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Mooring System Design for Floating Platforms

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TWIND Summer School
06/07/2021

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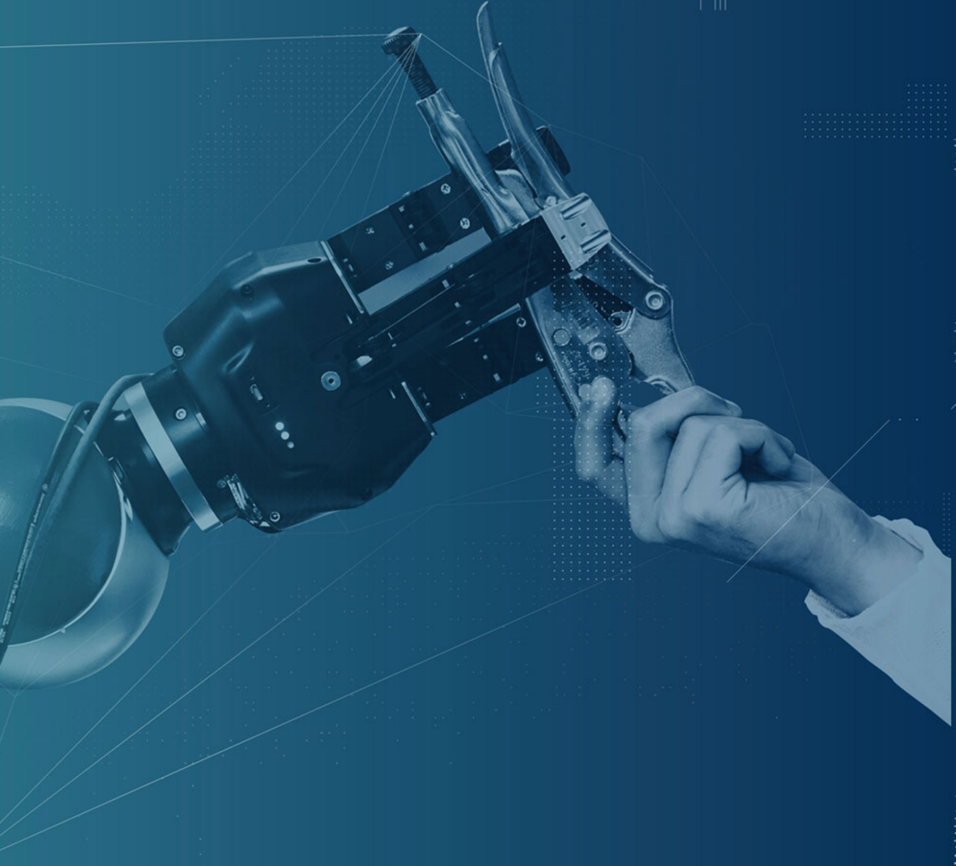
Outline



Mooring floating platforms

Mooring system mission

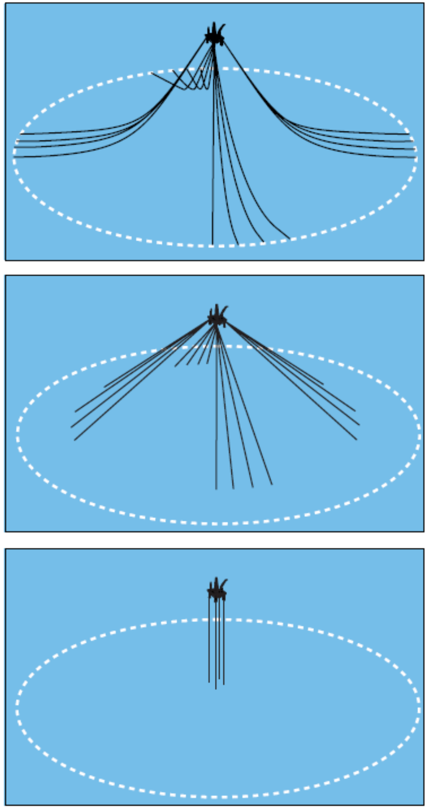
- **Keep floating device on station** to a given tolerance (maximum excursion allowed by dynamic cable and site requirements), and within maximum footprint. Inputs for mooring designer.
- Withstand aero/hydrodynamic forces for expected environmental conditions in the site: Ultimate Limit State (**ULS**), Accident Limit State (**ALS**) and Fatigue Limit State (**FLS**).
- Contribution to **platform stability** in different DOFs, given incident dynamic loads.

Main mooring system concepts in floating platforms

Catenary mooring
- No vertical load in anchors
- Easier to install
- Restoring force from line weight

Taut leg mooring
- For deeper water
- Vertical loads in anchors
- Smaller footprint
- Restoring force from elastic deformation

Tension leg mooring
- For very deep water
- Expensive anchoring
- Provides platform vertical stability



Vryhof

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Mooring Systems main components

Chain (studless / studlink)

- Studless more used for permanent moorings

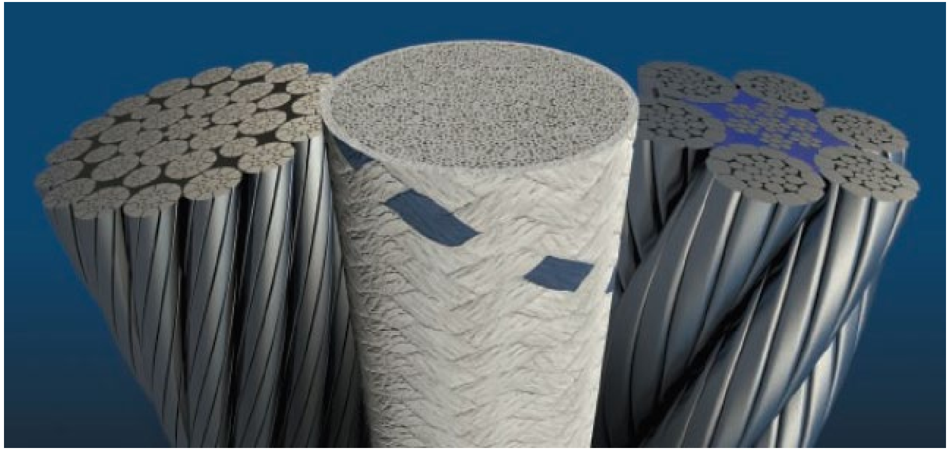
DIA mm	Break Load R5 ABS-DNV kN	R4S ABS-DNV kN	R4 ABS-DNV kN	R3S ABS-DNV kN	R3 ABS-DNV kN	API API kN	DIA mm	Weight kg/m
68	5706	5420	4885	4440	3976	3762	68	92
70	6021	5720	5156	4685	4196	3970	70	98
73	6507	6182	5572	5064	4535	4291	73	107
76	7009	6658	6001	5454	4884	4621	76	116
78	7351	6984	6295	5720	5123	4847	78	122
81	7877	7484	6745	6130	5490	5194	81	131
84	8418	7997	7208	6550	5866	5550	84	141
87	8971	8523	7682	6981	6252	5916	87	151
90	9539	9062	8167	7422	6647	6289	90	162
92	9924	9428	8497	7722	6916	6544	92	169
95	10512	9987	9001	8180	7326	6932	95	181
97	10911	10366	9343	8490	7604	7195	97	188
100	11520	10944	9864	8964	8028	7596	100	200
102	11932	11336	10217	9285	8315	7868	102	208
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Vicinay Cadenas

Mooring Systems main components

Wire rope / fiber rope

- Lower weight, higher elasticity and more sensitive to damage and corrosion than chain.
- Fiber rope (polyester, polyethylene) for deeper waters.



DYFORM® DB2K

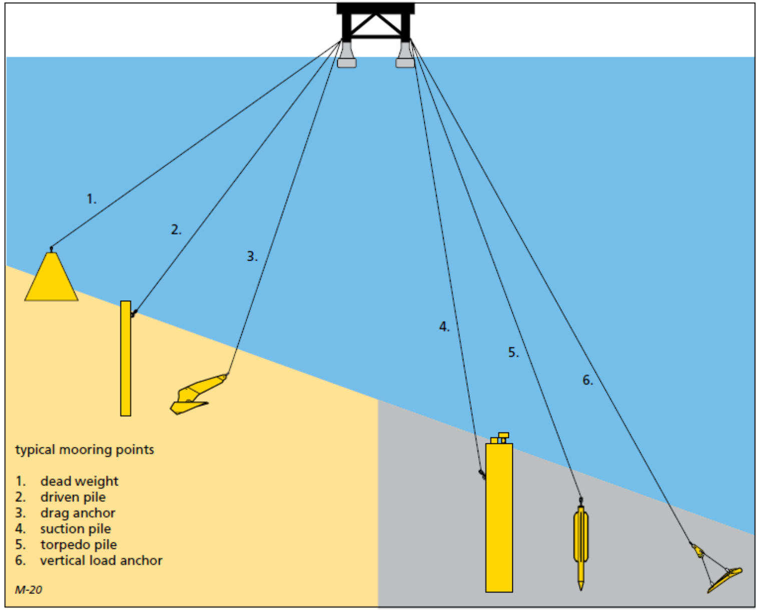
Rope diameter		Approximate mass				Minimum breaking force (Fmin)			Axial stiffness @20% load		Torque generated @20% load		Metallic cross section	
		In air		Submerged							Ordinary lay			
mm	in	kg/m	lb/ft	kg/m	lb/ft	kN	Tonnes	Tons (2000lbs)	MN	Mlbs	kN.m	lbs.ft	mm²	in²
52		12.2	8.87	11.5	7.72	2396	244	269	146	33	1.6	1195	1402	2.17
54	2 1/8	13.2	8.87	11.5	7.72	2584	263	290	157	35	1.8	1338	1512	2.34
56		14.2	9.54	12.4	8.30	2778	283	312	169	38	2.0	1492	1626	2.52
57.2	2 1/4	14.8	10.0	13.0	8.71	2899	295	326	176	40	2.2	1590	1696	2.63
60		16.3	11.0	14.2	9.53	3190	325	358	194	44	2.5	1835	1866	2.89
60.3	2 3/8	16.5	11.1	14.3	9.63	3222	328	362	196	44	2.5	1863	1885	2.92
63.5	2 1/2	18.3	12.3	15.9	10.7	3573	364	401	217	49	3.0	2175	2090	3.24
64		18.6	12.5	16.1	10.8	3629	370	408	221	50	3.0	2227	2123	3.29
66.7	2 5/8	20.2	13.5	17.5	11.8	3942	402	443	240	54	3.4	2521	2306	3.57
68		20.9	14.1	18.2	12.2	4097	418	460	249	56	3.6	2671	2397	3.72
69.9	2 3/4	22.1	14.9	19.3	12.9	4329	441	486	263	59	3.9	2902	2533	3.93
72		23.5	15.8	20.4	13.7	4593	468	516	279	63	4.3	3171	2687	4.17
76		26.2	17.6	22.8	15.3	5118	522	575	311	70	5.1	3729	2994	4.64
76.2	3	26.3	17.7	22.9	15.4	5145	524	578	313	70	5.1	3759	3010	4.67
80		29.0	19.5	25.2	16.9	5670	578	637	345	78	5.9	4350	3318	5.14
82.6	3 1/4	30.9	20.8	26.9	18.1	6045	616	679	368	83	6.5	4788	3537	5.48
84		32.0	21.5	27.8	18.7	6252	637	702	380	85	6.8	5036	3658	5.67
88		35.1	23.6	30.5	20.5	6861	699	771	417	94	7.9	5790	4014	6.22
88.9	3 1/2	35.8	24.1	31.1	20.9	7002	714	787	426	96	8.1	5969	4097	6.35
92		38.3	25.8	33.4	22.4	7321	746	822	456	103	8.8	6456	4387	6.80
95.3	3 3/4	41.1	27.6	35.8	24.1	7856	801	882	490	110	9.7	7176	4708	7.30
96		41.7	28.1	36.3	24.4	7972	813	896	497	112	9.9	7335	4777	7.40
100		45.3	30.4	39.4	26.5	8430	859	947	539	121	11	8086	5184	8.03
101.6	4	46.8	31.4	40.7	27.3	8702	887	978	556	125	12	8481	5351	8.29

Bridon

Mooring Systems main components

Anchors

- Dead weight, drag, pile, suction, vertical load anchor.



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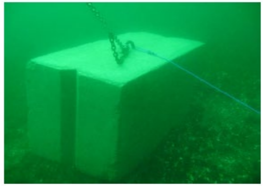
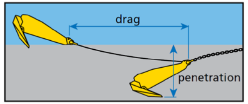
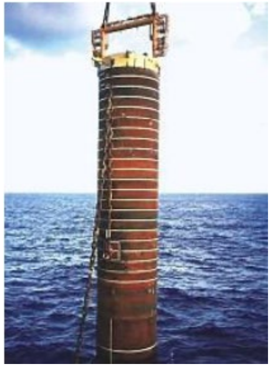
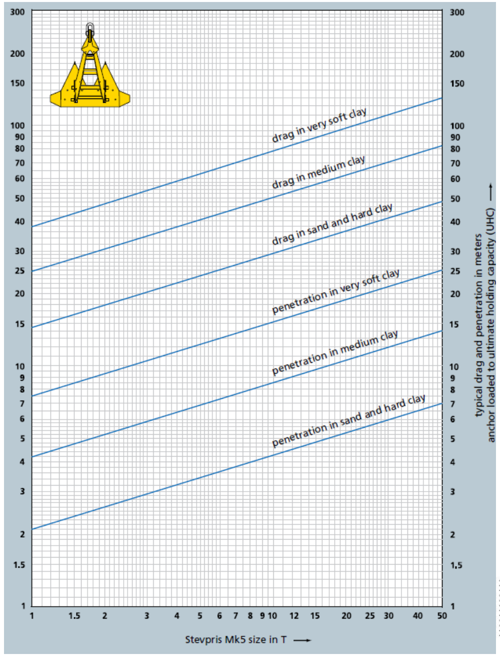




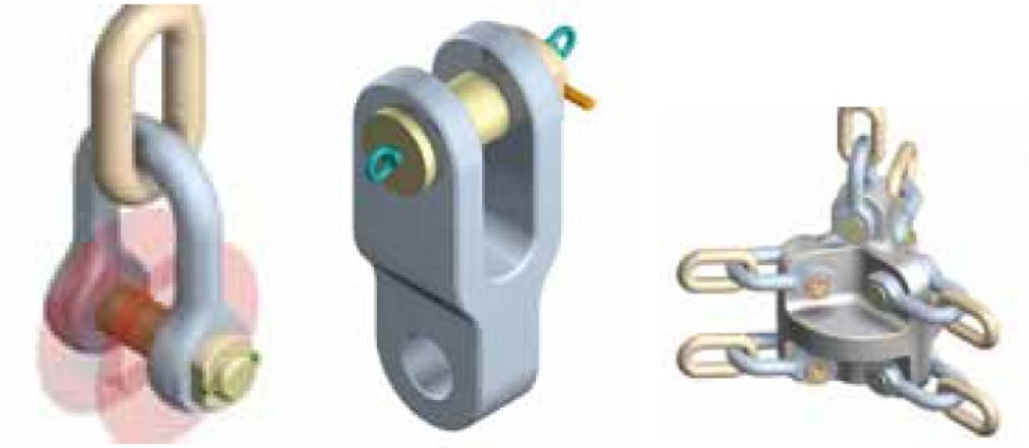




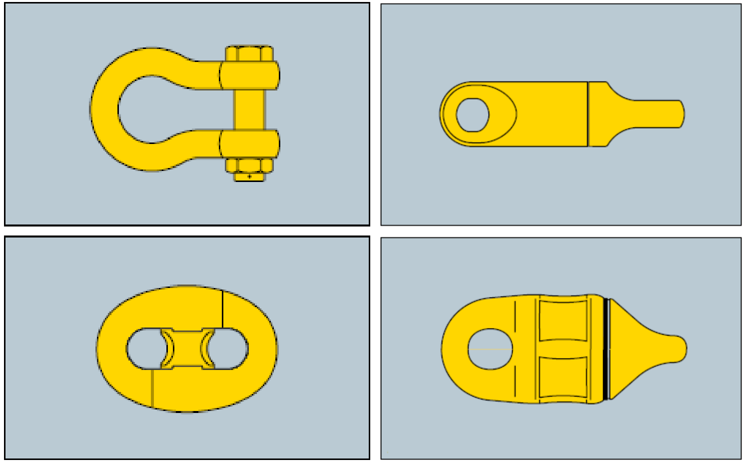
Mooring Systems main components

Line Connectors

- Shackles, Kenter, swivels, etc.



Vicinay Cadenas



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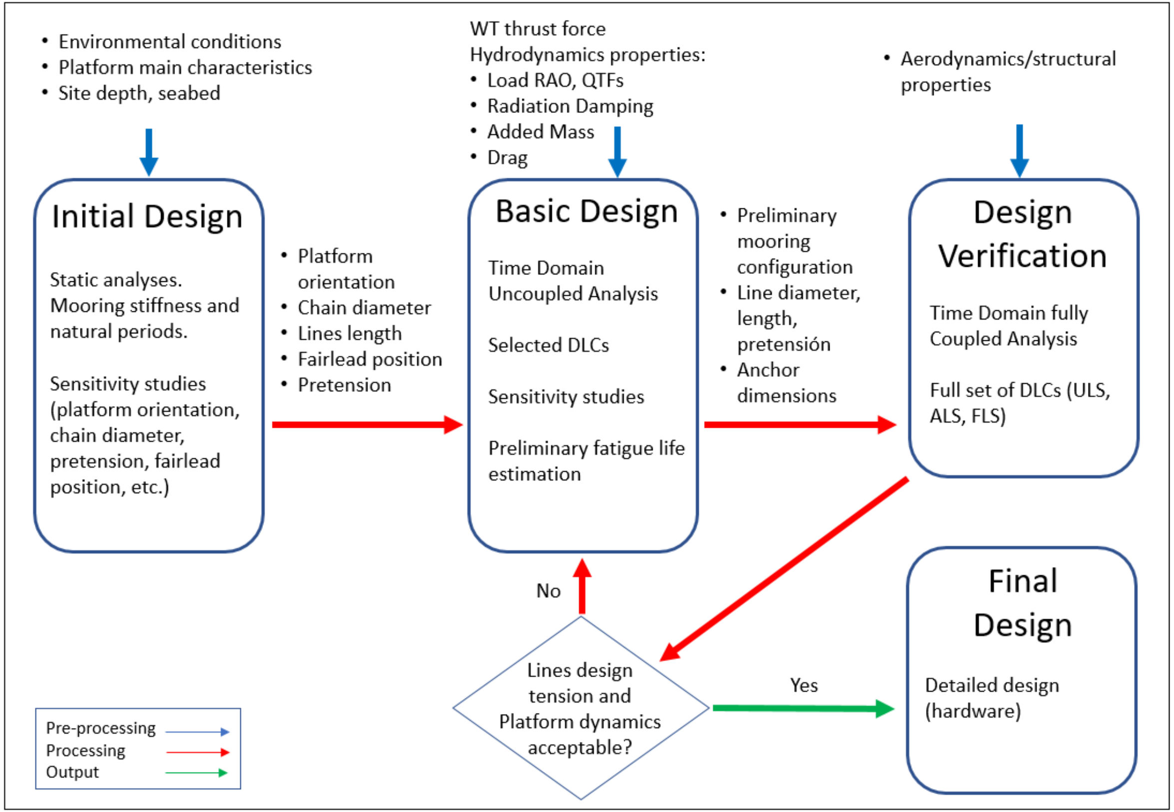
Mooring system design process

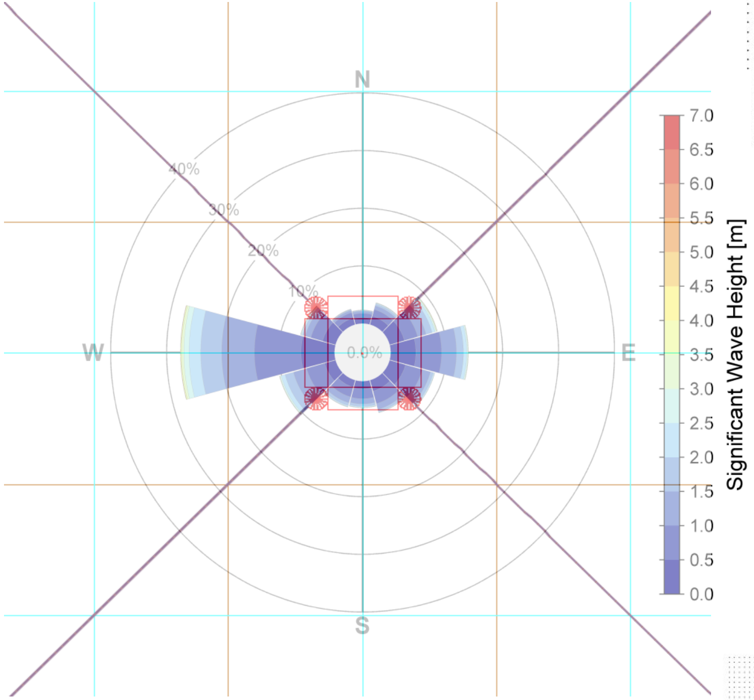
Mooring system basic design process



Initial Mooring System Design

Platform Orientation

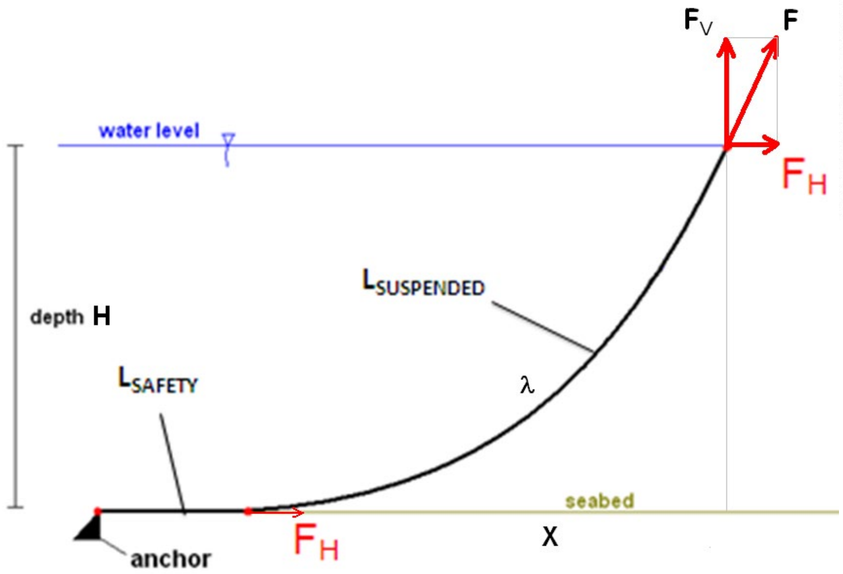
- Extreme wind, wave and current incident directions
- Swell incident direction. Fatigue life very sensitive to platform relative orientation
- Consider mooring layout symmetry



Initial Mooring System Design

Preliminary static considerations:

- Mooring system type depending on site depth and footprint available
- Preliminary force estimation and line characteristics (diameter, length)
- Mooring system stiffness and platform natural periods



$$H = \frac{F_H}{\lambda g}\left[\cosh\left(\frac{\lambda g}{F_H}X\right) - 1\right]$$

$$L_{susp} = \frac{F_H}{\lambda g}\sinh\left(\frac{\lambda g}{F_H}X\right)$$

Basic Mooring System Design

- Main forces estimation (WT thrust, aero/hydrodynamics forces)

- **Platform hydrodynamics**. Second order effects relevant for mooring system: Mean drift forces, Slow drift motions leading to larger displacements and lines peak tensions. Sum frequency components only important for TLP.

- **Time domain** simulations for **selected DLCs**, can be uncoupled in aero/hydrodynamics for basic design. Frequency domain or Quasiestatic (neglecting lines drag/added mass) approaches are faster but underestimate lines peak loads (more acceptable in O&G large platforms).

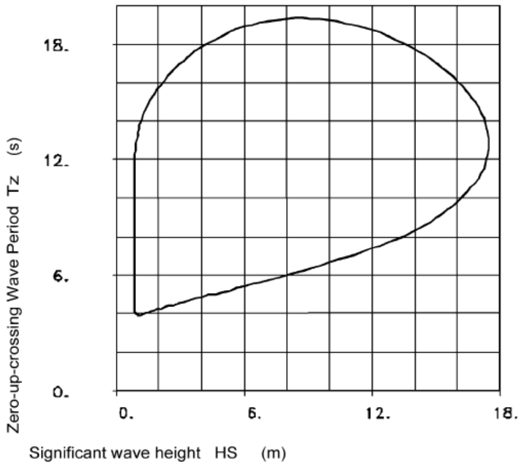
- Platform hydrodynamics modelling: **Potential Flow** model + Additional Damping for Operational cases (diffraction). **Morison** based model for Extreme cases (drag). Hybrid model also possible but can overestimate forces.

Basic Mooring System Design

- Extreme ULS cases and preliminary fatigue analysis for FLS cases provide **line diameter**, which can be driven by ULS or FLS.
- Platform excursion and surge period provide **lines pre-tension**. Consider maximum platform excursion allowed by dynamic cable.
- Preliminary ALS cases to be considered: maximum platform **excursion** with a broken line (pretension), mooring system **redundancy** (number of lines, often more redundant in O&G).

Load Cases definition

- Combinations from **wind/wave/current/tide** site conditions, normally non-collinear.
- Joint wind/wave/current probabilities to define LCs
- Select **worst cases** for basic mooring design: maximum line load, maximum platform offset.
- Wind, wave, current **magnitude**, incident **direction**, vertical **profile**…
- Standards provide some criteria (*DNVGL-ST-0437. Loads and site conditions for wind turbines*)



Environmental Contour: 100-year

DNV-OS-C301 Position Mooring

Significant wave height, H_s (m) \ Average wave period, T_{av} (s)	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13
0-0.5	0	1	0	1	1	0	0	0	0
0.5-1	18	132	290	387	262	137	28	8	0
1-1.5	0	291	434	763	929	718	395	103	7
1.5-2	0	32	333	696	1041	812	356	65	37
2-2.5	0	1	88	406	659	726	374	159	61
2.5-3	0	0	18	144	464	698	380	194	94
3-3.5	0	0	0	26	229	415	313	155	42
3.5-4	0	0	0	6	71	234	175	86	28
4-4.5	0	0	0	1	20	98	113	65	30
4.5-5	0	0	0	0	2	34	78	56	31
5-5.5	0	0	0	0	0	2	28	44	23
5.5-6	0	0	0	0	0	1	11	34	29
6-6.5	0	0	0	0	0	0	1	8	33
6.5-7	0	0	0	0	0	0	0	4	15
7-7.5	0	0	0	0	0	0	1	2	4
7.5-8	0	0	0	0	0	0	0	3	3
8-8.5	0	0	0	0	0	0	0	0	2
8.5-9	0	0	0	0	0	0	0	0	3

Modeling mooring lines: hydrodynamics

- Line **Drag**

$$f = \frac{1}{2}\rho C_D D \cdot v \cdot |v|$$

Drag coefficients

Mooring component	Transverse	Longitudinal
Stud chain	2.6	1.4
Stud less chain	2.4	1.15
Stranded rope	1.8	*

- **Marine growth** (weight and drag increased)

$$M_{growth} = \frac{\pi}{4}\left[(D_{nom} + 2\Delta T_{growth})^2 - D_{nom}^2\right]\rho_{growth} \cdot \mu$$

$$C_{Dgrowth} = C_D\left[\frac{D_{nom} + 2 \cdot \Delta T_{growth}}{D_{nom}}\right]$$

	56 - 59º N		59 - 72º N	
Water depth(m)	Thickness(mm)	Density ρ_{mg} (kg/m^3)	Thickness(mm)	Density ρ_{mg} (kg/m^3)
Above +2	0	-	0	-
-15 to +2	100	1300	60	1325
-30 to -15	100	1300	50	1325
-40 to -30	100	1300	40	1325
-60 to -40	50	1300	30	1100
-100 to -60	50	1300	20	1100
Below -100	50	1300	10*	1100*

*) Cold water corals can build up local colonies with no limitation regarding size in water depths between 100 and 800 m. Cold water corals are assumed not to occur for temperatures below 2 deg Celcius, i.e. for the Norwegian continental shelf it may be assumed that these occur in water depths between 100m and 450m. The density of the marine growth should be taken as 1300 kg/m3 in the whole water depth range where cold water corals can be found.

DNV-OS-C301 Position Mooring

Modeling mooring lines: corrosion

- Corroded line breaking strength value is lower:

$$S_{mbs-corr} = S_{mbs} \cdot \left(\frac{D_{corr}}{D_{new}}\right)^2$$

Corrosion allowance for chain

Part of mooring line	*Corrosion allowance referred to the chain diameter*			
	Regular inspection[1] (mm/year)	*Regular inspection[2] (mm/year)*	*Requirements for the Norwegian continental shelf*	*Requirements for tropical waters*
Splash zone [4]	0.4	0.2	0.8 [3]	1.0
Catenary [5]	0.3	0.2	0.2	0.3
Bottom [6]	0.4	0.3	0.2 [7]	0.4

DNV-OS-C301 Position Mooring

Mooring line diameter definition: Design Tension

Line **Design Tension** T_d:

$$T_d = \gamma_{mean} \cdot T_{c,mean} + \gamma_{dyn} \cdot T_{c,dyn}$$

in which $T_{c,mean}$ = characteristic mean tension, $T_{c,dyn}$ = characteristic dynamic tension, and γ_{mean} and γ_{dyn} are load factors for each component respectively.

$$S_C = 0.95 \cdot S_{mbs} \qquad S_C > T_d$$

Load factor requirements for design of mooring lines

Limit state	*Load factor*	*Consequence class*	
		1	*2*
ULS	γ_{mean}	1.3	1.5
ULS	γ_{dyn}	1.75	2.2
ALS	γ_{mean}	1.00	1.00
ALS	γ_{dyn}	1.10	1.25

DNV-ST-0119 - Floating wind turbine structures

Mooring line diameter definition: Design Tension

Line diameter given by ULS cases

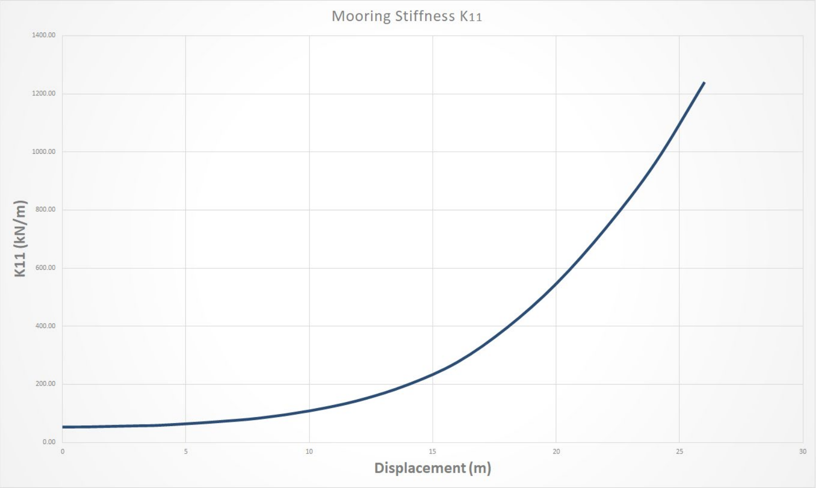
- Run 10 to 20 time-domain 3-hour simulations (different seeds)
- $T_{c,mean}$ is pretension plus mean environmental loads (static wind, current and wave drift). Mean tension value from overall time domain simulation.
- T_{dyn} dynamic part of line tension (oscillatory low-frequency and wave-frequency effects). *MPM* – $T_{c,mean}$; where *MPM (Most Probable Maximum)* can be estimated as mean peak load of each 3-hour simulation (conservative approach)
- Select chain **diameter/quality**. Check fatigue life estimation.

Mooring Pre-tension

Higher pretension means:

- Higher mooring stiffness / lower period (surge/sway/yaw given by mooring system, heave/roll/pitch mainly by hydrostatics)
- Higher line suspended weight
- Higher Installation cost
- Lower platform excursion
- Lower fatigue life

$$T \approx 2\pi\sqrt{\frac{M + A_{11}}{K_{11}}}$$



Mooring examples in FOW

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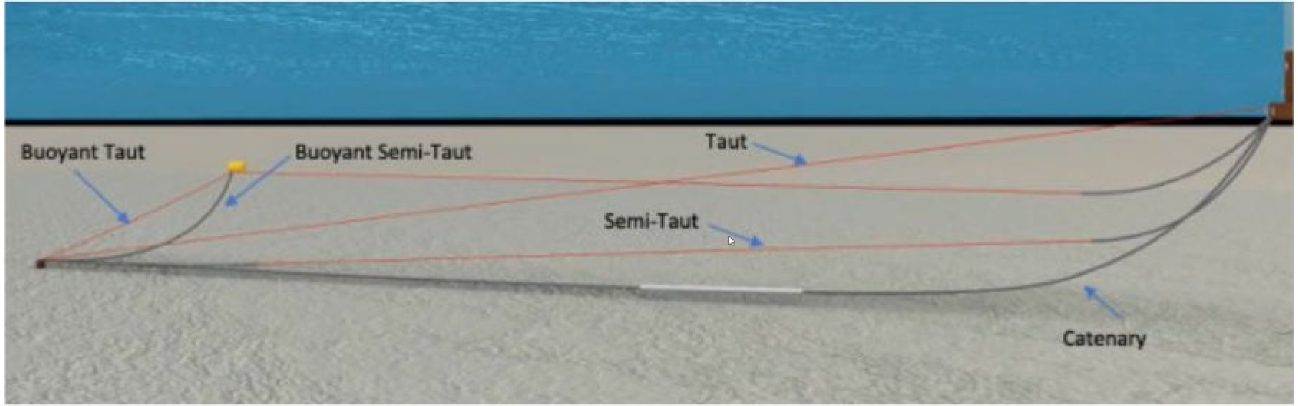
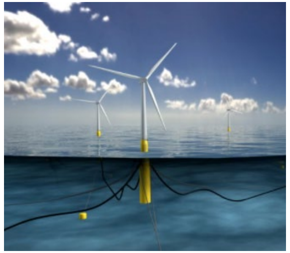
Depth as main site constraint

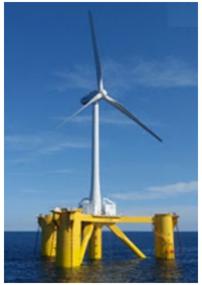
- **Shallow waters**: All chain, good seabed abrasion, adds hold capacity to anchor, clump weight near touchdown point.
- **Deeper waters**: Central section of wire rope reduces mooring weight and cost.
- **Ultra deep waters**: Rope wire section offers lighter weight, lower stiffness and cost, and longer fatigue life. Chain-polyester-chain is a possible configuration.

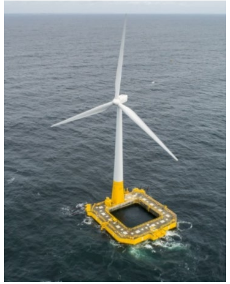


Some industry examples

- Catenary with Drag anchors concept mostly used, even for different platform concepts.
- Redundant lines used in some cases.


Hywind


Fukushima


Floatgen

	Hywind Scotland	Fukushima – MIRAI	Floatgen
Floater type	Spar	semi-sub	Concrete damping Pool concept
Turbine capacity	5 x 6MW (Siemens Gamesa)	2 MW	2 MW
Water Depth	95—129 metres (105 m)	120	33
Mooring configuration	Catenary	Catenary	Catenary
Number of lines	3	6	6
Mooring length	Mooring line lengths are ranging from 700 to 900	450-480	Mooring line radius at aft (4 mooring lines): 400m. Mooring line radius at fore (2 mooring lines): 850m.
Anchor type	Suction anchor (5m in diameter and 16m in height) made of steel weight of about 100 tonnes per anchor	Drag-embedded (Vryhof STEVSHARK)	Drag-embedded
Materials	Steel chain	Advanced steel chain (Nippon Steel 1 Sumito Metal)	Synthetic fiber (nylon) mooring rope and chain at both extremities of all mooring lines.
Mooring line characteristics	Offshore grade studless mooring chains. Dimensions are between 132 and 148 mm in diameter.	132mm diameter	

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