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Introduction to the Foundation Design for Offshore Wind Farm

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2024-05-23

Agenda

- Why do we need wind energy?
- Foundation selection
- Foundation design for offshore wind farm

Why do we need wind energy?

More energy, not less

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Driven globally by ….

More Data & Technology:

- Mobile phones everywhere, even in UK they have added ~8% to our total electricity demand

More People:

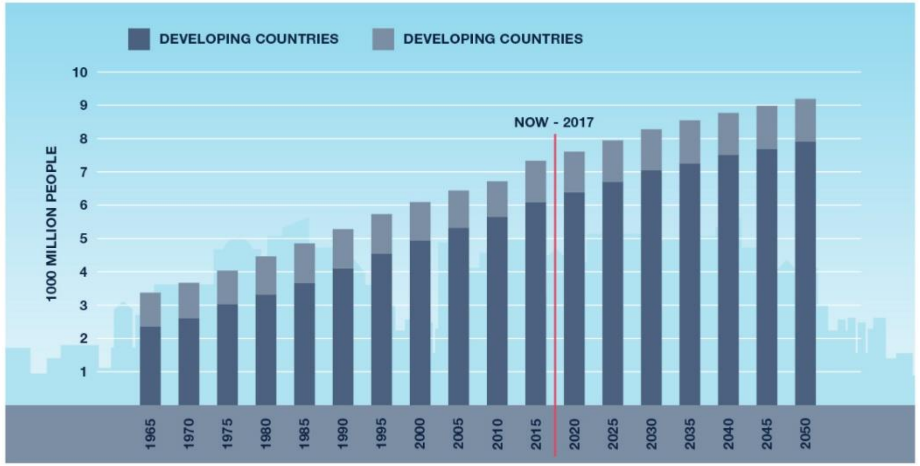
- Global population growth

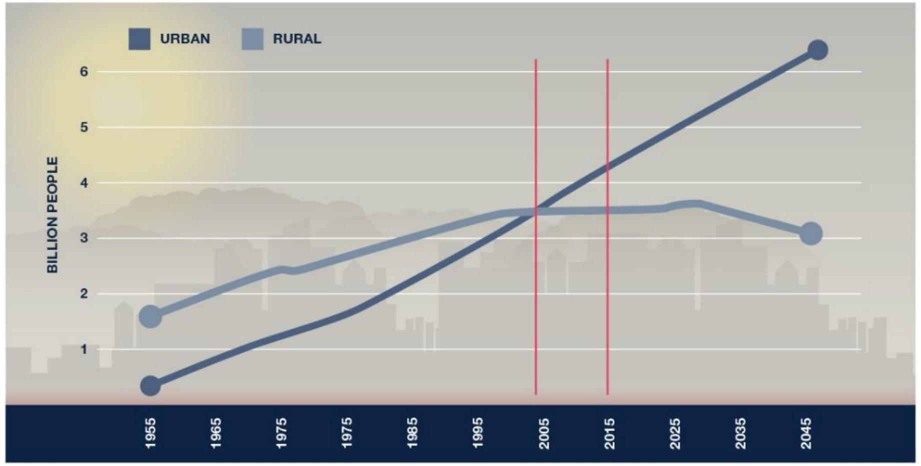
More Mobility:

- More widespread affluence, growth of middle-classes and transportation

More Urbanism:

- In the past decade the world’s population became more urban than rural with all of the associated demands





Applying the United Nations Sustainable Development Goals

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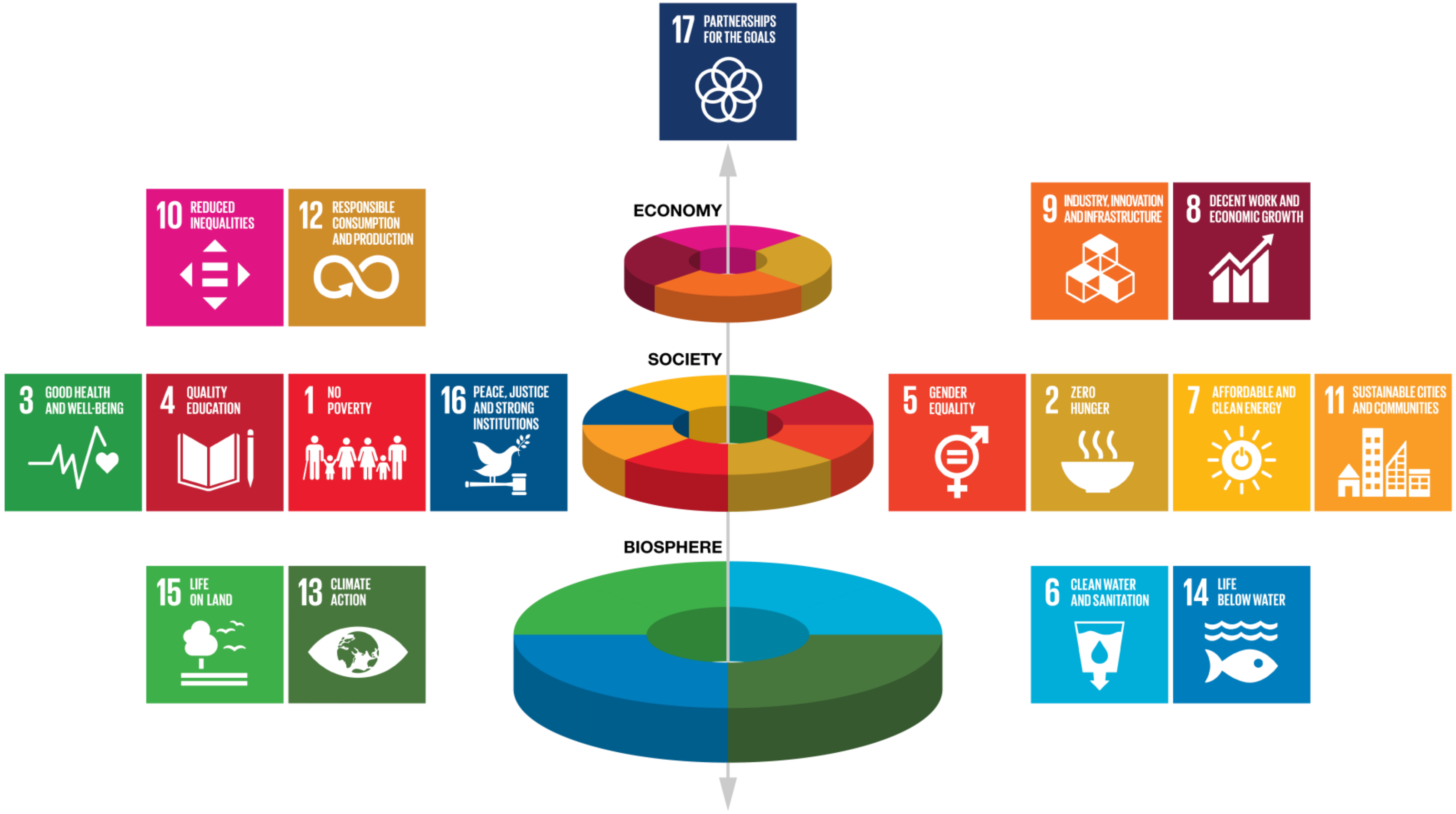
- The internationally recognised 17 UN SDGs



SUSTAINABLE DEVELOPMENT GOALS

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The UN SDGs and Energy

- Energy makes a contribution to many of the UN SDGs

SDG #7 – relates to affordable, reliable and clean energy.

SDG #13 – relates to climate action, so the association with global warming, transition from fossil fuels and 'whole system' thinking.

However, in addition energy is an essential enabler for many of the societal benefits identified:

SDG #1 – no poverty; for societies to function they need energy

SDG #2 – zero hunger; with energy for the food chain being crucial as the global population becomes increasingly urban

SDG #3 – good health & well being; assisted by achieving warmth, air quality, etc. by the appropriate availability of energy with reduced environmental impacts that can affect health (on air, soil, water…)

SDG #6 – clean water; with demands on energy to transport, pump and process water

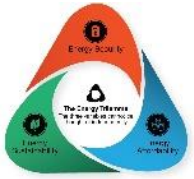
SDG #8 – decent work and economic growth is enabled by accessibility to energy

SDG #9 – resilient infrastructure; with 'whole system' thinking including energy being a core part of this

SDG #11 – make cities and human settlements resilient and sustainable, having a robust low-emissions energy infrastructure as a key component

SDG #12 – energy role in the circular economy transition

SUSTAINABLE DEVELOPMENT GOALS



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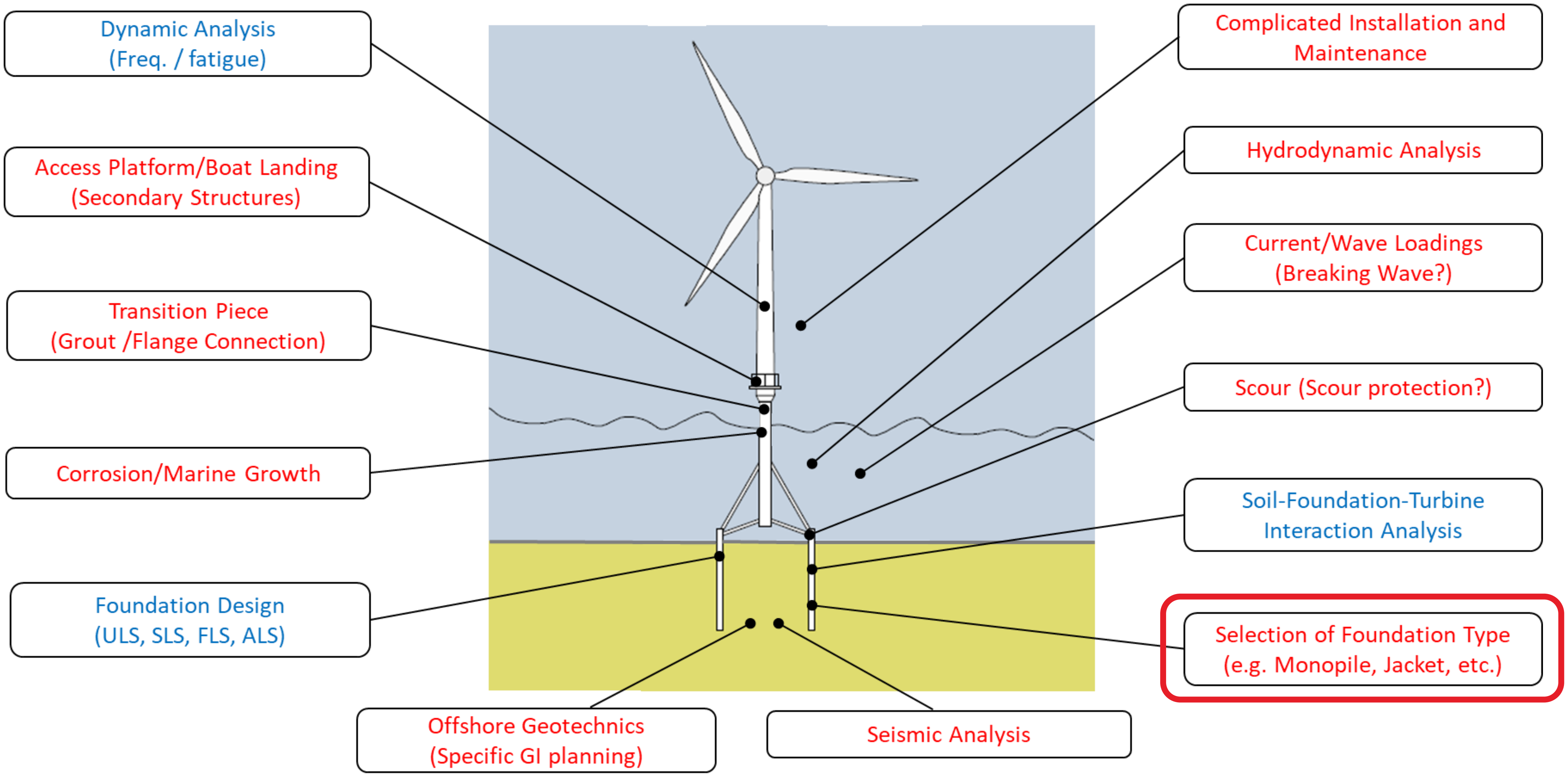
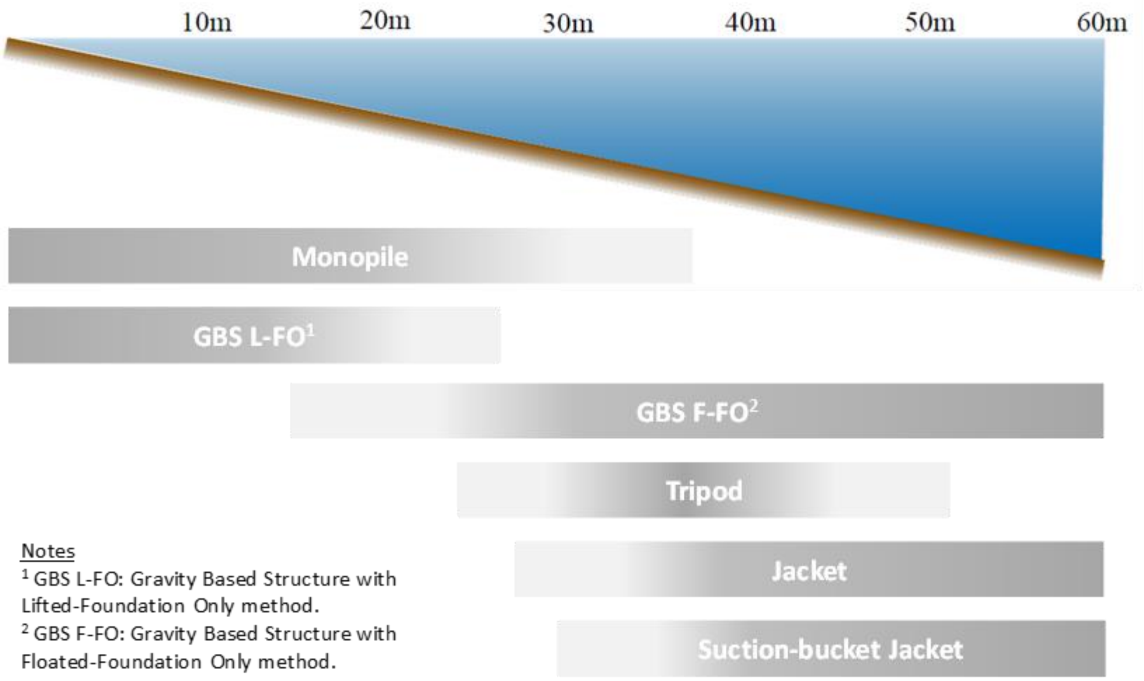
Design for Offshore Challenges

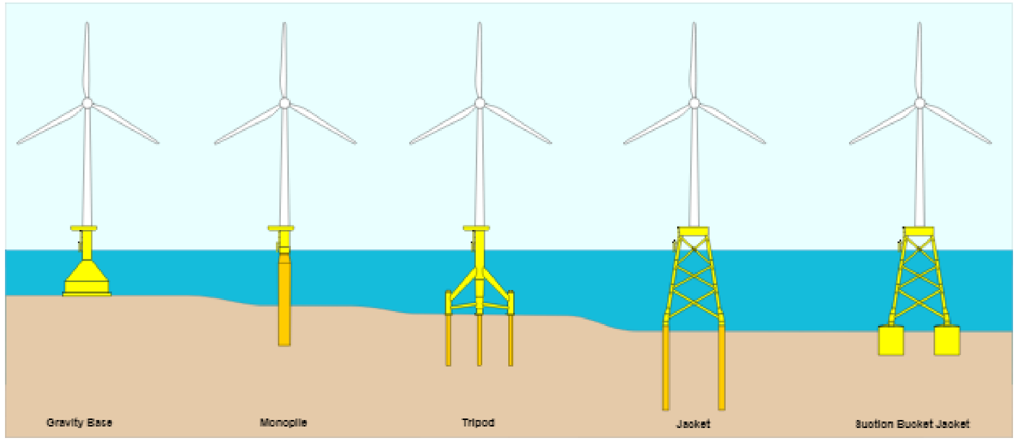


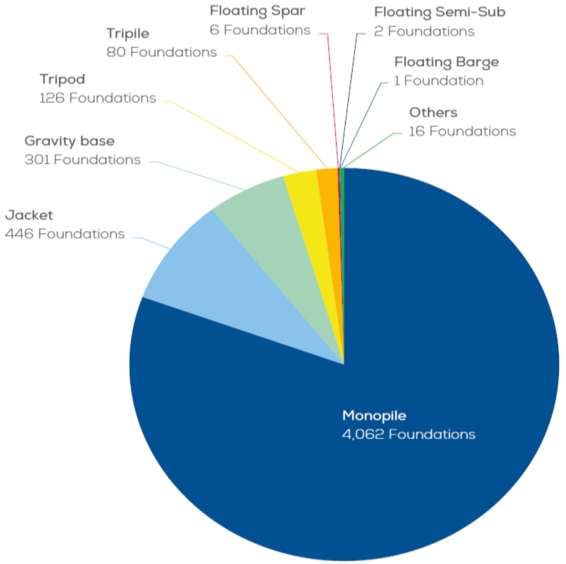
Foundation Selection

Foundation Selection

- Developers want the most suitable and most cost-effective foundation type
- Technically depends on several factors such as
  - Seabed ground conditions
  - Water depth
  - Loadings
  - Transportation and installation limitations,
  - Etc.







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Monopile vs Jacket

	Monopile	Jacket
Pros	• Simple design and quick installation • Suitable for shallow water (up to 40m) • Work well in sand and gravel soils	• Higher stiffness and stability • Lower weight and material consumption • Better performance in deeper waters and harsher environments • More adaptable to different site conditions and turbine sizes
Cons	• Lateral rigidity becomes insufficient at greater water depths (typically within 30m) • Limited to softer seabed conditions • Potential noise and vibration impacts on marine life	• More complex design and longer installation time • Higher manufacturing costs

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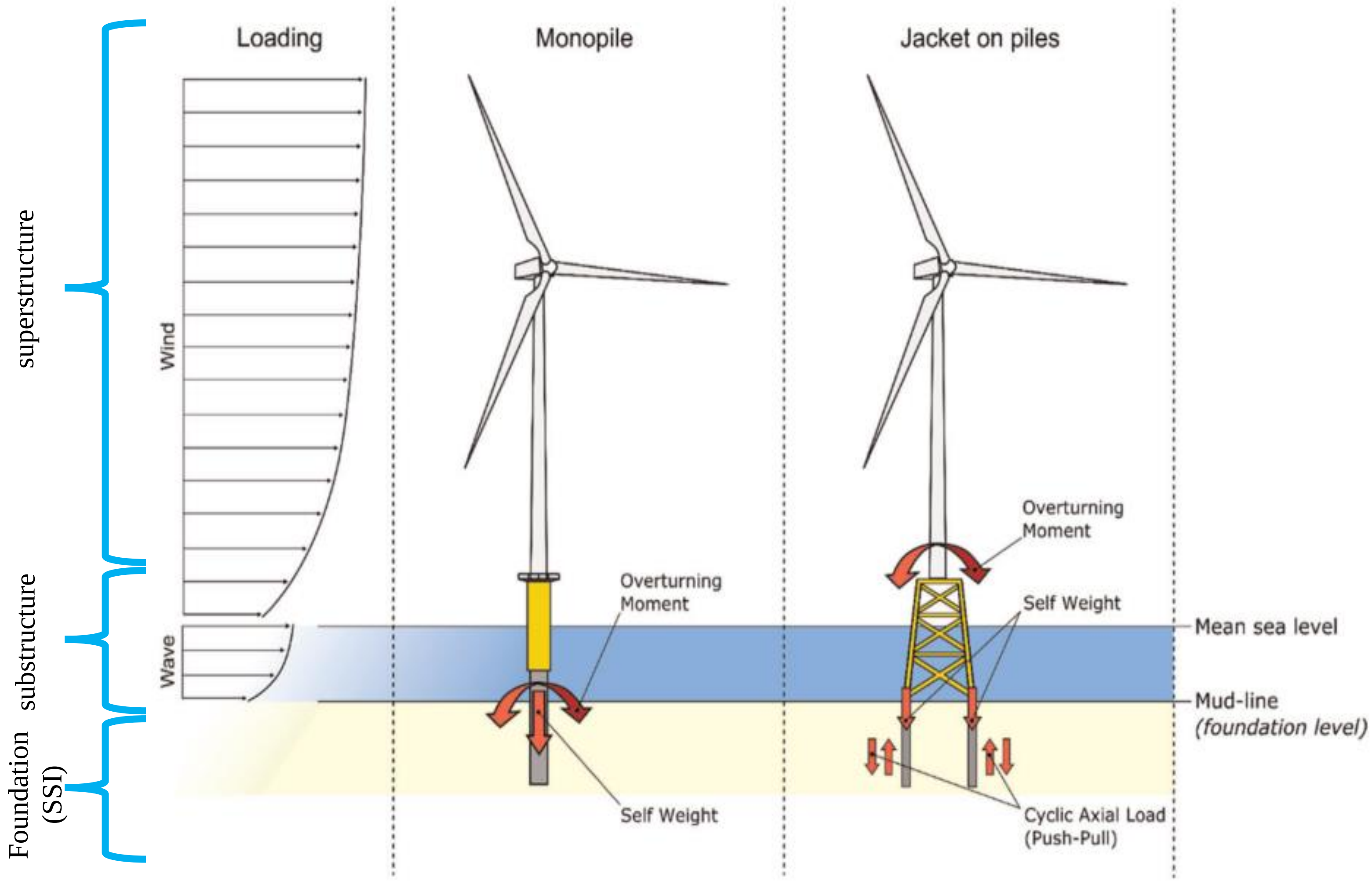
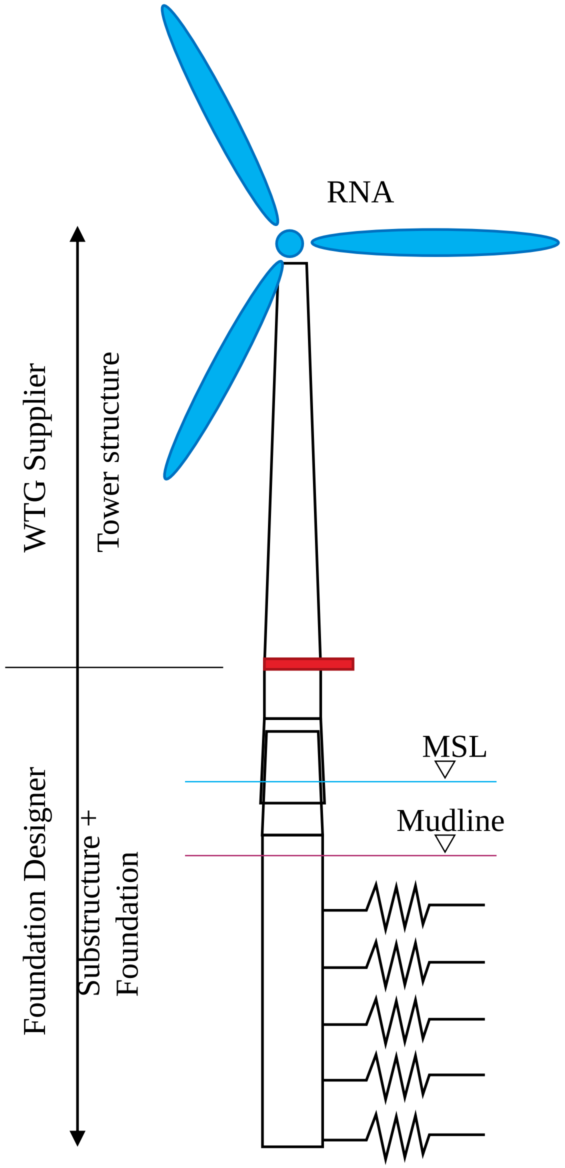
Foundation Design

Wind Turbine Structure



Design Inputs



- Geometry and masses of turbine structure
  - Tower and secondary structures – from WTG supplier
  - Foundation (TP, MP and associated secondary structures) – by foundation designer
- Design loads
  - Aerodynamic/ wind load – from WTG supplier
  - Hydrodynamic/ wave load – by foundation designer
- Soil springs – by foundation designer

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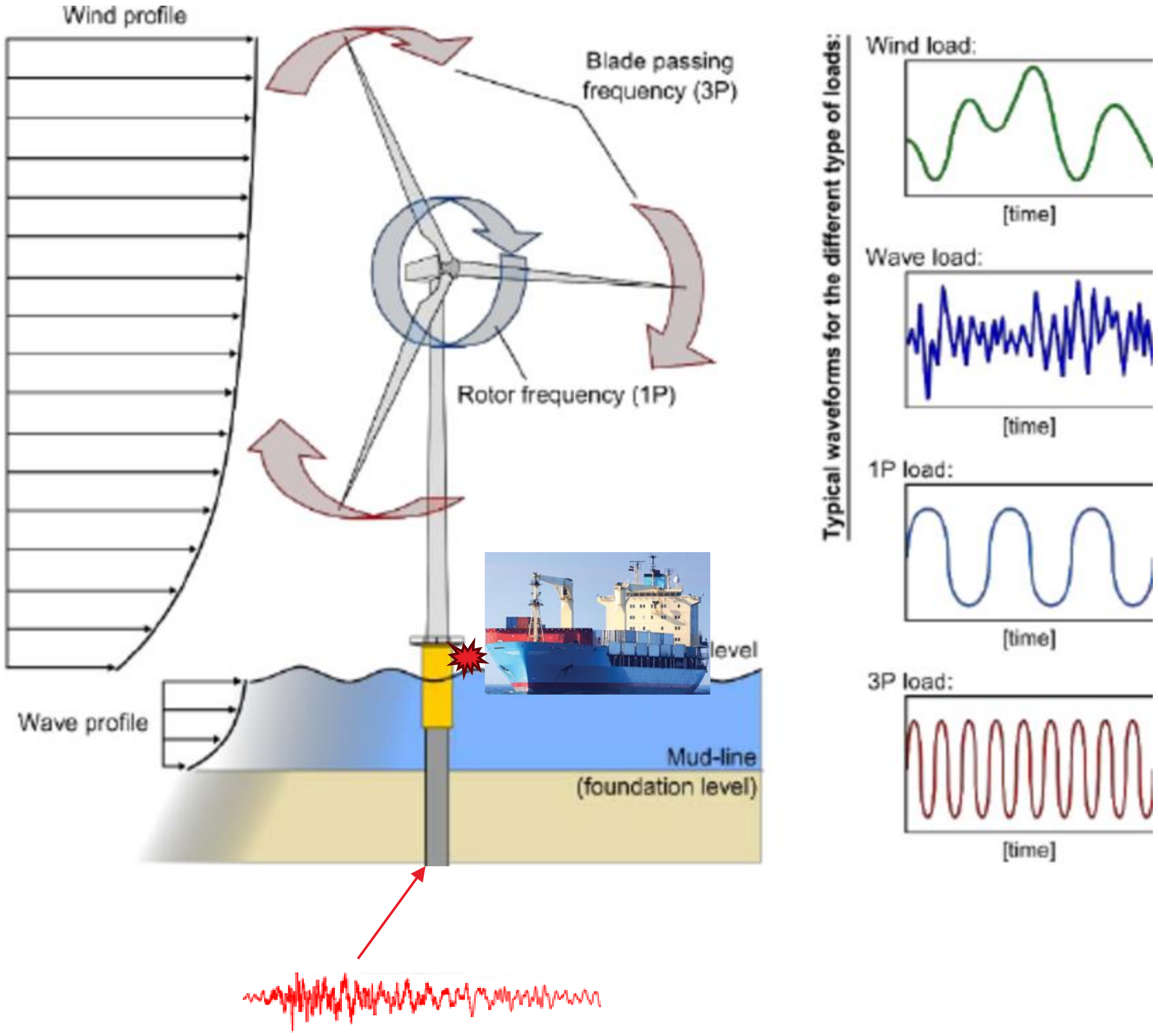
Design Loads

- Aerodynamic load (wind load)
- Hydrodynamic load (wave load)
- Ship impact
- Seismic load
- Etc.



Input earthquake

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Failures

Excessive movement

Blade fracture

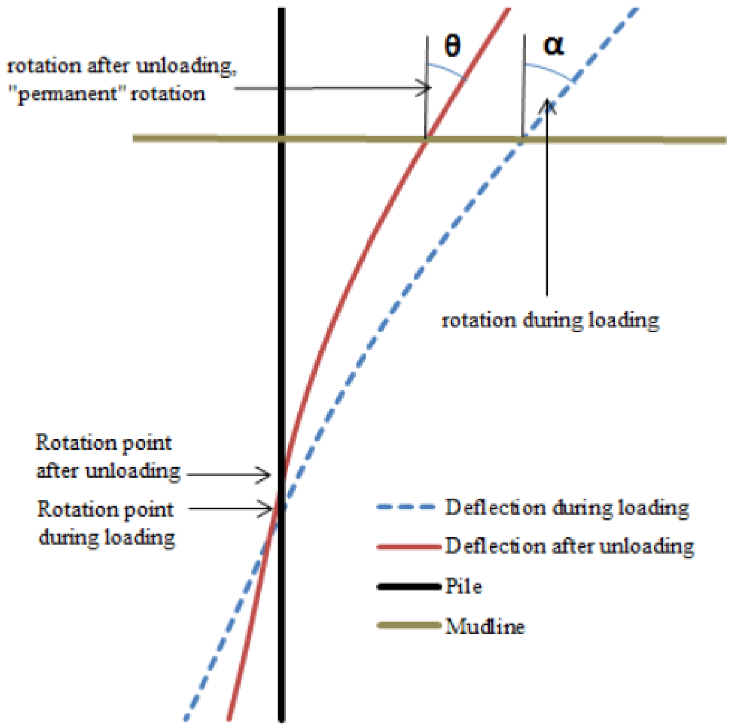
Foundation collapse

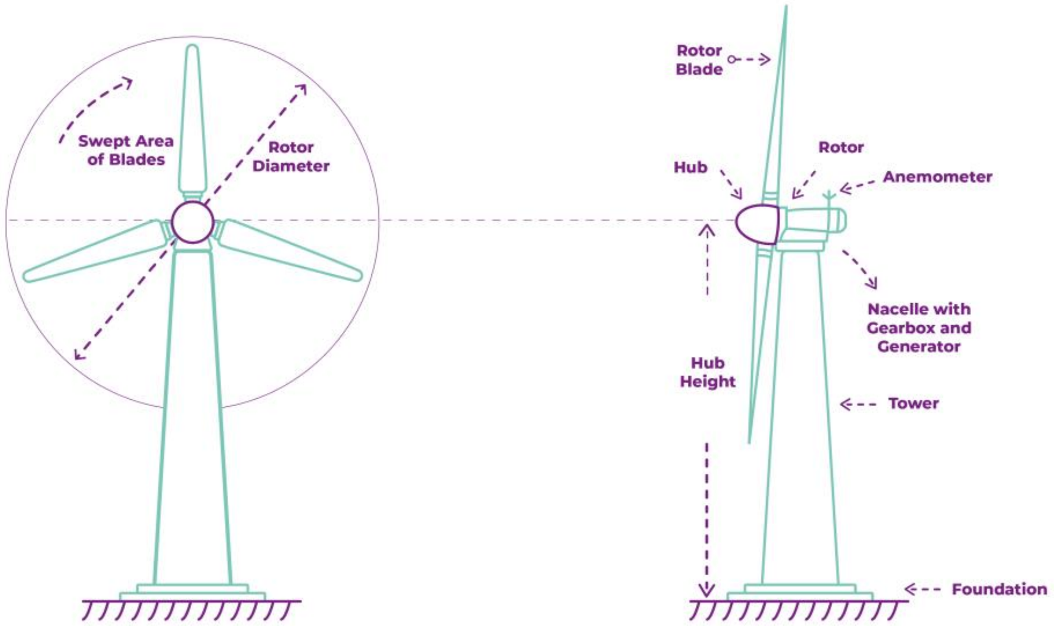
Design Checks

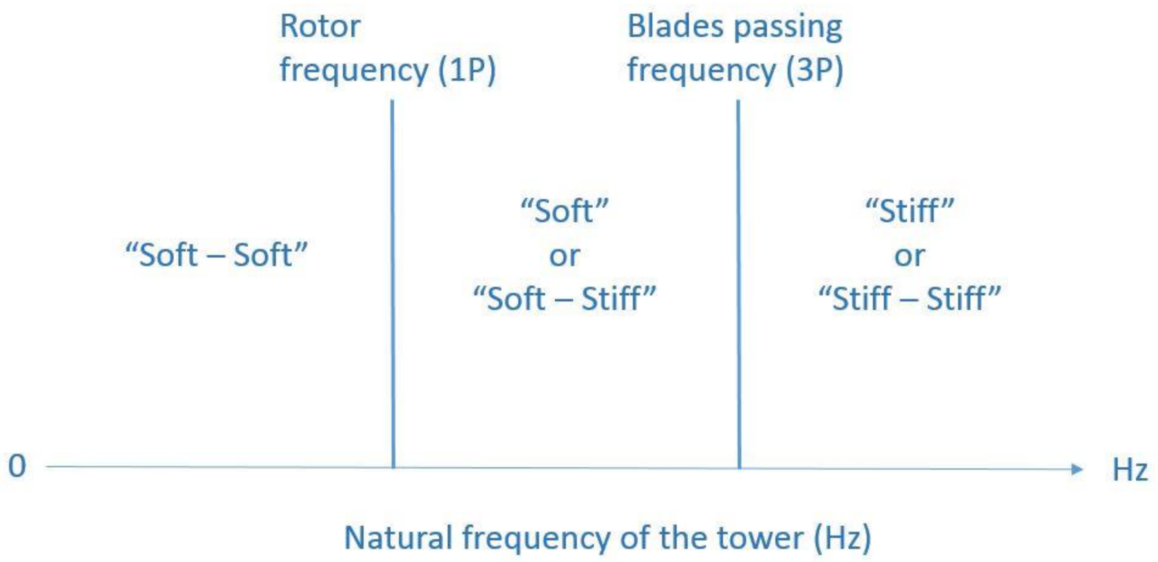
- **ULS – Ultimate Limit States**
  - Loss of structural resistance (excessive yielding and buckling)
  - Loss of static equilibrium of the structure, etc.
- **SLS – Serviceability Limit States**
  - Deformations or motions that exceed the limitation of equipment
- **FLS – Fatigue Limit States**
  - Cumulative damage due to repeated loads
- **ALS – Accidental Limit States**
  - Structural damage cased by accidental loads

SLS Checks

- Natural frequency
- Pile head movement (deflection and rotation)







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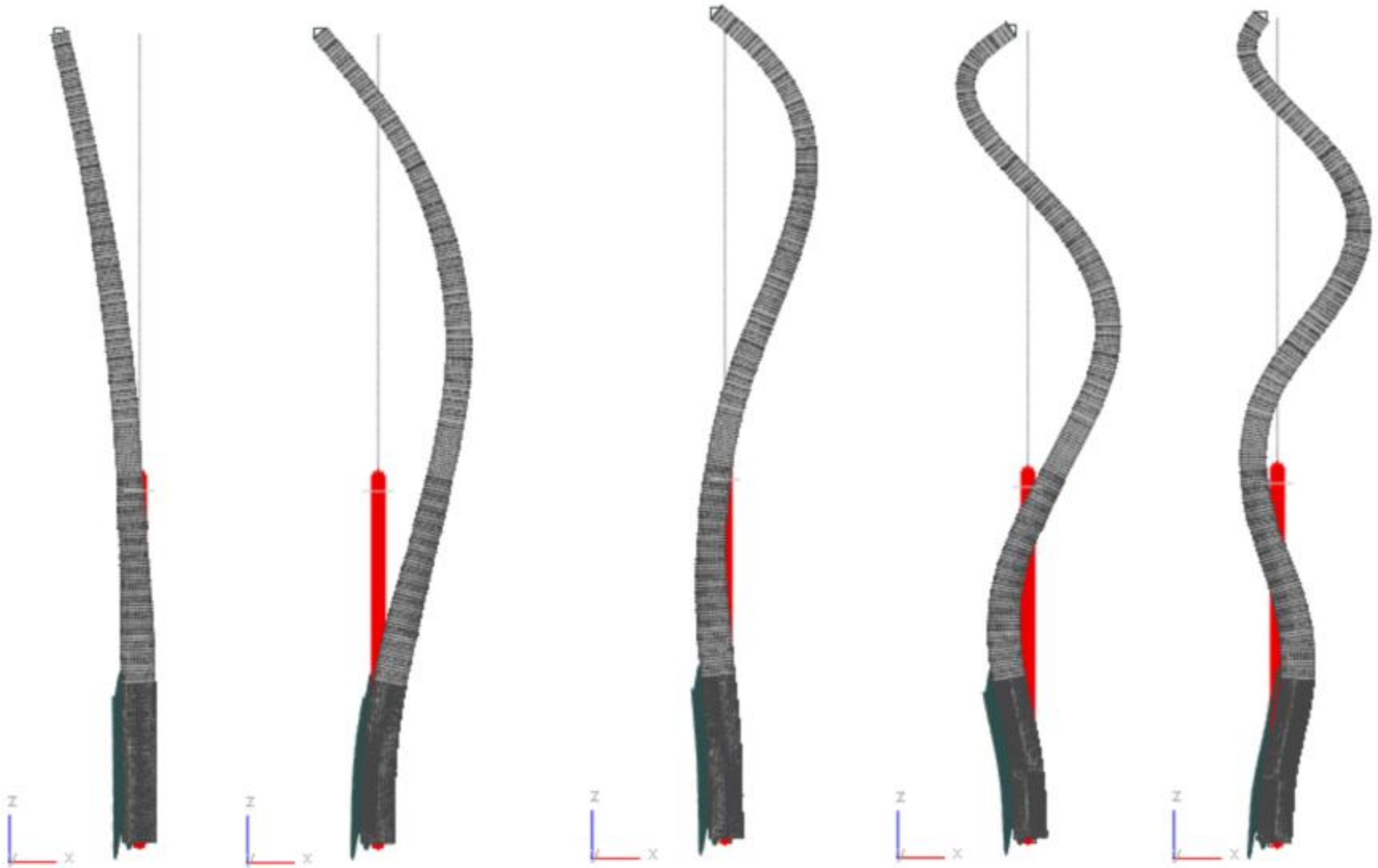
SLS

Natural Frequency Check



1st mode 2nd mode 3rd mode 4th mode 5th mode

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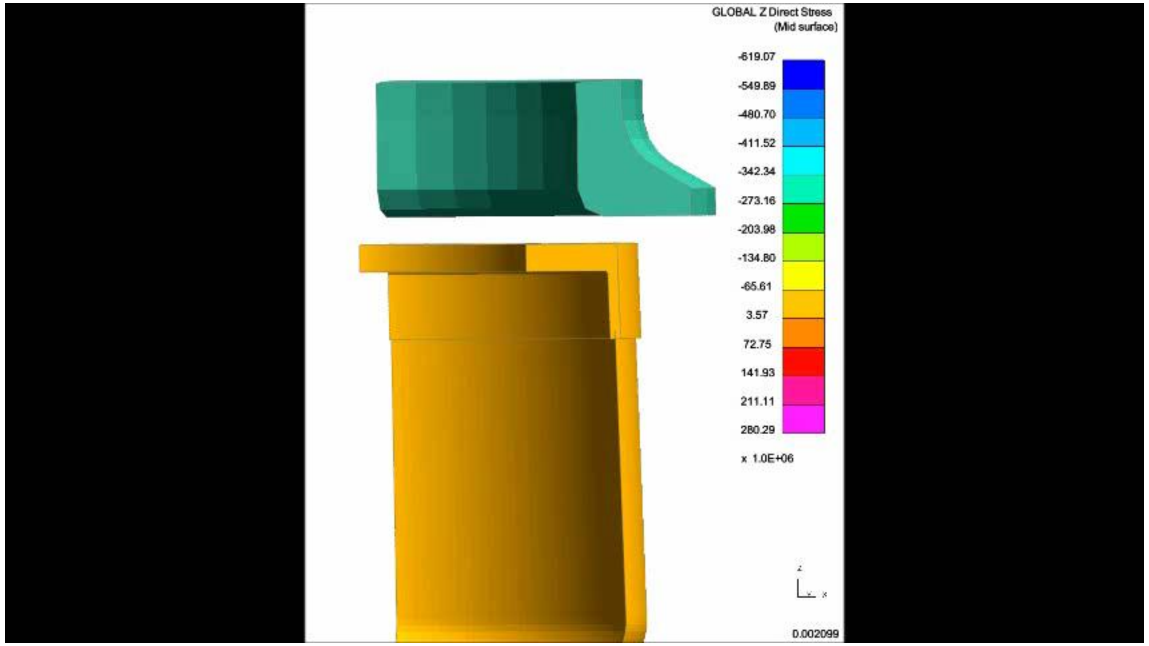
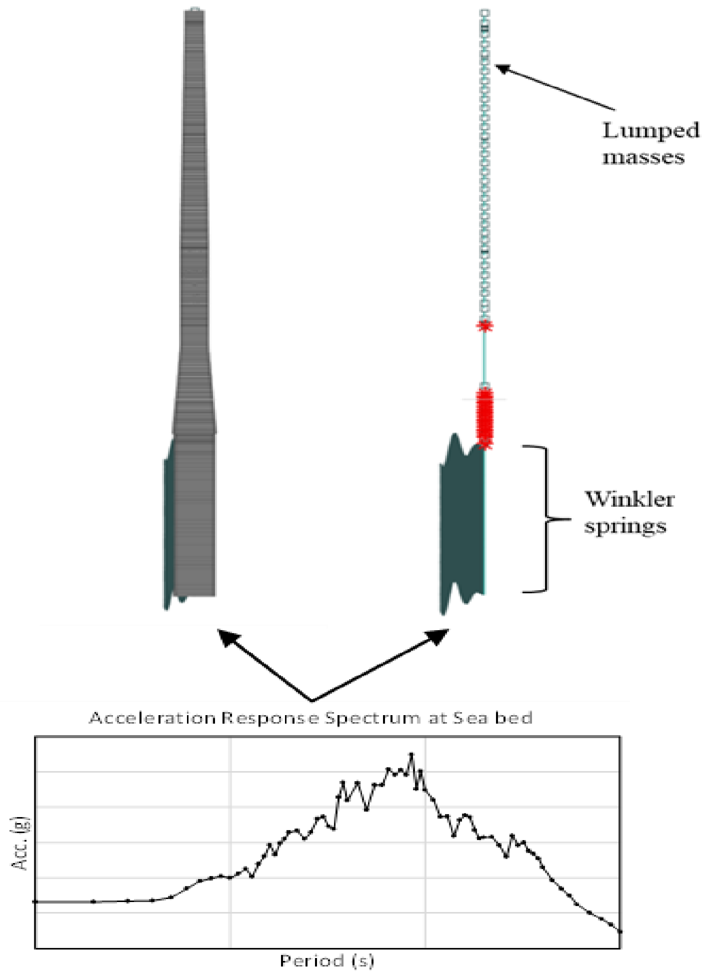
FLS Checks

- Oscillating over the design life
- Pile driving
- Transportation



ALS – Seismic Design

- Liquefaction assessment
- Site response analysis
- Response spectrum analysis + kinematic analysis, or
- Time-history analysis



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Design Load Case

DNV-ST-0437

Design Situation	DLC	Wind Condition	Marine Condition				Other Conditions:	Type of Analysis		Partial safety factor
			Waves	Wind and wave directionality	Sea Currents	Water Level		Onshore	Offshore	
1) Power Production:	1.1	NTM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL	For extrapolation of extreme loads (offshore – only RNA)	U	U	N (1.25)
	1.2	NTM $V_{in} < V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	No Currents	NWLR or ≥ MSL		F/U	F/U	F/N
	1.3	ETM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL		U	U	N
	1.4	ECD $V_{hub} = V_r - 2$ m/s, V_r, $V_r + 2$ m/s	NSS $H_s = E[H_s \| V_{hub}]$	MIS, wind direction change	NCM	MSL		U	U	N
	1.5	EWS $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL		U	U	N
	1.6	NTM $V_{in} < V_{hub} < V_{out}$	SSS $H_s = H_{s,SSS}$	COD, UNI	NCM	NWLR		-	U	N
	1.7	NTM $V_{in} < V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	No Currents	NWLR or ≥ MSL	Ice formation	F/U	F/U	F/N

Design situation:

1. Power Production
2. Power Production + occurrence of fault
3. Start up
4. Normal shutdown
5. Emergency stop
6. Parked (standing still or idling)
7. Parked and fault conditions
8. Transport, installation, maintenance and repair
9. Drifting sea ice
10. Temperature effects
11. Earthquake
12. Wind farm influence

Over thousands number of design load cases

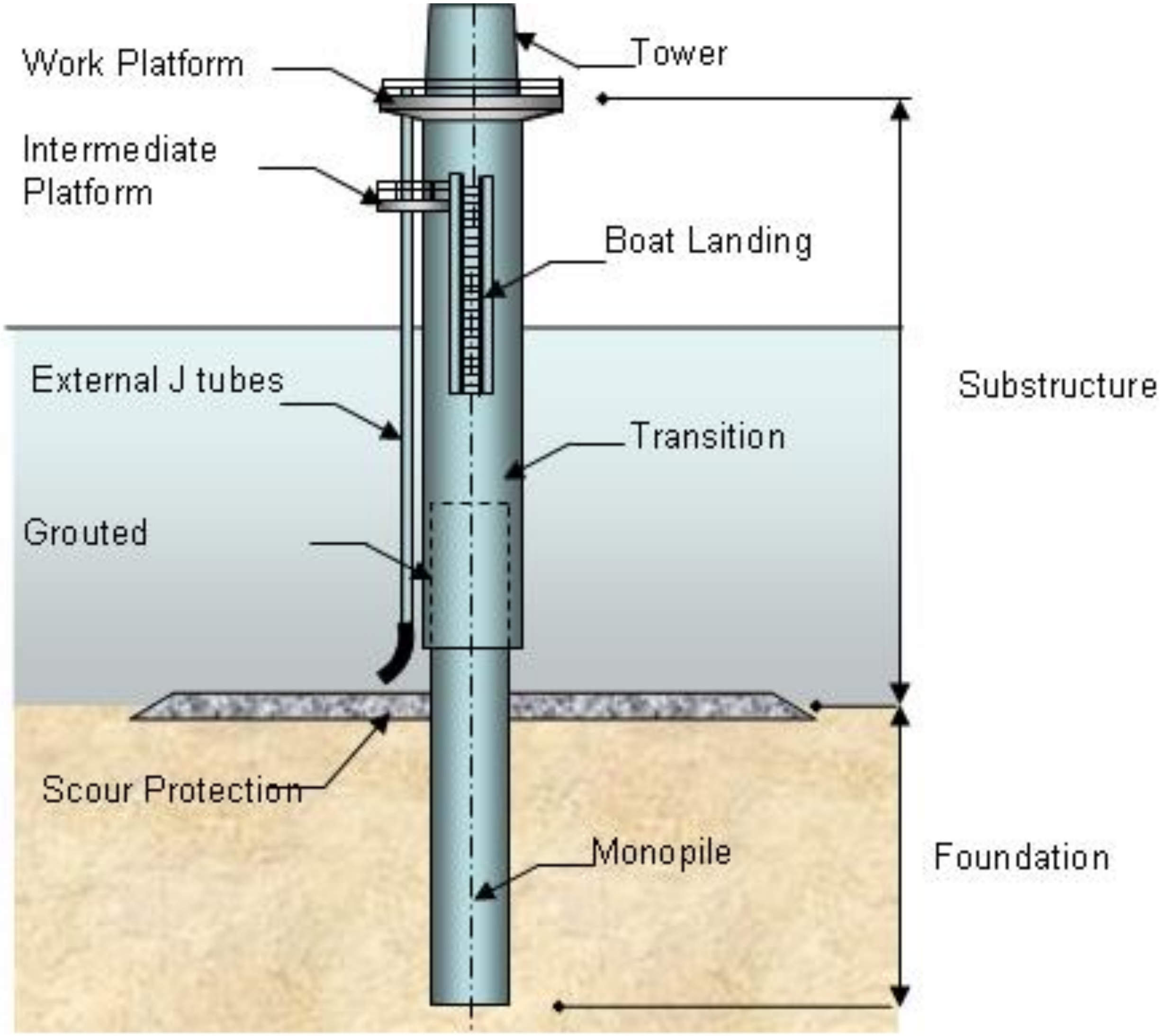
Appuntenance

Secondary Structures

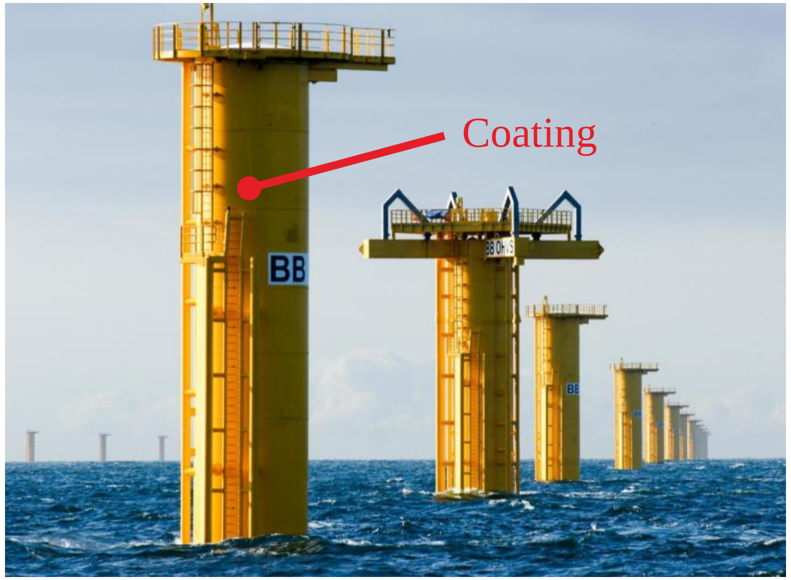
- Boat landing and ladders
- External Working Platform
- Internal Platforms
- Etc.

Non-structure components

- Marine growth
- Entrained water
- Soil mass
- Grout mass
- Etc.



Corrosion Protection



Coating

Cathodic protection

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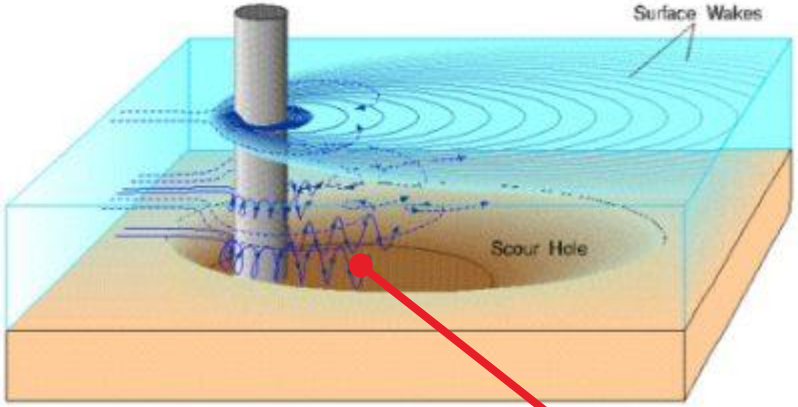
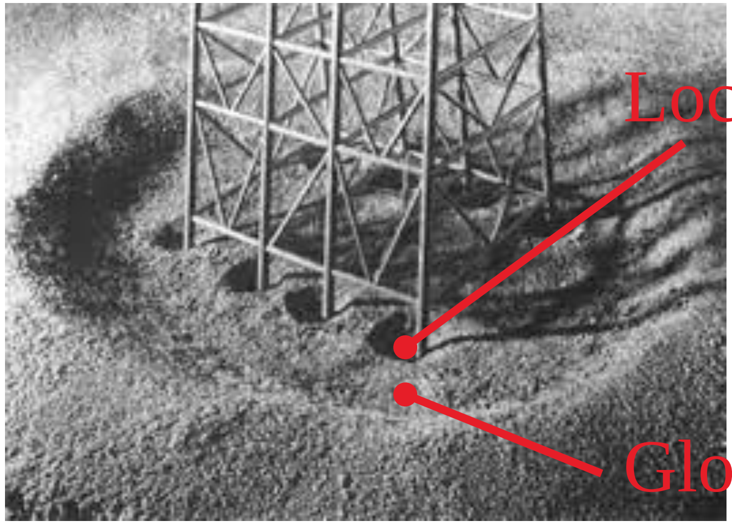
Scour Protection

DNV-ST-0126



Scour



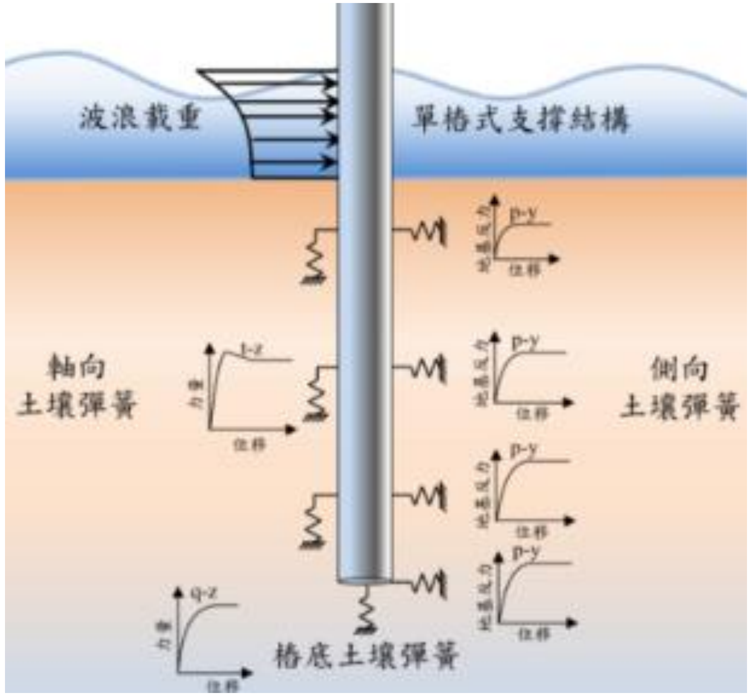
Local Scour

Global Scour

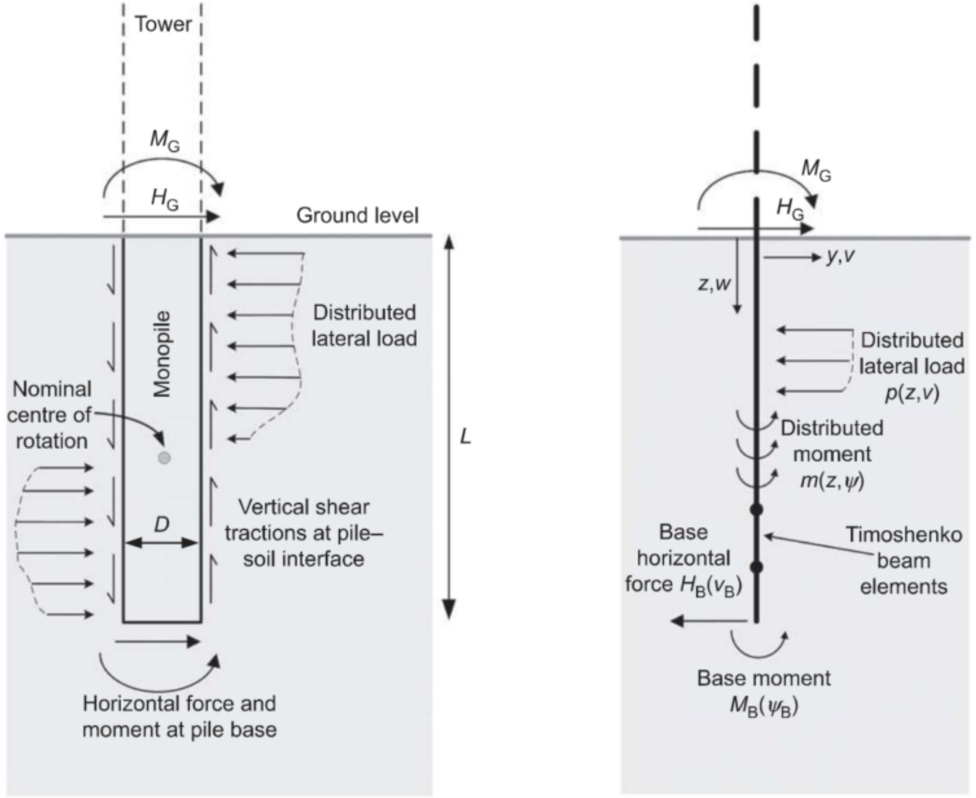
Scour Protection

Soil Springs

- API (American Petroleum Institute) method
- PISA (pile-soil analysis) method



API soil spring model



PISA soil spring model

Design Standards/ Guidelines

- DNV standards
- IEC 61400 standards
- ISO 19902
- API RP-2A-WSD
- Local standards/ guidelines
  - CNS (Taiwan)
  - JSCE, Unified design guideline, etc. (Japan)

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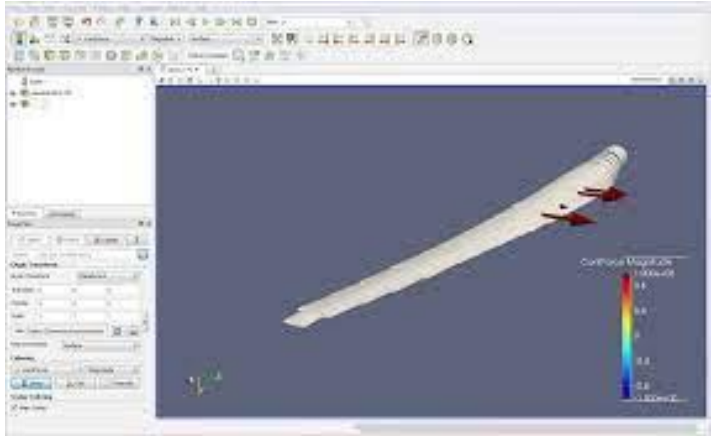
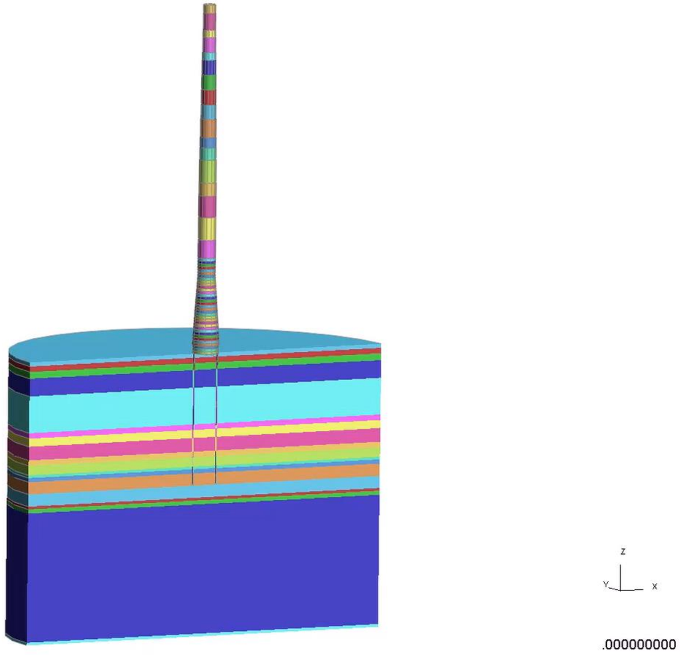
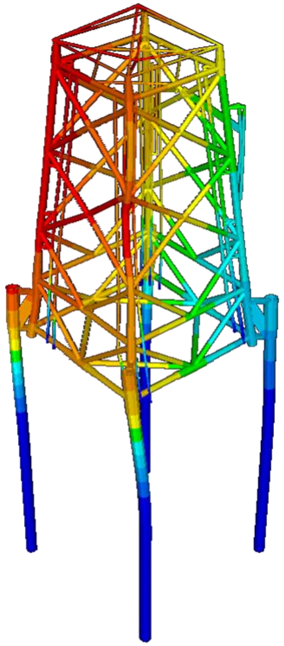
Design Tools

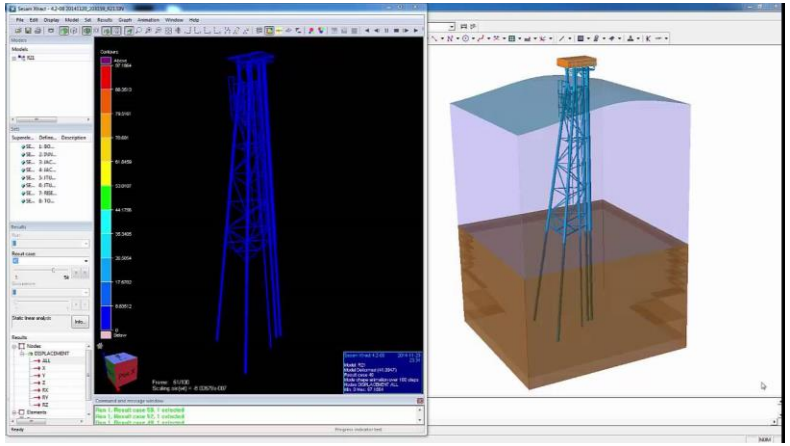


BLADE

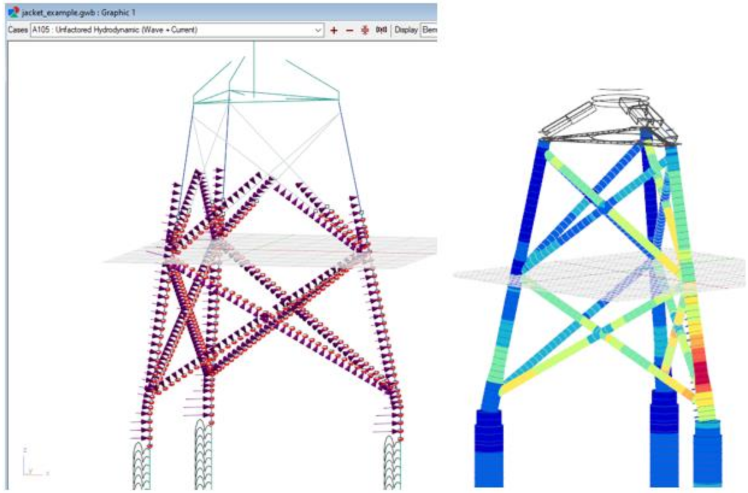




LS-Dyna



SESAM



Optif


10m
2m
ECIAL PIPE

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Thank you and questions