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Recommendations for berthing velocity in PIANC WG211

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With the preparation and development of the updated fender guidelines by PIANC WG211, it is evident that clear and uniform design recommendations for vessel berthing velocities need to be derived, since this is one of the most critical parameters in fender-system design. This paper outlines recommendations on how to ascertain characteristic berthing velocities for fender-system design, both in situations with and without the availability of site-specific information. The new PIANC WG211 fender design guideline advocates using site-specific information, knowledge and experience where available (for example, utilising berthing records, past service performance, vessel approach speed limits, or the input of pilots and harbour masters) when defining the characteristic berthing velocities. Acknowledging that site-specific information is not always readily available, the PIANC WG211 report also provides recommendations for berthing velocities that can be considered in such circumstances. Furthermore, this paper explains the rationale behind the proposed berthing velocity table, which will serve as a valuable resource in fender-system design when site-specific information is lacking. The recommended characteristic berthing velocities in this study are carefully derived, taking into consideration the berthing velocities recommended in various design guidelines, including PIANC WG33, PIANC WG145, the German EAU2020, BS6349, the Spanish ROM, Japanese OCDI, Indian Standard IS4651, American UFC and MOTEMS. Additionally, this paper incorporates insights from recently published and unpublished berthing velocity records from the United States, Northeast Europe and Korea. The comprehensive examination of available information prompted a reassessment of some historically embedded hypotheses within the fender industry. The key findings resulting from this study significantly contribute to the design and assessment of fender systems. In essence, this paper underlines the crucial role of site-specific information and experience in determining characteristic berthing velocities. Practical recommendations are provided for scenarios where such information is unavailable, emphasising the importance of monitoring and adopting site-specific velocities as effective measures to optimise fender designs.. This approach aims to bridge the gap between theoretical considerations and practical applications in the maritime engineering domain, offering valuable insights for engineers and practitioners involved in fender-system design and assessment.

Keywords: Fenders, Berthing velocity, PIANC WG211

Introduction

Fender systems installed on berthing facilities play a critical role in accommodating vessel berthing, mooring, and loading operations. Ueda et al. (2010) emphasised the significance of berthing velocity as a crucial design parameter, influencing the energy associated with berthing vessels. Despite this, the berthing velocity curves outlined in PIANC WG33 (2002), established during the 1970s by Brolsma et al. (1977), raise concerns regarding their validity and suitability for the present-day modern fleet of vessels.

The proposed mean design values of berthing velocities, also known as 'normal berthings', represent velocities with a probability of exceedance of 1/3000 for each berthing maneuver (Fig. 1). Since their original publication, Brolsma's velocity curves have been reproduced, slightly modified, and incorporated into PIANC WG33 (2002) and BS6349-4 (2014). Additional recommendations from German waterfront structures (EAU 2020), Spanish ROM (1990), and California's Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS), UFC (2017) and the Indian Standard IS4651 also provide guidance on 'characteristic values' of berthing velocity.

Notably, in the EAU 2020, berthing velocities for large seagoing vessels, with a Deadweight Tonnage (DWT) exceeding approximately 50,000 tonnes, are assumed to be independent of vessel size and type and are categorised under different navigational conditions such as favourable, normal, and unfavourable (Fig. 1). The Japanese OCDI (2010) presents mean berthing velocities, suggesting that the probability density function of berthing velocity records follows a Weibull distribution, which was confirmed by Roubos et al. (2017) and PIANC WG145 (2022).

Since the berthing velocity of a vessel is the critical parameter in the design of fender systems, PIANC

WG145 has undertaken data gathering and publication of berthing records for vessels with a DWT exceeding 30,000 tonnes. This led to the identification of two distinct categories of navigational conditions, namely Type A (moderate) and Type B (unfavourable), as illustrated in Figure 1. The comprehensive study conducted by PIANC WG145 concluded that berthing velocity is significantly influenced by the berthing policy, encompassing factors such as the type of berthing, the experience of captains/pilots, and the use of tug assistance or berthing aid systems.

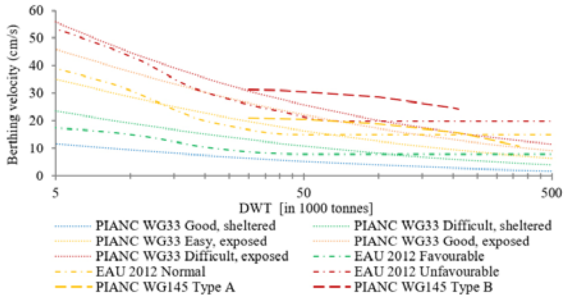

Figure 1 Berthing velocity curves presently in use (Roubos et al, 2022)

The data collected across the range of vessel sizes studied challenges the historical assumption that berthing velocities are inherently related to vessel dimensions (PIANC WG145). Furthermore, existing design guidelines, where berthing records are available, lack explicit recommendations on the statistical examination of berthing velocities. Consequently, it is unclear for designers how the outcomes of field observations should be integrated into fender-system design.

This paper explains the underlying rationale behind the recommendations for characteristic berthing velocities incorporated in PIANC WG211 (2024). The paper aims to provide clarity on important design aspects, such as navigation conditions, berthing policies, berthing aid systems and pilot assistance in order to contribute to a more informed design approach.

Combination of Design Variables

The uncertainty associated with the berthing velocity significantly influences the variability in the calculated kinetic energy, as highlighted by Ueda (2010), making berthing velocity the most influential design variable in the computation of vessel berthing energy. In addition to berthing velocity, the other three crucial, yet less dominant, variables are the displacement of the vessel (M), the berthing angle (α) and temperature (T). Simultaneously considering the largest displacement, highest berthing velocity, and extreme berthing angle and highest temperature (T) during the fender selection process can potentially result in a significant overdesign of the fender system.

To address this concern, PIANC WG211 recommends a considered combination of characteristic variables (Table 1). The combination of these variables aims to optimise the fender selection process, preventing unnecessary overdesign while ensuring the fender system is robust enough to handle realistic and challenging berthing conditions.

Table 1 Characteristic values PIANC WG211

Design Variable	Characteristic Value
Berthing velocity (V_c)	0.02 % of probability being exceeded per berthing manoeuvre
Displacement (M_c)	Largest operational displacement of the design vessel resulting in the highest characteristic berthing energy
Berthing angle (α_c)	5 % probability of exceedance per berthing manoeuvre

Characteristic Berthing Velocity

The berthing velocity is defined as the vessel's approach velocity at the initial contact with the fender-system. PIANC WG211 recommends that the responsibility for providing the berthing velocities, using appropriate inputs, lies with the asset owner, such as the port authorities or terminal..

Whilst the mean velocity for berthing manoeuvres at a specific berth tends to be relatively low, it is important to consider velocities significantly higher than the mean during the service life of the fender. To account for these higher velocities the concept of a 'characteristic' berthing velocity is introduced that will be strongly influenced by local navigation conditions (Table 2).

PIANC WG211 emphasises the use of site-specific information and experience when defining the characteristic berthing velocity. This may involve evaluating berthing records, past service performance, or insights from pilots and harbour masters. In cases where berthing records are available, the characteristic velocity can be estimated, aiming for a 0.02% probability of being exceeded per berthing manoeuvre. It is highlighted that when the berthing frequency reaches 100 berthings per year, the characteristic berthing velocity corresponds to a return period of 50 years. This signifies a time-variant berthing velocity with a 2% probability of being exceeded during a reference period of one year, providing a robust framework for the consideration of potential variations in berthing frequency over time.

$$P(V > V_c) = 0.0002 \qquad (1)$$

A method proposed for estimating the characteristic berthing velocity (V_c) involves extrapolating a Weibull distribution fit to the berthing records (Roubos et al., 2018). This estimation is conducted irrespective of the reference period and berthing frequency. Given the probability of exceedance set at 0.02%, the characteristic berthing velocities can be determined using the following equation:

$$V_c = \lambda\left(ln\left(\frac{1}{0.0002}\right)\right)^{\frac{1}{k}} = \lambda(ln(5000))^{\frac{1}{k}} \qquad (2)$$

where V = Berthing velocity [m/s]; V_c = Characteristic value of berthing velocity [m/s]; λ = Scale parameter in Weibull distribution [m/s]; k = Shape parameter in Weibull distribution.

Transverse Velocity

In alongside berthing manoeuvres, the vessel's rotational velocity and longitudinal berthing velocity (i.e., velocity parallel to the berthing line) at the moment of impact are assumed to be insignificant. Therefore, these velocities are generally not considered in the calculation of berthing energy. However, for angular berthing manoeuvres, where the vessel exhibits both parallel and perpendicular velocity components along with rotational velocity, all these components are taken into account in the berthing energy calculation. Despite this comprehensive approach for angular berthing, it is a common practice, especially for larger vessels and to a certain extent for smaller vessels, to simplify and consider only the transverse velocity when calculating the berthing energy.

In situations where specific information about the site is unavailable, PIANC WG211 recommends using the values given in Table 3 to ascertain the characteristic berthing velocity perpendicular to the berthing line at the initial moment of contact with a fender system. It is important to note that the values provided in Table 3 are significantly influenced by the prevailing navigational conditions, as defined in Table 2. PIANC WG211 ensures a standardised method for estimating characteristic berthing velocities when site-specific information is not available, offering practical guidance for fender-system design in these circumstances.

Discussion on Proposed Berhting Velocities in PIANC WG211 in the Absence of Site-specific Information

Use of Brolsma's velocity curves:

In light of the significantly higher velocities observed under 'moderate' and 'unfavourable' navigation conditions in PIANC WG211, when compared to the Brolsma berthing velocities, the authors seek to ascertain whether a trend break in fender dimensions has occurred and whether the proposed values in PIANC WG211 (Table 3) may be deemed overly conservative.

Table 2 Description of navigation conditions in PIANC WG211 (2024).

	Navigation Conditions		
	Favourable	Moderate	Unfavourable
Vessel approach strategy	The vessel can be brought to a controlled stop during the final berthing manoeuvre; AND	Vessels cannot be brought to a controlled stop during the final berthing manoeuvre, e.g. manoeuvring onto the berth by making use of the vessel momentum; OR	The capability to control the vessels approach, even with tug assistance, is significantly affected by the environmental conditions; OR
Resources for Vessel Control (main propeller, rudder, azipods, bow/ stern thrusters, tugs, etc.)	The vessel's movement can be fully controlled using the available resources, with margin. ; AND	The vessel's movement can be controlled using the available resources; however, environmental conditions are elevated and require active/continual use of the available resources to maintain control, margin is reduced. If neither tugs nor thrusters are present, this category may apply for benign environmental conditions.; OR	Environmental forces are significant compared to the available resources for controlling the vessel's movements, approaching limits of control. If neither tugs nor thrusters are present, this category may apply for moderate environmental conditions.; OR
Currents	During the berthing process currents at oblique angles or parallel to the berth having minimal effect on the manoeuvring vessel. Current forces are small and marginally effect the efficiency of the available tug power and/or vessel propulsion; AND	During the berthing process currents are generally parallel to the berth, however, may require continuous use of elevated vessel propulsion and/or tug power to stabilise control of the vessel in its final approach. Oblique current forces are controllable by available tug power and/or vessel propulsion; OR	During the berthing process, strong currents e.g. turbulent currents, at an oblique angle or parallel that require substantial use of propulsion to control the vessel; OR
Waves	During the berthing process wave effects on both the berthing vessel and the assisting tugs are negligible; AND	During the berthing process wave effects on the berthing vessel are small, however, the effectiveness of the tug assistance may be reduced; OR	During the berthing process waves substantially influence both the berthing vessel and the assisting tugs; OR
Wind	During the berthing process wind speeds and/or windage area result in small wind forces that marginally reduce the effectiveness of the available tug power and/or vessel propulsion.	During the berthing process wind speeds and/or windage area result in moderate wind forces that reduce the effectiveness of the available tug power and/or vessel propulsion.	During the berthing process wind speeds and/or windage area result in high wind forces that substantially reduce the effectiveness of the available tug power and/or vessel propulsion.

Table 3 Characteristic berthing velocity in the absence of site-specific information (PIANC WG211, 2024)

Navigation Condition:	Favourable	Moderate	Unfavourable
Type of Vessel[a]	$V_{B,c}$ (m/s)		
Coaster	0.180[f]	0.300[e]	0.400[e]
Feeder, Handysize	0.150[b]	0.225[c]	0.300[d]
Handymax, Panamax	0.120[b]	0.200[e,g]	0.275[d]
Vehicle Carriers	0.120[e]	0.200[e]	0.275[e]
Post Panamax, Capesize (small), Aframax	0.100[b,e]	0.175[c]	0.275[d]
New Panamax, Capesize (large), Suezmax, ULCV, VLBC, VLCC, ULCC	0.100[b,e]	0.150[c,f]	0.250[d]
Cruise & Passenger Vessels	0.100[e]	0.150[e,f]	0.250[e]

a. Typical vessel dimensions: Coaster (5,000-15,000 DWT), Feeder, Handysize (15,000-42,000 DWT); Panamax, Handymax (42,000-85,000 DWT); Post Panamax, Capesize, Aframax (85,000-115,000 DWT); New Panamax, Capesize, Suezmax (115,000-170,000 DWT); ULCV, VLBC, VLCC, ULCC (>170,000 DWT). For vessels not listed in the table (e.g. LNG) use equivalent size. Although most gas tanker owners have their own global data set.
b. These recommended berthing velocities are largely based on field measurements in Rotterdam and Wilhelmshaven. (PIANC WG145, 2022). (Roubos, Gaal, Hein, Iversen, & Williams, 2022).
c. These recommended berthing velocities are largely based on the normal navigation conditions distinguished by PIANC WG 145 (PIANC WG145, 2022) and verified by WG 211 against new data sets from Poland, Korea, US and India.
d. These recommended berthing velocities are largely based on the measurements conducted in Bremerhaven. (PIANC WG145, 2022). (Roubos, Gaal, Hein, Iversen, & Williams, 2022).
e. These recommended berthing velocities are based on interviews with masters, pilots, harbour masters and experienced port engineers. The values are based on comparison with similar vessel sizes.
f. These recommended berthing velocities are based on EAU 2012 and ROM 2.0-11 (2012).
g. Some unpublished berthing records, of berths claiming to be moderate, include slightly higher velocities. BS6349 and WG 211 consider this value to be sufficient for the majority of berths.

To answer this question, an extensive collection of approximately 40 design reports from actual fender projects worldwide was examined. Surprisingly, these reports consistently did not indicate the utilisation of Brolsma's velocity curves for 'moderate' and 'unfavourable' navigation conditions. For large seagoing vessels, velocities exceeding Brolsma's curves were frequently reported, with consideration for such velocities generally arising only when berthing aid systems or port operational limits were in place. Consequently, WG211 recommends that, given a speed limit or operational constraint, the velocities listed in Table 3 may be considered to be conservative, advocating the use of speed limits as a more prudent upper bound for the characteristic velocity. Following the design report analysis, interviews were conducted with experienced fender designers in the industry. Whilst many designers are familiar with Brolsma's berthing velocity curves, most did not confirm their actual use in designing or assessing fenders under challenging navigation conditions. Notably, the interview findings align with the design considerations outlined in the examined design reports.

Despite a potential industry preference towards using Brolsma's velocity curves, PIANC WG33 suggests, in the absence of more accurate 'figures', to use the berthing velocities recommended in Spanish ROM Standard 0.2-90 (Figure 2). These velocities are commonly embedded in the national design codes of Spain and Germany. Figure 2 illustrates that Brolsma's curves recommend significantly lower velocities for large seagoing vessels compared to the Spanish ROM. Consequently, it is important to emphasise that PIANC WG33 neither provides explicit recommendations for berthing velocities nor recommends the use of the Brolsma's velocity curves.

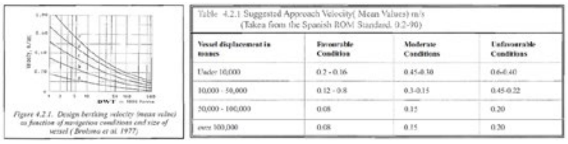

Table 4.2.1 Suggested Approach Velocity(Mean Values) m/s (Taken from the Spanish ROM Standard. 0.2-90)

Vessel displacement in tonnes	Favourable Condition	Moderate Conditions	Unfavourable Conditions
Under 10,000	0.2 - 0.16	0.45-0.30	0.6-0.40
10,000 - 50,000	0.12 - 0.8	0.3-0.15	0.45-0.22
50,000 - 100,000	0.08	0.15	0.20
over 100,000	0.08	0.15	0.20

Figure 2 Recommendations for berthing velocity in PIANC WG33 (2002).

In addition to the German EAU and Spanish ROM, the Indian Standard IS4651 (Shah et al., 2016) prescribes higher velocities for both 'moderate' and 'unfavourable' conditions, compared to Brolsma's berthing velocities. Conversely, the British Standard (BS 6349-4, 2016), MOTEMS (CBC, 2016), and UFC (2017) advocate for similar or lower velocities under 'moderate' and 'unfavourable' conditions.

Favourable navigation conditions:
For favourable navigation conditions, field records in relatively sheltered port basins highlight the need for caution when applying a characteristic berthing velocity lower than 0.10 m/s, especially in the absence of site-specific information. Generally, the members of PIANC WG211 and experienced fender designers that have been consulted appear to agree on the proposed values for 'favourable' navigation conditions outlined in Table 3. Figure 3 compares the recommended berthing velocities with measurements and recommendations of other codes and standards.

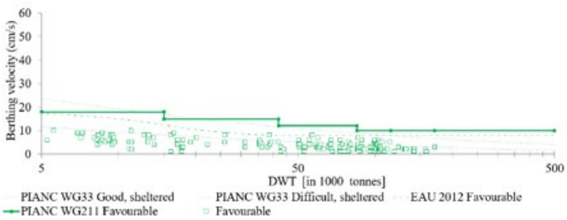

Figure 3 Comparison PIANC WG211 Favourable Moderate navigation conditions with other design codes

Moderate navigation conditions:
Initially, the authors considered the proposed values for 'moderate' to be comparatively high, particularly for large seagoing vessels. However, a comprehensive study of published data by PIANC WG145 and the actual design reports reviewed revealed that the proposed values in Table 3 align well with field observations and velocities utilised in fender design reports (Fig. 4).

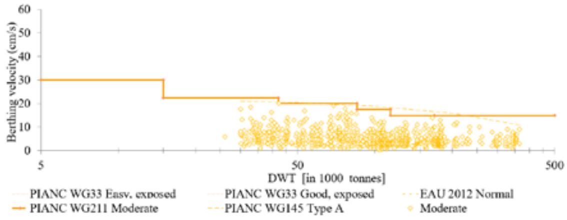

Figure 4 Comparison PIANC WG211 Moderate navigation conditions with other design codes

Moreover, confidential berthing velocity records, shared with PIANC WG211 from a container terminal in Northeast Europe and a general cargo terminal in the U.S. validated the values proposed for 'moderate' navigation conditions. Whilst the authors lack permission to disclose this confidential data, recently collected vessel data from a "sheltered Korean port with difficult docking conditions" (Cho et al., 2018; Lee et al., 2020; Kang et al., 2021) and data from a tanker berth in the U.S. (Iversen et al., 2019) also confirm the values for 'moderate' navigation conditions, see Figure 5 and Figure 6 respectively. Consequently, in the absence of site-specific information, the authors consider that the berthing velocities proposed in Table 3 are reasonable.

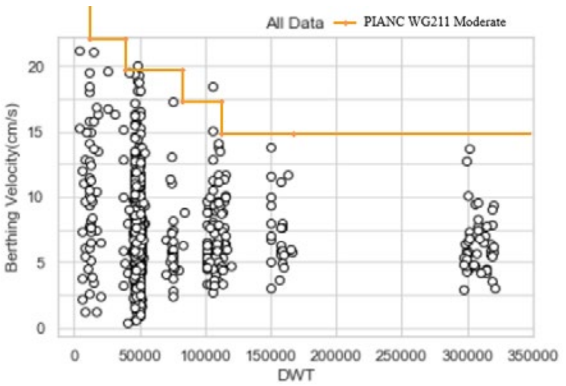

Figure 5 Comparison tanker berths Korea (Kang et al., 2021) and PIANC WG211 Moderate (2024).

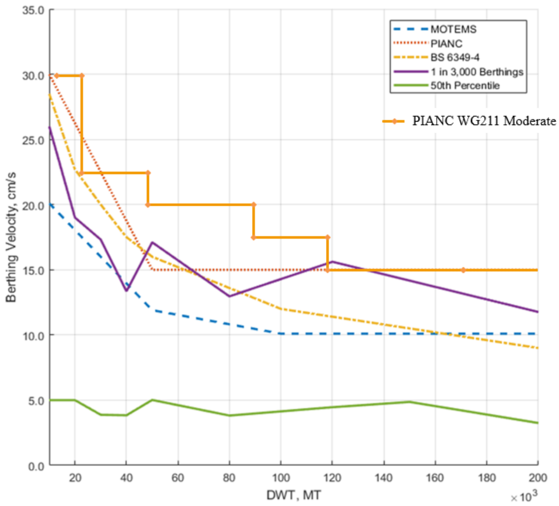

Figure 6 Comparison tanker berth USA (Iversen et al., 2022) and PIANC WG211 Moderate (2024).

Unfavourable navigation conditions:
The recommended berthing velocities for 'unfavourable' navigation conditions, primarily derived from measurements in the port of Bremerhaven (Fig. 7), align with recorded velocities of up to 0.25 and 0.26 m/s for the largest container vessels in the world (Roubos et al., 2022). However, there is a concern among several members of PIANC WG211 and BS6349 that the values proposed in Table 3 for 'unfavourable' navigation conditions may be overly conservative, potentially leading to the selection of much larger fenders. Concerns centre around the perception that the Bremerhaven berth is a unique case and might not be representative of other 'unfavourable' locations.

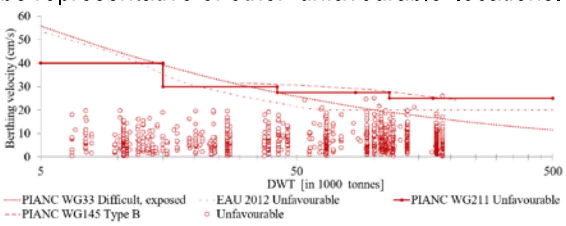

Figure 7 Comparison PIANC WG211 Unfavourable navigation conditions with other design codes

Given the absence of additional berthing velocity records for unfavourable navigation conditions, the authors conducted a study examining the actual design of fenders installed on six open island jetties in Australia (four), Afrika (one) and Brazil (one). The primary objective was to confirm the utilisation of lower velocities and ascertain whether any damage had occurred during the service life. Contrary to expectations, the study revealed that in the very exposed navigational conditions in Australia, much higher berthing energies were considered in the fender design compared to the approach of PIANC WG211 (Roubos et al., 2024). Whilst local authorities could not fully explain the rationale behind these higher energies, they suspect that past damage to one of the Australian facilities might have influenced the design approach. In Australia, other exposed berths were subjected to operational limits and specific berthing windows, such as during low tide to avoid peak currents and significant waves. In the assessed design reports for fenders on jetties located in exposed locations in Africa, measures have been implemented to mitigate the risk of hard berthing impacts, including the use of a shore-based docking system. It is important to note that PIANC WG211 does not recommend using the values proposed in Table 3 in circumstances where shore-based docking systems or operational limits are in place. Furthermore, an 'exposed' open island berth in Brazil was initially designed with a berthing velocity parameter set at 0.10 m/s. However, when examining the prevailing winds, currents, and waves in the area it was concluded that the navigation conditions align more with 'favourable' conditions, suggesting a potentially lower risk scenario for berthing operations.

Based on the available information, the authors are unable to recommend the use of lower velocities for unfavourable navigation conditions. Consequently, the preference of PIANC WG211 is to use the values recommended in Table 3 when site-specific information is unavailable or lacking, recognising the current limitations in conclusively establishing berthing velocities for 'unfavourable' conditions based on historical performance data.

Whether PIANC WG211 Results in a Trend Break

When incorporating site-specific information such as berthing records, past service performance, or input from pilots and harbour masters, the design approach recommended by PIANC WG211 generally leads to the selection of slightly smaller fender dimensions (Roubos et al., 2024a). Additionally, PIANC WG211 incorporates a method that optimises the fender system's geometry, considering the positive effects of multiple fender contacts (Roubos et al, 2024b).

In situations where site-specific information is unavailable, PIANC WG211 suggests higher berthing velocities compared to Brolsma's berthing velocity curves for 'moderate' or 'unfavourable' navigation conditions. Based on current knowledge, it appears that the fender industry does not frequently utilise Brolsma's velocity curves in these circumstances. For 'moderate' navigation conditions, a minor trend break is anticipated.

However, for 'unfavourable' navigation conditions, a more significant trend break can occur, especially in cases of single fender contact, i.e. with fenders installed on open island jetties accommodating large seagoing vessels. In the absence of risk mitigation measures and / or site-specific information, the design approach of PIANC WG211 would then result in larger fenders. Nevertheless, the number of open island berths situated in highly exposed navigational conditions seems limited globally. Typically, during berth configuration selection, the impact of wind, waves, and currents is thoroughly assessed, and if necessary, operational limits are introduced. Consequently, it is likely that only when no risk mitigation measures are implemented, some berths will be equipped with relatively large fenders based on the new PIANC WG211 design guideline. However, the majority of fenders are expected to have realistic and reasonable sizes and grades.

Conclusions

This paper discusses the backgrounds of the berthing velocity recommendations outlined in PIANC WG211, leading to the following key conclusions:

- **Underestimation by Brolsma's berthing Velocity Curves:** This study confirms that for larger seagoing vessels, the Brolsma berthing velocity curves appear to underestimate the characteristic berthing velocity for both 'moderate' and 'unfavourable' navigation conditions.
- **Recommendation for Site-Specific Information**: PIANC WG211 strongly advocates the use of site-specific information and experience, such as berthing records, past service performance, or insights from pilots and harbour masters, when determining the characteristic berthing velocity. When berthing records are available, the characteristic velocity can be estimated, aiming for a 0.02% probability of being exceeded per manoeuvre.
- **Use of Table 3 in the Absence of Site-Specific Information:** In cases where site-specific information is unavailable, PIANC WG211 recommends employing the characteristic berthing velocities presented in Table 3 for designing new fenders. It is noted that these values may be conservative, especially when berthing velocity is monitored or operational limits are in place. Under such circumstances, determining a project-specific berthing velocity is preferable.
- **Significance of Monitoring Berthing Velocity:** Monitoring berthing velocity can significantly reduce the characteristic berthing velocity. However, without a thorough evaluation of local navigation conditions, a berthing velocity limit lower than 80% of the values in Table 3 should not be considered or utilised. Nevertheless, the adopted berthing velocity limit for new or recently constructed berths is recommended to be not less than 0.10 m/s.

In summary, this paper emphasises the importance of site-specific information and experience in determining berthing velocities, while also providing practical recommendations for situations where such information is unavailable. Monitoring and adopting site-specific velocities are highlighted as effective measures for optimising fender design outcomes.

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