Design of Deep-Water Mooring Systems, Suspended Power Cables, and Array Layout

IEA Wind Task 49 Deep Water Design Team

January 15th, 2025

Photo courtesy of Principle Power. Artist: DOCK90

Task 49 Deep Water Design Team

Task 49 Integrated Design of Floating Wind Arrays

Work Package 2: Developing Reference Array Designs

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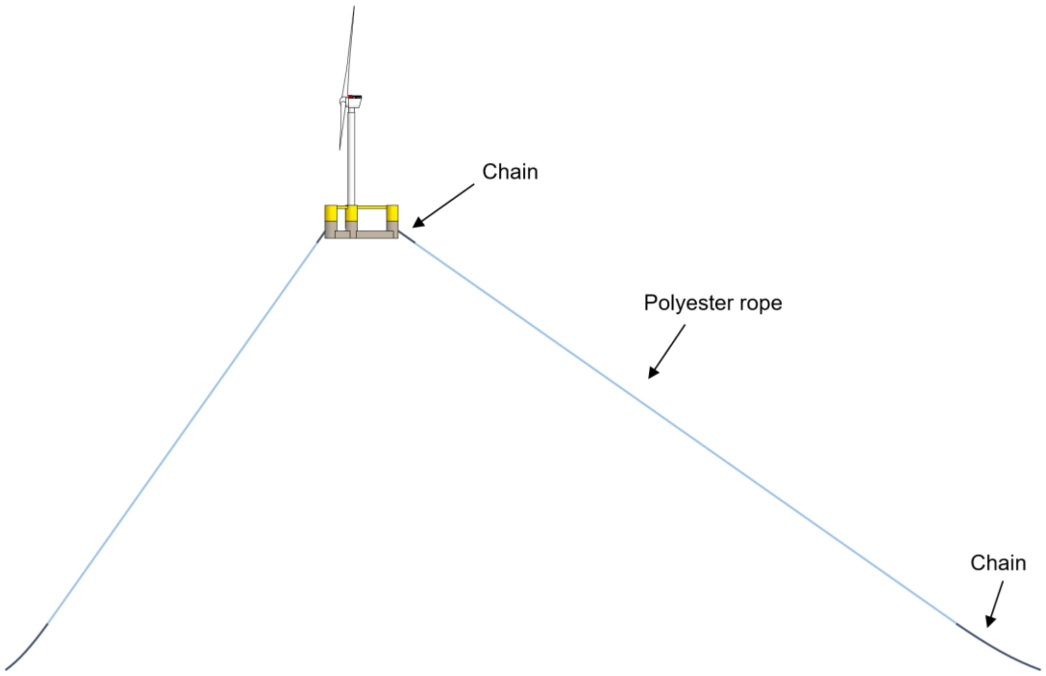
And ideas, feedback, and advice from many other Task 49 Contributors!

Design Basis

IEA Task 49 design basis document outlines assumptions

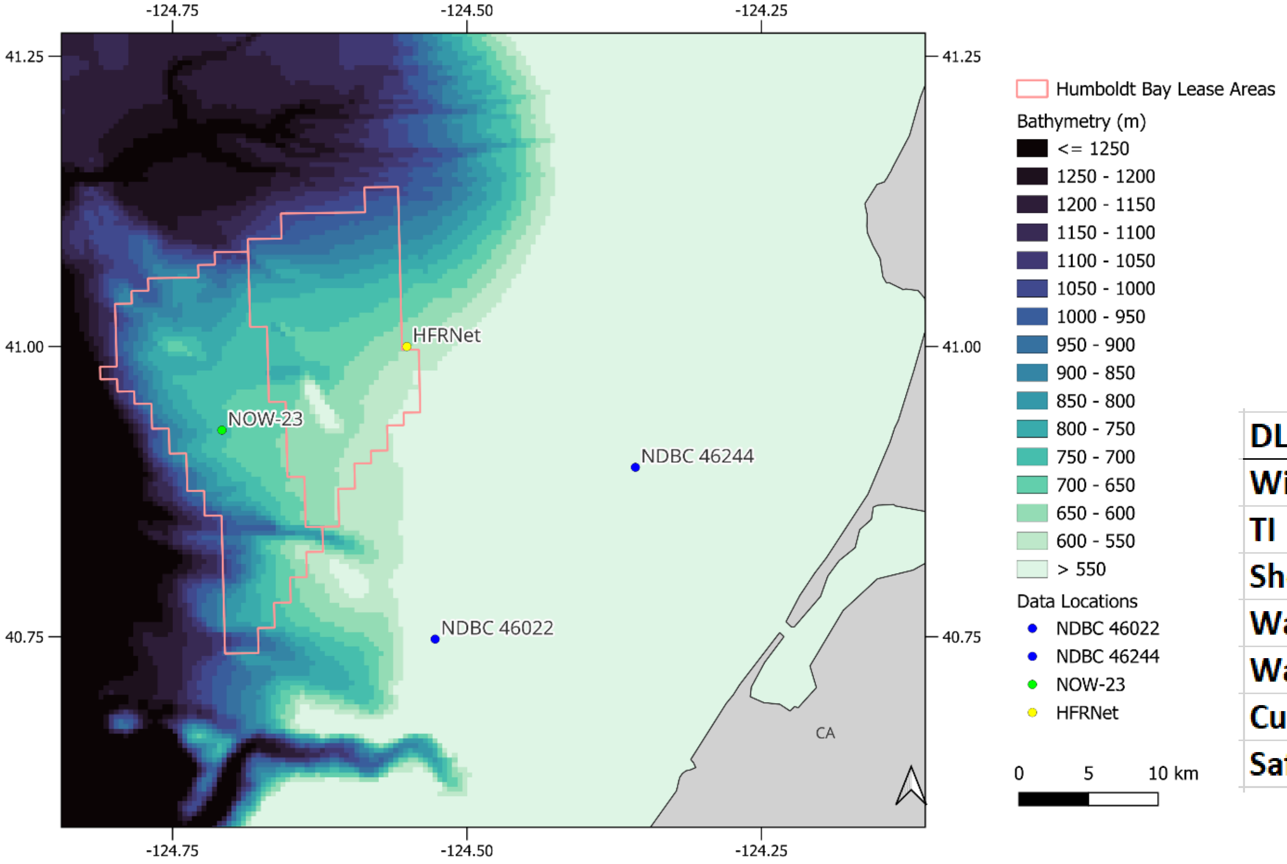


Initial Mooring Configuration

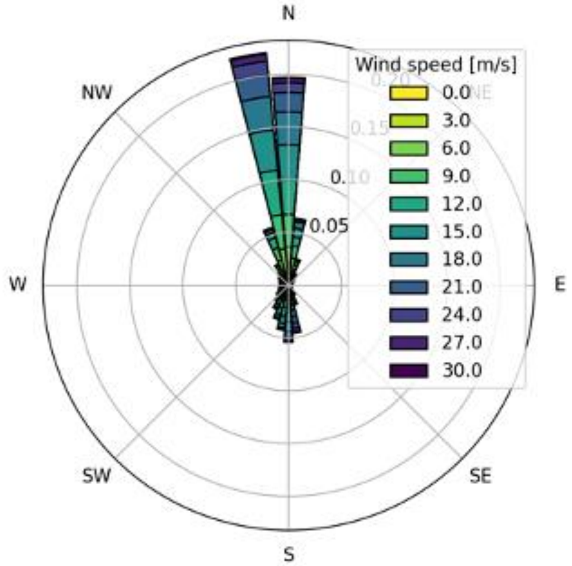
Scenario	Deep (800 m)
Key Features	Deep water challenges and solutions
Design Variants	**V1**: uniform *Optional variants:* **V2**: shared mooring option **V3**: TLP option
Array Layout	Rectangular
Platform and Turbine Type	VolturnUS-S semi-submersible and IEA 15 MW
Mooring Type	Taut (chain-polyester-chain)
Mooring Configuration	3-line mooring system, uniformly distributed headings
Anchors	Suction pile
Dynamic Cables	Catenary or lazy wave, fully suspended

Site Conditions

- 800 m uniform water depth
- Extreme and fatigue load cases



Wind rose at the Humbolt site



DLC	1.6	6.1	SLC
Wind speed (m/s)	10.59	39.44	42.97
TI	0.06	0.05	0.05
Shear	0.14	0.11	0.11
Wave height (m)	10.5	11.8	13.7
Wave period (s)	18.7	19.8	21.4
Current speed (m/s)	0.92	1.28	1.44
Safety factor	2	2	1.05

Mooring Design

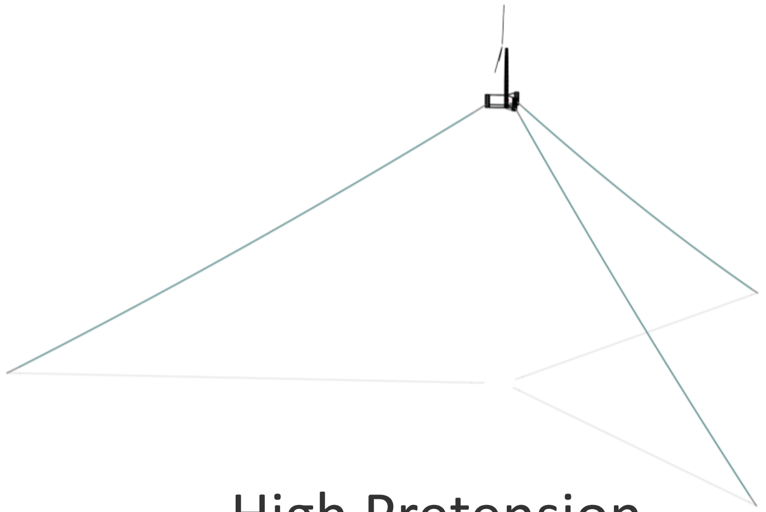
Key constraints:

- Tension safety factor
- Fatigue
- **Slack line events**

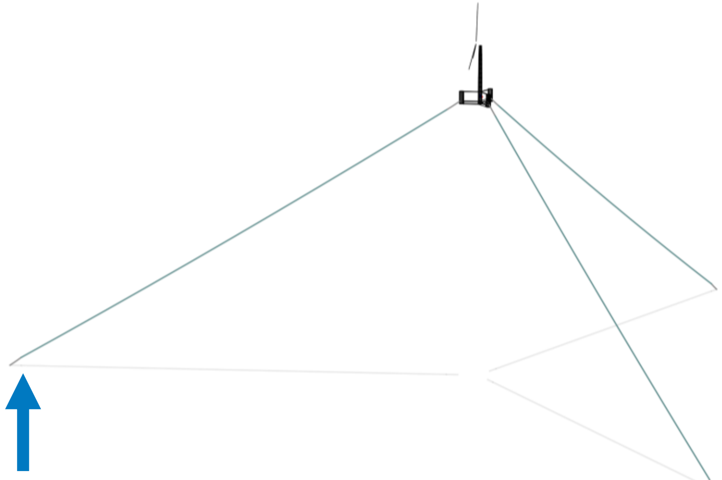
Three design paths to limit slacking:

	High pretension	Buoy	Clump weight
Anchoring radius (m)	1400	1400	1400
Chain diameter (mm)	135	135	135
Polyester diameter (mm)	210	183	200
Buoy (m^3)	0	27	0
Weight (t)	0	0	40
Pretension (kN)	3380	1600	1900 kN*

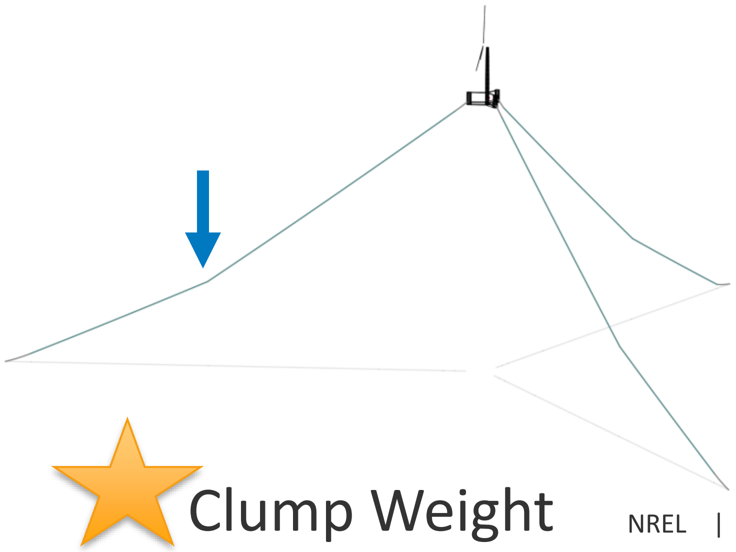
*Pretension without clump weight 900 kN



High Pretension



Buoy



Clump Weight

Mooring Design

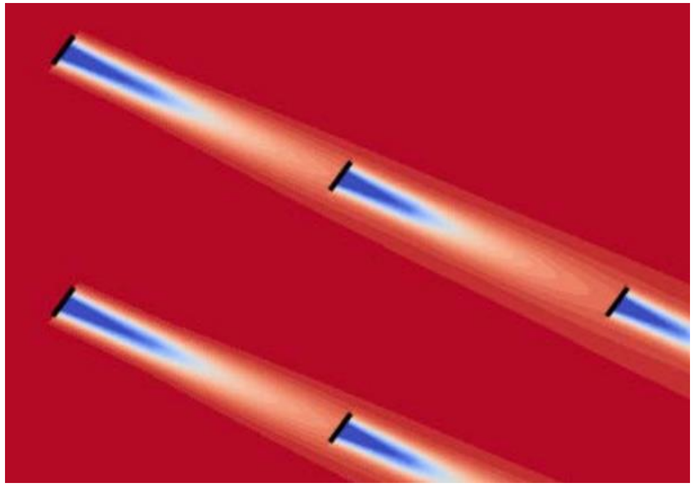
Mooring fatigue damage varies widely

At different orientations:

- 2.5x increase depending on mooring orientation relative to wind

Wake effects (incr TI and deficit):

- 5x increase with 5D spacing
- 4x increase with 8D spacing
- **Assumed 9.6D spacing based on layout design**



	Mooring fatigue damage
No wake effects	0.11
5D spacing	0.49
8D spacing	0.40
Allowable	0.33

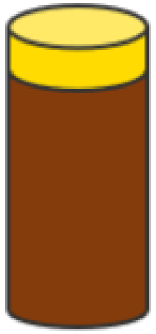
Anchor Design

Sediment type: mostly mud with rock areas

Optimize the suction anchor dimensions, using plastic limit analysis (PLA)

Key considerations:

- Geotechnical efficiency
- Suction installability
- Cost-effectiveness
- Carbon impact



Suction anchor

OPTIMIZED SUCTION ANCHOR DESIGN AND ITS SUCTION INSTALLABILILTY

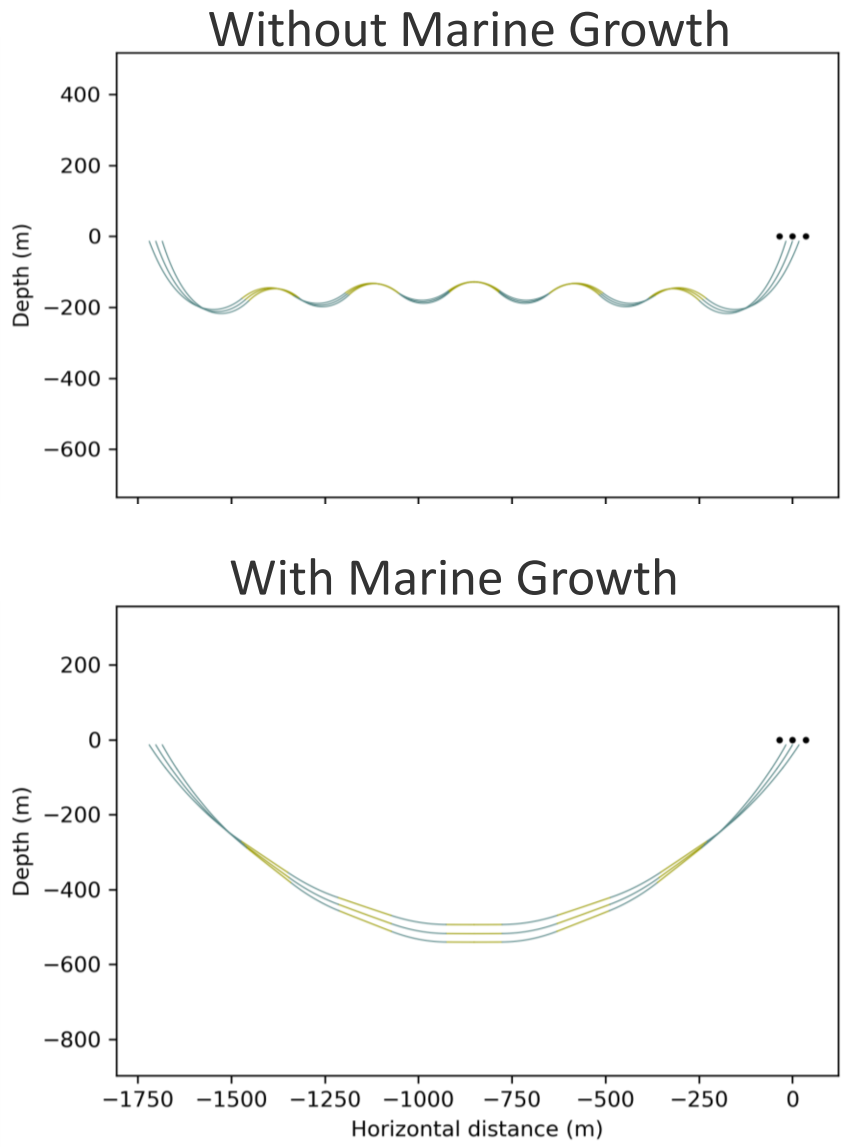
	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Aspect ratio (*L*/*D*)	4	5	6	7	8	9
Diameter (*D*, m)	3.90	3.53	3.23	3.0	2.82	2.65
Length (*L*, m)	15.6	17.7	19.4	21.0	22.6	23.9
Weight* (*W*, ton)	78.3	72.0	65.9	61.3	55.3	54.0
Vertical load (*V*, MN) (Green if *V*>5.8MN)	6.7	6.8	6.7	6.7	6.8	6.8
Inclined load (*I*, MN) (Green if *I*>10.7MN)	13.0	13.4	13.3	13.4	13.5	13.5
Horizontal load (*H*, MN) (Green if *H*>11.7MN)	13.5	15.2	16.5	17.7	19	19.7
Feasibility Check						
Geotechnical efficiency (=*V*/*W*)	8.9	9.8	10.6	11.3	12.8	13.1
Geotechnical efficiency (=*H*/*W*)	17.9	21.9	26.0	29.9	35.6	37.8
Suction installability *F.S.*	3.08	2.4	2.04	1.8	1.63	1.48
F.S. >1.5	Feasible	Feasible	Feasible	Could be feasible	Could be feasible	Not feasible

Suspended Cable Design

Key Constraint – Tension

Design challenge: Marine growth

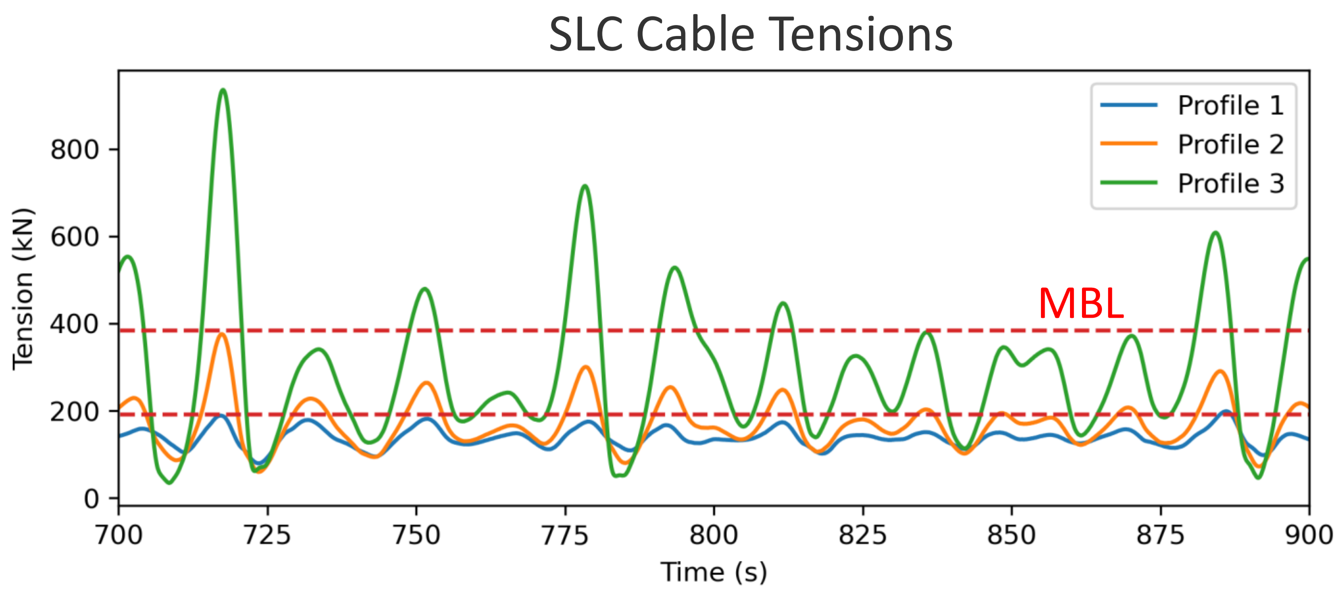
- Following DNV GL guidelines:
  - 100 mm growth to 50 m depth
  - 50 mm growth below 50 m depth
- Changed assumptions to 0 marine growth below 170 m depth

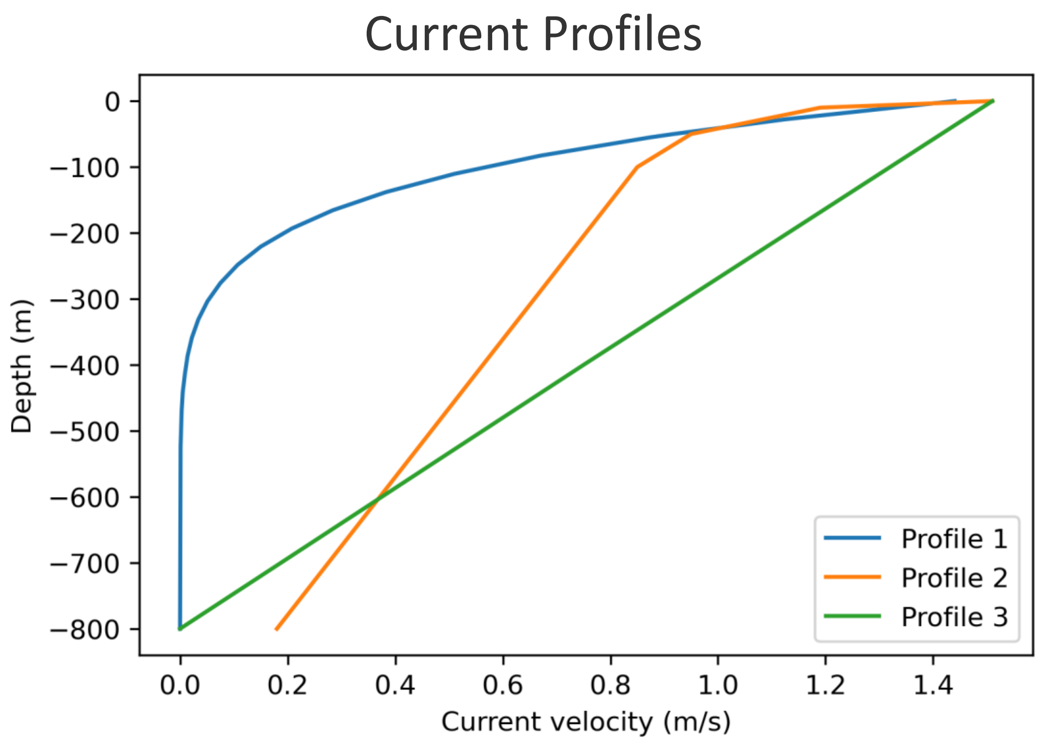


Suspended Cable Design

Design challenge: Current

- Current flow perpendicular to the cable is most challenging
- Tensions are highly sensitive to current profile with depth

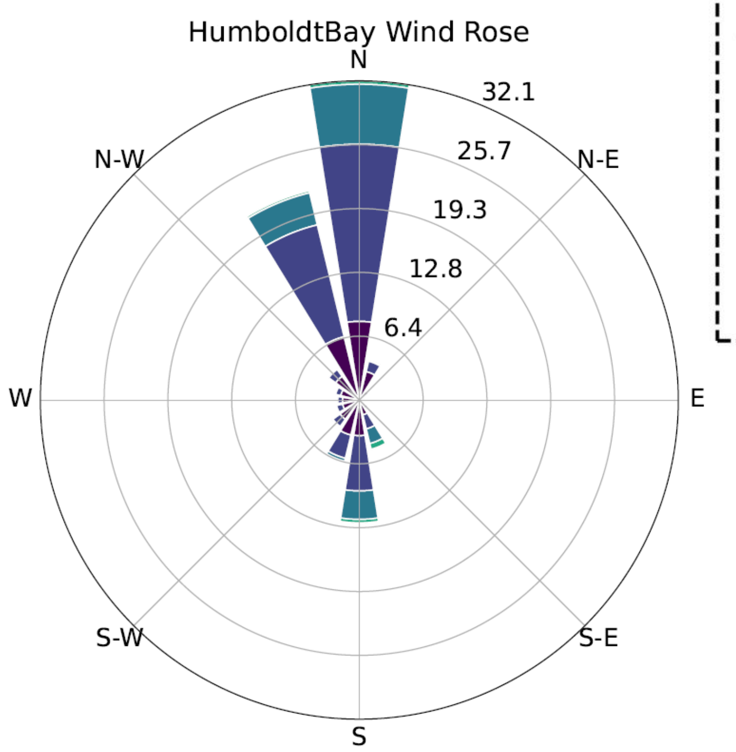


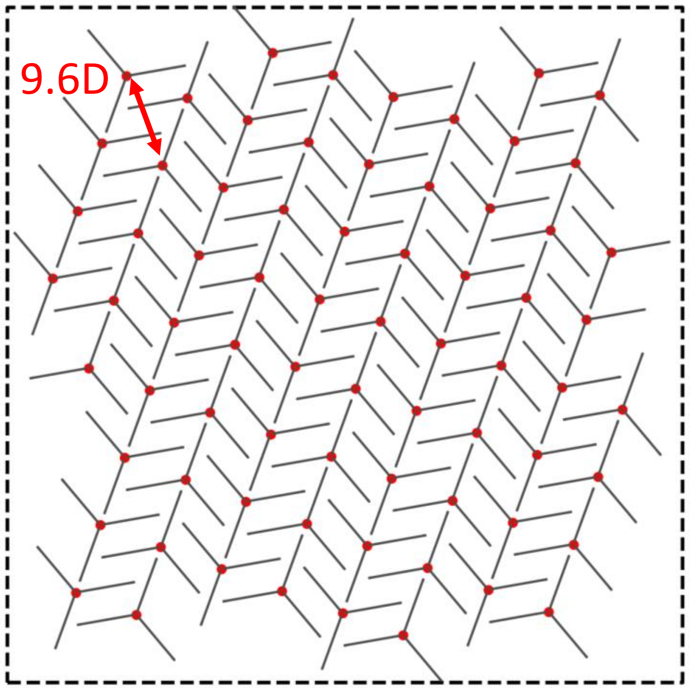


Array Layout

Layout goals to reduce mooring fatigue and wake losses:

- Increase turbine spacing in predominant wind direction
- Avoid mooring lines headed directly upwind



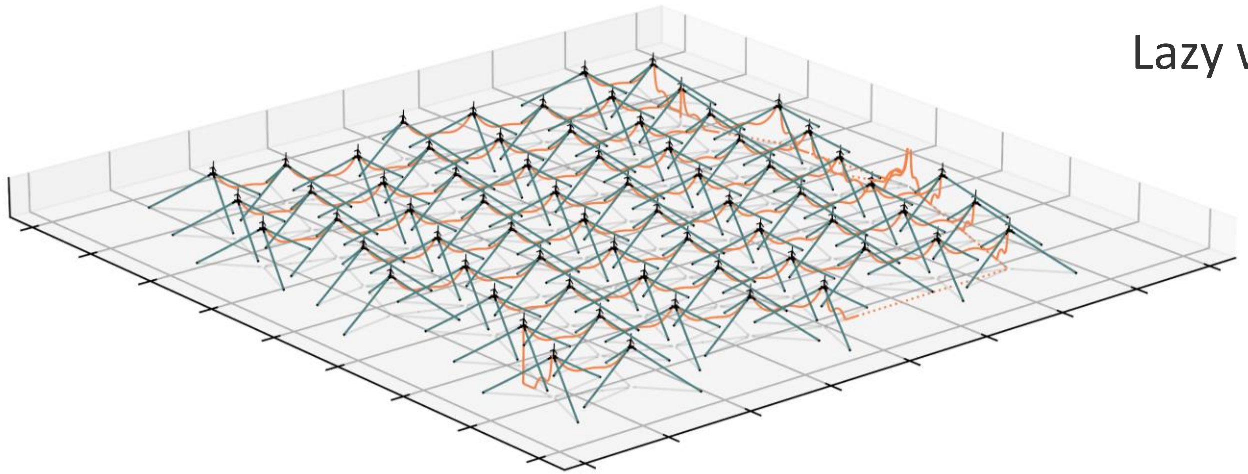


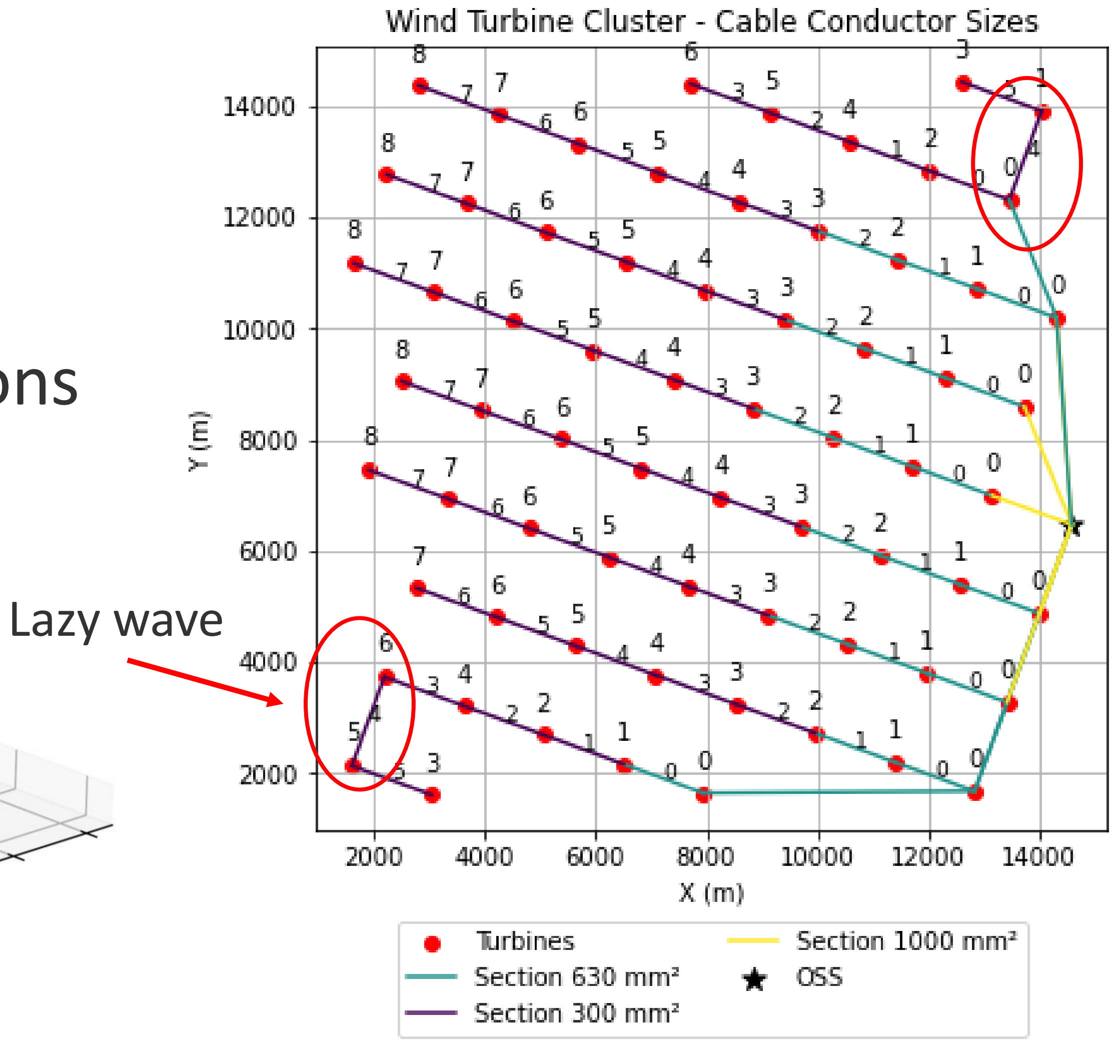
D = 240 m

$S'_x = 6.36D$
$S'_y = 7.09D$
$\alpha = 290°$
$\gamma = \pm 30°$

Cable Routing

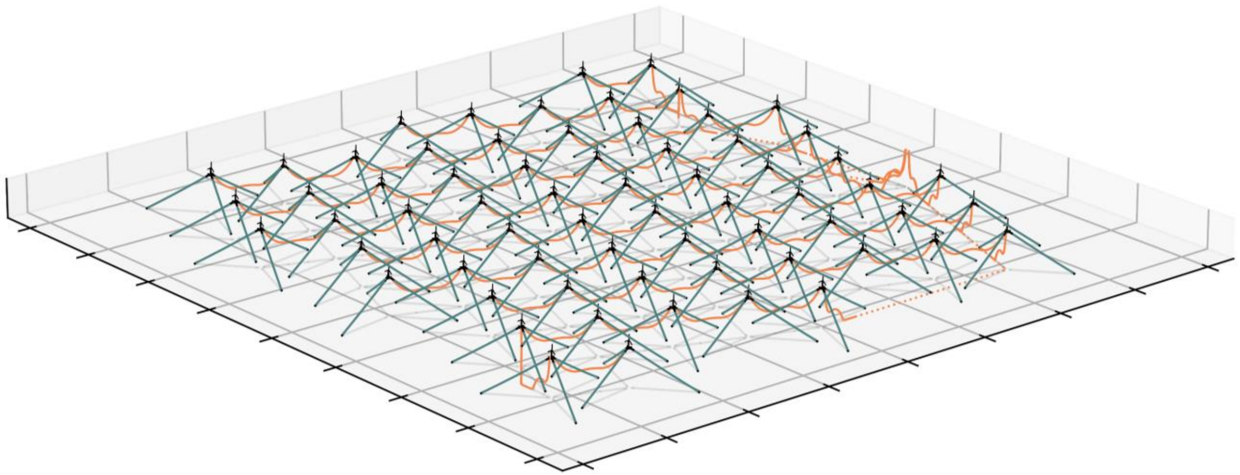
- Three conductor sizes
  - 300, 630, and 1000 mm^2
- OSS fits within gridded layout
- Lazy-wave and suspended configurations





Conclusions and Next Steps

- The finalized deep water array design will be made publicly available
- Currently working on an LCOE analysis
- Task 49 shallow and intermediate depth designs are also in progress



Questions?

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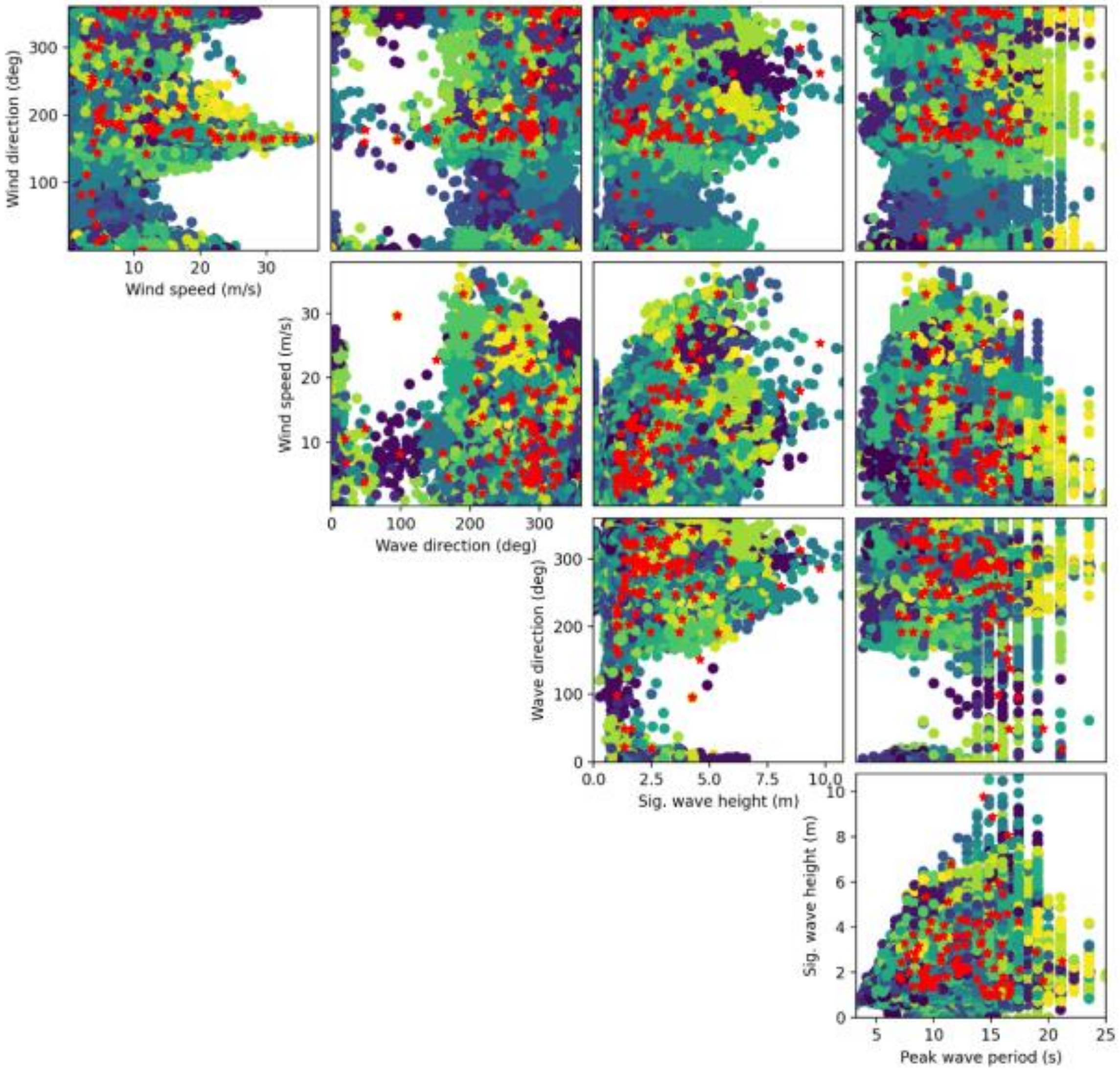
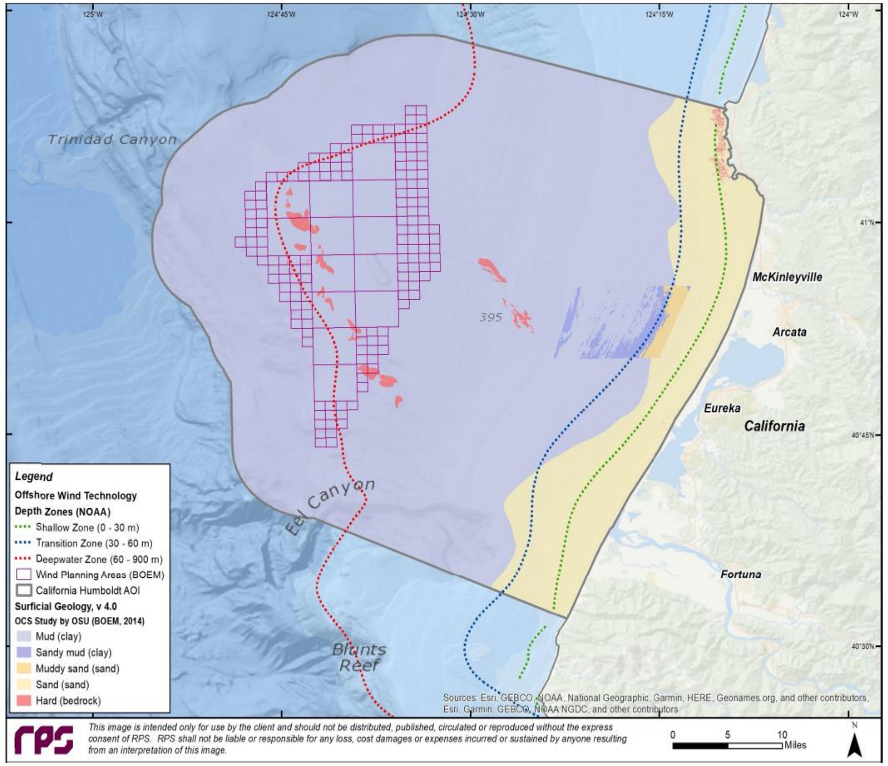
This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Wind Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Fatigue Bins

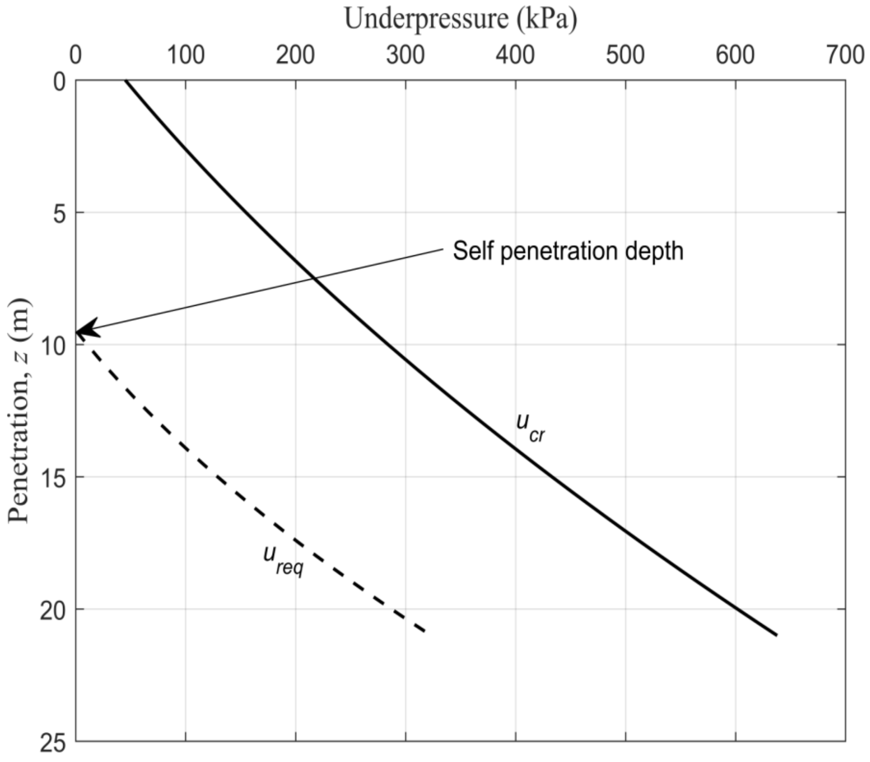
Fatigue bins generated using a maximum dissimilarity algorithm



Anchor Design



Sediment type: mostly “mud“ with localized hard rock and outcrops (BOEM. 2023)



Suction installability analysis