

Floating Wind Solutions

Moorings and Power Cables for US West Coast Deep Waters

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Quest Offshore

The logo for FWS, featuring a stylized blue wind turbine icon to the left of the letters "FWS" in a white, sans-serif font.

FWS

The Marriott Marquis, Houston 1-3 March 2022

Challenges for Mooring and Power Cable Configurations for Deep Waters FOWTs

- Moorings

- Adopted synthetic ropes to minimize chain usage to lower costs and weight to lower the levelized cost of energy (LCOE)
- Large footprint on the seabed, more sensitive to mooring hang-off angle
- Large offsets with failed mooring conditions, possible collision with neighboring FOWTs and possible power cable failure

- Power Cable

- High tension requirements near hang-off
- Long dynamic power cable lengths
- Design for larger foundation offsets
- Opportunity for suspended inter array cables for a lower LCOE

Mooring Configurations for US West Coast Deep Waters

Mooring Design Premise

- Taut mooring configurations for a 15MW FOWT
- Polyester and Nylon Synthetic Ropes
- Water Depth 1,000 m
- Mooring Design Conditions – 50yr Extreme, Parked

Turbine Status	Parked
IEC Design Load Case	6.1
Return Period	50 year
Wind Speed (m/s)	38
Hs (m)	12.5
Tp (s)	20
Surface Current Speed (m/s)	0.5

- Mooring Strength Utilization < 0.95 , DnV-ST-0119
Consequence Class 1 $>$ No collision with adjacent structures

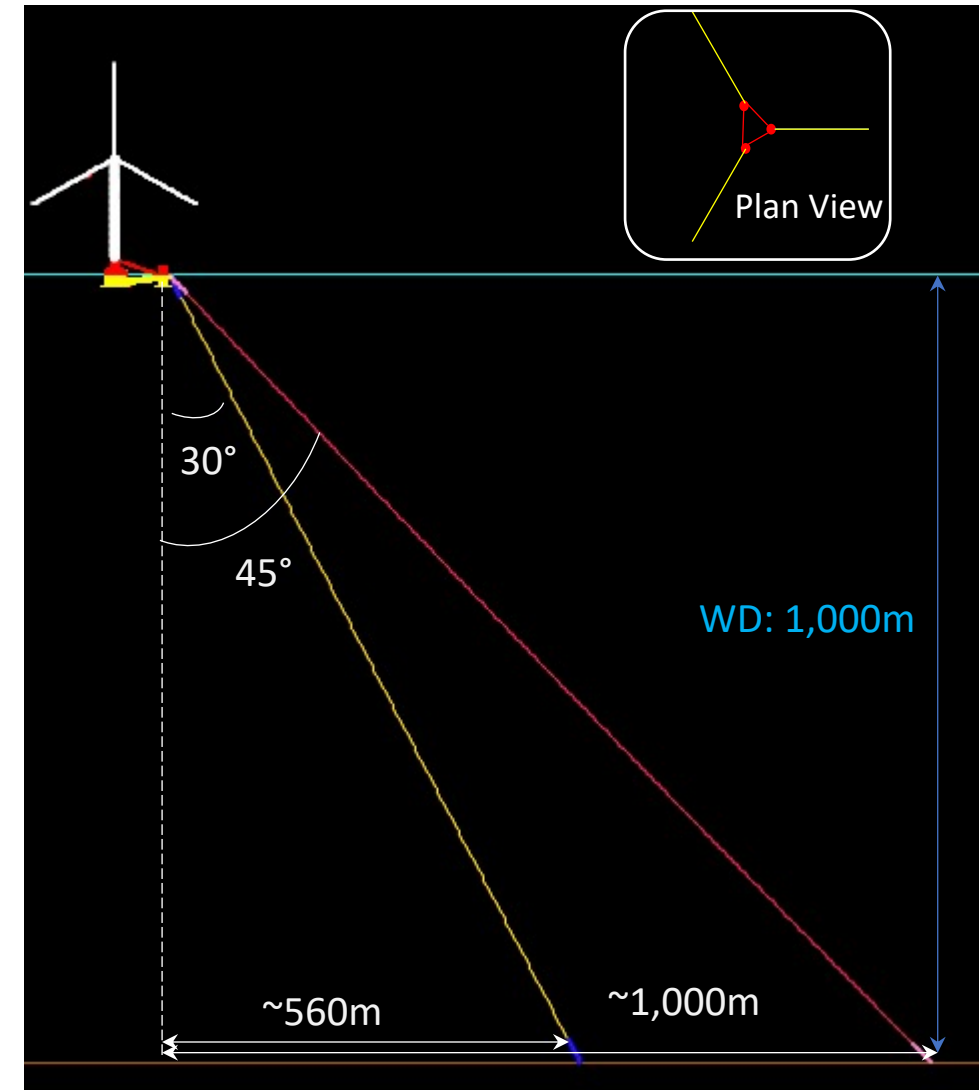


NREL/TP-5000-77411 – Oct, 2020

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Taut Mooring Configurations

- 15MW semi-submersible floating foundation
- Focused on taut to minimize cost and footprint
- 3 – leg mooring systems (base case) with 120-degree separations
- Top and bottom chains for hull and anchor connections
- Polyester and nylon synthetic ropes
- Mooring hang-off angle 30 to 45 degrees
- Fairlead to anchor distance 560 to 1,000 meters
- Mooring pre-load 10% to 30% of MBL



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Polyester Rope Mooring Configurations

Taut Polyester Mooring	Rope Minimum Breaking Load	Rope Preload	Hang-off Angle	Strength Utilization DnV-ST-0119	Max Offset	Max Tension at Anchor	Max Angle at Anchor
	Te	% MBL	Degree	-	m	kN	°
Configuration 1	2,500*	20	30	99%	48.1	15,651	61.8
Configuration 2	2,500	10	30	89%	60.5	13,754	61.1
Configuration 3	2,500	20	45	91%	37.1	14,256	45.2
Configuration 4	2,000	10	45	79%	49.8	9,675	44.6

* It is possible to further reduce polyester strength requirement with further project specific refinements such as increased hang-off angle

*Industry limit is around 2,500Te due to chain size limits

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Nylon Rope Mooring Configurations

Taut Nylon Mooring	Rope Minimum Breaking Load	Rope Preload	Hang-off Angle	Strength Utilization DnV-ST-0119	Max Offset	Max Tension at Anchor	Max Angle at Anchor
	Te	% MBL	Degree	-	m	kN	°
Configuration 1	2,500	10	45	47%	111.4 ¹	7,717	60.8
Configuration 2	2,500	25	45	67%	63.8	11,384	63.8
Configuration 3	1,500	30	45	80%	57.9	8,270	45.9
Configuration 4	1,500	30	30	96%	84.3	9,779	64.7
Configuration 5	1,000	20	45	81%	99.0	5,499	44.0

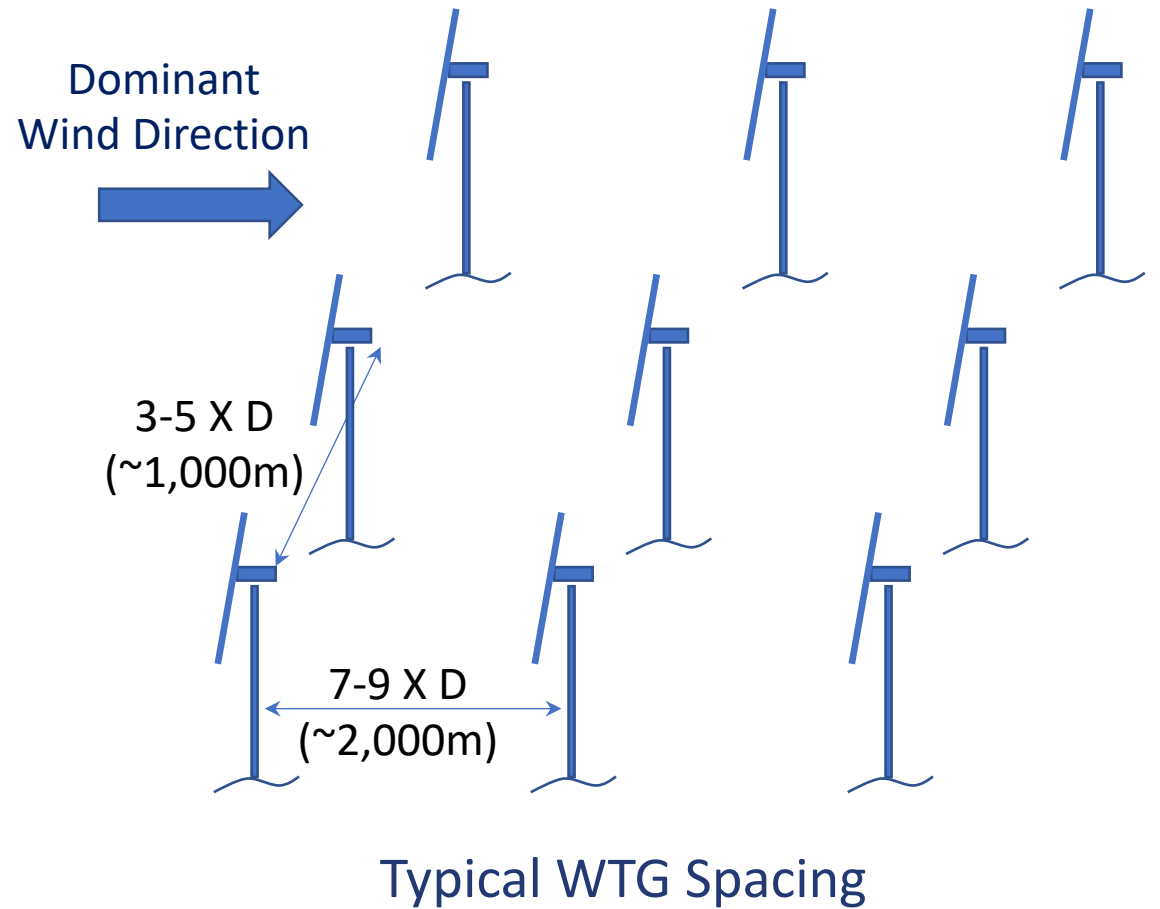
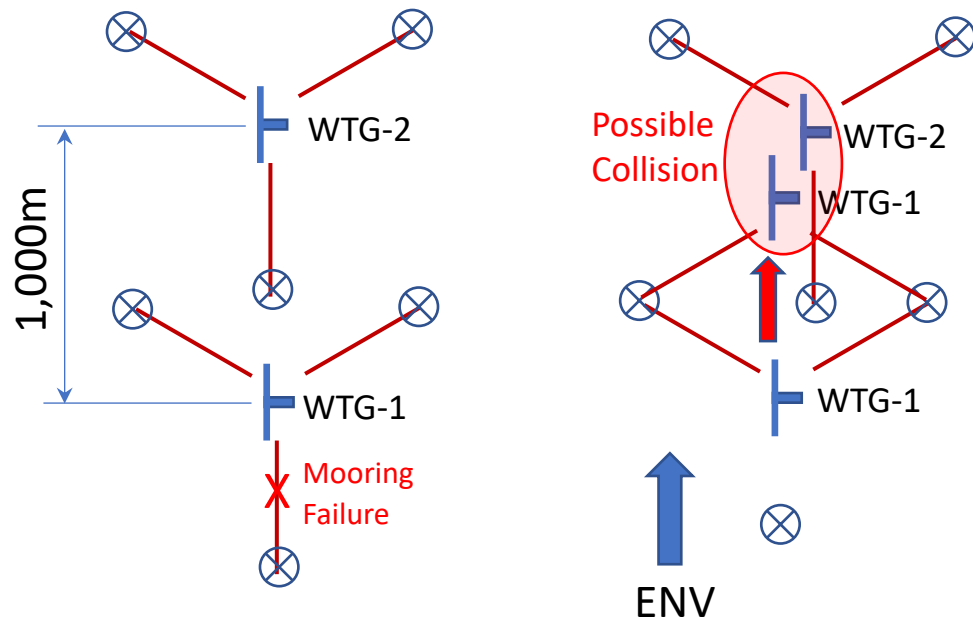
1: Slacking on the mooring line is observed

*Nylon is approximately 3 times less stiff than polyester for the same MBL

Mooring Redundancy and Turbine Spacing

Deep Water - Failed Mooring Line Scenario for 3-line Mooring Configuration

- Assuming $\sim 4 \times$ Rotor Diameter (D) spacing between WTGs
- $4 \times D = 1,000\text{m}$ (NREL's 15MW, $D = 240\text{m}$)



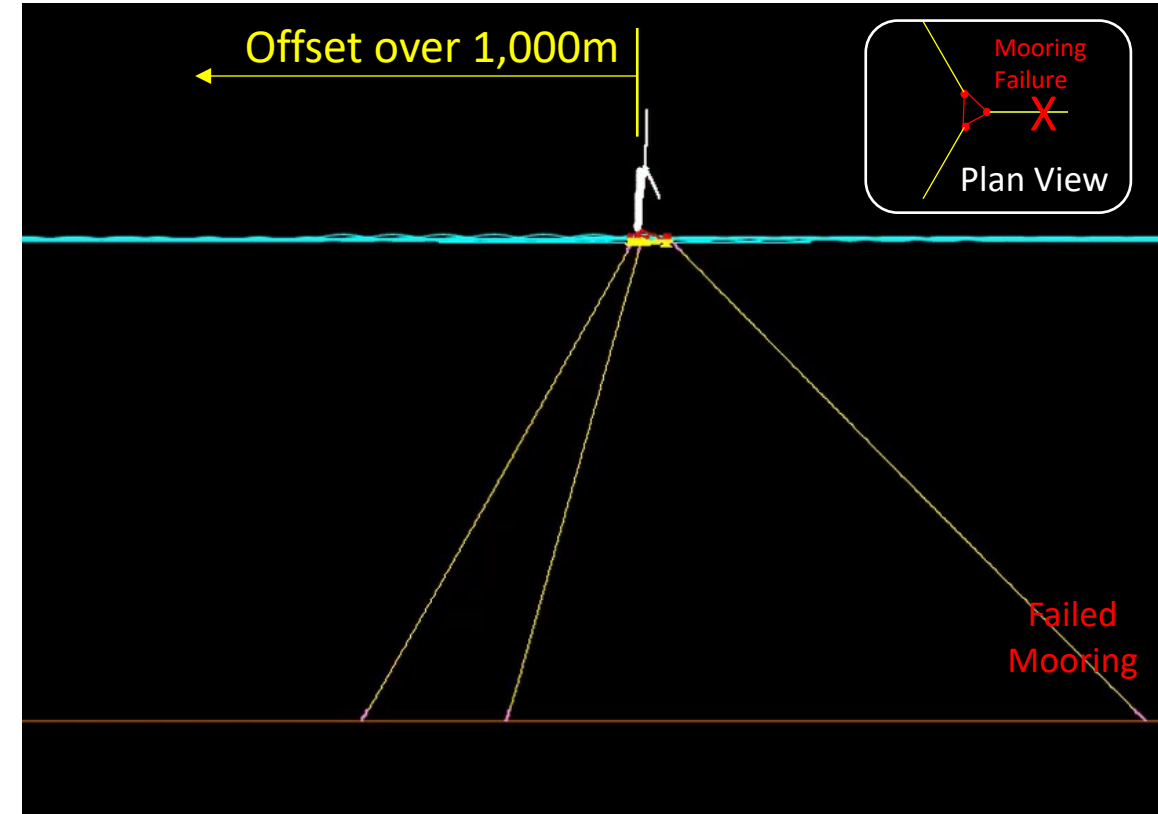
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Failed Mooring Line Scenario

3-Mooring Lines

Taut Nylon Mooring	Rope Minimum Breaking Load	Rope Preload	Hang-off Angle	Strength Utilization DnV-ST-0119	Max Offset
	Te	% MBL	Degree	-	m
3-Mooring Line (Config 6)	1,000	20	45	81%	99.0
3-Mooring Line (Config 6) – Failed Mooring	1,000	20	45	53%	1,044.4

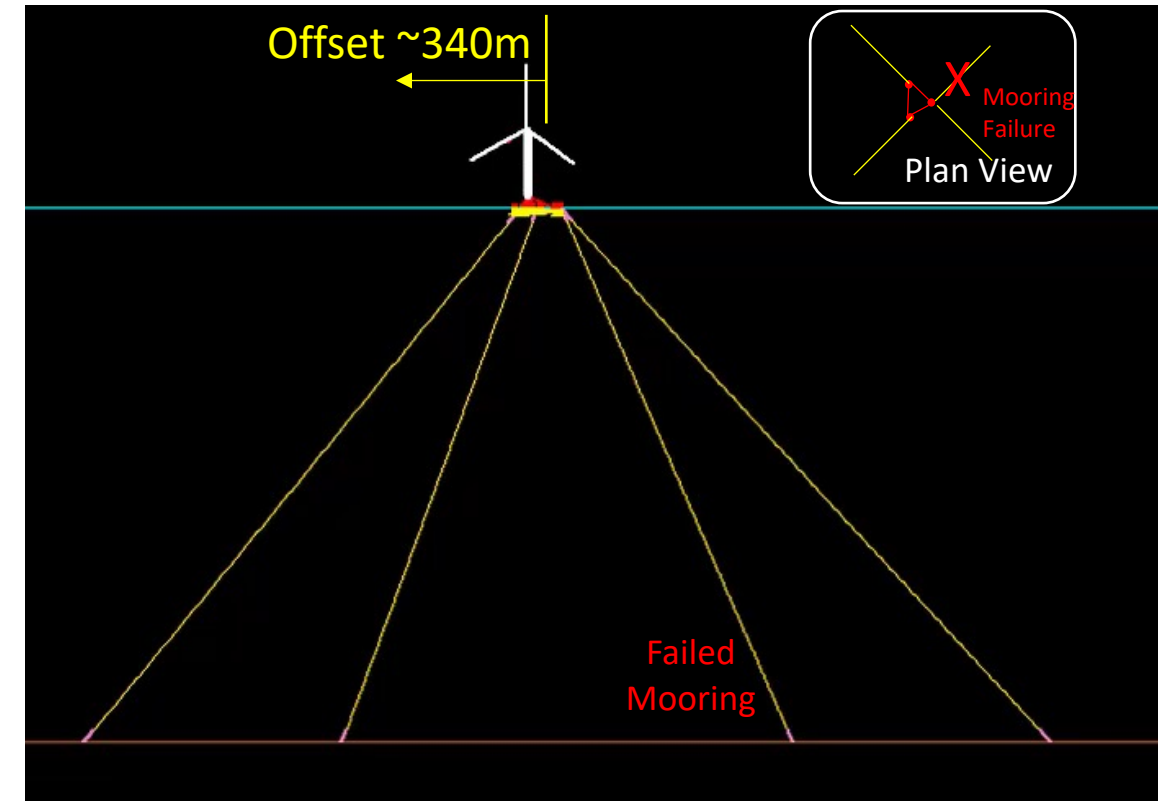
Possible collision and power cable failure



Failed Mooring Line Scenario

4-Mooring Lines

Taut Nylon Mooring	Rope Minimum Breaking Load	Rope Preload	Hang-off Angle	Strength Utilization DnV-ST-0119	Max Offset
	Te	% MBL	Degree	-	m
4-Mooring Line	1,000	20	45	57%	74.6
4-Mooring Line Failed Mooring	1,000	20	45	56%	338.5



Mooring Design Summary for US West Coast Deep Waters

- Taut mooring configurations with both polyester and nylon synthetic ropes are feasible for US West Coast deep waters.
- Nylon reduces mooring loads compared to polyester and it is currently going through qualification to be used as a long-term mooring for an upcoming demonstrator FOWT.
- Mooring footprint can increase significantly with increased mooring hang-off angle for deep water.
- DNV consequence class-1 may not be applicable for a 3-ML configuration due to large offsets (possible collision) for failed mooring conditions. Alternatively, a 4-ML configuration or DNV consequence class-2 can be adopted for mooring design.
- Shared mooring lines between FOWTs could be a more feasible mooring solution for deep water floating winds due to reduced number of anchors and mooring lengths.



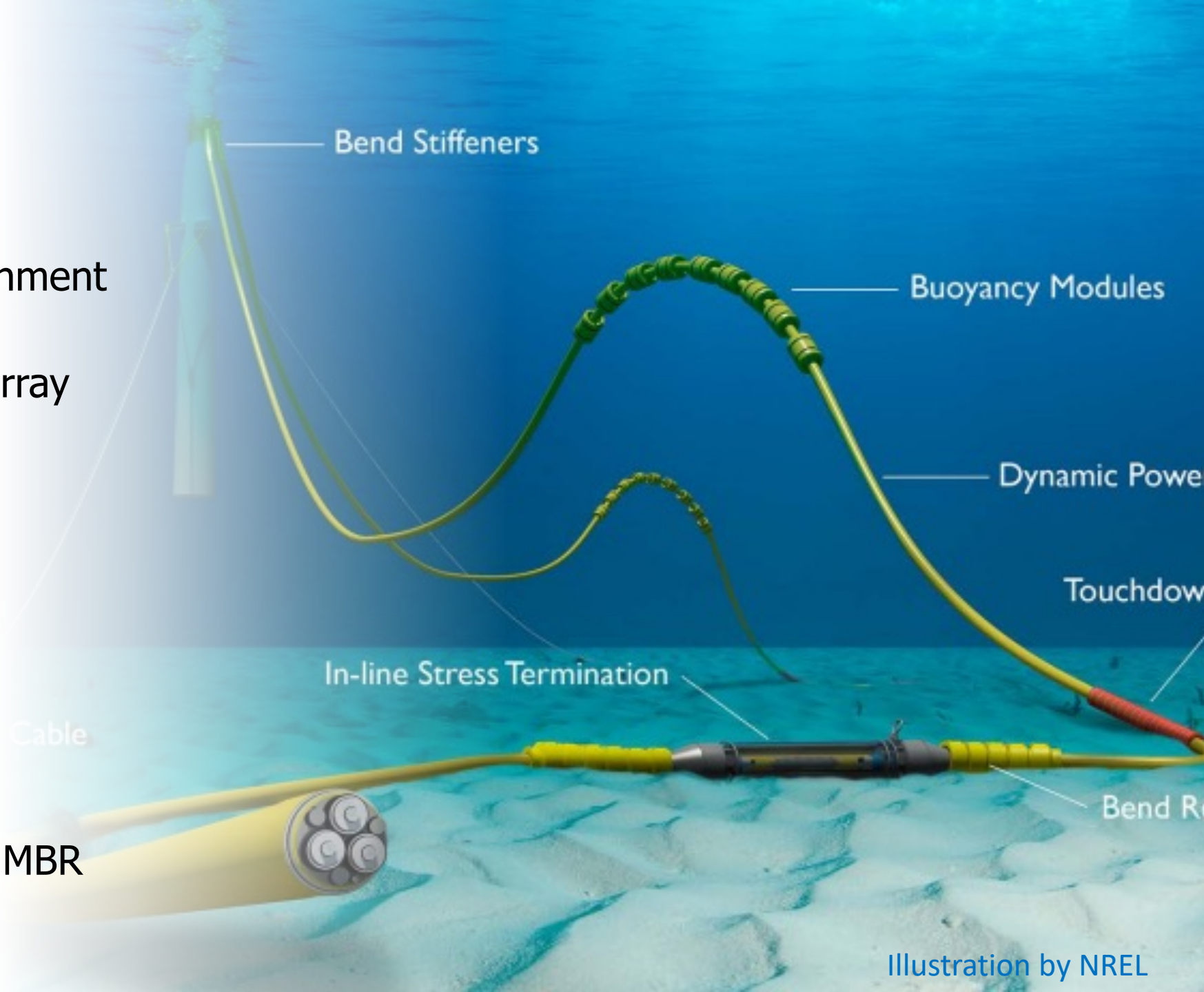
Power Cable Configuration for US West Coast Deep Waters

Power Cable Design Premise

- Same 50yr extreme environment as mooring design
- 66kV , 3x1,000mm² inter array dynamic power cable
- Power Cable Properties

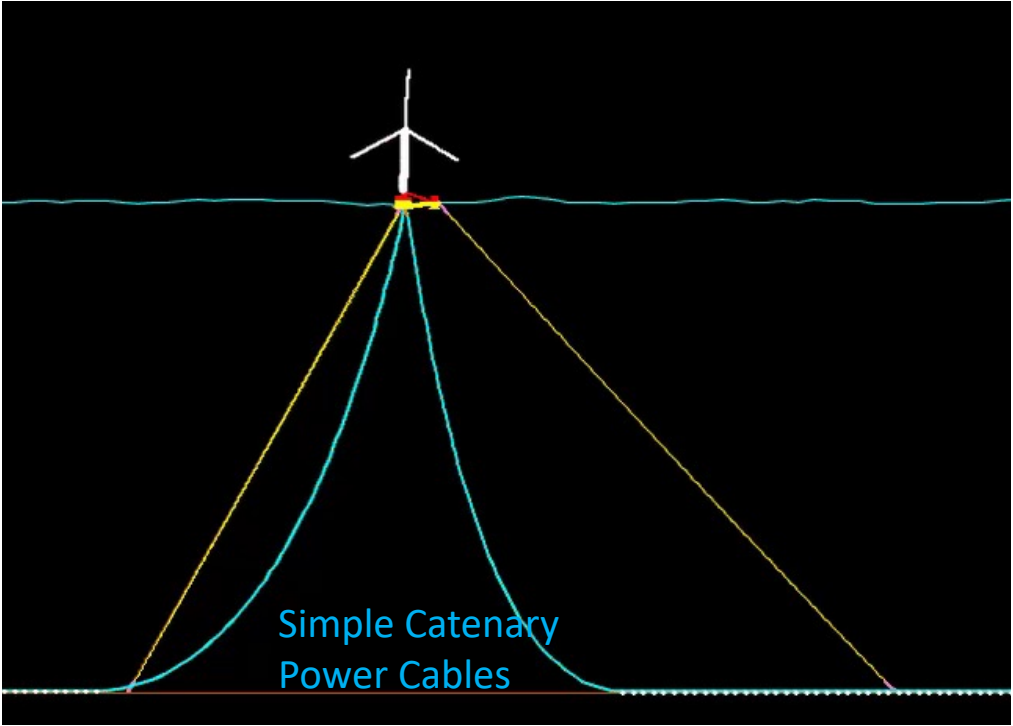
Parameter	Value
Dry Weight	90kg/m
Outer Diameter	200mm
Operational MBR	5.0m
Allowable Tension	500kN

- Power cable to stay within MBR and tension limits during extreme events



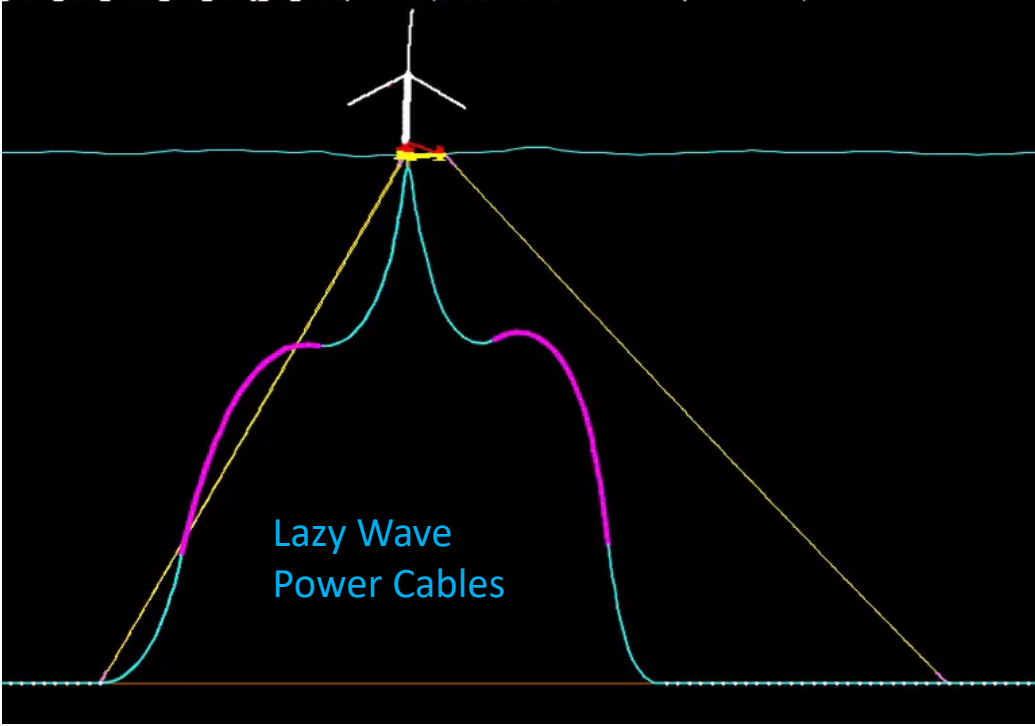
Power Cable Configurations for Deep Water

Simple Catenary



Inter Array Cable Length (m)	Max Static Tension (kN)	Max Dynamic Tension (kN)	MBR (m)
2,850	770	1,088	5.86

Lazy Wave



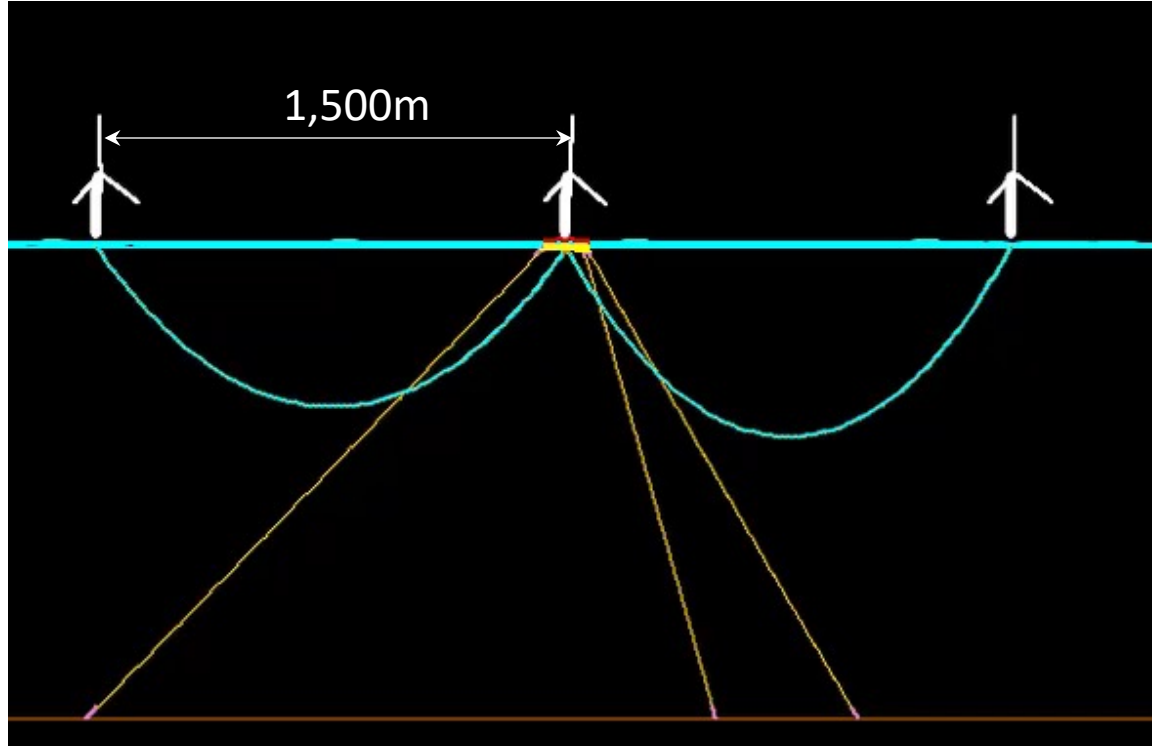
Inter Array Cable Length (m)	Max Static Tension (kN)	Max Dynamic Tension (kN)	MBR (m)
3,000	253	312	9.3

Power cable with higher tension capacity is required

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Power Cable Configurations for Deep Water

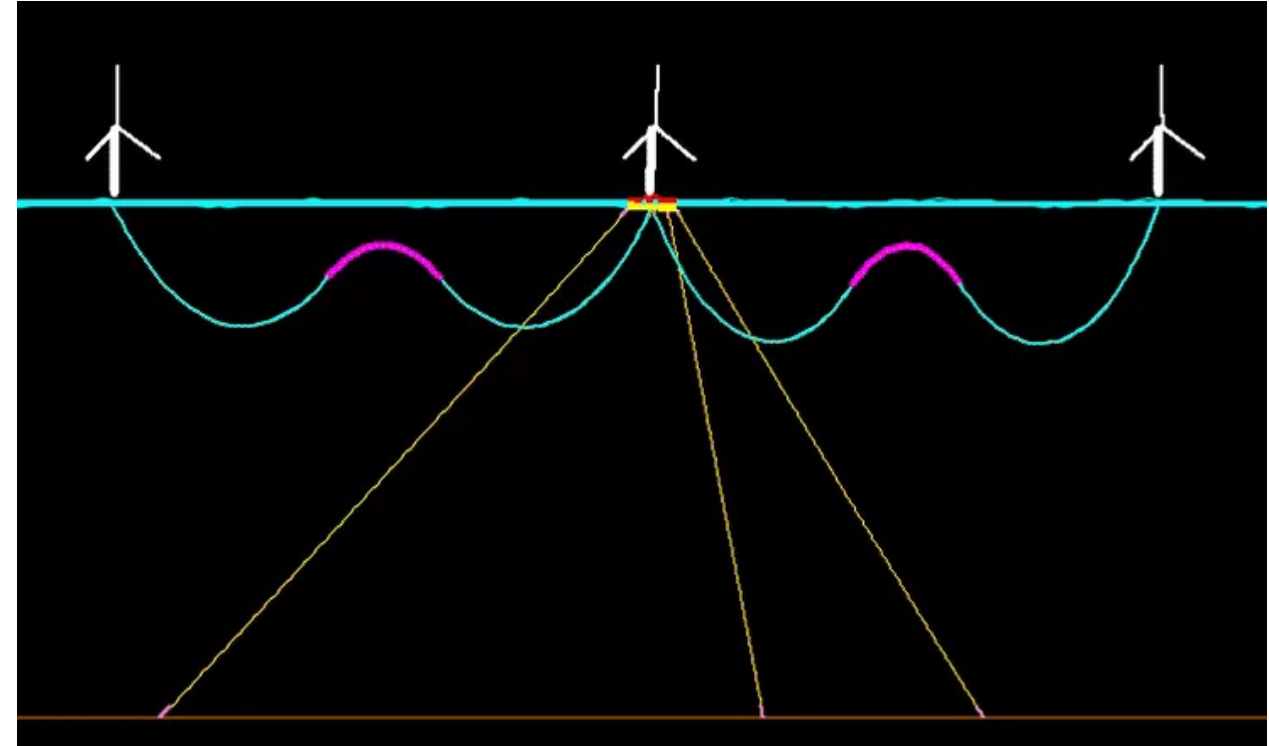
Suspended Catenary



Inter Array Cable Length (m)	Max Static Tension (kN)	Max Dynamic Tension (kN)	MBR (m)
1,720	794	1,845	3.45

Not recommended due to high dynamics

Suspended with Buoyancy

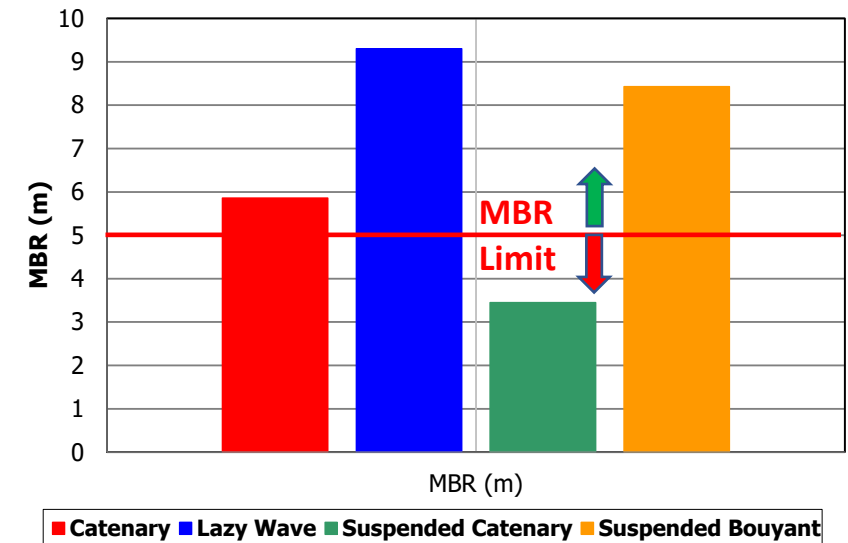
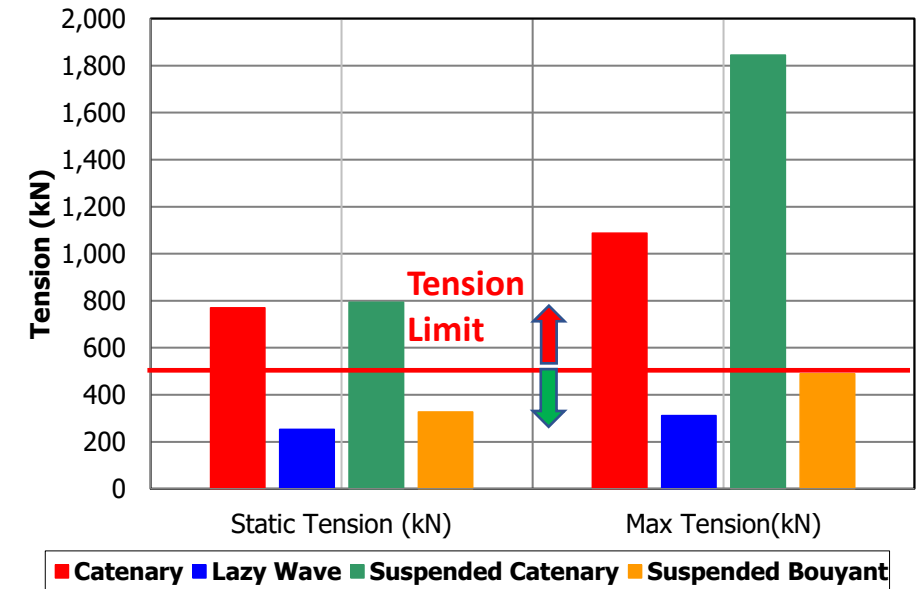


Inter Array Cable Length (m)	Max Static Tension (kN)	Max Dynamic Tension (kN)	MBR (m)
1,800	327	490	8.4

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Power Cable Design Summary for US West Coast Deep Waters

- Simple catenary power cable configurations can be used for US West Coast deep waters if the current dynamic power cable tension limits are increased.
- Lazy wave power cable configuration can be used to effectively reduce power cable maximum tensions.
- Due to deep waters, inter array power cables can be suspended in the water column and interconnected between FOWTs to reduce power cable length and eliminate seabed contact.
- Power cables can be suspended between FOWTs with or without the use of buoyancy. Further design optimization and increased cable tension limits are required for suspended catenary option. Suspension with buoyancy options offers a feasible solution.



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Key Takeaways

- Mooring

- Taut moorings with polyester and nylon synthetic ropes are feasible for US West Coast deep waters and can reduce LCOE.
- Nylon reduces mooring loads compared to polyester resulting in lower MBL requirement
- A mooring configuration with a minimum of 4 lines or DNV consequence class-2 (non-redundant) can be adopted for mooring design to avoid possible collision with neighboring FOWTs.

- Power Cable

- Both catenary and lazy wave configurations are feasible for deep water FOWTs, catenary configurations will require power cables with higher tension capacities
- Power cables can be suspended between FOWTs to reduce cable lengths and eliminate seabed contact.
- Lazy wave and suspended lazy configurations offers feasible solutions with the existing power cable designs

Questions?

Thank You