Case Study in Integrated Mooring & Cable Design and Its Importance to Feasibility of Floating Wind Farm Design in Shallow Water

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Agenda

- About 2H
- Introduction
- Inter Array Power Cable Design Requirements
- Cable Configuration Development Analysis Workflow
- Case Study
- Conclusions

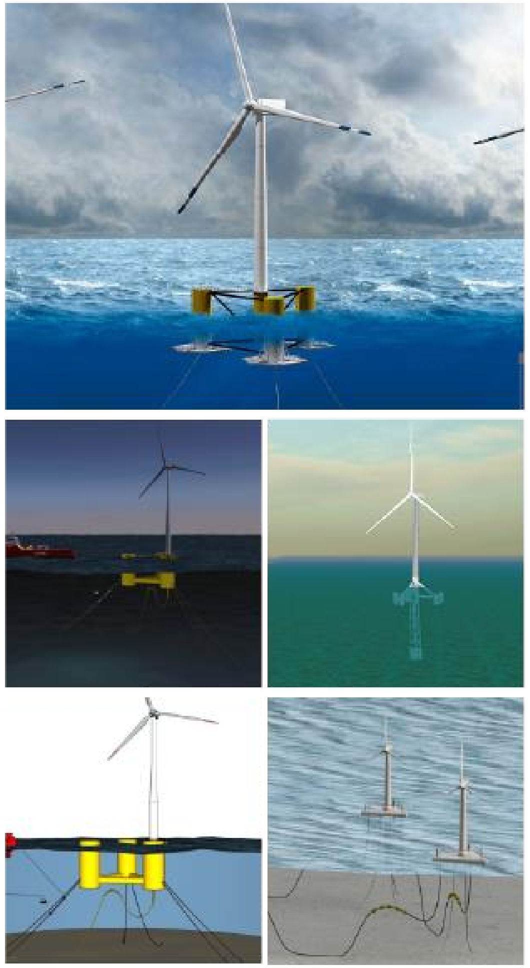
About 2H Offshore

Founded in 1993	300+ highly qualified engineers	Leader in marine structure dynamics	Renewable and decarbonization expertise	Independent technology driven company
Practical understanding of hardware and installation	Extensive experience in all riser types	International coverage	Seamless operations & procedures worldwide	Multi-disciplines

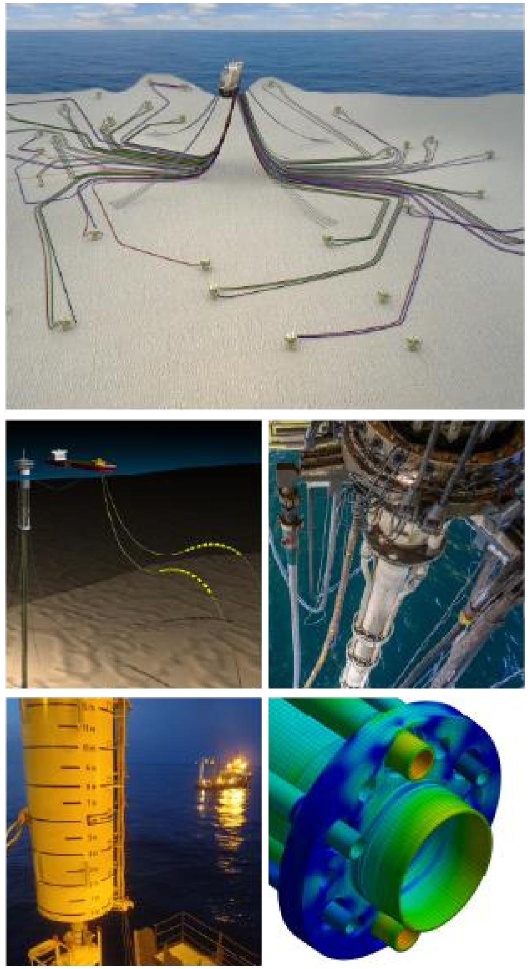
Principal Technical Offerings

Fixed Wind

Floating Wind



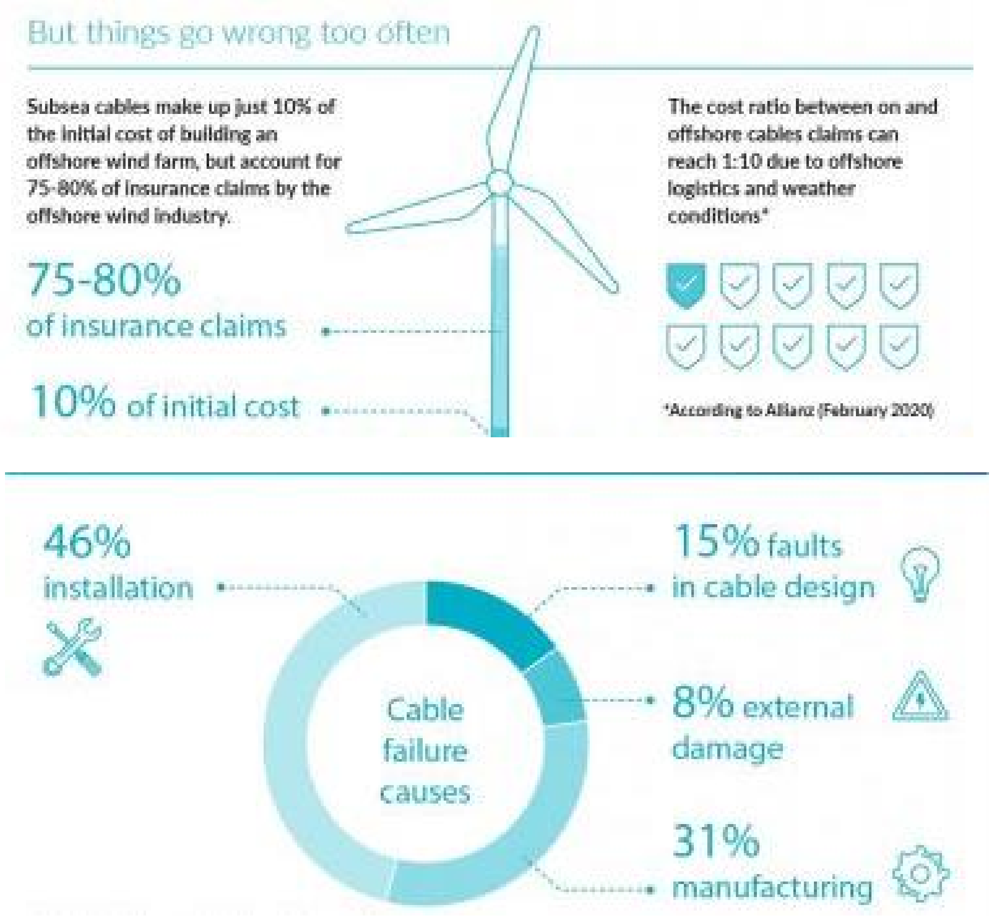
Risers and Pipelines



Fixed Platform

Introduction
Background

- 80% of Offshore Wind financial losses and insurance claims are attributed to power cable failures[1]
- Root cause: installation damage, manufacturing defects, **inadequate design** and external damage
- Most of these cables are static! Dynamic cables present a greater challenge.
- This presentation focus on integrated mooring & dynamic HV cable configuration development for shallow water floating wind



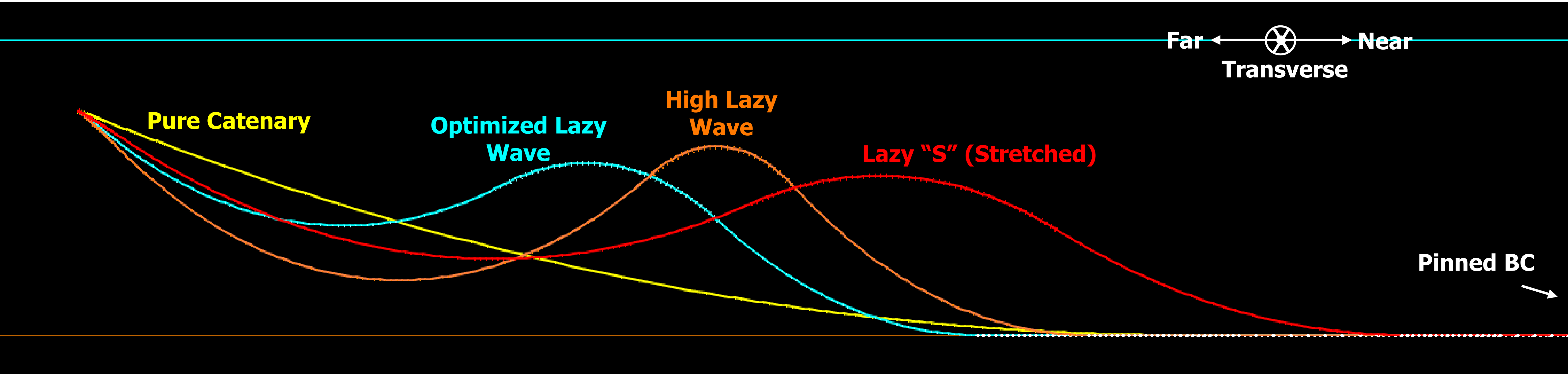
References:
[1] LLOYD Warwick International Offshore Wind Loss Adjusters Perspective, 28 April 2021, ORE Catapult
[2] https://ore.catapult.org.uk/stories/electrode/

Power Cable Design for Shallow Water
Design Requirements and Parameters

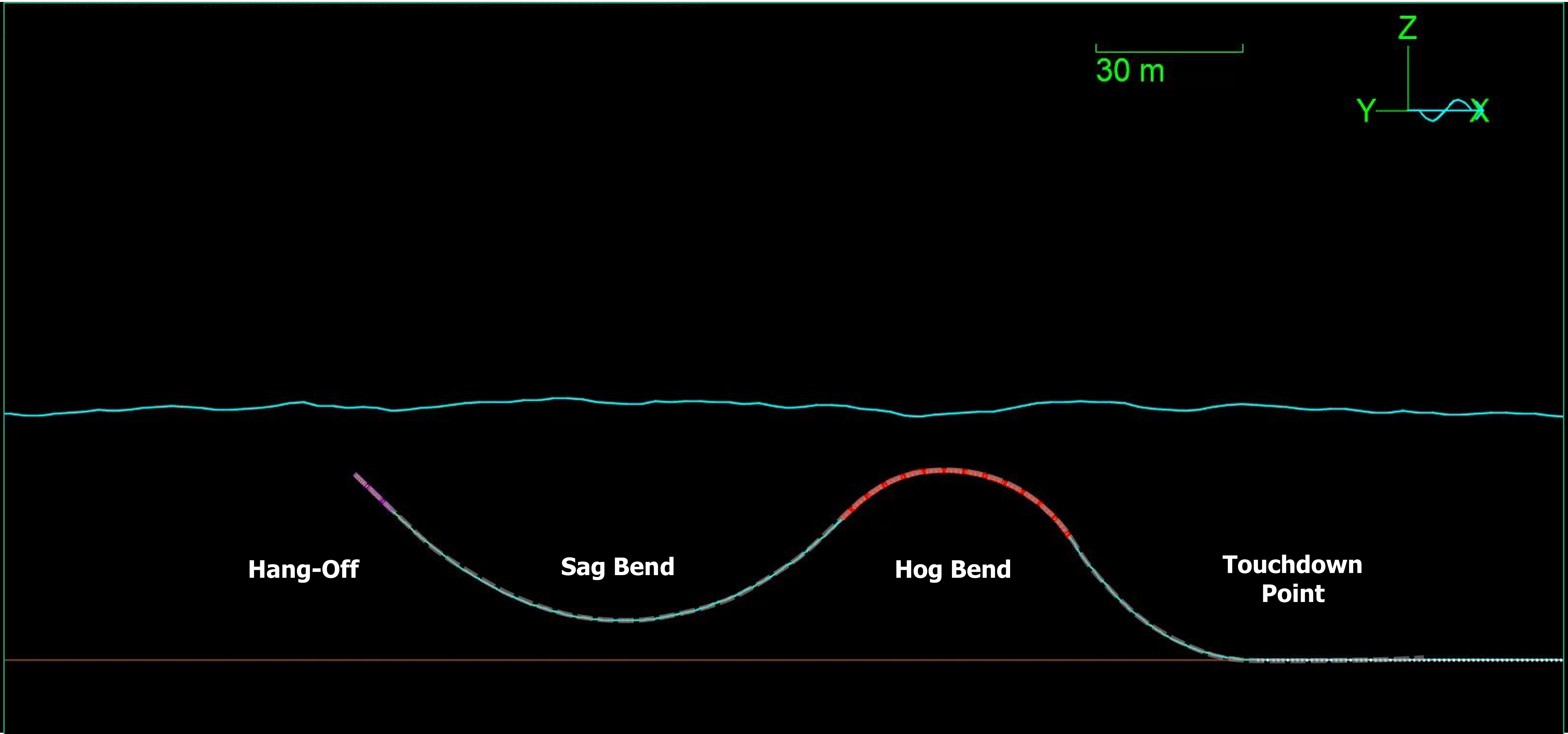
- **Power cable must accommodate harsh conditions:**
  - Large Floater lateral motions (~30% WD)
  - Floater dynamic rotations (~8-12deg)
  - High Wave Heights (~25m Hmax)
  - High currents (> 1.0m/s)
  - Marine Growth variation over life
- **Must still meet design requirements:**
  - Structural limits respected e.g. minimum bend radius (MBR), maximum tension, compression
  - Sag bend not to impact seabed
  - Hog bend to maintain sufficient clearance for vessel access
  - Minimizing compression
  - Minimizing seabed movement at touch down point
  - No clashing with adjacent structures (e.g. floater and mooring lines)

Power Cable Design for Shallow Water (<100m) Configuration Development

- **Typical findings in shallow water cable design:**
  - Many configurations to be considered to establish optimum design envelope
  - Pure catenary configuration not feasible - exceeds MBR at TDP, high compression, high tension
  - The distribution of buoyancy modules controls the shape of the lazy wave configuration (length, spacing, distance from hang-off)
  - High lazy wave (high arch, low sag) gives good compliance and smaller footprint but can compromise MBR (particularly in **near** conditions)
  - Lazy "S" (stretched) gives good response with near conditions, but can compromise tension (in **far** configuration) and has larger footprint
- **Final Optimised Configuration is selected based on based on a wide range of variation of top angle, section lengths and buoyancy modules as a compromise between competing parameters**



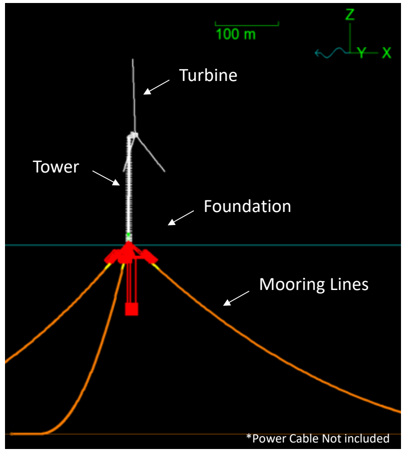
Power Cable Design for Shallow Water
Dynamic Behaviour – 50year Storm

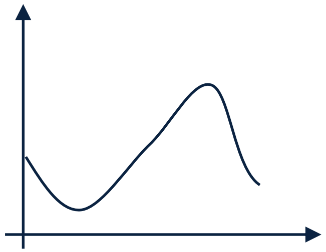


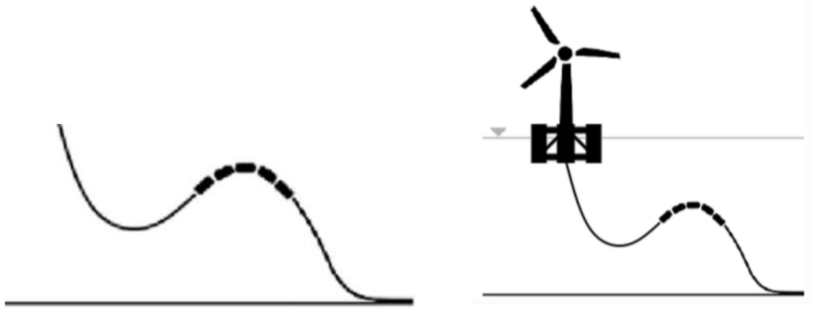
Cable Configuration Development Analysis Workflow

Iterations

Floater & Mooring Dynamic analysis → Motion Time-Traces Extracted at Power Cable Hang-Off → Governing load cases (LCs) Identified → Time-traces for Critical LCs Applied to Decoupled Cable Model → Decoupled Cable Model Assessed with reduced **Dynamic** LCM → Cable Configuration







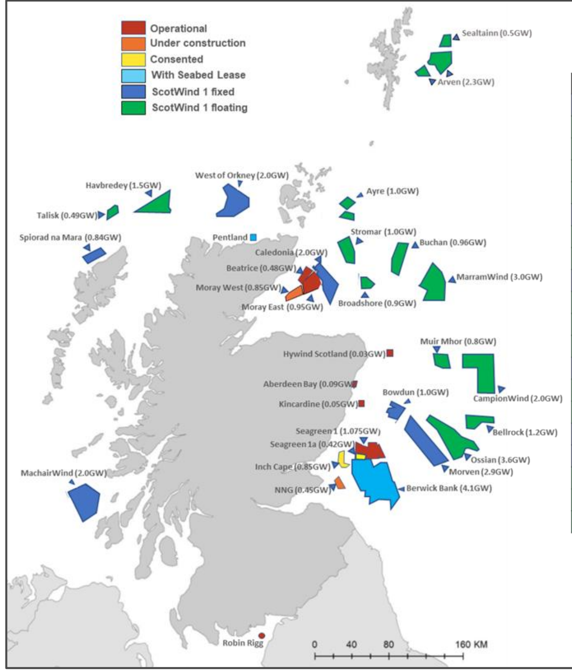
>> Cable design as part of a system

>> Iteration potentially inefficient as cable and mooring assessment decoupled

Case Study
ScotWind Wind Farm

Case Study Description

- 20MW Semi-submersible Floater
- Metocean (typical North Sea)
- 6-line **Catenary** Mooring System (3x2)
  - Comparison with 6-line Taut Mooring System (3x2)
- Water Depth: 65m
- 66kV Cable with conductor Cross Section of 1200mm^2
- Cable Configuration: Untethered Lazy wave
- Cable assessed in Start of Life (SOL) & End of Life (EOL) conditions



ScotWind Round

SITE	DEVELOPERS	CAPACITY
Morven	BP and EnBW	2,907MW
Ossian	SSE Renewables, CIP and Marubeni	3,610MW
Bellrock	BlueFloat Energy¦ Renantis Partnership	1,200MW
CampionWind	ScottishPower Renewables and Shell	2,000MW
Muir Mhor	Vattenfall and Fred Olsen Renewables	798MW
Bowdun	Thistle Wind Partners	1,008MW
Ayre	Thistle Wind Partners	1,008MW
Stromar	Orsted and BlueFloat Energy¦ Renantis Partnership	1,000MW
Caledonia	Ocean Winds	2,000MW
Broadshore	BlueFloat Energy¦ Renantis Partnership	900MW
MarramWind	ScottishPower Renewables and Shell	3,000MW
Buchan	Floating Energy Allyance	960MW
West of Orkney	RIDG, Corio Generation and TotalEnergies	2,000MW
Havbredey	Northland Power	1,500MW
Talisk	Magnora Offshore Wind	495MW
Spiorad an Mara	Northland Power	840MW
MachairWind	ScottishPower Renewables	2,000MW
Arwen 1a	Mainstream RP and Ocean Winds	500MW
Arwen	Mainstream RP and Ocean Winds	1,800MW
Sealtainn	ESB Asset Management	500MW

Total = 30,026MW
Floating Wind = 19,271MW (64%)

Case Study - Load Case Matrix (Strength Analysis)

- Strength DNV LC 6.1 Parked Turbine
- Omni-directional environmental loads assessed: 0deg to 360deg

DNV Load Case	DNV Analysis Condition	Limit State	Wind	Waves		Current (2)	Environmental Direction
6.1	Parked Turbine	ULS	50 Year [m/s]	Hs [50-yr]	Tp [50-yr]	50 Year [m/s]	(deg)
6.1	Parked Turbine	ULS	43.1	10.5	14.8	1.34	0 to 360

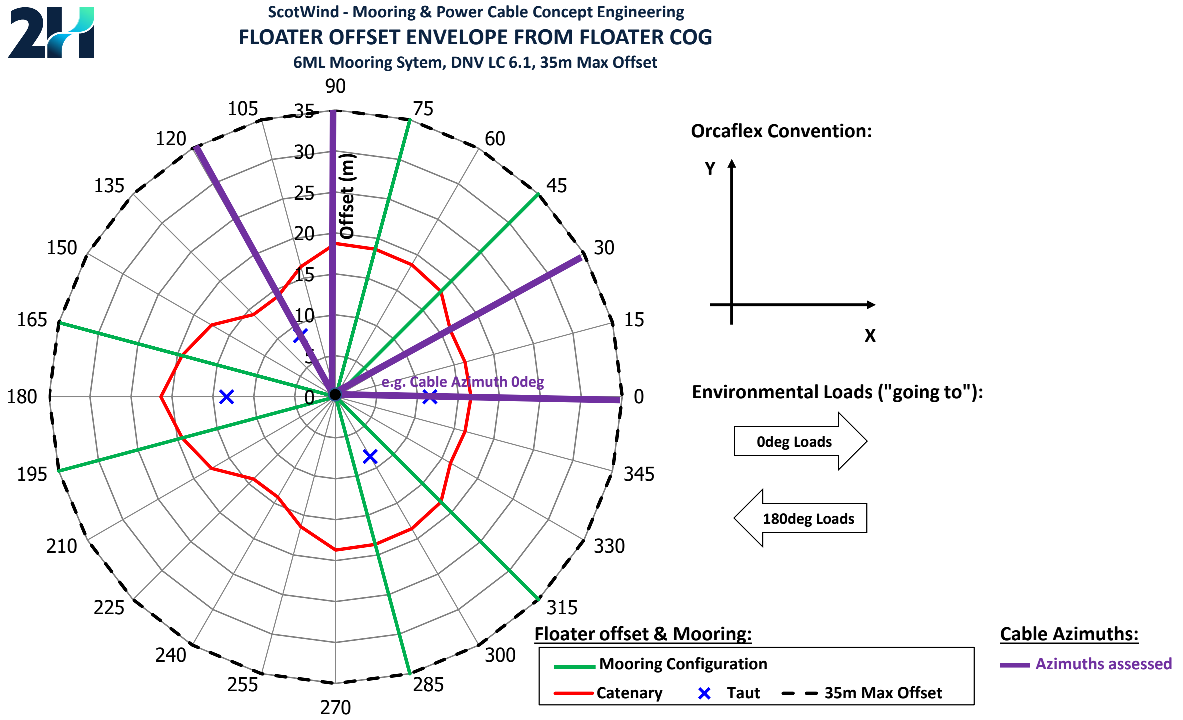
1/ Wind speed is defined as 1-hour average at 155m elevation

2/ Current speed at Near-surface

Case Study - Cable Design Criteria (Strength Analysis)

- Minimum bend radius (MBR) > 3.0m
- Maximum tension < 600kN
- SAG bend to remain off seabed with 3.0m clearance
- HOG bend to maintain sufficient clearance for vessel access
    - at this stage 10.0m clearance is assumed relative to the still water level regardless of the waves
- Maximum compression of 10% of the cable working limit is assumed
- No lateral buckling in TDZ

Case Study - Feasible Mooring Designs
Offset Envelope measured from Floater CoG



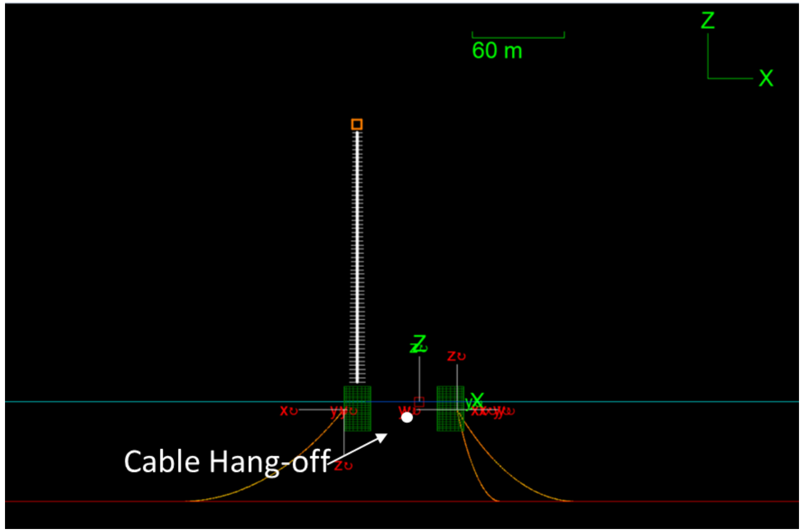
- Cable Azimuths Assessed:
  - 0deg
  - 30deg
  - 90deg
  - 120deg
- Maximum Floater Offset (180deg):

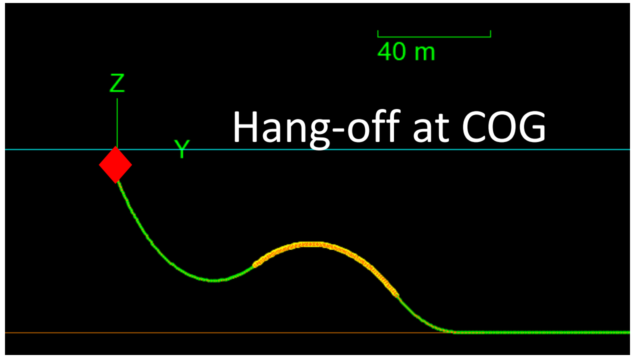
Mooring Type	Max. Floater Offset	
	(m)	(%)
Catenary	21.3	32.8%
Taut	13.3	20.5%

>> Feasible mooring systems design envelope developed based on mooring performance, anchor options and other parameters

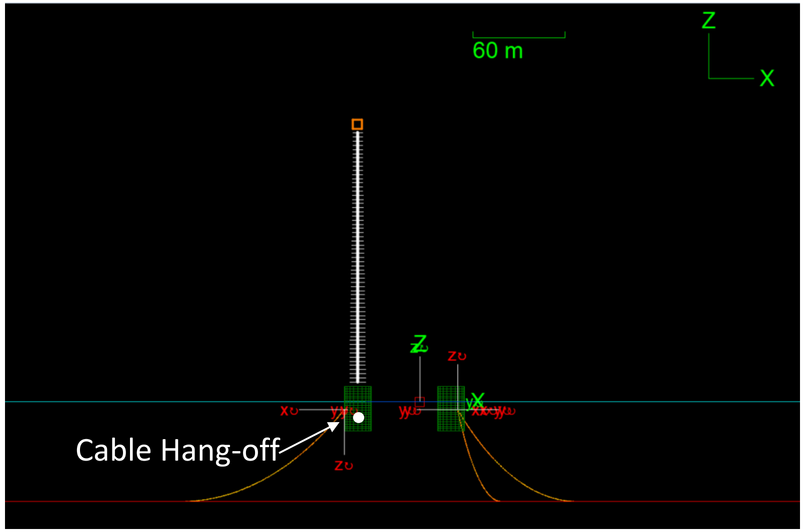
Cable Hang-off Position

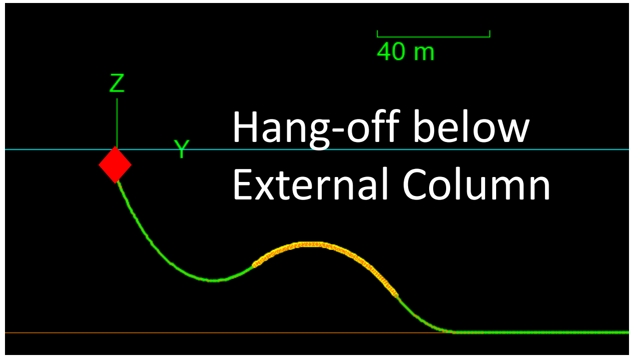
- Floater Centre (10m below MSL)





- External Column (10m below MSL)





>> Cable nominal configuration (without environmental loads) is the same regardless of the hang-off position

Cable Strength Results
Cable Hang-off at Floater Centre

Cable Cross Section	Cable Azimuth (deg)	Summary of Dynamic Results, Catenary Mooring System – DNV LC 6.1 (SOL & EOL) (All Environmental Directions Assessed, 65m Water Depth)				
		Maximum Tension (kN) >600kN	Minimum Tension (kN) >-60kN	MBR (m) >3.0m	SAG Clear. (m) >3.0m	HOG Clear. (m) >10.0m
Hang-off at Floater Centre (COG)						
1200mm^2	0	633.3 (1.06)	-4.6 (0.08)	2.5 (1.20)	8.9	14.0
	30	360.7 (0.60)	-11.0 (0.18)	2.5 (1.20)	3.1	14.6
	90	383.4 (0.64)	-4.4 (0.07)	2.6 (1.15)	8.9	14.8
	120	517.7 (0.86)	-4.1 (0.07)	2.8 (1.07)	8.9	15.4

>> Feasible cable design configuration based on design criteria

Legend:
- Within design criteria (Pass)
- Slightly outside design criteria
- Not within design criteria (Fail)

Cable Strength Results
Cable Hang-off at Floater Centre vs External Column

Cable Cross Section	Cable Azimuth (deg)	Summary of Dynamic Results, Catenary Mooring System – DNV LC 6.1 (SOL & EOL) (All Environmental Directions Assessed, 65m Water Depth)				
		Maximum Tension (kN) >600kN	Minimum Tension (kN) >-60kN	MBR (m) >3.0m	SAG Clear. (m) >3.0m	HOG Clear. (m) >10.0m
Hang-off at Floater Centre (COG)						
1200mm^2	0	633.3 (1.06)	-4.6 (0.08)	2.5 (1.20)	8.9	14.0
	30	360.7 (0.60)	-11.0 (0.18)	2.5 (1.20)	3.1	14.6
	90	383.4 (0.64)	-4.4 (0.07)	2.6 (1.15)	8.9	14.8
	120	517.7 (0.86)	-4.1 (0.07)	2.8 (1.07)	8.9	15.4
Hang-off below External Column						
1200mm^2	0	446.2 (0.74)	-5.5 (0.09)	2.5 (1.20)	3.8	17.0
	30	284.1 (0.47)	-28.6 (0.48)	2.9 (1.03)	4.7	15.5
	90	3433.4 (5.72)	-388.4 (6.47)	2.7 (1.11)	2.4	15.0
	120	3921.7 (6.54)	-444.5 (7.41)	2.4 (1.25)	2.7	16.8

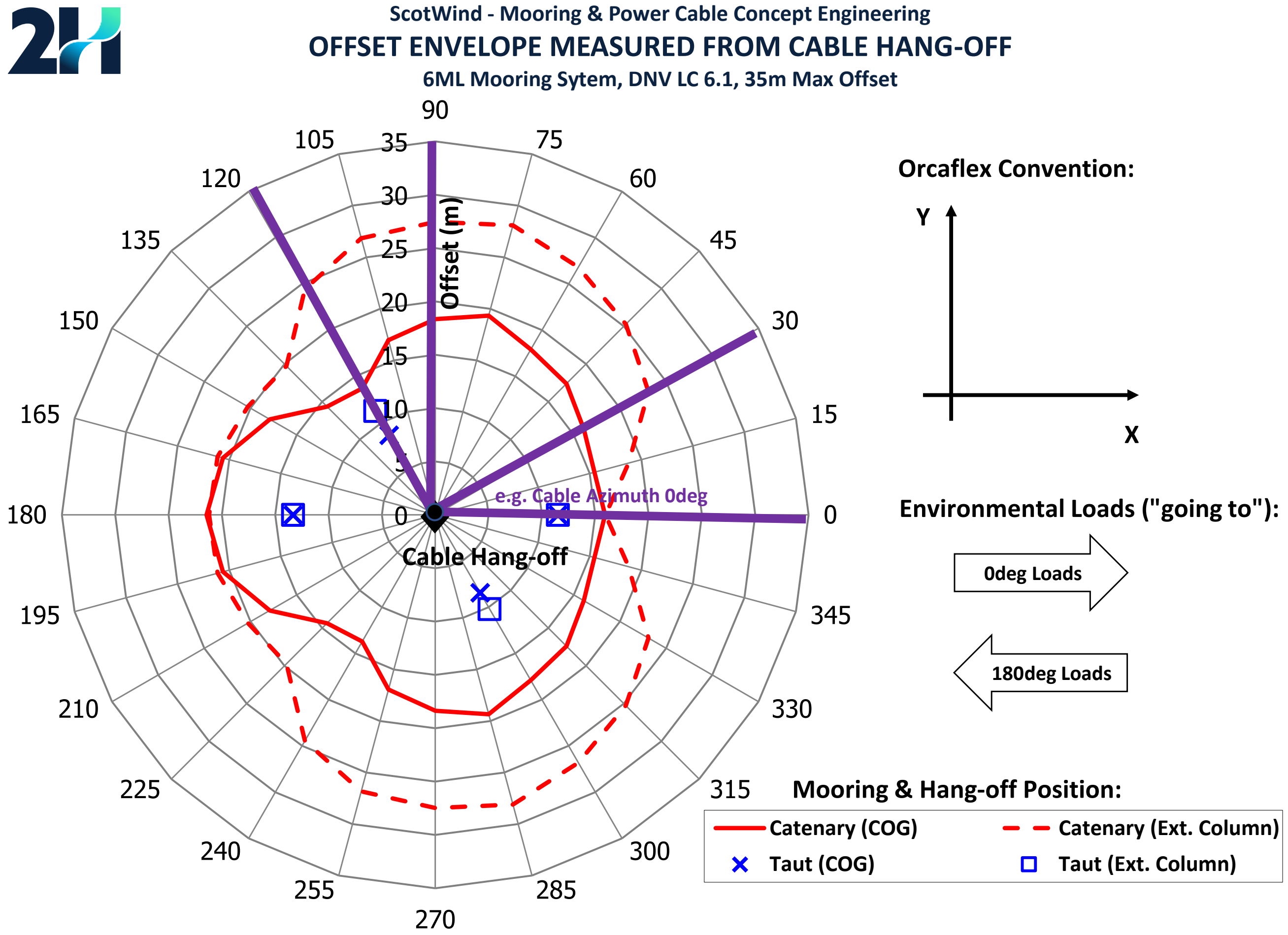
>> Maximum and minimum tension at cable for azimuths 90deg and 120deg are not within design criteria

>> Why does the hang-off position of the cable have such a great impact on the results?

Legend:

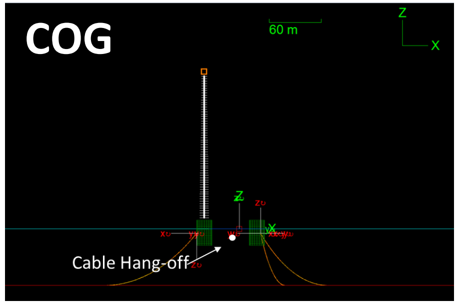
- Within design criteria (Pass)
- Slightly outside design criteria
- Not within design criteria (Fail)

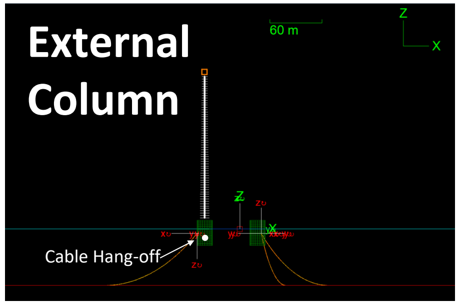
Cable Strength Results
Offset Envelope Comparison



Cable Azimuths:
Azimuths assessed

Hang-offs



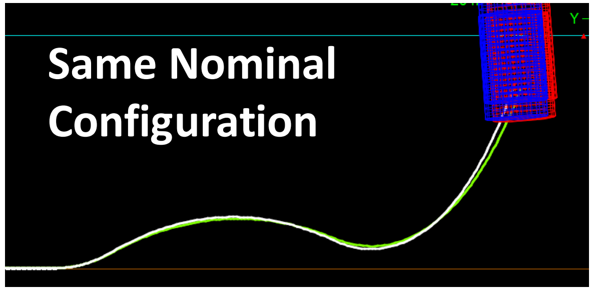


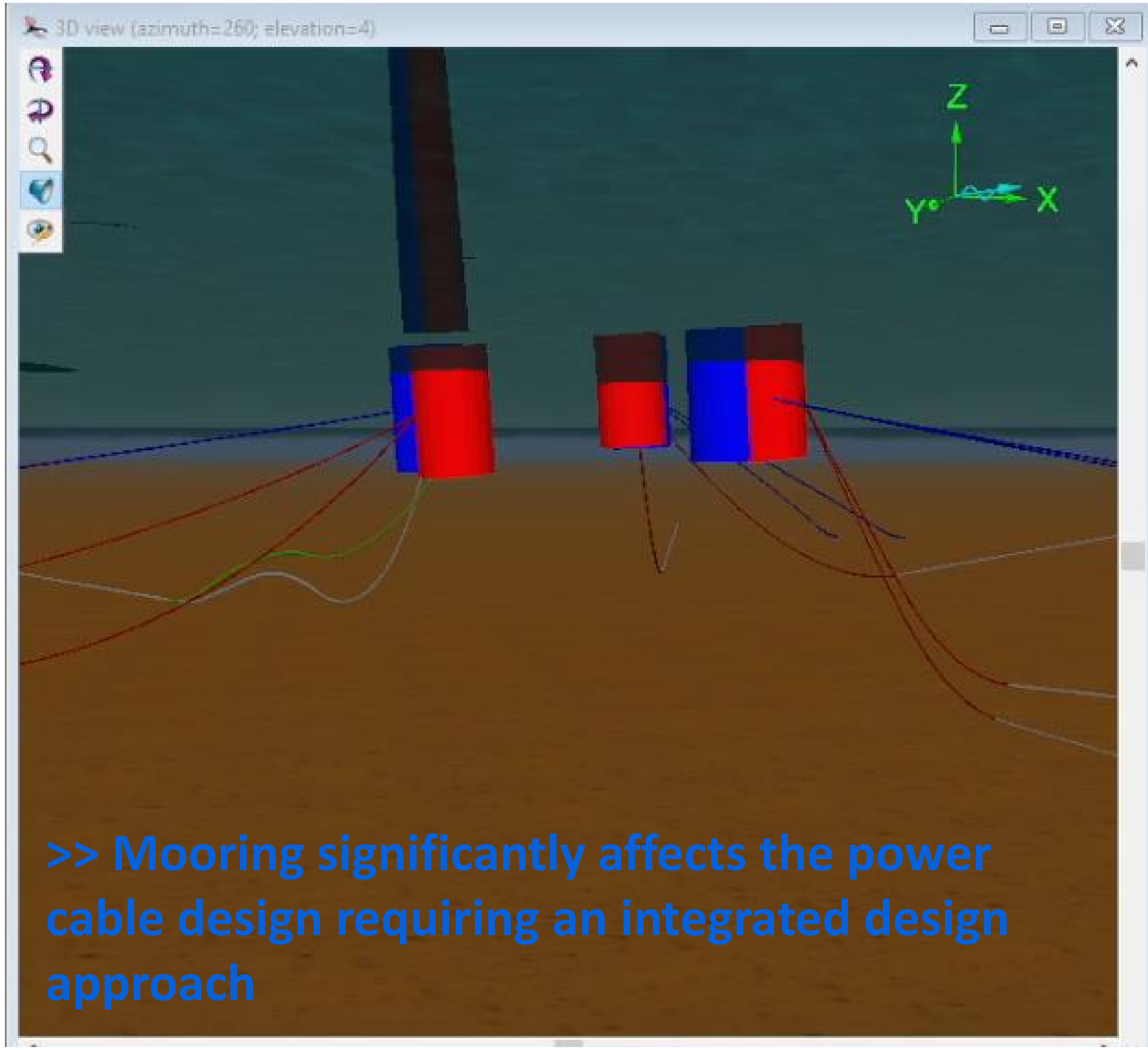
Effect of yaw on excursion at cable hang-off (120deg heading):

Mooring Type	Floater Centre (COG)	External Column
Catenary	+0m	+10.7m
Taut	+0m	+2.6m

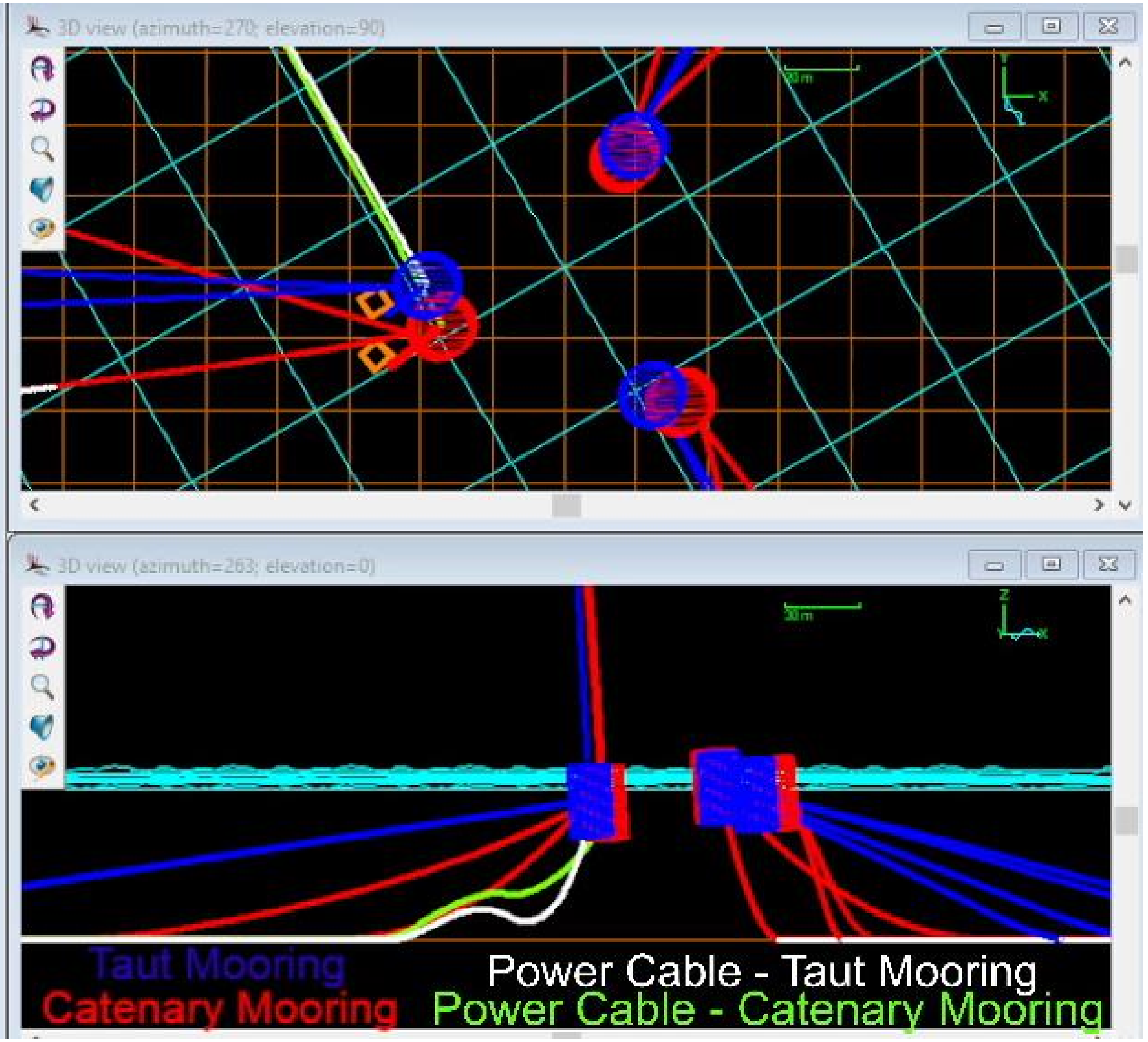
>> Motions at cable hang-off are sensitive to location, heading and mooring type **due to floater yaw**

Cable Strength Results
Offset Envelope Comparison





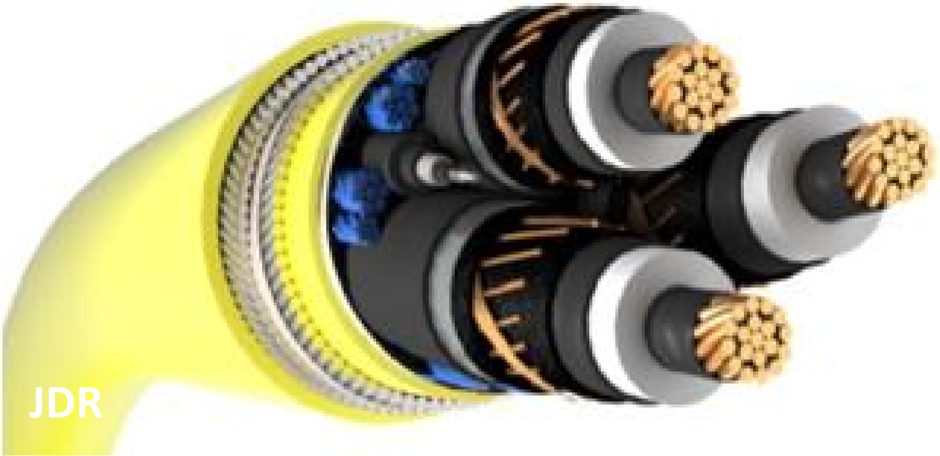
>> Mooring significantly affects the power cable design requiring an integrated design approach



Conclusions

Conclusions

- Power cables are leading cause of failures in Offshore Wind
- Engineering needed to reduce failure rates and maximize operability for dynamic cables
- The configuration of the dynamic power cable is unique to:
  - Floater type,
  - **Floater Hang-off location**
  - **Mooring system design**
  - Water depth
  - Metocean conditions



- For the case study:
  - Floater maximum offset and motions with feasible taut mooring system reduces in comparison with feasible catenary mooring
  - Cable hang-off position and mooring design have an impact on cable excursion
  - Large excursion leads to infeasible cable design
- **Mooring design and cable design must be integrated together to achieve feasible system design**

THANK YOU

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Questions?

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THANK YOU

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