Dynamic Analysis of Power Cable in Floating Offshore Wind Turbine

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Presentation Highlights

1 – Motivation and Background

2 – Offshore Wind Technology Development

3 - Modeling

4 – Fatigue Analysis and Electrical Cable

5 - Summary

Part 1. Motivation and Background

Between 1971 and 2015, global energy consumption more than doubled from 61,900 TWh to 160,000 TWh (EIA, 2017; IEA, 2017a).

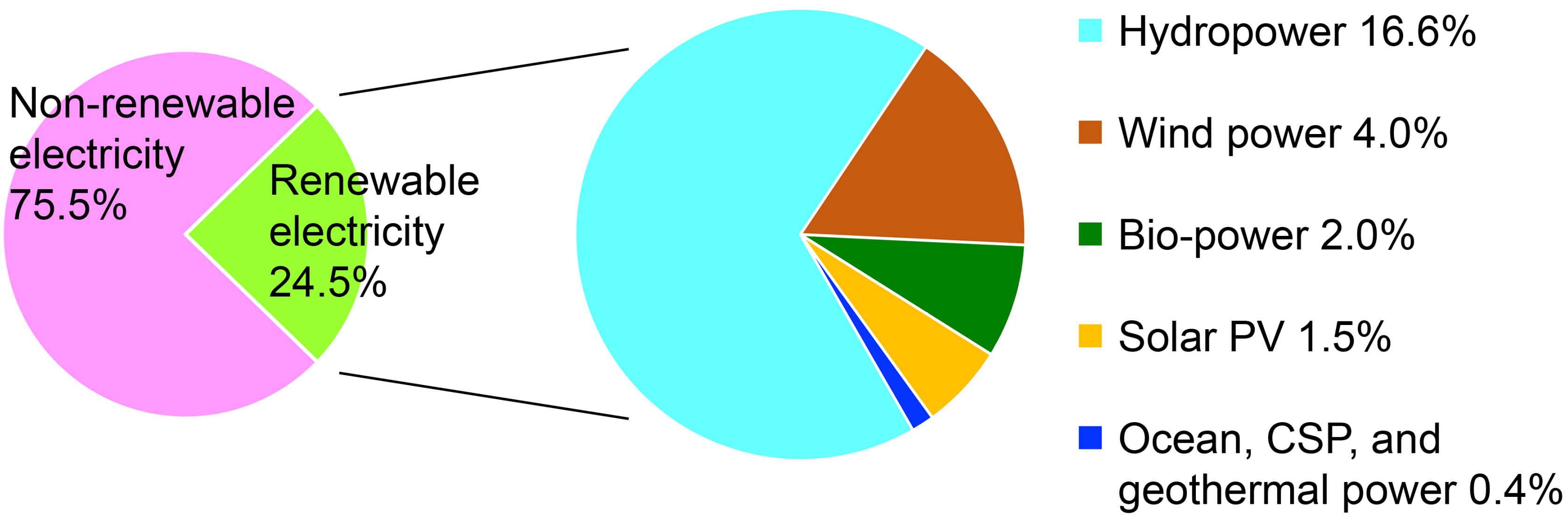


Figure 1. Estimated renewable energy share of global electricity production at the end of 2016; data extracted from REN21 (2017).

Part 1. Motivation and Background

Europe installed 11.7 GW (10.1 GW in EU-28) of new wind energy in 2018. This is a 32% decrease on 2017. Europe decommissioned 0.4 GW of wind turbines. So the net increase in Europe's wind energy capacity in 2018 was 11.3 GW.

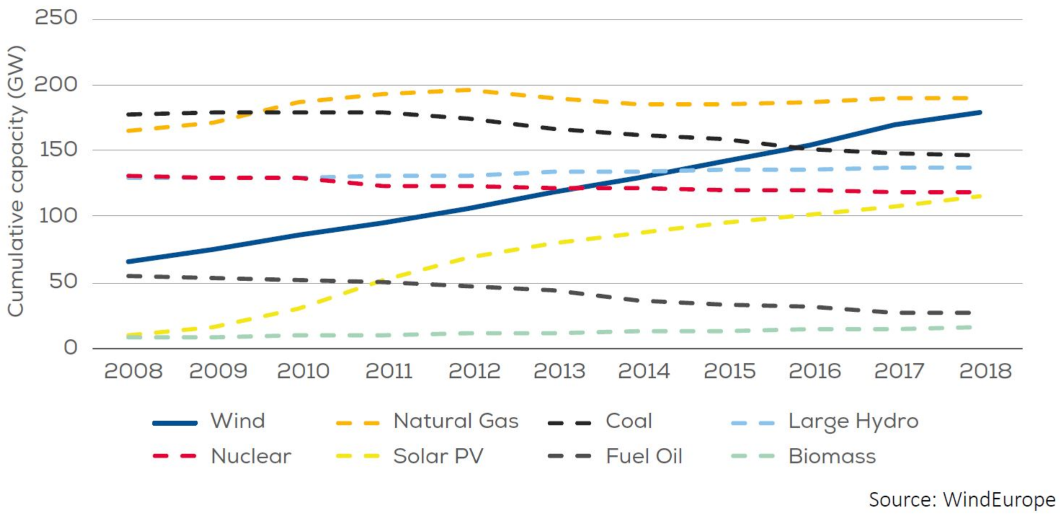


Figure 2. Total power generation capacity in the European Union 2008-2018

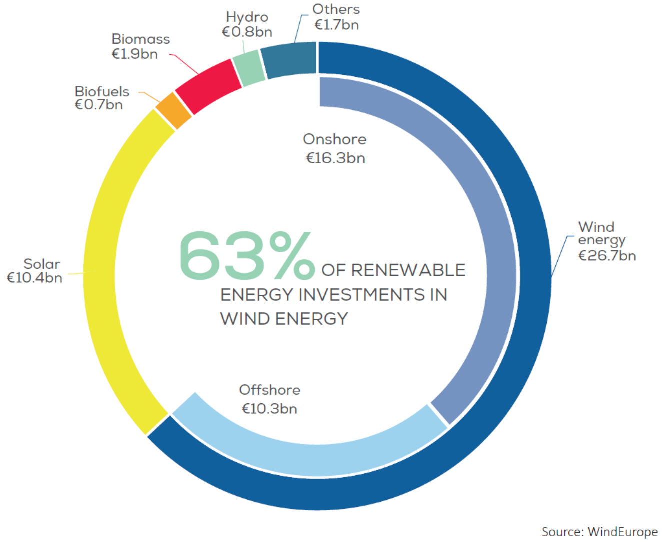


Figure 3. Renewable energy investments in 2018 (€bn)14

Wind energy accounted for 63% of Europe's investments in renewable energy in 2018, compared to 52% in 2017. Onshore wind projects alone attracted 39% of the total investment activity in the renewable energy sector

Part 2. Offshore Wind Technology Development

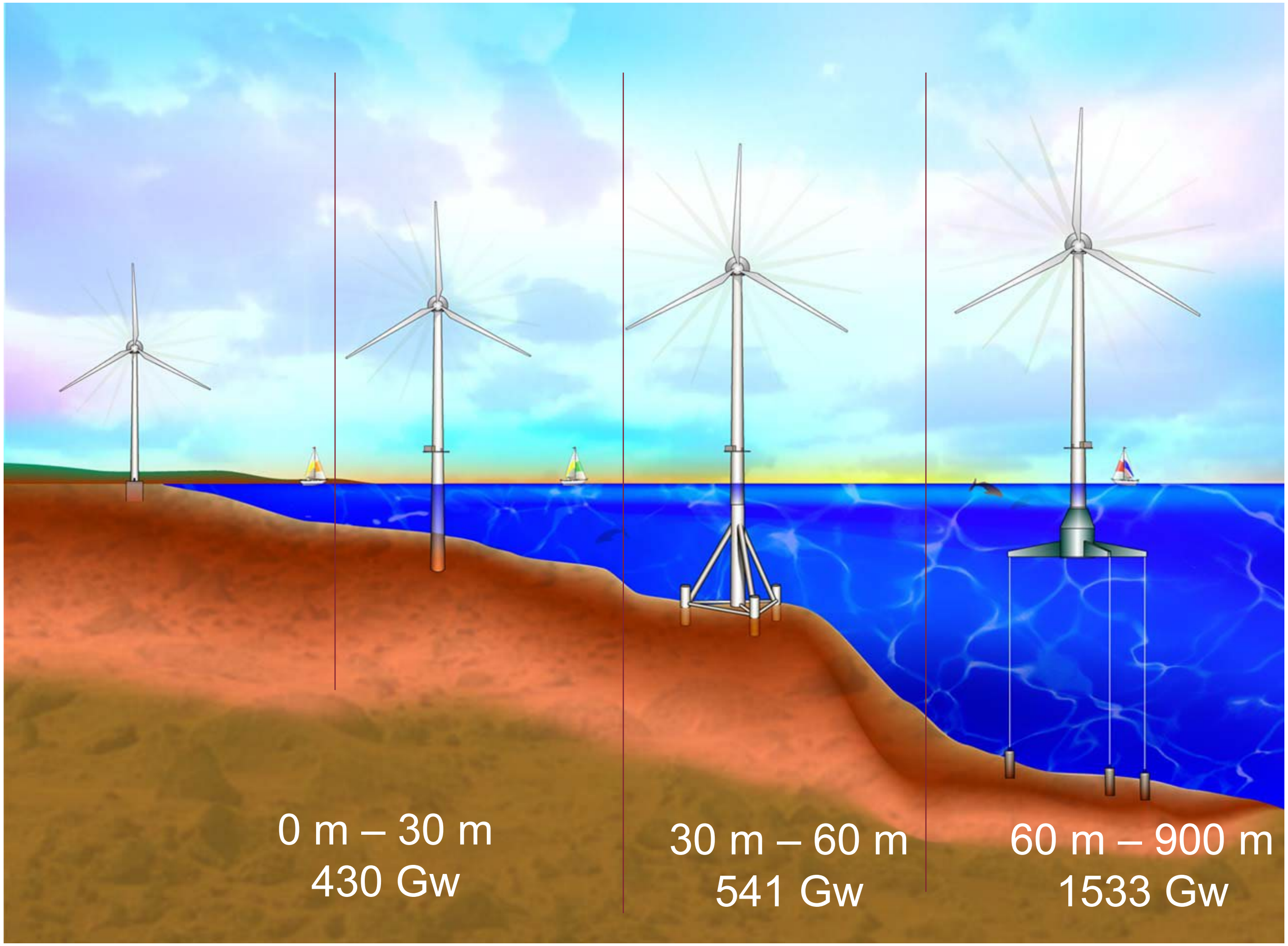


Figure 4. Natural progression of substructure designs from shallow to deep water(source NREL)

Part 2. Offshore Wind Technology Developement

- ✓ **Barge**
- ✓ **Spar-Buoy**
- ✓ **Tension Leg Platform (TLP)**

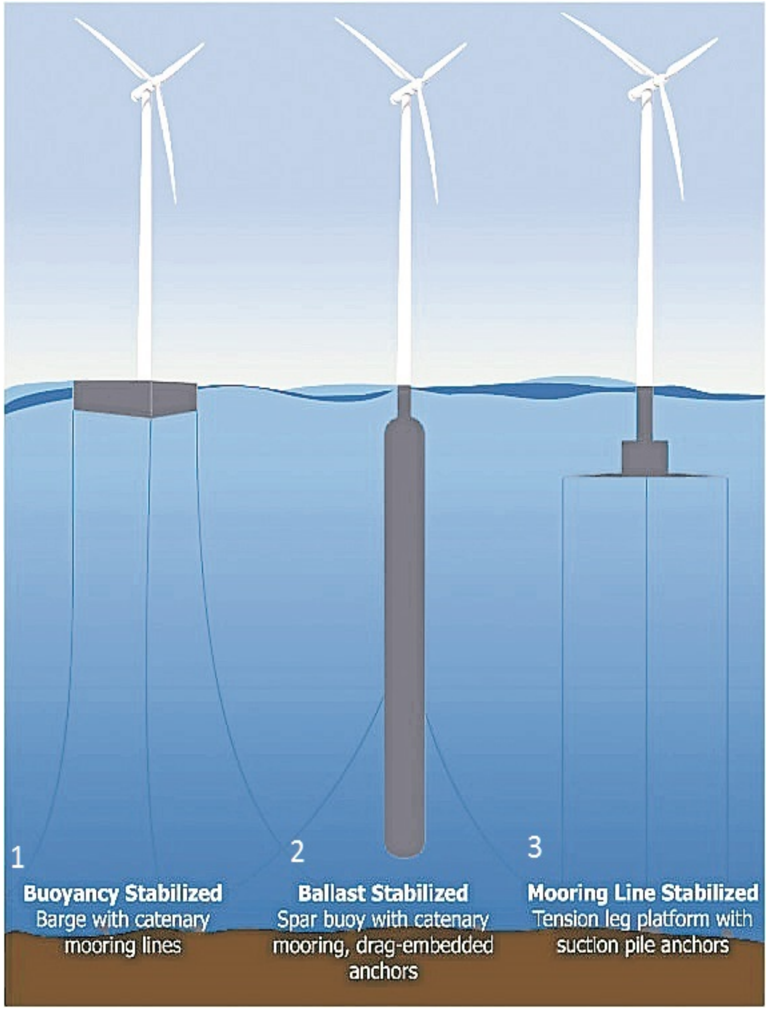
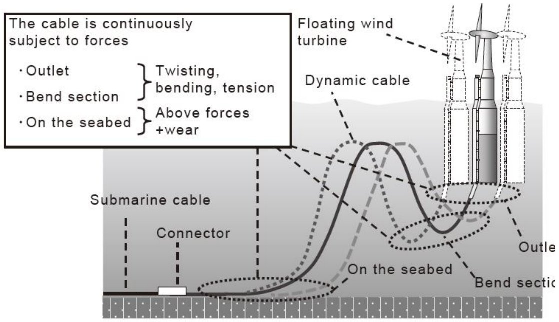
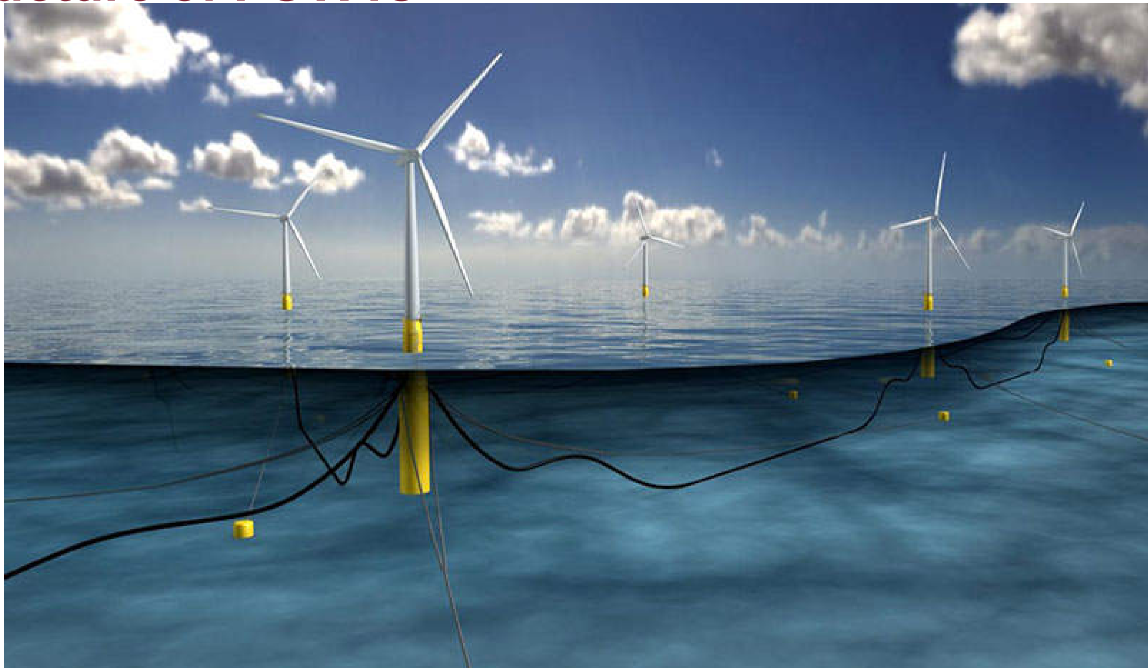


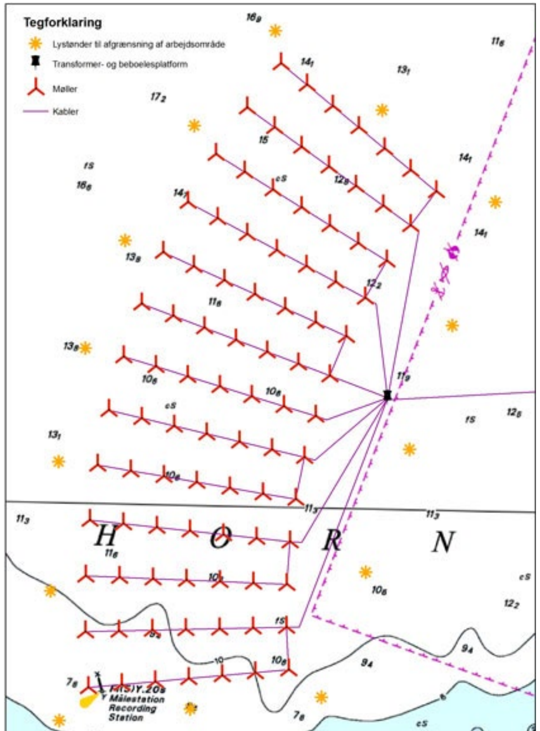
Figure 5. **Floating platform concepts for offshore wind turbines**

Part 2. Complexity of Infrastructure of FOWTs

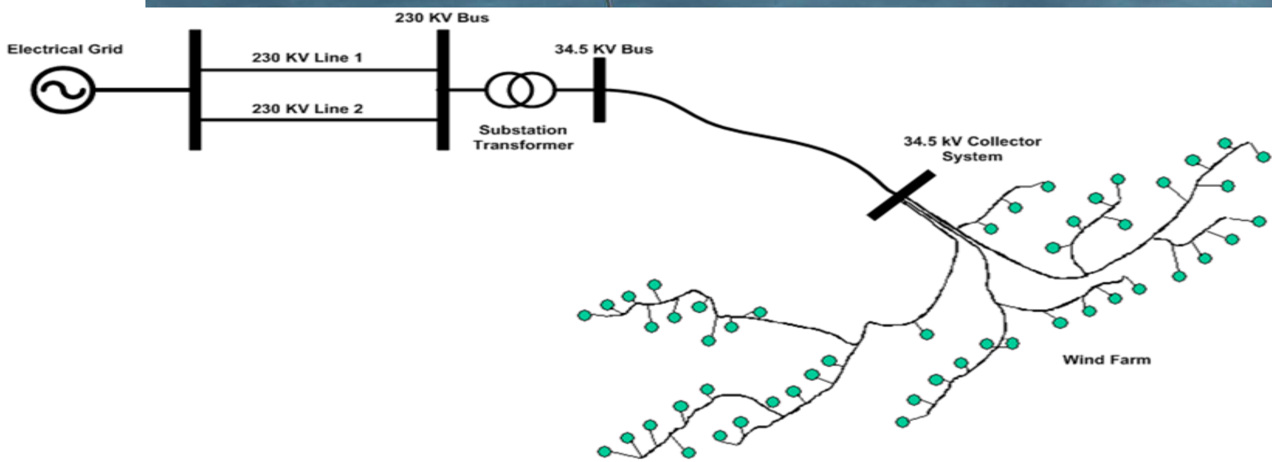




Layout of Horns Rev 2 Wind Farm



Source: Dong Energy. http:// www.dongenergy.dk.

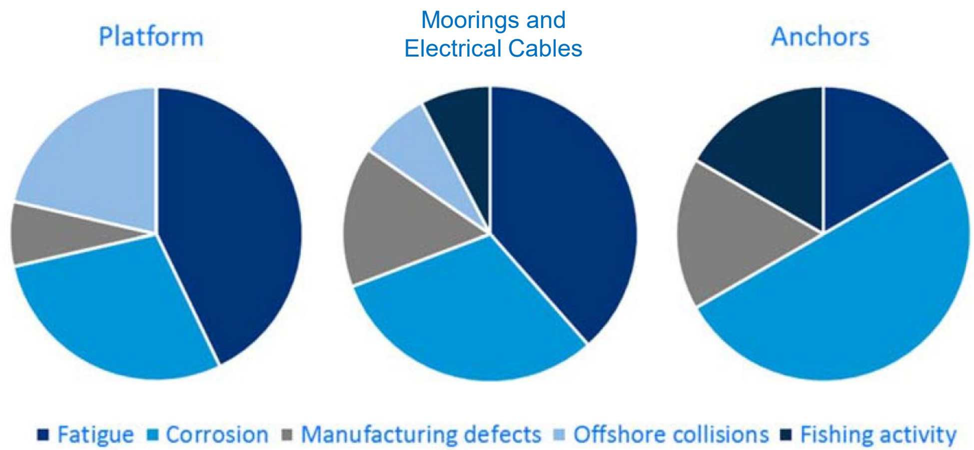


Source NREL

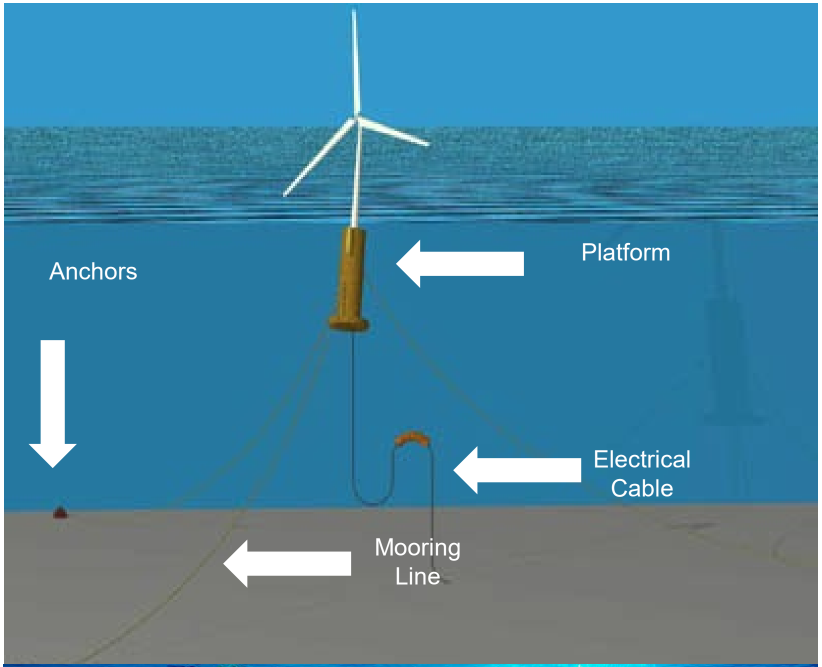
Part 2. Fatigue as an issue for FOWTs

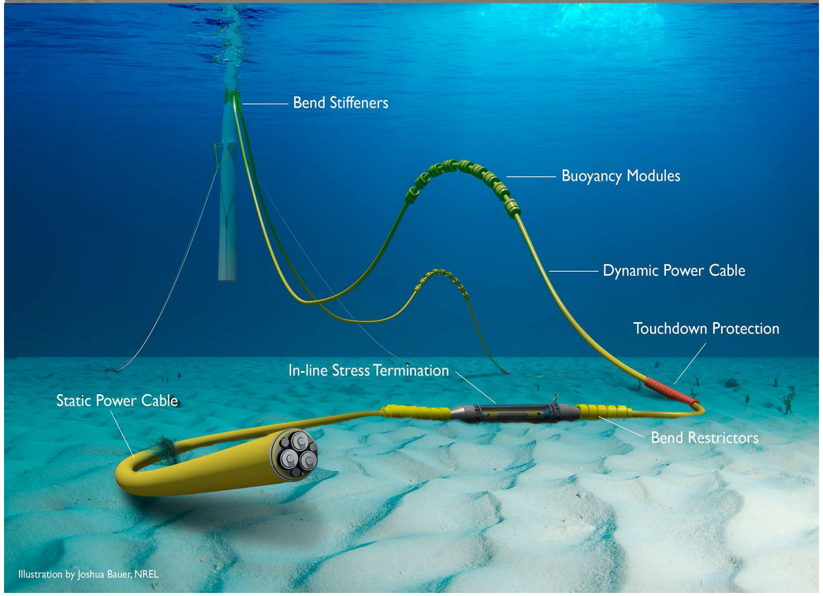
Source of Failure

- Fatigue
- Corrosion
- Fishing



Source: Floating Offshore Wind: Market and Technology Review






Modeling

Part 3. Numerical Modeling

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FAST

Is a tool for simulating the coupled dynamic response of wind turbines.

Figure 6. Model of FOWT in FAST code

ANSYS AQWA

Is an engineering analysis suite of tools for the investigation of the effects of wave, wind and current on floating and fixed offshore and marine structures,.

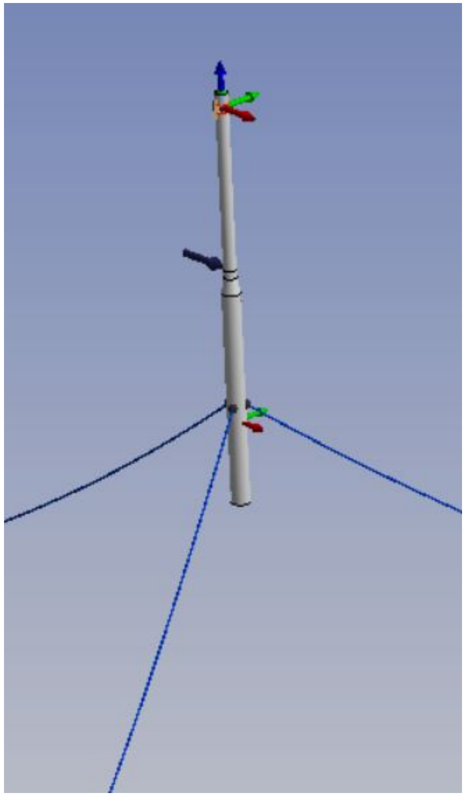


Figure 7. Model of FOWT in Ansys AQWA

Part 3. Global Dynamics and Loads

- Wind
  - Steady
  - Unsteady
- Wave
  - Regular
  - Irregular
- Current

Total Structural Load

$$F_i^{Platform} = F_i^{Structural} + F_i^{Hydro} + F_i^{Lines} + F_i^{Wind}$$

Total Hydro Load

$$F_i^{Structural} = F_i^{Inertia} + F_i^{Restoring} + F_i^{Gyro}$$

Total Wave Load

$$F_i^{Hydro} = F_i^{Waves} + \rho g V_0 \delta_{i3} - C_{ij}^{Hydrostatic} q_j - \int_0^t K_{ij}(t-\tau)\dot{q}_j(\tau)\,d\tau$$

Total Wave Load

$$F_i^{Waves}(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} W(\omega)\sqrt{2\pi S_\zeta^{2\text{-Sided}}(\omega)}\,X_i(\omega,\beta)\,e^{j\omega t}\,d\omega \,.$$

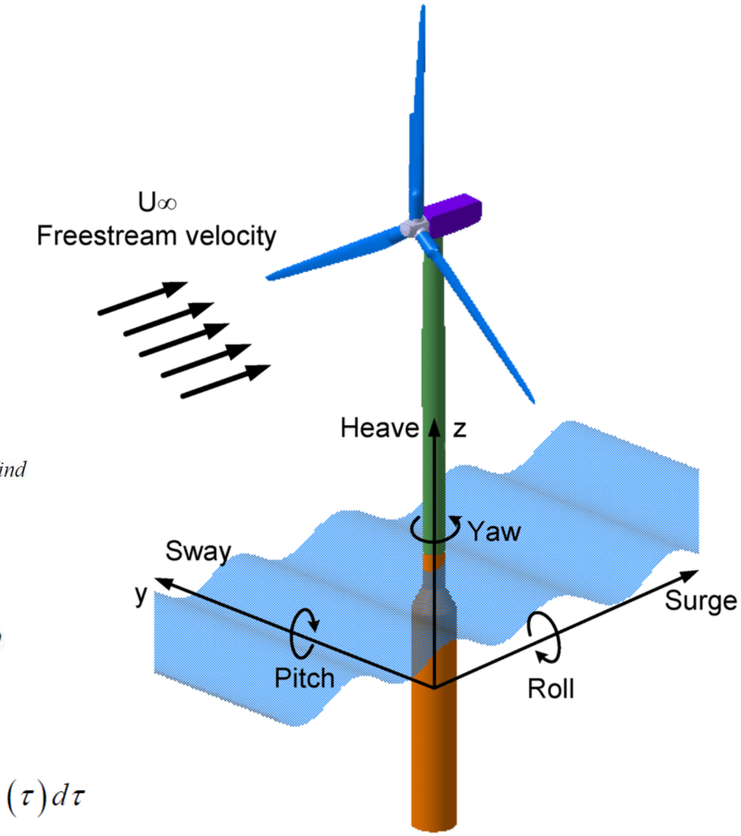
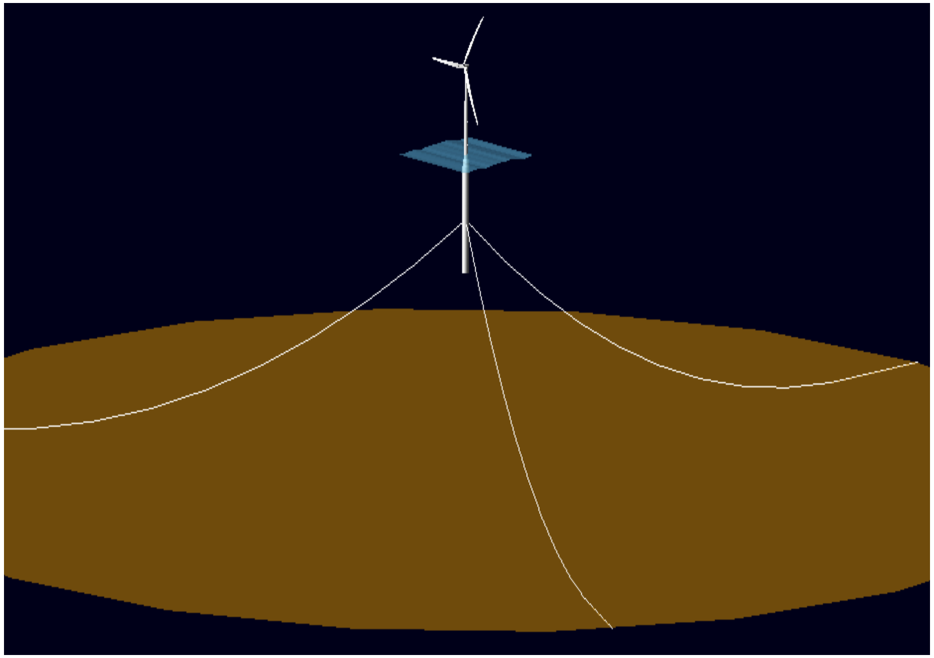


Figure 8. DOF's of FOWT

Part 3. Benchmark for Validation



NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Structural Properties of Mooring Lines

Description	Unit
the mass per unit length of the line (kg/m)	77.7066
the line stiffness, product of elasticity modulus and cross-sectional area (N)	384.243E6
Diameter (m)	0.09

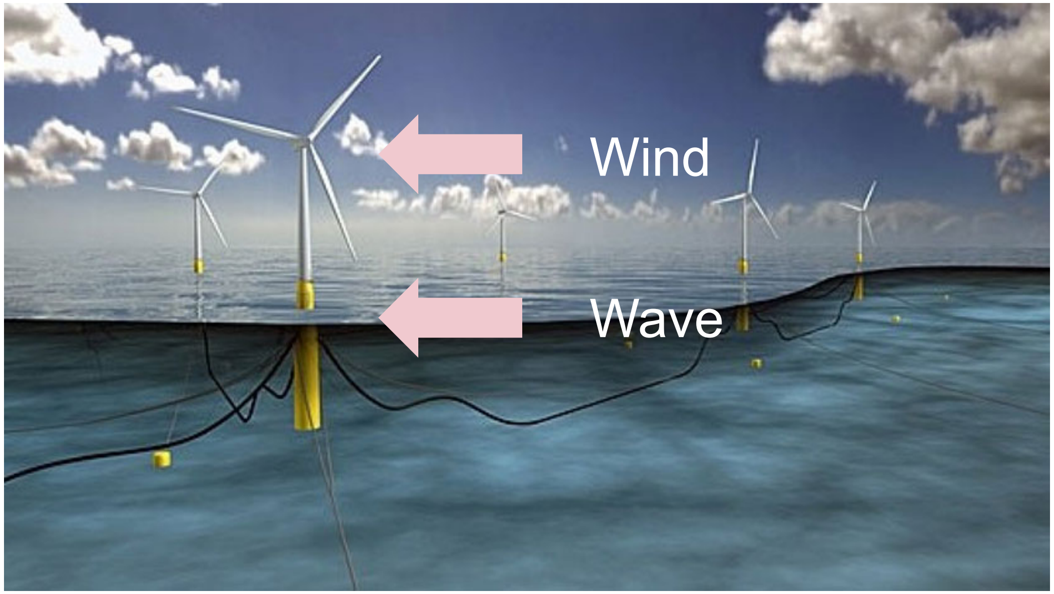
Hydrodynamic Properties of Model

Description	Unit
Water density (kg/m^3)	1025
Water depth (meters)	320
Displaced volume of water when the platform is in its undisplaced position (m^3)	8029.21
Incident wave kinematics model	Regular
Analysis time for incident wave calculations (s)	3630
Time step for incident wave calculations	0.25
Significant wave height of incident waves (meters)	6
Peak-spectral period of incident waves	10
Range of wave directions(degrees)	90
Wave Type	Stokes 2nd-order wave theory
Low frequency cutoff used in the summation-frequencies (rad/s)	0.1
High frequency cutoff used in the summation-frequencies (rad/s)	1.9132
Current profile model	No Current
Analysis time for wave (s)	1000
Time step for wave (s)	0.0125
Additional Linear Damping in Surge N/(m/s)	100,000
Additional Linear Damping in Sway N/(m/s)	100,000
Additional Linear Damping in Heave N/(m/s)	130,000
Additional Linear Damping in Yaw Nm(rad/s)	13,000,000
Hydrostatic Restoring in Heave (N/m)	332,941
Hydrostatic Restoring in Roll (Nm/rad)	-4,999,180,000
Hydrostatic Restoring in Pitch (Nm/rad)	-4,999,180,000

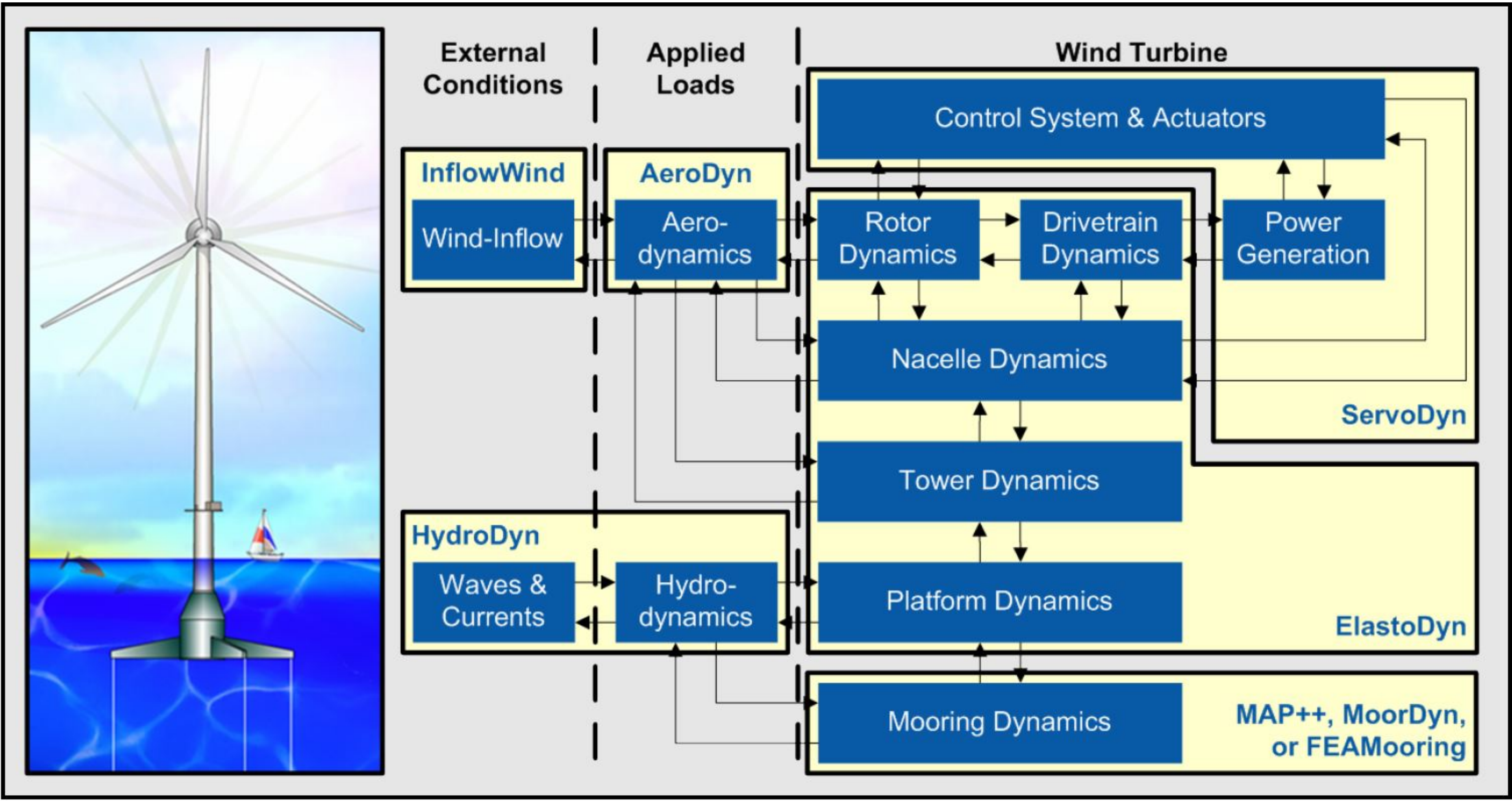
Part 3. Load Case for Validation

DOF	Wind Condition	Wave Condition	Analysis Type
Platform, Tower	Steady, Uniform Vhub = 8 m/s	Regular Airy: H=6m T=10S	Time-Series solution

Description	Unit
Total run time (s)	1000
Time steps for Analysis (s)	0.0125
Time step for tabular output (s)	0.1
Compute structural dynamics	ElastoDyn
Compute hydrodynamic	HydroDyn
Compute mooring system	MoorDyn
Compute inflow wind velocities	Off
Compute aerodynamic loads	Off
Compute control and electrical-drive dynamics	Off
Compute sub-structural dynamics	Off
Compute ice loads	Off

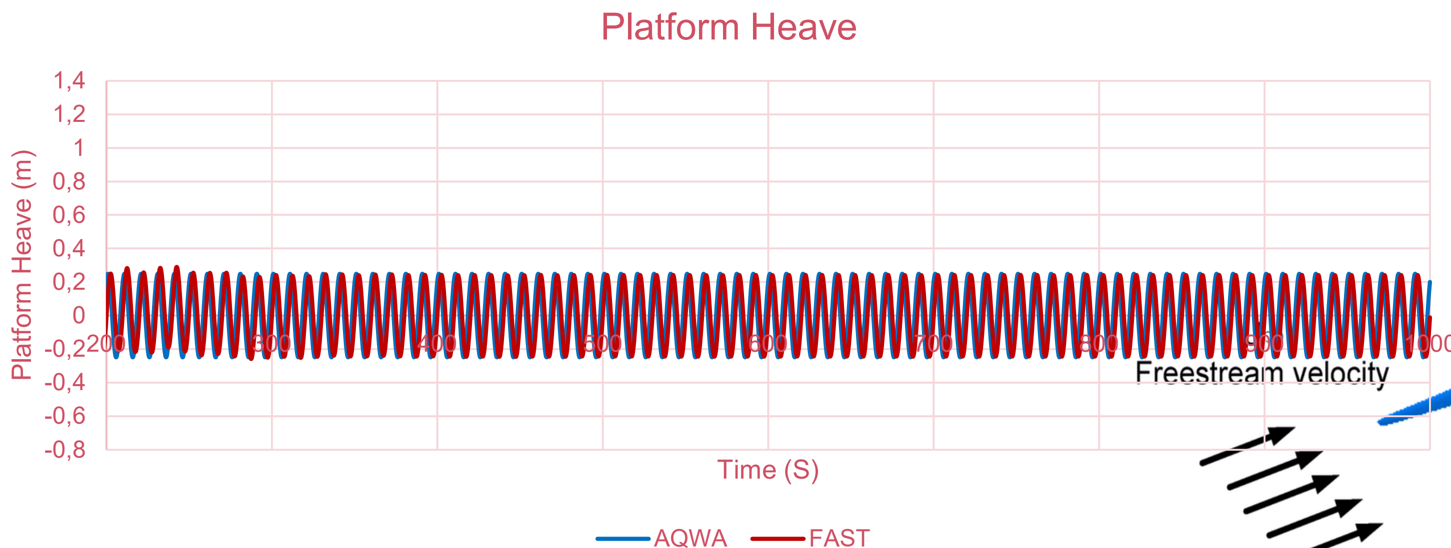


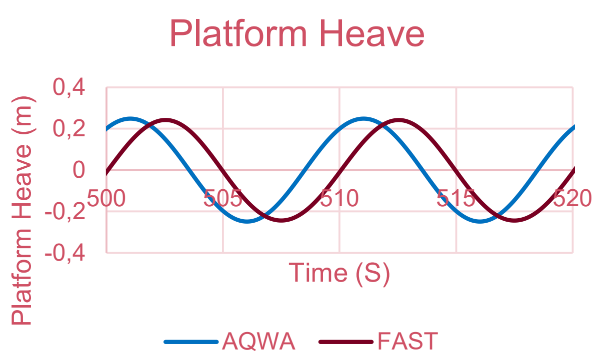
Part 3. Flowchart of modeling in FAST



Source NREL

Part 3. Result Validation





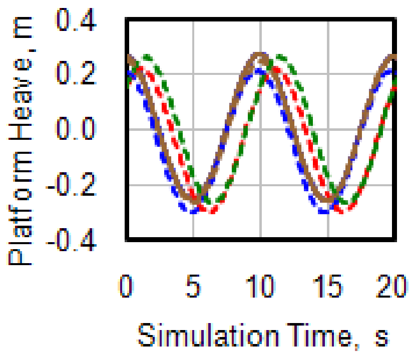
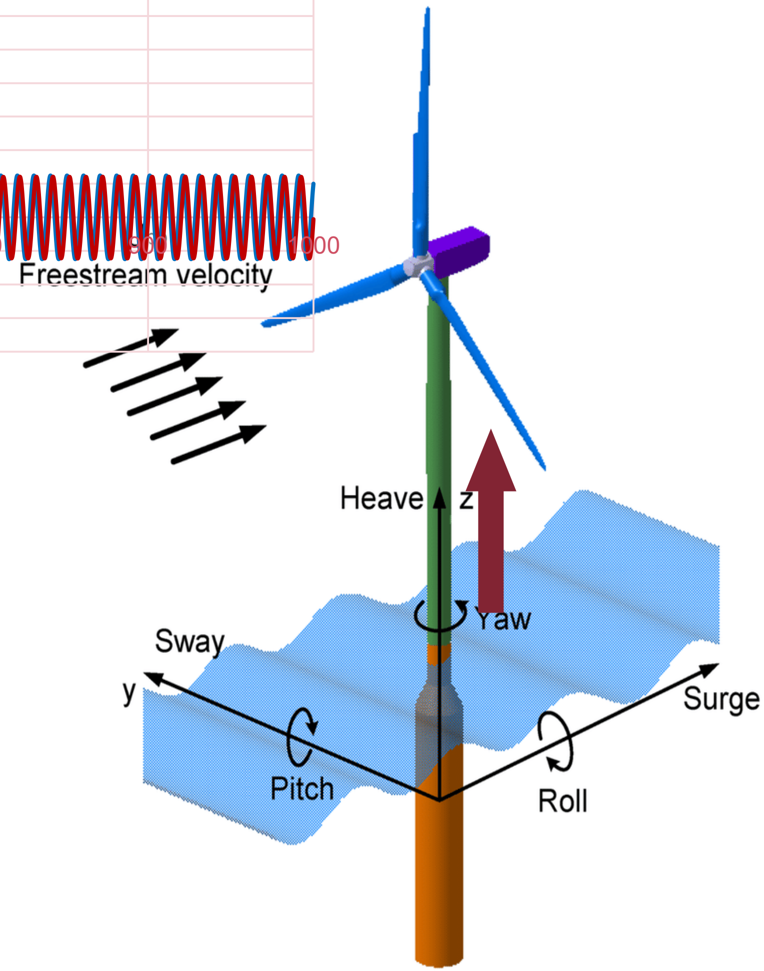
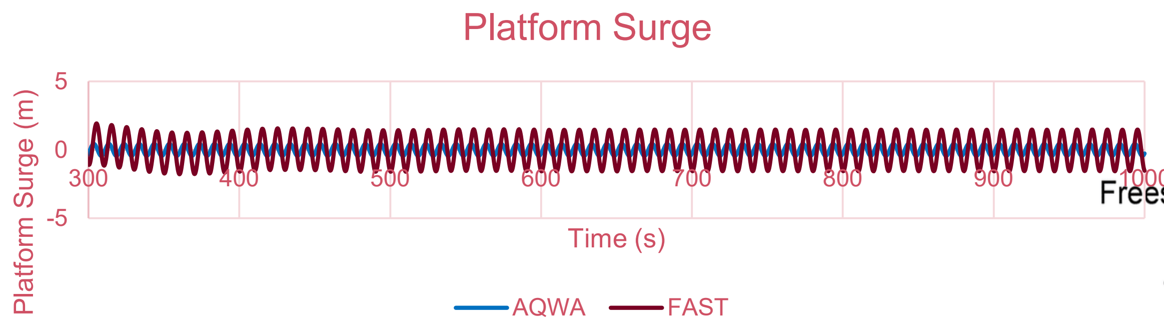
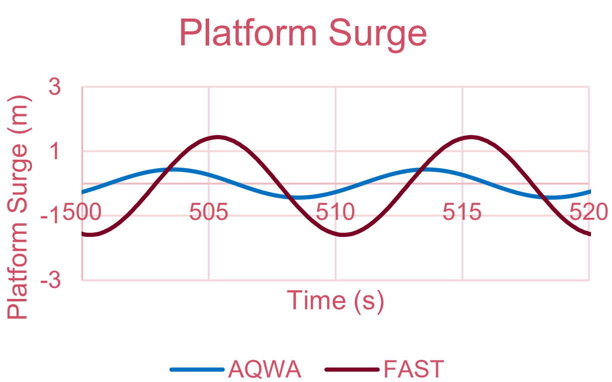


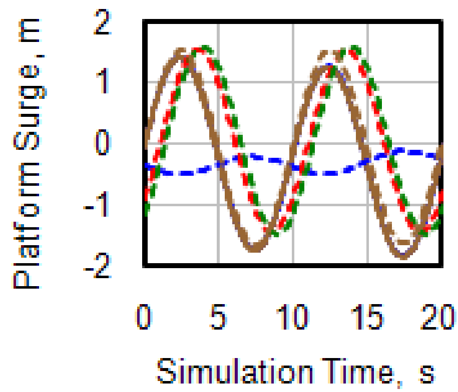
Figure 8. Jonkman Report Heave



Part 3. Result Validation







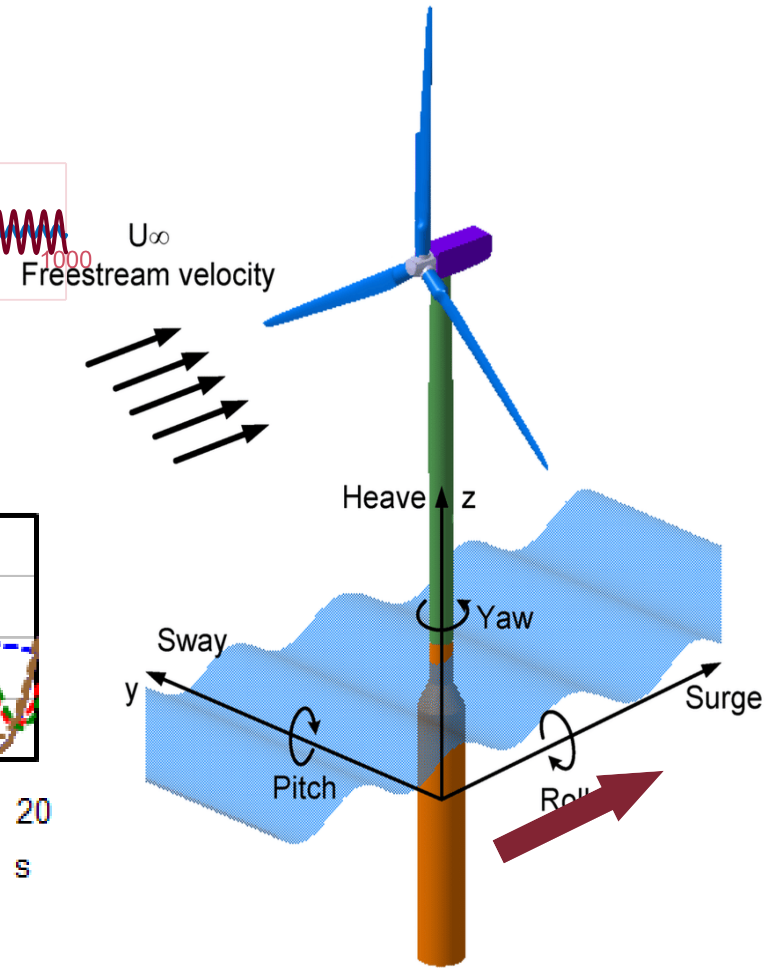
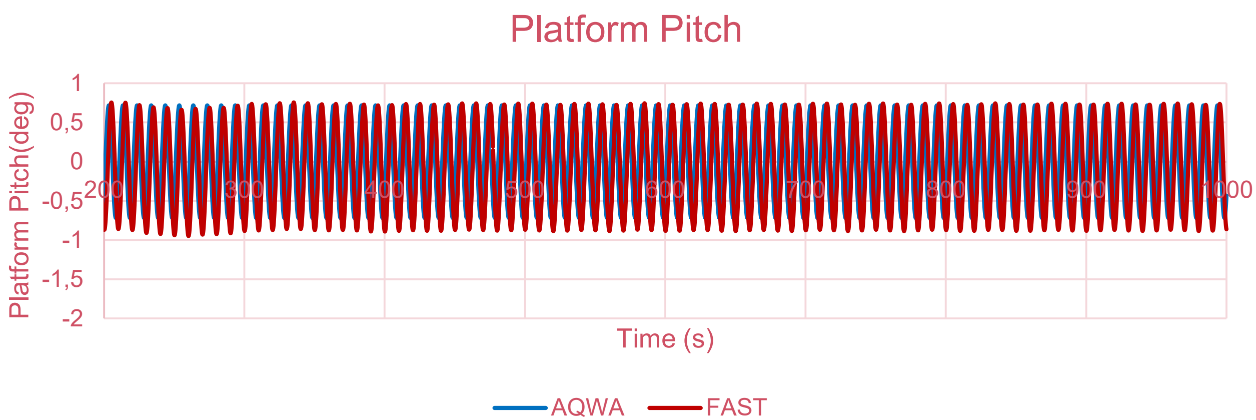
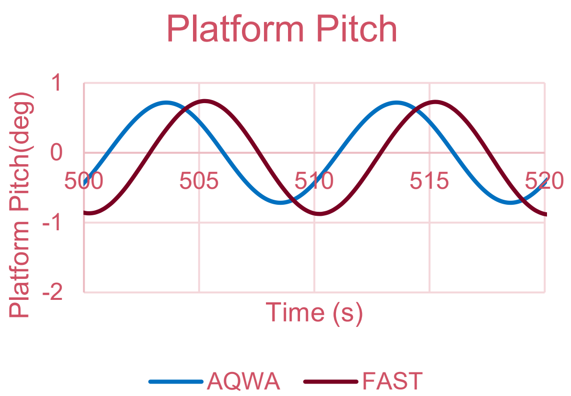
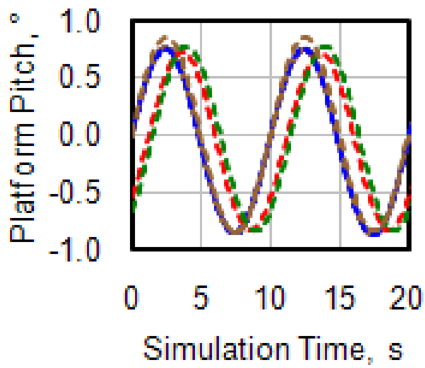


Figure 9. Jonkman Report Surge

Part 3. Result Validation







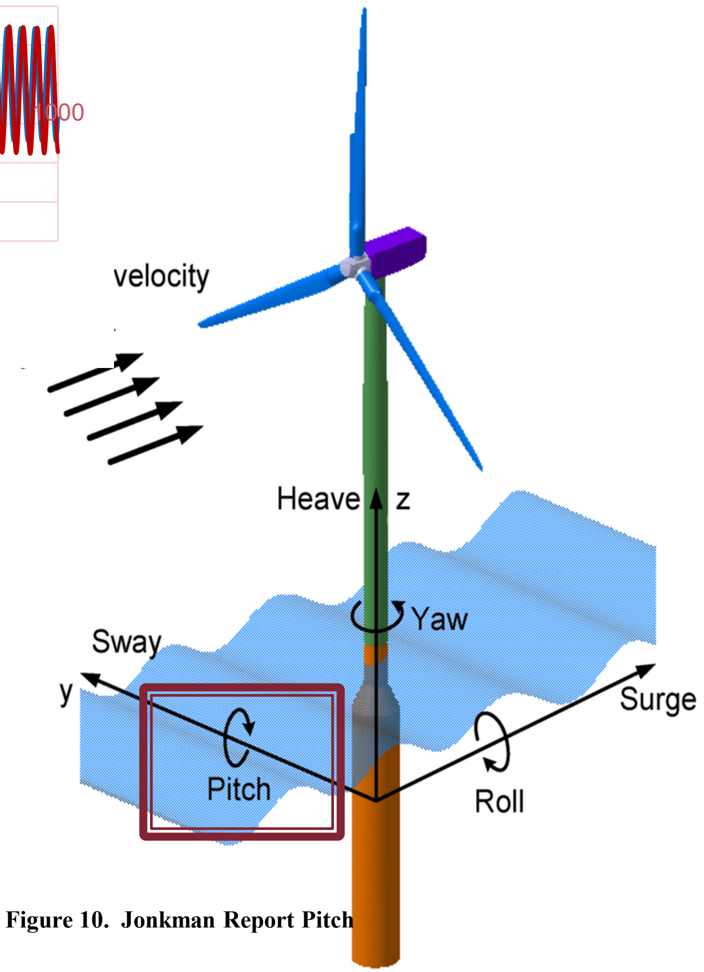
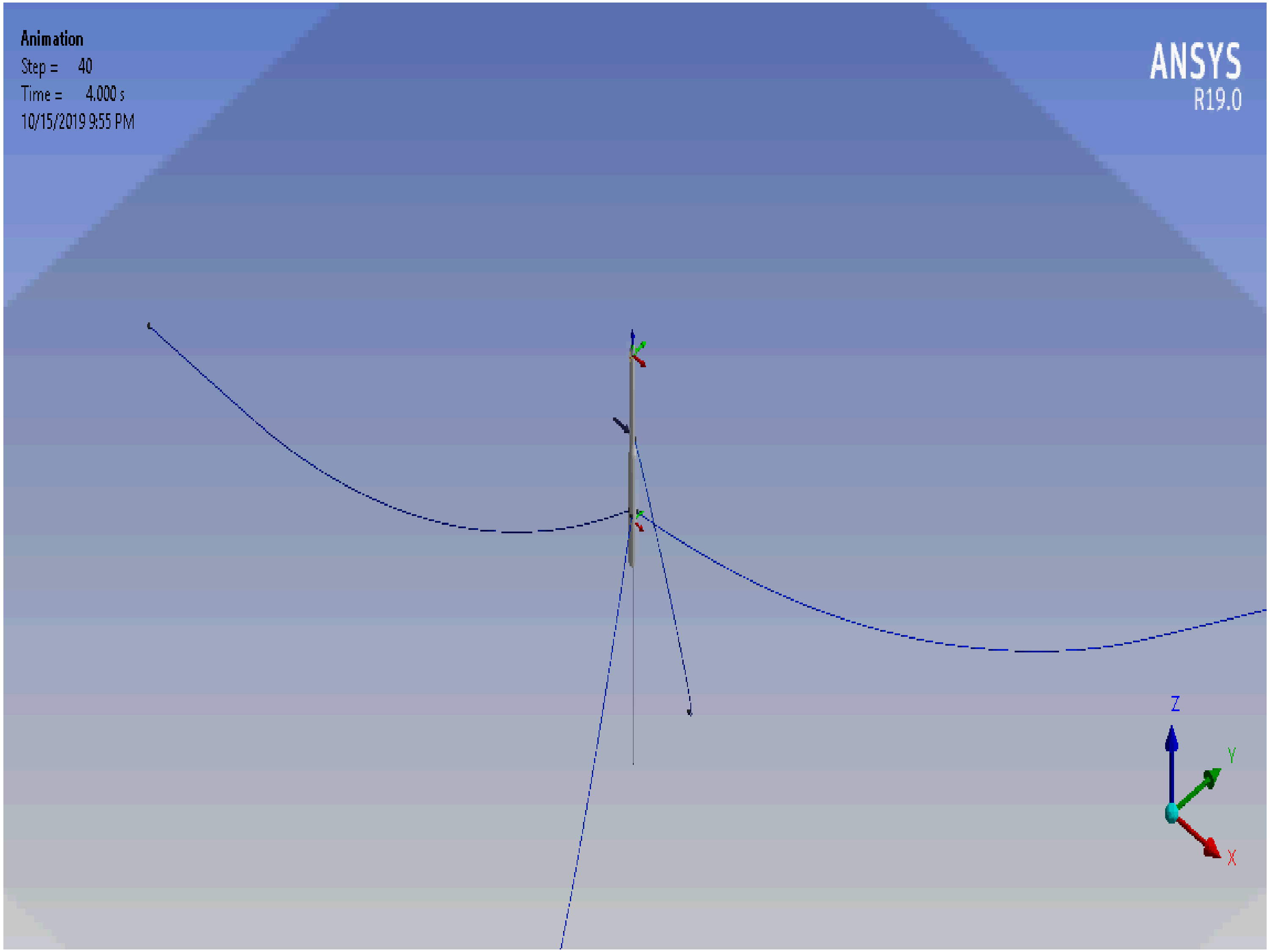
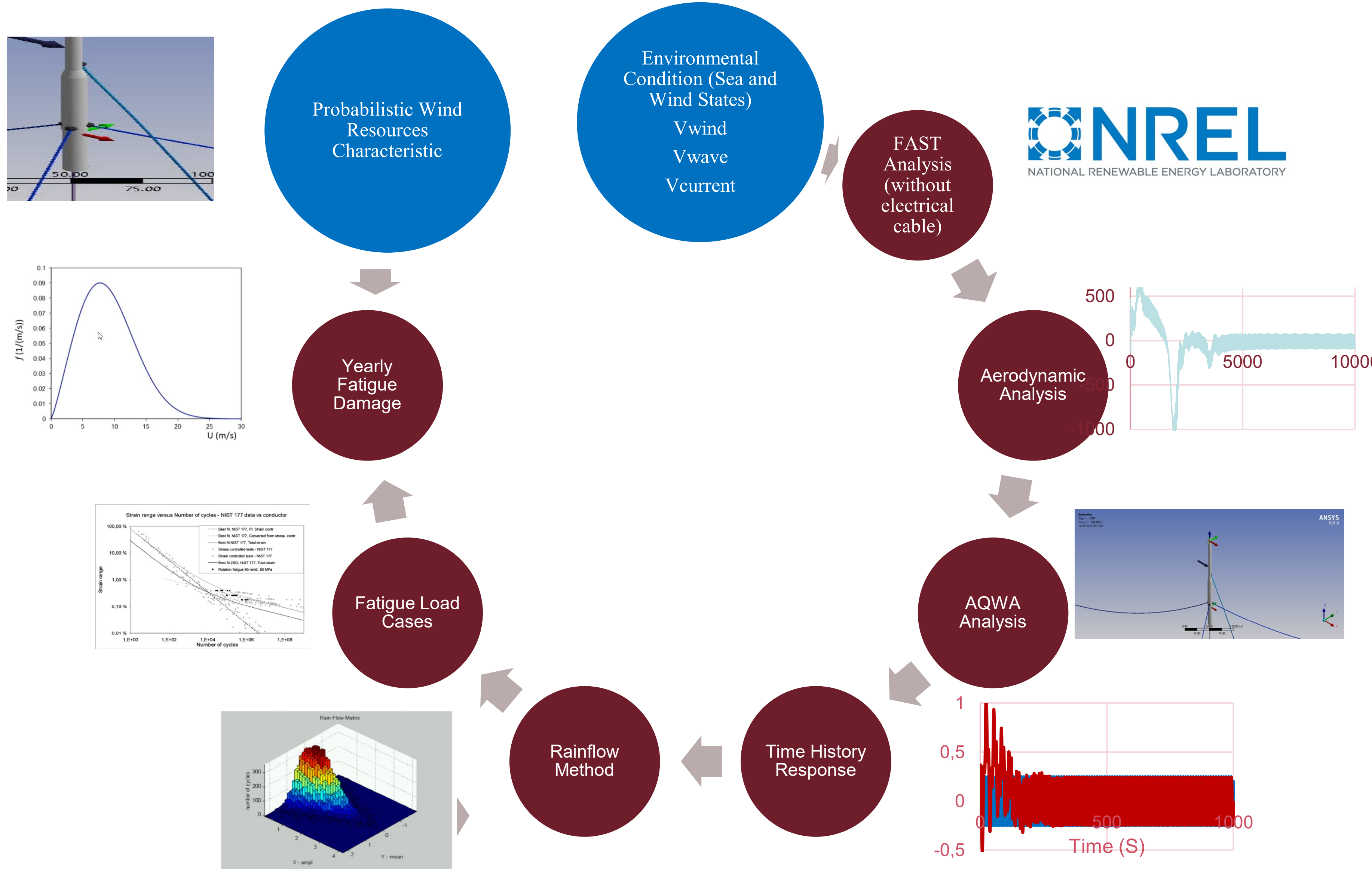


Figure 10. Jonkman Report Pitch

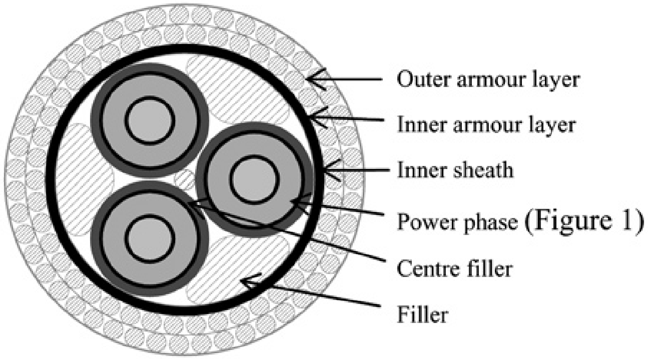
Part 3. Motion in Ansys AQWA



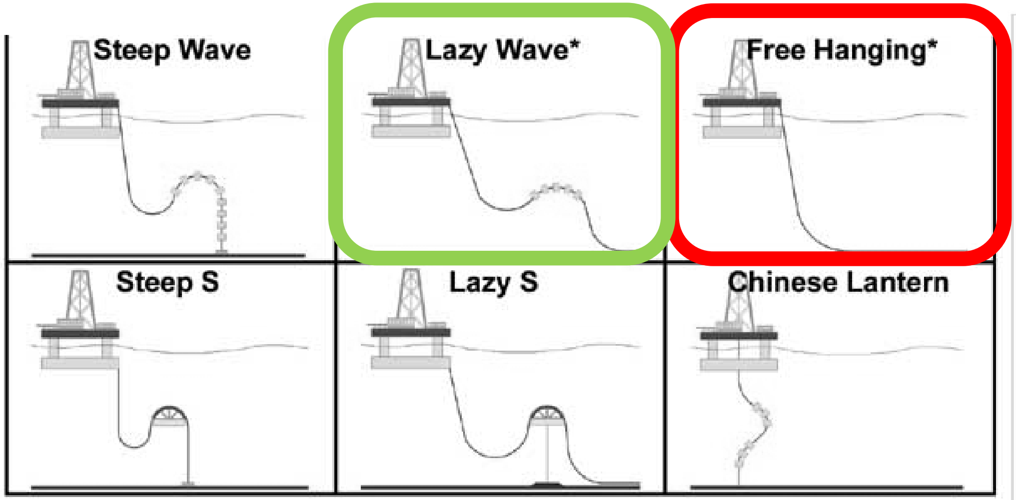
Part 4. Flowchart for fatigue analysis of electrical cable

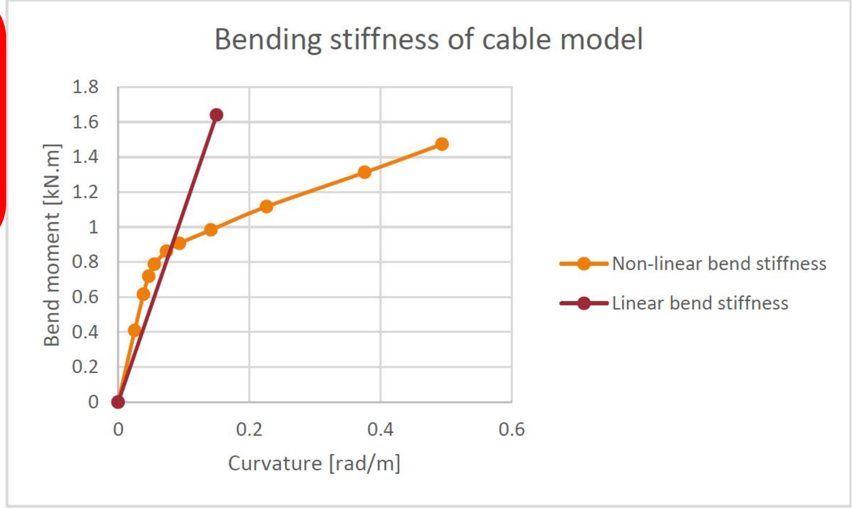


Part 4. Properties of Electrical Cable



Nominal outer Diameter (m)	0.121
Cross sectional Area (m^2)	0.0115
Weight in Sea water	16
Max Safe Load (N)	110,000
Stiffness (N)	50,000,000





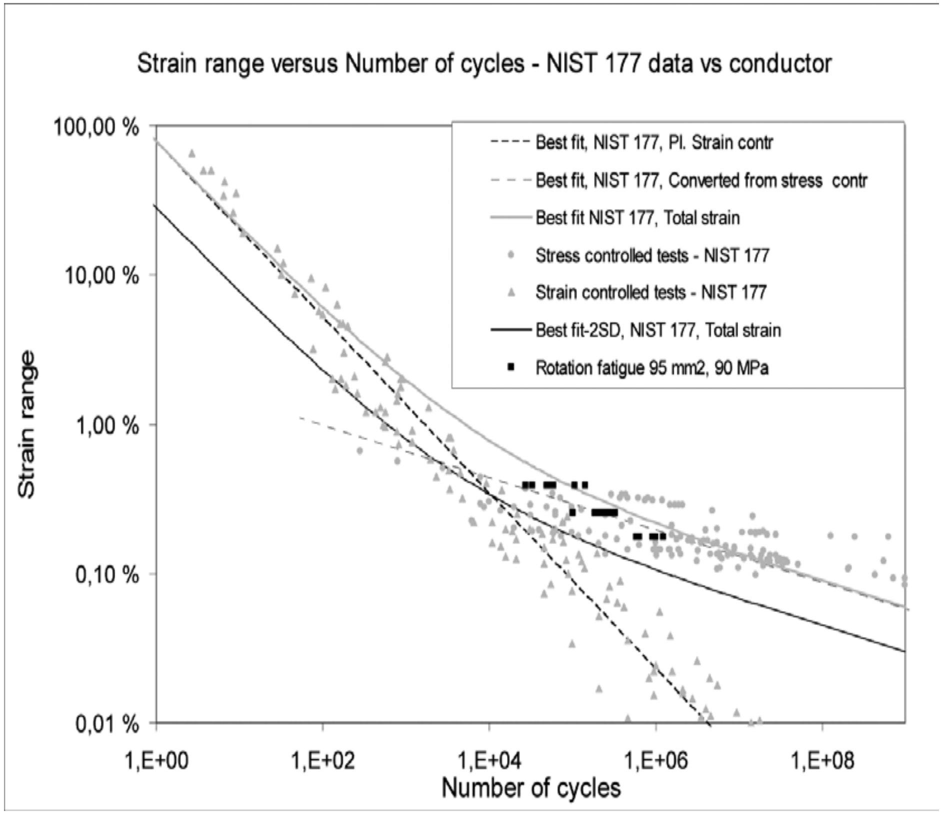
Standard flexible riser configurations for floating offshore structures

Part 4. Properties of Electrical Cable

Parameter of short-term sea state (South China Sea)

Sea State	Wind (m/s)	H (m)	T (s)	Cv (m/s)	P (%)
1	5.6	0.675	4	0.168	2.24096
2	6	0.675	5	0.180	8.68372
3	7	1.050	4	0.210	1.96084
4	7.80	1.050	6	0.234	14.006
5	8.5	1.550	4	0.255	1.4006
6	9	1.550	5	0.270	10.36444
7	9.40	1.550	6	0.282	20.16864
8	10.8	2.175	5	0.324	5.32228
9	11.2	2.175	6	0.336	15.4066
10	12	2.875	6	0.360	8.96384
11	13.2	3.625	6	0.396	3.08132
12	14.5	4	6	0.432	0.56024
13	15.0	4.5	7	0.450	3.64156
14	16.1	5	7	0.483	0.84036
15	16.7	4.5	10	0.501	0.84036
16	17.2	4.5	11	0.516	0.28012
17	17.4	5.5	10	0.522	0.56024
18	18	5.5	11	0.540	0.56024
19	19.1	6.750	10	0.573	0.84020
20	20	3.625	12	0.6	0.280

S – N Curve Used for Cable Section



Source: Karlsen, S., Slora, R, Heide, K., Lund, S. Eggertsen, F. and **Osborg, P.A.** Dynamic Deep Water Power Cables. 2009 RAO/CIS Offshore, pp.184-203.

Part 4. Cable tension in different sea states

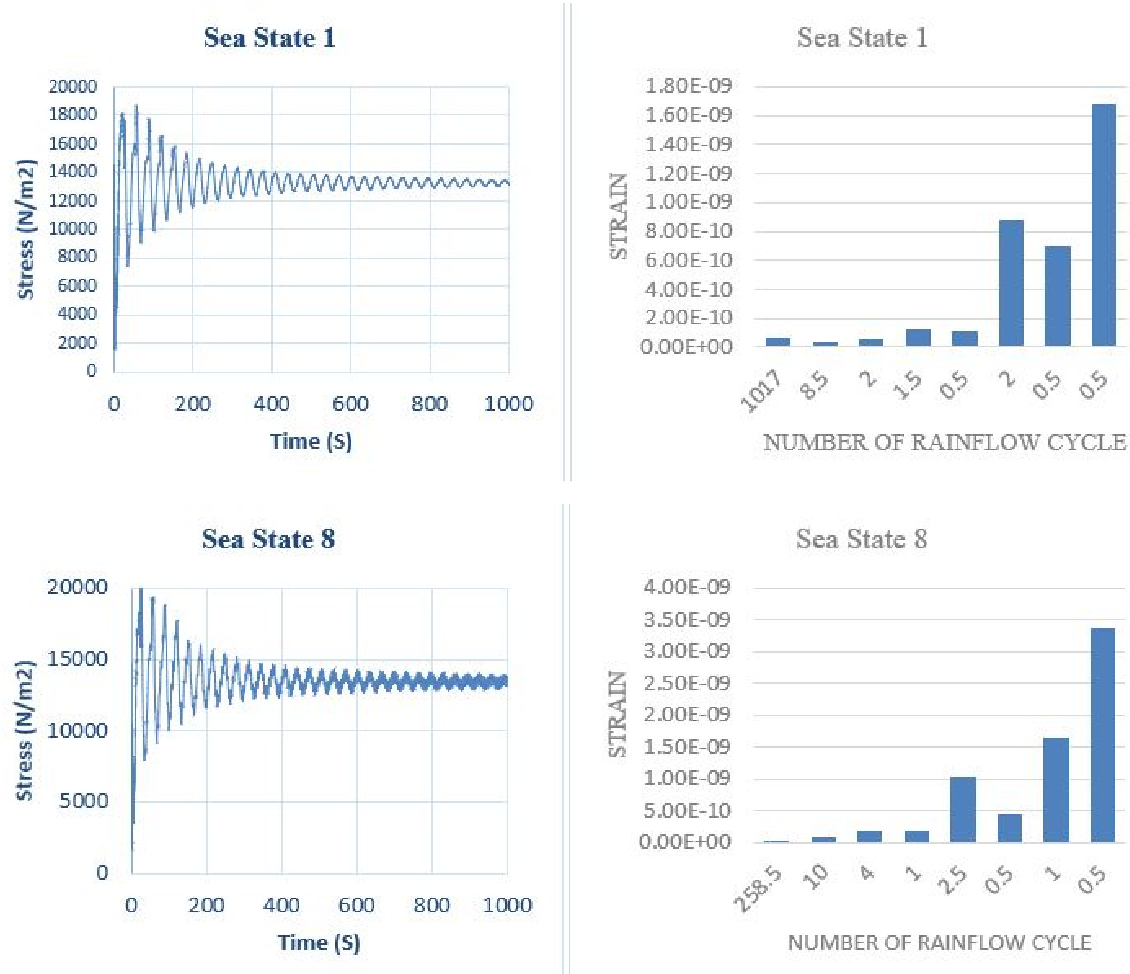
Tension (N)

$$\sigma = \frac{F}{A}$$

Stress

$$E = \frac{Stress}{Strain}$$

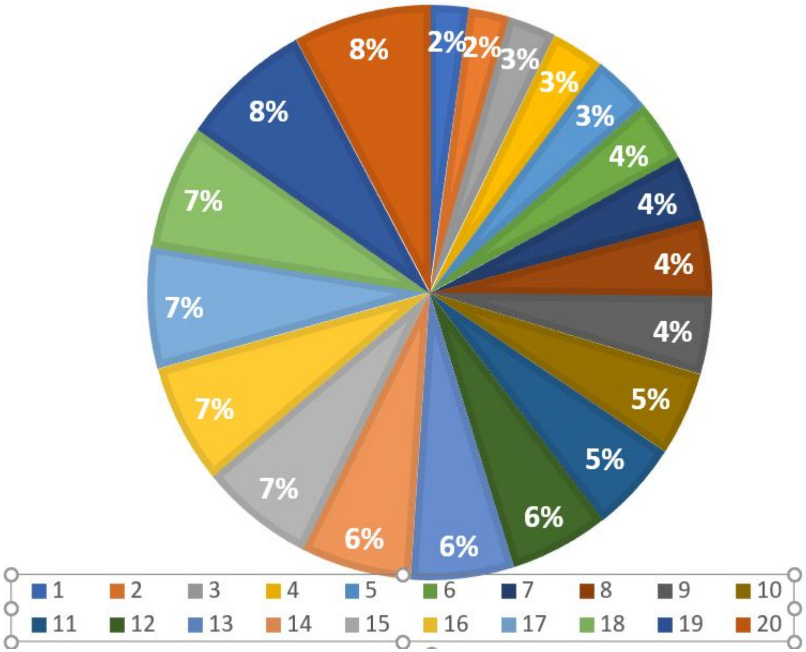
Strain



Stress Time History in Different Sea States and Rainflow Cycles

Part 4. Fatigue Life estimation

Vw (m/s)	total damage (1000 sec)	total damage (1 day)	P (%)	Yearly Damage
5.6	3.60407E-09	3.11392E-07	2.241	2.54703E-06
6	4.37E-09	3.77725E-07	8.6837	1.19722E-05
7	2.64145E-09	2.28221E-07	1.9608	1.63339E-06
7.8	3.95964E-09	3.42113E-07	14.006	1.74894E-05
8.5	1.87E-09	1.61391E-07	1.4006	8.2506E-07
9	3.9601E-09	3.42152E-07	10.364	1.29437E-05
9.4	5.12178E-09	4.42522E-07	20.169	3.25765E-05
10.8	6.85957E-09	5.92667E-07	5.3223	1.15133E-05
11.2	7.69934E-09	6.65223E-07	15.407	3.74082E-05
12	8.92858E-09	7.71429E-07	8.9638	2.52396E-05
13.2	1.01E-08	8.68329E-07	3.0813	9.76594E-06
14.5	1.06209E-08	9.17649E-07	0.5602	1.87648E-06
15	3.07823E-08	2.65959E-06	3.6416	3.53505E-05
16.1	1.74282E-08	1.5058E-06	0.8404	4.61876E-06
16.7	2.41503E-08	2.08658E-06	0.8404	6.4002E-06
17.2	2.81661E-08	2.43355E-06	0.2801	2.48816E-06
17.4	3.74334E-08	3.23425E-06	0.5602	6.61364E-06
18	5.1396E-08	4.44061E-06	0.5602	9.0805E-06
19.1	9.12866E-08	7.88716E-06	0.8402	2.41878E-05
20	3.61286E-08	3.12151E-06	0.28	3.19018E-06
Sum of yearly damage				0.000257721
Safety Factor				10
Lifetime				388 years



$$FD = \sum \frac{ni}{Ni}$$

Yearly Damage = P * Total Windy Days

In Process

- More Sea States and Different Seed Numbers
- Considering Bending Stiffness
- Modeling Lazy Wave Configuration for the cable

Future

- Using Irregular sea states

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Thanks for Your Attention