

A large ship is docked at a pier. The ship's hull is visible on the left side of the frame. In the center, a yellow crane or mooring equipment is positioned over the water. The pier structure consists of several vertical concrete pillars. The water is visible in the foreground and background. The overall scene is industrial and maritime.

BERTHING VELOCITIES AND BROLSMA'S CURVES

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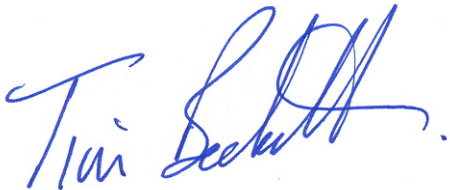
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1.0 INTRODUCTION

1.1 When designing berthing structures for ships the design team is required to define the berthing velocity of the design vessel(s) and this task is usually carried out using the "Brolsma Curves". These curves provide guidance on berthing velocity with regard to the displacement of the vessel and the difficulty of the berthing operation in accordance with the degree of exposure of the site. The curves are a key component of BS6349 Pt. 4 1994 "*Code of Practice for Design of Fendering and Mooring Systems*" (ref.1) and PIANC's "*Guidelines for the Design of Fenders*":2002 (ref.5).

1.2 As the curves are part of a well established British Standard designers would normally expect:

- to have confidence that these curves have been accurately derived from a wide base of data;
- that they reasonably reflect vessels' handling and to have been updated to reflect recent developments in vessel handling;
- that they could correctly and readily assign the appropriate difficulty of berthing to be used for a given berth.

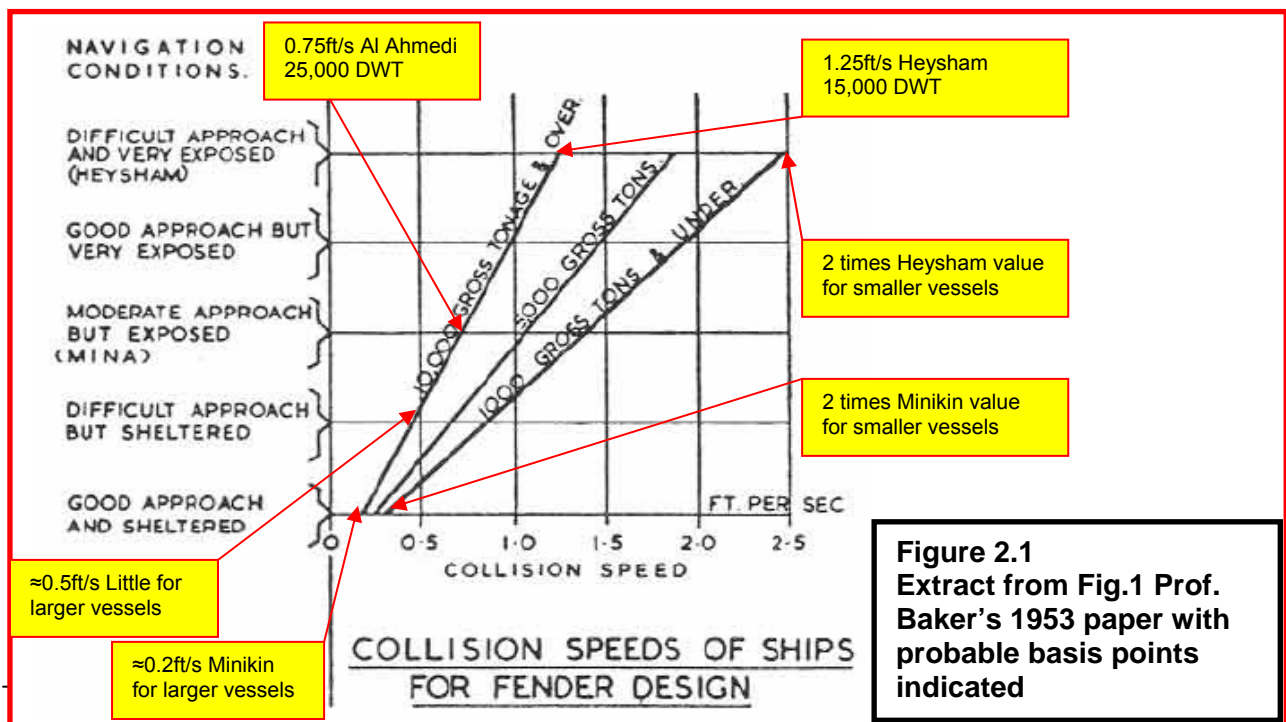
1.3 From our work using BS6349 and the PIANC guidelines we have discovered that the berthing velocity data provided by the Brolsma Curves does not have the sound statistical basis that a designer may expect of it; furthermore the data used is of questionable value for modern ships. In this paper the history of the development of Brolsma Curves is set out in order to provide a better understanding of their limitations and, hopefully, to encourage their revision.

2.0 A HISTORY OF THE DEVELOPMENT OF BERTHING VELOCITY CURVES

2.1 Professor A.L.L.Baker presented a paper to the 1953 International Navigational Congress in Rome (ref. 9) which introduced a design chart for fender impact or 'collision' speed for differing degrees of approach and berthing difficulty (refer to Fig 2.1). Baker's chart was based upon estimated approach velocities from the following stated data sources:-

- Assessments of berthing velocities at a 15,000DWT tanker jetty (which no longer exists) outside Heysham Harbour based upon Prof. Baker's 1948 ICE paper "Heysham Jetty" (ref.6). The navigation assessment was "**Difficult Exposed**" with design approach velocity of 1 to 1.25 ft/sec (0.3 to 0.38 m/s);
- An oil and cargo berth at Mina Al-Ahmadi as reported in McGowan, Harvey and Lowden's 1952 ICE paper "Oil Loading and Cargo Handling Facilities at Mina Al-Ahmadi, Persian Gulf" ((ref 9), based on 3 years of operation with 185 berthings per month (fender damage rate of 1 in 800 berthings). The navigation assessment was "**Moderate Approach but Exposed**" with approach velocity of 0.75 ft/sec (0.23m/s) for up to 25,000DWT vessels;
- General observations by D.H.Little in his 1952 ICE paper "Some Designs for flexible fenders" (ref.8). The assessment was to allow for approach velocities of 0.5 ft/sec (0.15m/s) for large and 1 ft/sec (0.3m/s) for small vessels;
- General observations by R.R.Minikin from his book "Wind, Waves and Maritime Structures", which indicated approach velocities ranging between 0.2 and 0.75 ft/sec (0.06 and 0.27m/s) in various conditions.

Baker's chart (Figure 2.1 below) has been annotated to point out the possible genesis of the chart from the above data.



2.2 In 1977 J.U.Brolsma and colleagues presented a paper entitled "On Fender Design and Berthing Velocities" at the 24th International Navigation Congress (ref.11), this paper referenced the 1953 work of Baker as the basis for five navigation conditions and indicated that the concept had been adopted by the German Working Committee on Bank Protection in its recommendation E40 (dated 1955). The German Waterfront Committee appears to have continued to adopt the same navigation conditions, which are given in Table R40-1 of the Recommendations of the Committee for Waterfront Structures, Harbours and Waterways-EAU 1990 6th Edition (ref.4), although the basis for this table is stated to be PIANC Bulletin No 15 (1973) and No 25 (1976). Subsequently, in 1994, Part 4 of the British Standard for Marine Structures (ref.1), concerned with berthing and mooring adopted the same concept but varied the wording, detracting from the concept that the berth needed to be assessed for both difficulty of approach and degree of exposure to wind/waves. The descriptions provided within the PIANC 2002 fender design guidelines (ref 5) are slightly more fulsome. The various descriptions provided in each of these publications are listed in Table 2.1.

Baker 1953	Brolsma 1977		EAU 1990		BS6349: Pt 4:1994	PIANC Guidelines for Design Fender Systems: 2002
	Navigation	Condition	Condition	Approach		
Good Approach Sheltered	1) Good	Sheltered	Protected	Favourable	Good Berthing Sheltered	a) Good Berthing conditions, sheltered
Difficult Approach but Sheltered	2) Difficult	Sheltered	Protected	Difficult	Difficult Berthing Sheltered	b) Difficult berthing conditions, sheltered
Moderate Approach but exposed (Mina)	3) Moderate (easy)	Exposed	Moderate wind & heavy sea	Moderate	Easy Berthing Exposed	c) Easy berthing conditions, exposed
Good Approach but Very Exposed	4) Good Berthing	Exposed	Strong wind & heavy sea	Favourable	Good Berthing Exposed	d*) Good berthing conditions, exposed
Difficult Approach and Very Exposed (Heysham)	5) Difficult	Exposed	Strong wind & heavy sea	Difficult	Difficult Exposed	e*) Navigation conditions difficult, exposed

* PIANC notes that these figures to be used with caution as they are considered too high

2.3 In his 1953 paper Baker acknowledged that insufficient records were available to assign fully appropriate berthing speeds for various conditions. The data collected by Brolsma for his 1977 paper sought to improve on this statistical basis by considering the

results from measurements at several berths in Rotterdam and also incorporating the results from a paper by B.F. Saurin regarding tanker berthing measurements at Finnart, Scotland (ref.10). The results were then extrapolated using extreme probability graphs to generate the maximum approach velocity for 3,000 berthings.

2.4 The berthing velocity measurements were all taken on vessels of greater than 200m length with tug assistance at the following locations:-

- Rotterdam: 150 tanker berthings in Europort on Maatschap 2 and 3 jetties, described as subject to some current and wave exposure, with less dominant effect by wind on a fully laden tanker. The tankers between 95,000 and 285,000 DWT were assisted by up to 4No 100t bollard pull tugs. The navigation was described as easy with some exposure ("**Easy Exposed Condition**"). The results from 150 berthings were considered and the transverse speed at a point 0.5m from the "substantial" jetty fender line was taken as the contact speed. The velocities were measured and plotted as extreme probability graphs (refer Fig.7 of Figure 2.2 below);
- Rotterdam: 6 bulk carrier berthings were recorded at Calandkanaal quay for 150,000DWT vessels berthing on "hard" azobe timber piles, which Brolsma classified as "**Easy Exposed**". The speeds were much less than for the tankers;
- Rotterdam: 15 berthings of 3rd generation container vessels at the Eemhaven berth with timber fenders and 10 berthings at Waalhaven berth which was fitted with Yokohama fenders. Both berths were classified as "**Easy Exposed**". The conclusion was that the speed of approach was similar irrespective of the fender system although the velocities measured were slightly greater for soft fenders (NB 3rd Generation Container vessels size range is 36,000 to 50,000 DWT);
- Finnart Tanker Terminal Loch Long Scotland: From the paper "Berthing Forces of Large Tankers" by B.F.Saurin presented at 6th World Petroleum Congress, Frankfurt in 1963 (ref.10) the results from 70 tanker berthings at BP's terminal. The navigation condition at the terminal was described by Brolsma as "**Easy Berthing Exposed**" with the tidal range being twice that of Rotterdam.

2.5 The Saurin paper estimated that the maximum impact energy for a berth life of 3,000 berthings (2 per week for 30years) was 1 ton metre per 1,000DWT, which for 30,000DWT vessels converted into an approach velocity of 20cm/sec. Brolsma applied the same method to the Europort measurements and, in a whole life context of 3,000 berthings, produced an estimated 95% probability maximum velocity of approach of 10cm/sec for a 265,000 DWT vessel and 16cm/sec for 120,000 DWT vessel (refer Fig.8 and 10 of Figure 2.2 below).

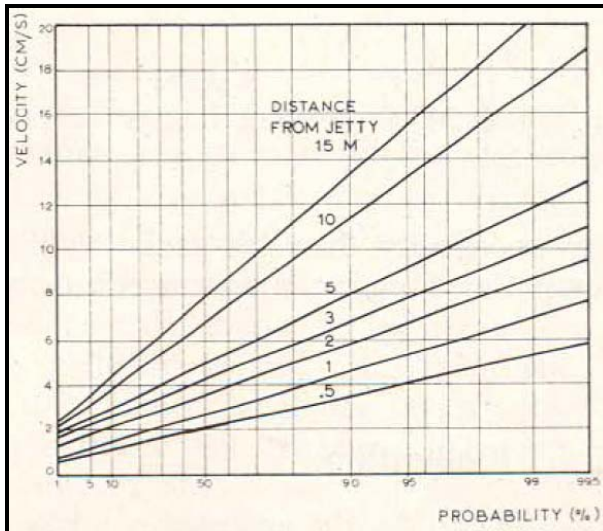


Fig. 7. — Probability of berthing velocity as function of distance from jetty, as derived from 150 berthings at 2 jetties in Europoort.

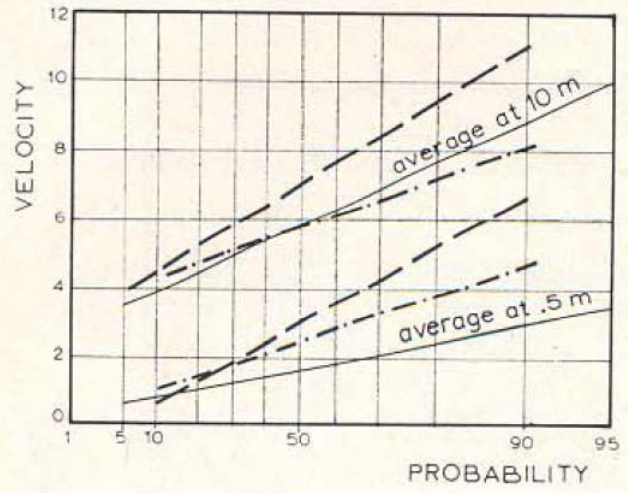


Fig. 8. Probability of berthing velocity as function of distance from jetty and size of ship, comparing the 10 largest vessels from Fig. 7 with the 10 smallest.

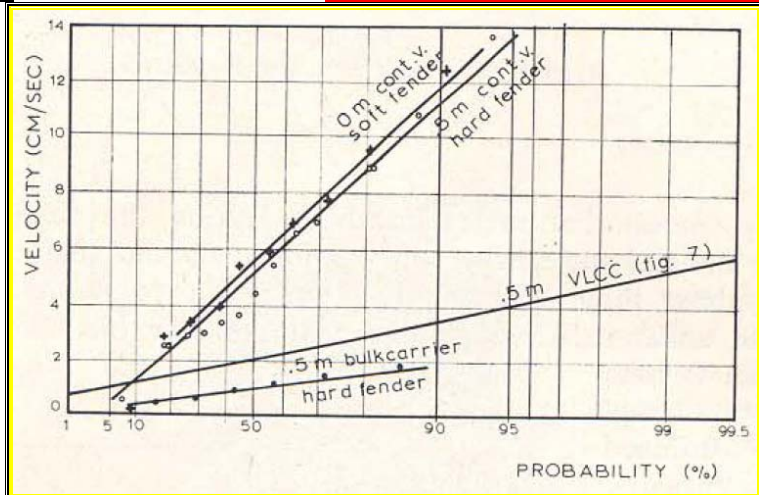


Fig. 9. Probability of berthing velocity as function of type of ship and fender at 3 berths in Rotterdam.

Fig. 10. Probability of berthing velocity as function of size of tanker, as derived from extrapolation of Fig. 8 for 3000 berthings.

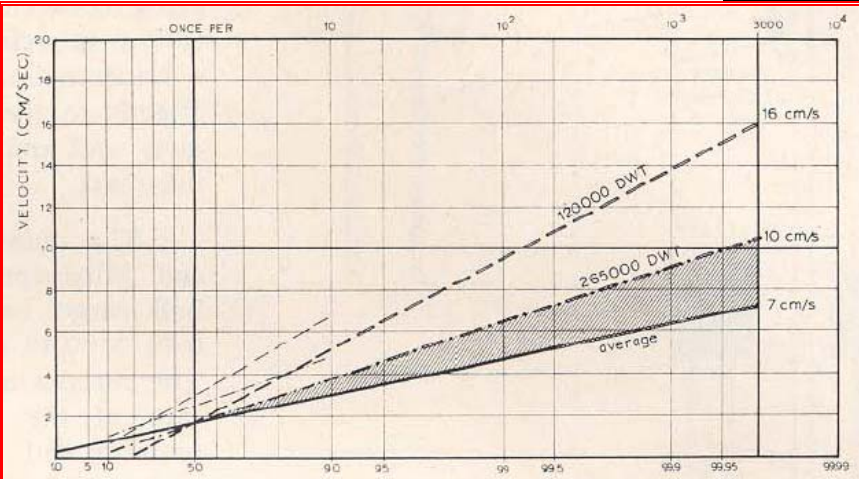


Figure 2.2
Extract from Brolsma 1977 paper "On Fender Design and Berthing Velocities"
Figures 7, 8, 9 and 10

- 2.6 Brolsma presented a composite velocity probability chart for the data collected in Rotterdam identifying each type of vessel and the fendering system (see Fig. 9 within Figure 2.3 above), which indicated little variance in berthing velocities in respect of type of fendering but considerable variance between container and large VLCC / Dry Bulk cargo ships.
- 2.7 Brolsma then combined the data from Rotterdam with that presented by Baker and Saurin as a chart of berthing velocity against the vessel deadweight tonnage (refer Fig.11 within Figure 2.3 below).

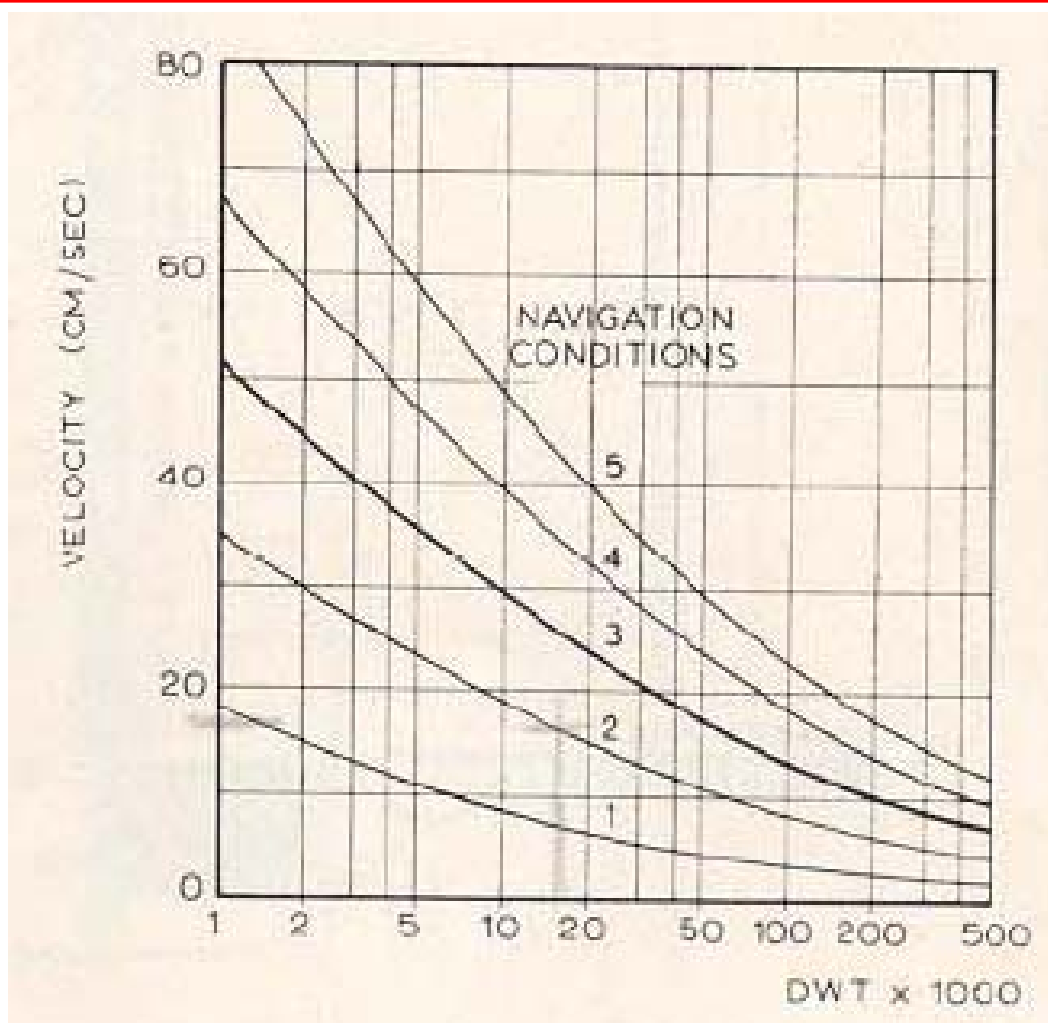


Fig. 11. — Design berthing velocity as function of navigation conditions and size of tanker (combination of results from Baker, Saurin and Brolsma).

Figure 2.3 Extract Fig. 11 from Brolsma 1977 paper "On Fender Design and Berthing Velocities"

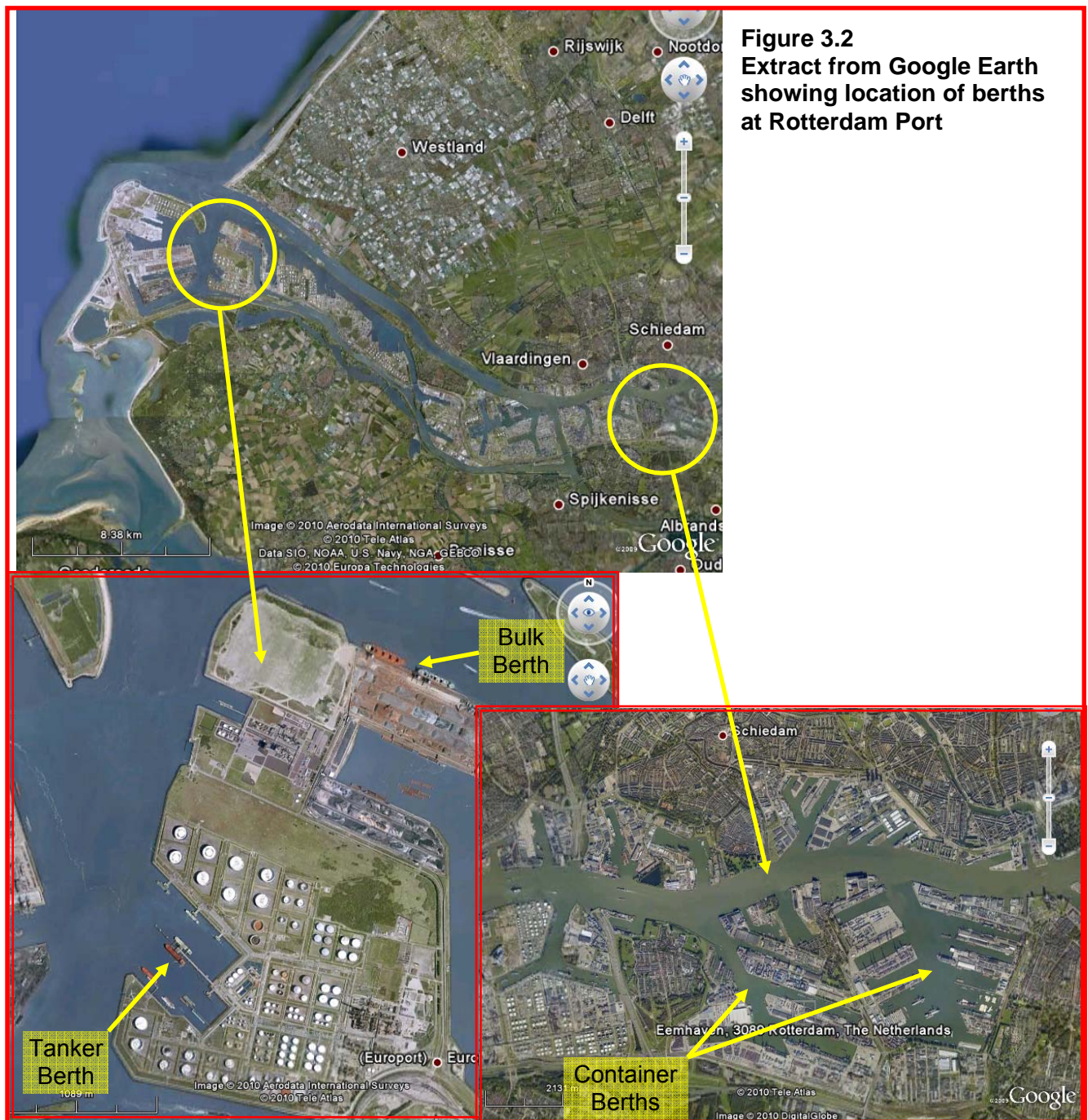
3.0 THE BASIS FOR BROLSMA'S CURVES

3.1 There are two main areas where the assessments made by Brolsma in deriving his curves need to be reviewed so that their implications can be fully appreciated:-

- the first is in the assessment of berthing difficulty assigned to the Rotterdam and Finnart Berths in comparison to those considered by Baker for Mina Al Hamadi
- the second is the narrow range of vessel sizes/berth exposures for which data was collected and how this was then extrapolated to cover a broader range of vessels and berth exposures.

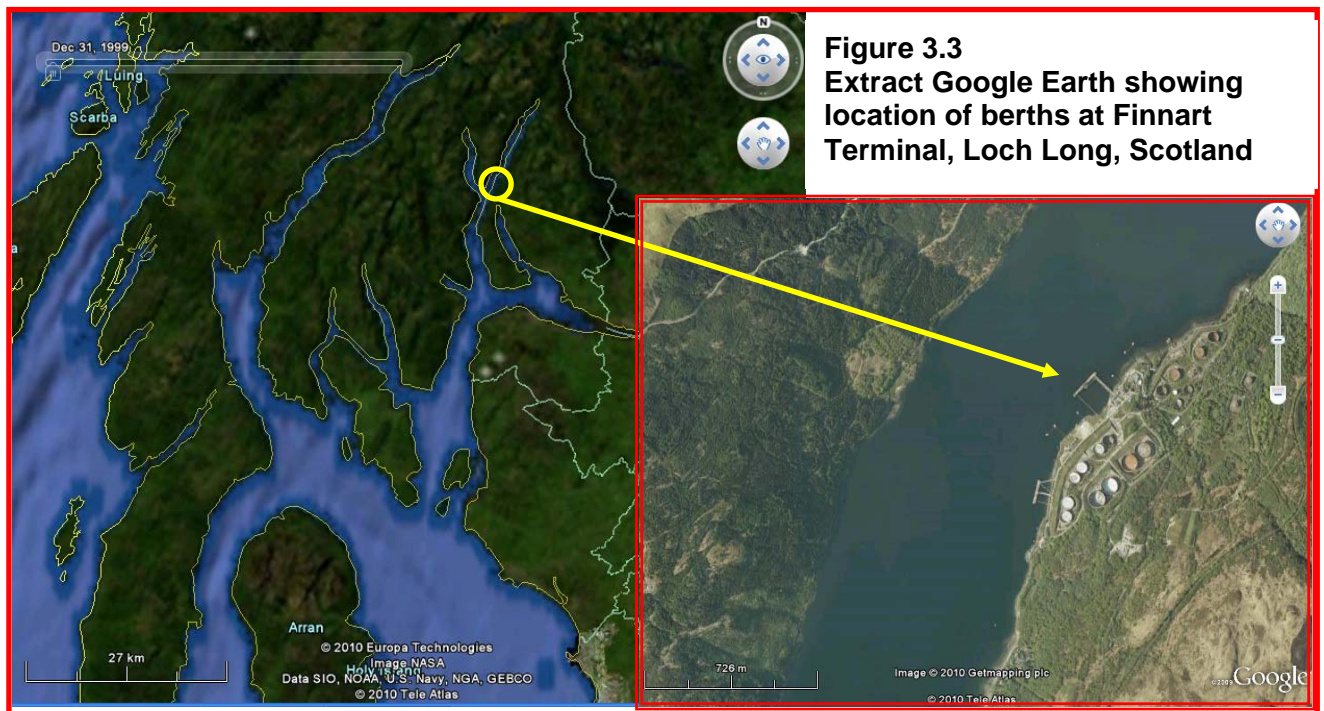
3.2 In respect of the difficulty of berthing Brolsma describes all of the berths in both Rotterdam and Finnart as "Curve 3 : Easy berthing exposed" and indicates that this is the same as the Baker designation of "Moderate Berthing, exposed" for berths at Mina Al Ahmadi, Kuwait . It can be seen from the Google image of the Mina Al Hamadi berths (Figure 3.1 below) that these berths are exposed to the full fetch of the Arabian Gulf and can take considerable waves on occasion combined with a moderate tidal current; the designation 'Moderate Berthing Exposed' would appear to be applicable.





Considering the berths at Europort, Rotterdam (Fig 3.2 above) then the berths are generally protected from wave activity with little current so their location would normally be described as sheltered from the sea, but exposure to wind may cause some difficulty in the approach to the berths on occasion. Certainly this would be the case for the Eemhaven Container Berths further up river (refer Figure 3.2) and also for the Finnart Tanker Terminal in Scotland, which is in a deep sea loch (refer Figure 3.3). This highlights the very subjective nature of the assessment of berthing difficulty and exposure of berth. No examples of berths matching the definitive descriptions are provided by EAU, PIANC or BS 6349 although the EAU description does indicate that a heavy sea would be associated with the berth for curve 3. With the benefit of

hindsight it may have been better for Brolsma to place this data on a new curve which covered estuary and river situations which were not really considered in Baker's original chart. Alternatively the data might have been assigned to the "Difficult Approach, sheltered" category of the Baker chart, but as no major port owner is likely to want to assign any difficulty to its berths it would be understandable why this option might have been disregarded. In the event Brolsma super-imposed results onto Baker's "moderate berthing exposed" description and adjusted the title to "easy berthing exposed" thereby including data from the smaller vessels used in the Mina Al Hamadi berths; arguably this change compromised the validity of the data.



- 3.3 As stated above, all of the data provided by Brolsma and Saurin was for berths assessed by Brolsma to be Navigation Condition 3 (Easy Berthing Exposed). The 251 berthings recorded by Brolsma and Saurin's papers (ref.11&10) were for vessels between 36,000 and 265,000 DWT, of which 87% were tankers. Therefore only the section of curve 3 for vessels above 36,000DWT can be considered to be based upon actual data from Rotterdam/Finnert. The remainder of the curve 3 for the smaller vessels is based upon extrapolations of data from the 1953 Baker paper for Mina Al-Ahmadi which reported on 25,000DWT vessels berthing at 22.5cm/sec.
- 3.4 Brolsma's paper contains no information on how curves 1, 2, 4 and 5 have been derived. The only case which can be used to verify these curves is the Navigation Condition 5 (Difficult exposed) Heysham case, for which the Baker paper anticipated 0.38m/s for a 10,000GRT (about 15,000DWT) vessel, but Brolsma's curve 5 gives a

figure of 0.47m/s for this vessel. This suggests that the Brolsma curves may be conservative for smaller vessels at exposed berths.

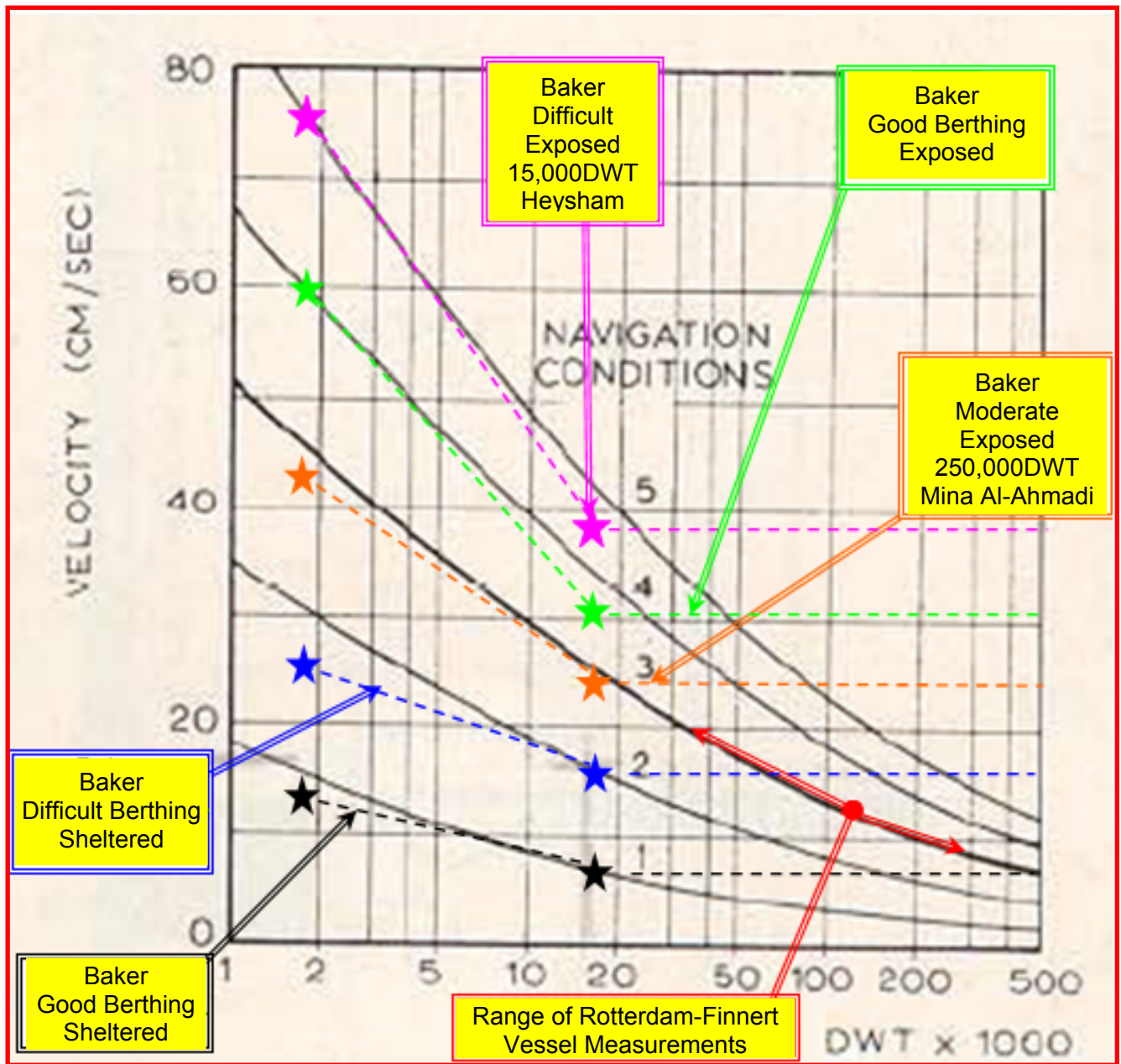


Figure 3.4 showing Brolsma's 1977 Fig. 11 curves overlaid with Baker Chart Values

3.5 In Figure 3.4 above the Brolsma curves have been overlaid with the Baker Chart using an approximate conversion from the GRT (GT) values to DWT which show a reasonable fit. However, given the very limited data used by Baker to derive his curves, and the lack of information about the basis of the other curves, the validity of every curve except that part of curve 3 for vessels between 36,000 and 285,000 DWT should be considered as being unverified.

3.6 The following additional facts need to be noted:

- The Brolsma curves are all based on tug assisted berthings;
- The energy equation used by Brolsma required the deadweight tonnage of the vessel to be used in the equation.

4.0 BROLSMA'S CURVES WITHIN BS6349 Pt. 4

4.1 The British Standard Code of Practice relating to the design of fender systems is BS6349:Pt4 1994. This BS sets out guidelines for berthing velocities at a normal berth but also contains a reference to Table 6 in the now superseded BS6349 Pt.1 1984. The relevant sections of these two standards are reproduced in Figures 4.1 and 4.2 below:

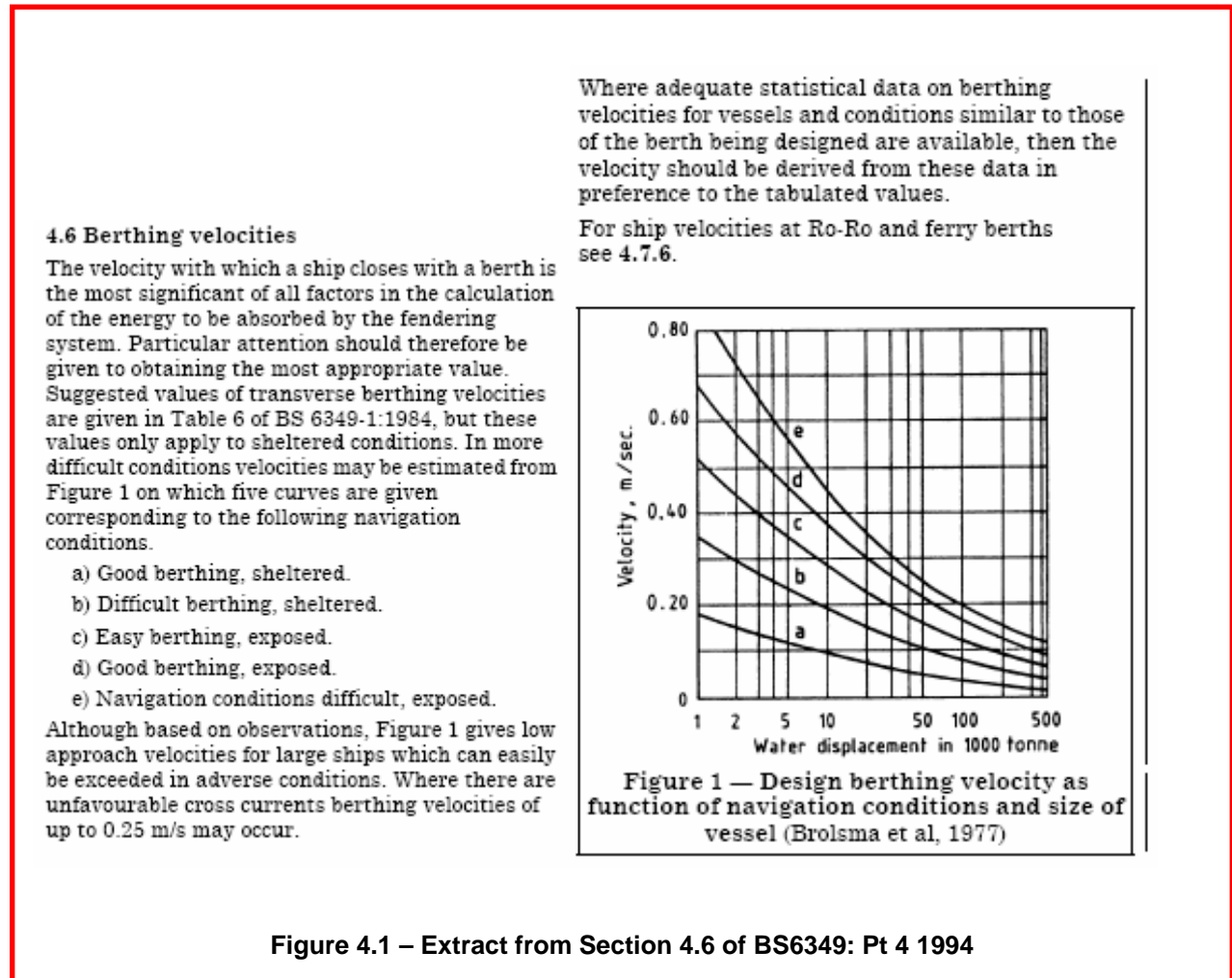


Table 6 — Suggested transverse berthing velocities

Displacement t	Transverse velocity m/s
Up to 2 000	0.30
2 000 to 10 000	0.18
10 000 to 125 000	0.16
Over 125 000	0.14

Figure 4.2 – Extract Table 6 from Section 41.5 of BS6349: Pt 1 1984
Stated to be for Sheltered conditions (not reproduced in 2000 version)
accompanying text indicates use of tugs on vessels over 10,000t displacement

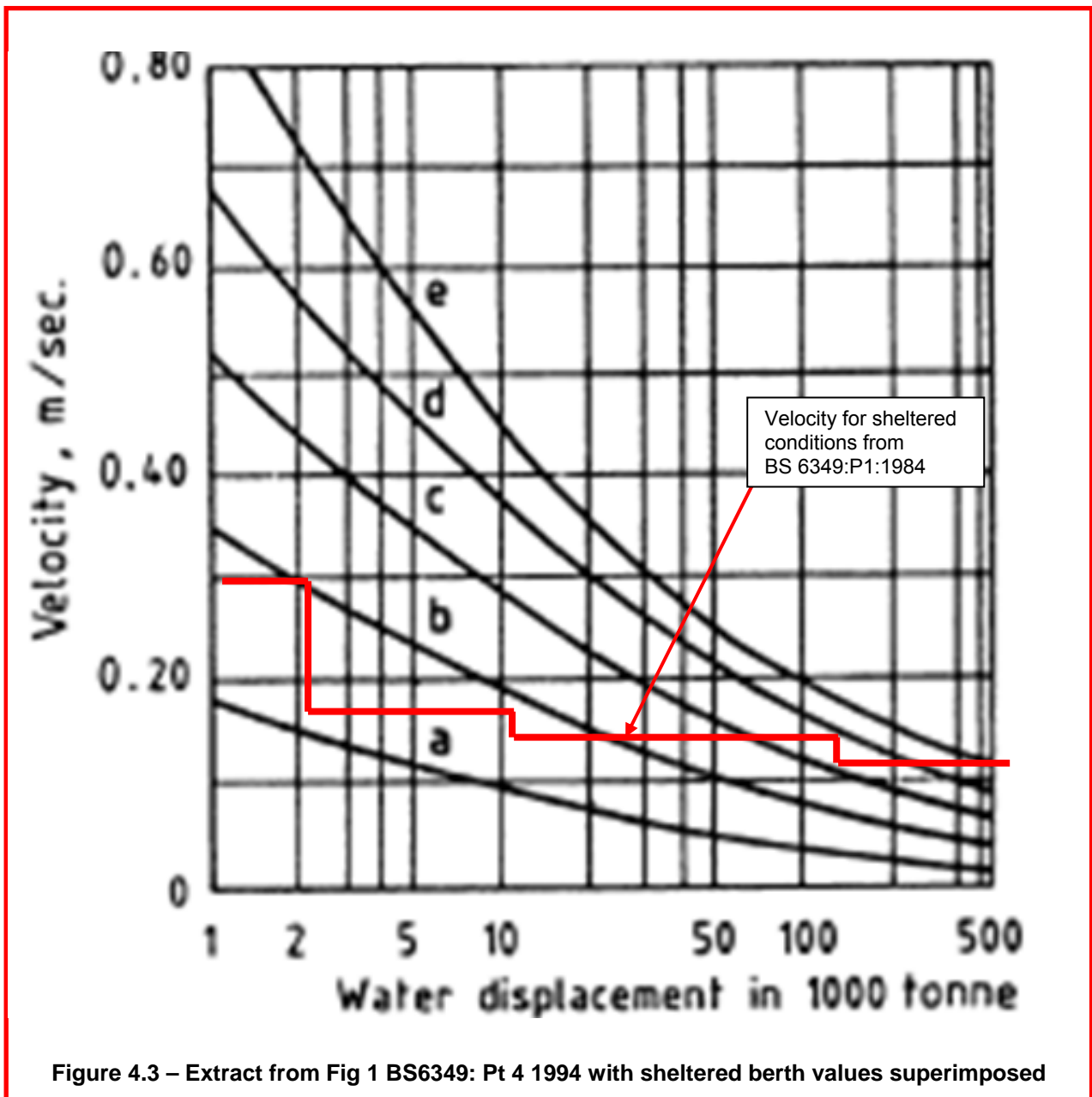


Figure 4.3 – Extract from Fig 1 BS6349: Pt 4 1994 with sheltered berth values superimposed

4.2 Comparing Brolsma's curves from his 1977 paper (reproduced in Figure 2.3 of this paper) with the Fig. 1 from BS6349 Pt 4 1994 (reproduced in Figure 4.1) the following differences can be seen :-

- the x-axis on the Brolsma 1977 curves is for DWT whereas the x-axis for BS 6349:Pt4 Fig 1 is Water Displacement in tonnes. There is no definition of Water Displacement given in BS6349 although generally this is assumed to be simply the displacement weight of the vessel. The reasoning behind this change appears to have been that total energy imparted to the fenders is based upon the whole mass of the vessel moving towards the berth rather than just the cargo weight; although DWT and Displacement tonnage are reasonably close for tankers for other vessels the DWT can be considerably less than the displacement;

- the curves in BS6349 Pt 4 Fig.1 appear nearly identical to the 1977 Brolsma curves and if this is indeed the case and no adjustment has been made to the horizontal axis to convert from DWT to Displacement then lower velocities will be predicted than those generated in the original Brolsma curves for the same vessel. To investigate this we have considered 3 examples :-
 - On curve c in Fig.1 BS6349 the design approach speed of 11cm/sec would be equivalent to a tanker with displacement of 155,000t. Converting this displacement tonnage using the standard vessel tables in EAU 1990 publication gives close to 125,000 DWT. From the Brolsma curves (Fig 10) the approach velocity would be 12.5cm/sec (refer red lines Figure 4.4 below). Using the BS 6349 Pt 4 Fig 1 value results in nearly 30% less calculated berthing energy;

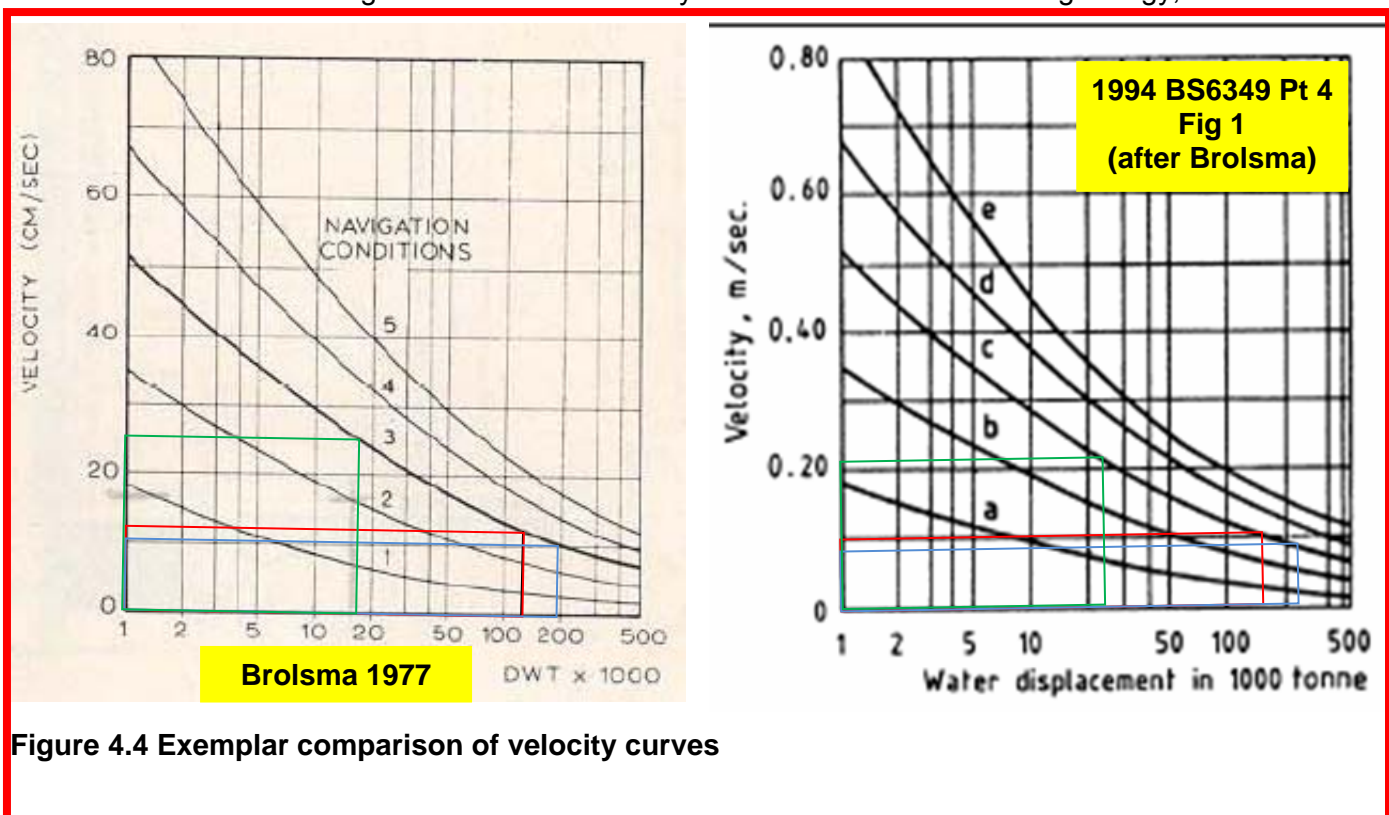


Figure 4.4 Exemplar comparison of velocity curves

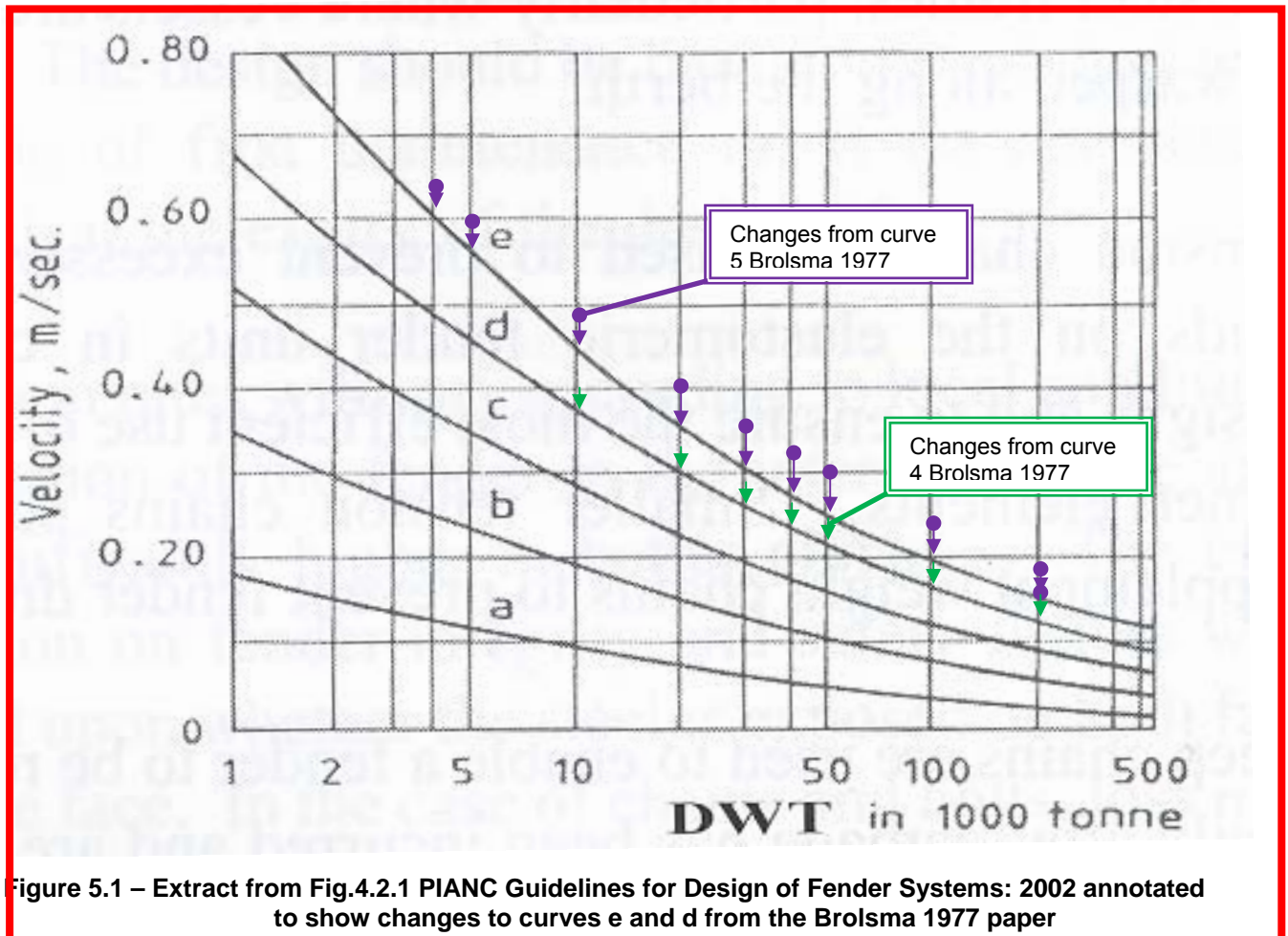
- A tanker of 200,000DWT would, from EAU 1990 table, displace around 240,000t. Fig 1 BS6349 gives an approach speed of 9cm/sec on curve c, whereas the Brolsma 1977 curves give an approach speed of 10cm/sec (refer blue lines Figure 4.4). Using the BS value would result in almost a 23% decrease in calculated berthing energy;
- Looking at the same curve c for a 25,000t displacement vessel which is approximately 17,000DWT, the Brolsma curve 3 gives a design speed of about 25cm/sec while the BS6349 Fig 1 curve c gives a speed of 0.21cm/sec (refer green lines Figure 4.4). Using the BS value would result in almost a 40% decrease in calculated berthing energy.

- in respect of the d and e curves in Fig. 1 the extreme end vessel sizes appear to be the same as those for the 1977 Brotsma curves 4 and 5 respectively, but the mid-range vessel size velocities have been reduced, e.g. for a 30,000tonne vessel curve d =0.3m/s but 1977 Brotsma curve 5 value is 0.35m/s;
- in respect of the a and b curves in Fig. 1 the extreme end vessel sizes appear to be the same as those for the 1977 Brotsma curves 1 and 2, but the mid-range vessel size velocities have been slightly increased e.g. for a 30,000tonne vessel curve d =0.125m/s but 1977 Brotsma curve 5 value is 0.13m/s.

4.3 It appears that the compilers of the BS6349 version of the Brotsma curves may have made an error and the logic behind simply changing the X-axis from DWT to Displacement for curve c without modifying the velocities appropriately is unclear. The BS compilers' rationale for altering the mid-range vessel size velocities also needs justification.

5.0 BROLSMA'S CURVES WITHIN PIANC GUIDELINES FOR DESIGN OF FENDER SYSTEMS 2002

5.1 The PIANC publication at first inspection appears to reproduce the Brolsma 1977 curves without adjustment from the original text in that DWT is used in the horizontal axis.



5.2 However values for the curves 4 and 5 have been reduced from the 1977 Brolsma values and there is no reference as to why this change was made, although there is a note in the text which indicates that even these reduced figures are considered conservative. Given the uncertainty as to the basis for curves a, b, d and e (refer section 3) it is unsurprising that Brolsma's original velocity values have been challenged; but without adequate references as to the basis for the changes these curves must also be considered unverified.

5.3 In the title of PIANC's Fig. 4.2.1 it is stated that the velocities are the design berthing speed (mean values) and within the text it is stated that the mean speed is equivalent to the 50% confidence limit. This statement is at variance with Brolsma's paper, which

uses extreme probability to generate the maximum berthing speed considering the maximum readings from a large number of berthings (possibly 3,000).

- 5.4 For example considering category 3 “easy berthing exposed” Brotsma's curves suggest, for a 125,000 DWT vessel, that the design velocity is 12.5cm/sec and for a 265,000DWT ship 9cm/sec, with the 200,000DWT ship at 10cm/sec as stated in the paper. Referring back to Brotsma's Fig 10 (refer Figure 2.2 above), the velocity for the 265,000DWT tanker would be associated with a 1 in 1000 berthing event but the 125,000DWT tanker velocity would be associated with a more frequent event say 1 in 900. There is therefore some doubt as to frequency of event which Brotsma's curves represent although it appears to be of the order of 1 in 1,000 berthings or 99.9% confidence.
- 5.5 PIANC appear to recommend a decrease to the berthing velocities used for the more exposed berths, whilst seeking to make designers increase all the other velocities by the statement that their velocity curves represent a fifty percent confidence limit.

6.0 SUMMARY AND CONCLUSIONS

- 6.1 Brotsma's curves for berthing velocity have been use by designers of fendering systems for a number of decades however, with the exception of the curve for 'easy, exposed' berthing the curves appear to be based on very little statistical data. Subsequent alterations to the curves made by British Standards and PIANC, which are without supporting explanation, cast further doubt on the curves' accuracy.
- 6.2 The statistical basis for the curves is not only limited it is also dated and modern ships are much more manoeuvrable than ships of half a decade ago. In particular Brotsma's assumption that ships over 10,000DWT would have tug assistance is no longer valid; today twin screw ships of up to 30,000DWT with powerful bow thrusters regularly berth without tug assistance.
- 6.3 An updating of Brotsma's curves is therefore long overdue; the first requirement is the gathering of as wide range of data as is practical for different ship types, sizes and berth exposures. Much of this data will already be held where either ships or berths have been fitted with equipment for measuring berthing velocity. We appreciate that some ship owners consider this data to be confidential but we hope they will make their records available to a learned body such as PIANC or BSI for the general benefit of the industry.

6.4 BIBLIOGRAPHY

No	Reference	Title
1	BS6349 - 4 : 1994	Marine Structures : Part 4: Code of Practice for Design of Fendering and Mooring Systems
2	BS6349 – 1 : 2000	Marine Structures : Part 1: Code of Practice General
3	BS6349 – 1 : 1984	Marine Structures : Part 1: General Criteria
4	EAU 1990 6 th Ed.	Recommendations of the Committee for Waterfront Structures, Harbours and Waterways
5	PIANC Fenders 2002	“Guidelines for the Design of Fenders:2002” Report of Working Group 33 of the Maritime Navigation Commission.
6	Heysham ICE 1948	“The Heysham Jetty” ICE Paper 1948 by Prof. Arthur Lemprière Lancy Baker
7	Mina Al-Ahmadi ICE 1952	“Oil Loading and Cargo Handling Facilities at Mina Al-Ahmadi, Persian Gulf” 1952 ICE paper by McGowan, Harvey and Lowden
8	Little ICE 1952	“Some Designs for Flexible Fenders” ICE Maritime Paper 1952 by Donald Hamish Little
9	Baker I.N.Congress Rome 1953	1953 International Navigation Congress in Rome Paper SII-Q2 Prof. Arthur Lemprière Lancy Baker
10	Saurin 1963	“Berthing Forces of large tankers” 6 th World Petroleum Congress, Frankfurt B.F.Saurin
11	Brotsma PIANC 1977	“Paper on Fender Design and Berthing Velocities” PIANC 1977 Leningrad by Ir.J.U.Brotsma, Ir J.A.Hirs and Ir. J.M. Langeveld