ABP LOWESTOFT

VESSEL MOORING SYSTEMS IN TIDAL PORTS

ABP | KEEPING BRITAIN TRADING

From Good to Great

Contents

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1. Introduction

In their paper entitled "Impact of the Scheme on the Port" (SCC, 2019), Suffolk County Council (SCC) as the Lake Lothing Third Crossing (LLTC) applicant, has proposed a vessel mooring plan, as set out in Figure 1. This is suggested to be an acceptable method of securing vessels at the port of Lowestoft.

In the opinion of experienced Mariners and Pilots employed by ABP at Lowestoft, this mooring proposal is deficient and unsuitable for a tidal port such as Lowestoft.

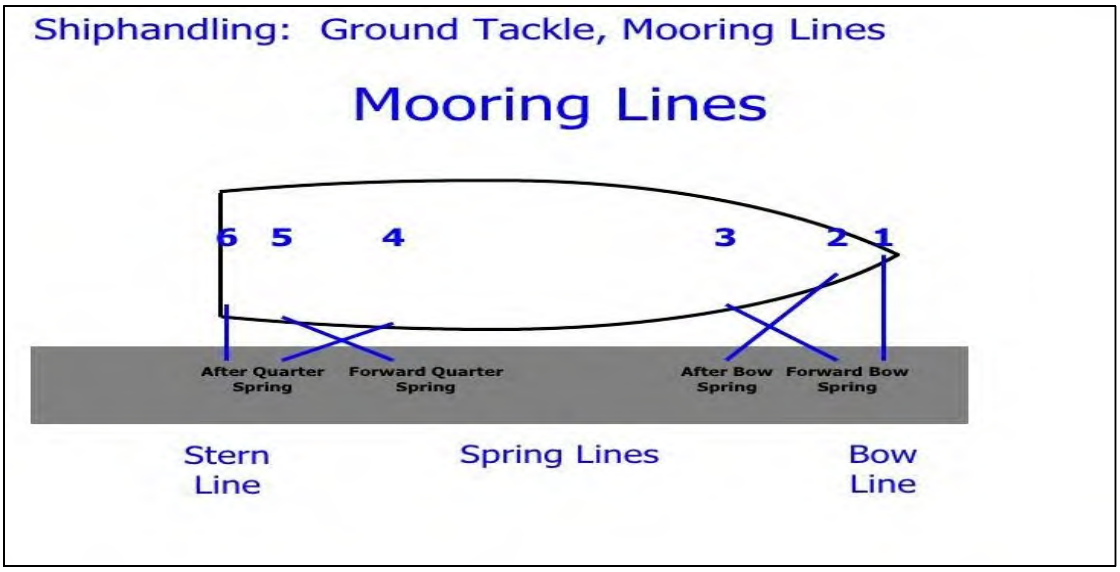


Figure 1 – SCC's LLTC proposed mooring plan

2. Vessel Mooring Systems - Purpose

The purpose of a vessel's mooring system is to hold the vessel safely alongside the designated berth and to minimise any movement away from, or along, the quay face.

It should do this without imposing excessive loads on the vessel's fixed mooring equipment, the port's mooring bollards, or the ropes deployed to achieve the mooring plan.

A vessel alongside a quay will be subject to several forces, that can act to move the vessel and impose extra loads on the moorings, these are;

- Wind effects – both steady strength and gusts;
- Tidal current flow;
- Tidal rise and fall;
- Ranging caused by interaction with passing vessels; and
- Wave and swell action.

Vessels in the Port of Lowestoft Inner Harbour berths are subject to all the above forces, to a greater or lesser degree (other than swell).

It must also be borne in mind the mooring plan deployed by a vessel is the responsibility of the vessel's Master, who is the representative of the vessel's owner. The Harbour Master, or authorised deputy, can and will propose a mooring plan to the vessel Master, but cannot impose a mooring system of a lesser standard than that required by the vessel's Master. It has been noted, that on occasion vessels have not attended to their lines whilst alongside, prompting port staff to raise this with vessel Masters. This is often due to reduced crewing levels whilst alongside.

In our professional opinion, the plan illustrated in the SCC document (and replicated in Figure 1, above) is deficient in that:

(a) it is highly unlikely to be accepted by a vessel's Master; and

(b) is not generally acceptable to the Harbour Master Lowestoft, except in extremely time-limited circumstances. For example, it may be a short turnaround port call (measured in minutes) to load a single item of cargo or stores – a very infrequent occurrence. In this circumstance, if the vessel is Piloted, the Pilot would remain aboard to coordinate the mooring and unmooring – providing management of the evolution by competent port staff.

The system shown in Figure 1 is not practical to deploy. The figure shows a single (presumably) representative bow and stern line; this simplifies what is in effect a multi-line system. In nearly all cases for commercial vessels, it is necessary to deploy a number of bow and stern lines. It is not practical, from a force/loading point of view, to use just one bollard at the bow and one at the stern, this would impose excessive loadings on the mooring equipment, as a vessel rises and falls on the tidal cycle or as cargo is loaded or discharged.

Furthermore, it would provide extremely limited holding power in the event of offshore winds or ranging caused by vessel interaction and could pose a risk to the safety of the vessel and its crew as well as other users of the port. At times, the mooring ropes could be nearly perpendicular to the horizontal plane – particularly the bow and stern lines 1 & 6 shown in Figure 1 - at which point they would be prone to failure or overloading of the mooring infrastructure as the strain in the mooring lines exceeds the force applied, at such high angles to the horizontal.

The positioning of vessel mooring equipment and fairleads (structures mounted near a vessel's side to guide the mooring ropes, keeping them clear of obstructions and preventing them from cutting or chafing) are often determined by the operational use of the vessel, rather than the most efficient mooring design. This will often preclude the use of spring lines as shown in the SCC mooring plan (Figure 1).

Moreover, mooring decks can often be in the region of 5 m above quay level, depending upon state of tide and whether the vessel is loaded or in ballast, with a horizontal distance between the ship's side and the quayside mooring bollard of 2 m or less (See Photos 1-5, below). These factors can result in very steep lead angles above the horizontal for mooring lines, which decreases the safe working load of the ropes as the strain imposed exceeds the force applied. The use of long head and stern lines leading beyond the vessel's body provides an increased radius scope for the lines, which greatly reduces the angle above horizontal, and thereby providing a reduction in safe working load.

Images are provided below of a typical North Sea Platform Supply Vessel moored at Lowestoft, with moorings that demonstrate the height differential between vessel mooring points and the quay edge.

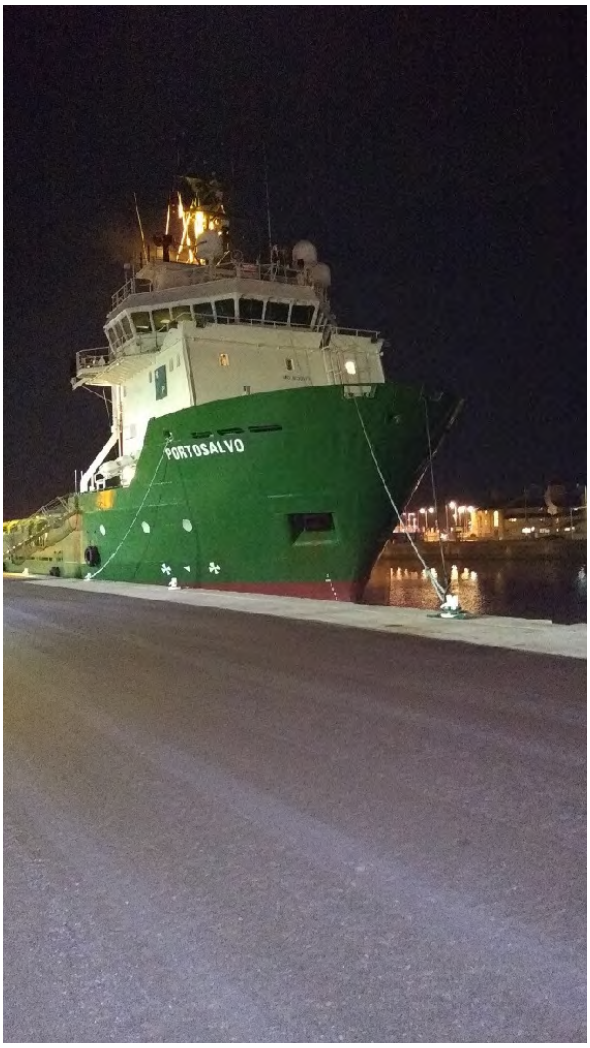


Photo 1 Portosalvo Bow

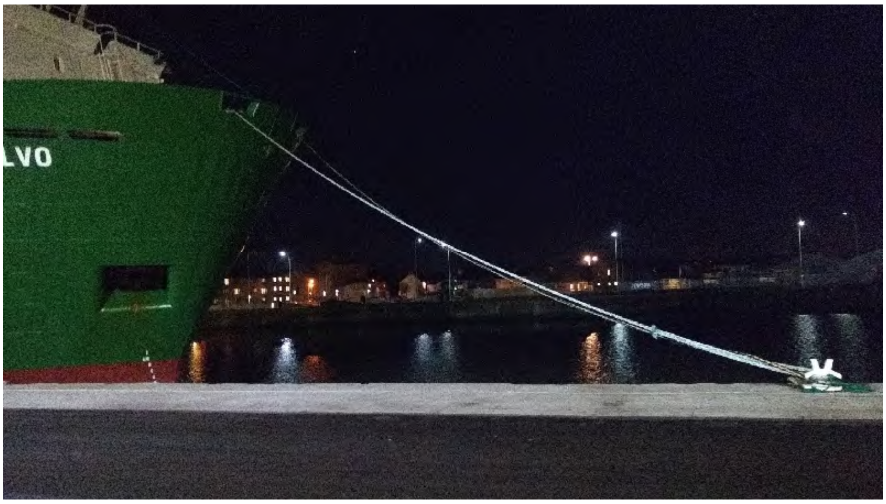


Photo 2 Portosalvo Headline

Photo 3 – Portosalvo's Bow towering over Town Quay

Photo 4 – Portosalvo Stern

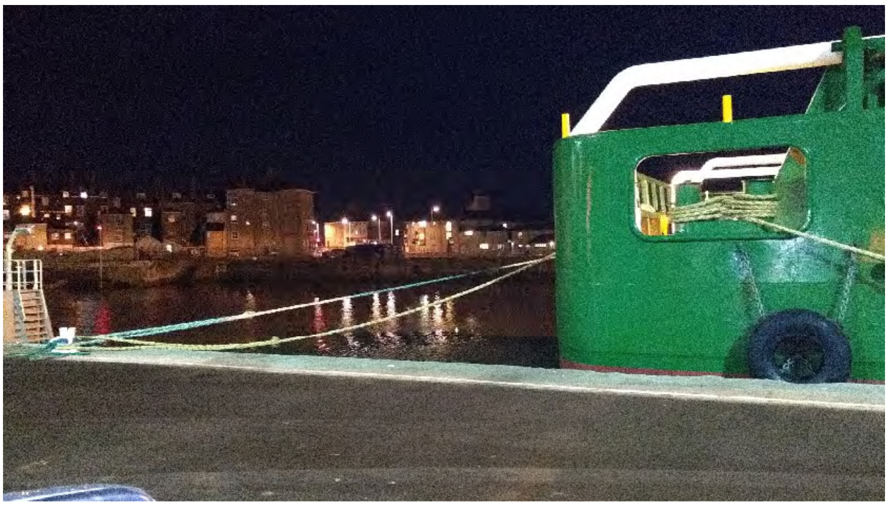


Photo 5 – Portosalvo Sternlines

The mooring system proposed by SCC as shown in Figure 1 overly simplifies the reality of mooring within a port. The spacing of bollard, relative to the vessel's fairleads is very important. Unless the berth has been designed specifically for the vessel, with mooring points aligned to fairleads, it is necessary for vessels to deploy lines along the quay, with due regard to the rated capacity of the line, bollard and vessel mooring equipment. A different approach can be taken in non-tidal dock systems with lock gates, where there is little or no tidal rise and fall, limited tidal streams and little or no passing vessel traffic. The Lowestoft Inner Harbour berths adjacent to the proposed LLTC Bridge do not meet these criteria. The mooring plan proposed by SCC is therefore deficient and unsuitable for a tidal port such as Lowestoft.

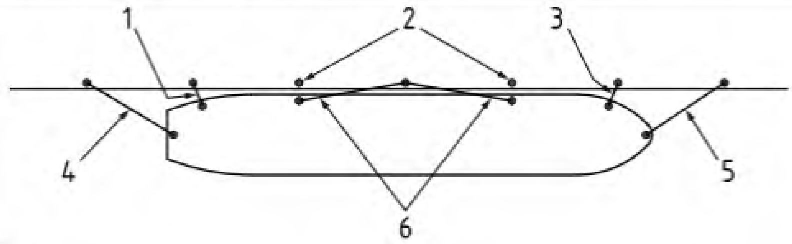
The mooring arrangements that would typically be deployed at a tidal port, such as Lowestoft, are considered in Section 3 of this report.

3. Typical Mooring Systems used in Tidal Ports

The diagram below shows the typical vessel mooring arrangement as outlined in the British Standards Document BS6349-4 Fendering and Mooring Systems. It should be noted that the typical mooring system depicted includes the use of long headlines and stern lines and not just springs and short perpendicular lines as proposed by the applicant. It should also be noted that short breastlines are not generally used by vessels at Lowestoft where there is a large difference between quay and vessel mooring deck heights. In such circumstances additional head and stern lines are used.

BS 6349-4:2014 BRITISH STANDARD

Figure 11 Typical mooring pattern for continuous quay



Key
1 Aft breast line
2 Bollards
3 Forward breast line
4 Stern line
5 Head line
6 Spring lines

Figure 2 – A mooring plan for a continuous quay as found in British Standard BS6349-4

To consider and review berthing for vessels at North Quay 1 and 2, ABP Lowestoft commissioned ABPmer to investigate the environmental limits and mooring pattern. The mooring assessment provided mooring line configuration for each 'design' vessel considered by the study; Section 4 of the study (ABPmer, 2019) presented mooring layouts following recommendations for mooring line lead angles given in BS 6349-4:2014 (BSI, 2014). The full report (including mooring layouts) is provided as Appendix A of this Report.

This information is presented to demonstrate the approach taken by ABP, as Harbour Authority, in designing mooring arrangements; this is in contrast to the suggested approach taken in the 'Impact of the Scheme on the Port' paper (SCC, 2019).

The following section of this report (Section 4) examines other Ports on the east coast of the U.K., to assess mooring systems generally in use.

4. Google Maps Images of Typical Mooring Systems used in Tidal Ports

The predominance of this type of mooring system in tidal ports is shown in the following photos which are extracted from Google Maps images. They show vessels berthed in various tidal ports on the east coast of the U.K. Of the ports considered, the authors would like to note that only the Port of Ipswich (Photo 14) is owned by ABP.

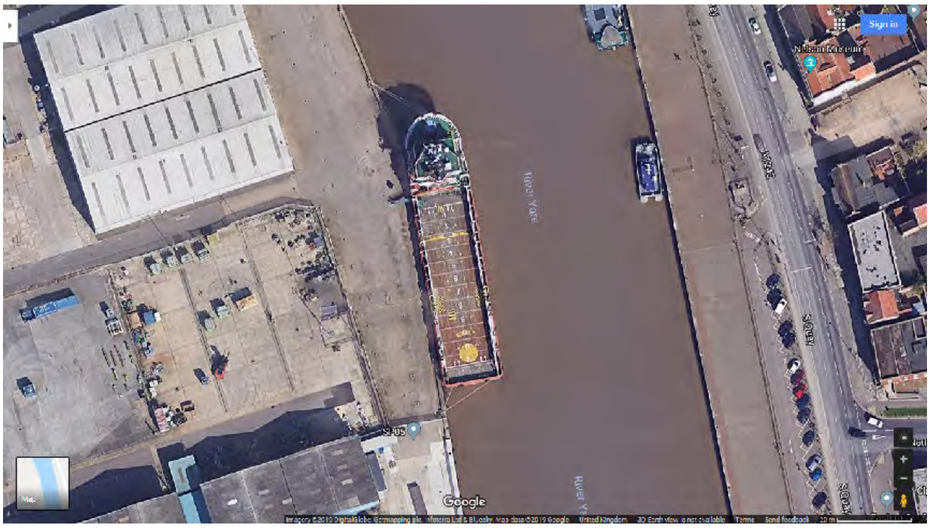


Photo 6 - Vessel berthed in Great Yarmouth

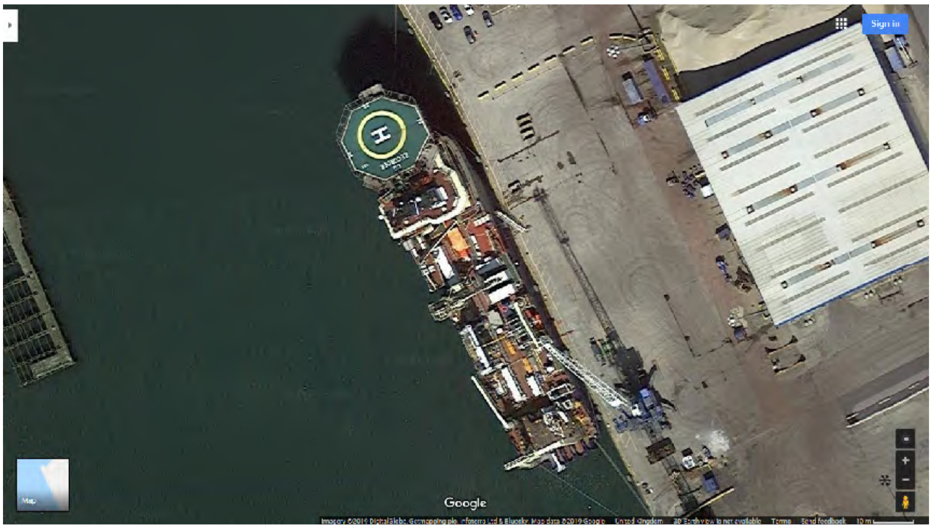


Photo 7 - Vessel berthed in Blyth

Photo 8 - Vessel berthed in Peterhead

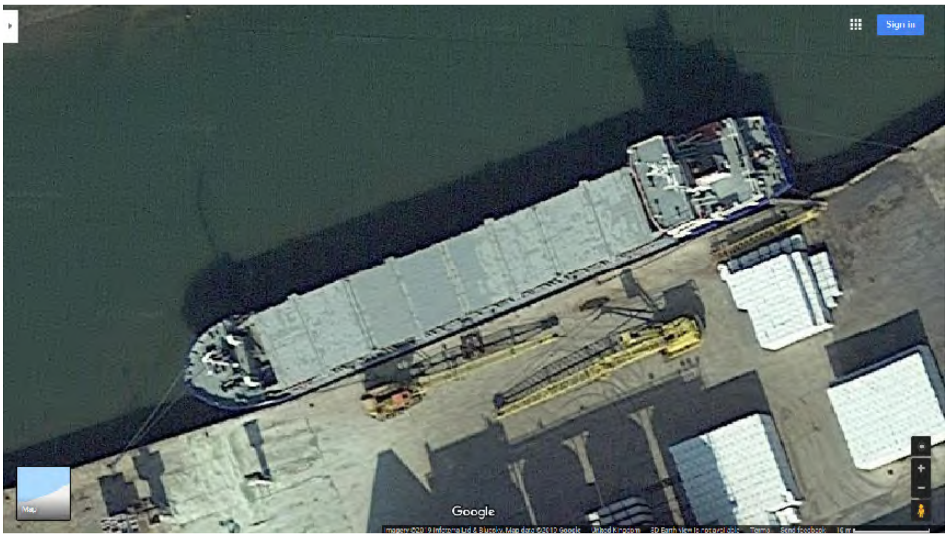


Photo 9 -Vessel berthed in Mistley

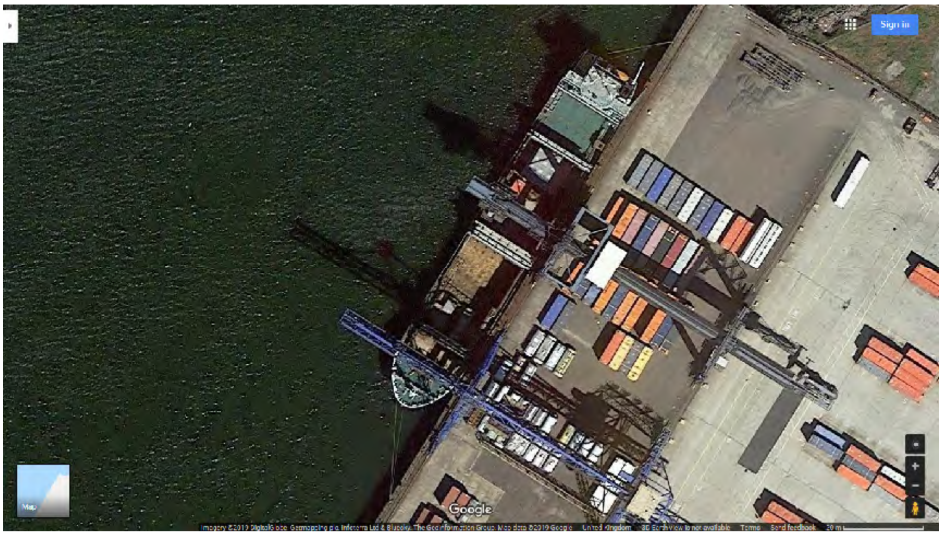


Photo 10 - Vessel berthed in Teesport

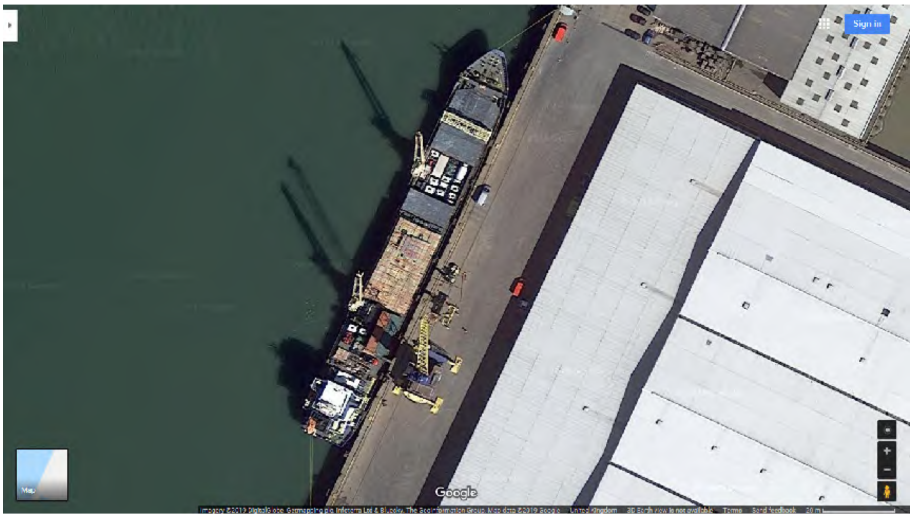


Photo 11 - Vessel berthed in Sheerness

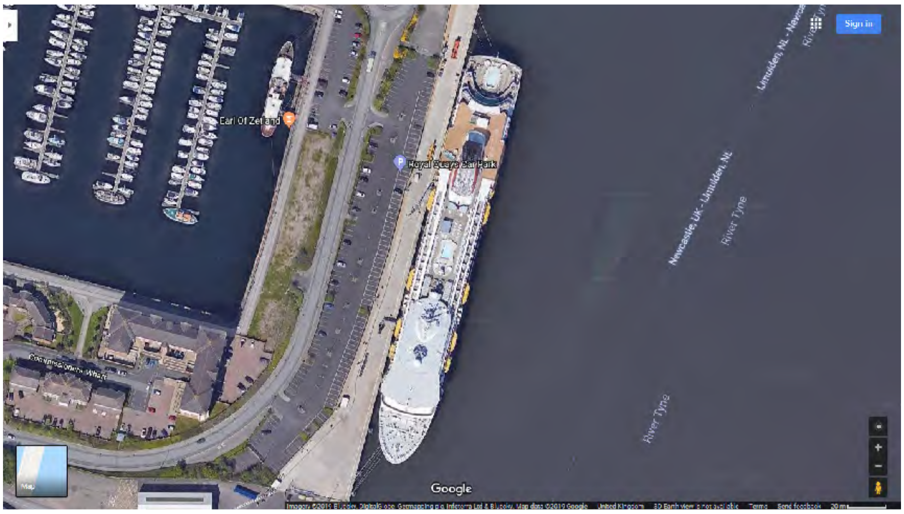


Photo 12 - Vessel Berthed on the River Tyne

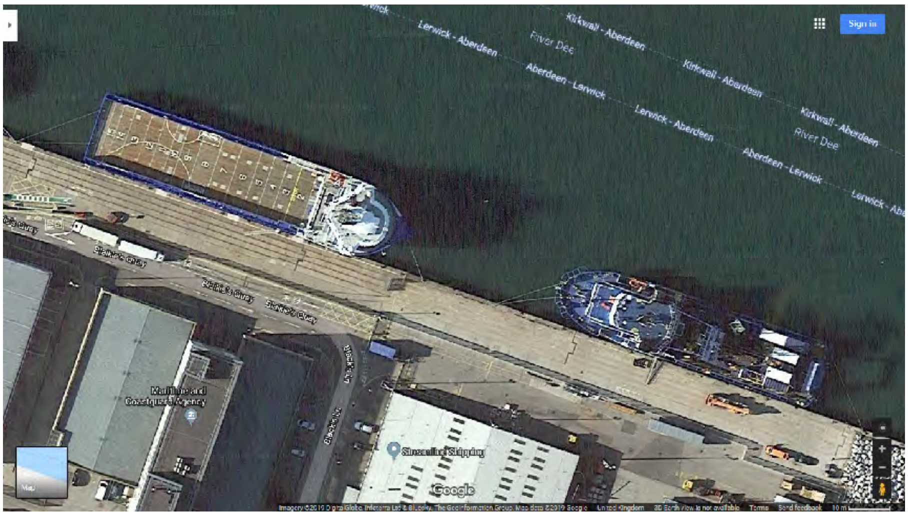


Photo 13 - Vessels berthed in Aberdeen

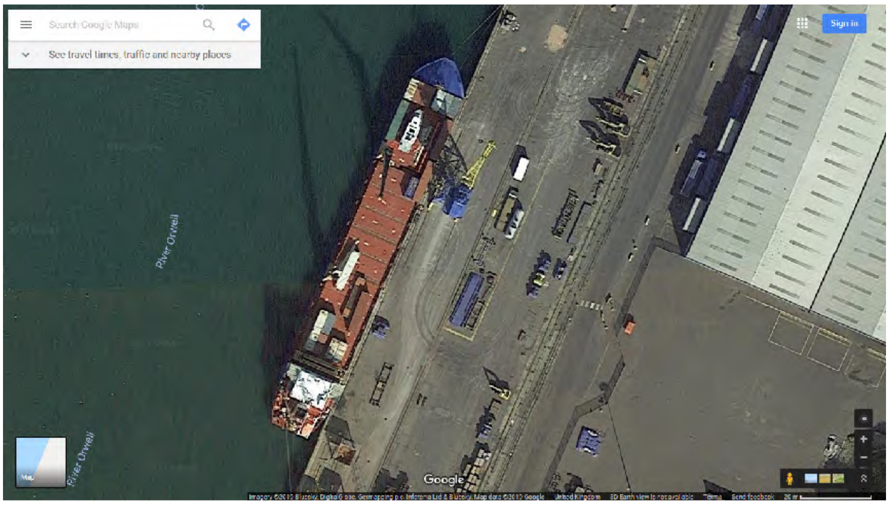


Photo 14 - Vessel Berthed in Ipswich

As each of the above photos show, all the vessels are utilising head and stern lines extending many metres beyond the physical length of the vessel, which reflects very closely the typical mooring plans in use in tidal ports.

5. Vessel General Arrangement Plans

Vessel general arrangement plans are provided below, showing typical fairlead locations for some example vessels, which have used, or are likely to use, the Port of Lowestoft. This sample is representative of the vessel layouts of the vast majority of vessels likely to moor on the North Quay at the port.

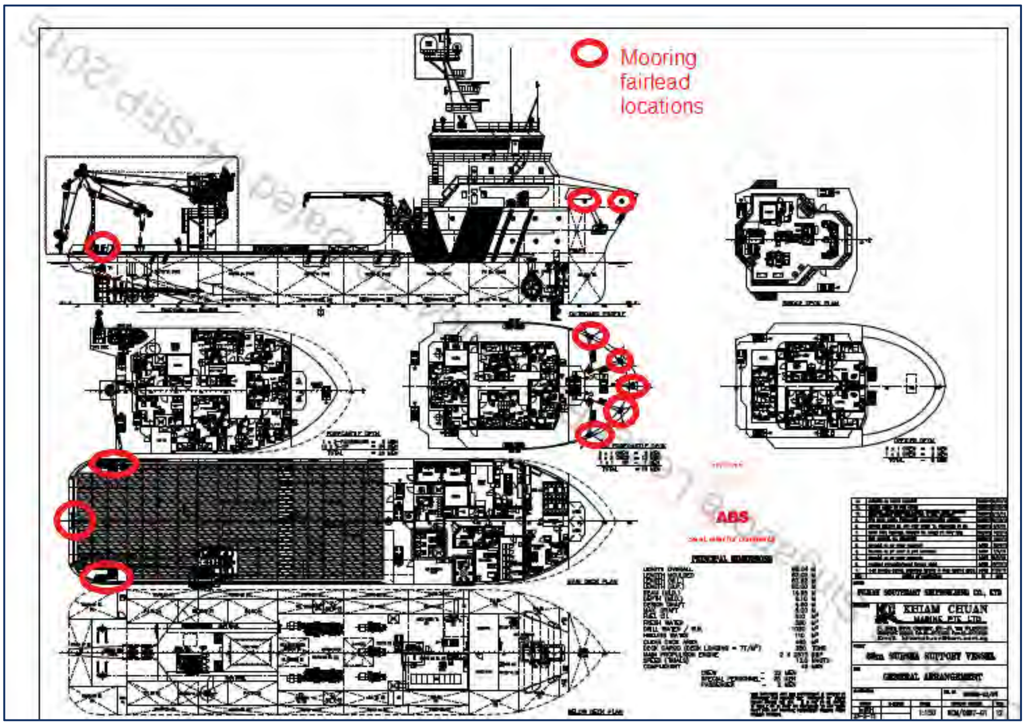


Figure 3 – Vos Star fairlead locations

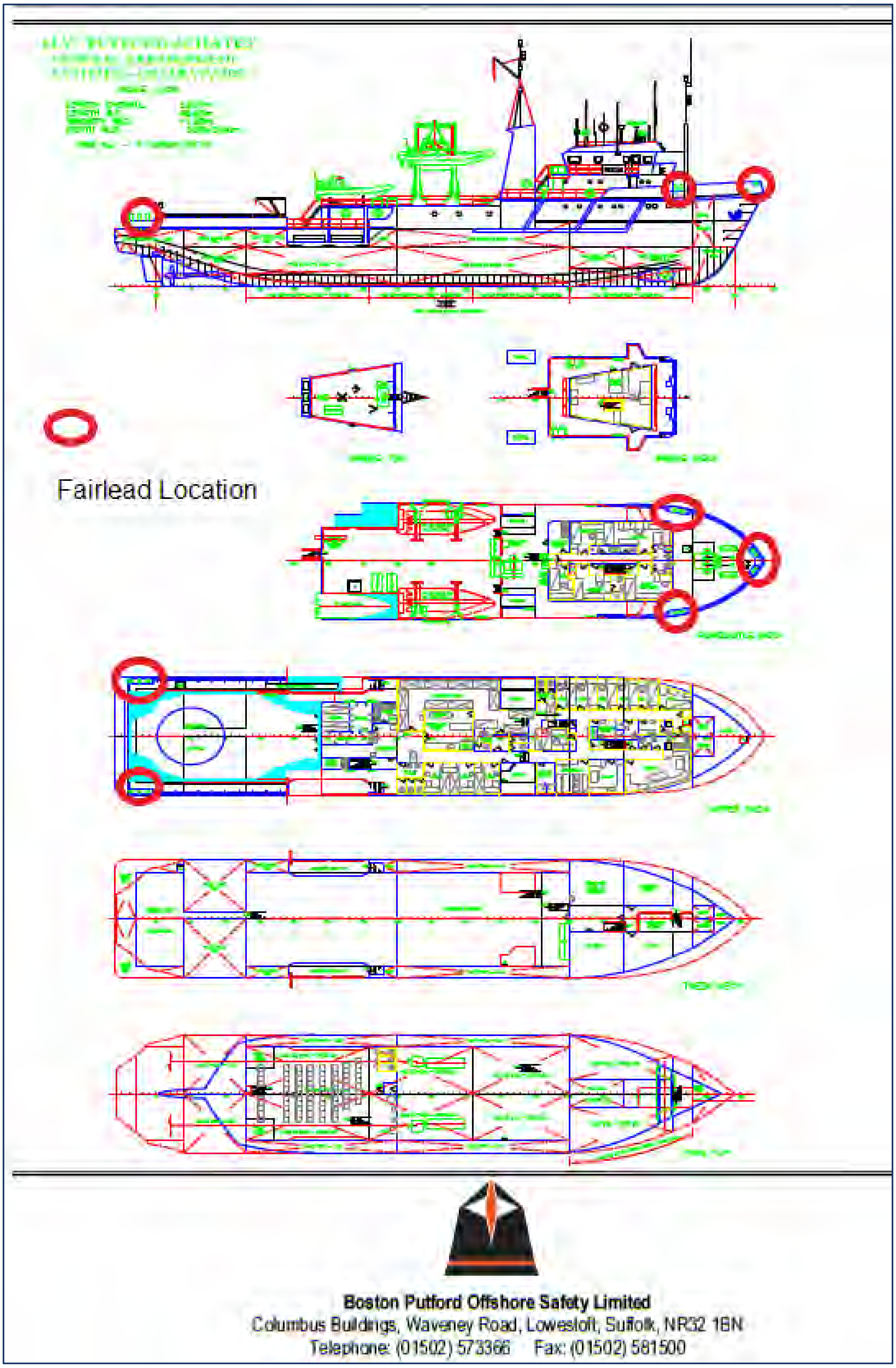


Figure 4 – Putford Achates fairlead locations

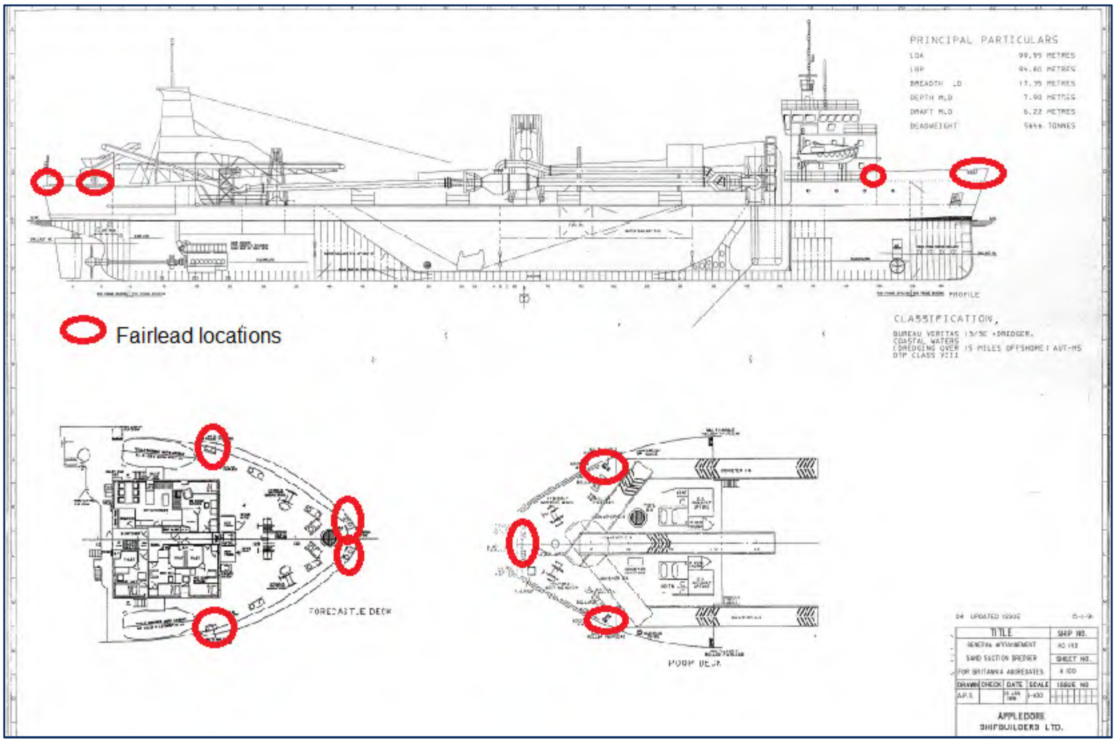


Figure 5 – Britannia Beaver Fairlead Locations

The position of mooring points and fairleads on such vessels would not suit the mooring arrangement as proposed by SCC in their paper ‘Impact of the Scheme on the Port’ (as in Figure 1), as the arrangements would not provide for sufficient mooring line lengths, in lieu of bow and stern lines, that do not extend beyond the length of the vessels.

6. References

- Cover Photo: R. Musgrove; 2017
- Suffolk County Council (SCC), 2019. 'Impact of the Scheme on the Port of Lowestoft' Document SCC/LLTC/EX/59 Figure 1; Suffolk County Council; 2019
- Photos 1-5; R. Musgrove; 2019
- BSI, 2014. BS 6349-4:2014 Maritime works – Part 4: code of practice for design of fendering and mooring systems. British Standards Institution, June 2014.
- Photos 6-14; Google Maps Images; Downloaded 2019
- General Arrangements Plans Figures 6-8: Vessel Owners; Supplied 2019
- ABPmer, (2019). Mooring Analysis, North Quay 1 and 2, ABPmer Report No. R.3109. A report produced by ABPmer for ABP Lowestoft, January 2019.

Appendix A

ABP Lowestoft Mooring Analysis: North Quay 1 and 2

(ABPmer Report R.3109, January 2019)

ABP Lowestoft

Mooring Analysis

North Quay 1 and 2

January 2019





Innovative Thinking - Sustainable Solutions

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Mooring Analysis

North Quay 1 and 2

January 2019

Document Information

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[redacted]	[redacted]	[redacted]

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Summary

A mooring analysis has been completed to determine the environmental limits for mooring vessels at North Quay 1 and 2 in the port of Lowestoft. The moorings have been analysed using the OPTIMOOR Software, Version 6.4.4.

A set of scenarios was developed to determine the worst credible conditions for height of tide, current speed and direction and vessel load state, to be taken forward for wind sensitivity analysis. This worst credible scenario was used to determine the limiting speed wind conditions beyond which mooring lines or bollards would become overloaded. The worst credible scenario was also used to identify the forces acting on bollards under different wind speeds to identify if any bollards need to be uprated to a higher safe working load.

The analysis has also considered the proposed Lake Lothing Third Crossing (LLTC) bridge development, which would reduce the available mooring length along the North Quay. This scenario was analysed for the aggregate dredger, Britannia Beaver, to identify if the vessel could safely use the berth on completion of the proposed development.

The wind sensitivity analysis carried out for each design vessel was compared with a hindcast dataset of wind speeds from the National Oceanographic and Atmospheric Administration (NOAA), to determine the proportion of time that the limiting wind speeds for safe working loads in mooring lines or bollards would be exceeded. There are no recorded periods where the wind speed and direction would result in overloading of bollards or mooring lines.

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Images

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Tables

1 Introduction

Associated British Ports (ABP) Lowestoft has commissioned ABPmer to perform mooring analysis on North Quay 1 and 2. The vessels to be tested were an aggregate dredger, which may be used for the future transhipment of aggregates and two offshore supply vessels that commonly use the berth. A separate analysis was also carried out for the aggregate dredger to determine if a suitable mooring configuration is still possible following completion of the proposed Lake Lothing Third Crossing (LLTC) bridge development, which would reduce the available space on North Quay for vessel mooring.

This mooring analysis has been carried out using OPTIMOOR Software, Version 6.4.4, using inputs provided by the hydrodynamic model of the port, created by ABPmer.

2 Design Vessels

This section details the design vessels that have been used to perform the mooring analysis. The design vessels comprise an aggregate dredger (Britannia Beaver) and two offshore supply vessels (VOS Star and Putford Achates). These vessels have been chosen as they represent the dredger that would be used for a proposed aggregate facility at ABP Lowestoft and the vessels which currently berth at North Quay 1 and 2. To perform the mooring analysis, measurements for fairlead locations and windage areas are required. These vessel parameters have been measured from the general arrangement plans that provide locations for fairleads, winches and bitts.

Table 1 to Table 3 provide the general dimensions for the vessels used in the mooring analysis. Full vessel inputs for the software are presented in Appendix A.

Table 1. Britannia Beaver

Vessel Dimension	Value
Length overall	99.95 m
Length between perpendiculars	94.80 m
Breadth	17.35 m
Loaded draught	6.00 m
Ballast draught	3.40 m
End on windage	237.00 m^2
Lateral windage	638.00 m^2

Table 2. VOS Star

Vessel Dimension	Value
Length overall	68.04 m
Length between perpendiculars	60.00 m
Breadth	14.95 m
Loaded draught	5.70 m
Ballast draught	4.60 m
End on windage	270.60 m^2
Lateral windage	494.19 m^2

Table 3. Putford Achates

Vessel Dimension	Value
Length overall	53.77 m
Length between perpendiculars	48.00 m
Breadth	11.60 m
Loaded draught	3.86 m
Ballast draught	3.30 m
End on windage	100.70 m^2
Lateral windage	277.20 m^2

The vessels selected will allow the evaluation of mooring point configurations and effective mooring restraint for the full range of vessel sizes that may use the berth.

3 Berth Layout

This section details the current layout and mooring equipment configuration on North Quay 1 and 2 and the effects of the proposed LLTC project.

3.1 Current berth layout

North Quay is located on the north bank of Lake Lothing between the A12/A47 Bascule Bridge and Mutford Lock. Image 1 shows the location of North Quay 1 and 2.

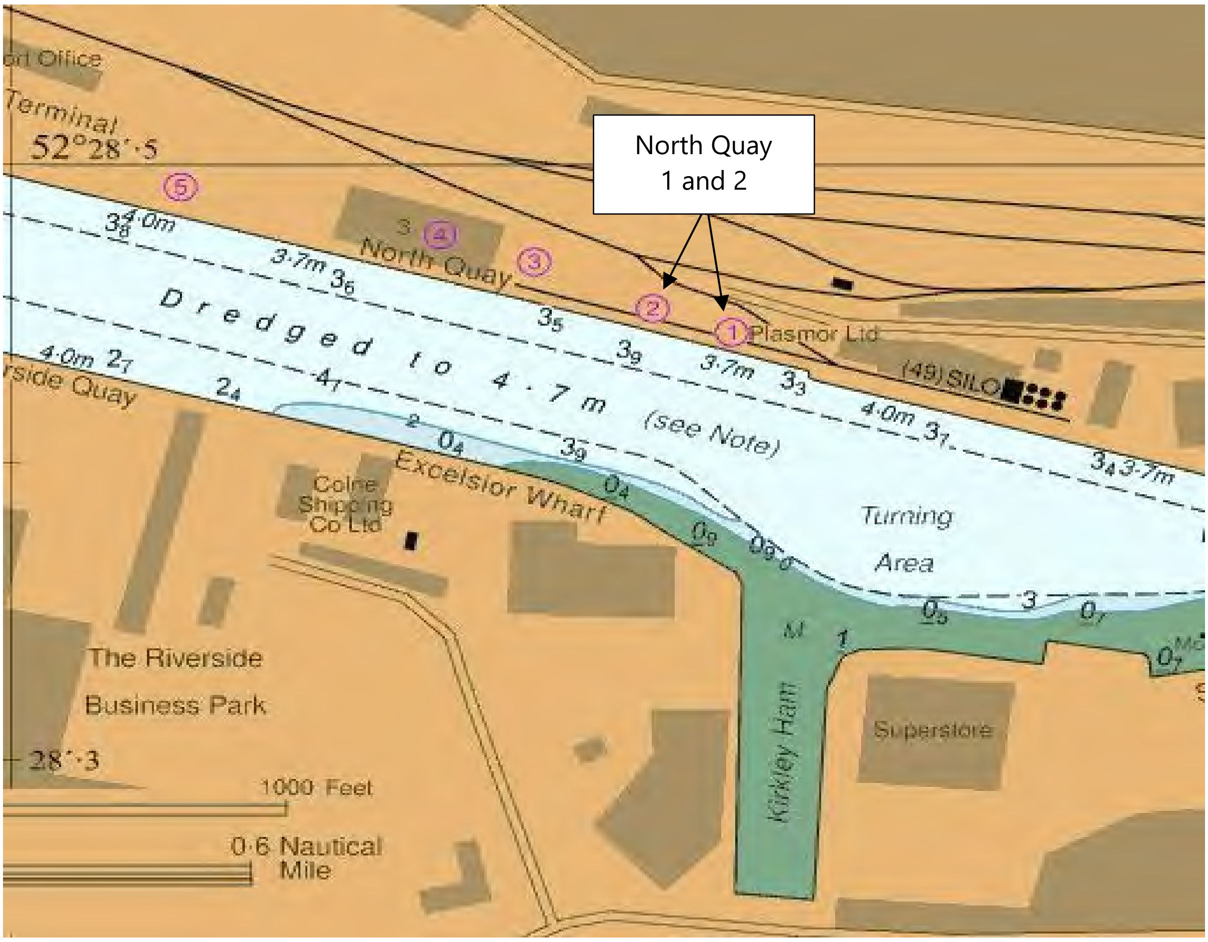

Image 1. North Quay 1 and 2 location

North Quay is currently a multipurpose berth with a current proposal for long term use to discharge aggregate dredgers. The current configuration of mooring equipment on North Quay 1 and 2 comprises 18 t bollards and vertical timber fenders. Image 2 shows the current configuration of North Quay 1 and 2.

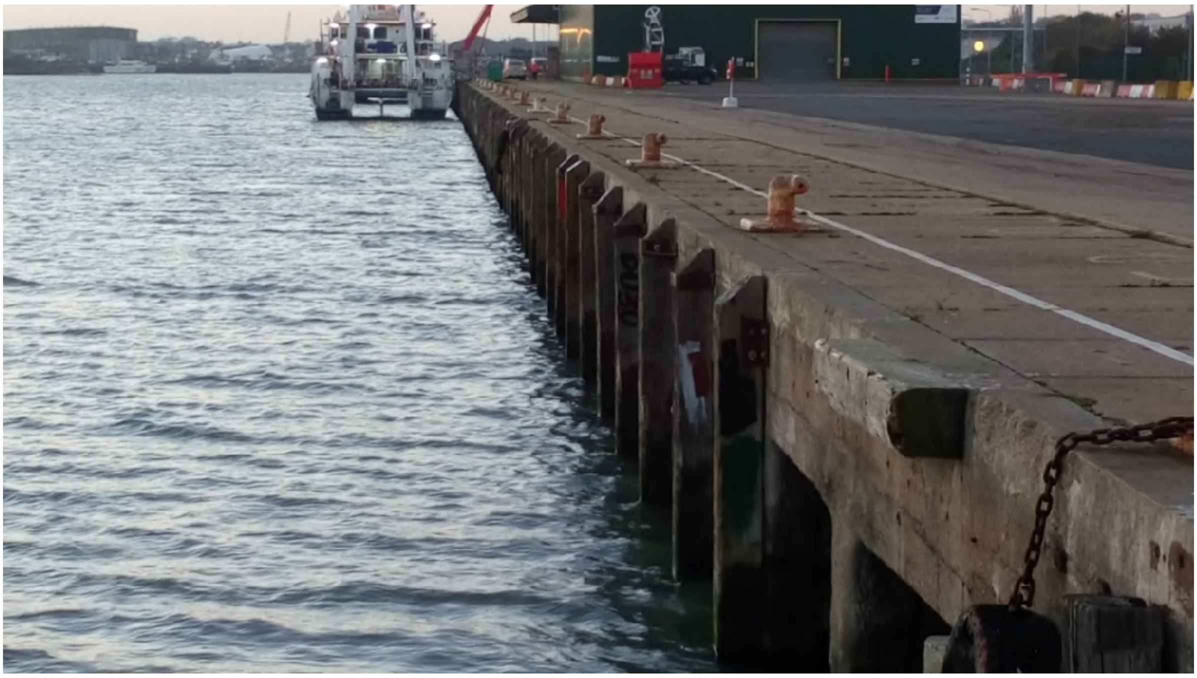

Image 2. North Quay 1 and 2

3.2 The LLTC project

The LLTC project proposes to construct a bridge across Lake Lothing which would bisect North Quay between Berths 2 and 3. The proposed location for the LLTC bridge is shown in Image 3.

Source: Preliminary Navigation Risk Assessment,Figure 2.1 (SCC, 2018)

Image 3. LLTC bridge location

The footprint of the bridge at the point it crosses the berth is approximately 25 m wide. In addition, there will be a 10 m safety margin either side of the bridge, where vessels will not be permitted to berth. These margins will therefore extend to around 33 m either side of the carriageway, giving an overall footprint width for the bridge and safety areas of 91 m. Image 4 shows the safety margins and associated loss in berth space.

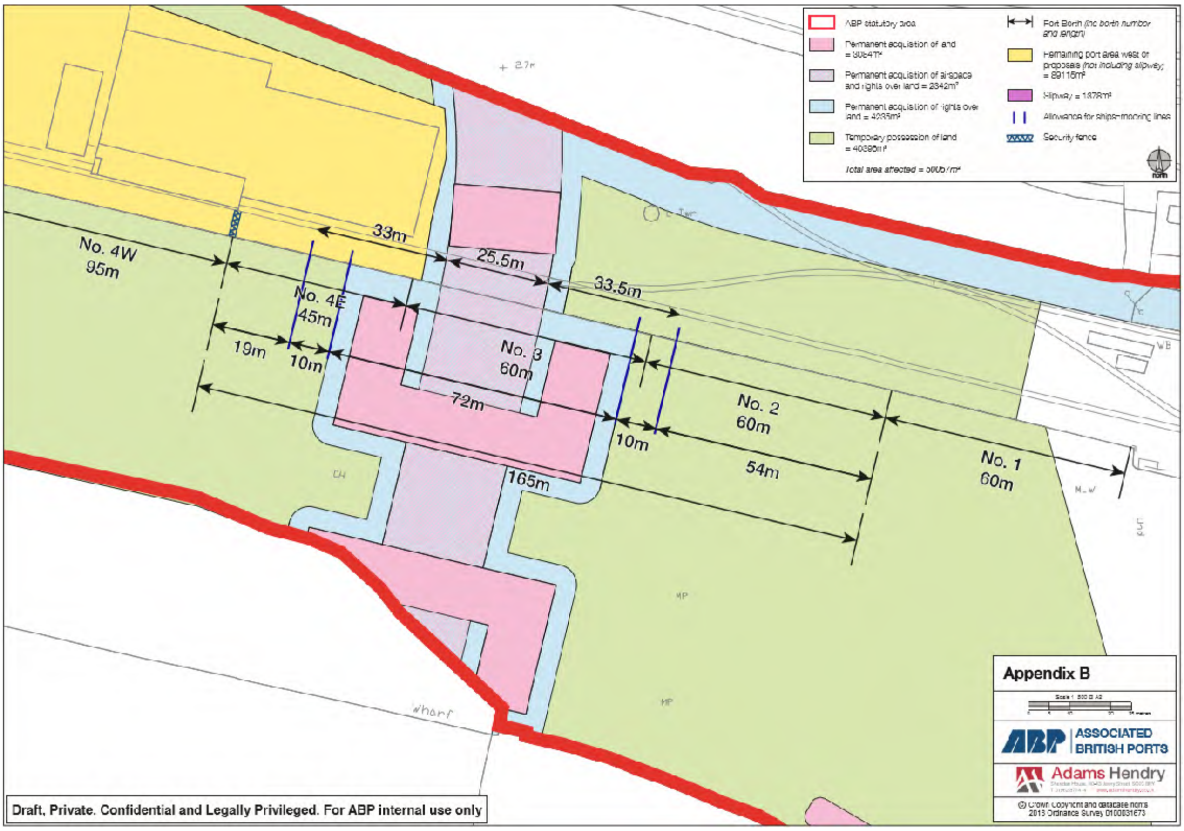

Image 4, Bridge safety margins

There is not expected to be any change to the mooring equipment available at North Quay 1 and 2 after construction of the proposed LLTC bridge.

4 Mooring Layout

The mooring line configuration for each vessel has been developed with consideration to current mooring practices at ABP Lowestoft and recommendations for mooring line lead angles given in BS 6349-4:2014 (BSI, 2014). There is an operating limitation of two lines per bollard at Lowestoft, which has been used in the mooring configurations adopted.

4.1 Current berth layout

Image 5 to Image 7 show the mooring configurations tested for the design vessels using the current berth conditions at ABP Lowestoft.

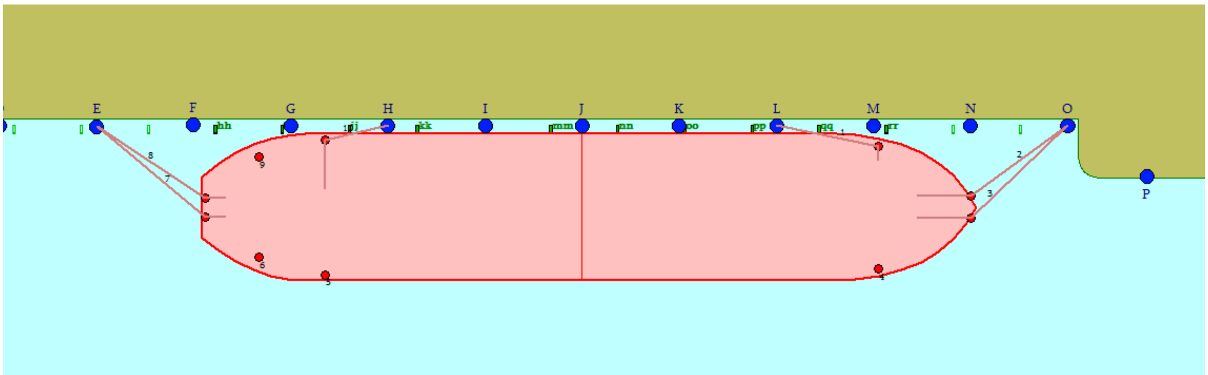

Image 5. Mooring layout – Britannia Beaver

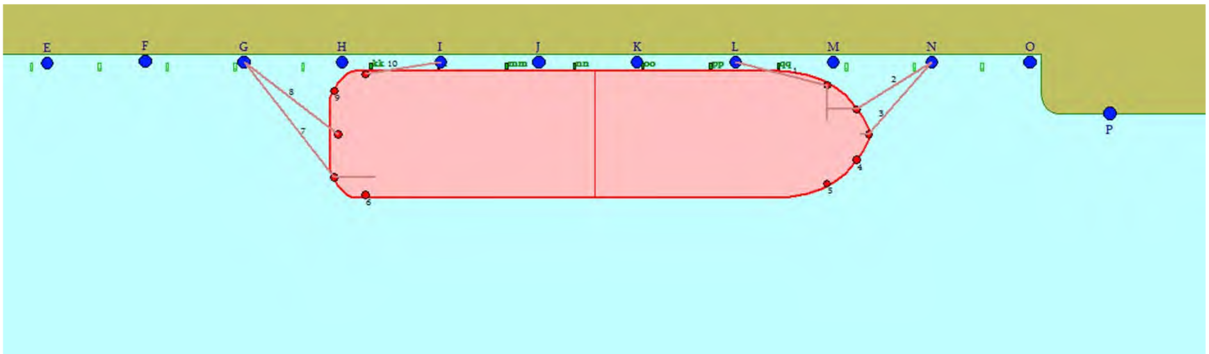

Image 6. Mooring layout – VOS Star

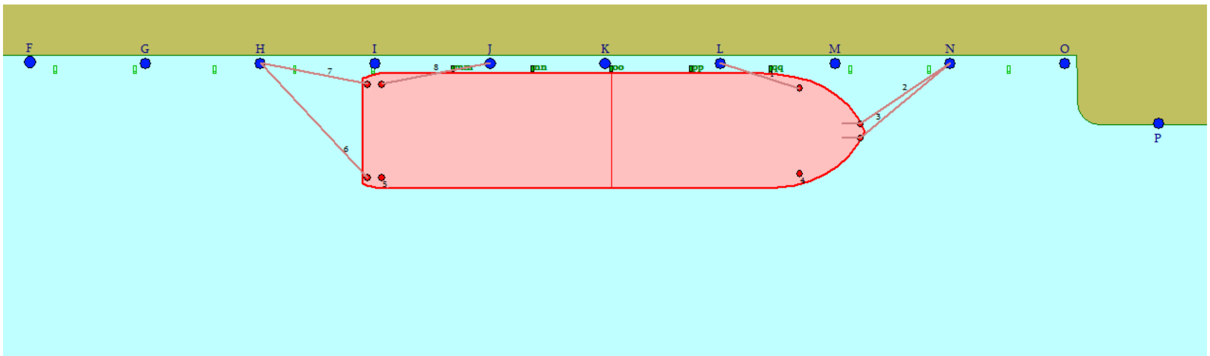

Image 7 Mooring layout – Putford Achates

4.2 The LLTC project

The proposed LLTC bridge and safety margins would limit the bollards available for mooring the Britannia Beaver. Image 8 shows the mooring configuration tested with the LLTC bridge in place; the proposed bridge location and safety margins have been underlaid for reference.

Image 8. Mooring layout – Britannia Beaver (with bridge development)

Bollard F, used for the stern lines of the Britannia Beaver, falls within the two vertical blue lines which delineate an area to be used for mooring lines only, but within which the vessel should not be located.

4.3 Restraint capacity

4.3.1 Mooring lines

The specific mooring lines that will be used by the visiting vessels are not known. The following properties have been assumed for the mooring lines of all design vessels used in the analysis, based on vessel size and type, and commonly used lines.

- Material: Polypropylene
- Diameter: 48 mm
- Breaking load 41 t

4.3.2 Bollards

The current bollards used on the North Quay have maximum load capacity of 18 t. This capacity has been used for all bollards for the purposes of this analysis. This nominal value will be used to evaluate the maximum prevailing environmental conditions, before bollards become overloaded.

5 Mooring Analysis

This section details the mooring analysis undertaken and the corresponding results for the design vessels.

5.1 Mooring scenarios

Six mooring scenarios have been analysed for each design vessel to determine which conditions result in the highest loading on vessel lines and mooring bollards. Table 3 details the conditions for the mooring scenarios used. The values for the current speed, direction and the height of tide have been derived from the 'A12 Lowestoft Relief Road Inner Harbour Hydrodynamic Study' for ABP Lowestoft in 1991 (ABP R&C, 1991), over a spring tidal cycle.

Scenarios one to six test the highest current speed during a flood and ebb tide. As part of these scenarios, the associated height of tide at the peak flows has been used with the vessels in both loaded and ballast condition.

Table 3. Mooring scenarios

Scenario	Wind Direction	Wind Speed (kn)	Current Speed (kn)	Current Direction (°T)	Height of Tide (m)	Vessel Loading Condition
1	Sweep through all directions	30	0.30	105	1.80	Loaded
2			0.30	105	1.80	Ballast
3			0.27	296	2.87	Loaded
4			0.27	296	2.87	Ballast
5			0.17	277	1.20	Loaded
6			0.17	277	1.20	Ballast

From the results, the scenario with the highest forces on vessel lines and/or bollards has been determined. The resultant tidal state was then used as criteria to carry out sensitivity testing to determine the limiting wind speed from all directions (at 10° intervals) for which mooring line or bollard SWLs are exceeded. The conversion of wind speed to different unit of measurement and comparison with the Beaufort Scale is shown in Appendix C.

5.2 Mooring scenario results (current berth layout)

The maximum loading for bollards and vessel lines arising from the test scenarios are detailed in the following sections. The force in tonnes on vessel lines and bollards is presented with the corresponding wind direction and a description of the lines with the greatest recorded loading (i.e. head line, stern line or spring).

5.2.1 Britannia Beaver

Table 4. Scenario results – Britannia Beaver

Scenario	Bollards			Vessel Lines		
	Wind Direction (°T)	Total Force (t)	Lines Attached	Wind Direction (°T)	Total Force (t)	Line Function
1	000	7.4	2 x Stern Line	000	3.9	Stern Line
2	350	7.6	2 x Stern Line	350	4.0	Stern Line
3	000	7.7	2 x Stern Line	000	4.0	Stern Line
4	000	8.7	2 x Stern Line	000	4.6	Stern Line
5	000	7.3	2 x Stern Line	000	3.8	Stern Line
6	350	7.5	2 x Stern Line	350	3.9	Stern Line

At low water, when the vessel is loaded, it will be aground. It has been assumed that the draught of the vessel will be managed at low water to avoid grounding and so it has been reduced when testing the moorings at low water.

It can be seen from Table 4 that Scenario 4 resulted in the highest loading on a bollard of 8.7 t and on a mooring line of 4.6 t. The environmental conditions used in Scenario 4 have been taken forward for use with wind sensitivity testing and bollard load analysis for this vessel.

5.2.2 VOS Star

Table 5. Scenario results – VOS Star

Scenario	Bollards			Vessel Lines		
	Wind Direction (°T)	Total Force (t)	Lines Attached	Wind Direction (°T)	Total Force (t)	Line Function
1	035	5.3	2 x Head Line	035	3.1	Head Line
2	050	7.6	2 x Head Line	020	5.2	Head Line
3	040	5.4	2 x Head Line	035	3.2	Head Line
4	040	5.6	2 x Head Line	035	3.3	Head Line
5	040	5.3	2 x Head Line	035	3.2	Head Line
6	040	5.3	2 x Head Line	035	3.2	Head Line

It can be seen from Table 5 that Scenario 4 also resulted in the highest loading on a bollard of 5.6 t and on a mooring line of 3.3 t. The environmental conditions used in Scenario 4 have again been taken forward for use with wind sensitivity testing and bollard load analysis for this vessel.

5.2.3 Putford Achates

Table 6. Scenario results – Putford Achates

Scenario	Bollards			Vessel Lines		
	Wind Direction (°T)	Total Force (t)	Lines Attached	Wind Direction (°T)	Total Force (t)	Line Function
1	045	3.9	2 x Head Line	045	2.0	Head Line
2	045	3.9	2 x Head Line	045	2.0	Head Line
3	045	3.9	2 x Head Line	045	2.0	Head Line
4	045	4.0	2 x Head Line	045	2.0	Head Line
5	045	3.9	2 x Head Line	045	2.0	Head Line
6	045	4.0	2 x Head Line	045	2.0	Head Line

It can be seen from Table 6 that Scenarios 4 and 6 resulted in the highest loading on a bollard of 4.0 t and on a mooring line of 2.0 t. The environmental conditions used in Scenario 4 have been taken forward for use with wind sensitivity testing and bollard load analysis for this vessel.

5.3 Mooring scenario results (with LLTC Project)

The Britannia Beaver has been tested for all scenarios with the mooring configuration shown in Image 8. The results are presented in Table 7.

Table 7. Scenario results – Britannia Beaver

Scenario	Bollards			Vessel Lines		
	Wind Direction (°T)	Total Force (t)	Lines Attached	Wind Direction (°T)	Total Force (t)	Line Function
1	350	6.1	2 x Stern Line	350	3.0	Stern Line
2	350	6.3	2 x Stern Line	350	3.2	Stern Line
3	350	6.4	2 x Stern Line	350	3.2	Stern Line
4	350	7.3	2 x Stern Line	350	3.7	Stern Line
5	350	6.0	2 x Stern Line	015	3.0	Stern Line
6	350	6.2	2 x Stern Line	350	3.1	Stern Line

It can be seen from Table 7 that Scenario 4 resulted in the highest loading on a bollard of 7.3 t and on a mooring line of 3.7 t. The environmental conditions used in Scenario 4 have been taken forward for use with wind sensitivity testing and bollard load analysis for this vessel.

6 Wind Sensitivity Analysis

Sensitivity testing for wind conditions has been undertaken to determine the maximum wind speed from any direction before either 50% of the breaking load for a mooring line, or the safe working load of a bollard, is exceeded. This testing has utilised the scenarios identified in Section 5.2 and Section 5.3 that resulted in the highest loadings on mooring lines and bollards. The red plot in the figures below shows the wind speed from each direction at which a mooring line load will reach 50% of the line breaking load; the limiting wind speed for the mooring lines. The blue plot shows the maximum wind speed, for the same direction, derived from the wind dataset.

6.1 Wind observation data

The above limiting wind conditions for the vessel design were compared with a combination of the NCEP II and CFSR hindcast datasets from NOAA, providing a total duration of 39 years of wind data (January 1979 to December 2017) at hourly intervals. The data represent wind speed and wind direction, at 10 m above mean sea level, with a representative one hour averaging period, for a location geographically representative of Lowestoft Harbour.

To compare these windspeeds with the 30 second gusts that are used in the OPTIMOOR software, a conversion was applied using the following formula to provide a representative gust speed for the data.

$$U(T,z) = U_{T_0}(1 + 0.137 ln\frac{z}{H} - 0.047 ln\frac{T}{T_0}$$

where:

U	is the wind speed;
T	is the averaging period;
z	is the height of observation; and
H	is the height required.

Source: DNV, 2014

6.2 Current berth layout

6.2.1 Britannia Beaver

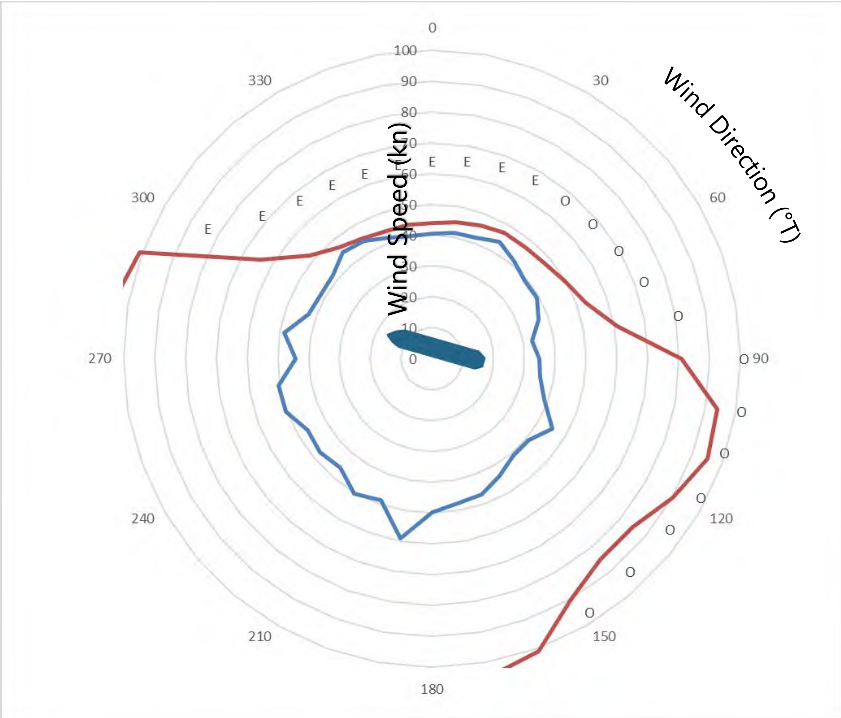

Figure 1. Wind sensitivity – Britannia Beaver

6.2.2 VOS Star

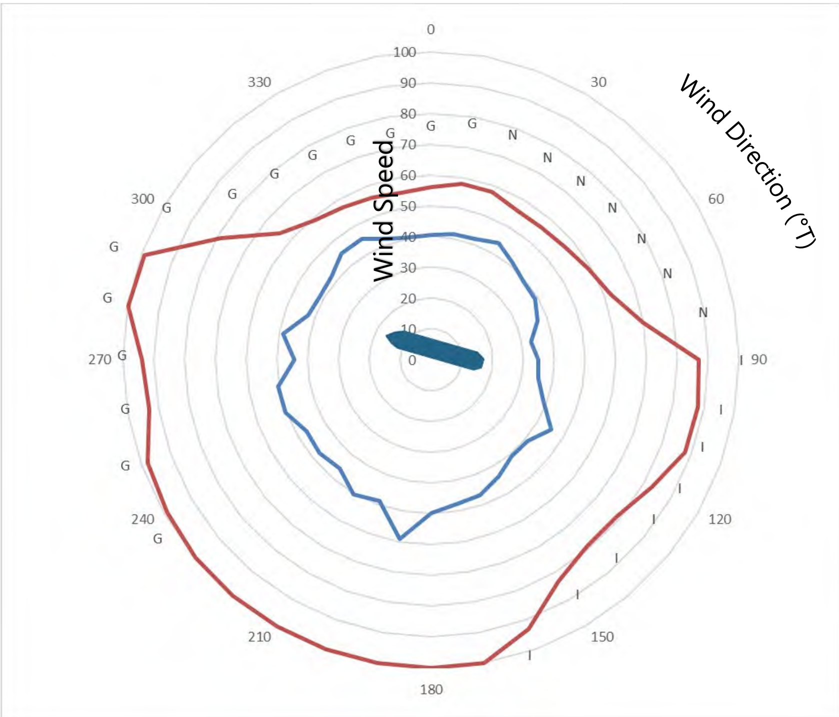

Figure 2. Wind sensitivity – VOS Star

6.2.3 Putford Achates

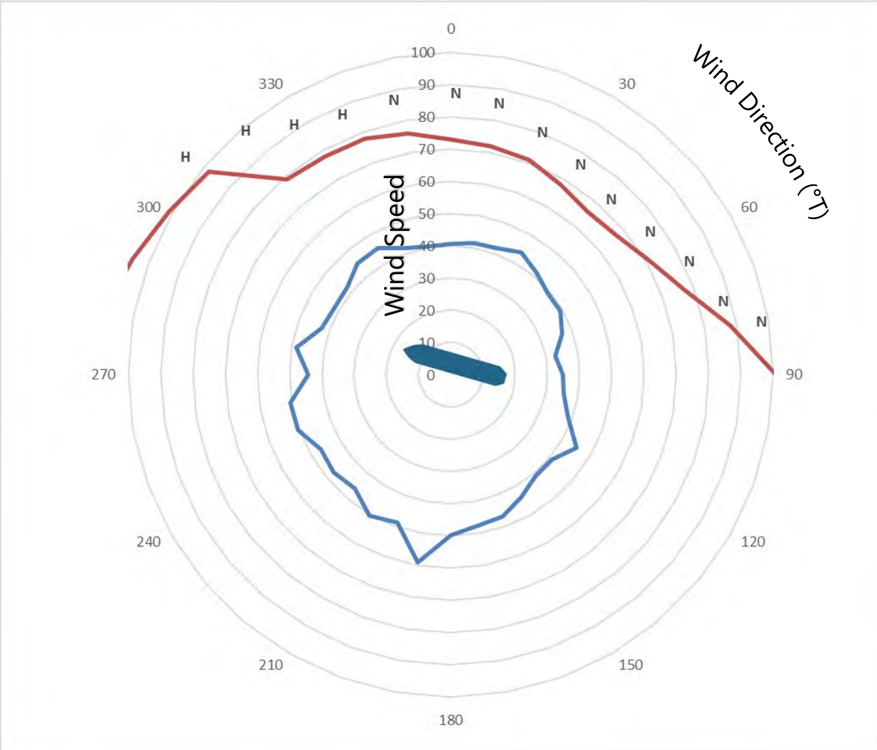

Figure 3. Wind sensitivity – Putford Achates

6.3 The LLTC project

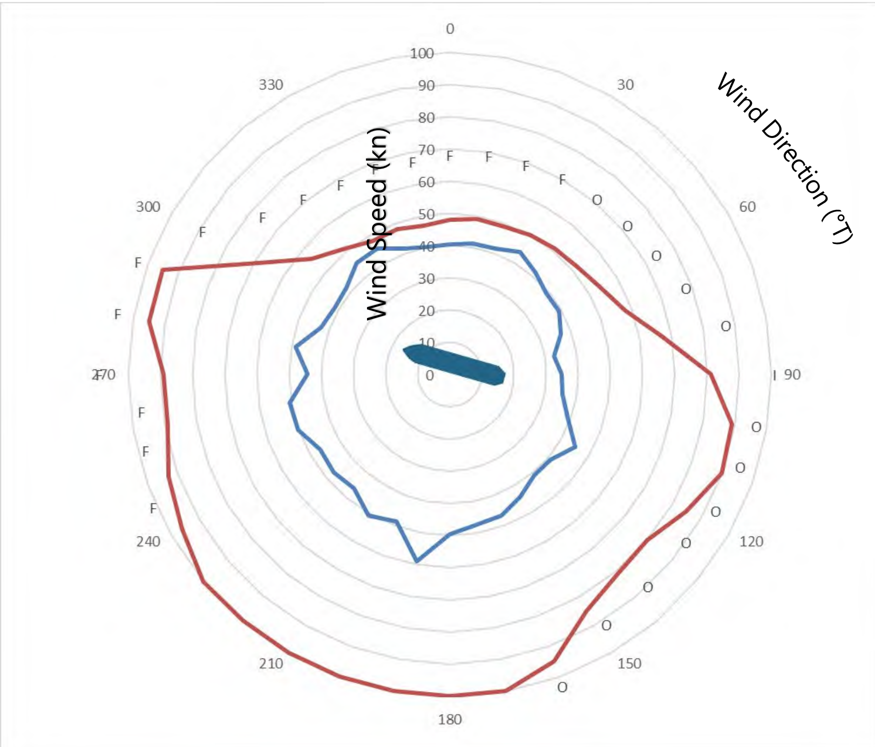

Figure 4. Wind sensitivity – Britannia Beaver

Sensitivity testing for the LLTC Project analysis makes no account for the effects of the bridge on the prevailing local wind conditions, which will be dependent of final design and availability of local wind records for comparison with the NOAA dataset.

6.4 Wind sensitivity results

By comparing the results of the wind sensitivity analysis with the hindcast dataset, it has been identified that there are no periods where the prevailing wind conditions (speed and direction) would result in overloading bollards or mooring lines. There are periods where the maximum wind conditions are close to the limits for Britannia Beaver, specifically wind acting on the starboard bow.

The percentages of time that the prevailing wind speed falls within 10 kn intervals are detailed in Table 8 and Table 9.

Table 8. Wind observation statistics

Year	Wind Speed (Percentage of Year)					Total (%)
	0 kn-10 kn	10 kn-20 kn	20 kn-30 kn	30 kn-40 kn	40 kn- 50 kn	
1979	29.1	51.8	16.7	2.2	0.3	100
1980	24.8	53.6	19.4	2.2	0.1	100
1981	26.7	53	17.8	2.4	0.1	100
1982	31.4	49	17.9	1.6	0.1	100
1983	24.9	54.2	18.6	2.2	0.1	100
1984	29.2	52.9	15.4	2.3	0.2	100
1985	27.8	54	16.9	1.3	0	100
1986	24.5	48.6	23.4	3.3	0.1	100
1987	33	51.9	13.2	1.7	0.2	100
1988	24.3	54.5	18.9	2.2	0.2	100
1989	28.8	53	15.9	2.2	0.1	100
1990	26	48.6	21.1	3.7	0.6	100
1991	33.3	48.3	16	2.1	0.2	100
1992	30.3	50.1	18	1.5	0	100
1993	28.3	53.6	15.6	2.3	0.3	100
1994	25.6	53.4	18.8	2.1	0.1	100
1995	25.9	52.7	18.6	2.7	0.2	100
1996	30.3	47.9	19.2	2.4	0.1	100
1997	29.1	52.9	16.6	1.4	0	100
1998	20.8	56.4	20	2.7	0.2	100
1999	28.8	49.3	18.8	2.9	0.1	100
2000	28.4	48.7	20.2	2.5	0.2	100
2001	28	53.7	17	1.2	0	100
2002	28.7	50.8	18	2.4	0.1	100
2003	31.2	53.2	14.4	1.1	0.1	100
2004	31.9	47.9	18.2	1.9	0	100
2005	29.4	52.5	15.9	2.1	0	100
2006	28.3	52.6	17.5	1.5	0.1	100
2007	27.6	52.1	18.4	1.7	0.2	100
2008	25.4	53	18.9	2.5	0.1	100
2009	29.7	53	15.8	1.6	0	100
2010	32.3	54.3	12.8	0.6	0.1	100

Year	Wind Speed (Percentage of Year)					Total (%)
	0 kn-10 kn	10 kn-20 kn	20 kn-30 kn	30 kn-40 kn	40 kn- 50 kn	
2011	32.4	55.1	11.8	0.7	0	100
2012	33.2	53.8	11.8	1.2	0	100
2013	32.8	52.4	13.4	1.2	0.2	100
2014	33.5	49.7	14.6	2	0.1	100
2015	28.2	55.7	14.7	1.4	0	100
2016	35.4	52.3	10.9	1.4	0	100
2017	33.4	54.4	11.4	0.8	0	100

Table 9 presents the percentage distribution of wind strength over the period of the dataset and reveals that the wind speed is mostly 10-20 knots and rarely reaches 40-50 knots.

Table 9. Wind percentage over observation period

Wind Speed (Percentage)					Total (%)
0 kn-10 kn	10 kn-20 kn	20 kn-30 kn	30 kn-40 kn	40 kn- 50 kn	
29.0	52.2	16.7	1.9	0.1	100

7 Bollard Loading

To provide an indication of the distribution of forces acting on the bollards a series of OPTIMOOR calculations have been run for each design vessel, using the conditions from Scenario 4 in Section 5.1 with wind from all directions and speeds from 10 kn to 40 kn at intervals of 10 kn. For wind speed conversion and Beaufort Scale, see Appendix C.

At each wind speed a sweep through all wind directions was run to identify which wind direction results in the highest mooring forces on each bollard. The results of these calculations are shown for each design vessel in following sections, with the bollard that has the highest total force highlighted in grey. This provides an indication of how the forces are acting on the bollards and includes the vertical component of the mooring force (bollard uplift).

7.1 Current berth layout

7.1.1 Britannia Beaver

Table 10. Bollard forces – 10 kn Britannia Beaver

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	1.6	1.1	2.0	11	0.5	290
F	Not used	Not used	Not used	Not used	Not used	Not used
G	Not used	Not used	Not used	Not used	Not used	Not used
H	0.9	0.2	1.0	6	0.5	140
I	Not used	Not used	Not used	Not used	Not used	Not used
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	0.9	0.2	1.0	5	0.3	270
M	Not used	Not used	Not used	Not used	Not used	Not used
N	Not used	Not used	Not used	Not used	Not used	Not used
O	1.5	1.2	2.0	11	0.7	110
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 11. Bollard forces – 20 kn Britannia Beaver

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	3.1	2.2	3.9	22	1.0	350
F	Not used	Not used	Not used	Not used	Not used	Not used
G	Not used	Not used	Not used	Not used	Not used	Not used
H	1.5	0.4	1.8	10	0.9	045
I	Not used	Not used	Not used	Not used	Not used	Not used
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	1.2	0.2	1.3	7	0.4	265
M	Not used	Not used	Not used	Not used	Not used	Not used
N	Not used	Not used	Not used	Not used	Not used	Not used
O	2.5	2.0	3.4	19	1.2	040
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 12. Bollard forces – 30 kn Britannia Beaver

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	6.8	5.0	8.7	49	2.3	000
F	Not used	Not used	Not used	Not used	Not used	Not used
G	Not used	Not used	Not used	Not used	Not used	Not used
H	2.8	0.7	3.3	18	1.6	045
I	Not used	Not used	Not used	Not used	Not used	Not used
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	1.6	0.3	1.7	9	0.6	265
M	Not used	Not used	Not used	Not used	Not used	Not used
N	Not used	Not used	Not used	Not used	Not used	Not used
O	5.6	4.6	7.6	42	2.5	040
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 13. Bollard forces – 40 kn Britannia Beaver

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	11.6	9.0	15.2	84	3.9	355
F	Not used	Not used	Not used	Not used	Not used	Not used
G	Not used	Not used	Not used	Not used	Not used	Not used
H	4.5	1.4	5.4	30	2.5	045
I	Not used	Not used	Not used	Not used	Not used	Not used
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	2.2	0.5	2.4	13	0.8	020
M	Not used	Not used	Not used	Not used	Not used	Not used
N	Not used	Not used	Not used	Not used	Not used	Not used
O	9.6	8.1	13.3	74	4.3	035
P	Not used	Not used	Not used	Not used	Not used	Not used

For the Britannia Beaver the maximum force acting on a bollard at 40 kn of wind was identified to be 15.2 t. This bollard has been used for the stern lines and so the maximum force on the bollard will be when the wind and current are acting on the port quarter pushing the stern away from the quay.

7.1.2 VOS Star

Table 14. Bollard forces – 10 kn VOS Star

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	Not used	Not used	Not used	Not used	Not used	Not used
G	1.6	1.3	2.1	11	0.0	310
H	Not used	Not used	Not used	Not used	Not used	Not used
I	1.2	0.2	1.2	7	0.0	165
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	0.9	0.2	1.0	6	0.4	080
M	Not used	Not used	Not used	Not used	Not used	Not used
N	1.4	1.3	2.1	12	1.0	080
O	Not used	Not used	Not used	Not used	Not used	Not used
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 15. Bollard forces – 20 kn VOS Star

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	Not used	Not used	Not used	Not used	Not used	Not used
G	1.8	1.5	2.4	13	0.0	340
H	Not used	Not used	Not used	Not used	Not used	Not used
I	1.1	0.3	1.7	10	0.1	135
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	1.7	0.2	1.2	7	0.5	265
M	Not used	Not used	Not used	Not used	Not used	Not used
N	1.1	1.5	2.5	14	1.2	080
O	Not used	Not used	Not used	Not used	Not used	Not used
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 16. Bollard forces – 30 kn VOS Star

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	Not used	Not used	Not used	Not used	Not used	Not used
G	4.0	3.4	5.3	29	0.1	350
H	Not used	Not used	Not used	Not used	Not used	Not used
I	2.8	0.5	2.8	16	0.1	065
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	1.3	0.3	1.5	8	0.6	335
M	Not used	Not used	Not used	Not used	Not used	Not used
N	3.4	3.4	5.4	30	2.5	040
O	Not used	Not used	Not used	Not used	Not used	Not used
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 17. Bollard forces – 40 kn VOS Star

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	Not used	Not used	Not used	Not used	Not used	Not used
G	7.1	6.1	9.4	52	0.2	350
H	Not used	Not used	Not used	Not used	Not used	Not used
I	4.5	0.9	4.6	25	0.1	065
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	1.8	0.4	2.1	11	0.8	265
M	Not used	Not used	Not used	Not used	Not used	Not used
N	6.0	6.0	9.5	53	4.4	040
O	Not used	Not used	Not used	Not used	Not used	Not used
P	Not used	Not used	Not used	Not used	Not used	Not used

For the VOS Star the maximum force acting on a bollard at 40 kn of wind was identified to be 9.5 t. This bollard has been used for the head lines and so the maximum force on the bollard will be when the wind and current are acting to the vessel's port bow pushing the bow away from the quay.

7.1.3 Putford Achates

Table 18. Bollard forces – 10 kn Putford Achates

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	Not used	Not used	Not used	Not used	Not used	Not used
G	Not used	Not used	Not used	Not used	Not used	Not used
H	1.7	0.8	1.9	11	0.1	300
I	Not used	Not used	Not used	Not used	Not used	Not used
J	1.1	0.2	1.1	6	0.0	105
K	Not used	Not used	Not used	Not used	Not used	Not used
L	0.9	0.2	1.1	5	0.2	300
M	Not used	Not used	Not used	Not used	Not used	Not used
N	1.5	1.3	2.1	12	0.6	100
O	Not used	Not used	Not used	Not used	Not used	Not used
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 19. Bollard forces – 20 kn Putford Achates

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	Not used	Not used	Not used	Not used	Not used	Not used
G	Not used	Not used	Not used	Not used	Not used	Not used
H	1.9	0.8	2.0	11	0.1	290
I	Not used	Not used	Not used	Not used	Not used	Not used
J	1.2	0.3	1.1	6	0.1	100
K	Not used	Not used	Not used	Not used	Not used	Not used
L	1.0	0.2	1.1	6	0.3	275
M	Not used	Not used	Not used	Not used	Not used	Not used
N	1.6	1.4	2.1	12	0.7	100
O	Not used	Not used	Not used	Not used	Not used	Not used
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 20. Bollard forces – 30 kn Putford Achates

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	Not used	Not used	Not used	Not used	Not used	Not used
G	Not used	Not used	Not used	Not used	Not used	Not used
H	2.7	1.4	3.0	17	0.1	340
I	Not used	Not used	Not used	Not used	Not used	Not used
J	1.6	0.4	1.6	9	0.1	005
K	Not used	Not used	Not used	Not used	Not used	Not used
L	1.3	0.3	1.4	8	0.3	45
M	Not used	Not used	Not used	Not used	Not used	Not used
N	2.7	2.4	3.8	21	1.1	45
O	Not used	Not used	Not used	Not used	Not used	Not used
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 21. Bollard forces – 40 kn Putford Achates

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	Not used	Not used	Not used	Not used	Not used	Not used
G	Not used	Not used	Not used	Not used	Not used	Not used
H	4.4	2.7	5.1	28	0.1	340
I	Not used	Not used	Not used	Not used	Not used	Not used
J	2.1	0.5	2.2	12	0.1	005
K	Not used	Not used	Not used	Not used	Not used	Not used
L	2.0	0.5	2.1	12	0.5	045
M	Not used	Not used	Not used	Not used	Not used	Not used
N	4.8	4.4	6.8	38	2.0	045
O	Not used	Not used	Not used	Not used	Not used	Not used
P	Not used	Not used	Not used	Not used	Not used	Not used

For the Putford Achates, the maximum force acting on a bollard at 40 kn of wind was identified to be 6.8 t. This bollard has been used for the head lines and so the maximum force on the bollard will be when the wind and current are acting to the vessels port bow pushing the bow away from the quay.

7.2 The LLTC project

7.2.1 Britannia Beaver

Table 22. Bollard forces – 10 kn Britannia Beaver

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	1.2	1.5	2.1	11	0.7	310
G	Not used	Not used	Not used	Not used	Not used	Not used
H	Not used	Not used	Not used	Not used	Not used	Not used
I	1.1	0.1	1.2	6	0.3	140
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	1.0	0.1	1.1	6	0.3	270
M	Not used	Not used	Not used	Not used	Not used	Not used
N	Not used	Not used	Not used	Not used	Not used	Not used
O	1.1	1.6	2.2	12	0.9	080
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 23. Bollard forces – 20 kn Britannia Beaver

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	1.8	2.4	3.2	18	1.2	350
G	Not used	Not used	Not used	Not used	Not used	Not used
H	Not used	Not used	Not used	Not used	Not used	Not used
I	1.6	0.2	1.6	9	0.3	060
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	1.3	0.2	1.3	7	0.5	265
M	Not used	Not used	Not used	Not used	Not used	Not used
N	Not used	Not used	Not used	Not used	Not used	Not used
O	1.4	2.1	2.8	16	1.1	040
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 24. Bollard forces – 30 kn Britannia Beaver

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	4.1	5.6	7.3	41	2.5	350
G	Not used	Not used	Not used	Not used	Not used	Not used
H	Not used	Not used	Not used	Not used	Not used	Not used
I	2.8	0.4	3.0	16	0.9	075
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	1.7	0.2	1.7	10	0.4	265
M	Not used	Not used	Not used	Not used	Not used	Not used
N	Not used	Not used	Not used	Not used	Not used	Not used
O	3.2	4.8	6.4	36	2.8	040
P	Not used	Not used	Not used	Not used	Not used	Not used

Table 25. Bollard forces – 40 kn Britannia Beaver

Bollard	Longitudinal Force (t)	Lateral Force (t)	Total Force (t)	Percentage of SWL (%)	Bollard Uplift (t)	Wind Direction (°T)
A	Not used	Not used	Not used	Not used	Not used	Not used
B	Not used	Not used	Not used	Not used	Not used	Not used
C	Not used	Not used	Not used	Not used	Not used	Not used
D	Not used	Not used	Not used	Not used	Not used	Not used
E	Not used	Not used	Not used	Not used	Not used	Not used
F	7.2	10.0	13.0	72	4.4	350
G	Not used	Not used	Not used	Not used	Not used	Not used
H	Not used	Not used	Not used	Not used	Not used	Not used
I	4.8	0.7	5.1	28	1.5	075
J	Not used	Not used	Not used	Not used	Not used	Not used
K	Not used	Not used	Not used	Not used	Not used	Not used
L	2.5	0.3	2.6	14	0.6	265
M	Not used	Not used	Not used	Not used	Not used	Not used
N	Not used	Not used	Not used	Not used	Not used	Not used
O	5.6	8.6	11.3	63	4.8	040
P	Not used	Not used	Not used	Not used	Not used	Not used

For the Britannia Beaver the maximum force acting on a bollard at 40 kn of wind was identified to be 13.0 t. This bollard has been used for the stern lines and so the maximum force on the bollard will be when the wind and current are acting on the port quarter pushing the stern away from the quay.

8 Conclusion

A mooring analysis has been completed to determine the environmental limits for mooring vessels at North Quay 1 and 2 in Lowestoft. The moorings have been analysed using the OPTIMOOR Software, Version 6.4.4.

The analysis has also considered the proposed LLTC bridge development which would reduce the available mooring length along the North Quay. This scenario was analysed for the Britannia Beaver aggregate carrier to identify if the vessel could safely use the berth on completion of the proposed development.

A set of scenarios was developed to determine the worst credible conditions for height of tide, current speed and direction and vessel load state that could be taken forward for wind sensitivity and bollard force analysis. This worst credible scenario was used to present the limiting wind conditions beyond which mooring lines or bollards are overloaded. The worst credible scenario was also used to identify the forces acting on bollards under different wind speeds to identify if any bollards need to be uprated for a higher safe working load.

The wind sensitivity analysis carried out for each design vessel was compared with hindcast windspeed datasets from NOAA to determine the proportion of time that the calculated limiting wind speeds for safe working loads in mooring lines or on bollards would be exceeded. There are no periods where the prevailing wind conditions (speed and direction) would result in overloading of bollards or mooring lines.

9 References

ABP R&C, 1991. A12 Lowestoft Relief Road, Inner Harbour Crossing, Hydraulic Study, ABP Research & Consultancy Ltd, Report No. R.412: October 1991.

BSI, 2014. BS 6349-4:2014 Maritime works – Part 4: code of practice for design of fendering and mooring systems. British Standards Institution, June 2014.

DNV, 2014. DNV-RP-C205 Environmental Conditions and Environmental Loads. Det Norske Veritas, April 2014.

Suffolk County Council (SCC), 2018 Preliminary Navigation Risk Assessment, Lake Lothing Third Crossing. Document 6.7. June 2018

10 Abbreviations/Acronyms

ABP	Associated British Ports
BS	British Standard
BSI	British Standards Institution
CFSR	Climate Forecast System Reanalysis
DNV	Det Norske Veritas
kn	Knots
LBP	Length between perpendiculars
LLTC	Lake Lothing Third Crossing
LOA	Length overall
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanographic and Atmospheric Administration
OPTIMOOR	Mooring Analysis Software for Ships and Barges
pp	Polypropylene
SCC	Suffolk County Council
SWL	Safe Working Load

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Appendices





Innovative Thinking - Sustainable Solutions

A Vessel Inputs

This section details the vessel inputs for the OPTIMOOR software. Figure A1 displays the terminology used by the software for the different dimensions of the vessel.

To ensure that the wind area used during the calculation process is accurate the depth input for the software has been set as the maximum draught for the vessel.

The following sections detail the specific inputs for each of the design vessels.

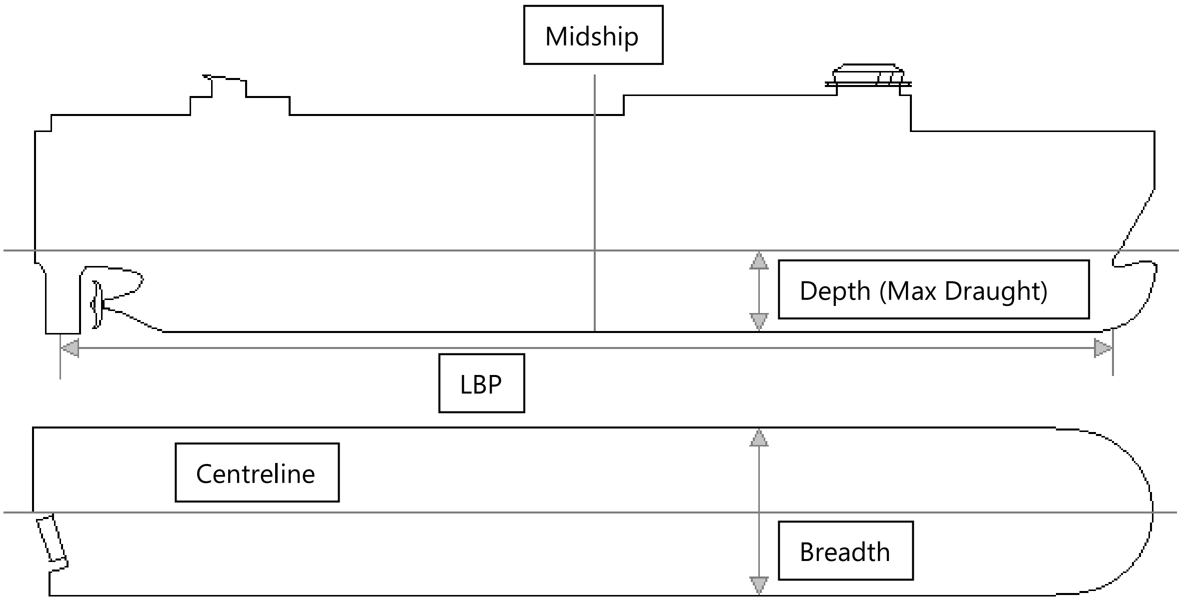

Figure A1. Vessel dimension terminology

A.1 Vessel Inputs – Britannia Beaver

Software Input	Value
Length Between Perpendiculars (LBP)	94.80 m
Breadth	17.4 m
Depth (set same as max draught)	6.20 m
End-on wind area (above max draught)	237 m^2
Side-on wind area (above max draught)	638 m^2

Line Number	Midship to Fairlead (m)	Centreline to Fairlead (m)	Height Above Draught (m)	Distance of Fairlead to Winch (m)	Winch Brake Limit (t)	Line Diameter (mm)	Line Material	Line Breaking Strain (t)
1	37.5	7.3	4.4	1.7	45	48	pp	41
2	49.2	1.3	5.2	6.7	45	48	pp	41
3	49.2	-1.3	5.2	6.7	45	48	pp	41
4	37.5	-7.3	4.4	1.7	45	48	pp	41
5	-32.6	-8.0	4.2	5.8	45	48	pp	41
6	-41.0	-6.0	4.2	1.3	45	48	pp	41
7	-47.8	-1.1	4.2	2.6	45	48	pp	41
8	-47.8	-1.1	4.2	2.6	45	48	pp	41
9	-41.0	-6.0	4.2	1.3	45	48	pp	41
10	-32.6	-8.0	4.2	5.8	45	48	pp	41
pp	Polypropylene							

A.2 Vessel Inputs –VOS Star

Software Input	Value
Length Between Perpendiculars (LBP)	60.00 m
Breadth	15.00 m
Depth (set same as max draught)	5.70 m
End-on wind area (above max draught)	271 m^2
Side-on wind area (above max draught)	494 m^2

Line Number	Midship to Fairlead (m)	Centreline to Fairlead (m)	Height Above Draught (m)	Distance of Fairlead to Winch (m)	Winch Brake Limit (t)	Line Diameter (mm)	Line Material	Line Breaking Strain (t)
1	29.1	5.8	7.1	4.1	45	48	pp	41
2	32.8	3.0	7.1	3.6	45	48	pp	41
3	34.3	0.0	7.1	1.0	45	48	pp	41
4	32.8	-3.0	7.1	3.6	45	48	pp	41
5	29.1	-5.8	7.1	4.1	45	48	pp	41
6	-28.7	-7.1	1.8	0.0	45	48	pp	41
7	-32.6	-5.1	1.8	5.1	45	48	pp	41
8	-32.1	0.0	1.8	0.0	45	48	pp	41
9	-32.6	5.1	1.8	5.1	45	48	pp	41
10	-28.7	7.1	1.8	0.0	45	48	pp	41
pp	Polypropylene							

A.3 Vessel Inputs –Putford Achates

Software Input	Value
Length Between Perpendiculars (LBP)	48.0 m
Breadth	11.6 m
Depth (set same as max draught)	3.4 m
End-on wind area (above max draught)	101 m^2
Side-on wind area (above max draught)	277 m^2

Line Number	Midship to Fairlead (m)	Centreline to Fairlead (m)	Height Above Draught (m)	Distance of Fairlead to Winch (m)	Winch Brake Limit (t)	Line Diameter (mm)	Line Material	Line Breaking Strain (t)
1	20.1	4.3	4.8	0.0	20	48	pp	41
2	26.6	0.7	5.4	1.9	20	48	pp	41
3	26.6	-0.7	5.4	1.9	20	48	pp	41
4	20.1	-4.3	4.8	0.0	20	48	pp	41
5	-24.6	-4.7	2.6	0.0	20	48	pp	41
6	-26.1	-4.7	2.6	0.0	20	48	pp	41
7	-26.1	4.7	2.6	0.0	20	48	pp	41
8	-24.6	4.7	2.6	0.0	20	48	pp	41
pp Polypropylene								

B Berth Inputs

This section details the vessel inputs for the OPTIMOOR software. Figure B1 displays the terminology used for the different dimensions of the berth.

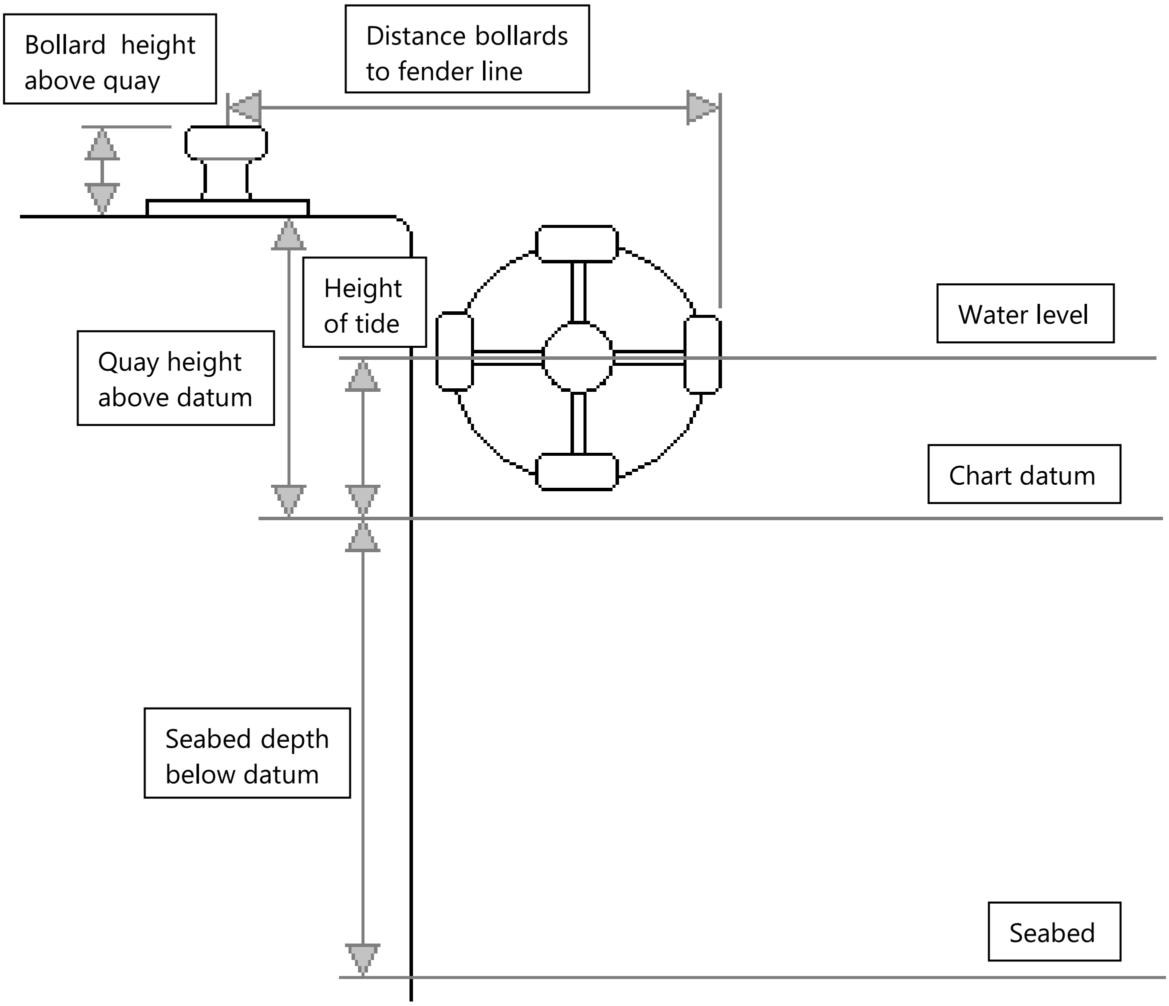

Figure B1. Berth dimension terminology (not to scale)

Software Input	Value
Line of berth	106°T
Width of channel	112 m
Quay height above	4.6 m
Seabed depth below datum	4.0 m
Wind specified at height	10 m

Bollard Number	Distance From Bollard 1 (m)	Distance Bollard to Fender Line (m)	Height Bollard Above Quay (m)	Maximum Bollard Load (t)
A	0.3	1.0	0.5	18
B	12.3	1.0	0.5	18
C	24.9	1.0	0.5	18
D	37.2	1.0	0.5	18
E	49.5	1.0	0.5	18
F	61.8	1.0	0.5	18
G	74.1	1.0	0.5	18
H	86.4	1.0	0.5	18
I	98.7	1.0	0.5	18
J	111.0	1.0	0.5	18
K	123.3	1.0	0.5	18
L	135.6	1.0	0.5	18
M	147.9	1.0	0.5	18
N	160.2	1.0	0.5	18
O	172.5	1.0	0.5	18
P	182.5	-0.5	0.5	18

C Conversion of Wind Speeds

Unit	m/s	km/h	mph	knot	ft/s
1 m/s	**1.000**	3.600	2.237	1.944	3.281
1 km/h	0.278	**1.000**	0.621	0.540	0.911
1 mph	0.447	1.609	**1.000**	0.869	1.467
1 knot	0.514	1.852	1.151	**1.000**	1.688
1 ft/s	0.305	1.097	0.682	0.592	**1.000**

Beaufort Scale	Windspeed (knots)	Windspeed (mph)	Description	Sea State
0	0	0	Calm	Sea like a mirror
1	1-3	1-3	Light Air	Ripples but without foam crests
2	4-6	4-7	Light Breeze	Small wavelets. Crests do not break
3	7-10	8-12	Gentle Breeze	Large wavelets. Perhaps scattered white horses.
4	11-16	13-18	Moderate Breeze	Small waves. Fairly frequent white horses.
5	17-21	19-24	Fresh Breeze	Moderate waves, many white horses.
6	22-27	25-31	Strong Breeze	Large waves begin to form; white foam crests, probably spray. Warnings issued to small craft.
7	28-33	32-38	Near Gale	Sea heaps up and white foam blown in streaks along the direction of the wind.
8	34-40	39-46	Gale	Moderately high waves, crests begin to break into spindrift.
9	41-47	47-54	Strong Gale	High waves. Dense foam along the direction of the wind. Crests of waves begin to roll over.
10	48-55	55-63	Storm	Very high waves with long overhanging crests. The surface of the sea takes a white appearance.

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