Floating Wind Solutions

Evaluation of Mooring Load Reduction Devices for Floating Wind

Yusuf Arikan, Sr. Project Manager
Alex Keierleber, Senior Engineer
Rose Walker, Engineer

2H Offshore

Organized by FWE Quest Offshore

FWS

The Marriott Marquis, Houston Jan. 30 - Feb. 1 2023

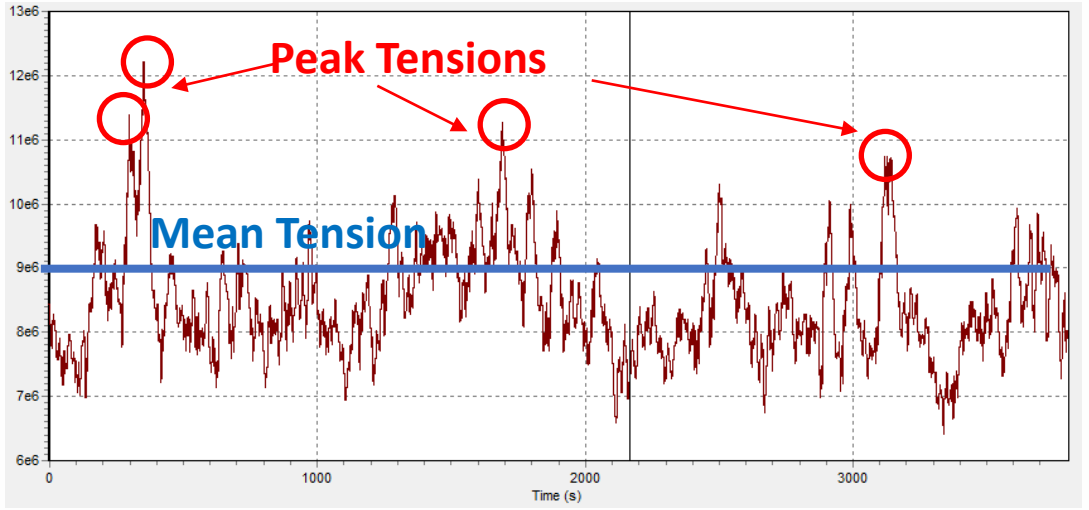
Floating Offshore Wind Mooring Design Challenges

- Mooring design tensions are governed by the peak tensions that occur only few times during extreme storm events

Design Tension = LF_M x Mean Tension + LF_D x Dynamic Tension

Load Factors (ULS)	Design Consequence Class	
	1 - Redundant	2 – Non-redundant
Mean (LF_M)	1.3	1.5
Dynamic (LF_D)	**1.75**	**2.2**

Dnv-ST-0119

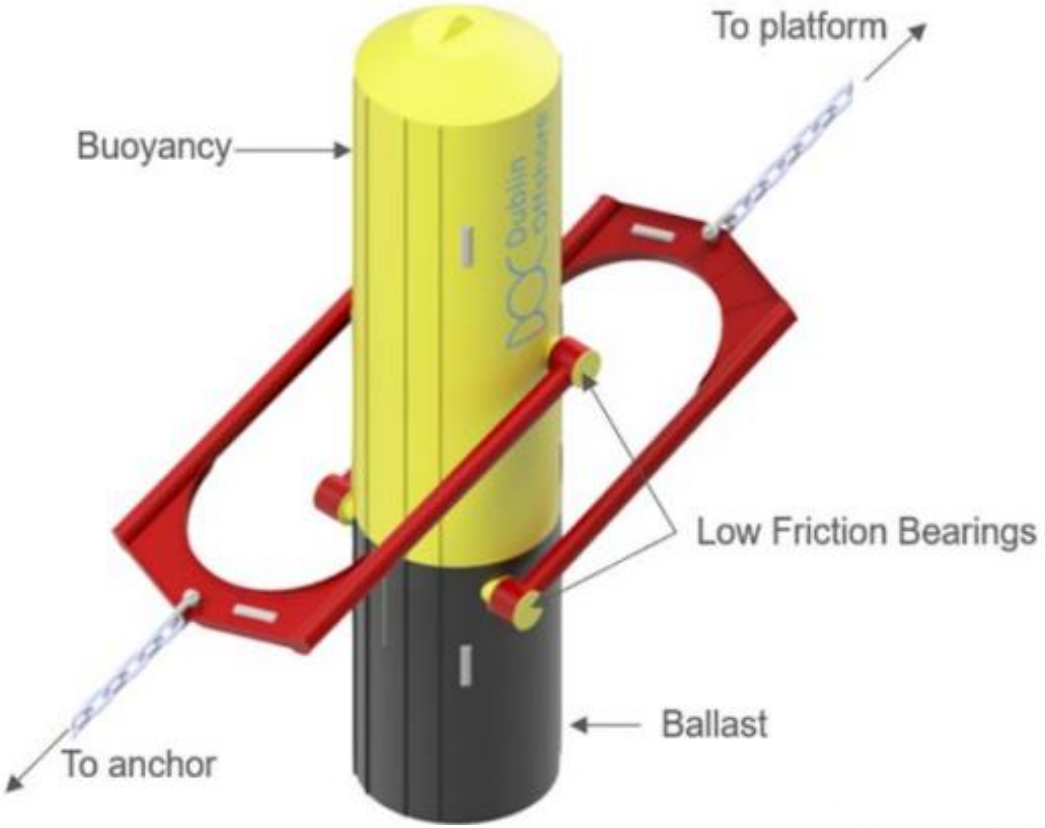


- Peak mooring tensions are governed by mooring stiffness and FOWT response
- Anchor sizes are also governed by high design tensions

Evaluation of Mooring Load Reduction Devices for Floating Wind

Mooring Load Reduction Devices – Dublin Offshore

- Patented by Dublin Offshore
- LRD comprised of a rigid shaft with a buoyant top and weighted end, and two attachment arms for mooring line connection;
- The neutrally buoyant LRD is oriented vertically in unloaded states, and rotates to extend the overall length of the mooring system when tension is applied;
- The LRD is scalable to suit site-specific metocean conditions.



https://www.dublinoffshore.ie

Mooring Load Reduction Devices – TFI Marine

- Patented by TFI Marine
- Custom shaped polymer-based plastic spring with steel structure
- Changes mooring system response
- Suitable for catenary and taut moorings with chain and synthetic ropes
- Several LRDs can be installed in series in a single mooring line

https://www.tfimarine.com

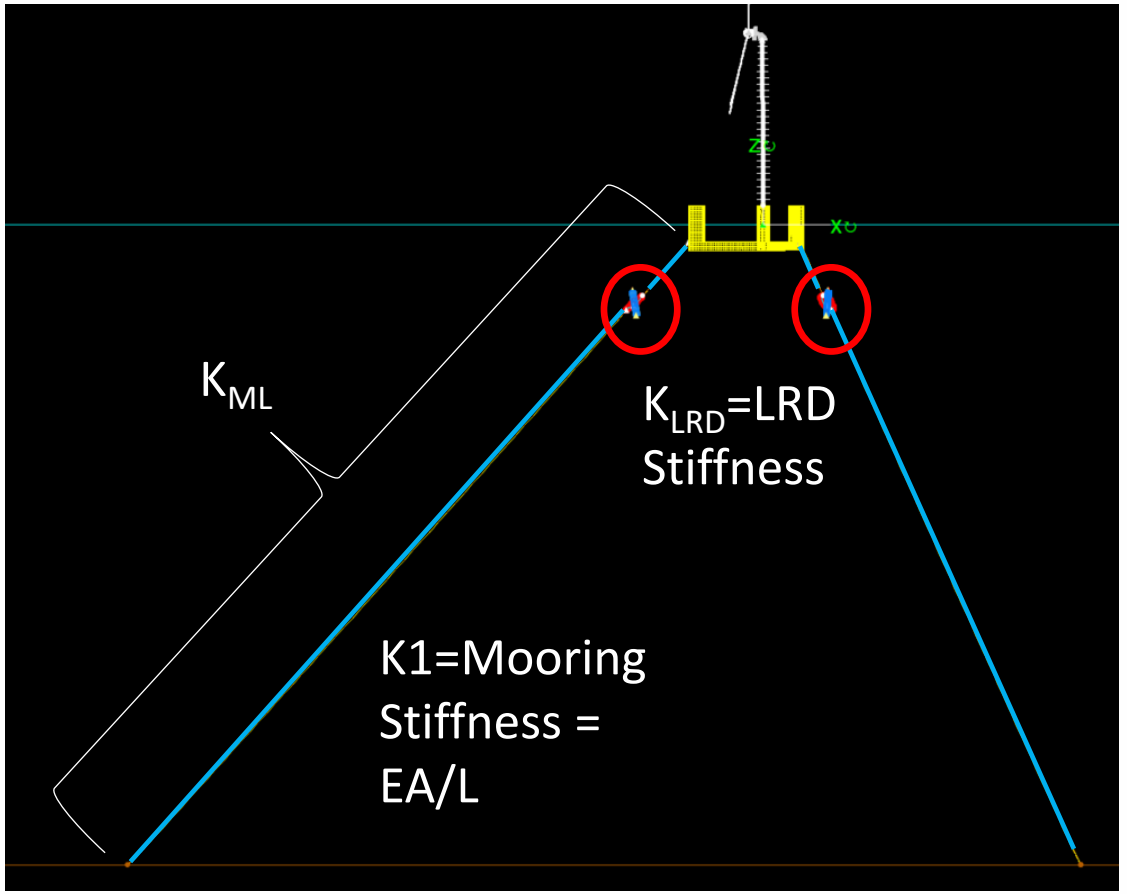
Mooring Load Reduction Devices – Mooring Stiffness

- K_1 = Mooring Line Stiffness = EA/L
- K_{LrD} = LRD Stiffness (Non-Linear)

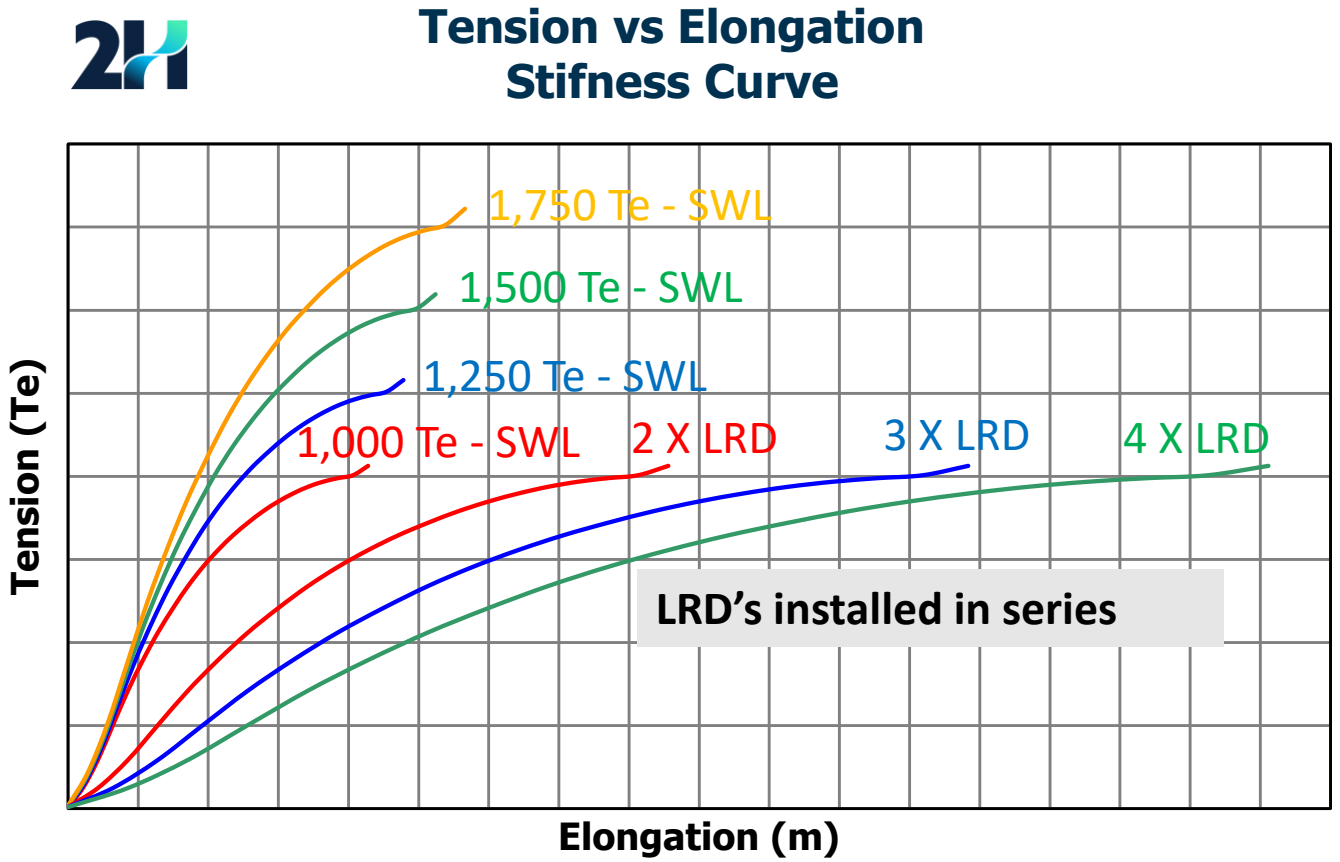
- K_{ML} = Mooring System Stiffness

$$K_{ML} = \frac{K_1 \, x \, K_{LRD}}{K_1 + K_{LRD}}$$

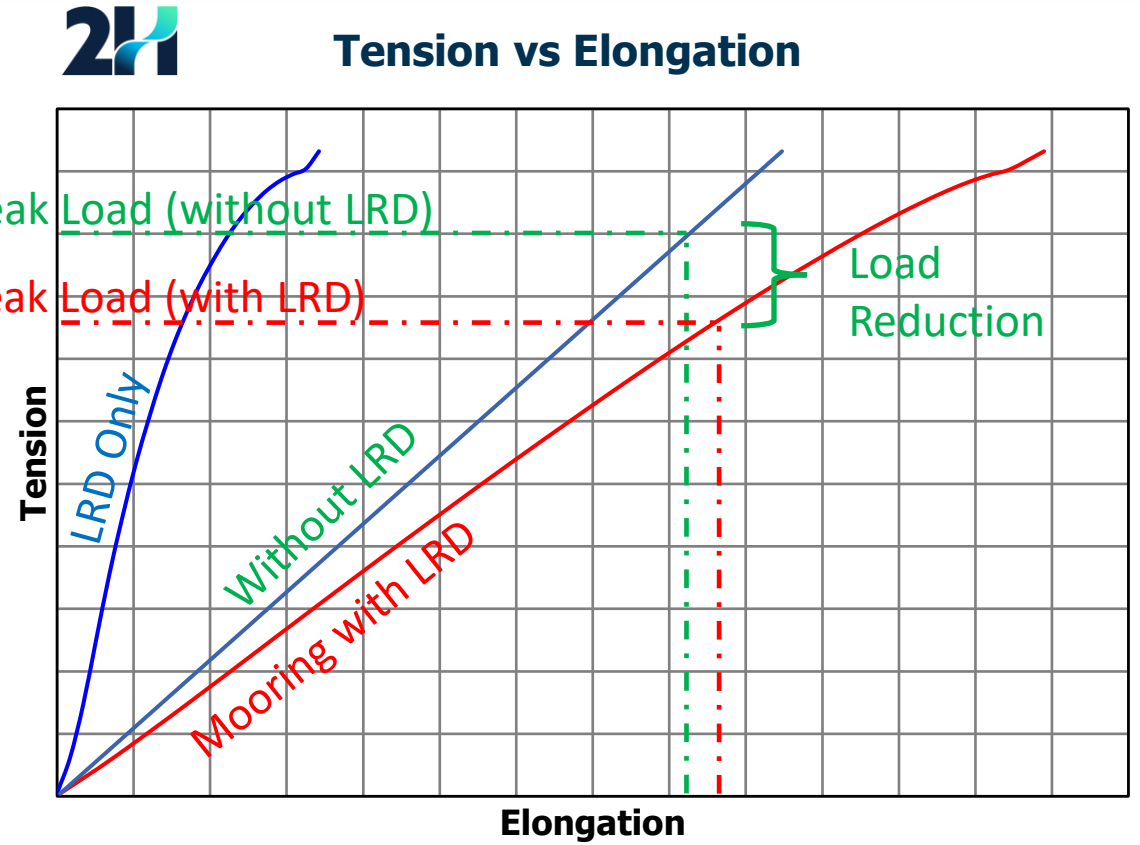
- Soft LRD stiffness governs the system stiffness
- Ex: If K_1=1.0, K_{LRD}=0.1, K_{ML}=0.099
- K_{ML}~K_{LRD}



Mooring Load Reduction Devices – TFI LRD (Taut)

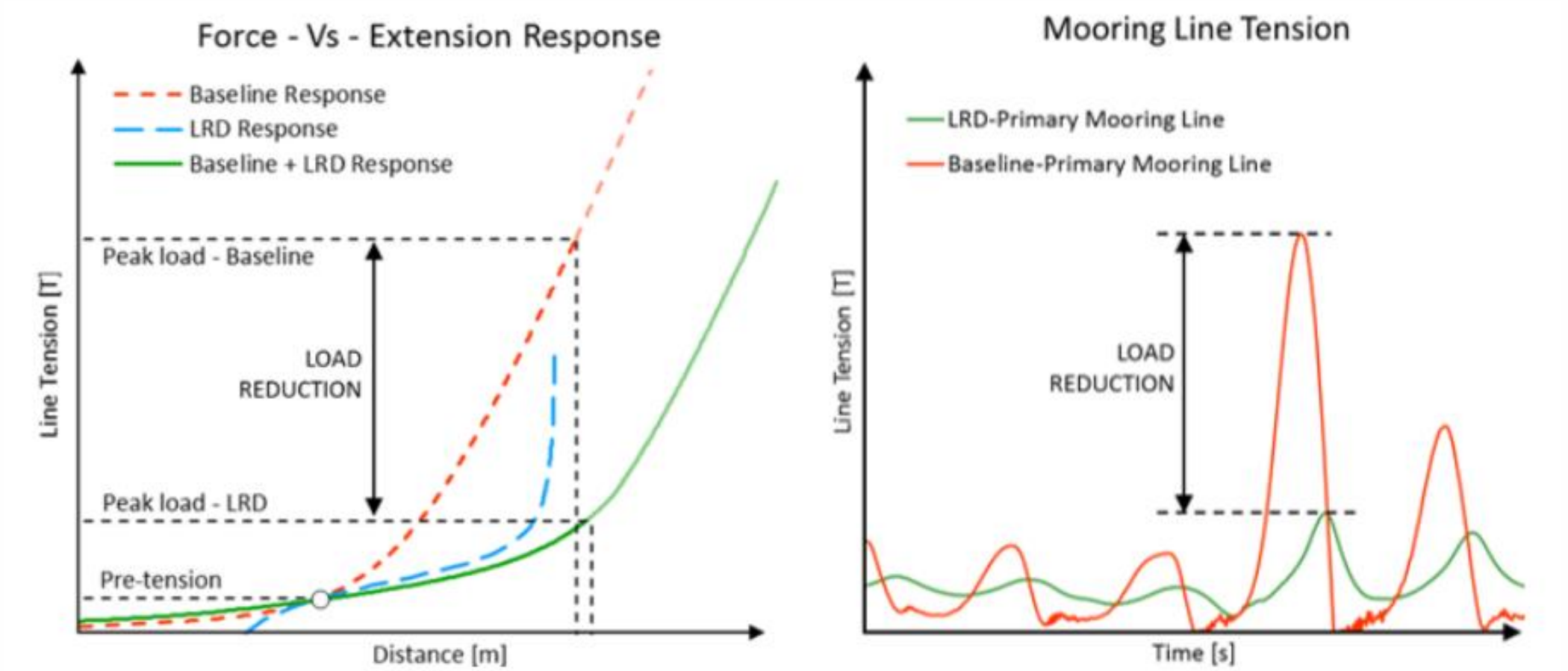


LRD Stiffness Curves



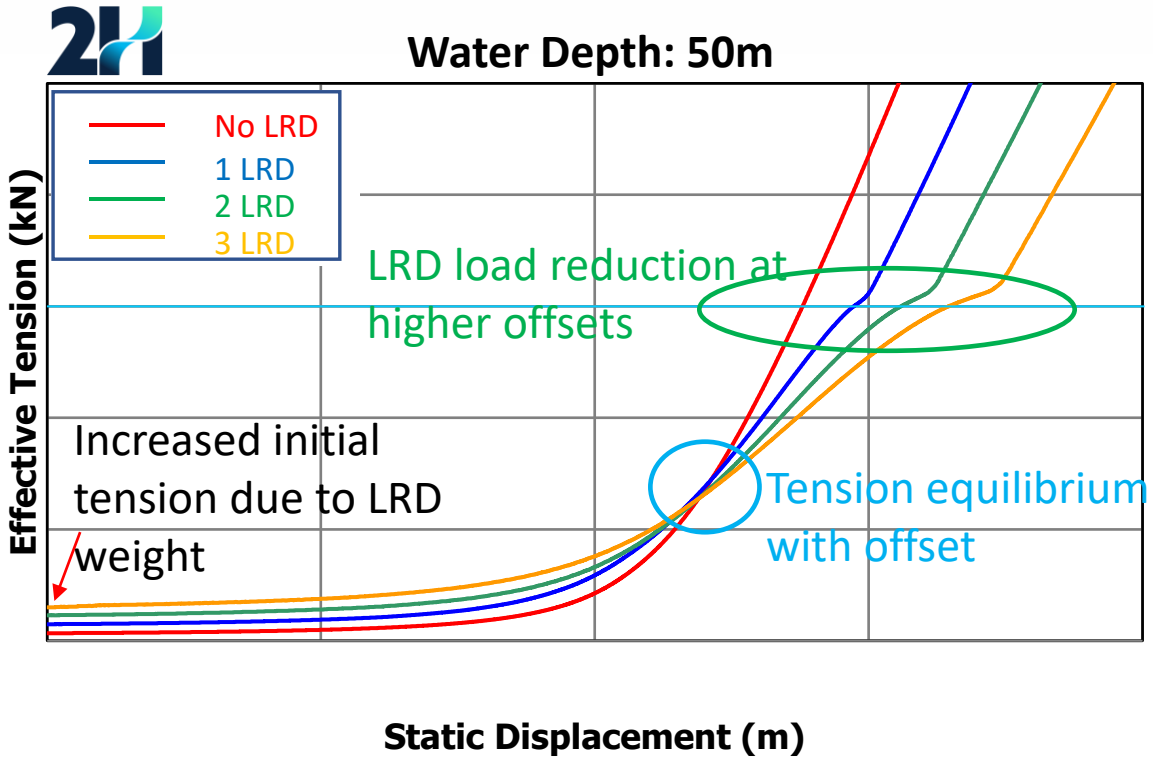
Mooring System Response – Peak Load Reduction

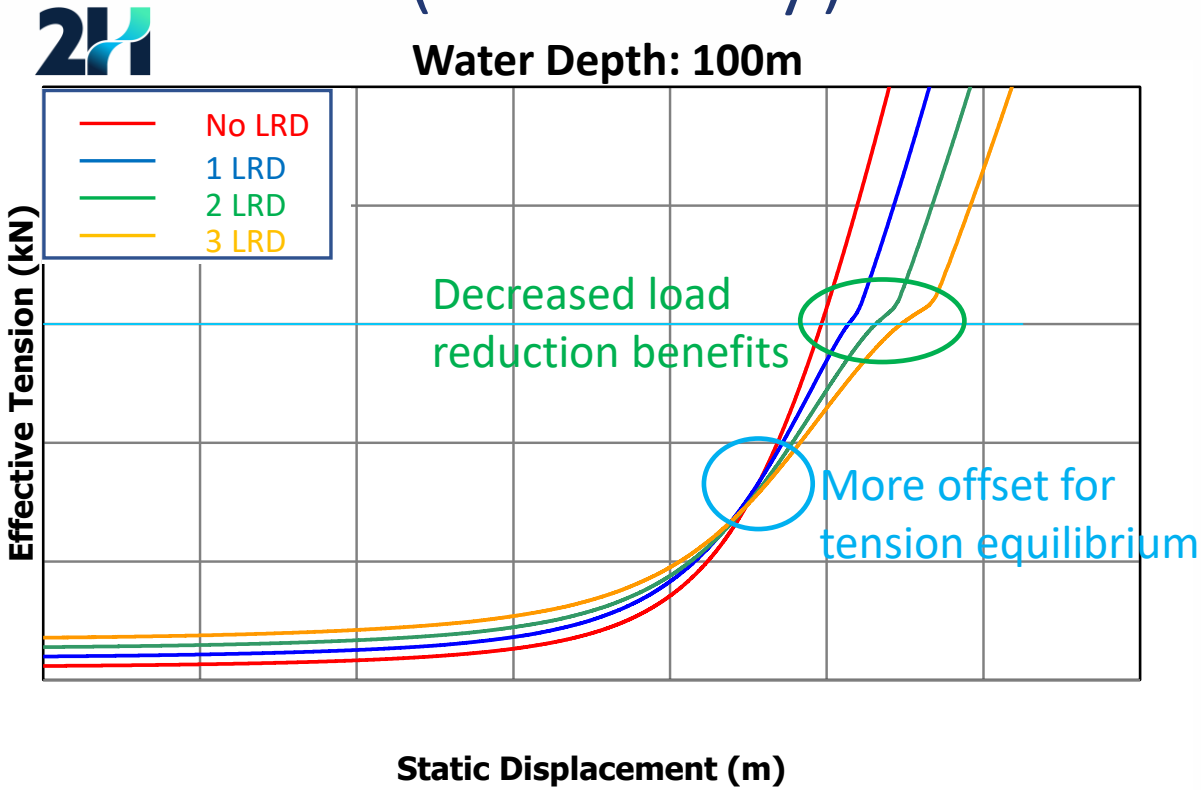
Mooring Load Reduction Devices – Dublin Offshore



https://www.dublinoffshore.ie/media/pages/technology/6f4e7419f6-1635594571/how-it-works.pdf

Mooring Load Reduction Devices – TFI (Catenary)





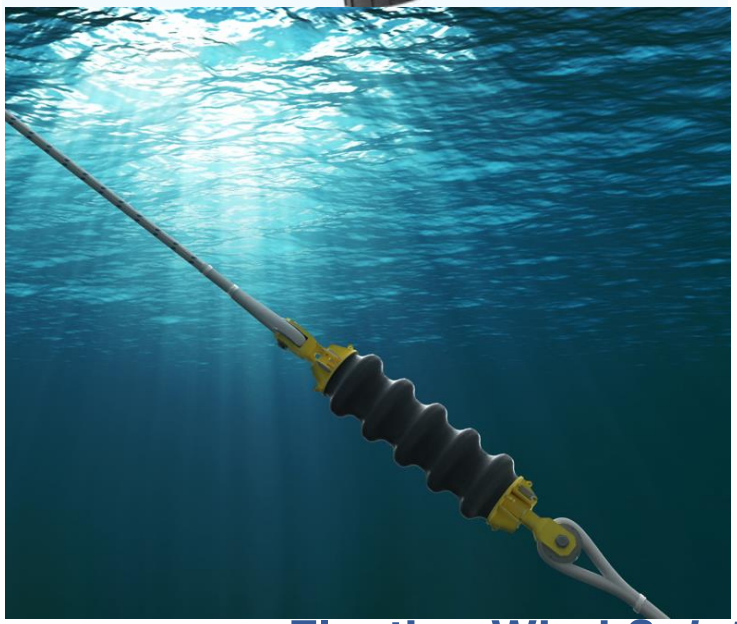
- Initial increased mooring hang-off loads due to LRD self-weight
- With FOWT offset, tension equilibrium is reached
- Peak load reduction is achieved at higher offsets
- As water depth increases efficacy of LRD decreases as mooring stiffness decreases

Case Studies for 50m to 1200m Water Depths

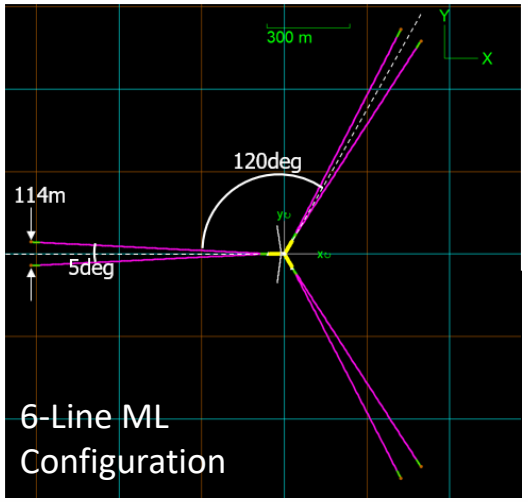
Mooring Design Premise

- 4 taut mooring configurations with polyester rope and chain systems are developed with no LRD's
  - 50m, 100m, 500m, and 1,200m water depths
  - Investigated for the critical head-on environment
- Configurations are then modified with one LRD on each mooring line and evaluated for the same environmental conditions;
- Rope and chain MBL and line hang-off angle are changed to optimize strength utilization
- 50yr extreme environment (DLC 6.2 parked)

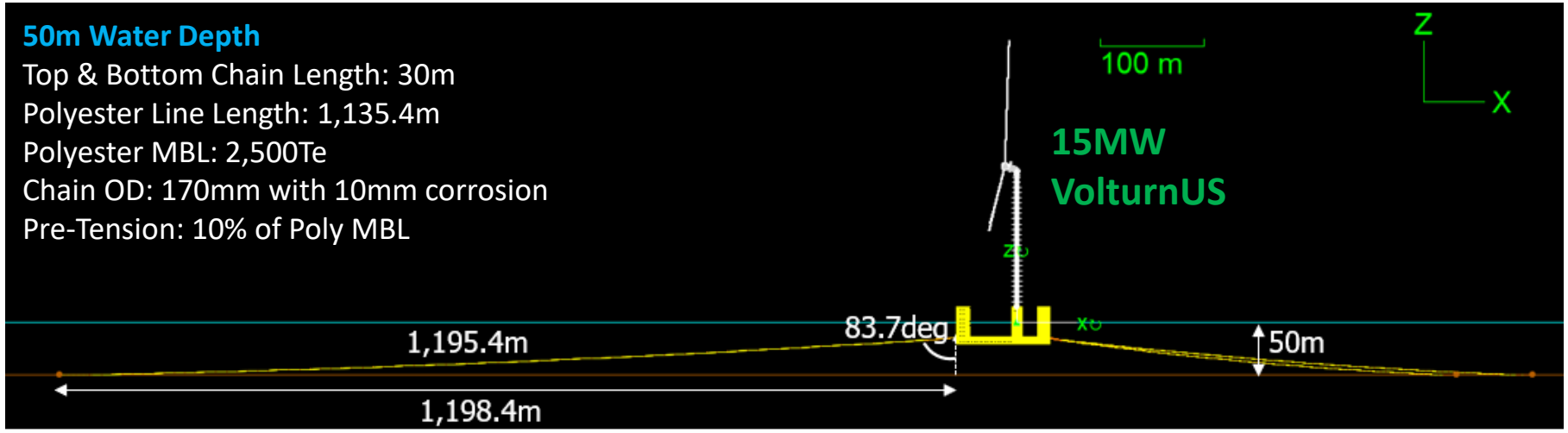
Parameter	Hs (m)	Tp (s)	Surface Current (m/s)	Wind Speed @ 10m (m/s)
Value	12.5	20	0.5	38

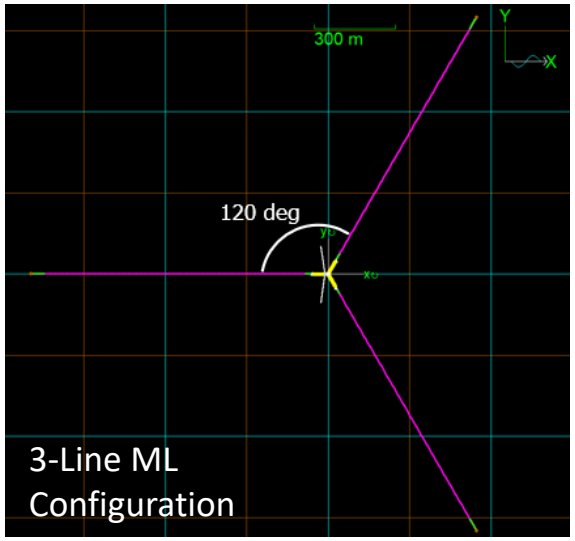


Base Mooring Configurations – No LRD (50m, 100m)

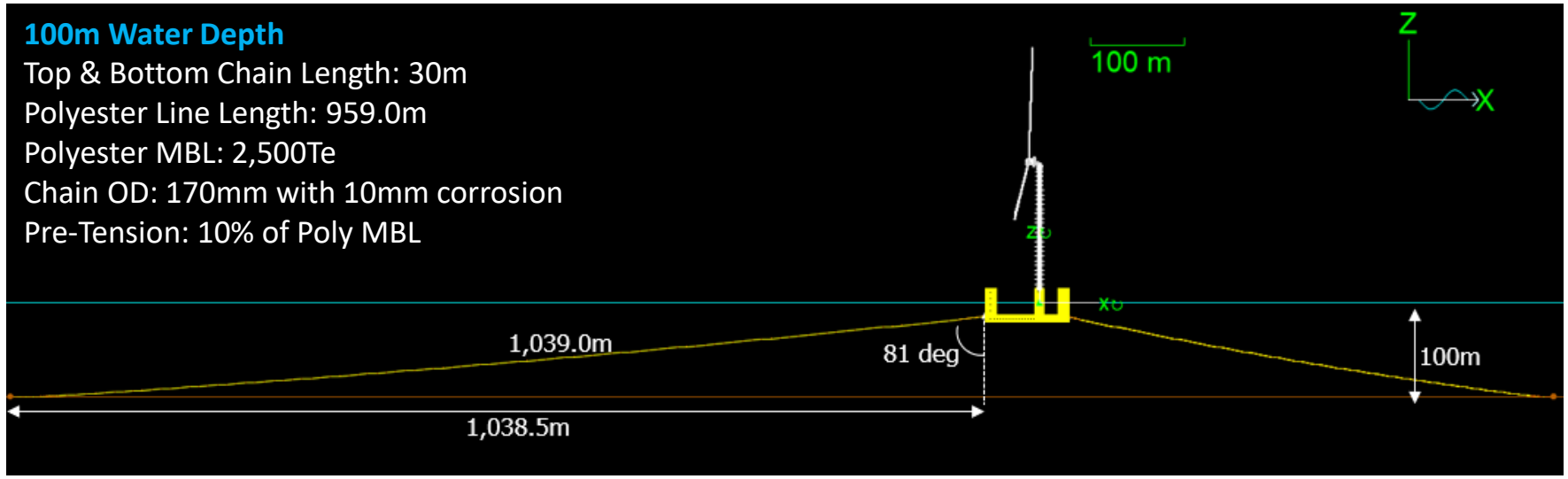


50m Water Depth
Top & Bottom Chain Length: 30m
Polyester Line Length: 1,135.4m
Polyester MBL: 2,500Te
Chain OD: 170mm with 10mm corrosion
Pre-Tension: 10% of Poly MBL



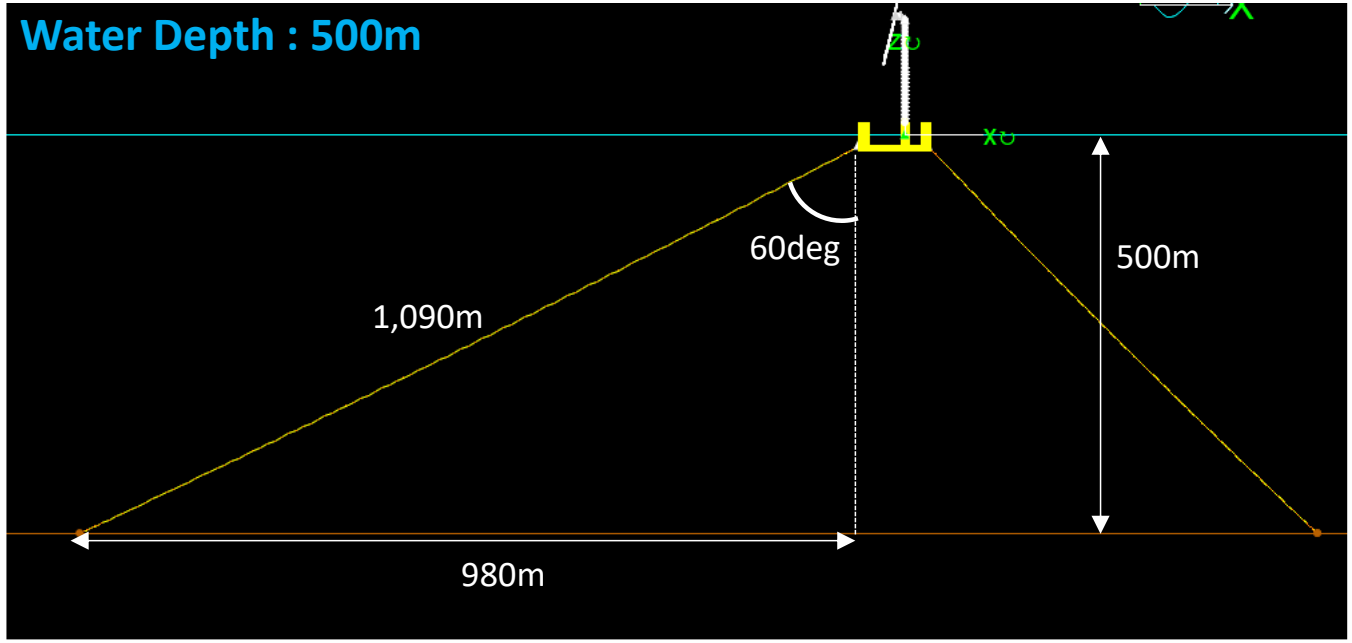


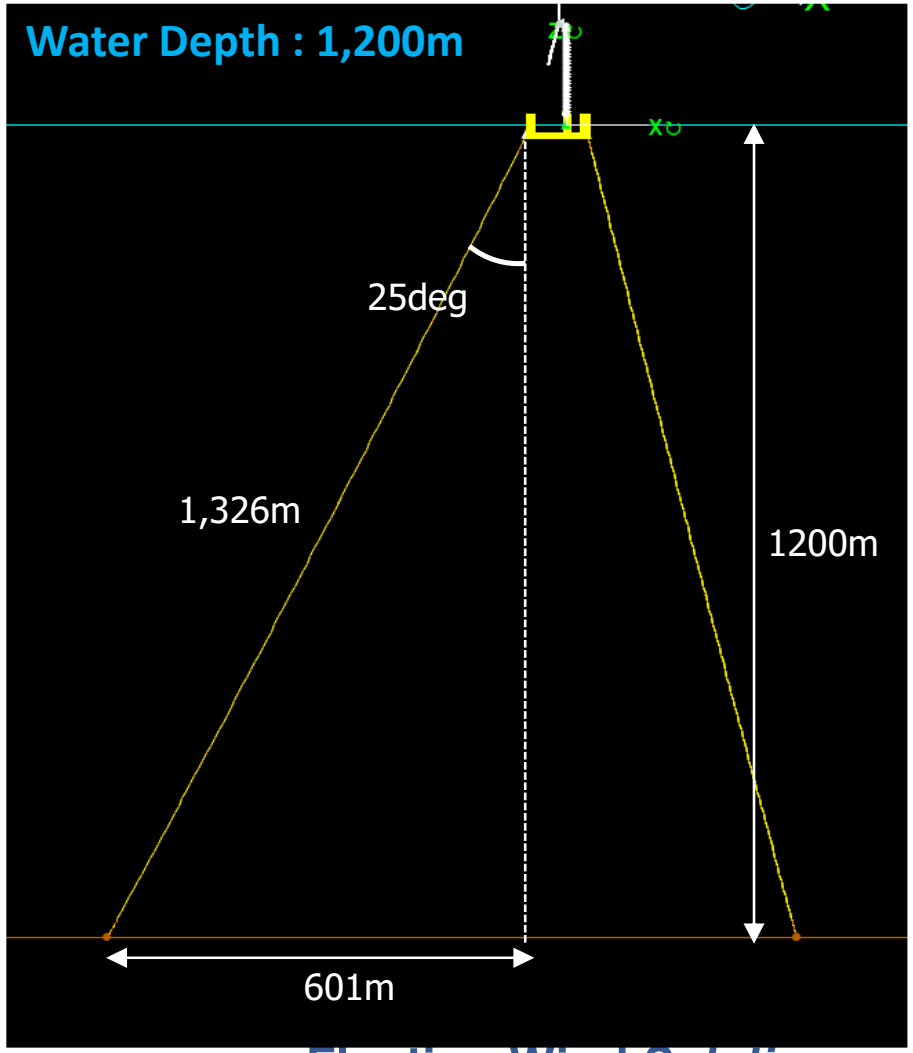
100m Water Depth
Top & Bottom Chain Length: 30m
Polyester Line Length: 959.0m
Polyester MBL: 2,500Te
Chain OD: 170mm with 10mm corrosion
Pre-Tension: 10% of Poly MBL



Base Mooring Configuration – No LRD (500m, 1200m)

- Polyester MBL: 2500Te & 2000Te
- Chain OD @ 500m: 170mm
- Chain OD @ 1200m: 150mm
- Top and Bottom Chain Length: 30m
- Pre-Tension @ 500m : 12.5% of Poly MBL
- Pre-Tension @ 1200m : 10% of Poly MBL





Mooring Configuration Summary – No LRD

Water Depth	Hang-Off Angle	Preload	Polyester Line MBL[1]	Chain OD	Chain MBL[2][3]	Anchor Radius	Total ML Length	Overall Strength Utilization[4]
m	degrees	% of Polyester MBL	Te	mm	Te	m	m	-
50	83.7	10%	2,500	170	2,606	1,198	1,195	**80.7%**
100	81	10%	2,500	170	2,606	1,038	1,039	**87.0%**
500	60	12.5%	2,500	170	2,606	980	1,090	**88.9%**
1,200	25	10%	2,000	150	2,098	601	1,326	**85.1%**

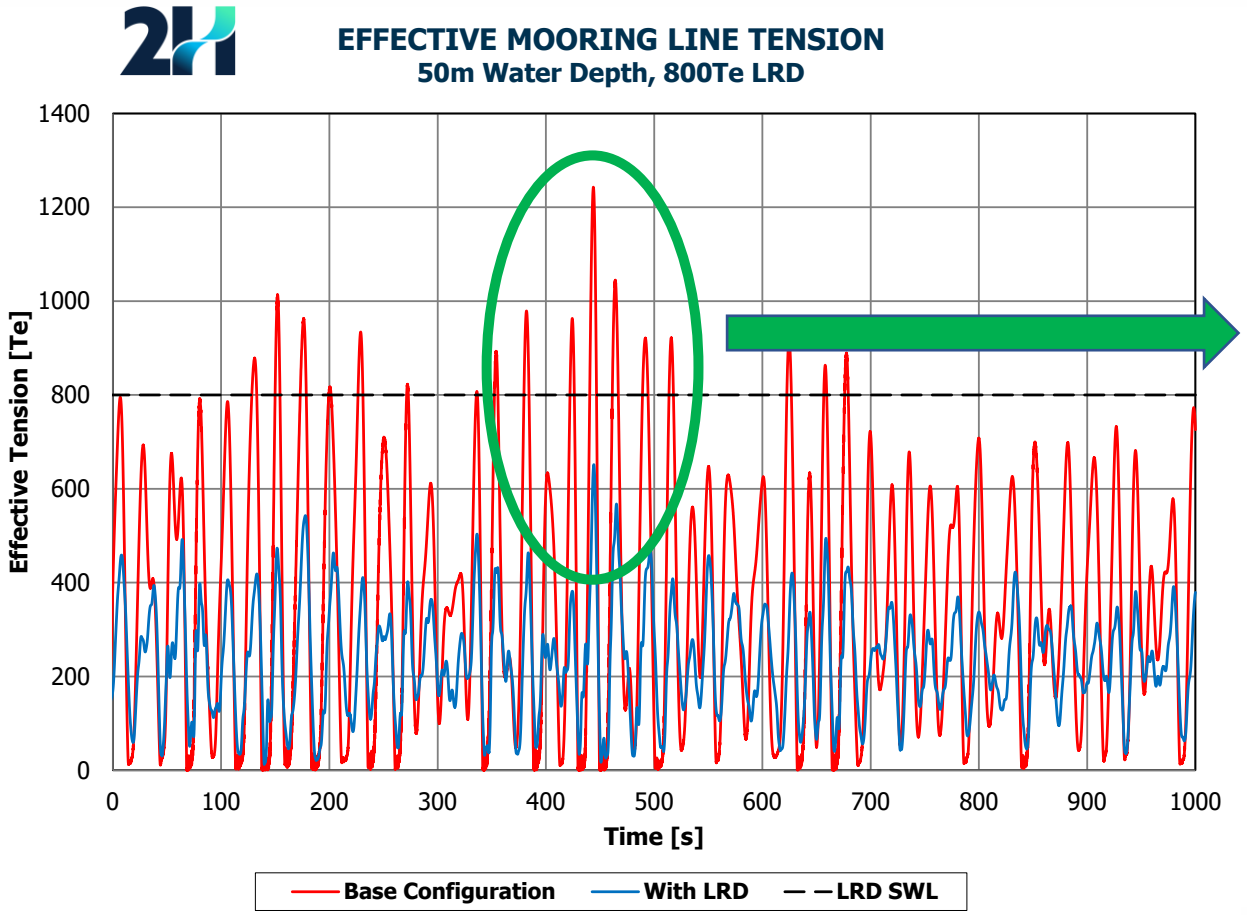
Similar ML Lengths

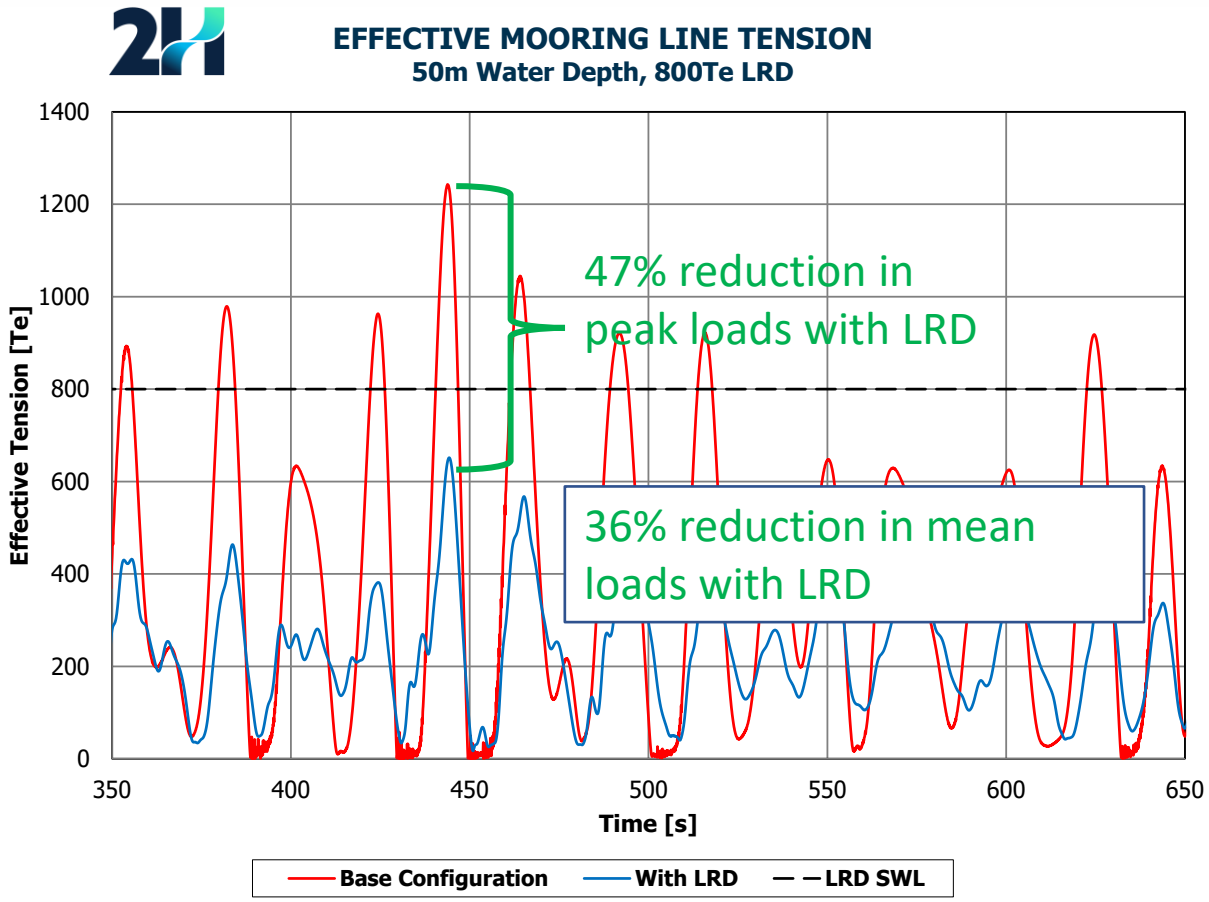
1\ Polyester axial stiffness (30XMBL).
2\ Considering 10mm of corrosion.
3\ Polyester line MBL controls for strength.
4\ Maximum allowable overall strength utilization = 95%, calculated per DnV-ST-0119, consequence class 1.

Mooring Configurations for 50m and 100m – with DO LRD

Water Depth	Configuration	LRD SWL	Rope MBL	Pre-Tension	Hang-Off Angle	Anchor Radius	ML Length	Strength Utilization	Max Tension
		Te	Te	% MBL	Degrees	m	m	-	Te
50m	Base Configuration	-	2,500	10	83.7	1,198	1,195.4	80.7%	1,243
	800Te LRD, 2000Te Poly	800	**2,000**	10	83.7	1,198	1,175.6	71.0%	743
	800Te LRD, 1500Te Poly	800	**1,500**	10	83.7	1,029	1,007.6	81.0%	636
	800Te LRD, 1000Te Poly	800	**1,000**	44%	83.7	**1,029**	1,007.9	36% .7%	441
	800Te LRD, 1000Te Poly	800	1,000	10	**83.5**	**942**	**920.7**	88.9%	470
	800 Te LRD, 1400Te Poly,	800	**1,400**	10	83.2	771	**762.2**	88.9%	656

Mooring Configurations for 50m WD – with DO LRD





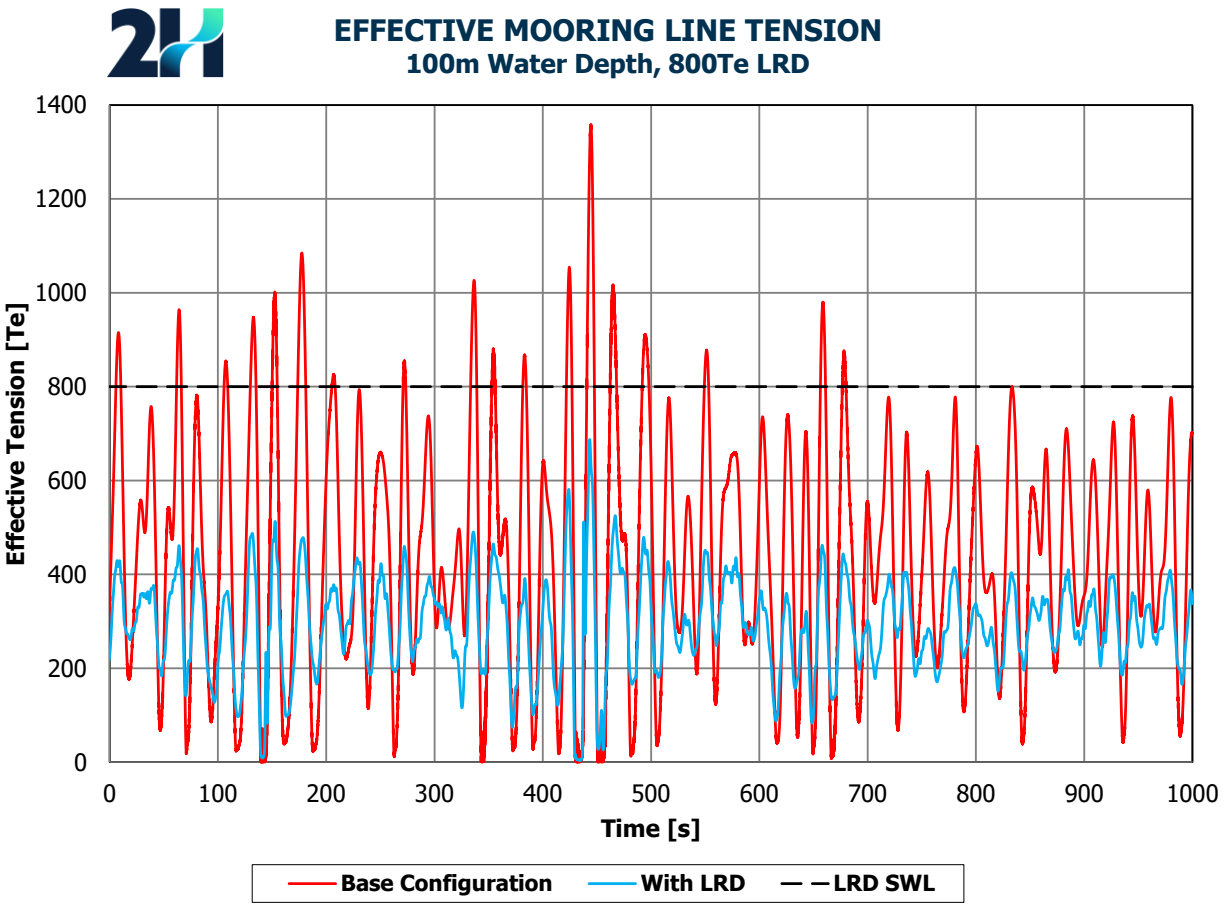
Mooring Configurations for 500m & 1200m WD – with DO LRD

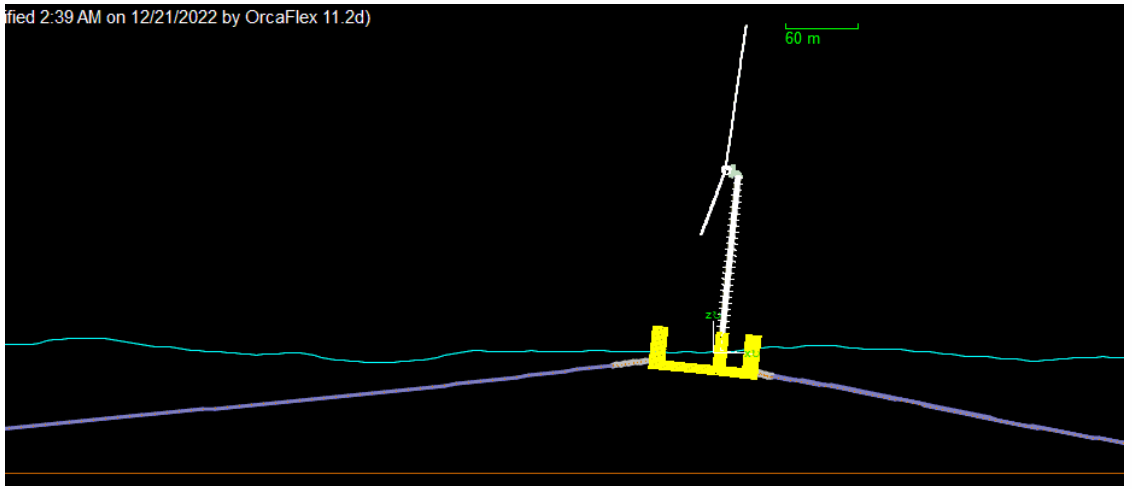
Water Depth	Configuration	LRD SWL	Rope MBL	Pre-Tension	Hang-Off Angle	Anchor Radius	ML Length	Strength Utilization	Max Tension
		Te	Te	% MBL	Degrees	m	m	-	Te
500m	Base Configuration	-	2,500	12.5	60	980	1,089.9	88.9%	1,407
	800Te LRD, 1500Te Poly	800	**1,500**	12.5	60	975	1,067.1	72.2%	678
	800Te LRD, 1000Te Poly	800	**1,000**	12.5	60	975	**1,067.6**	79.4%	494
	800Te LRD,1000Te Poly HOA: 46.5 deg	800	1,000	12.5	46.5	557	**719.6**	91.9%	587
	800Te LRD, 1400Te Poly HOA: 40 deg	800	**1,400**	12.5	40	439	**635.8**	90.1%	781

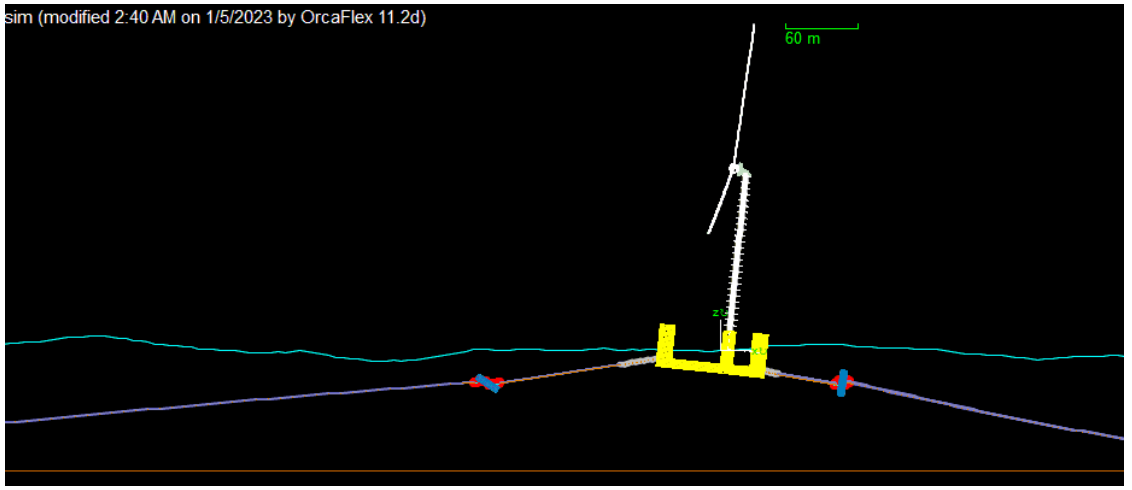
44%

42%

Mooring Response for 100m with and without DO LRD





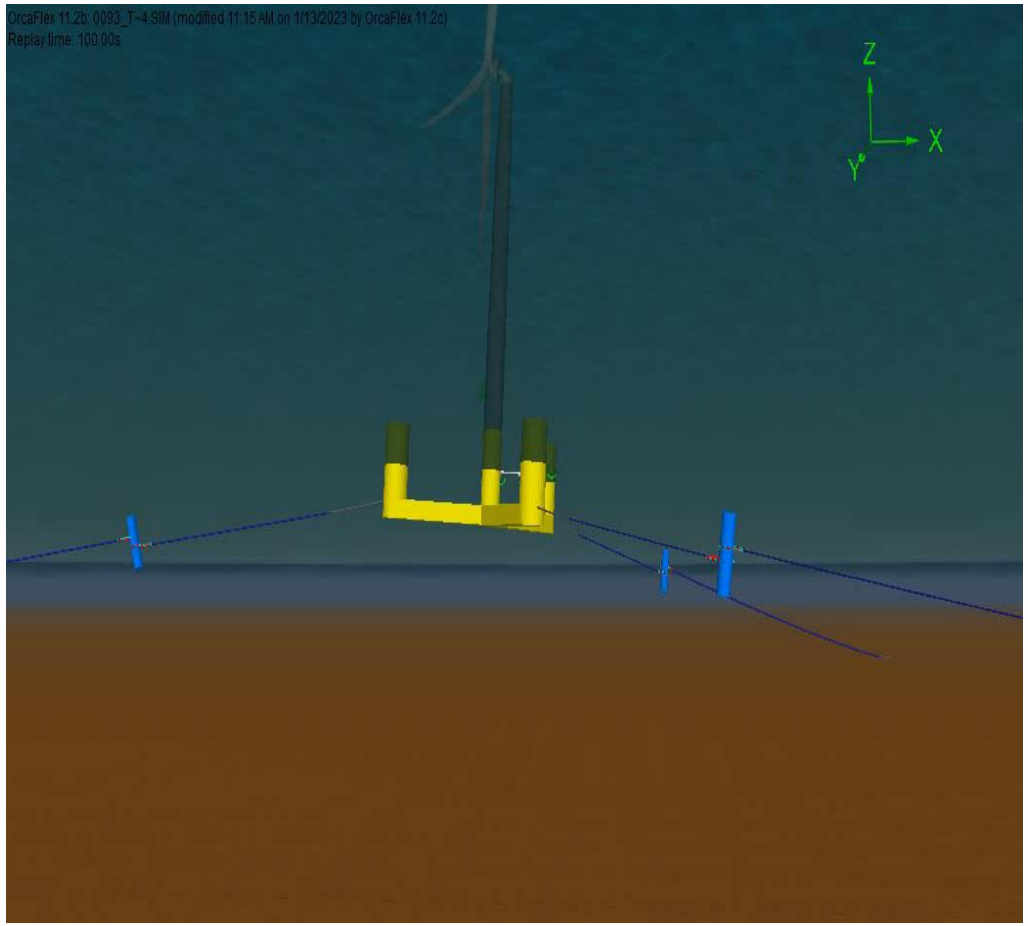


Results Comparison Summary

Water Depth	Mooring Line MBL Reduction	Max Tension Reduction	Mean Tension Reduction	Anchor Radius Reduction	Mooring Length Reduction
50m	44%	48.2%	35.7%	34.7%	36.2%
100m	52%	53.5%	33.6%	25.4%	27.0%
500m	44%	47.4%	18.0%	55.2%	41.6%
1,200m	40%	49.1%	13.2%	-5.8%	0.0%

Key Takeaways

- Mooring and anchor designs are governed by the peak mooring tension that occurs only few times during extreme conditions.
- Mooring load reduction devices can effectively reduce mooring peak and mean tensions by altering the mooring stiffness characteristics.
- LRDs can come in different shapes and forms with different response behavior.
- LRDs can be customized based on FOWT response, mooring configuration, metocean, and water depth to reduce mooring and anchor strength requirements and/or to reduce mooring footprint.



For any questions, please contact

Yusuf Arikan, Sr. Project Manager Renewables
yusuf.arikan@2hoffshore.com