Oil Companies International Marine Forum

Estimating The Environmental Loads On Anchoring Systems

Information Paper

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The OCIMF mission is to be the foremost authority on the safe and environmentally responsible operation of oil tankers and terminals, promoting continuous improvement in standards of design and operation

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The Oil Companies International Marine Forum (OCIMF)
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Contents

1 Introduction

During the review and update of the OCIMF publication 'Anchoring Systems and Procedures', several incidents were referenced where Masters had remained at anchor during deteriorating weather conditions, with the result that significant damage was caused to anchor system components and, in some cases, serious personal injuries were sustained.

The Master's judgement and knowledge of the capability and limitations of anchoring systems, based on sound seamanship principles, is relied on when making decisions as to the potential security of an anchored vessel. However, unlike other mooring situations, such as mooring alongside using the ship's outfit of lines, there is very little information available to assist in estimating the likely forces being imposed on the anchoring system. This paper attempts to address this by providing a methodology and data to assist in estimating the forces acting on an anchored vessel in varying environmental conditions.

The paper provides general guidance on the assumptions made and methodology used in estimating the forces and includes an interactive calculation sheet. Plots and graphs used in support of the calculation process are included as an Appendix.

2 Scope

The forces acting on a ship when at anchor are primarily comprised of wind, current and wave drift loads.

Wind loading data is presented for oil tankers and LNG carriers (prismatic and spherical containment systems) and is valid for vessels of 16,000 dwt and above.

Loads due to current are presented for oil tankers and are based on model test data for 190,000 dwt and above. The data is considered applicable for smaller vessel sizes down to 16,000 dwt.

Wave drift forces are presented for oil tankers from 20,000 dwt to 300,000 dwt and for LNG vessels of 150,000, 210,000 and 260,000 m^3, irrespective of containment system type.

3 Key Assumptions

The process described in this paper is a simplified approach to estimating the forces acting on an anchored vessel and is designed to be achievable through the application of relatively straightforward calculations. As a result, a number of assumptions have been made which are briefly described, as follows:

- 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

4 Environmental Forces

Calculations consider the environmental forces acting on an anchored vessel from wind, current and waves.

For wind and current loads, data is presented in the form of non-dimensional coefficient curves. For wave drift forces, three dimensional surface plots are presented.

Note: where data is available for a specific ship, this should be used in preference to the general data presented in this paper.

When comparing the OCIMF/SIGTTO drag data contained in this paper with that from other sources, it should be noted that the data has been increased above the original measured mean results to allow for scatter in the raw data, scaling effects and variations in hull geometry. This resulted in the wind drag coefficients for VLCCs being increased by 20% and those for LNG vessels by 10%.

No increase in the measured data has been made to the current drag coefficients.

Wave drift forces were calculated by Tension Technology International (TTI) Ltd. for the purposes of this paper and no increases in the calculated data have been made.

As it is assumed the vessel lies at a single anchor and will swing to an equilibrium position as a result of the combined action of wind, current and waves, it is considered necessary only to calculate the longitudinal force components when assessing the force acting on the anchored vessel.

Through the application of several equations, the magnitude of the total environmental force may be calculated. This value can then be compared to the anchor holding power to provide guidance as to whether the anchor is likely to drag.

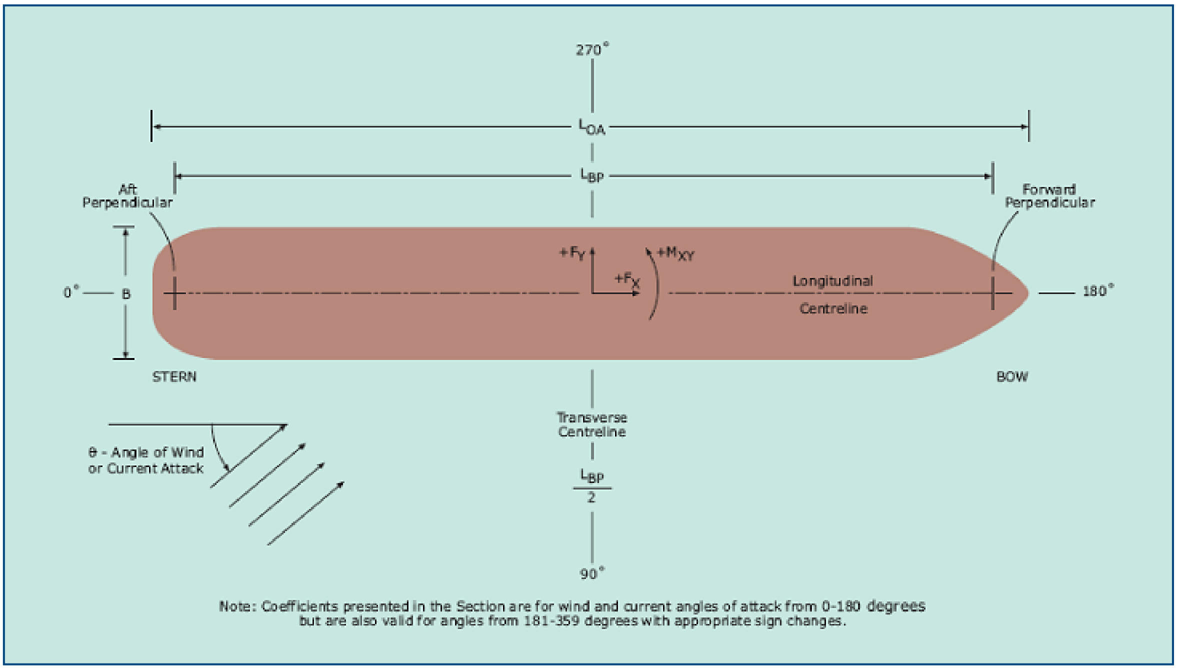

Figure 1: Sign Convention

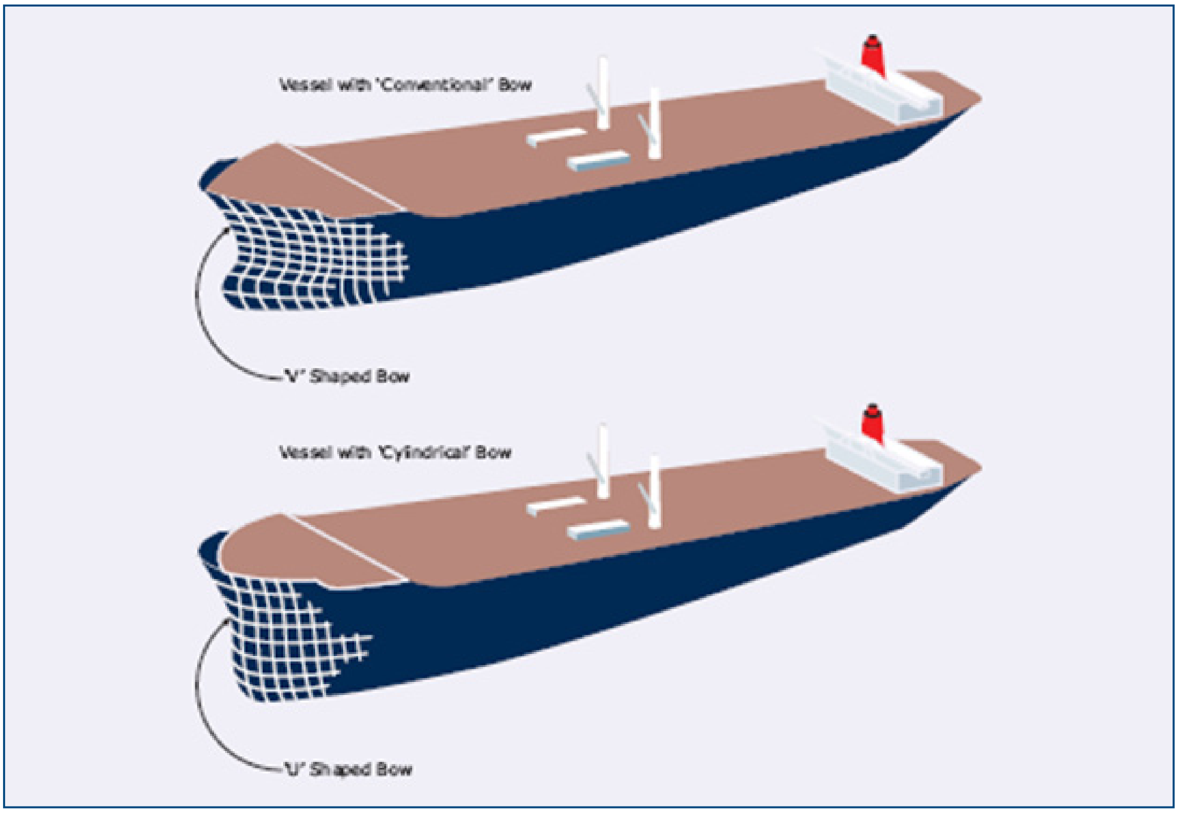

Figure 2: Bow Configurations

A_T	Transverse (head-on) windage area	m^2
B	Beam	m
C_{Xc}	Longitudinal current drag force coefficient	non-dimensional
C_{Xw}	Longitudinal wind force coefficient	non-dimensional
F_{Xc}	Longitudinal current force	N (Newton)
F_{Xw}	Longitudinal wind force	N (Newton)
h	Height above water/ground surface	m
K	Current velocity correction factor	non-dimensional
L_{BP}	Length between perpendiculars	m
S	Water depth measured from water surface	m
T	Draught (average)	m
V_c	Current velocity (average)	m/s
v_c	Current velocity at depth s	m/s
V_w	Wind velocity at 10m elevation	m/s
v_w	Wind velocity at elevation h	m/s
WD	Water depth	m
θ_c	Current angle of attack measured from ship centreline	degrees
θ_w	Wind angle of attack	degrees
ρ_c	Density of water	kg/m^3
ρ_w	Density of air	kg/m^3
H_S	Significant wave height	m
T_Z	Mean Wave Period	s (seconds)
Density for salt water is taken as 1025 kg/m^3 and for air 1.28 kg/m^3		
Approximate conversion factors: 10 kN = 1 Tonne.f (10,000N = 1 Tonne.f) 1 m/s = 2 knots		

Table 1: Symbols And Notations Used In Calculations

4.1 Wind Loads

OCIMF has published wind load data in 'Mooring Equipment Guidelines' (MEG3) which includes a method of estimating the wind loads. It is not intended to reproduce this data in its entirety in this paper, although relevant extracts are included.

The wind force prediction is based on wind tunnel model tests using four models representing tankers of 155, 280, 400 and 500 kdwt, and involves the use of non-dimensional coefficients which were transferred into curves relating the wind angle to coefficient magnitude. Knowledge of the wind speed, direction and cross sectional area of the vessel allows a force to be estimated.

Recent model test data on more modern tanker forms confirms that the same coefficients are, in most cases, sufficiently accurate when applied to smaller ships and that they therefore may be used for a range of oil tankers down to approximately 16,000 dwt.

OCIMF/SIGTTO conducted wind tunnel tests to determine the wind load coefficients for LNG vessels in the 75,000 m^3 - 125,000 m^3 range. Zero trim was assumed in all cases and two cargo containment types were considered (spherical and prismatic-type tanks).

Wind angles are shown from 0 degrees at the stern to 180 degrees bow on, as shown in Figure 1 'Sign Convention'.

The coefficients are only valid for vessels with superstructures at the stern. The coefficient 'C_{Xw}' and area 'A_T' refer to the head-on projected area of the above waterline portion of the vessel.

Changes in freeboard have the most significant impact on the wind coefficient. Separate curves have therefore been developed for the fully loaded and ballasted conditions.

Variations in bow configuration also produce a substantial difference in the longitudinal force coefficient for a ballasted tanker. For consistency with MEG3, the configuration changes are characterised by tankers with a so-called 'conventional' bow shape, versus a 'cylindrical' bow shape (Figure 2).

The wind drag coefficients assume zero trim in the fully loaded condition and, for tankers, 0.8 degrees trim in the ballast condition.

4.1.1 Typical windage areas

Vessel Type	Size	Length B.P (m)	Draught (m)		A_T (m^2)	
			Loaded	Ballast	Loaded	Ballast
Products Tanker	37,000 dwt	175	10.80	6.80	675	760
Aframax Tanker	113,000 dwt	239	13.40	8.30	1,290	1,580
VLCC	305,000 dwt	320	22.00	9.80	1,740	2,460
LNG (Spherical)	125,000 m^3	274	11.00	9.00	1,300	1,400
LNG (Prismatic)	75,000 m^3	220	10.00	8.00	900	1,000
LNG (Prismatic)	150,000 m^3	275	11.50	9.50	1,550	1,630
LNG (Prismatic)	210,000 m^3	302	12.00	9.6	1,586	1,706
LNG (Prismatic)	260,000 m^3	332	12.00	9.6	1,698	1,827

Table 2: Typical Vessel Characteristics

Example windage areas are provided as guidance in Table 2 for oil tankers and LNG carriers. These may be used in the calculations to estimate the wind force if a specific vessel's windage area is not known, although it is recommended that appropriate, ship-specific data is used where available.

The presence of spherical tanks on gas carriers has the most significant impact on the wind drag coefficient. The deviations in the coefficients result from the differences in the relative force contribution and distribution due to the configuration of the spherical tanks. Therefore, separate curves for prismatic and spherical tanks have been developed where the deviations are significant. Differences in wind loads due to the ship's loaded condition are not significant due to the relatively small change in draught from a ballasted to fully loaded condition for the size of gas carriers reviewed.

4.1.2 Wind load calculation procedure

Step 1: Determine the ship characteristics
(see Table 2 if ship-specific data is not known)

A_T
L_{BP}

note the bow configuration (see Figure 2)
measure/estimate wind speed and heading relative to the stern (see Figure 1)
note the height of the wind speed measuring point above the surface of the water.

Step 2: Obtain the wind drag coefficients
Obtain the value C_{Xw} relating to the wind heading angle using Figure B1 for oil tankers and Figure B2 for LNG vessels.

Step 3: Correct wind velocity for the measuring height

$$V_w = v_w \left(\frac{10}{h} \right)^{1/7}$$

where:

V_W = wind velocity at 10 m height (m/s)
v_w = the wind velocity at elevation h (m/s)
h = elevation above ground/water surface (metres)

Step 4: Calculate longitudinal wind force component
Substitute C_{Xw}, ρ_w, V_W, A_T into the following equation:

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

4.2 Current Loads

MEG3 contains information for the use in calculating current loads on VLCCs. This work was based on model tests conducted at the Maritime Research Institute Netherlands (MARIN) between 1968 and 1975 for models representing 190, 270 and 540 kdwt tankers and also investigated the influences of water depth to draught ratios.

It should be noted that unlike longitudinal wind drag calculated using transverse sectional area, the longitudinal current drag is calculated by reference to the hull length multiplied by the draught.

Underkeel clearance has the greatest influence on the current drag coefficient. This is primarily due to the blockage effect of the hull that causes a proportionally larger volume of water to pass around rather than under the hull as the underkeel clearance decreases.

The magnitude of the current forces is also influenced by the bow form in a similar manner to the wind. Separate curves are provided in the appended data to represent a 'conventional' versus a 'cylindrical' bow shape. For a cylindrical bow with a bulb, it is recommended to use the data for the cylindrical bow without a bulb. For the conventional bow shape without bulb, the larger coefficient with or without bulb should be used.

The test programme mainly considered L/B ratios between 6.3 and 6.5 to reflect the majority of existing VLCCs at the time. However, more recent VLCCs tend to have L/B ratios in the range from 5.0 to 5.5. As L/B ratios decrease, the longitudinal drag coefficients tend to increase. For a VLCC with an L/B of 5.0, a maximum increase in the longitudinal drag coefficients of 25-30% may be expected for smaller current angles (up to a maximum of 15 degrees).

The trim is assumed to be zero for all the current drag data and the effects of trim on current coefficients have not been investigated.

The coefficients used to compute current loads on VLCCs were also generally applicable to the computation of current loads on LNG vessels in the 75,000 - 125,000 m^3 range, and are still considered as applicable for larger vessel sizes. Therefore, separate current coefficients have not been developed for gas carriers.

4.2.1 Current load calculation procedure

Step 1: Determine the ship characteristics
L_{BP} and draught (T)
note the bow configuration (see Figure 2)
measure/estimate current speed and heading relative to the stern (see Figure 1)
note the depth at which the current was measured and express as a percentage of the vessel's draught.

Step 2: Obtain the longitudinal current drag force coefficient
C_{Xc} relating to the current heading angle using Figures B3 - B8 as appropriate, depending on water depth:draught ratio (WD/T).

Step 3: Correct for average current
Obtain the current velocity correction factor, K from Figure B9 for the specific depth: draught ratio and for the depth the current velocity is measured (as a % of ship draught).

Step 4: Compute the average current velocity

$$V_c = K \times v_c$$

Step 5: Calculate longitudinal current force
Substitute C_{Xc}, ρ_c, V_C, L_{BP}, T into the following equation:

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

4.3 Wave Drift Forces

The mean force induced by waves is related to the reflection of the incident wave by the immersed body, and the movements/oscillations of the body (i.e. pitch and heave).

Generally, waves of shorter period are reflected when they come into contact with the ship's hull, which imparts a greater force than a longer wave, which tends to 'roll' past the vessel, exerting a lower drift force.

Wave drift force data is based on analysis performed by Tension Technology International Ltd. (TTI) for a range of ship types in varying sea states.

A Pierson-Moscowitz sea spectrum was used in the analysis, which represents a fully developed sea.

All vessels were considered in the loaded condition.

Wave Height
Wave height is defined as the 'significant wave height' which is the average wave height (trough to crest) of the one-third largest waves. There is generally good agreement between the wave heights estimated by an observer and the actual significant wave height. Drift force increases with significant wave height and is proportional to wave height squared

Wave Period
The wave period used refers to the 'Mean Wave Period'. Shorter wave periods generally result in higher drift forces; when the wave comes into contact with the ship's hull, the wave is largely reflected

Depth: Draught Ratio
Analysis showed that the wave drift force is influenced by the ratio of water depth to ship draught (WD/T) and that for low WD/T ratios (for example, 1.2) the reduction in underkeel clearance at higher wave heights began to impact the analysis, leading to uncharacteristically high drift forces occurring.

This occurrence was shown to reduce as the WD/T ratio increased, and no undue effects were recorded at

WD/T = 2, which were in the same order of magnitude as higher WD/T ratios. Using WD/T = 2 was also felt to be appropriate when considering the IACS design criteria of a cable scope (the ratio of cable paid out to the water depth) of between 6 and 10.

Consequently, the results for wave drift forces presented in the Appendix are based on a WD/T= 2, that is, water depth is twice the vessel draught.

Wave Heading
Head sea conditions result in only longitudinal wave drift forces acting on the vessel. However, as the wave heading shifts, transverse forces begin to dominate and the total drift force acting on the vessel increases markedly.

As an example, a VLCC in a 4m sea with a wave angle of incidence of 40 degrees to the bow would have a total resultant force acting on the hull of 74 tonnes, consisting of 35 tonnes of longitudinal force and 66 tonnes of transverse force. In such cases the vessel would swing at anchor as a result of the transverse force component until equilibrium is reached.

In certain cases, a vessel may yaw while at anchor. This may result in transverse forces being imposed on the vessel which may be transferred into the anchor chain cable. Generally, a 40 degree yaw angle can increase the total force acting on the chain by approximately a factor of 3.

4.3.1 Using the surface plots

Wave drift forces are presented for a range of vessel sizes as three-dimensional surface plots. This allows the determination of the wave drift force for estimated mean wave periods and significant wave heights. Contour lines at 10 tonnes increments are superimposed on the surfaces to assist in interpolating the data (see Figures B10 - B17).

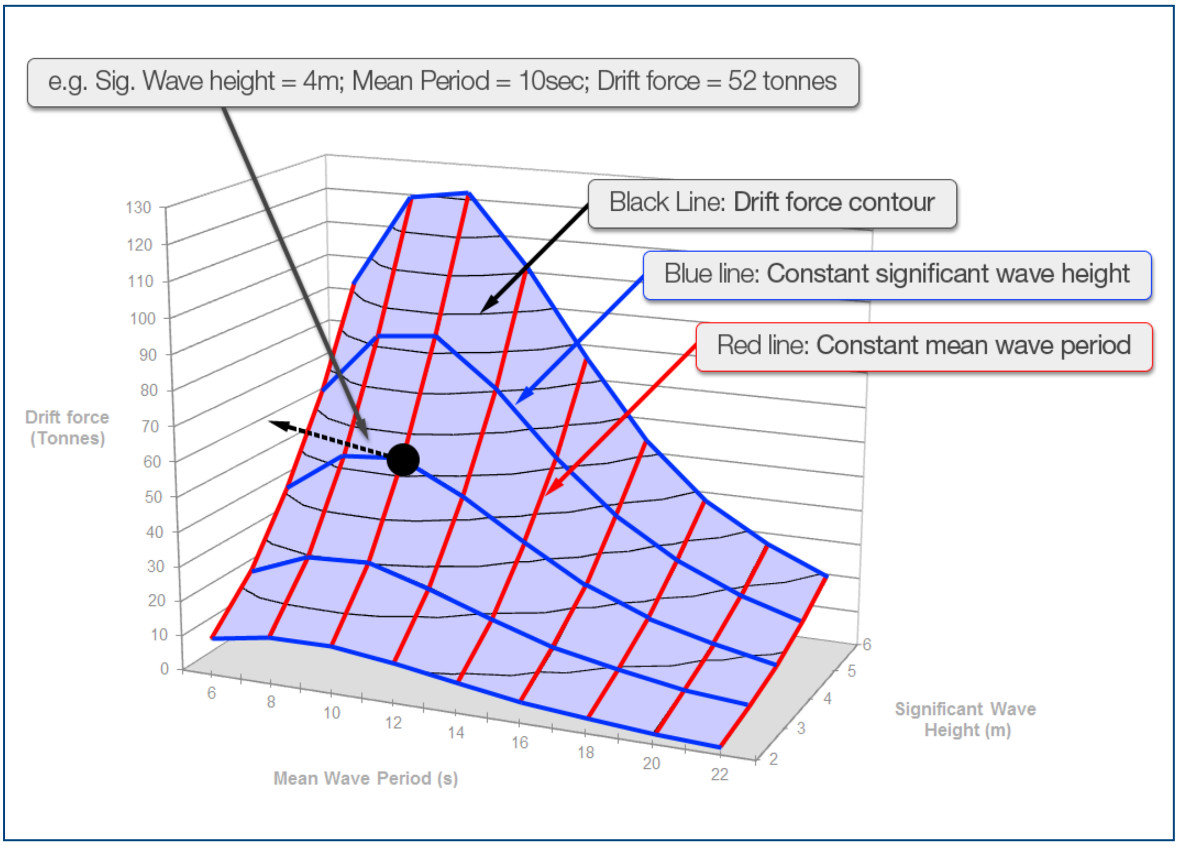

Figure 3: Using The Surface Plots

It should be noted that the surface plots represent the longitudinal force acting on the vessel due to the specified wave conditions. For an anchored vessel which is in a steady state (i.e, lying at anchor and not swinging) with the anchor chain deployed in line with the ship's centreline, only the longitudinal components of forces are considered to be producing tension in the anchor chain.

However, it is recognised that the vessel may 'yaw' up to 40 degrees while at anchor, exposing the vessel's side to the waves and resulting in both longitudinal and transverse forces being imposed on the ship. Transverse forces are markedly higher than the longitudinal forces for a given sea state, with the resultant total force that may be imposed on the anchor chain being of the order of 2-3 times higher than that presented in the surface plots.

In such conditions, the value obtained from the surface plot should be multiplied by 2 and 3, for 20 and 40 degrees yaw angles, respectively.

Significant yawing will lead to high forces acting on the cable, although some may be damped by the catenary in the chain cable.

It is stressed that the methodology and data presented in this paper provides only an estimate of forces acting on the anchor system. The considerations of good seamanship should always guide the actions taken by the Master and crew.

5 Anchor Holding Power

Anchor holding power is influenced by the nature of the seabed and the fluke area. However, it is convenient to estimate the holding power of the anchor as a function of anchor weight.

The following equation may be used to estimate the anchor holding power:

Anchor Holding Power (tonnes) = Anchor Weight (tonnes) x Seabed Factor

Table 3 details the seabed factors for a range of seabed and anchor types.

Type of Anchor	Seabed Factors			
	Shingle/Sand	Rock with Thin Mud Layer	Soft Mud	Blue Clay
Standard Stockless	3.5	1.8	1.7	207
High Holding Power (HHP)	8	2.4	6	12

Table 3: Seabed Factors

Table 4 provides estimated weights of typical high holding power anchors for a variety of ship sizes. This information is provided for reference and guidance only as the actual weights of anchors may vary from ship to ship.

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^3) Prismatic	6069	13.35	160	32
LNG (210,000 m^3) Prismatic	7109	17.5	207	41
LNG (260,000 m^3) Prismatic	7855	18.375	220	44

Note: the anchor weights depicted above for the 210,000 and 260,000 m^3 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.

Table 4: Typical Anchor Weights (High Holding Power)

Appendix A: Calculation Sheet

P. Ship Particulars	Equation	Value	Notes
P1. Length, L_{BP} (m)	-		
P2. Beam, B (m)	-		
P3. Draught, T (m)	-		
P4. Windage Area, A_T (m^2)	-		
P5. Deadweight, DWT (t)	-		
P6. Anchor Weight (t)	-		
A. Wind Force Estimation			
A1. Wind Speed, v_w (m/s)	-		
A2. Wind Direction, θ_w (degrees)	-		Relative to 0 degrees at stern - see Fig. 1
A3. Measuring Height, h (m)	-		Relative to elevation above water surface
A4. Wind Speed Correction For Measuring Height, V_W (m/s)	$V_w = v_w\left(\frac{10}{h}\right)^{1/7}$		
A5. Determine Wind Drag Coefficient For Direction As Per A2, C_{Xw}	-		Use Figure B1 for tankers and Figure B2 for LNG vessels.
A6. Calculate Wind Force (longitudinal), F_{Xw} (N)	$F_{Xw} = \frac{1}{2} C_{Xw} \rho_w V_w^2 A_T$		Substitute values from A1, A4, A5 $\rho_w = 1.28 kg/m^3$
A7. Convert to Tonnes	$F_{Xw}/10{,}000$		
B. Current Force Estimation	-		
B1. Current Speed, v_c (m/s)	-		
B2. Current Direction, θ_c (deg)	-		Relative to 0 degrees at stern, see Fig.1
B3. Water Depth, WD (m)	-		
B4. Depth:Draught ratio	WD/T		
B5. Compute Average Current Velocity, V_c	$K \times v_c = V_c$		Use Figure B9 to obtain 'K'
B6. Determine Current Drag Coefficient For Direction as Per B2 and WD/T Ratio As Per B4, C_{Xc}	-		Use Figures B3 - B8
B7. Calculate Current Force (longitudinal), F_{Xc} (kN))	$F_{Xc} = \frac{1}{2} C_{Xc} \rho_c V_c^2 L_{BP} T$		Note calculation uses L_{BP} x T $\rho_c = 1025 kg/m^3$
B8. Convert to Tonnes	$F_{Xc}/10{,}000$		

C. Wave Drift Force Estimation		
C1. Estimate Significant Wave Height (m)	-	
C2. Estimate Mean Wave Period (s)	-	
C3. Select Appropriate Plot	-	Use Figures B10 - B17. Data for intermediate ship sizes may be obtained through interpolation.
C4. Read Off Wave Drift Force (t)	-	
D. Total Environmental Loads On Vessel (t)	A7 + B8 + C4	
E. Anchor Holding Power Estimate		
E1. Determine Seabed Factor	-	Use Table 3
E2. Estimate Likely Holding Power	P6 x E1	Anchor weight x seabed factor
F. Compare D and E2.		**If D > E2, possibility of anchor dragging. Consider weighing anchor/taking appropriate action. Also note the impact of yawing on calculated loads.**

Users of this Calculation Sheet should refer to the Key Assumptions contained in Section 3.

To use the interactive version of this calculation please click here

Appendix B: Environmental Force Graphs

Appendix B contains the graphs/plots required to estimate the forces due to wind, wave and current, using the calculation procedures detailed in Section 4.

Wind and Current coefficient plots are taken from the OCIMF publication 'Mooring Equipment Guidelines' (MEG3). Wave drift force surface plots for a variety of ship sizes and types are based on research work completed for the purposes of this paper by OCIMF and TTI Ltd.

B1 Wind Coefficient Plots

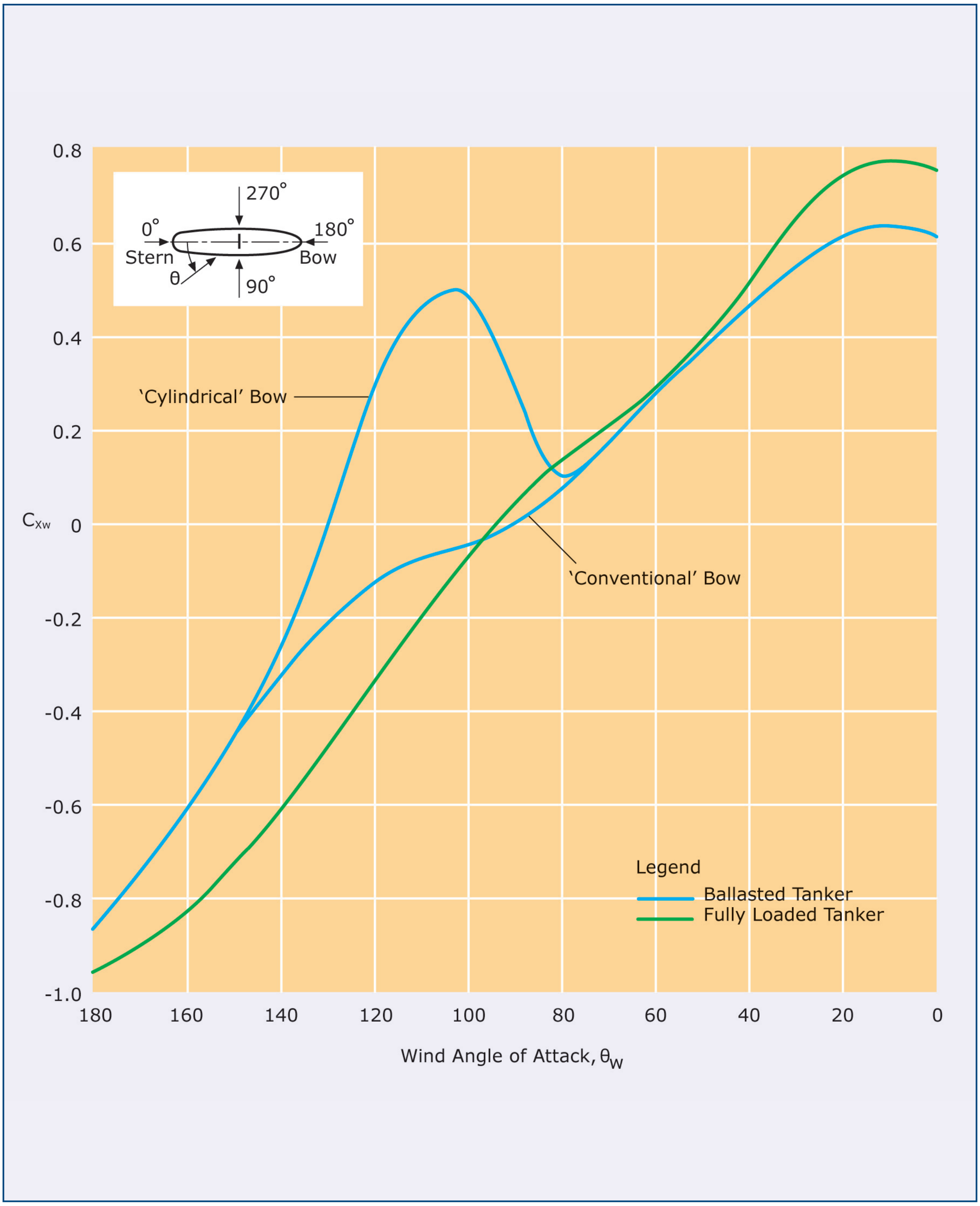

Figure B1: Longitudinal Wind Drag Force Coefficient – Tankers

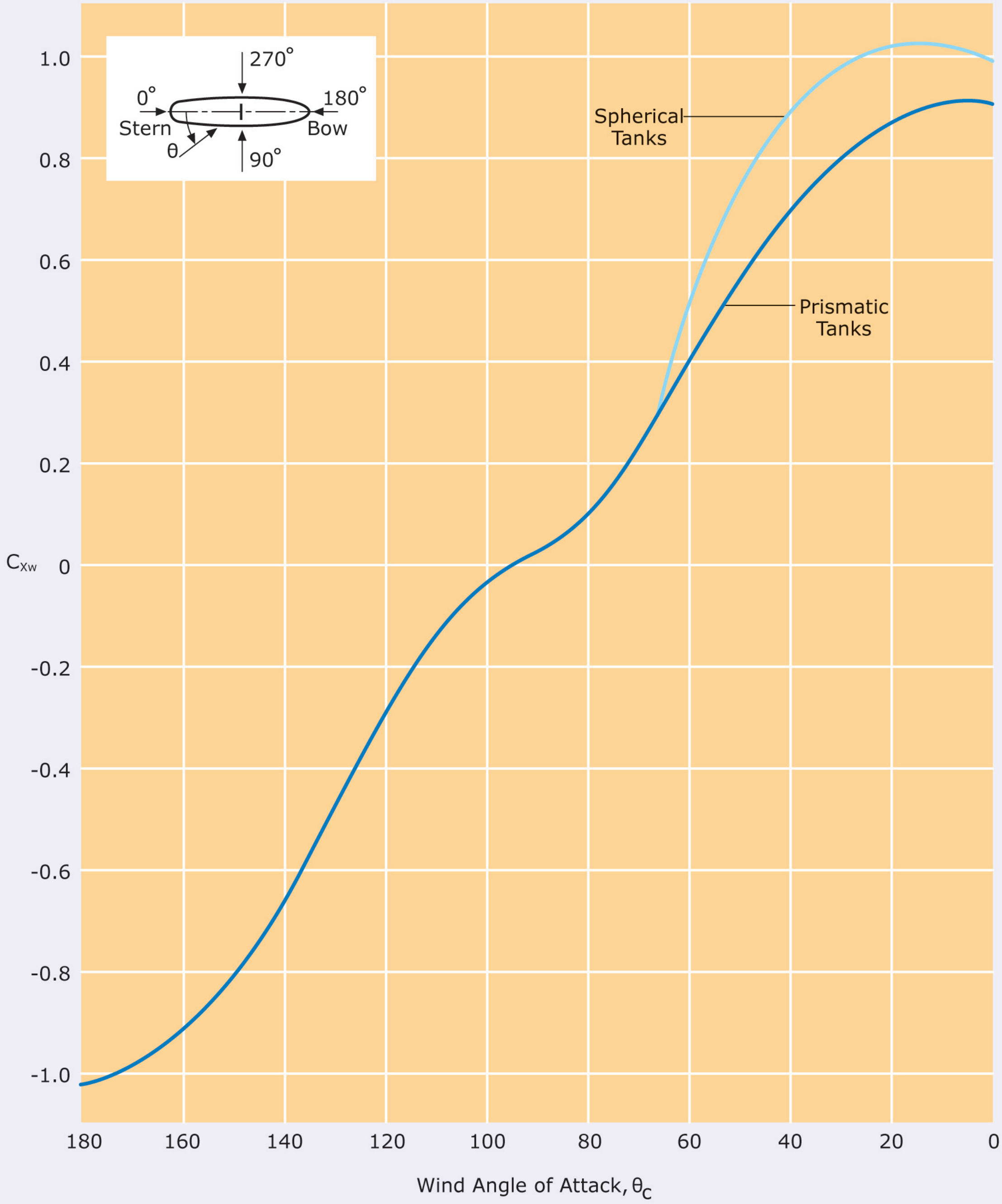

Figure B2: Longitudinal Wind Drag Force Coefficient – Gas Ships

B2 Current Coefficient Plots

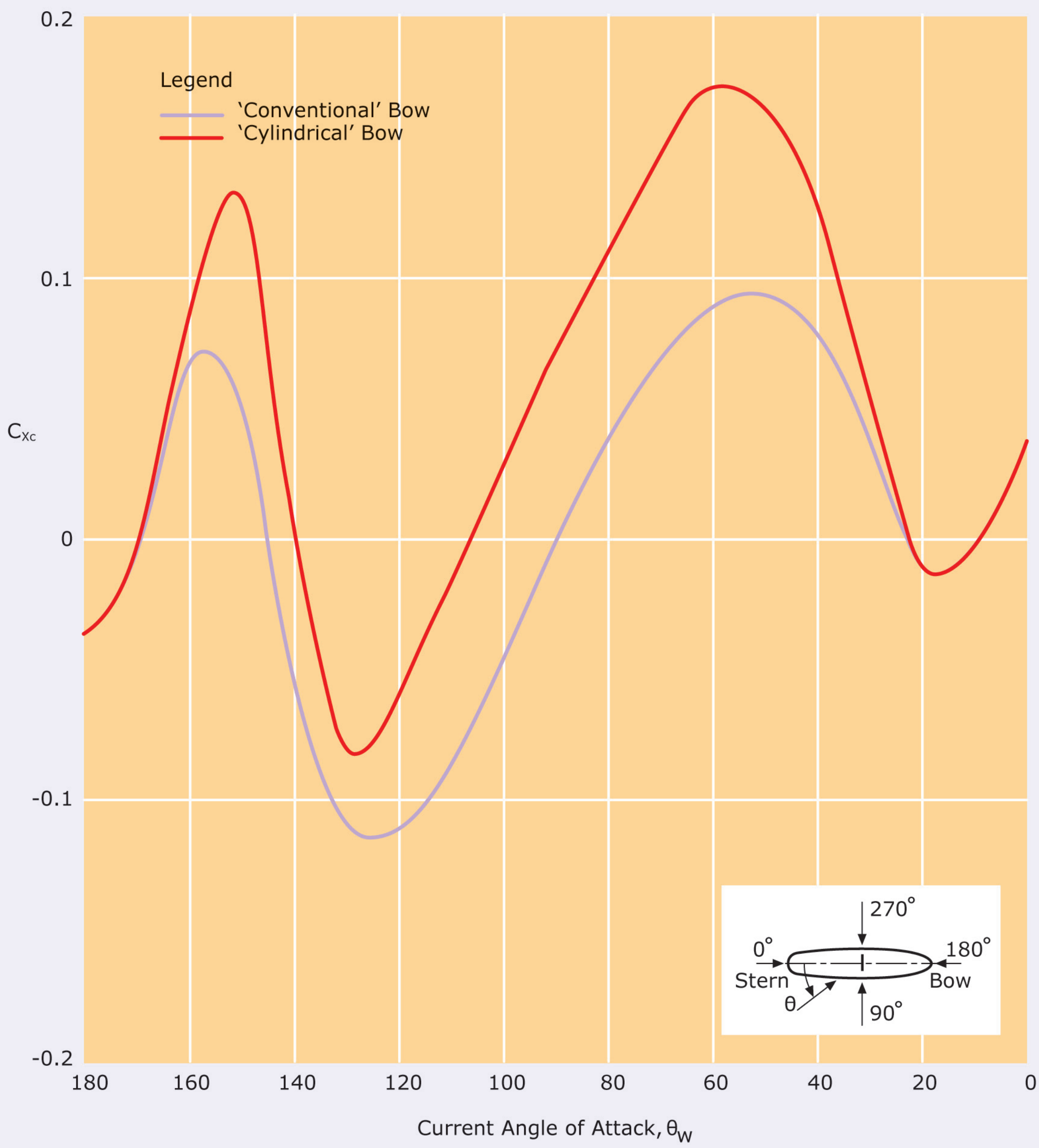

Figure B3: Longitudinal Current Drag Force Coefficient - WD/T = 1.1 Loaded Tanker

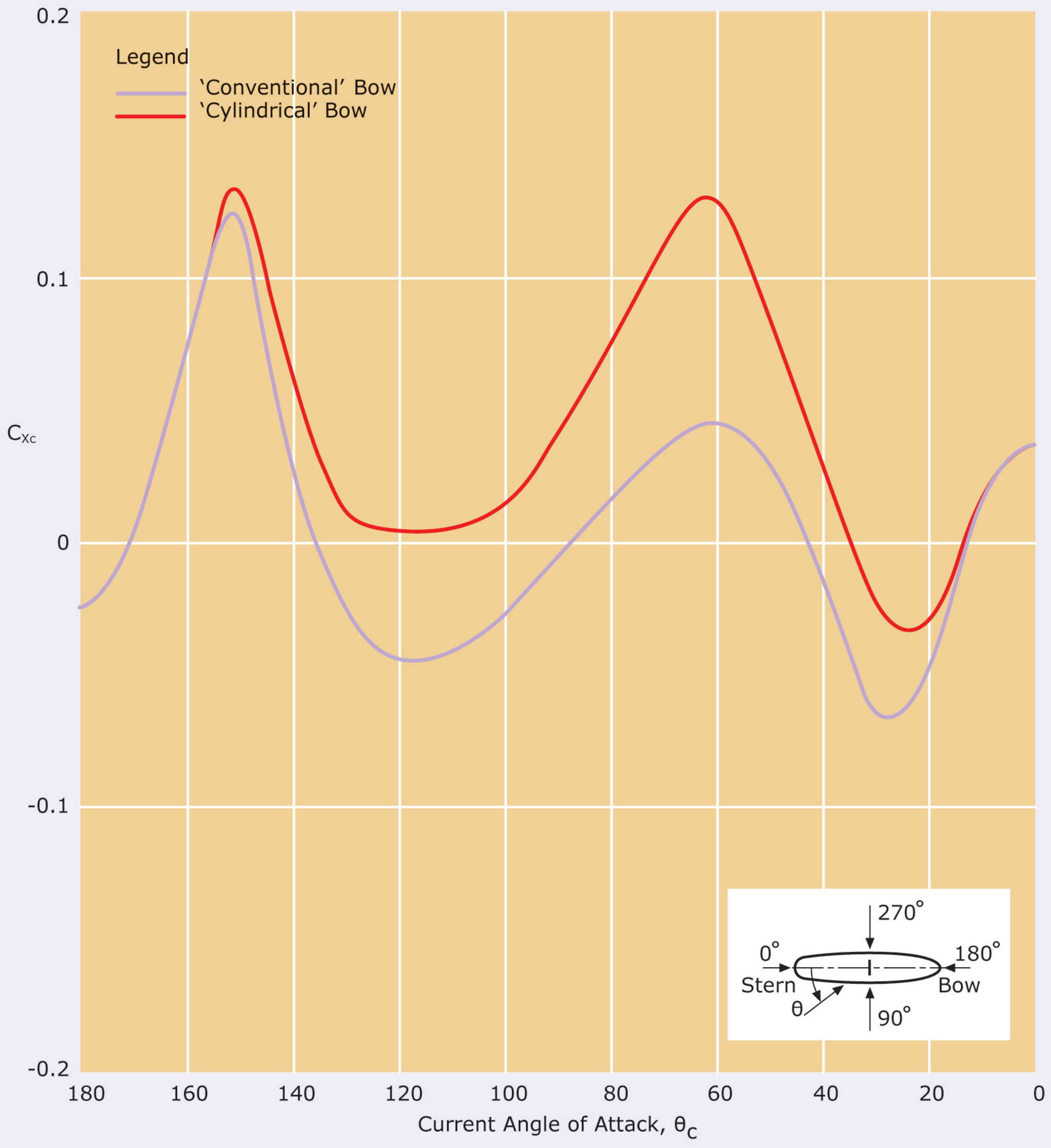

Figure B4: Longitudinal Current Drag Force Coefficient - WD/T = 1.2 Loaded Tanker

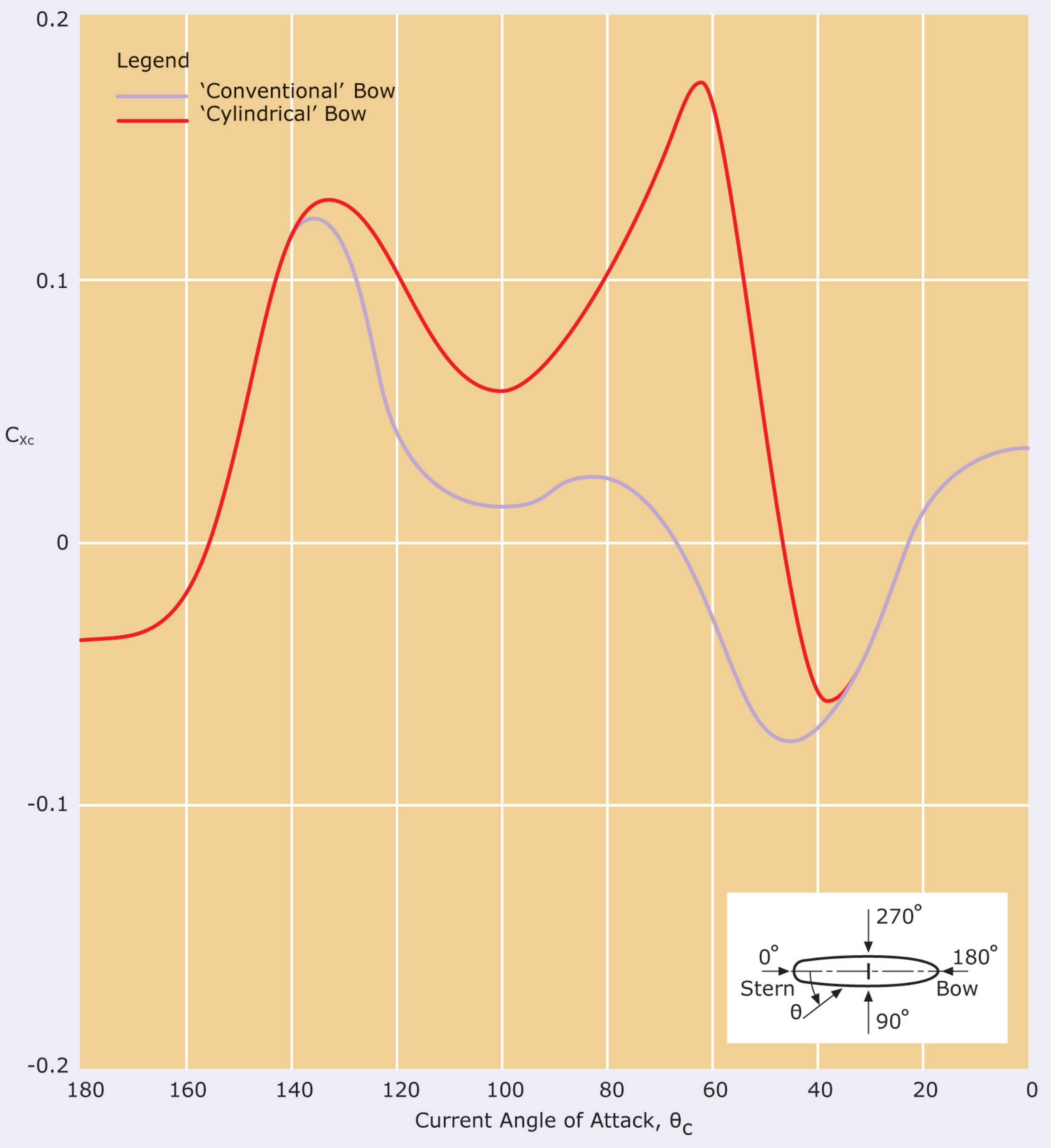

Figure B5: Longitudinal Current Drag Force Coefficient - WD/T = 1.5 Loaded Tanker

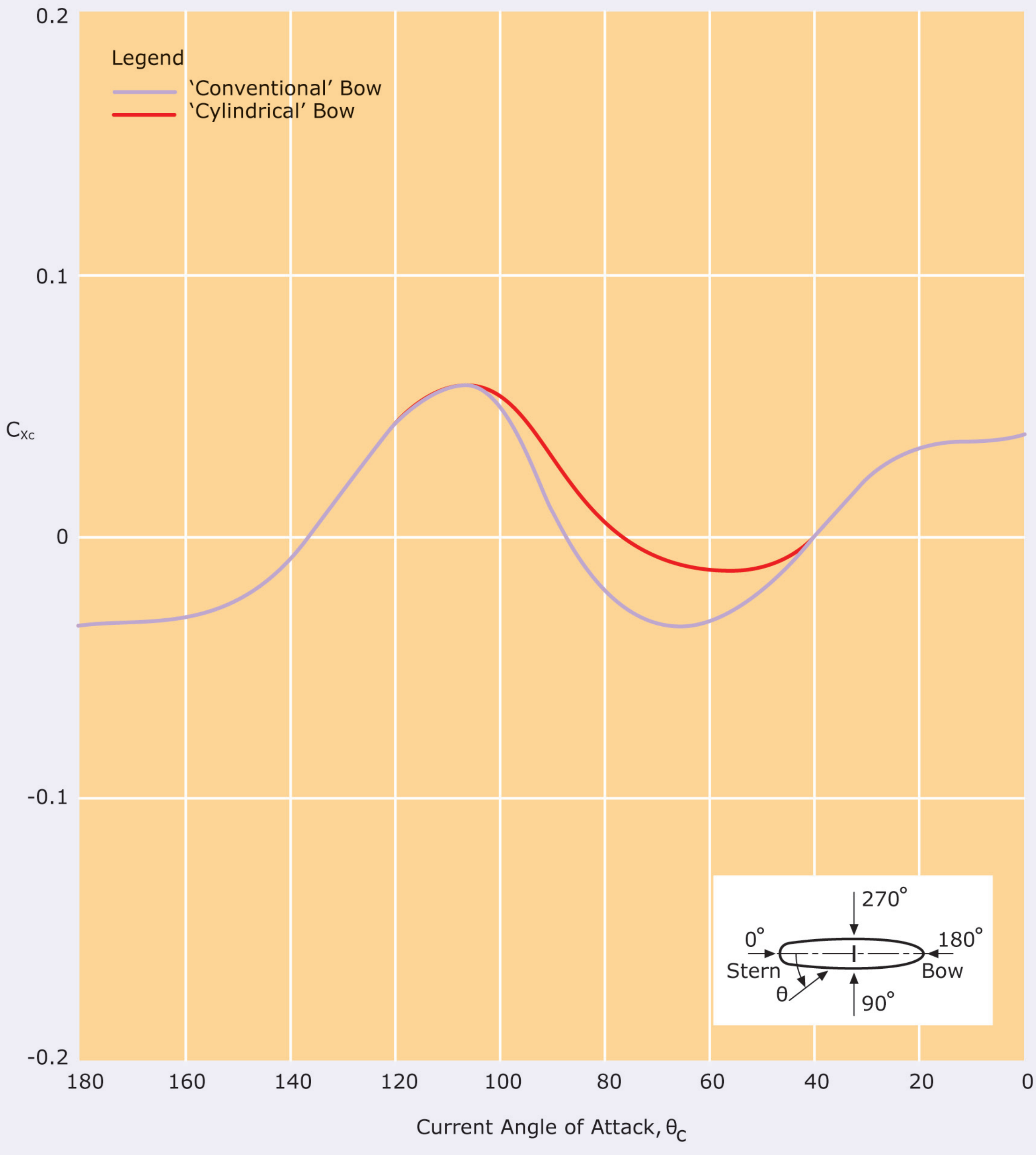

Figure B6: Longitudinal Current Drag Force Coefficient - WD/T = 3.0 Loaded Tanker

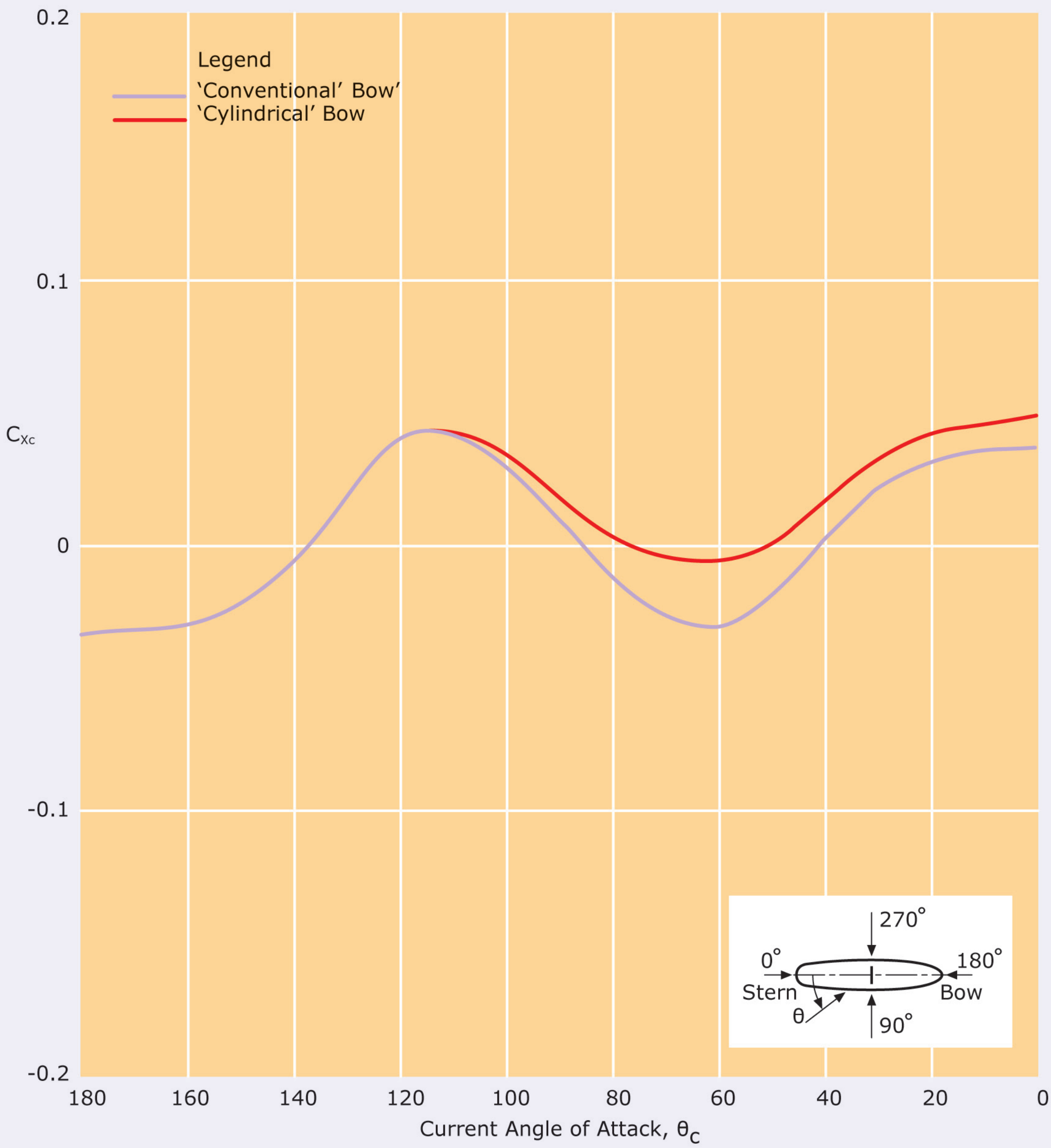

Figure B7: Longitudinal Current Drag Force Coefficient - WD/T > 4.4 Loaded Tanker

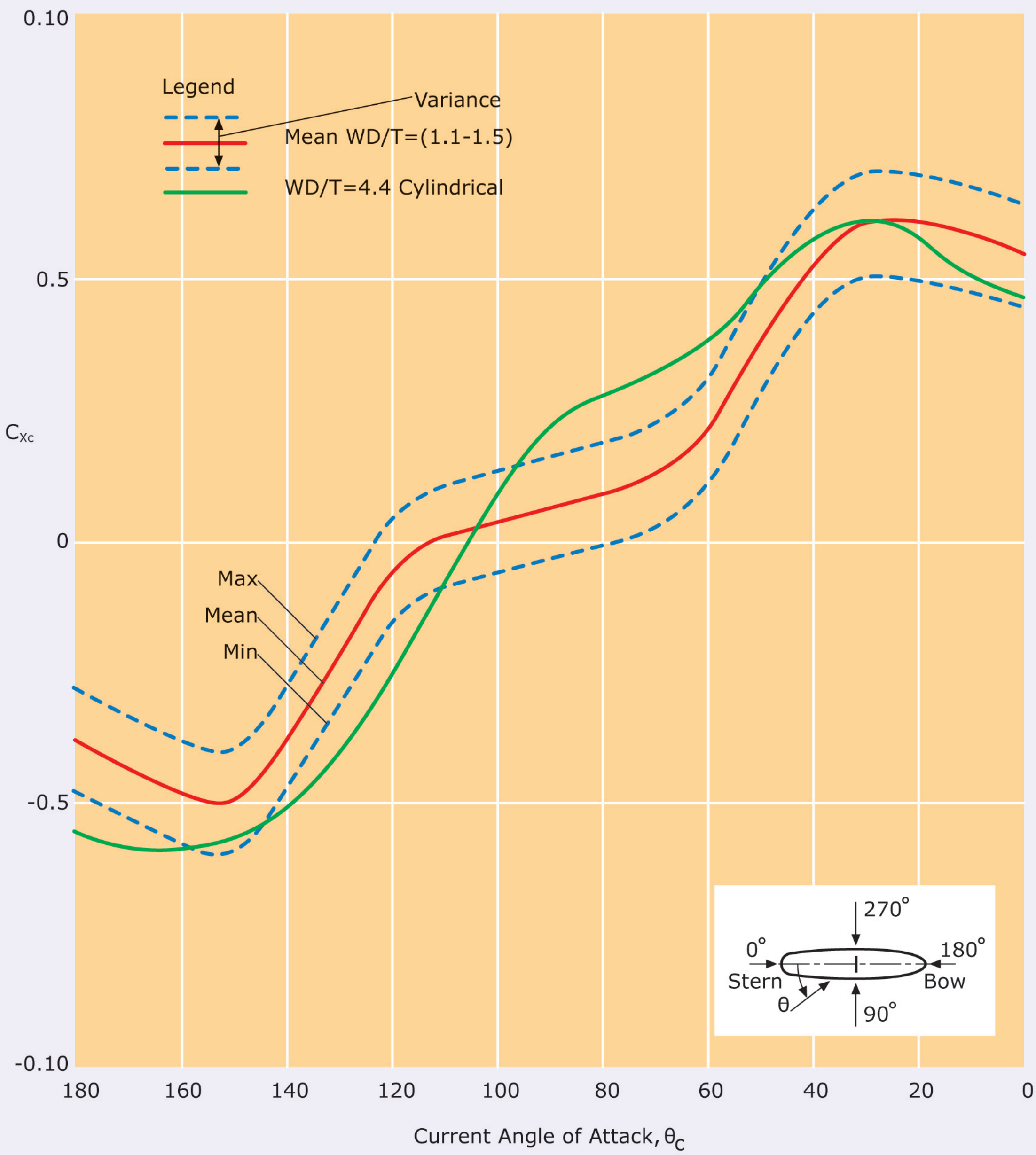

Figure B8: Longitudinal Current Drag Force Coefficient - Ballasted Tanker (40% Loaded Draught)

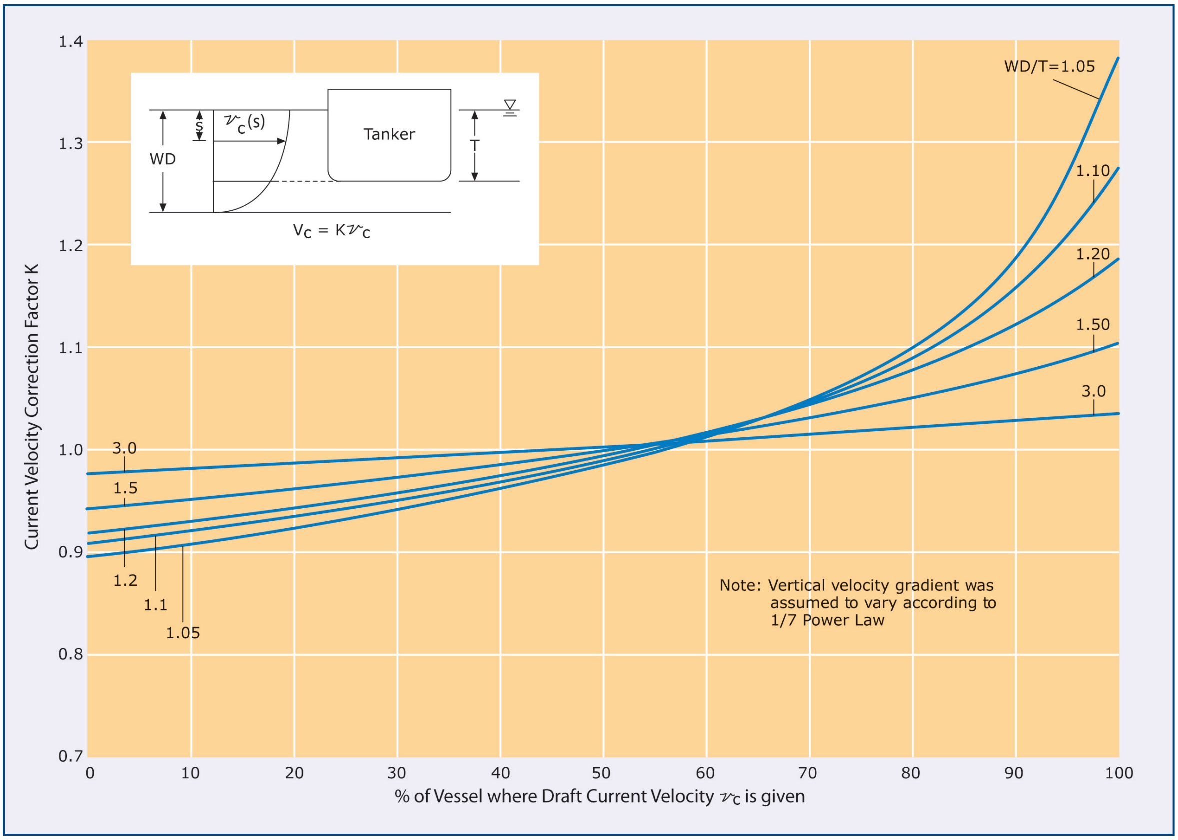

Figure B9: Current Velocity Correction Factor

Note ref. use of the above Figure.

Figure B9 is used to calculate the average current velocity over the submerged hull, based on the depth at which the current speed was measured and the depth:draught ratio.

Steps:

- Determine the depth at which the current was measured, as a percentage of the ship's draught.
- note the depth:draught (WD/T) ratio and select the correct curve.
- read up from the x-axis at the appropriate percentage value
- at the intersection with the correct curve for the WD/T ratio, determine the value of 'K' from the y-axis.

For example, a VLCC at 22m draught, measured the current velocity at 16.5 metres. [16.5/22 = 75%). Assuming the WD/T = 1.50, then K = 1.04.

B3 Wave Drift Force Plots

Surface Plots detailing the longitudinal mean wave drift force for the head sea condition have been prepared for the following vessels in the laden condition:

Vessel Type	Deadweight	Length B.P (m)	Beam (m)	Draught (m)	Figure
Oil tankers	20,000 dwt	164	23.10	11.40	B10
	50,000 dwt	174	32.20	12.20	B11
	100,000 dwt	230	42.00	14.90	B12
	200,000 dwt	280	51.00	18.00	B13
	305,000 dwt	320	58.00	22.50	B14
LNG	150,000 m^3	275	44.00	11.40	B15
	210,000 m^3	302	50.00	12.00	B16
	260,000 m^3	332	57.00	12.00	B17

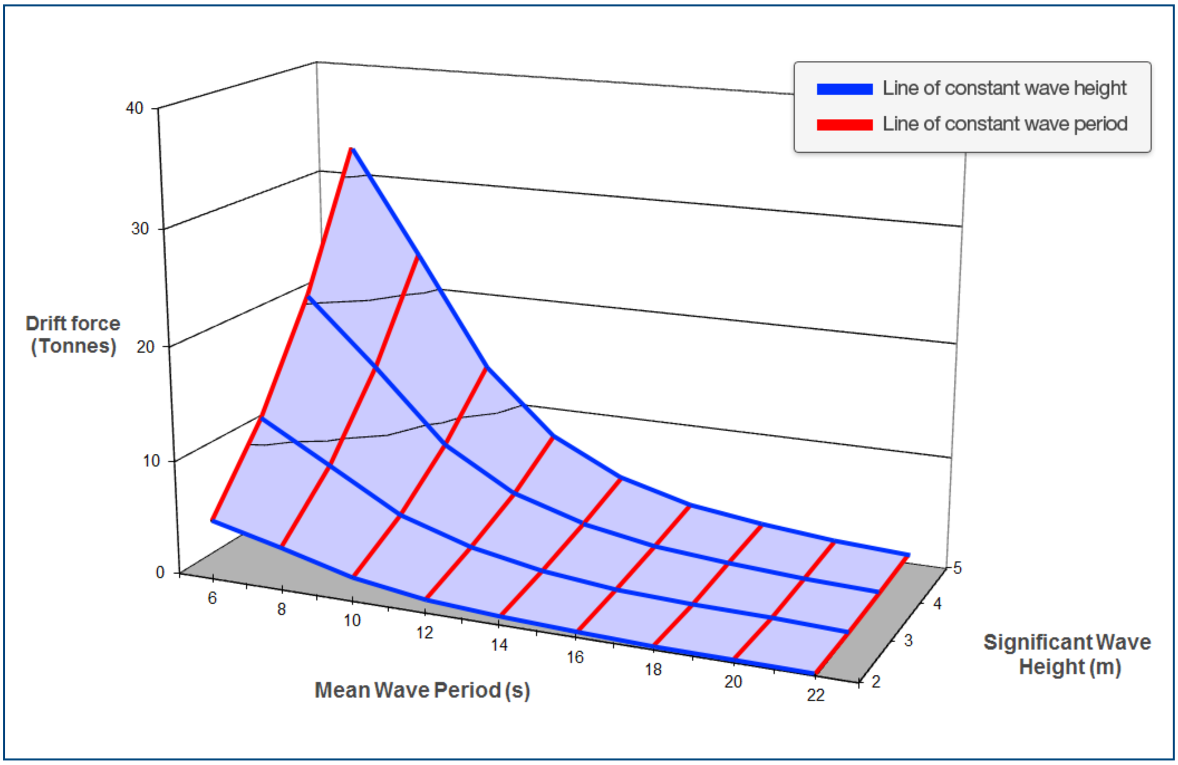

Figure B10: Wave Drift Force (Longitudinal) Head Sea Condition

20,000 dwt Tanker - LBP: 164 m; B: 23.1 m; D: 15.4 m; Loaded draught: 11.4 m

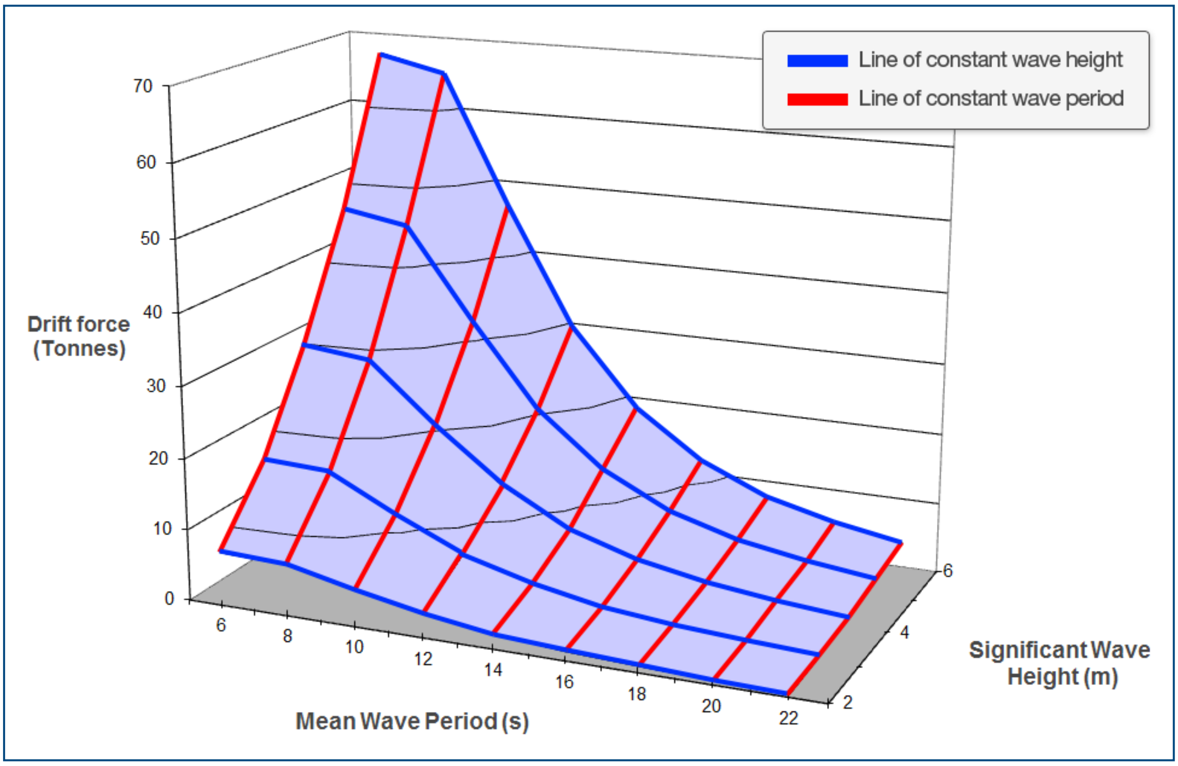

Figure B11: Wave Drift Force (Longitudinal) Head Sea Condition

50,000 dwt Tanker - LBP: 174 m; B: 32.2 m; D: 18.8 m; Loaded draught: 12.2 m

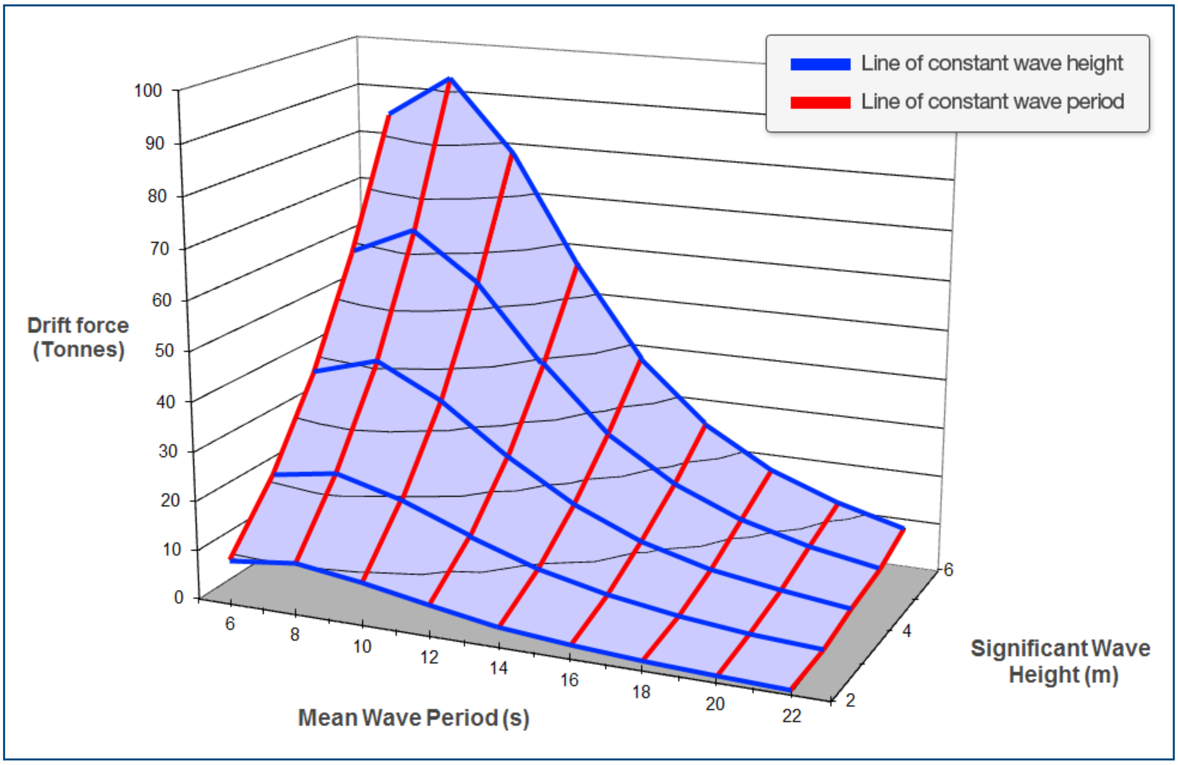

Figure B12: Wave Drift Force (Longitudinal) Head Sea Condition

100,000 dwt Tanker - LBP: 230 m; B: 42 m; D: 21.2 m; Loaded draught: 14.9 m

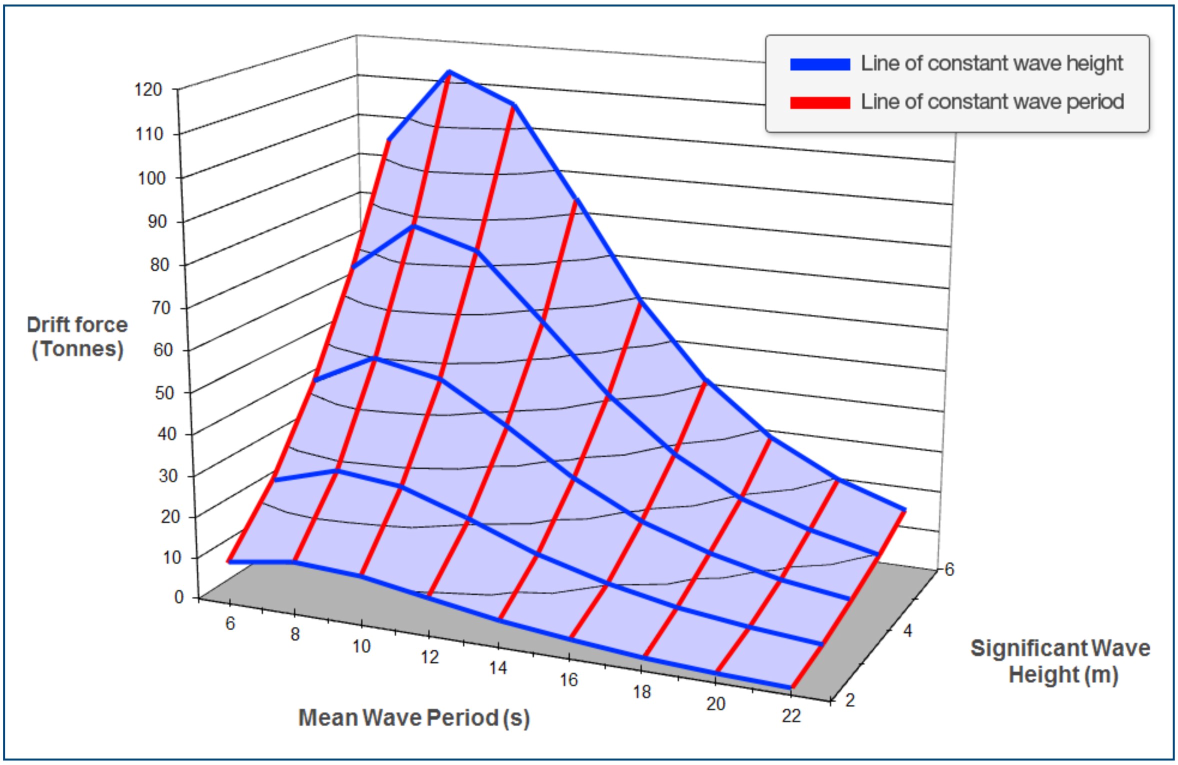

Figure B13: Wave Drift Force (Longitudinal) Head Sea Condition

200,000 dwt Tanker - LBP: 280 m; B: 51 m; D: 26 m; Loaded draught: 18 m

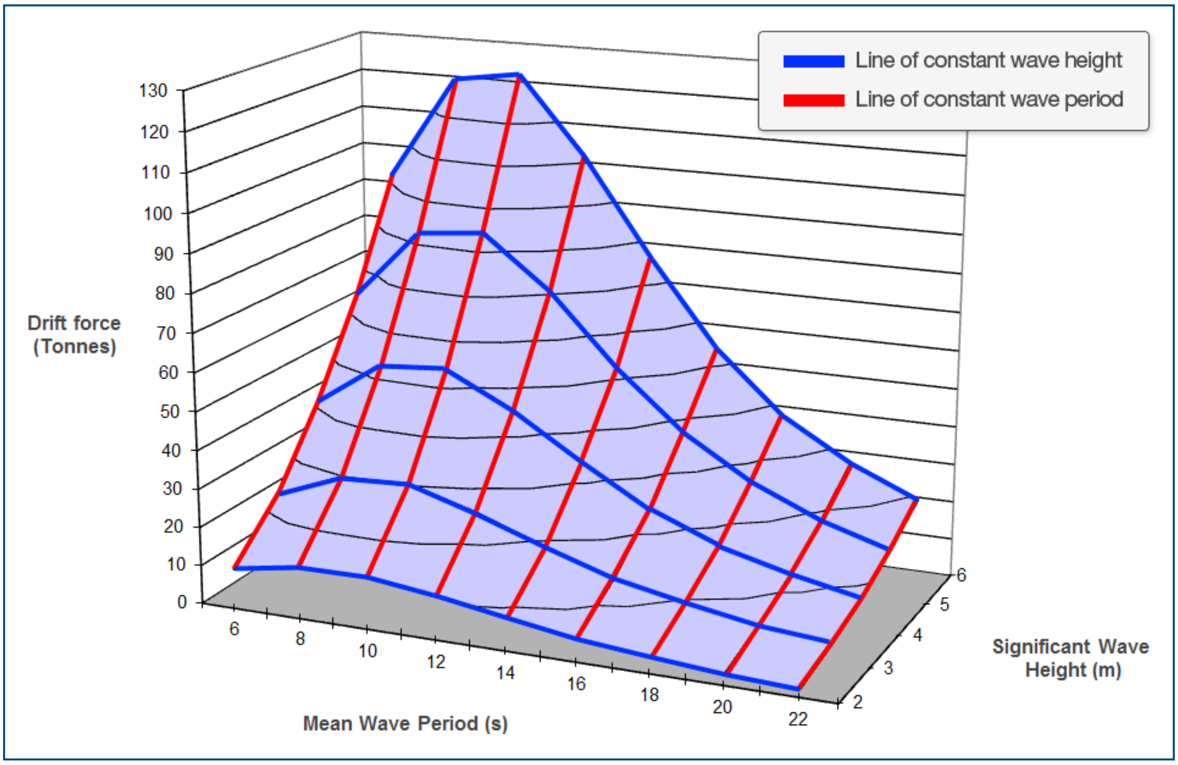

Figure B14: Wave Drift Force (Longitudinal) Head Sea Condition

305,000 dwt Tanker - LBP: 320 m; B: 58 m; D: 31.3 m; Loaded draught: 22.5 m

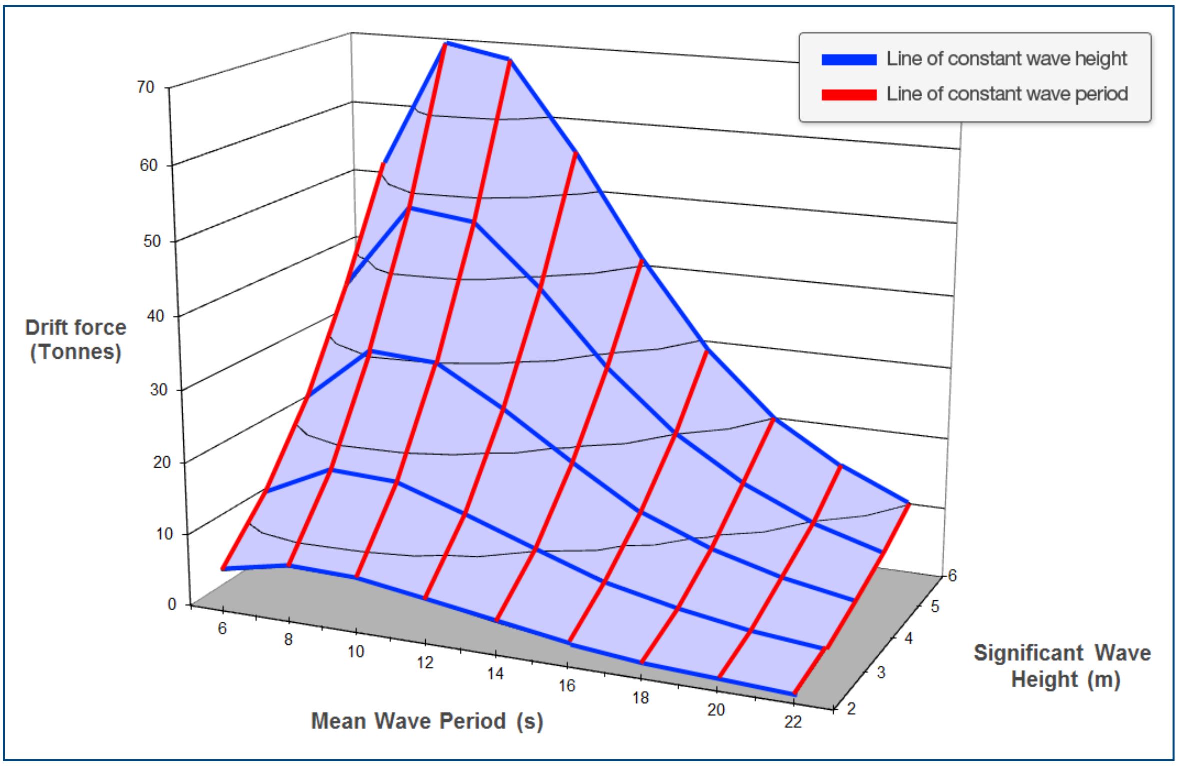

Figure B15: Wave Drift Force (Longitudinal) Head Sea Condition

150,000 m³ Prismatic LNG - LBP: 275 m; B: 44 m; D: 26 m; Loaded draught: 11.4 m

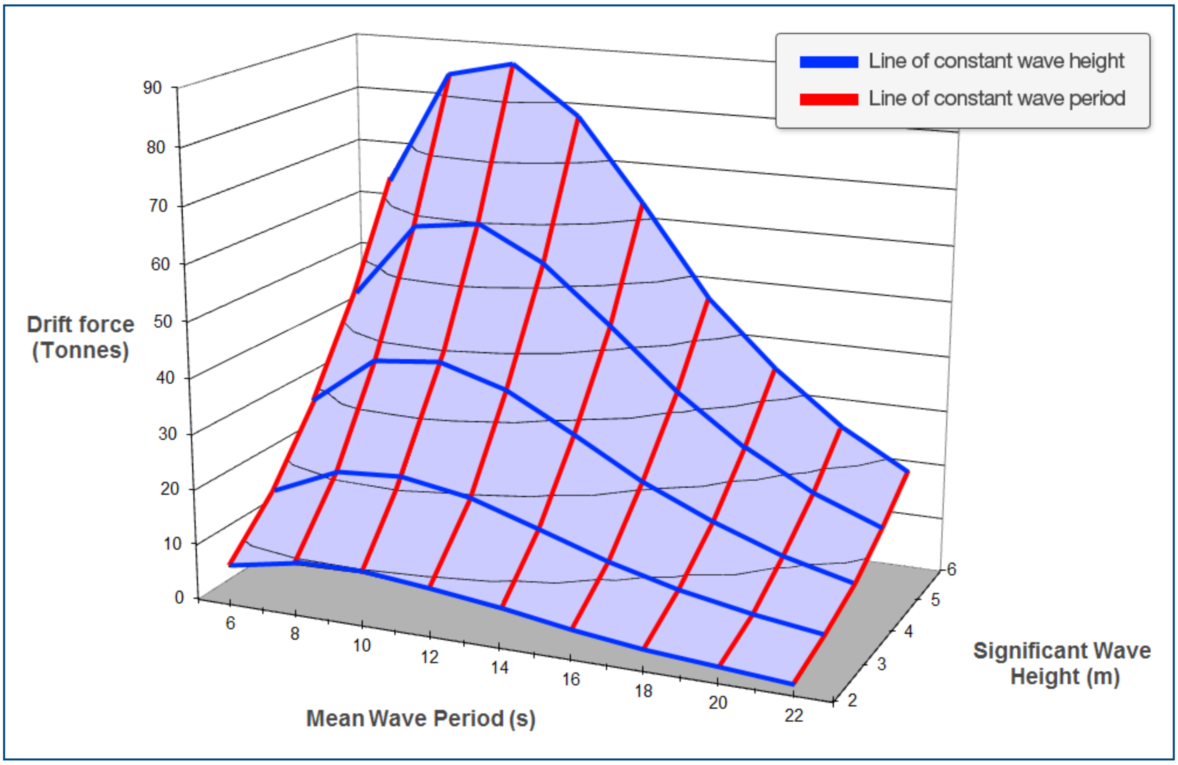

Figure B16: Wave Drift Force (Longitudinal) Head Sea Condition

200,000 m³ Prismatic LNG - LBP: 302 m; B: 50 m; D: 27 m; Loaded draught: 12 m

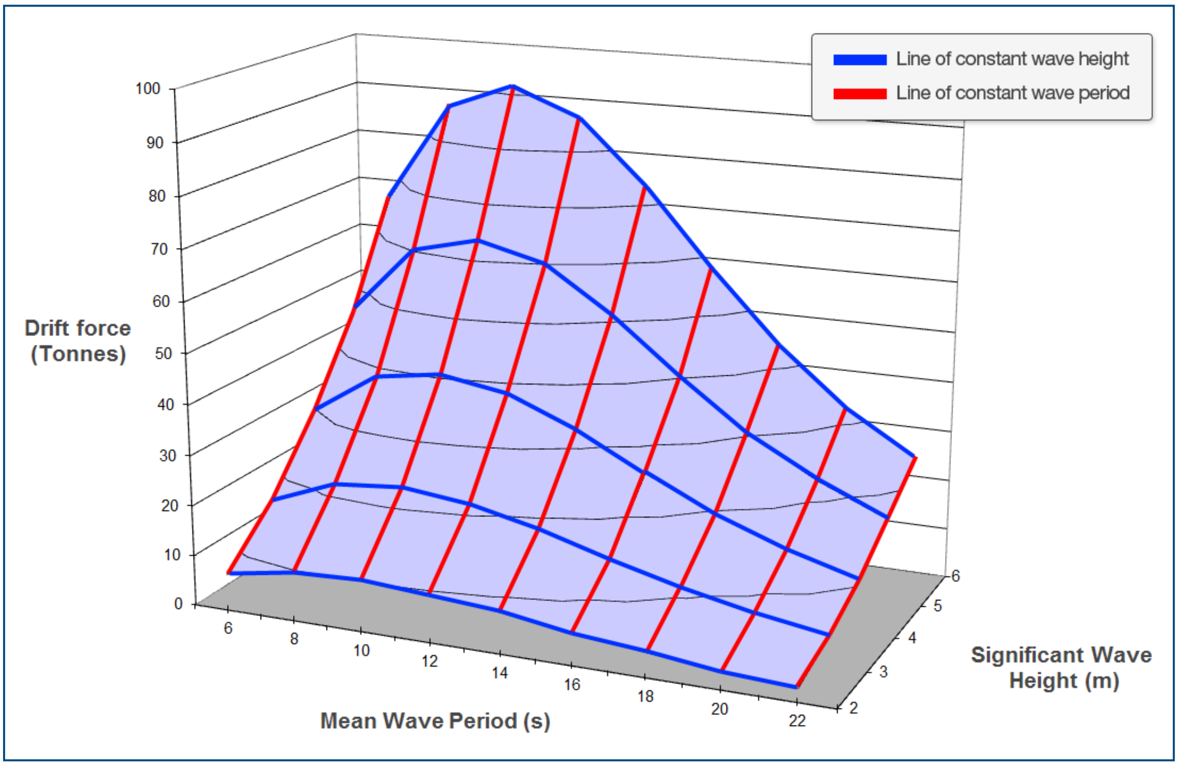

Figure B17: Wave Drift Force (Longitudinal) Head Sea Condition

260,000 m³ Prismatic LNG - LBP: 332 m; B: 53.8 m; D: 27 m; Loaded draught: 12 m

B4 Useful Data

Densities

For salt water: ρ_c = 1025 kg/m^3
For air: ρ_w = 1.28 kg/m^3

Beaufort Wind Scale

Beaufort Wind Scale	Mean Wind Speed		Limits Of Wind Speed		Wind Descriptive Terms
	Knots	m/s	Knots	m/s	
0	0	0	<1	0-0.2	Calm
1	2	0.8	1-3	0.3-1.5	Light air
2	5	2.4	4-6	1.6-3.3	Light breeze
3	9	4.3	7-10	3.4-5.4	Gentle breeze
4	13	6.7	11-16	5.5-7.9	Moderate breeze
5	19	9.3	17-21	8.0-10.7	Fresh breeze
6	24	12.3	22-27	10.8 - 13.8	Strong breeze
7	30	15.5	28-33	13.9 - 17.1	Near gale
8	37	18.9	34-40	17.2 -20.7	Gale
9	44	22.6	41-47	20.8 - 24.4	Severe gale
10	52	26.4	48-55	24.5 - 28.4	Storm
11	60	30.5	56-63	28.5 - 32.6	Violent storm
12	-	-	64+	32.7+	Hurricane

Douglas Sea States

Sea State	Wave Height (m)	Description
0	No wave	Calm (glassy)
1	0.00 - 0.10	Calm (rippled)
2	0.10 - 0.50	Smooth
3	0.50 - 1.25	Slight
4	1.25 - 2.50	Moderate
5	2.50 - 4.00	Rough
6	4.00 - 6.00	Very Rough
7	6.00 - 9.00	High
8	9.00 - 14.00	Very High
9	14.00+	Phenomenal

Approximate Conversions

kN to Tonnes:
1 kN = 0.1 x Tonnes.f

Knots to m/s:
1 knot = 0.514 m/s
1 m/s = approx 2 knots

Knots	m/s
1	0.514
5	2.57
10	5.14
15	7.71
20	10.28
25	12.85
30	15.42
35	17.99
40	20.56
45	23.13
50	25.7