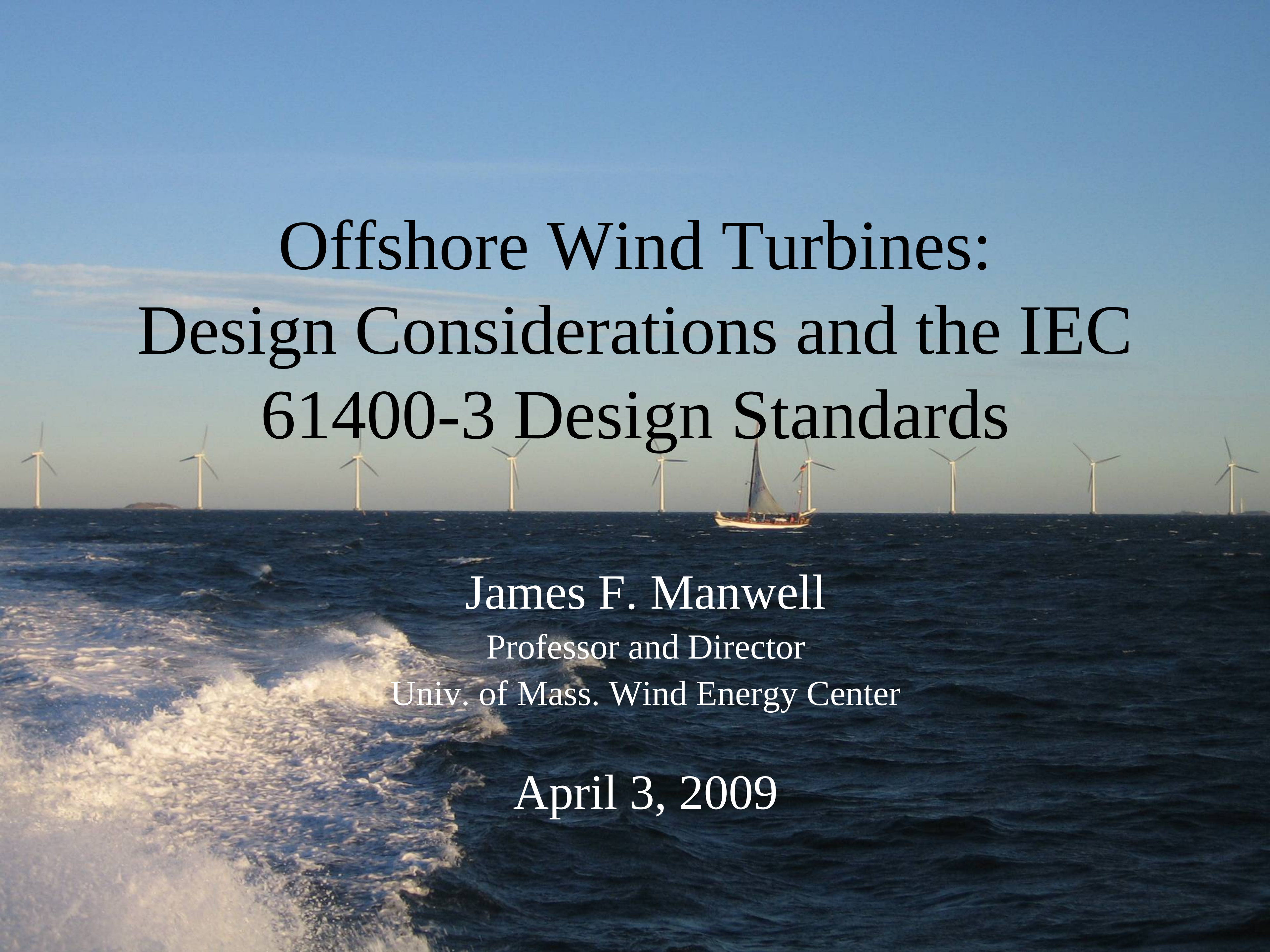

Offshore Wind Turbines: Design Considerations and the IEC 61400-3 Design Standards

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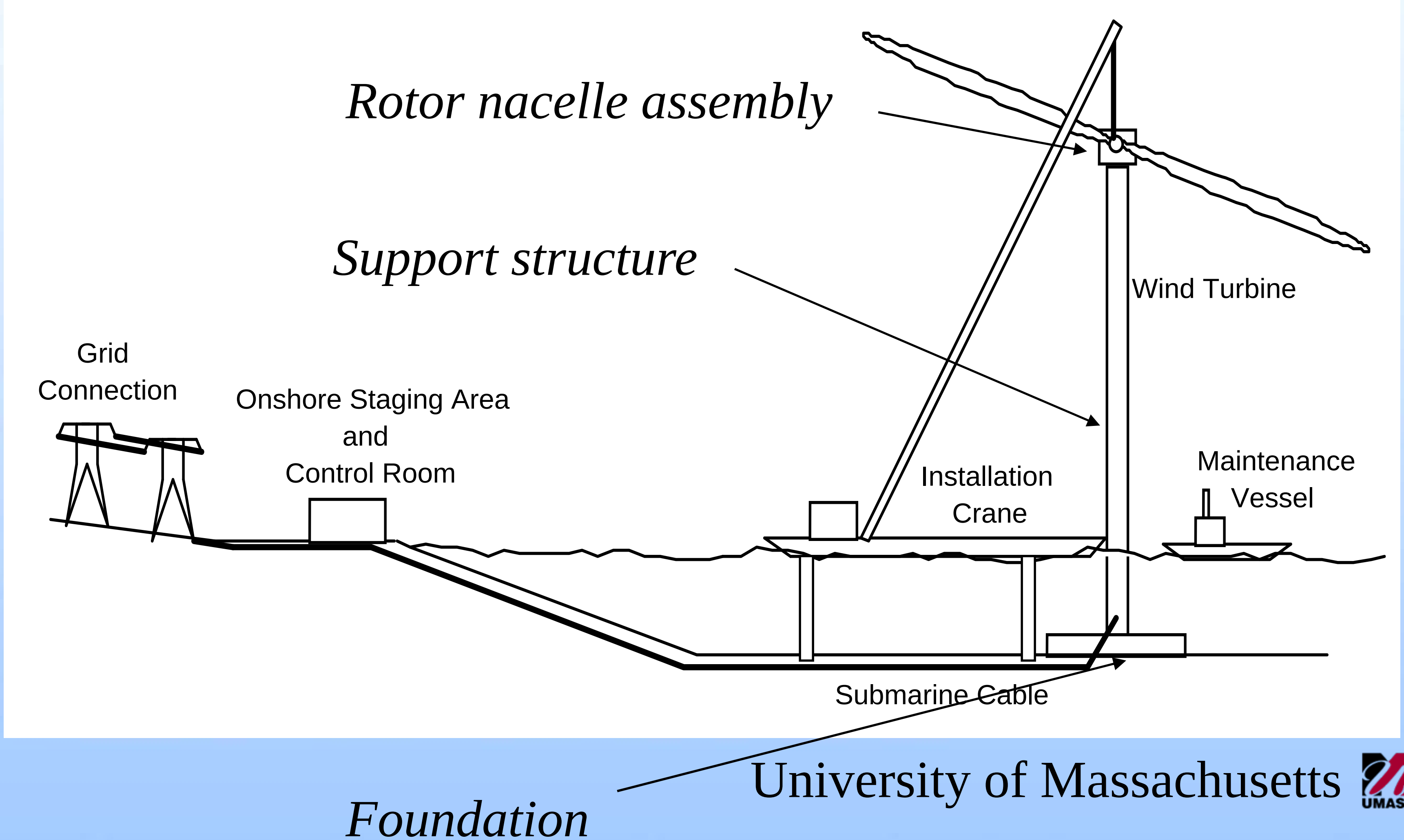
What are Offshore Wind Turbines?

- According to IEC 61400-3 (Design Standards):

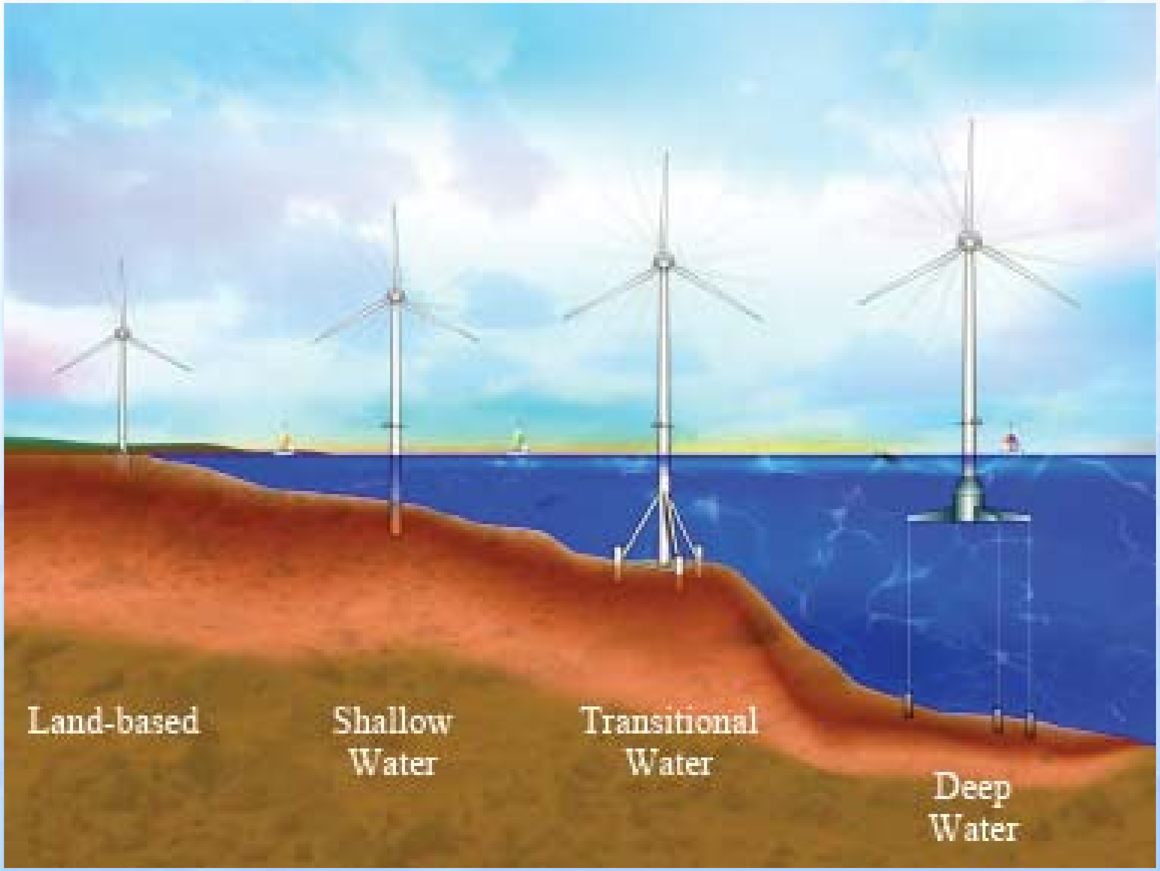
  “Offshore wind turbines are those wind turbines whose support structures are subject to <u>hydrodynamic</u> loading”

  That means **waves**!

Conceptual Illustration of Offshore Wind Turbine



Support Structures vs. Depth

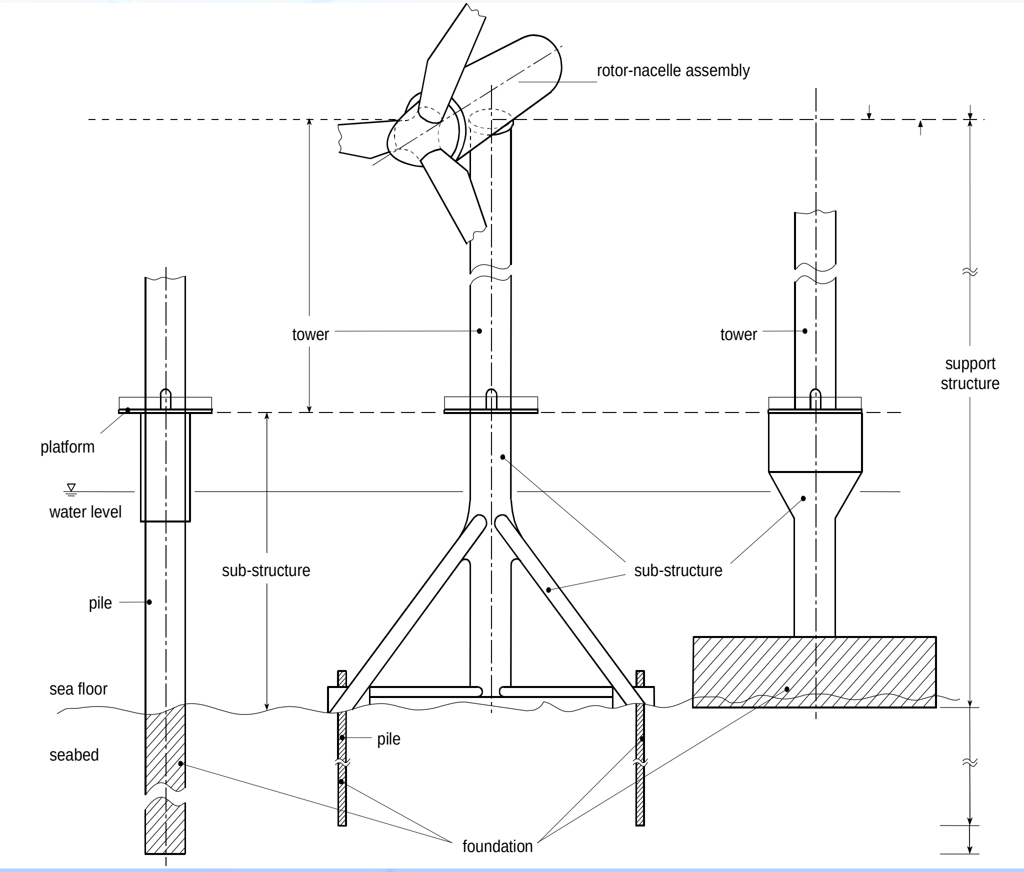


Shallow < 30 m
Transitional 30-60 m
Deep > 60 m

Photo: National Renewable Energy Laboratory

Wind Turbine Support Structure for Shallow and Intermediate Depths

- Typical offshore wind turbine support structure options →
- Type used will depend on seabed properties



Monopile Multimember Gravity

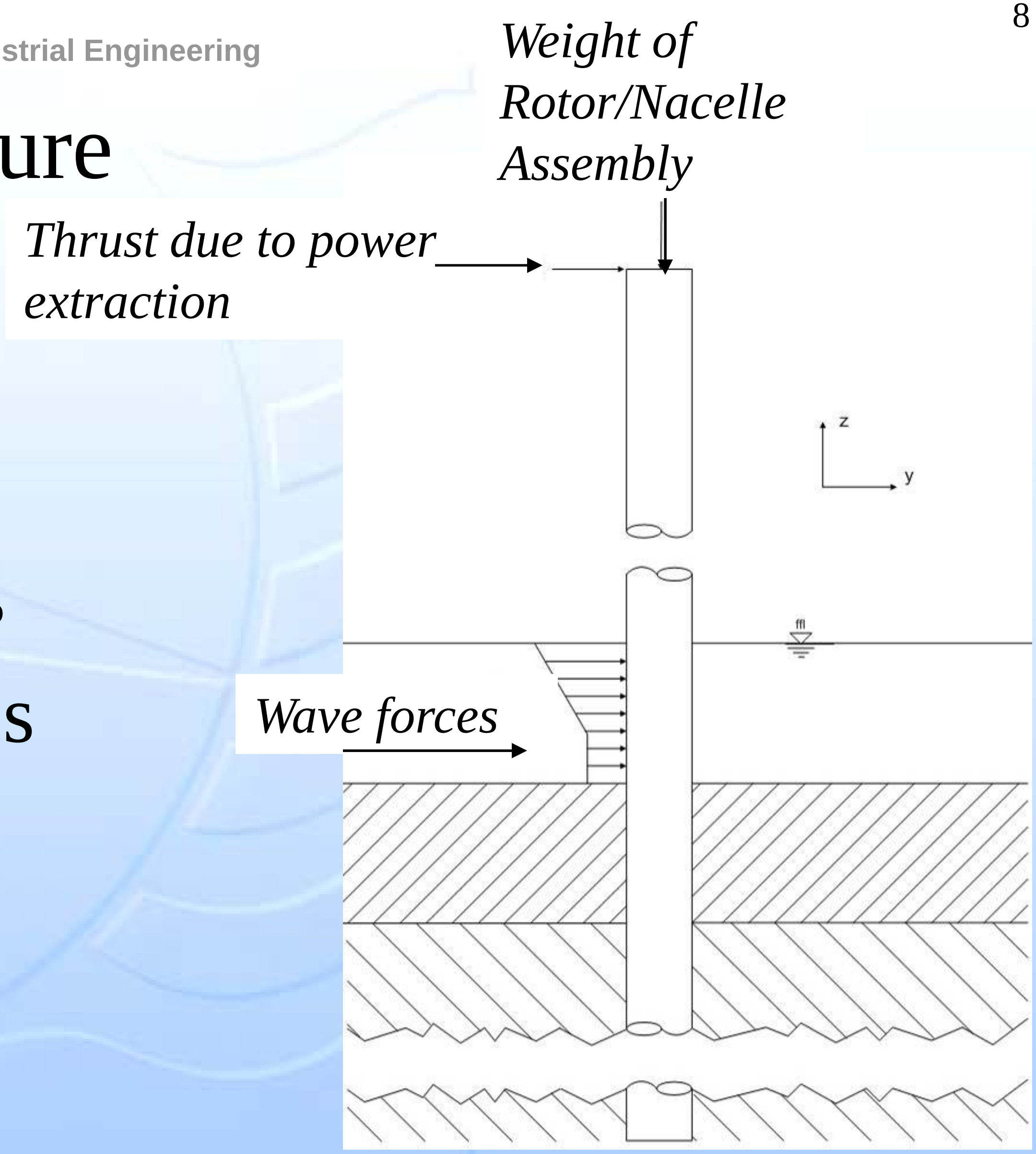
External Design Conditions

- Wind:
  - Power production
  - Rotor/nacelle assembly & support structure: extremes, fatigue
- Waves:
  - Support structure: extremes, fatigue
- Currents:
  - Support structure, rip-rap
- Ice:
  - Support structure
- Others:
  - Salinity, temperature

Design Considerations

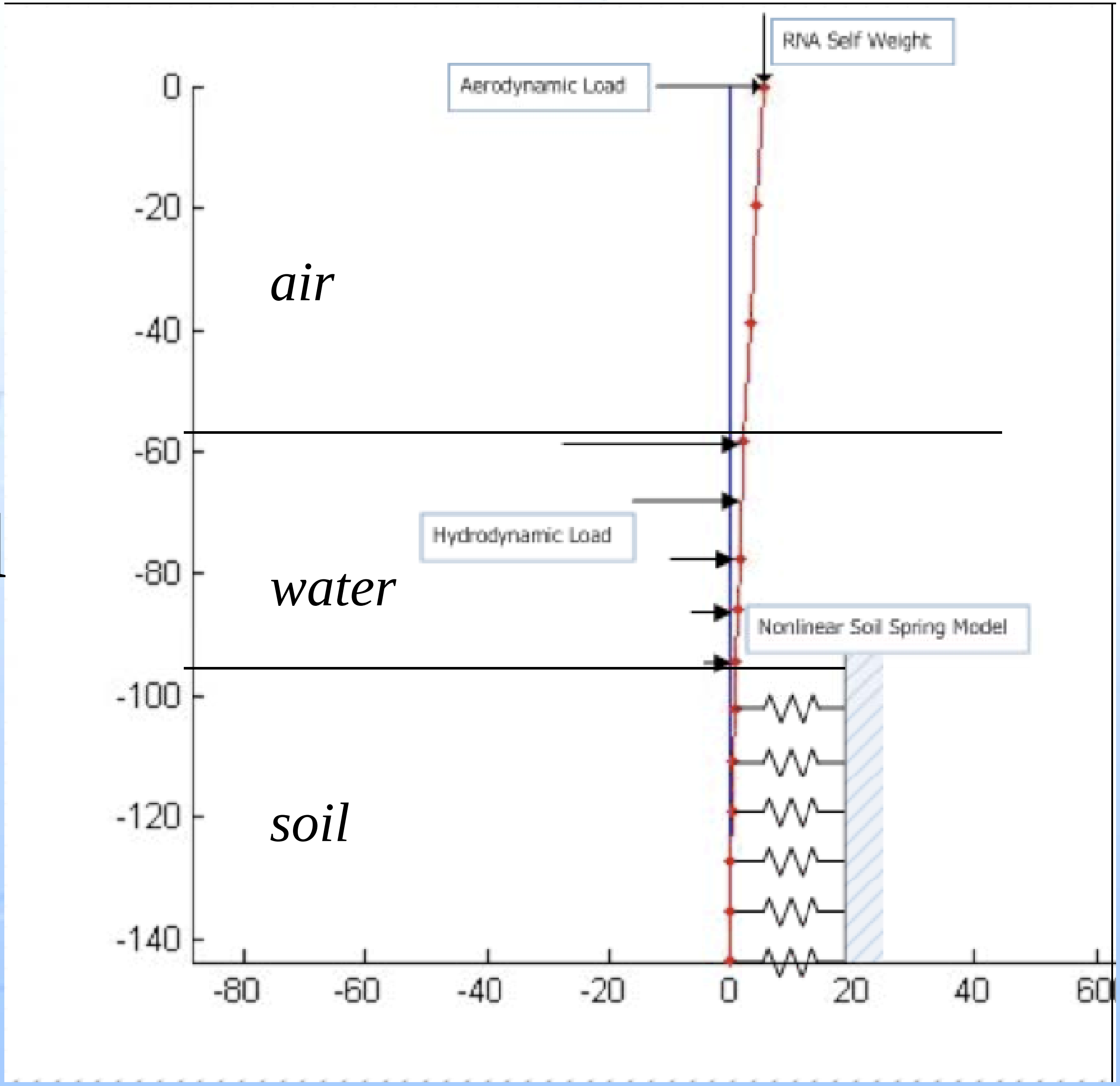
- Turbine size
- Support structure options
- Water depth
- Soil characteristics
- External design conditions
- Infrastructure (i.e. ship yards, vessels, etc.)
- Environmental concerns
- Maintainability
- Cost!

Monopile Structure



- Sediment thickness
- Lateral soil stiffness

Forces on the rotor/ nacelle assembly (RNA) and Support Structure



Gravity Structure

- Bearing capacity of soil
- Resistance to overturning
- Resistance to sliding
- Cost of steel vs. concrete

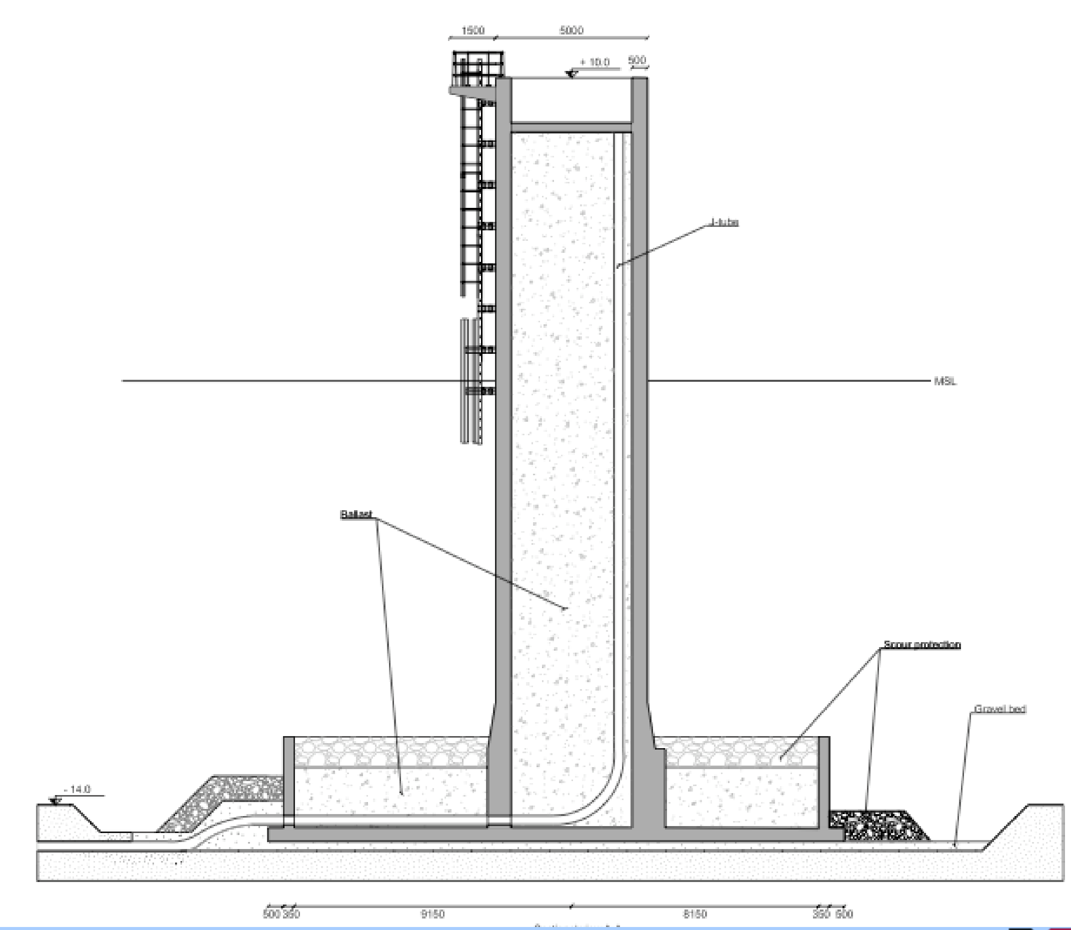


Photo: Carl Bro A/S

Manufacture

- Monopile
  - Welded steep tube
  - Prepared off site

Manufacture

- Gravity
  - Precast concrete or steel structure
  - Fabricate in dry dock

Photo: Carl Bro A/S

Manufacture

- Multimember
  - Tubular steel
  - Fabricated off site

Manufacture of Similar Structures (Offshore Oil & Gas)

Installation (1)

Pile driving

Installing tower

Lifting nacelle

Photos: Courtesy GE Wind and hornsrev.dk

Installation (2)

Photos: Courtesy GE Wind

Installation

Gravity

- Remove soft surface material
- Place gravel layer
- Lower foundation with heavy lift vessel
- Fill with ballast

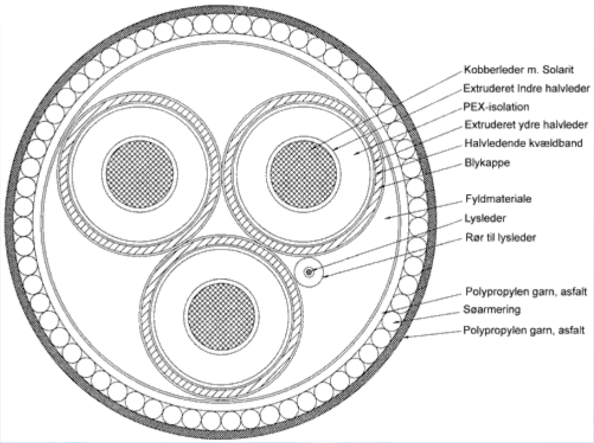
Photo: Carl Bro A/S

Multimember Structure Installation

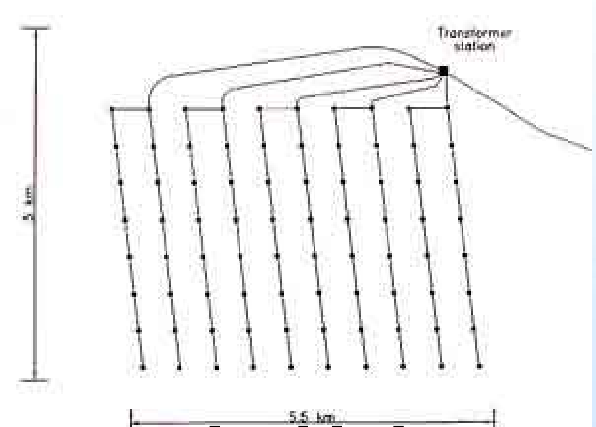
- Place in seabed
- Secure to seabed with multiple piles

Photo: http://beatricewind.co.uk

Electrical Cables



Cable cross section



Typical cable layout

Cable laying ship

Cable trencher

Illustrations from www.hornsrev.dk

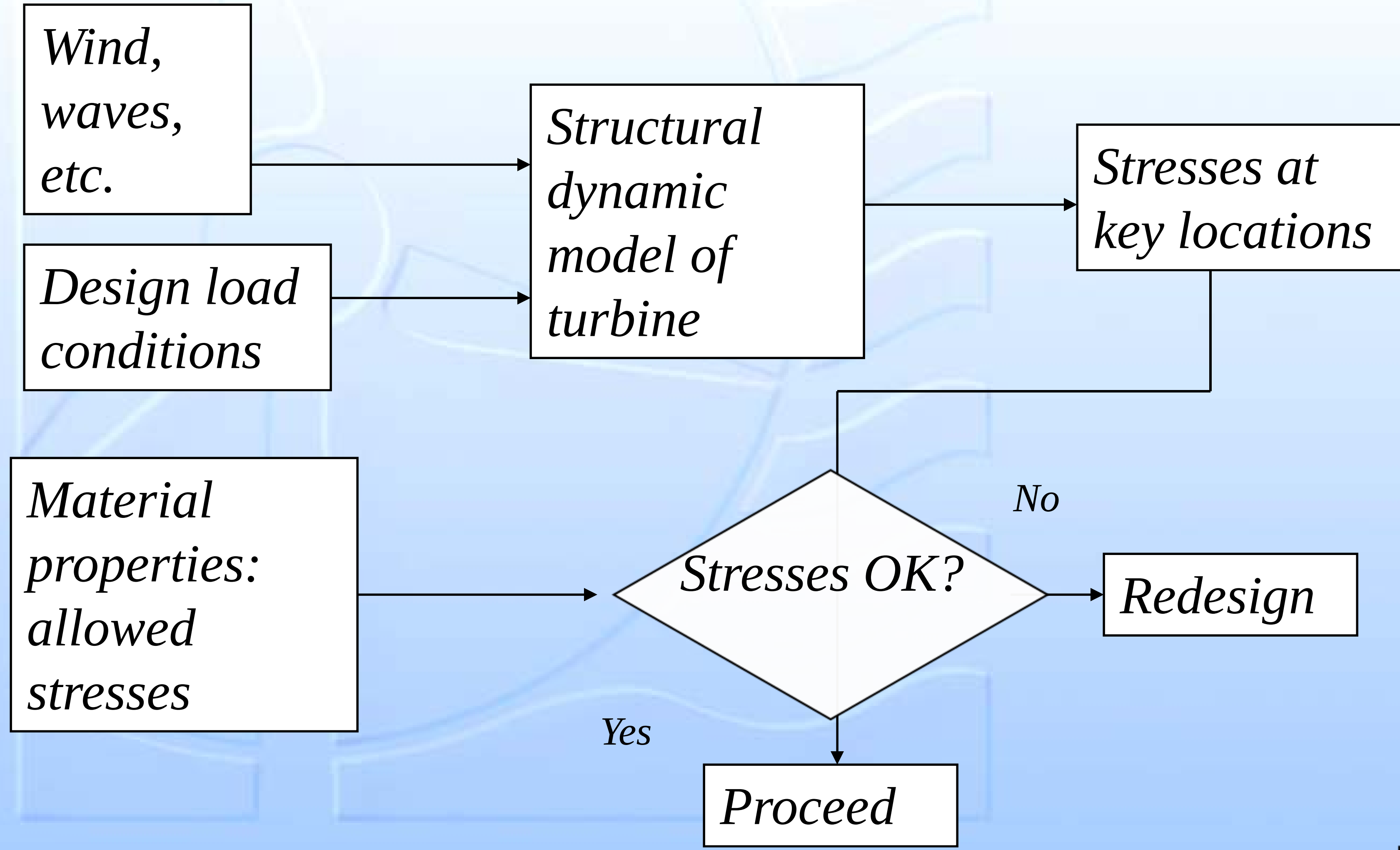
Offshore Wind Turbine Design Standards IEC 61400-3

- Background
  - IEC = International Electrotechnical Commission
  - IEC oversees all wind turbine standards (61400)
  - Standards ensure safety, financibility, insurability
  - Standards relate **strength** of structure to **external** conditions and **design load** conditions

IEC 61400-3 External Conditions

- Key external factors
  - Wind
  - Waves
  - Other (currents, salinity, floating ice, …)
- Values chosen to find:
  - Normal loads, extreme loads, fatigue loads
  - Under Design Load conditions

IEC 61400-3 Process



Design Load Conditions

- Normal operation
- Start up/shut down
- Stationary in high winds
- Faults
- Transport
- Installation

Sample Design Load Cases

Table 1 – Design load cases

Design situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
1) Power production	1.1	NTM $V_{in} < V_{hub} < V_{out}$ RNA	NSS $H_s = E [H_s \| V_{hub}]$	COD, UNI	NCM	MSL	For extrapolation of extreme loads on the RNA	U	N (1,25)
	1.2	NTM $V_{in} < V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, MUL	No currents	NWLR or ? MSL		F	*
	1.3	ETM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E [H_s \| V_{hub}]$	COD, UNI	NCM	MSL		U	N
	1.4	ECD $V_{hub} = V_r - 2\ m/s, V_r, V_r + 2\ m/s$	NSS (or NWH) $H_s = E [H_s \| V_{hub}]$	MIS, wind direction change	NCM	MSL		U	N

Conclusions

- OWT design affected by many factors
  - Water depth
  - Distance from shore
  - External design conditions (wind, waves, etc.)
  - Soil type
  - Turbine size, details
  - Available infrastructure
  - Costs
- IEC 61400-3 will help avoid problems!