

# MOORING OPERATIONS GUIDE



## VOLUME #1

### A GUIDEBOOK OF SELECTED TECHNICAL ARTICLES ON MOORING

Over the years, TheNavalArch has been supporting its customers, readers and followers with technical content relevant to their daily work. With the endeavor to bring quality online content to the maritime industry, we present to you our industry guides - selected articles covering different aspects of the industry - encompassing maritime design and operations.

In this guide, we bring to you a collection of technical articles on mooring operations, which is a critical and frequently encountered aspect of Maritime industry. This guide will be helpful for mooring engineers, port captains, naval architects, and anyone else interested in the fascinating engineering that goes behind mooring operations.



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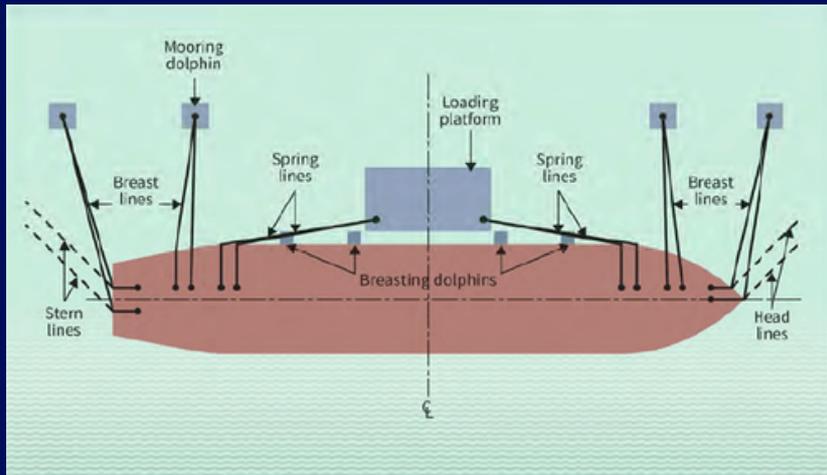
## OCIMF MEG-4 and Mooring Design of your vessels

### Environment and Environmental forces

The OCIMF (Oil Companies International Marine Forum) has come out with the latest edition of mooring Equipment Guidelines (MEG) – Rev 4. This revision incorporates significant changes and updates over the MEG-3, the third Edition. The changes include, besides other additions, a guidance on documentation of mooring equipment (Mooring System Management Plan), addition of a section on human factors in mooring operations, and significant updates to the Appendix A for calculating environmental forces on tankers/gas carriers.

Mooring in the context of MEG-4 means mooring to a fixed structure like a berth, jetty, terminal or another ship.

# Mooring Forces and Mooring Design



In simplest terms, mooring involves tying the vessel to a berth using ropes so that the vessel stays in place and is not carried away by the environment. The environment may comprise wind, current, tides, waves, ice, swell etc. which the berth is subject to.

Hence, the steps to designing a mooring system can be:

The design of mooring at berth can be broken down into a certain number of steps by thinking in very basic terms.

The problem at hand is - we are given a vessel, and we need to moor it to a berth. The first question which pops is why at all we need to berth the vessel? Why can't we just leave it floating? Well, if we leave it floating, it is subject to environmental elements of wind, current, waves, tides etc. These will make it drift, with the possibility of hitting another vessel in the vicinity.

The next thought that comes is: what's the best way to secure it to a berth? The simplest solution we can imagine is using ropes to tie it to strong and fixed structures on the berth. A ship needs equipment like bollards, fairleads and winches which can help secure the rope from ship to the mooring equipment on the berth.

So, how do we go about selecting the right sized rope? What about the bollards, fairleads and winches on the vessel? How big should they be? It is natural to expect that a bigger ship will require bigger sized equipment (bollard, winches, fairleads etc.) and ropes to secure it. How could we devise a method to do it?

- Step 1: Get the environmental data for the berth – wind, wave, current, tide etc.
- Step 2: Calculate, based on the size and geometry of the vessel, the total environmental forces on the vessel
- Step 3: Design a mooring system comprising ropes and equipment adequate for resisting the environmental forces obtained in Step 2. This includes designing the mooring pattern and selecting the right equipment.

## Step 1 – Environmental data

The application of environmental data depends on the purpose which we're using it. If we're designing the mooring equipment of a specific berth or terminal, then the environment experienced at that specific berth is important. This is obtained from Metocean data for the specific berth location.

However, things are different if we're designing the mooring equipment for a ship (which is what this article talks about). A ship may visit multiple berths over its lifetime, and each berth may be subject to different environments. Does that mean that we gather the environmental data of each berth the ship is expected to visit over its lifetime, and then take the worst-case environment? Such an exercise will be extremely cumbersome.

MEG-4 provides a simple solution: Section 3 of MEG-4 provides the 'Standard' environmental criteria which are to be used for ships. These criteria cover a wide range of environmental conditions and can be used for the mooring design. However, these are applicable only for vessels with DWT 16000 MT and above. The criteria are shown below:

60 knot wind (defined below) from any direction simultaneously with:  
3 knots current at 0 degrees or 180 degrees  
or  
2 knots current at 10 degrees or 170 degrees  
or  
0.75 knots from the direction of maximum beam loading

## Loading Conditions and tidal variations

The ship may be loaded to different drafts, which leads to different windage and current areas. For example, when the vessel is ballasted, it has a higher windage area and so the wind forces are expected to be higher compared to other loading conditions with higher draft. Similarly, fully loaded condition will fetch higher current forces compared to other loading conditions.

For the purpose of mooring design, it is generally recommended to investigate two extreme conditions:

- Fully loaded condition at lowest astronomical tide (LAT)
- Ballasted condition at highest astronomical tide (HAT)

## Water Depth to Draft Ratio

The ratio of Water Depth (WD) to Draft (T) is a critical parameter affecting the current forces on a vessel. OCIMF recommends the following values to be used for the WD/T ratio:

- For tankers, WD/T to be taken as 1.05 when loaded and 3.0 when in ballast condition
- For a gas carrier the WD/T should be taken as 1.05 for all conditions

We can see here that there will be multiple cases for which the forces have to be calculated.

Since the wind of 60 knots can be from any direction, simultaneously with current from either head/following seas or beam seas, we need to investigate all cases while varying the direction of current from 0 to 360 deg, and also varying the loading condition (ballast/loaded). To simplify, we can create cases by considering wind and current to be collinear (along the same direction), and investigate the cases listed below:

The cases are listed below:

Case	Environment				Loading Condition
	Wind Speed	Wind Direction	Current Speed	Current Direction	
Case 1	60 knots	0	3 kn	0	Ballast
Case 2	60 knots	180	3 kn	180	Ballast
Case 3	60 knots	10	2 kn	10	Ballast
Case 4	60 knots	170	2 kn	170	Ballast
Case 5	60 knots	90	0.75 kn	90	Ballast
Case 6	60 knots	0	3 kn	0	Loaded
Case 7	60 knots	180	3 kn	180	Loaded
Case 8	60 knots	10	2 kn	10	Loaded
Case 9	60 knots	170	2 kn	170	Loaded
Case 10	60 knots	90	0.75 kn	90	Loaded

Now that we have defined the environmental conditions – wind and current, which also included the loading conditions and water depth to draft ratio, we can move on to the next step: calculation of environmental forces.

## Step 2 – Environmental forces

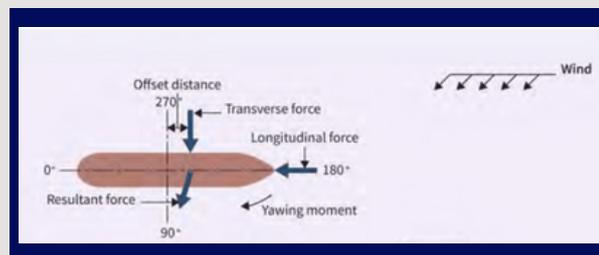
At a berth, generally it is only wind and current forces which significantly impact the design of moorings.

The environmental forces on the vessel can be calculated using the force coefficients provided in Appendix A of OCIMF MEG-4. These tables provide the coefficients for Wind and Current forces depending on the vessel heading, loading condition (ballasted/loaded) and also the Water Depth to Draft ratio. At this stage, and for the purpose of this article, waves and other factors which are ‘dynamic’ in nature (i.e., which cause time-varying forces on the ship) are not considered, and the analysis is limited to a ‘static’ analysis.

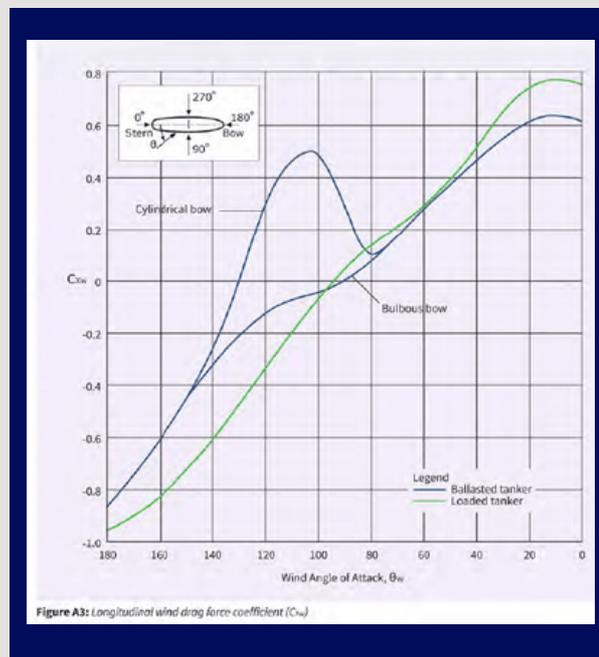
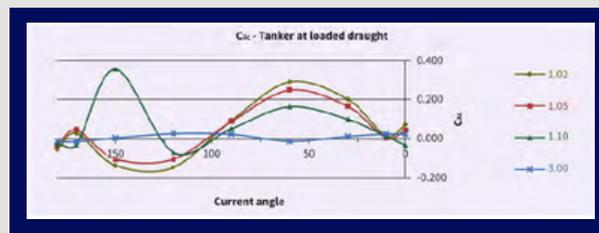
The environmental force coefficients comprise the following:

- Surge force or longitudinal force – wind and current forces faced by the fore or aft of the vessel
- Sway force or transverse force – wind and current forces faced by the beam of the vessel
- Yaw moment – wind and current yaw moment which makes the vessel turn about its vertical axis

The force coefficients provided in MEG-4 follow a specific sign-convention as per the figure below:



The coefficients can be obtained from the charts and tables provided in Appendix A of OCIMF MEG-4.



Next, we calculate, for all cases listed in Step 1, the environmental forces of wind and current (forces and moments).

The forces are obtained from the coefficients by using the standard formulae:

$$\begin{aligned} F_{XW} &= \frac{1}{2} C_{XW} \rho_w V_w^2 A T & F_{Xc} &= \frac{1}{2} C_{Xc} \rho_c V_c^2 L B P T \\ F_{YW} &= \frac{1}{2} C_{YW} \rho_w V_w^2 A L & F_{Yc} &= \frac{1}{2} C_{Yc} \rho_c V_c^2 L B P T \\ M_{XYW} &= \frac{1}{2} C_{XYW} \rho_w V_w^2 A L L B P & M_{XYc} &= \frac{1}{2} C_{XYc} \rho_c V_c^2 A L L B P^2 T \end{aligned}$$

Once we have the environmental forces, the next step is to design/select the mooring equipment based on the forces obtained.

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Mooring equipment can be the following:

- Mooring lines and shackles
- Bollards
- Fairleads
- Winches

Each mooring equipment is specified by its Safe Working Load (SWL), which is what we need to determine.

OCIMF provides a simple approach to calculating the SWL once environmental forces are calculated.

OCIMF proposes calculation of a parameter called the 'Ship's Design MBL'.

In Part 2, we'll look into what is Ship's Design MBL, and also how the mooring pattern for the vessel can be designed.

# Calculating a Ship's Design MBL using OCIMF MEG-4

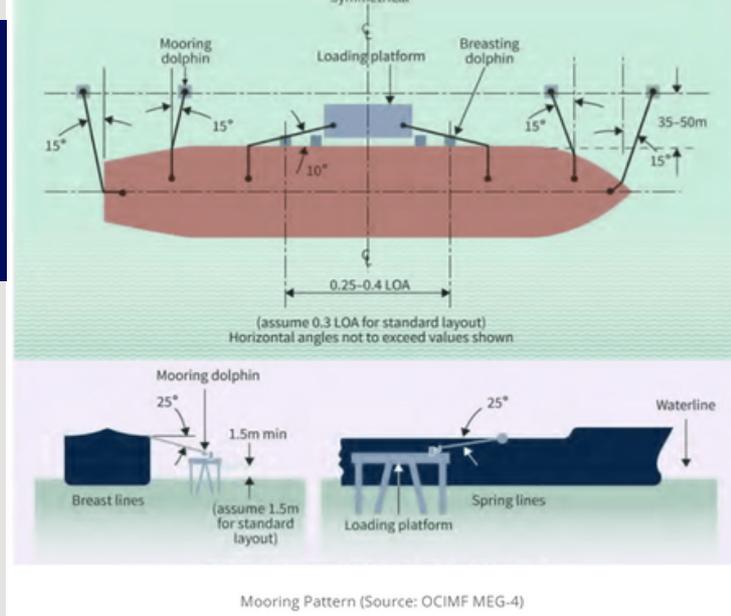
In Part 1 of this article, we saw a step by step guide to calculate the Environmental forces on a vessel based on “Standard” environmental criteria defined in Section 3 of OCIMF Mooring Equipment Guidelines Fourth Edition (MEG-4) in order to determine the ship’s design MBL which in turn can be used to size the various components of the vessel’s mooring system, like bollards, fairleads and winches. Various parameters like loading conditions, tidal variations, WD/T ratio etc. were discussed and calculation of wind and current forces on the vessel based on coefficients was presented.

In Part 2 of the article we will look into how to

1. Select a generic mooring line layout
2. Calculate static Equilibrium of the vessel and stiffness of mooring line layout
3. Determine Ship design MBL

## Mooring Pattern

The vessel mooring pattern is to be designed to effectively counter the environmental forces from any direction. This means that the lines should be able to cope horizontal as well as transverse loads. The mooring pattern should therefore have lines along longitudinal direction to prevent motion in forward and aft directions and also in the transverse direction to prevent motion away from the berth. The longitudinal lines are known as spring lines and the transverse lines are known as breast lines. The pattern also depends on the provisions at the terminal and it should be chosen, as much as possible, to keep the spring lines parallel and breast lines perpendicular to the ship length.



MEG4 provides the below guidelines for a generic mooring line layout.

- Breast mooring lines should be at an angle less than 15° to the perpendicular axis of the ship.
- Spring mooring lines should be at an angle less than 10° to the side of the ship.
- Maximum vertical angles of 25 degrees should be assumed for the lightest ballasted condition.

## Static Equilibrium

A vessel subject to environmental forces/moments will move in the forward or transverse directions or rotate about the vertical axis i.e. the vessel will have surge, sway or yaw respectively. The vessel motion will change the relative distance of the fairlead from the shore anchor point, changing the length of the mooring lines. The lines, generally speaking, behave like a spring and the force exerted is proportional to the change in length of the line. This characteristic of the lines can be found from the data sheet of the line from the manufacturer. The change in length of the lines increases the tensions in the lines and the combined load exerted by all the lines then balances the total environmental loading. This condition of the vessel where the environmental loading is balanced by the mooring lines is known as static equilibrium.

# Ship design MBL calculation

A simple spring formulation can be applied to evaluate the translations/rotations of the vessel in static equilibrium under the effect of the calculated environmental loads. Once a mooring system for the vessel at the berth has been chosen, for given position of the vessel the change in length of each mooring line with respect to its initial (un-stretched) length can be calculated using a simple spring formulation  $F = k \delta L$  where  $F$  is the line tension,  $k$  is the stiffness of the line and  $\delta L$  is the change in line length. Tension in each line can be aggregated to get the net loading on the vessel. Hence we can calculate the translation/rotation of the vessel that will result in unit force/moment on the vessel by the mooring lines. Let's call this the inverse stiffness  $k'$ . If  $k'$  is displacement produced by unit force on the vessel, the total displacement  $X$  produced by the net environmental loading  $F$  can be calculated as  $X = F k'$ . The new position for the ship can be used to re-calculate the net mooring loads on the vessel and compared to the environmental forces and the whole process can be repeated until static equilibrium is achieved. The total length of the mooring line from winch to bollard should be used in the calculations. Also the stiffness of the lines change with use and the calculations should use the stiffness of used lines instead of new lines. The above can be summarized in below steps,

1. Calculate total environmental forces/moments on the vessel in surge, sway and yaw directions. E.g.  $F_x$  is the net environmental force in the surge direction
2. Determine the inverse stiffness of the mooring system in terms of amount of surge/sway/yaw per unit force/moment. E.g.  $k'$  m/N is the stiffness of the vessel in surge direction.
3. Calculate the total amount of surge/sway/yaw. E.g. Surge (m) =  $F_x * k'$
4. Calculate the resultant mooring forces based on the new position. E.g.  $R_x$  is the net mooring force in the surge direction.
5. Compare the environmental forces and resultant mooring forces i.e.  $F_x = R_x$ ?
6. Several iterations of steps 2-5 may be required until static equilibrium is achieved.

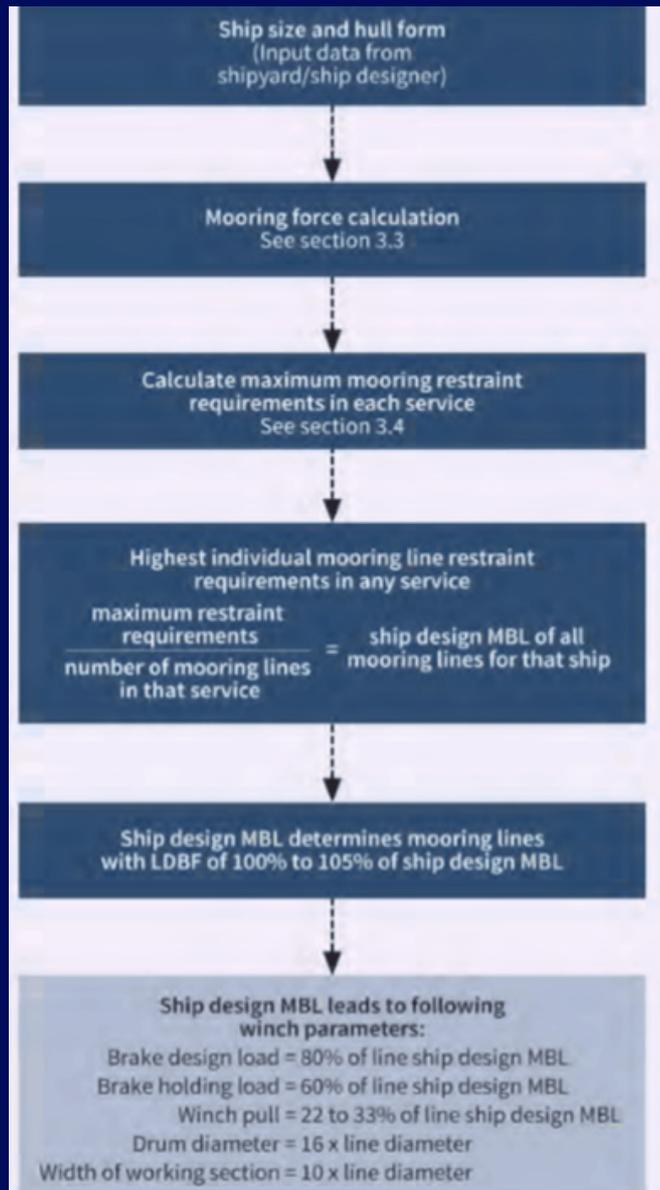
Once static equilibrium is achieved, maximum mooring restraint force can be determined and used in the flowchart below, provided by MEG4, to calculate the ship design Minimum Breaking Load i.e. Ship design MBL. With the vessel in static equilibrium, the tensions in each mooring line can be determined. Since there are several components in the mooring pattern that support multiple mooring lines, the total loading on such component can be used to calculate the Ship design MBL as

$$\text{Ship design MBL} = \frac{\text{Total mooring load}}{\text{number of lines}}$$

The ship design MBL is the MBL of a new, dry mooring line for which a ships mooring system is designed and that meets the mooring restraint requirements as defined in MEG4, section 3. All other components of a ship's mooring system are based on this ship design MBL, with defined tolerances.

It must be noted that static analysis may only be suitable for benign environment as we are assuming the lines as simple springs. In other cases dynamic analysis for the vessel motions and line tensions should be performed.

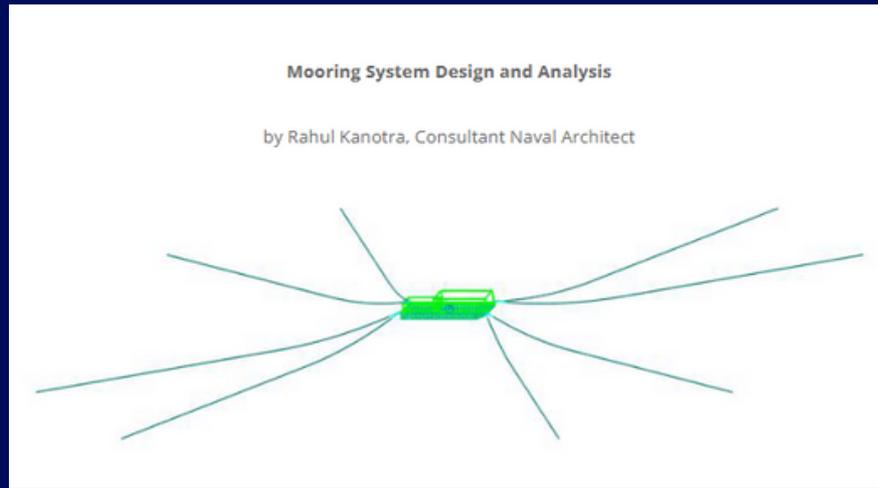
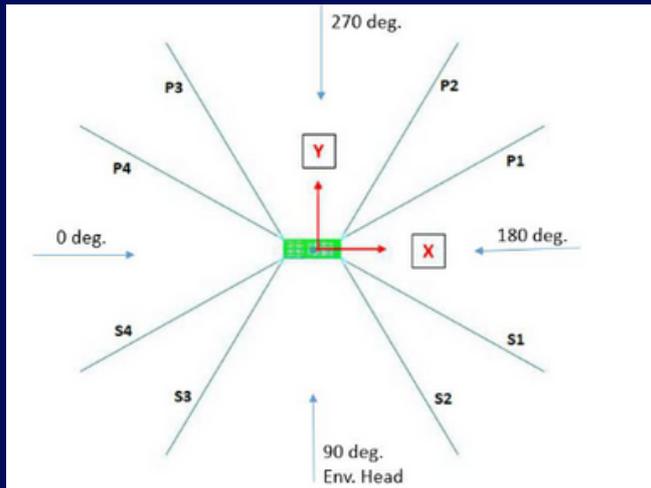
The steps above are also lined out in OCIF MEG-4, and shown in the figure below.



Ship's Design MBL Calculation Steps (Source: OCIMF MEG-4)

In Part 3, we will further look into using this Ship design MBL for line selection and to determine D/d ratio (bend dia/rope dia) of mooring line and other parameters.

# Mooring System Design and Analysis



As the offshore industry moves towards greater technological advancements, one thing that has plagued the engineers is the “plug and play” computer programs or software. I am not against any software as such, and in fact, I am a big fan and power user of Bentley’s MOSES program. What I do not like is engineers blindly feeding inputs in the software to get outputs without actually understanding the theory behind engineering problem at hand. Engineers these days spend more time on mastering the software manual than the actual theory itself. I have been extremely fortunate to be mentored by some of the best Engineers/Managers/Professors in both industry and academia. As a passionate Naval Architect, I have always had a deep interest in the interaction of floating/fixed bodies with sea waves. In an attempt to share my knowledge of offshore installation engineering, I am going to write a series of articles on various offshore engineering analysis. The target audience is fellow Naval Architects, Engineers, Project Managers and anyone interested in learning about the field. As these articles will be targeted for the audience from diverse backgrounds, I will try to keep things as simple as possible. I will use Bentley’s MOSES as the prime software and get into the details of inputs and outputs. I recently delivered a training session to a group of structural engineers on the topic “Mooring Analysis and Design,” and I have chosen the same topic for my first article.

## Mooring System Fundamentals

A mooring system comprises a floating body (or collection of bodies) which are connected to the sea floor (or terminals) by a system of lines that provide restoring forces against external loads. The General purpose of mooring lines is:

- To keep the body in reasonable proximity of some target location (Station Keeping).
- To operate in deep water (Drilling Rigs, FPSOs, TLPs, ).
- To allow re-location of the units such as pipe laying barges.
- To check clearance with other units or pipelines during drilling campaigns or installation procedures.
- Loading/Unloading operations.

# Mooring System Classification

Mooring systems are broadly classified into two categories namely slack (or catenary) mooring system and taut mooring system as shown in **Figure 1**.

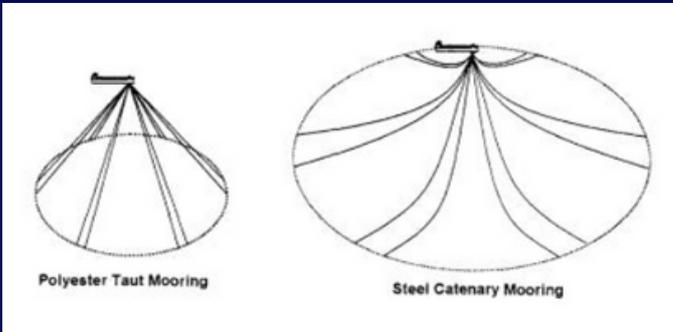


Figure 1: Taut Mooring vs. Catenary Mooring (Source: Chakrabarti, S. K. (2005). Handbook of offshore engineering. Amsterdam: Elsevier.) It is important to understand the fundamental differences between the two as the restoring forces generated in both are due to different mechanisms. In slack (catenary) mooring lines the restoring forces are mainly due to the result of a change in suspended weight of lines whereas in taut mooring the restoring forces are generated primarily due to the result of the elasticity of the line. Below figures demonstrates the difference between taut mooring and catenary mooring.

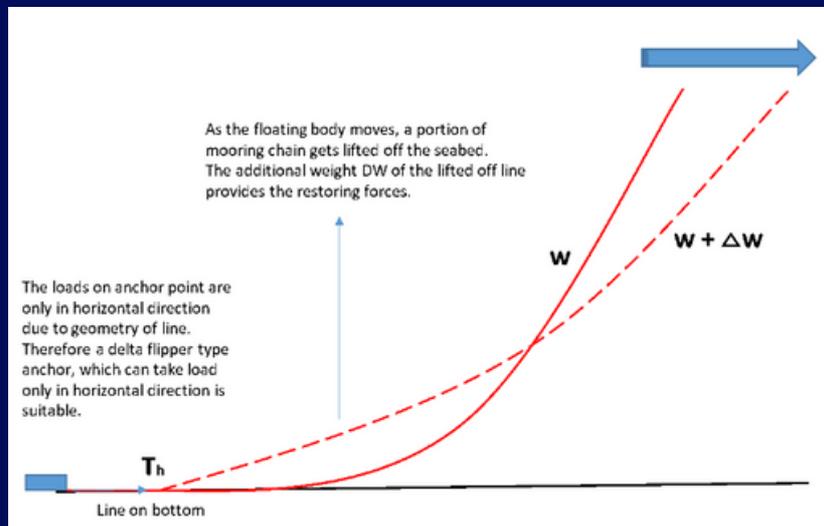


Figure 2: Restoring forces – Catenary Mooring

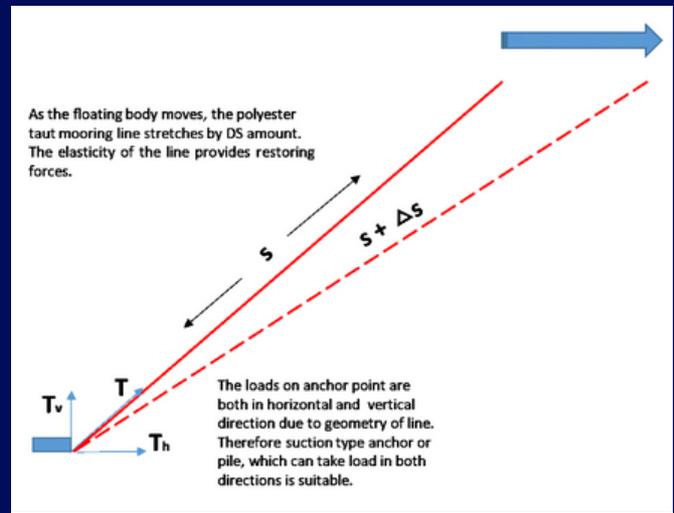


Figure 3: Restoring forces – Taut Mooring

Ever wondered why slack mooring is also called as catenary mooring? It is easy to mathematically prove that any line/chain suspended under its self weight assumes a shape of a geometric curve called catenary. The geometry of the offshore slack mooring line is the same as a chain suspended between two poles. The only difference is that one end of the offshore mooring line is connected to the anchor and another end to the fairlead of the floating body. Also, the offshore mooring line has buoyancy and hydrodynamic forces acting on it unlike in case of a chain suspended in air between two poles. I have pointed out this similarity between offshore mooring line and a chain suspended between two poles to illustrate the simplicity of the problem at hand. The physics behind mooring line behavior is not different from that of a suspended chain in the air.

In the below figure let's assume that the length of the chain is  $S$  and weight per unit length is  $W$ . The Tension on each side of the pole is same as  $T$  (due to symmetry) and the angle it makes with horizontal is  $\Phi$ . Now balancing forces in vertical direction gives us :

$$2 T \sin \Phi = WS \quad T = WS/2 \sin \Phi$$


Figure 4: Chain suspended between two poles – Catenary

## Mooring System Design and Analysis

Now that we understand the basic difference between taut mooring and catenary mooring lines let's look at the design and analysis aspects of a mooring system. Let's assume a simple scenario of a barge moored by 8 point catenary mooring system. To analyze this system in any software, we need to input the properties of each mooring line and barge system. One of the best software's out there is Bentley's MOSES software. I like working in MOSES due to its inbuilt coding language environment which makes it possible to look at different scenarios and be creative with the problem at hand. Below are the inputs provided in MOSES software.

Barge Particulars	
L x B x D	120 m x 40 m x 9 m
Draft	6.0 m
Displacement	28000 MT

**Table 1: Barge Particulars**

Mooring Particulars	
No. of Mooring Lines	8
Type	Wire Rope
Effective Diameter	52 mm
Weight Per Unit Length	11 Kg/m
Horizontal Distance from Fairlead to Anchor.	1000m
Anchor Type	Flipper Delta

**Table 2: Mooring Particulars**

The mooring pattern of the barge is symmetric about X and Y axis as shown in the Figure 5. The horizontal distance between fairlead and anchor point is considered to be 1000m for each line. It should be noted that the mooring pattern will not always be as pretty in the real world. There may be subsea assets (pipelines, manifolds, etc.) in the vicinity and therefore the length and orientation of each line may differ. Engineers must strive to keep the mooring pattern as symmetrical as possible for better load distribution.

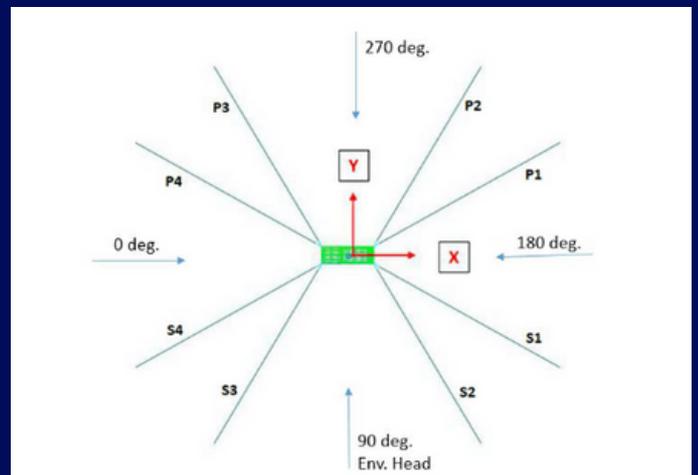


Figure 5: Top View – 8 Point Mooring Spread.

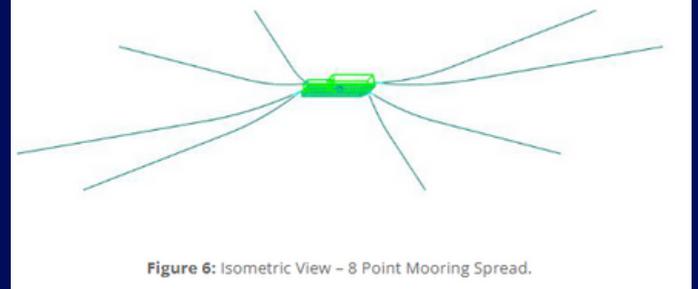


Figure 6: Isometric View – 8 Point Mooring Spread.

Now before analyzing this mooring system let us look at the things which we have some control over, during the actual field operation. The anchor drop location and therefore the length of each mooring line can be changed. The individual mooring lines can be tended based on the direction of environmental forces. The mooring tension in the line can be increased/ decreased by paying out/in line from the winch. Below Figure 7 illustrates the effect of line tension on the catenary profile of any one mooring line. As the tension is increased (line length reduced) more length of the line is lifted off the seabed. For slack condition, the whole length of the line is laying on the seabed whereas for 200 MT tension the entire line is off the seabed. The Delta Flipper type anchor can only take loads in the horizontal direction, and therefore it will not hold ground for 200 MT line tension. From this exercise, we get a good idea of tension limitations on each line from anchor uplift point of view. It is to be noted that line tension/ geometry of line will also change with the change in horizontal distance between anchor and fairlead.

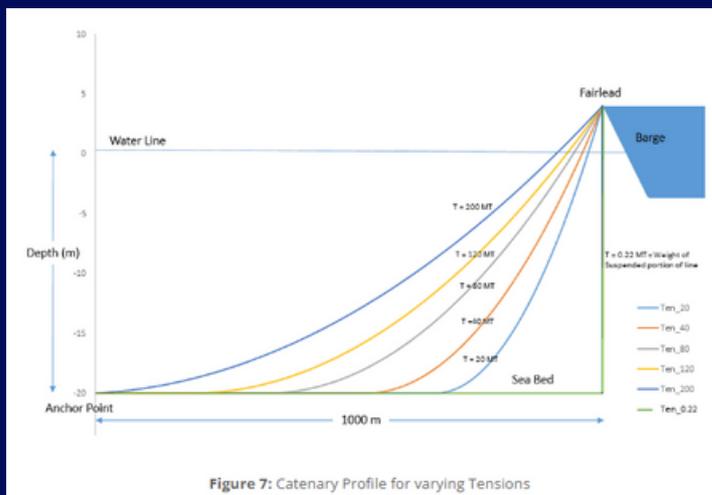


Figure 7: Catenary Profile for varying Tensions

Now that we have looked at the characteristics of the individual lines, the next step is to study the characteristics of the whole barge mooring system.

From a mathematical point of view, it is useful to see the restoring force due to mooring vs. the barge excursion. Figure 8 plots the mooring system restoring force due to barge excursion in the X direction (Refer to Figure 5) for different pre-tension. As we know that the pre-tensions in each mooring line can be increased or decreased by the deck crew by operating the winches. It can be seen that higher the pre-tension the stiffer the system, i.e., lesser excursion for the same amount of force. However, the higher stiffness also means higher line forces and risk of breaking of highest loaded lines. Therefore, we need to keep a balance between barge stiffness vs. excursion to ensure safe mooring design.

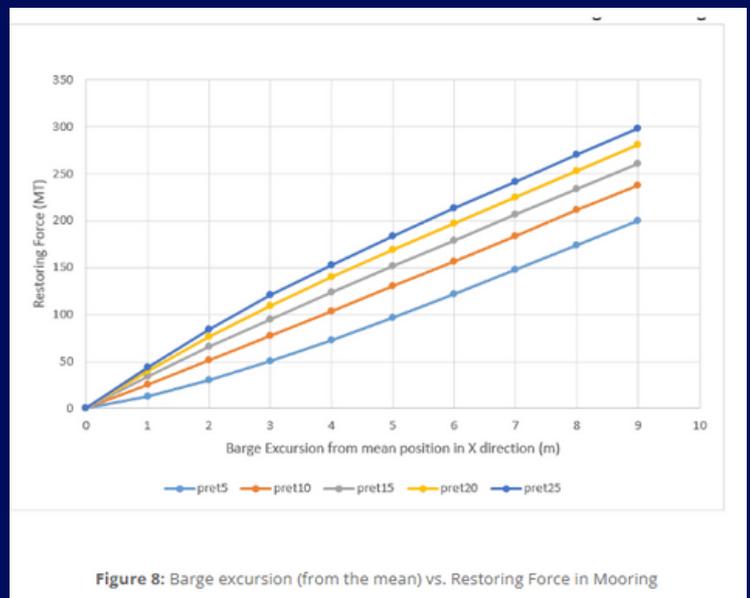


Figure 8: Barge excursion (from the mean) vs. Restoring Force in Mooring

Up until now, we have talked about the characteristics of internal forces generated by the mooring system, i.e., the restoration forces. In the following section, we will discuss the external excitation forces on the barge mooring system. Any floating body in the sea is subject to some, or possibly all of the following loads:

- Winds
- Current
- Waves/ Swell
- Tides

For all practical purposes the environmental forces due to winds, current and mean wave forces can be considered as static and are easy to deal with using static analysis. The total forces due to static components are calculated and equated to the restoring force to calculate total barge excursion from mean position. One thing which is very crucial for Engineers is to have a “feel” of the magnitude of environmental force for a given size of the barge and operational sea states. A great resource that every Engineer should refer to when analyzing a mooring system is OCIMF – Mooring Equipment Guidelines 3rd Edition. Appendix A of this document provides detailed calculations for calculating environmental forces due to wind and currents. Now that we have talked about static forces the next step is to look at the dynamic forces due to waves and swells. In a typical mooring analysis in MOSES, the hydrodynamic model of the vessel is created to perform the analysis to identify the optimum mooring configuration. The software considers steady state loading from current, wind and wave drift and oscillatory loading from direct waves and low frequency components of wave/wind drift. The required hydrodynamic database is generated using the ‘three diffraction theory. The analysis is performed in the time domain. The expected peak values of the barge motion, excursion and line tensions are derived from a computer simulation time of 1200-1800 seconds using input sea spectra (such as JONSWAP, ISSC, etc.). The analysis is usually performed for eight headings (head, stern, beam, quartering seas) as shown in Figure 5. In order to calculate maximum excursions and forces the loads due to wind, wave and currents are applied collinearly for each heading. The mooring analysis is performed for Intact and Damaged condition as shown in Table 3.

Condition ->	Intact	Damaged
Mooring Line Loads	Maximum Line Tensions are generated for all heading.	Damaged condition aims to find out maximum loads and excursions when one line is damaged. Usually, three damaged cases are considered. The highest three tensioned lines from intact cases <u>are considered to be</u> damaged separately for each damage case. The time domain analysis is carried out with one line damaged and maximum mooring line tension and excursion are calculated for worse case heading.
Barge Excursions	Maximum Barge Excursions are generated for all headings.	Maximum barge excursions are generated for <u>one line</u> damage case and worse case heading.
Safety Factor	Based on API-RP-2SK recommendation, the minimum factor of safety of mooring line load for temporary mooring and using dynamic analysis is 1.67 (60% of MBL) for Intact condition.	Based on API-RP-2SK recommendation, the minimum factor of safety of mooring line load for temporary mooring and using dynamic analysis is 1.25 (80% of MBL) for Intact condition.

**Table 3: Intact and Damaged Condition**

The predicted maximum mooring tensions and excursion results of mooring analysis in MOSES are summarized in Table 4 and Table 5 respectively. It is no surprise that maximum tension occurs for beam seas where the largest underwater and above water surface area is exposed to winds, waves, and current.

Figure 9 shows the mooring line tensions for the environment in which the highest tension occurs in line S2. Figure 10 shows the barge excursion in the Y direction for the same case.

Hs (m)	Tp (Sec)	Head (Deg.)	P1 (MT)	P2 (MT)	P3 (MT)	P4 (MT)	S1 (MT)	S2 (MT)	S3 (MT)	S4 (MT)
2	5.1	0	19	19	32	43	19	19	32	43
	6.4		18	19	31	41	18	19	31	41
	7.8		17	18	30	38	17	18	30	38
	5.1	45	20	21	21	25	31	86	76	78
	6.4		19	18	20	25	31	81	72	73
	7.8		17	15	20	23	32	69	62	62
	5.1	90	19	15	21	20	59	102	98	65
	6.4		18	16	22	21	58	100	94	63
	7.8		18	15	22	21	53	89	82	57
	5.1	135	26	21	26	20	74	85	91	37
	6.4		24	19	23	20	67	77	80	35
	7.8		22	18	20	18	56	66	66	32
	5.1	180	40	31	19	18	40	31	19	18
	6.4		38	30	18	17	38	30	18	17
	7.8		36	29	18	17	36	29	18	17
	5.1	225	74	85	91	37	26	21	26	20
	6.4		67	77	80	35	24	19	23	20
	7.8		56	66	66	32	22	18	20	18
	5.1	270	59	102	98	65	19	15	21	20
	6.4		58	100	94	63	18	16	22	21
	7.8		53	89	82	57	18	15	22	21
	5.1	315	31	86	76	78	20	21	21	25
	6.4		31	81	72	73	19	18	21	25
	7.8		32	69	62	62	17	15	20	23

Table 4: Mooring Line Loads – Intact Condition

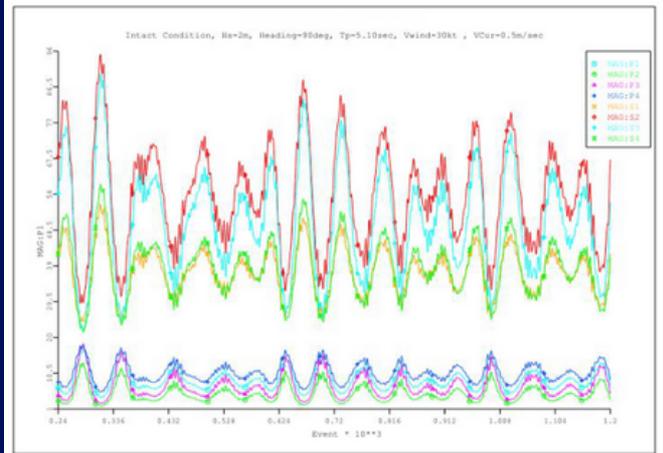


Figure 9: Mooring Line Tensions – Intact Condition

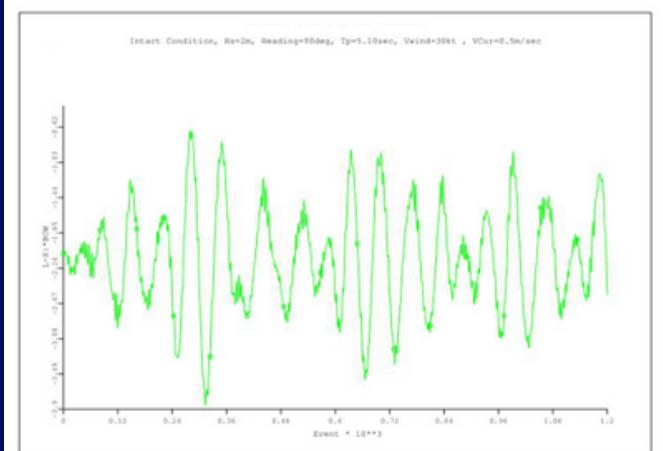


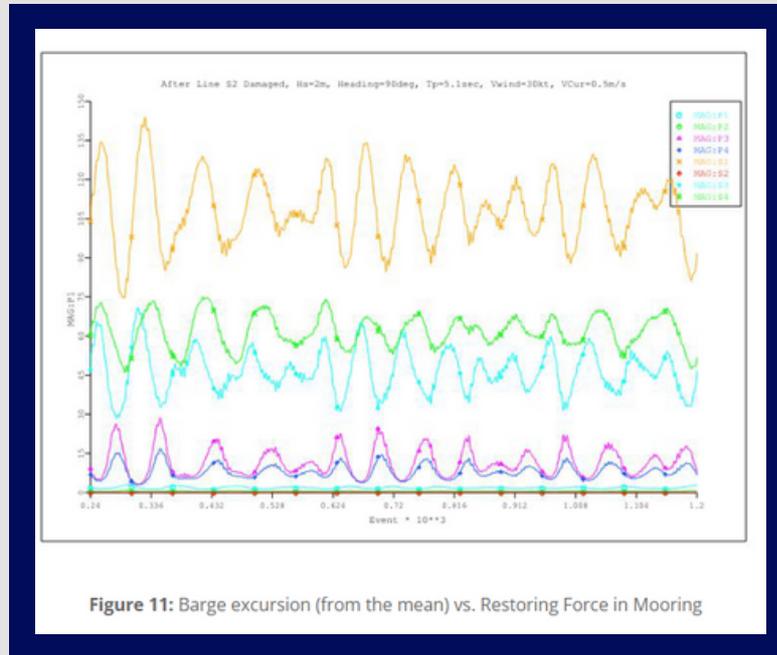
Figure 10: Barge excursion (from the mean) in Y direction – Intact Condition

Hs (m)	Tp (Sec)	Head (Deg.)	X (m)	Y (m)	Z (m)
2	5.1	0	0.69	0	0.06
	6.4		0.57	0	0.27
	7.8		0.44	0	0.74
	5.1	45	0.82	2.43	0.1
	6.4		0.75	2.1	0.43
	7.8		0.63	1.65	0.89
	5.1	90	0.15	2	0.18
	6.4		0.14	1.88	0.46
	7.8		0.22	1.65	0.79
	5.1	135	0.6	1.2	0.2
	6.4		0.59	1.01	0.64
	7.8		0.49	0.85	1.23
	5.1	180	0.55	0	0.22
	6.4		0.44	0	0.53
	7.8		0.37	0	1.01
	5.1	225	0.6	1.2	0.2
	6.4		0.59	1.01	0.64
	7.8		0.49	0.85	1.23
	5.1	270	0.15	2	0.18
	6.4		0.14	1.88	0.46
	7.8		0.22	1.65	0.79
	5.1	315	0.82	2.43	0.1
	6.4		0.75	2.1	0.43
	7.8		0.63	1.65	0.89

Table 5: Barge Excursions – Intact Condition

Once the intact case is analyzed, the next step is to study the mooring system for one line damaged condition. In damaged case, the time domain simulation is run for top three load cases that generated the highest line tension in the intact condition.

Remember damaged condition aims to find out maximum tension and excursion that would occur if any one line is damaged. In our example, the damaged case is analyzed for  $H_s = 2\text{m}$ ,  $T_p = 5.1$  seconds, Heading 90 deg., and line S2 is considered damaged. The maximum line tensions from MOSES time domain simulation in the damaged case are plotted below in Figure 11. It can be seen that line S1 that is adjacent to S2 takes the maximum load when S2 is damaged.



The maximum loads and excursions obtained from analysis should be within maximum allowable limits as per guidelines such as API RP-2SK. The maximum loads should not exceed the “weakest link” of the Mooring system. I would like to conclude by emphasizing that Mooring analysis and design is an iterative process dependent on environmental as well as operational constraints. Engineers should exercise due diligence while analyzing any mooring pattern for the safety of crew and offshore assets. Feel free to share this article and post comments if any. Until next time, have a great day.

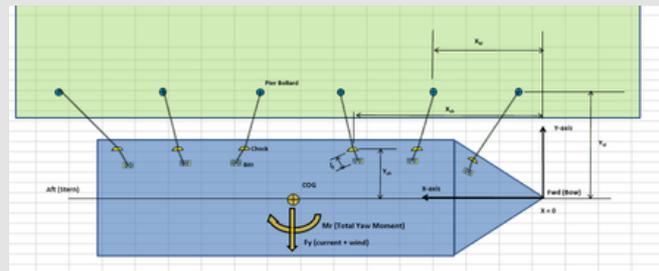
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by Team TheNavalArch | May 12, 2020 | Marine Operations, Mooring

## Designing the berth mooring of your vessel with this simple yet effective method

A vessel at berth experiences much lower forces compared to a vessel in the open sea due to the milder environment, but it still requires a mooring configuration suited to the forces it experiences, and also suitable for the type of berthing configuration adopted. The berthing configuration depends on the geometry of the berth, and also on the available space depending on the traffic at the berth and size of the vessel. The most widely used berthing configuration is one with the vessel's Port or Starboard side aligned with the Quay.



A possible berth mooring arrangement

For any configuration of mooring adopted, the design has to be adequate to restrain the forces which the vessel experiences. In this article, we will analyze the configuration with Port or Starboard on Quay in more detail, and present a simplified method for calculating the line loads for such a mooring pattern.

Thinking in very basic terms, the vessel will have its Port or Starboard pressing against the Quay (with fenders between the vessel and Quay to take the load). This vessel will be subjected to environmental loads coming from the fwd/aft end (longitudinal) and beam side of the vessel (athwartship) which will tend to drift it off away from the berth. A simple way is to tie the vessel to the quay side using ropes, and there could be many ways and configurations to do it.

We'll be following a guideline developed by US Navy called DDS-582 to explain the method. Though DDS-582 has now been superseded by another document Mil-HDBK-1026\_4a\_Mooring Design, the principles outlined in DDS-582 are still effective and a good source of learning.

## Calculation Steps

- Get the vessel's dimensions and cargo dimensions
- Get the environmental parameters of the Quay - wind speed and current speed (waves have been ignored)
- Calculate all the environmental forces on the vessel by using standard physical formulae and coefficients provided in DDS-582

When calculating the wind and current forces, the standard physics formula of Force = Pressure x Area shall be used. In the method by DDS-582, wave forces have not been considered for doing the calculation.

For wind force, the formula is  $F_{wind} = 1/2 \times C_{wind} \times \rho_{wind} \times V_{wind}^2 \times A_{wind}$ , where  $C_{wind}$  is the coefficient of wind force,  $\rho_{wind}$  is the density of air,  $V_{wind}$  is the wind speed, and  $A_{wind}$  is the total area of ship and cargo which is exposed to the wind from head or beam direction (the above-water area)

Similarly, for current force, the formula is  $F_{current} = 1/2 \times C_{current} \times \rho_{water} \times V_{current}^2 \times A_{underwater}$ , where  $C_{current}$  is the coefficient of current force,  $\rho_{water}$  is the density of water,  $V_{current}$  is the current speed, and  $A_{underwater}$  is the total underwater area of ship which is exposed to the current from head or beam direction.

The forces need to be calculated for both the directions: head wind and beam wind



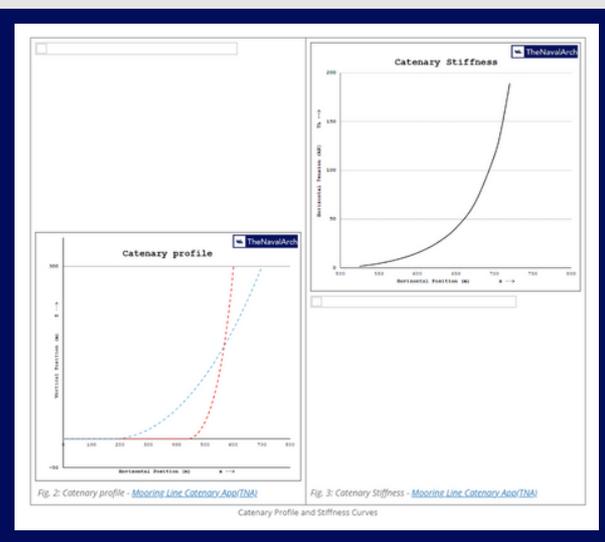
## Understanding how buoys affect the catenary of a Mooring line

### What is a mooring line?

Mooring lines generally comprise ropes, wires, chains or combination of wire and chain used to keep ships, offshore platforms and other floating vessels in position. It connects the structure either to the seabed using an anchor or the quay side using a bollard and prevents the vessel from drifting away due to loading from waves, winds and current. Offshore moorings are typically used for drilling and production platforms and their configuration depends on the water depths. For small water depths, e.g. below 300 m, a chain only line may be used but as we go deeper, the required length of the mooring line increases and it becomes hard for the vessel to support the weight of the chain. Hence a lighter alternative of a chain-wire-chain composite line is used. The line has chains at each end to be able to connect to the anchor (end on seabed) and the chain stopper (end on structure). For ultra-deep waters, a polyester rope is used in between chains to further reduce the weight.

## Catenary Principle

A mooring line is just a suspended cable and so the shape it assumes is catenary shape. The weight of the suspended length of the cable translates into tension at either ends. For offshore mooring line the cable is anchored on the seabed and attached to the structure on top. If the vessel moves, the catenary shape changes there by changing the tensions in the line. The further the top end is from the anchor, the larger is the suspended length and hence the tension is larger. This increased tension acts as a restoring force (stiffness) to the motions of the structure. The lines are laid out in a symmetric pattern to provide stiffness in all directions. Also the change in tension with offset of the structure is non-linear i.e. as the structure moves farther and farther, the rate of increase in tension is larger and larger. Thus the structure remains within a region for a given environment and the footprint of the structure's offset is called a watch circle.



it is important to understand the catenary shape in order to design the moorings and choose the right material properties of the line that will allow the structure to remain within limits of operation and also keep the loading on the line well below its breaking limit. The factor of safety associated with the design of mooring lines is defined in standards from API and DNV, but will not be discussed here.

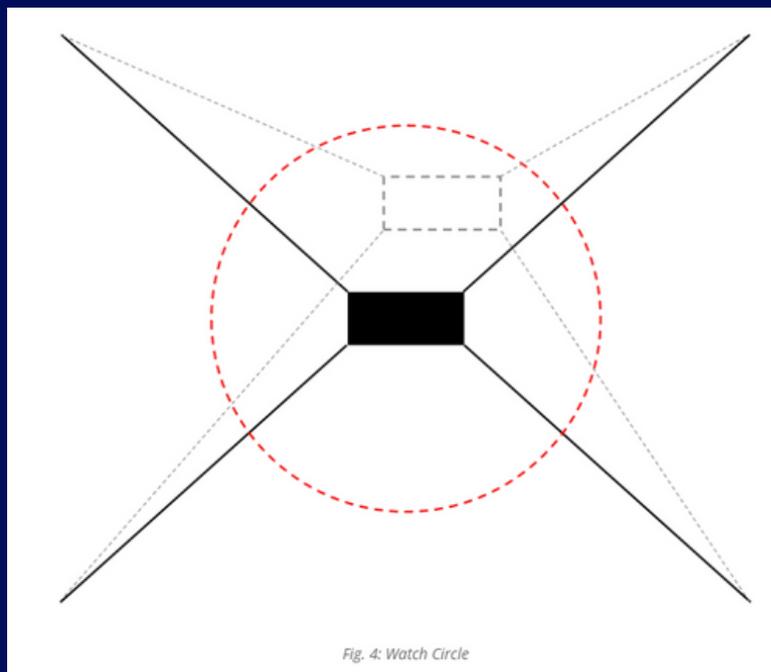


Fig. 4: Watch Circle

## Catenary equation

Let's get into the math behind a catenary shape. A cable suspended from two points will have its weight supported by the reactions at the two points. This net reaction is the same as the tension in the line at that point. The tension at any point in the line can be divided into its horizontal and vertical components.

## Boundary Conditions

We will focus on offshore mooring lines and use the boundary conditions suited for this application. We will also assume that the line is non-stretchable such that the catenary effect is only due to the weight of the line.

Since for an offshore mooring line, one of the ends is anchored to the seabed and if correctly designed, the line will always have a certain length on the ground, we can assume that the vertical component of the tension at the anchor is zero. At the touchdown point, where the line leaves the ground and becomes suspended, the vertical component of tension will also be zero.

## Pretension

From the equations below we will see that the distance of the fairlead from the anchor and the length of the line paid out determines the tension in the line. If the vessel is assumed to be in static equilibrium without any external loads, this tension is called pretension. Pretension for a mooring system has to be chosen appropriately to achieve the desired watch circle. A lower pretension will result in lower max tensions in the line but the offsets will be large while a higher pretension will result in large max tensions with smaller offset. Hence it has to be tuned appropriately to achieve the desired performance of the mooring system while not risking damage to the line.

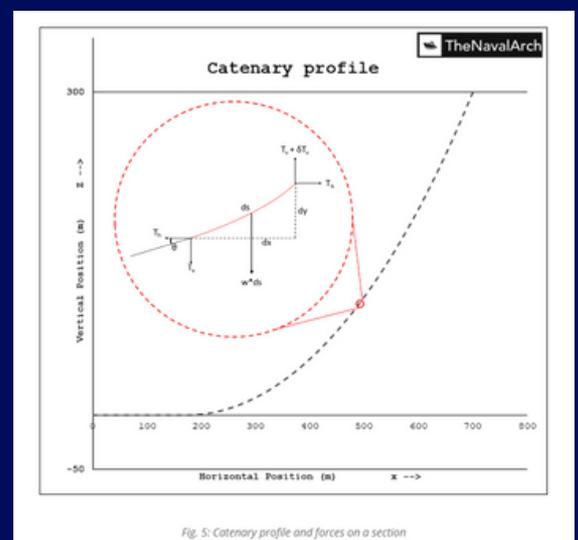


Fig. 5: Catenary profile and forces on a section

Assume a section anywhere in the suspended section of the line as show in the figure below. Each end has the tension components and the weight of the section acts vertically down wards. If the line is static, the forces should be balanced. Which means the horizontal tensions ( $T_h$ ) at the two ends are equal while the vertical tension ( $T_v$ ) at the top end is larger than the vertical tension at the lower end by the weight of the section. Below equations show the force balance for this section in the vertical direction.

$$\begin{aligned} T_v + \partial T_v &= T_v + w \cdot ds \\ \partial T_v &= w \cdot ds \end{aligned} \tag{1}$$

where  $w$  is the weight per unit length of the line. From Fig. 5,

$$\begin{aligned} \tan \theta &= \frac{\partial y}{\partial x} = \frac{T_v}{T_h} \\ T_v &= y' \cdot T_h \\ \frac{\partial T_v}{\partial x} &= y'' \cdot T_h \end{aligned} \tag{2}$$

Substituting Eq. 1 in Eq. 2

$$\begin{aligned} y'' &= \frac{w \cdot ds}{T_h \cdot dx} = \frac{1}{a} \cdot \frac{ds}{dx} \\ a &= \frac{T_h}{w} \end{aligned} \tag{3}$$

Substituting Eq. 4 in Eq. 3 and integrating we can derive the equation for the catenary shape.

$$\begin{aligned} y'' &= \frac{1}{a} \cdot \sqrt{1 + y'^2} \\ \Rightarrow \int \frac{dy'}{\sqrt{1 + y'^2}} &= \frac{1}{a} \int dx \\ \Rightarrow \sinh^{-1} y' &= \frac{1}{a} \cdot x + C \\ \Rightarrow y' &= \sinh(x/a + C) \end{aligned} \tag{5}$$

If we assume the origin at the touchdown point such that the boundary condition at  $x = 0$  are,

$$\begin{aligned} y'' &= \frac{1}{a} \cdot \sqrt{1 + y'^2} \\ \Rightarrow \int \frac{dy'}{\sqrt{1 + y'^2}} &= \frac{1}{a} \int dx \\ \Rightarrow \sinh^{-1} y' &= \frac{1}{a} \cdot x + C \\ \Rightarrow y' &= \sinh(x/a + C) \end{aligned} \tag{5}$$

If we assume the origin at the touchdown point such that the boundary condition at  $x = 0$  are,

$$y = 0; y' = 0; T_v = 0; \text{ at } x = 0 \tag{6}$$

$y'$  here is the slope of the catenary line at horizontal position  $x$ . Since the line rests tangent to the ground at  $x=0$ , the slope of the catenary  $y'$  is also 0. Using this condition in Eq. 5 yields  $C = 0$ . Further integrating Eq. 5 and using the boundary conditions from Eq. 6 gives the catenary shape i.e.  $y$  coordinate of the line for a given  $x$  and horizontal tension.

$$\begin{aligned} y' &= \sinh(x/a) \\ \Rightarrow \int dy &= \int \sinh(x/a) \cdot dx \\ \Rightarrow y &= a \cosh(x/a) + C', \quad \text{using } y=0|_{x=0} \text{ from Eq. 6} \\ \Rightarrow y &= a[\cosh(x/a) - 1] \end{aligned} \tag{7}$$

These results can be substituted back in Eq. 4 and integrated to get an expression for  $s$  or arc length for a given  $x$ .

$$s = a \cdot \sinh(x/a) \tag{8}$$

Assume a section anywhere in the suspended It should be noted here that the  $x$  coordinate in the equations above are measured from the touchdown point and the vertical tension at the touchdown point will always be 0 since the equations are derived for this boundary conditions (Eq. 6).

# How to solve

Lets say we have line length of 300 m, the anchor is 200 m away from the fairlead and the vertical separation between anchor and fairlead is 100 m. We start with some initial values of line length on ground and horizontal tension  $T_h$ . Subtracting the line length on ground from the total length will give us the suspended length  $s$ . This can be used in Eq. 8 to get the calculated horizontal position  $x$  of the fairlead. Using this  $x$  in Eq. 7 gives us the calculated vertical position of the fairlead. If the calculated position of the fairlead is different from the required position i.e. (200, 100) from the anchor, the process has to iterated again by suitably changing the length on ground and horizontal tension. This problem of minimizing the error between calculated and target fairlead positions by changing length on ground and  $T_h$  can be easily setup using an Excel Solver.

The above equations assume that the line is homogeneous i.e. the line is made of a single material like all chain or all wire. For composite lines that are combination of different line types like chain-wire-chain, each segment's catenary equations have to be solved maintaining the continuity of the boundary conditions at the joints.

## Catenary with a buoy

Simply put a buoy is just a floating device tethered to the seabed and used in several applications like

- marking specific locations in the sea, e.g. ship wreck, limits, divers
- as a light demarcation for navigation at night,
- as a measurement device with several sensors to measure, wave height, temperature etc.
- Mooring of ships

For an offshore mooring line, a buoy could be used for

- Single Point Mooring (SPM) where a surface buoy is moored to the sea bed and the vessel is tethered to the buoy using hawsers,
- or as a part of a hybrid mooring line where the buoy is attached along the line length. This is done either to change the stiffness characteristics of the line or get more clearance from nearby structures, pipelines etc.

The boundary conditions for a SPM is no different than a simple catenary but a hybrid line needs to consider additional boundary conditions and have been discussed below.

# Boundary conditions at Buoy

Solving the static equilibrium condition for a mooring line with buoy is very similar to solving the catenary equations as discussed above. If we have a single buoy the line is considered to be made of two catenaries and each catenary is solved individually. Additionally, the boundary conditions at the buoy i.e. horizontal and vertical forces are also to be satisfied. Fig. 6 shows the forces at the buoy connection point.  $T_{h1}$  and  $T_{v1}$  are horizontal and vertical forces due to one segment and  $T_{h2}$  and  $T_{v2}$  are horizontal and vertical forces due to the other segment respectively. Since no external forces are considered here,  $T_{h1}$  and  $T_{h2}$  must be equal while the sum of the vertical forces,  $T_{v1} + T_{v2}$  should balance the nett buoyancy ( $B_{buoy} - w_{buoy}$ ) from the buoy.

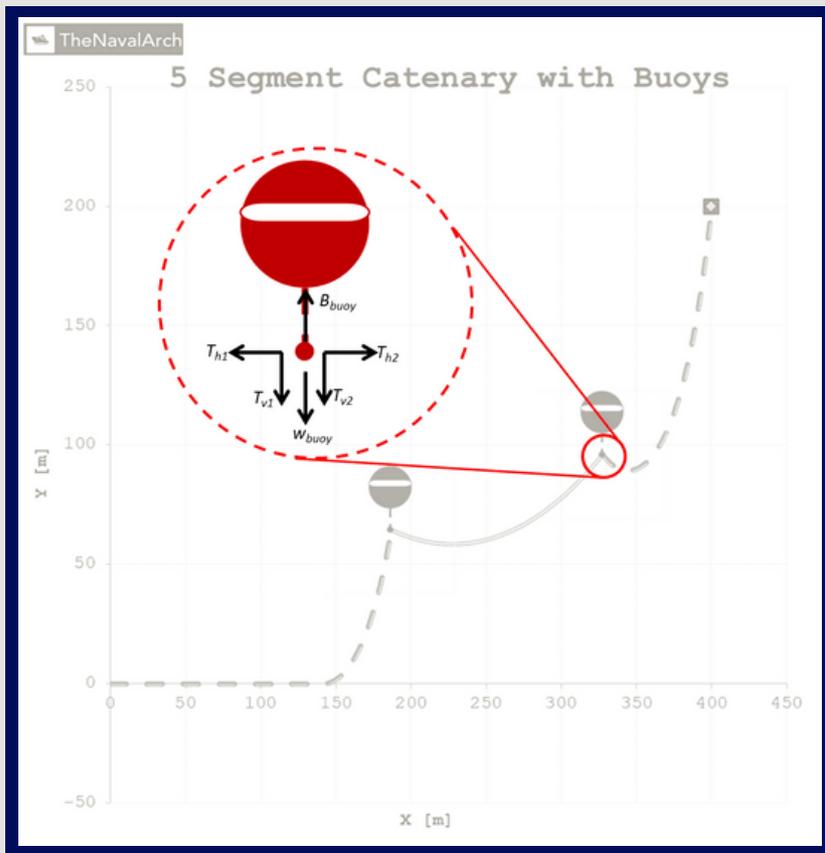


Fig. 6: Boundary conditions at a Buoy

It should be noted here that while solving for the catenary segments, not all segments will touch the ground. The above equations (Eq. 1 - 8) are derived for the boundary conditions where the segment is touching the ground such that the tangent ( $y'$ ) of the segment at the ground is zero. This may not be true for the segments with buoy and the correct boundary conditions have to be used.

## Conclusion

We saw in the article above how to derive the equations for a catenary shape with a length on the ground and the boundary conditions that apply if a buoy is attached to the line. the equations can be easily used to calculate the shape of the line and the tensions anywhere in the line. However, the calculations can become quite complicated as the number of segments in the line increase and if there are multiple buoys.

The Naval Arch offers two applications to solve the above equations and also includes more complex boundary conditions to solve for realistic scenarios. Both the apps offer to solve for multiple segmented line while one of them also offers including buoys along the line length. The apps are listed below with links to their product page.



# A simple method of selecting the right anchor for mooring a tanker/gas carrier

Anchoring is a fundamental and sensitive operation for a vessel. When a vessel is at anchor, it swings to align itself along the direction of the dominant environment. The anchor is supposed to hold the vessel in varying environmental conditions depending on where the vessel is being anchored. Thus, it is critical to know if the anchor has enough holding power when the weather goes inclement. While vessel masters have reliable experience in knowing the holding power of their vessels and decide based on their invaluable practical knowledge, an estimate of the forces which the vessel is experiencing in a particular weather is always useful in knowing whether the anchor can hold or not, helping in critical decision making on whether to remain at anchor or let go - thus saving the vessel from a potential damage of anchoring systems.

In this article we will present a simple method based to estimate the holding power required for an anchor operating in a given environmental condition. The method is based on OCIMF's publication 'Estimating The Environmental Loads On Anchoring Systems'.

Basically, the two steps involved are:

Step 1 : Calculating the wind, current and wave load on the vessel to give the total environmental load

Step 2: Selecting the right anchor with holding power sufficient to take the total environmental load

# Applicability and Assumptions

An anchoring system is subjected to the three primary environmental loads - Wind, Wave and Current. The simple outline of the method is to find out what these loads are, sum them up and check if the anchor has enough holding power to overcome the combined environmental loads.

However, the method is NOT universally applicable to all types of vessels, and is limited only to Oil Tankers or Gas Carriers with accommodation located aft. The method can be used for tankers down to a DWT of 16000 MT. Further, only a static condition has been considered for calculation of forces. This means that the effects of the vessel's own motion (pitching, heaving etc.) have been ignored. The vessel is considered as static while the environmental forces of wind, wave and current act on it. It is to be noted that dynamic effects can have a multiplier effect on the forces obtained from the static condition. The method also ignores the interaction among the three forces, and assumes that the vessel is lying to a single anchor and longitudinally aligned with the anchor chain. Thus, all the three forces of wind, current and wave need to be considered only in the longitudinal direction of the vessel. Catenary effects of the mooring chain are ignored.

However, there are some important assumptions which the method relies upon. These are:

- the vessel is an oil tanker or an LNG carrier (spherical or prismatic) with accommodation aft
  - environmental forces acting on the vessel comprise:
    - wind
    - current
    - waves (mean wave drift force).

- the data presented refers to the static condition. It should be noted that dynamic effects (e.g. yawing, pitching) can result in forces in the anchor system being 2 or 3 times higher than the estimated static forces.
- the environmental forces are considered as individual components that are summed to provide a total force. Interaction effects between the forces are not considered.
- the vessel is lying to a single anchor.
- the anchored vessel is in a steady position, having swung at anchor in the direction of the dominant environmental force or has reached an equilibrium position.
- the vessel lies at anchor such that the lead of the anchor chain is parallel to the centreline of the vessel. As a result, only the longitudinal components of the wind, waves and current forces need be considered.
- wave drift forces have been estimated using a Pierson-Moskowitz sea spectrum.
- the catenary effect of the anchor chain is not considered

# Step 1: Calculating the environmental loads

## Wind and Current Forces

The environmental loads of wind and current are estimated from the non-dimensional coefficient curves provided in the OCIMF document, which in turn are taken from OCIMF Mooring Equipment Guidelines (MEG). The OCIMF document on anchoring refers to MEG Edition 3; however, MEG has been updated to Edition 4, and the same shall be referred to in this article.

The wind coefficients depend upon

- the wind angle of attack
- the type of bow - conventional/cylindrical
- loading condition of the vessel - ballasted or fully loaded

The current coefficients depend upon

- the current angle of attack
- the ratio of Water Depth to Draft of the vessel

**B1 Wind Coefficient Plots**

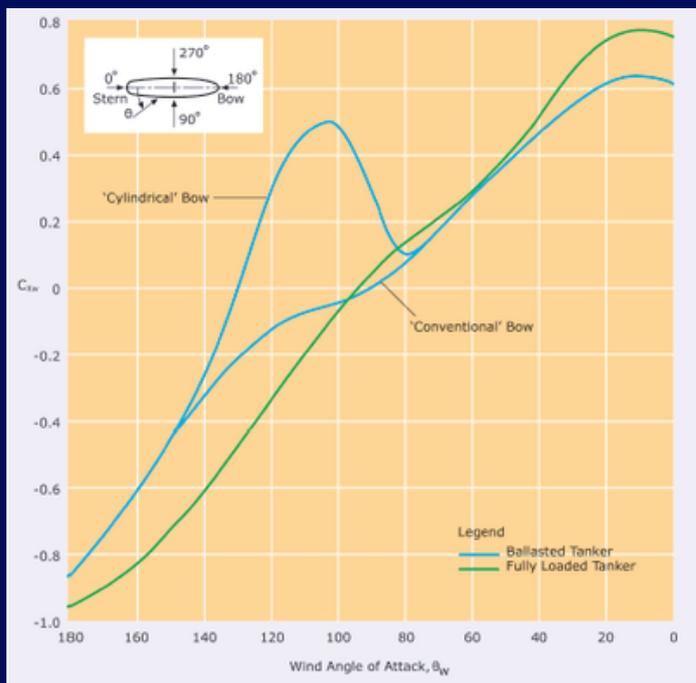
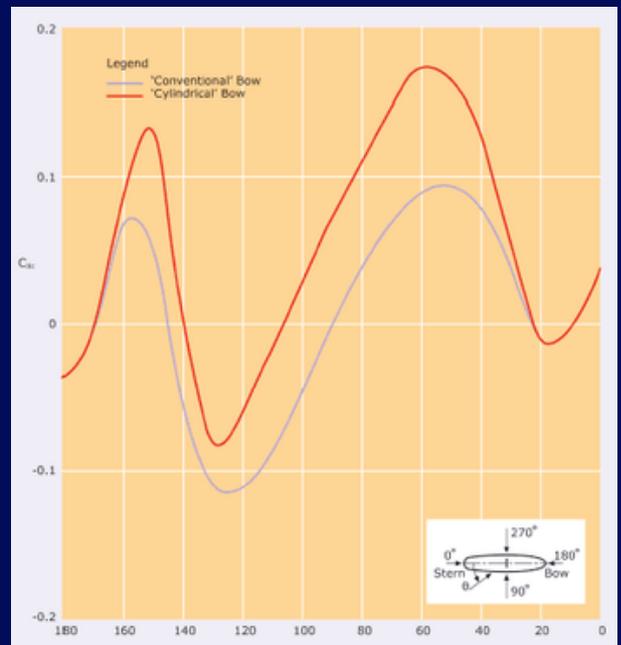


Figure B1: Longitudinal Wind Drag Force Coefficient – Tankers

**B2 Current Coefficient Plots**



Current and Wind Coefficients taken from OCIMF MEG-4

Once the wind and current drag coefficients are obtained, the standard physical equations can be used to determine the applicable forces. Only the forces in longitudinal direction are considered. The formulas are presented below:

$$F_{Xw} = \frac{1}{2} C_{Xw} \rho_w V_w^2 A_T \text{ (N)}$$

Wind Force Formula

$C_{Xw}$  = Wind Coefficient in Longitudinal direction

$\rho_w$  = Density of Wind ( $1.28 \text{ kg/m}^3$ )

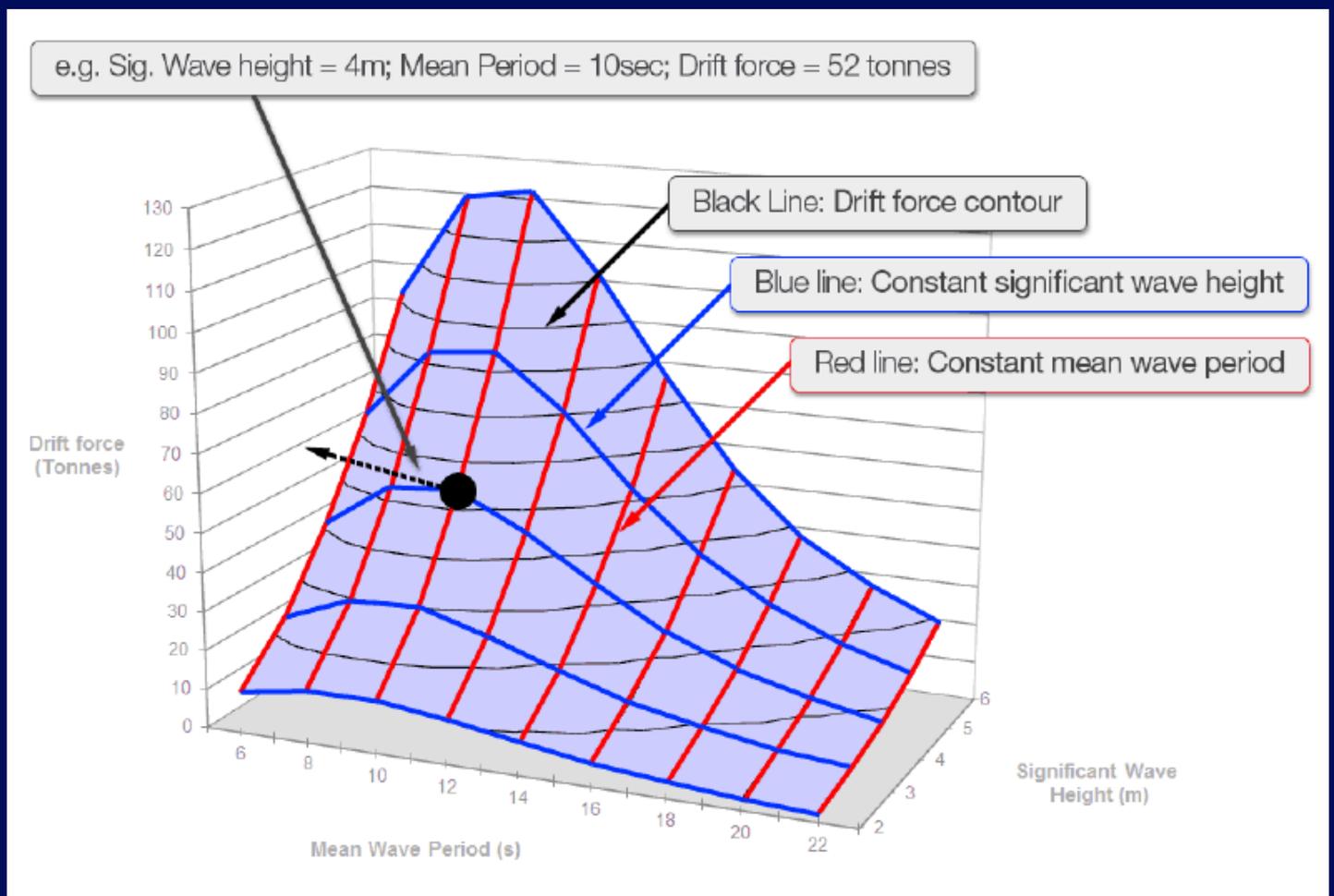
$V_w$  = Wind Speed (m/s)

$A_T$  = Transverse Windage Area of the Vessel ( $\text{m}^2$ )

$$F_{Xc} = \frac{1}{2} C_{Xc} \rho_c V_c^2 L_{BP} T \text{ (N)}$$

Wave drift forces - these are calculated from three dimensional surface plots. The surface plots provide the wave force in tonnes, depending upon the two parameters of Significant Wave Height and Mean Wave Period which can be obtained from the environmental data (nautical charts/Metocean data) of the location under consideration.

These wave loads are only the longitudinal forces which act on the vessel when the vessel is at anchor (since the vessel aligns itself along the environment). However, in the case the vessel is yawing, transverse forces also come into play which can be multiple times higher than longitudinal forces, and need to be accounted for in the force on anchor. As a thumb rule, for 20 degrees yaw, the longitudinal force obtained from the surface plot is multiplied by 2; for 40 degrees yaw, the force is multiplied by 3.



3D plots from OCIMF document to calculate wave drift forces

## Step 2: Calculating the anchor holding power and selecting the right anchor

The next step is to calculate the anchor holding power from the environmental forces. Let's say the total environmental force  $F_{ENV}$  has been calculated:

$$F_{ENV} = F_{XC} + F_{XW} + F_{wave}$$

where,  $F_{XW}$  = Wind Force,  $F_{XC}$  = Current force and  $F_{wave}$  = Wave Drift Force

For the anchor to be adequate for holding this vessel in the given environment, the anchor's holding power  $F_{HOLD}$  must be greater than the environmental force, i.e.,

$$F_{HOLD} > F_{ENV}$$

The anchor's holding power,  $F_{HOLD}$  depends on the the type of anchor, the size of the anchor's fluke and also on the seabed type. Soft mud is considered the weakest sea bed in terms of holding power, and sand is a better surface with higher holding power. Anchors with higher fluke area also have higher holding power. Generally, heavier anchors provide higher holding power too. See this article for more detail -> [Article on anchors](#)

Anchor holding power can be estimated from the anchor's weight and a factor for the type of seabed. The formula is below:

$$\text{Anchor Holding Power} = \text{Anchor Weight (tonnes)} \times \text{Seabed Factor}$$

The table from OCIMF (reproduced below) gives the typical anchor weights for Tankers and Gas carriers of different sizes.

Ship Size	Equipment Number	HHP Anchor Weight (t)	Max Holding Power - Clay (t)	Min Holding Power - Rock with Mud (t)
Medium Range (47,000 dwt)	3105	7	84	16.8
Aframax (115,000 dwt)	4825	11	132	26.4
VLCC (300,000 dwt)	8597	19.5	234	46.8
LNG (150,000 m <sup>3</sup> ) Prismatic	6069	13.35	160	32
LNG (210,000 m <sup>3</sup> ) Prismatic	7109	17.5	207	41
LNG (260,000 m <sup>3</sup> ) Prismatic	7855	18.375	220	44

Note: the anchor weights depicted above for the 210,000 and 260,000 m<sup>3</sup> LNG vessels are one size greater than the Rule requirement but have been included as they represent 'as-fitted' anchors on a large number of vessels of this size.

### Typical Anchor Weights for tankers and gas carriers

The seabed factor depends on the type of seabed and also the category of anchor (Standard Anchor vs High Holding Power, HHP Anchors). The following table from OCIMF document gives the seabed factors

Type of Anchor	Seabed Factors			
	Shingle/Sand	Rock with Thin Mud Layer	Soft Mud	Blue Clay
Standard Stockless	3.5	1.8	1.7	2.7
High Holding Power (HHP)	8	2.4	6	12

If the anchor holding power is found insufficient against the environmental load, then there's a possibility of the anchor being dragged which is a dangerous situation and can lead to collisions and grounding. This calls for corrective action like preparing the vessel for manoeuvring, deploying more cable etc. However, prevention is always better than corrective action, and it always helps in knowing beforehand the expected environmental forces on the vessel and check if the anchor has sufficient holding power.

You can check the app below.

<https://thenavalarch.com/software/marine-operations/anchoring/ocimf-anchoring-environment-loads-calculator/>



# SELECTING THE RIGHT CAPSTAN FOR BERTHING A VESSEL

## INTRODUCTION

Capstans are frequently deployed mooring equipment used on all types of vessels. Capstans are berthing/mooring equipment used to multiply the pulling force on mooring ropes. Traditionally, Capstans were operated manually but in modern ships, they are operated wither electro-hydraulically or electromechanically.

When Capstans are used in mooring ships, they have to be sufficient in size and number to overcome the forces which the ship experiences in the lateral direction due to environmental forces of wind and current. How do we know what size capstans will be sufficient? We'll take a detailed look at in this article.

This article is based on DDS-582-1 Calculations for Mooring Systems, Department of the Navy, Naval Sea Systems Command, Washington DC, 20362-5101.

## THE CONCEPT

When berthing a vessel, a number of capstans on the vessel may be utilized simultaneously. How do we determine if the capstan size is sufficient?

Thinking in basic terms, the berthing operation of the vessel will impose some forces on the vessel, which are transferred through the berthing lines to the capstans.

What forces are these?

At the berth, the two major forces are the wind and current forces that the vessel experiences. Also, since the vessel is mostly berthed sideways, these forces must be calculated on the side of the vessel (not on the front).

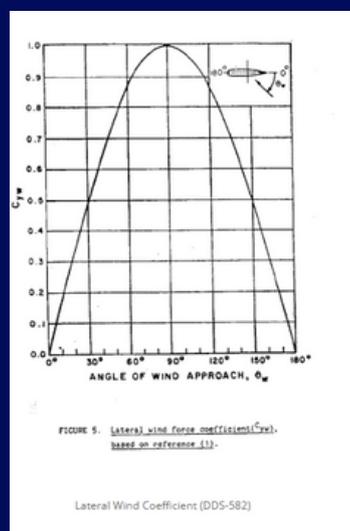
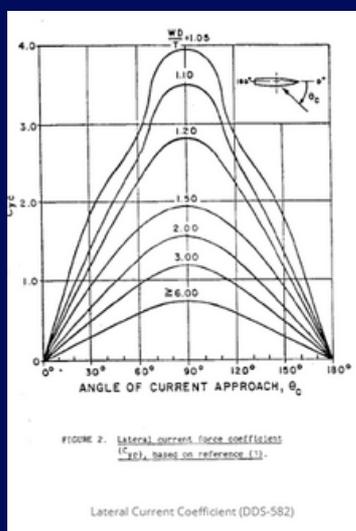
# ENVIRONMENTAL FORCES

The first step is calculating the environmental forces on the vessel. Generally, at berth, wind, and current are the most significant forces, while wave forces can be generally ignored. When calculating the wind and current forces, the standard physics formula of Force = Pressure x Area shall be used. In the method by DDS-582 (Ref 3), wave forces have not been considered for doing the calculation.

For wind force, the formula is  $F_{wind} = 1/2 \times C_{wind} \times \rho_{wind} \times V_{wind}^2 \times A_{wind}$ , where  $C_{wind}$  is the coefficient of wind force,  $\rho_{wind}$  is the density of air,  $V_{wind}$  is the wind speed, and  $A_{wind}$  is the total area of ship and cargo which is exposed to the wind from beam direction (the above-water area). Similarly, for current force, the formula is  $F_{current} = 1/2 \times C_{current} \times \rho_{water} \times V_{current}^2 \times A_{underwater}$ , where  $C_{current}$  is the coefficient of current force,  $\rho_{water}$  is the density of water,  $V_{current}$  is the current speed, and  $A_{underwater}$  is the total underwater area of ship which is exposed to the current from beam direction.

The critical items in the calculations for Wind and Current forces are the force coefficients for wind and current.

These coefficients can be obtained from the coefficient plots provided in DDS-582, and some plots are presented below:



We can see that the lateral current force is dependent on an additional factor: the underkeel clearance which is measured as Water Depth to Draft ratio (WD/T).

At the end of this exercise, we'll have the following with us:

- Wind Force – transverse
- Current force – transverse

Next exercise is using these forces and calculate the capstan line pull using the environmental forces.

# Capstan Design



From the above process, we can obtain the minimum required Capstan's power using which we can select the right capstan, or we can evaluate the suitability of an existing capstan for berthing.

Once we have the wind and current lateral forces, we add them up together to give the total lateral force on the vessel.

Total Lateral Force,  $FY = FYW + FYC$ , where

$FY$  = total lateral force on the vessel

$FYW$  = lateral wind force on the vessel

$FYC$  = lateral current force on the vessel

If the number of capstans is 'n', then the line pull per capstan is given by:

$$PCP = FY/n$$

Once the line pull is available, the minimum required Capstan power is determined as follows:

$$PCAPSTAN = PCP \times VCP/\eta_{CP}$$

Here,

$PCAPSTAN$  = Required minimum capstan power

$VCP$  = Capstan's warping line speed

$\eta_{CP}$  = Capstan's efficiency

The Capstan's efficiency has the following components:

- Capstan Head Efficiency
- Overall bearing and gear efficiency
- For electro-hydraulic capstans additionally - Efficiency of Hydraulic Pump and Motor

# Equipment Numeral Calculation for a Ship – a Guide



Intriguing as it sounds, Equipment Number (or Equipment Numeral) throws a plethora of questions when heard for the first time. Is it something which tells the number of equipment on a ship, or is it a catalog which assigns specific number to the equipment on a ship?

Cutting to the chase, Equipment Number (abbreviated as EN) is just a non-dimensional parameter which can be used to select the right sized anchoring and chain cables for a new ship. However, it is to be noted that these equipment are only meant for harbor mooring, and not for open sea or rough weather mooring.

Once the EN is known, a set of adequately sized equipment for mooring/anchoring of the vessel can be selected. Following are some equipment which can be selected based on EN:

- Stockless bower anchors
- Stud-link chain cables
- Towlines – made of Steel or fiber ropes
- Mooring lines – made of steel or fiber ropes

# First Principles

Thinking in very basic terms, the problem at hand is to select the right set of equipment for anchoring/mooring a vessel at port/harbor. That brings us to the basic question – why do we need to anchor a vessel? The simple reason is to prevent it from drifting away. What causes the drift? It is the forces of the environment acting on the vessel. What are these forces? The forces are wind, current and wave. Wave is generally non-significant at harbors.

How is wind/current force on the vessel calculated? Wind and current forces are drag forces, and they follow the simple drag equation

$$F = \frac{1}{2} \times \rho \times V^2 \times A$$

where,  $F$  = drag force,  $\rho$  = density of the medium (air/water),  $V$  = speed of wind/current,  $A$  = Area of vessel exposed to wind/current

From the above formula, we can understand that the Area of the vessel exposed to the wind or current is a critical input in calculation of the drag force. Inferring further, Wind force will depend on the projected windage area of

- the hull above the waterline, and
- topsides/superstructure/deckhouse

Current force will depend upon the wetted surface area of the hull underwater

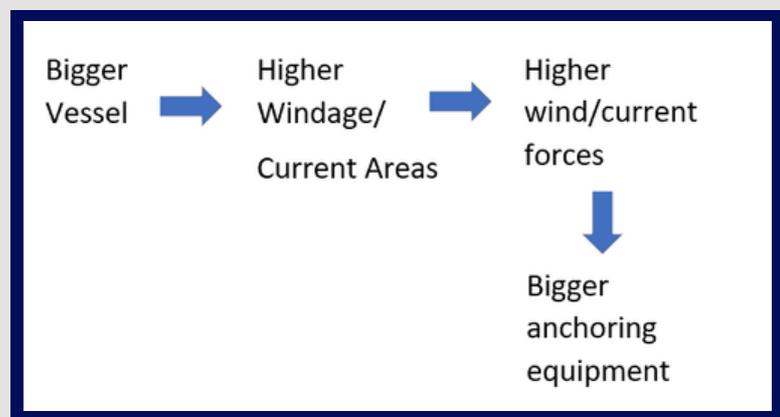
# Analysis

Now that we know the basis of the calculation, let's move on to establish the how a number (the Equipment Number) can be used to gauge the environmental forces for a vessel.

One thing is clearly obvious – that a bigger ship will have higher windage and current areas, and thus will attract higher forces. Similarly, a smaller ship will have smaller forces. These forces depend upon the projected areas, which become the determining parameter.

Also, we can infer that a ship with higher forces will need heavier equipment to anchor itself.

Thus, we can establish the following relationship



The above relationship is good to know but is obvious and not really spectacular or particularly helpful in selecting the anchoring or mooring equipment. The question remains - How do we select the right size equipment?

Do we go about calculating the forces for each port/harbor the vessel is expected to dock at? That will be a tedious exercise.

Won't it be great if there was some standard table which recommends the equipment size based on the size of the vessel? That would make our lives much easier. Say, given the windage/current areas of the vessel and its topsides/superstructure, the table can belt out the sizes of anchors and cables to be used. Further, it will be much better to combine both windage and current areas as one input against which the equipment sizes can be presented.

The windage and current areas are combined in a number called Equipment Number (EN). The table which gives the sizes of anchoring/mooring equipment for various Equipment Numbers is called the Equipment Number/Numeral (EN) Table. EN Tables are provided in most Classification Society rules and the formula to calculate the Equipment Number (EN) is also provided.

For example, the DNV-GL rules provide the formula and table for EN in its Rules for Ships, Part 3, Chapter 11, Section 1-3. An extract of the EN formula is presented below:

**3 Equipment specification**

**3.1 Equipment number**

**3.1.1 Equipment number for anchors and chain cables**

The equipment number is given by the formula:

$$EN = \Delta^{2/3} + 2 BH + 0.1 A$$

where:

$H$  = effective height in m from the summer load waterline to the top of the uppermost deckhouse, to be measured as follows:  
 $H = a + \sum h_i$

$a$  = distance in m from summer load waterline amidships to the upper deck at side

$h_i$  = height in m on the centre line of each tier of houses having a breadth greater than  $B/4$ . For the lowest tier,  $h_i$  shall be measured at centre line from the upper deck, or from a notional deck line where there is local discontinuity in the upper deck

$A$  = area in  $m^2$  in profile view of the hull, superstructures and houses above the summer load waterline, which is within  $L$  of the ship. Houses of breadth less than  $B/4$  shall be disregarded.

In the calculation of  $\sum h_i$  and  $A$  sheer and trim shall be ignored.

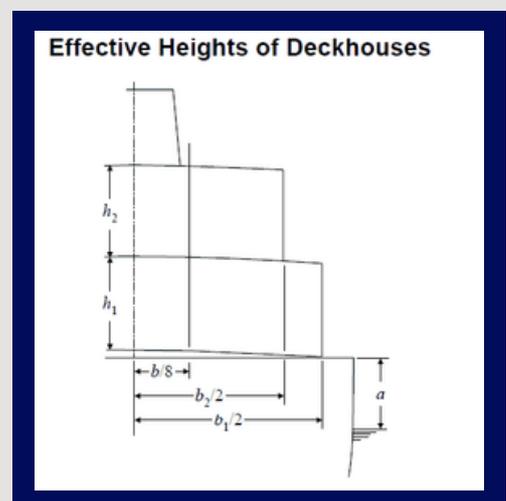
$\Delta$  = Rule Displacement in MT

The formula is a sum of the different components of current and windage areas.

- The first term,  $\Delta$ , is the vessel displacement. This term, being the weight of the underwater portion of the ship, relates to the area exposed to current forces (the displacement raised to the power of fraction 2/3 factors the cubic displacement term to a squared area term, roughly)
- The second term  $2 BH$ , is an indicator of the transverse windage area of the vessel. We can see that  $H$  is the height of effective height of the uppermost deckhouse. Calculation of  $H$  has two parts:

1. The part representing the hull exposed to wind – captured by the term ‘a’
2. The part representing deckhouses – captured by adding the heights of deckhouses present on the vessel.

The following diagram from ABS Rules Part 3, Ch 5, Sec 1/3.5 demonstrates the calculation of  $H$ . Only deckhouses which have width greater than  $B/4$  ( $B$  = breadth of the vessel) are considered in the calculation



The third term 0.1A, is an indicator of the profile windage area of the vessel. The profile area is not a governing one for windage area calculation, as the anchored vessel will weathervane to face the wind direction, and thus the transverse windage area of the vessel governs. Thus, the profile area is factored by the value 0.1. When EN has to be calculated to select the towing or mooring lines, then the area A has to additionally include the profile area of the maximum stacks of deck cargoes above the summer water line.

We can see that EN is obtained as a numerical value from the above formula and has the units of area (m<sup>2</sup>). Also, the value obtained from the above formula should be rounded off to the nearest higher integer to get the EN.

### Getting equipment sizes

Once we have the EN, what next? How do we select the right sized equipment from EN? Once again, Class rules come to assistance.

Class Rules provide standard tables for getting the equipment sizes once the EN has been calculated.

Once such table for DNV Rules is shown below:

We can see below that the first column has different ranges of Equipment Number (EN). Every EN range is allotted an equipment 'letter' which is an alphabet (sometimes with a subscript). This is a notation used for classifying the equipment based on equipment number.

**Table 1 Equipment, general**

Equipment number	Equipment letter	Stockless bower anchors		Stud-link chain cables			Towline (guidance)		Mooring lines <sup>1)</sup> (guidance)			
		Number	Mass per anchor kg	Total length m	Diameter and steel grade			Steel or fibre ropes		Steel or fibre ropes		
					VL K1 mm	VL K2 mm	VL K3 mm	Minimum length m	Minimum breaking strength kN	Number	Length of each m	Minimum breaking strength kN
30 to 49	a <sub>0</sub>	2	120	192.5	12.5			170	88.5	2	80	32
50 to 69	a	2	180	220	14	12.5		180	98.0	3	80	34
70 to 89	b	2	240	220	16	14		180	98.0	3	100	37
90 to 109	c	2	300	247.5	17.5	16		180	98.0	3	110	39
110 to 129	d	2	360	247.5	19	17.5		180	98	3	110	44
130 to 149	e	2	420	275	20.5	17.5		180	98	3	120	49
150 to 174	f	2	480	275	22	19		180	98	3	120	54
175 to 204	g	2	570	302.5	24	20.5		180	112	3	120	59
205 to 239	h	2	660	302.5	26	22	20.5	180	129	4	120	64
240 to 279	i	2	780	330	28	24	22	180	150	4	120	69
280 to 319	j	2	900	357.5	30	26	24	180	174	4	140	74

Range to be used for EN = 250

The above table is straightforward – from the value of EN, we locate the correct range in the first column. For example, if the EN is 250, then the range to be used is 240 – 279, as highlighted in the table above.

It is to be noted here that for the same vessel, the EN to be used for Towline and Mooring line selection can be higher compared to the EN used for the rest of the equipment (cables and anchors), since additional profile areas of deck cargoes are also included while calculating EN for towline/mooring line selection.

### Exceptions and deviations

- For fishing vessels with EN up to 720, the table to be used is separate. For EN above 720, the regular table can be used (as per DNV rules, Ref [2])
- For vessels operating in harbored/restricted service areas, the EN can be reduced. Please see DNV Rules (Ref [2]) for more details.

# Vessel with Stern on Quay:

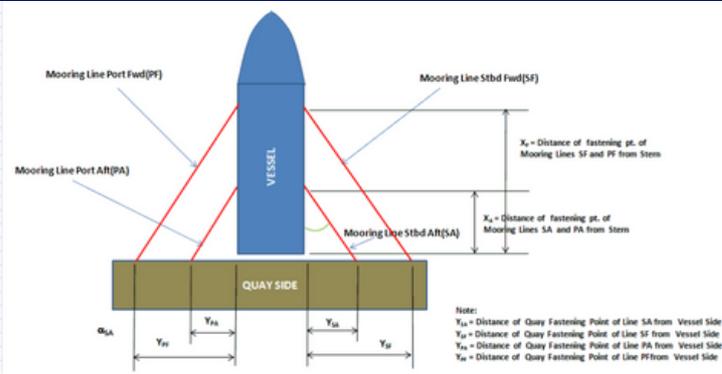
## A simplified method for mooring design

### Concept

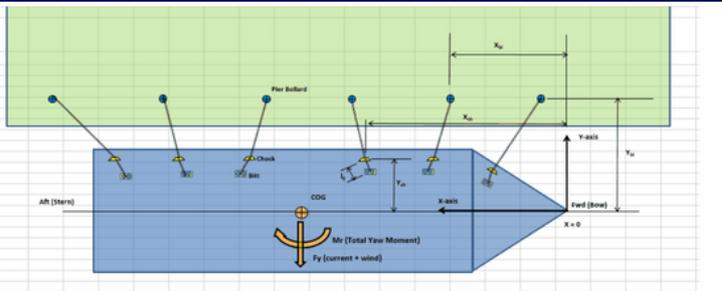
For each configuration, the mooring design has to be adequate to restrain the forces which the vessel experiences. In this article, we will analyse the first configuration - the Stern on Quay in more detail, and present a simplified method for calculating the line loads for a 4-point mooring pattern with the vessel's Stern on Quay.

The Stern-on-Quay configuration can be used when there's limited space available for the Port-on-Quay configuration, or when specialized operations like loadout are needed. During these operations, it is important to hold the vessel in place when the loadout operation is being carried out. The vessel will be subject to external forces of wind, current and wave, and so it is important to design a mooring system which can overcome these forces.

Thinking in very basic terms, the vessel will have its Stern pressing against the Quay (with fenders between the vessel and Quay to take the load). This vessel will be subjected to environmental loads coming from the beam side of the vessel (athwartship) which will tend to drift it off. A simple way is to tie the vessel to the quay side using ropes, and the simplest solution is to use a rope on each side, running each from the Port or Starboard side of the vessel, and tied to a bollard on the Quay. However, this simplest solution, while feasible, doesn't have any backup in case the rope on either side breaks. Also, if the ropes are tied closer to the fwd end of the vessel, the aft end may be subjected to an undesirable yaw moment. Thus, a safer and more recommended solution is to have two ropes on either side, running to different bollards on the Quay Side. This ensures that the entire load is distributed over two ropes on either side.



MOORING CONFIGURATION 1 - STERN ON QUAY, 4-POINT



MOORING CONFIGURATION 2 - PORT/STBD ON QUAY

A vessel at berth experiences much lower forces compared to a vessel in the open sea due to the milder environment, but it still requires a mooring configuration suitable to the forces it experiences, and also suitable for the type of berthing configuration adopted. The berthing configuration depends on the geometry of the berth, and also on the available space depending on the traffic at the berth and size of the vessel. Two berthing configurations which are mostly used are:

- Configuration 1: with the vessel's Stern aligned with the Quay
- Configuration 2: with the vessel's Port or Starboard side aligned with the Quay.

Both these configurations are shown in the sketches above.

# Calculation Steps

- Get the vessel's dimensions and cargo dimensions
- Get the environmental parameters of the Quay - Wave height, wind speed and current speed
- Calculate all the environmental forces on the vessel from the beam side (either port or Starboard). Also calculate the location along the length of the ship where the net force acts.
  - It should be noted here that while current and wave forces can be considered to be acting at the longitudinal centre of floatation of the vessel (which is close to midship), the point of application of wind force will depend on the size and location of cargo (if any) along the length of the vessel.
  - For a conservative analysis, the forces are considered to be collinear, i.e., all forces acting at the same time along the same direction
- Using basic physics formulae, balance the mooring line tensions against the force and moment due to the force. Here, the moment arm is the distance of the net force from the Quay.
  - There are two sets of equations - one balancing the line tensions against the net environmental force, and the other balancing the moments.
  - The combination of the above two equations gives the line tensions on the lines on either side. It is assumed that the lines are non-elastic

# Environmental Forces

When calculating the wind and current forces, the standard physics formula of Force = Pressure x Area shall be used.

For wind force, the formula is  $F_{wind} = 1/2 \times \rho_{wind} \times V_{wind}^2 \times A_{wind}$ , where  $\rho_{wind}$  is the density of air,  $V_{wind}$  is the wind speed, and  $A_{wind}$  is the total area of ship and cargo which is exposed to the wind from beam direction (the above-water area)

Similarly, for current force, the formula is  $F_{current} = 1/2 \times \rho_{water} \times V_{current}^2 \times A_{underwater}$ , where  $\rho_{water}$  is the density of water,  $V_{current}$  is the current speed, and  $A_{underwater}$  is the total underwater area of ship which is exposed to the current from beam direction.

The exposed areas to current and wind are shown in the figure below:

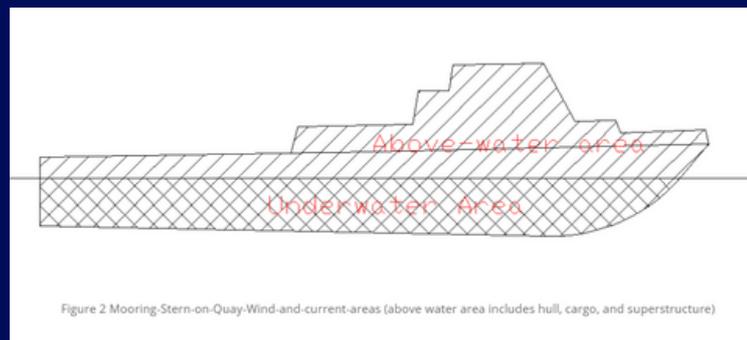


Figure 2 Mooring Stern-on-Quay Wind and current areas (above water area includes hull, cargo, and superstructure)

The Wave force is the additional wave load (Wave Drift Force) which will arise due to the harbour waves which the vessel experiences. Though the wave heights at Quay are generally low, this force would also be considered. These are related to wind speeds, and high wind speeds may lead to significant wave heights as well.

Please see below Beaufort scale to get the idea of relation between wave height and wind speed:

Force	Description	Sea State Description	Speed (Knots)	Range	Forecast Description	Sea State	Waves (metres)
0	Calm	Sea like a mirror	0	< 1	Calm	Calm	0
1	Light	"Ripples with the appearance of scales are formed but without foam crests"	2	1 - 3	Light	Smooth	0.1
2	Light Breeze	"Small wavelets still short but more pronounced. Crests have a glassy appearance and do not break"	5	4 - 6	Light	Smooth	0.2
3	Gentle Breeze	Large wavelets. Crests begin to break. Foam of glassy appearance. Scattered white horses	9	7 - 10	Light	Slight	0.6
4	Moderate Breeze	Small waves becoming longer fairly frequent white horses	13	11 - 16	Moderate	Moderate	1
5	Fresh Breeze	"Moderate waves taking a more Pronounced long form; many white horses are formed.Chance of some spray"	19	17 - 21	Fresh	Rough	2
6	Strong Breeze	Large waves begin to form; white foam crests are more extensive everywhere. Probably some spray.	24	22 - 27	Strong	Very rough	3
7	Near Gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.	30	28 -33	Strong	High	4
8	Gale	Moderately high waves of greater length; edges of crests begin to break into spindrift.The foam is blown in well-marked streaks along the direction of the wind.	37	34 -40	Gale	Very high	5.5
9	Strong Gale	"High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple tumble and roll over. Spray may affect visibility"	44	41 - 47	Severe gale	Very high	7
10	Storm	"Very high waves with long over-hanging crests. The resulting foam in great patches is blown in dense white streaks along the direction of wind. On the whole the surface of the sea takes a white appearance. The 'tumbling' of the sea becomes heavy and shock-like. Visibility is affected"	52	48 - 55	Storm	Phenomenal	9
11	Voilet Storm	Exceptionally high waves (small & medium sized ships might be lost to view for a time behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility is affected.	60	56 - 63	Violent storm	Phenomenal	11.5
12	Hurricane	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected	64	64+	Hurricane		14

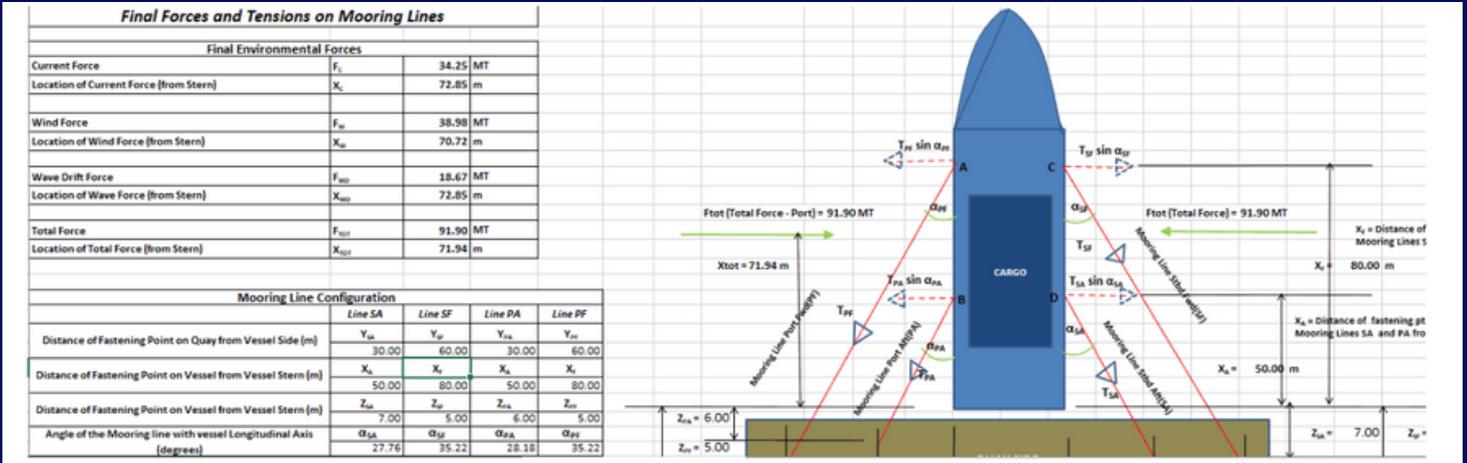
Figure 3 Beaufort-Scale

The Wave drift force can be calculated from DNV-RP-H103, Sec 7.2.6, taking the reflection coefficient R as 1. L is ship's length and HS is the significant wave height.

$$F_{WD} = 1/8 * \rho_{water} * R^2 * L * H_S^2$$

# Line Force Calculation

Once the forces have been calculated, the calculation of the line forces on the mooring line on either side can be done using the two equations of balance of forces, and balance of moments. The calculations based on TheNavalArch's own App, are shown below:



<b>A. Balance of Forces in Transverse Direction gives:</b>		
$T_{PF} \sin \alpha_{PF} + T_{PA} \sin \alpha_{PA} = F_{TOT}$		
$\Rightarrow T_{pf} \sin 35.22 + T_{pa} \sin 28.18 = 91.90$		
$\Rightarrow T_{pf} \times 0.58 + T_{pa} \times 0.47 = 91.90$ — Equation (i)		
<b>B. Balance of Moments about Point B</b>		
$T_{PF} \sin \alpha_{PF} \times (X_s - X_A) = F_{TOT} \times (X_{TOT} - X_A)$		
$\Rightarrow T_{pf} \sin 35.22 \times (80.00 - 50.00) = 91.90 \times (71.94 - 50.00)$		
$\Rightarrow T_{pf} \times 0.58 \times 30.00 = 91.90 \times 21.94$ — Equation (ii)		
Solving Equations (i) & (ii)		
" $\Rightarrow T_{PF}$ (Tension in Mooring Line Port Fwd) = "	<b>116.562</b>	MT
" $\Rightarrow T_{PA}$ (Tension in Mooring Line Port Aft) = "	<b>52.252</b>	MT
<b>Stbd Side</b>		
<b>A. Balance of Forces in Transverse Direction gives:</b>		
$T_{SF} \sin \alpha_{SF} + T_{SA} \sin \alpha_{SA} = F_{TOT}$		
$\Rightarrow T_{sf} \sin 35.22 + T_{sa} \sin 27.76 = 91.90$		
$\Rightarrow T_{sf} \times 0.58 + T_{sa} \times 0.47 = 91.90$ — Equation (i)		
<b>B. Balance of Moments about Point D</b>		
$T_{SF} \sin \alpha_{SF} \times (X_s - X_A) = F_{TOT} \times (X_{TOT} - X_A)$		
$\Rightarrow T_{sf} \sin 35.22 \times (80.00 - 50.00) = 91.90 \times (71.94 - 50.00)$		
$\Rightarrow T_{sf} \times 0.58 \times 30.00 = 91.90 \times 21.94$ — Equation (ii)		
Solving Equations (i) & (ii)		
" $\Rightarrow T_{SF}$ (Tension in Mooring Line Stbd Fwd) = "	<b>116.562</b>	MT
" $\Rightarrow T_{SA}$ (Tension in Mooring Line Stbd Aft) = "	<b>52.978</b>	MT

Figure 4 Sample calculations for 4-point, Stern-on-Quay mooring arrangement

The above simple method can serve as a quick check to help design a simple 4-line mooring pattern for vessels moored with their Stern on Quay. However, if high accuracy is demanded, or if multiple cases of environment from different directions are to be investigated, then a full fledged mooring analysis can also be carried out using standard software like Orcaflex (you may contact us for the same). For simple cases, the above calculation should suffice. Please do take a moment to explore our own excel-based App which performs the above detailed calculation. With simple user interface and basic inputs, it performs a quick assessment of the line loads and presents a basic mooring plan.



## MoorXL

(Mooring Forces Calculator (Port or Stbd on Quay))

This spreadsheet helps user to design a mooring pattern for a ship mooring by its side (Port or Stbd) to the Quay. The spreadsheet is based on the US Navy DDS-582-1 Calculations for Mooring Systems

<https://thenavalarch.com/software/maritime-industry-thenavalarch/marine-operations/mo-2-mooring-forces-calculator-port-stbd-quay/>



## Tankers Forces

(OCIMF Environment Forces Calculator - Tankers (Updated to MEG-4))

This Excel sheet helps you calculate the Wind and Current forces on a VLCC as per OCIMF Mooring Equipment Guidelines 4th Ed Appendix A (MEG 4)

<https://thenavalarch.com/software/maritime-industry-thenavalarch/marine-operations/mo-3-ocimf-environment-forces-calculator-vlcc/>



## Mooring Line Catenary App

This tool calculates the catenary profile and the tension in a multi-segmented line. It can simulate a free hanging catenary line or a line anchored on the ground.

This tool defines the catenary profile by calculating three basic parameters,

- Horizontal Tension at Anchor
- Departure angle at Anchor
- Length of line on ground (if Ground Active)

<https://thenavalarch.com/software/maritime-industry-thenavalarch/marine-operations/mo-09-mooring-line-catenary-app/>



## Mooring Forces Calculator (Stern on Quay, 4-Point Mooring)

This Excel sheet calculates the Mooring Line Tensions for a four point Mooring in a Stern on Quay configuration which is generally adopted for Load-outs

Features:

- Calculates the Wind, Wave and Current forces separately
- Wind force calculated based on ABS MODU 2012, Wave Force calculated based on DNV Rules RP-H-103

<https://thenavalarch.com/software/maritime-industry-thenavalarch/marine-operations/mo-01-mooring-forces-calculator-stern-quay-4-point-mooring/>



## Motion ResponseXL

This tool takes the RAO of the vessel as input and calculates the response spectrum for 6 DOF motions and statistical significant and max response. The RAO is usually computed for the COG or a fixed origin on the vessel.

<https://thenavalarch.com/software/maritime-industry-thenavalarch/marine-operations/motion-response-calculator/>



## OCIMF Anchoring Environment Loads Calculator

This application can be used to estimate the environmental forces on a Tanker/LNG carrier due to wave, wind and current based on coefficients defined by Mooring Equipment Guidelines (MEG) 4th edition and OCIMF Information paper Estimating The Environmental Loads On Anchoring Systems.

<https://thenavalarch.com/software/maritime-industry-thenavalarch/marine-operations/ocimf-anchoring-environment-loads-calculator/>



## OCIMF Forces Gas Carrier (updated to MEG4)

This Excel sheet helps you calculate the Wind and Current forces on a Gas Carrier as per OCIMF Mooring Equipment Guidelines 4th Ed Appendix A (MEG 4)

<https://thenavalarch.com/software/maritime-industry-thenavalarch/marine-operations/mo-4-ocimf-environment-forces-calculator-gas-carrier/>



## Mooring Line Catenary with Buoy

This application can be used to calculate the Catenary of a Mooring line with 5 segments and comprising Buoys

<https://thenavalarch.com/software/maritime-industry-thenavalarch/marine-operations/mooring-line-catenary-with-buoy/>



## Capstan Design XL

Capstan Design (Required power for Berthing)

This Excel sheet helps the user obtain the required Capstan Line Pull and Capstan Power for berthing operations

[https://thenavalarch.com/marine-calculators/?wfp=tna\\_products&wfp\\_cols=3&wfp\\_page=1&wfp\\_cat=mooring](https://thenavalarch.com/marine-calculators/?wfp=tna_products&wfp_cols=3&wfp_page=1&wfp_cat=mooring)



## Ship Design MBL-IACS

This Excel app helps you calculate a ship's design MBL as per IACS Rec.10.

Ship's design MBL is an important parameter that can be used further to select the towing and mooring fittings.

<https://thenavalarch.com/software/maritime-industry-thenavalarch/marine-operations/ship-design-mbl-calculator-iacs/>



## Fishing Vessel Equipment Number Calculator

This excel spreadsheet calculates the Equipment number for a Fishing Vessel from DNV rules. It further recommends specifications for the anchoring and mooring equipment for the vessel

<https://thenavalarch.com/software/maritime-industry-thenavalarch/ship-design/fishing-vessel-equipment-number-calculator/>



## Equipment Numeral as per IACS

This Excel app helps you calculate a ship's Equipment Numeral (EN) as per IACS UR A1

<https://thenavalarch.com/software/maritime-industry-thenavalarch/marine-operations/equipment-numeral-as-per-iacs/>