DESIGN VALUES FOR BERTHING VELOCITY OF LARGE SEAGOING VESSELS

**by**

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**ABSTRACT**

While ships evolve constantly, berthing velocity curves developed during the 1970s are still embedded in the design of marine structures. Associated safety factors for the design of fender systems have not been verified and validated by measurement campaigns. In this study, field observations of modern large seagoing vessels during berthing manoeuvres in Bremerhaven, Rotterdam and Wilhelmshaven were used to evaluate safety factors for berthing energy and berthing impact loads in line with the Eurocode design philosophy. Berthing velocities were examined for several types and categories of vessels at various berths and under different operational conditions, resulting in an increased understanding of the factors influencing berthing energy. Navigation conditions were accounted for by differentiating factors such as vessel characteristics, environmental conditions and berthing policy. The results show that characteristic values of berthing velocity with a return period of 50 years are in line with design recommendations in the relevant literature. Design values of berthing velocity are quite sensitive to the number of berthing operations during the service life of a marine structure. The measured berthing velocities largely depend on the general berthing regulations and local experience of pilots and navigational aids. Due to newly acquired insights, some historically embedded hypotheses will need to be reconsidered. For instance, the assumption that berthing velocities are correlated to the size of large seagoing vessels could not be confirmed based on the measurements for ships larger than 30,000 DWT. The key findings of this study are useful for the design of new berthing facilities and for the assessment of existing marine structures. It is highly recommended to update the PIANC 2002 guideline titled ‘Berthing velocities and fender design’ in the upcoming years.

1. **INTRODUCTION**

 Marine structures, such as quay walls, jetties and flexible dolphins, are required all over the world to accommodate ships’ berthing, mooring and loading operations. During the service life of a marine structure, functional requirements may change. These changes often result in uncertainty regarding the actual berthing energy of vessels and structural integrity of marine structures, especially if the size of the design vessels due to modified operational requirements increases at existing berthing facilities [15]. The current design guidelines for assessing berthing energy, such as PIANC [17], British Standards [4], EAU [6] and Spanish ROM [13], propose to use safety factors for abnormal berthing. These recommendations are not based on a semi-probabilistic design method and do not include partial factor analyses of individual parameters. Hence, it is not clear how resultant fender forces derived from such analyses should be applied in accordance with the design philosophy of the Eurocode Standards [10].

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Metzger et al. [9] stated that load demands on berthing structures are not well understood due to a lack of information about berthing parameters. Therefore, there is a strong need to determine corresponding design values for these parameters and partial safety factors by using field observations. Although design guidelines recommend to collect comprehensive berthing records, data are mostly not available. Ueda et al. [19] showed that berthing velocity is the crucial design parameter in defining berthing energy. The port authorities of Bremerhaven [7] and Rotterdam [14] therefore decided to start a measurement campaign on berthing velocity in order to evaluate and validate the performance of existing berthing facilities and the design guidance of EAU and PIANC. The objective of this campaign was to validate the berthing velocity curves given by the EAU and PIANC, presented in Figure 1, for modern vessels.

Figure 1: Berthing velocity curves of PIANC 2002 (Brolsma curves [2]) and EAU 2012 as a function of navigation conditions and vessel size [14]

The berthing velocities given by the PIANC and the EAU ‒ EAU values are based on the ROM recommendations ‒ represent berthing velocities with a return period of 30 and 50 years, respectively [1] ,[15]. Since the development of the Brolsma curves in the 1970s, new measurements of berthing velocities have become available [7], [14], [20]. These studies resulted in a better understanding of various factors influencing berthing velocity. The most important conclusion was that the collected data do not confirm the historical assumption that berthing velocities are strongly related to ship dimensions of large seagoing vessels. Where berthing records are available, existing design guidelines do not provide explicit recommendations with regard to the statistical examination of berthing velocities. It is therefore mostly unclear how the results of field observations could be incorporated in the design process.

This paper aims to provide guidance on the use of field observations in the assessments of marine structures. It should be noted that ship collision impact is not taken into consideration in this study [18]. During the study, recently recorded field observations of berthing velocity in the ports of Bremerhaven, Rotterdam and Wilhelmshaven were used to determine theoretical design berthing velocities and corresponding partial safety factors in accordance with the Eurocode Standard [10].

1. **GENERAL PRINCIPLES OF BERTHING ENERGY AND IMPACT**

The objective of this section is to elucidate the definition of berthing energy *E* and the associated resulting berthing impact load *F*. The berthing energy is generally calculated using the following equation:

|  |  |  |
| --- | --- | --- |
|  |  |  |

in which:

*Ekin*  Kinetic energy [kNm]

*M*Mass of vessel/water displacement [tonnes]

νTotal translation velocity of centre of mass at time of first contact [m/s]

*Cm*Virtual mass factor [-]

*Cs*Ship flexibility factor [-]

*Cc*Waterfront structure attenuation factor [-]

*CE*Eccentricity factor [-]

PIANC berthing velocity curves are widely used by the industry to determine the ‘normal’ berthing energy. Given a normal berthing energy, a berthing impact factor *Cab* is applied to derive an abnormal berthing energy. An overview of abnormal berthing factors in literature is given in Table 1.

|  |  |  |
| --- | --- | --- |
|  |  |  |

in which:

*Eabnormal*  Abnormal berthing energy [kNm]

*Cab*  Abnormal berthing factor [-]

*Enormal*  Normal berthing energy [kNm]

**Table 1: Abnormal berthing factor *Cab* [-] in literature.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Ship type** | **Size** | **PIANC [17]** | **EAU [6]** | **BS 6349-4 [4]** | **ROM [13]** | **OCDI [16]** | **EN 1990 [10]** |
| Tankers | Largest-Smallest | 1.25-2.00 | 1.25-2.001 | - | 2.00 | - | - |
| Bulkers | Largest-Smallest | 1.25-2.00 | 1.25-2.001 | - | 2.00 | - | - |
| Container | Largest-Smallest | 1.50-2.00 | 1.50-2.001 | - | 2.00 | - | - |
| General Cargo | - | 1.75 | 1.751 | 1.502 | 2.00 | - | - |
| RoRo, ferries | - | ≥ 2.00 | ≥ 2.001 | - | 2.00 | - | - |
| Tugs, workboats | - | 2.00 | 2.001 | - | 2.00 | - | - |
| LNG, LPG | - | - | - | 2.00 | 2.00 | - | - |
| Island berth | - | - | - | 2.00 | 2.00 | - | - |

1) Based on PIANC 2002 [17]

2) Continuous quay handling conventional cargo vessels

The berthing impact load *F* to which a marine structure is subjected is a function of the kinetic energy absorbed by the berthing system and of its deformation characteristics *δ* [13], [15]. Given a certain berthing velocity, the resulting berthing impact load largely depends on the stiffness of the marine structure and the soil conditions [13]. When significant softening occurs between a characteristic berthing impact load (service limit state) and a design berthing impact load (ultimate limit state), a reduction of the partial factor could be considered, for instance in the design of flexible dolphins equipped with cone fenders. The effect of softening on energy absorption due to linear and non-linear behaviour is illustrated in Figure 2. When the hatched areas below the linear (left) and non-linear (right) load-deflection curve are equal, the design berthing impact load *Fd* is lower in the case of softening.

|  |  |  |
| --- | --- | --- |
|  |  |  |

in which:

*F*  Berthing impact load [kN]

*δ*Deflection of berthing structure [m]

*Fd*

*Fd*

*Ekin;linear*

Deflection *δ*

Deflection *δ*

Berthing impact load *F*

Berthing impact load *F*

*Ekin;non-linear*

**Figure 2: Linear system (left) and non-linear system with significant softening (right)**

1. **MATERIAL & METHODS**

**3.1 Data collection**

Approximately 1950 records of berthing operations were collected in Germany (#1393) [7] and the Netherlands (#555) [14]. Various types of vessels, berths and navigation conditions were represented in the datasets. All berthing records were collected in well-organised port environments, namely Bremerhaven (1235), Rotterdam (555) and Wilhelmshaven (158). An overview of the collected data is given in ***Table 2***. The berths in Bremerhaven were classified as exposed and berthing operations seemed to be influenced by strong tidal currents; the tidal range is typically about 3.8 m with tidal currents of 2.5–3.5 knots. All other berths were classified as sheltered.

***Table 2: Overview of field observations of berthing velocity [15]***

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ship type  *[-]* |  | *n*  *[-]* | *v*µ  [cm/s] | *v*max  [cm/s] | Berth type  *[-]* | Berthing aids  *[-]* | Wind  *[-]* | Waves  *[-]* | Current  *[-]* |
| Container | □ | 177 | 4.0 | 10 | Closed quay | None | High | Sheltered | Low |
| Tankers | ○ | 329 | 4.3 | 12 | Jetty / dolphin | PPU/ docking system | High | Sheltered | Low |
| Bulkers | ◊ | 144 | 4.4 | 13 | Closed quay | Portable pilot units | High | Sheltered | Low |
| Container | □ | 1235 | 6.6 | 26 | Closed quay | None | High | Exposed | High |

**3.2 Partial factors**

A probabilistic study by Ueda et al. [19] showed that the contribution of berthing velocity to the uncertainty in kinetic berthing energy was approximately 85%, indicating that safety factors should be applied predominantly to berthing velocity. When defining kinetic berthing energy, berthing velocity is assumed to be the only stochastic variable in Equation (1). The partial factors derived in the present research were therefore applied to a characteristic value of berthing velocity. The partial factor *γv* was defined as the ratio between a design berthing velocity *vd* and a characteristic berthing velocity *vk* [15]:

|  |  |  |
| --- | --- | --- |
|  |  |  |

in which:

*γv*  Partial factor for berthing velocity [-]

*vd*Design value of berthing velocity [cm/s]

*vk*  Characteristic value of berthing velocity [cm/s]

OCDI [16] and Roubos et al. [14] statistically examined field observations of single berthing velocities. Both studies showed that a distribution fit of the low-probability tail was closer to a Weibull distribution *F(x;λ,k)* than to a normal or lognormal distribution. In the present study, the characteristic and design values of berthing velocities were therefore described using a Weibull distribution fit on the basis of maximum likelihood estimation. Assuming that the number of berthings per year *n* and the required target reliability *βd* during a certain reference period *tref* are known, characteristic *vk* and design berthing velocities *vd* were established by extrapolating the Weibull distribution fit.

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  |  |  |

in which:

*λ* Scale parameter Weibull distribution [cm/s]

*k* Shape parameter Weibull distribution [-]

*TR* Return period [years]

*n* Number of berthings per year [-]

*αS*Sensitivity factor for dominating load/solicitation [-]

*βd*Target reliability index [-]

*Φ-1*Inverse of standard normal distribution function [-]

*tref*Reference period [years]

In the present study, characteristic berthing velocities had a return period of 50 years representing a time-variant berthing velocity with a 2% probability of being exceeded during a reference period of one year. This is in accordance with the recommendations of the ROM [13] and EAU [6], whereas the Brolsema curves [2] in PIANC 2002 [17] and the BS2394 [4] represents a reference period of 30 years. For comparison, the number of berthings was set at approximately 100 berthings of a design vessel per year. This is similar to the underlying assumption of the berthing velocity curves derived by Brolsma et al. [2].

A design value for berthing velocity is typically selected such that a marine structure has sufficient reliability (or a sufficiently low probability of failure). Target reliability indices *βd* and importance factors *αS* are generally prescribed in design codes, such as Eurocode Standards [10] and ISO 2394 [8]. The target reliability indices for the different Reliability Classes RC1, RC2 and RC3 are 3.3, 3.8 and 4.2, respectively. For non-dominant and dominant loads *αS* are is typically 0.4 and 0.7, respectively [5], [8].

When establishing extreme berthing velocities from field observations, the size of the datasets was of significant importance, because extreme berthing velocities are influenced by the fit of the low probability tail of an extreme value distribution to field observations. In the present study, three large datasets were developed, namely ‘All tankers’, ‘All sheltered’ and ‘All exposed’. The dataset of all tankers is a subset of the dataset all sheltered and represents the use of berthing aid systems, such as portable pilot units (PPU) and fixed shore-based laser docking systems. The use of berthing aid systems could reduce the probability of extreme/ uncontrolled berthing events. Further, the available data were subdivided into sheltered and exposed navigation conditions. An overview of the datasets is given in Table 3. The reader is referred to the studies of Hein [7] and Roubos et al. [15] for further details.

**Table 3: Large datasets**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Large datasets**  **[-]** | *n*  **[-]** | ***v*µ**  **[cm/s]** | **λ**  **[cm/s]** | **k**  **[-]** | **Berth type**  **[-]** | **Berthing aids**  **[-]** | **Wind**  **[-]** | **Waves**  **[-]** | **Current**  **[-]** |
| All tankers ○1 | 392 | 4.6 | 5.2 | 2.69 | Open | PPU/dock. system | High | Sheltered | Low |
| All sheltered ∆ | 713 | 4.4 | 4.9 | 2.28 | Mixture | Mixture | High | Sheltered | Low |
| All exposed □ | 1235 | 7.1 | 7.4 | 1.61 | Closed | None | High | Exposed | High |
| All data | 1948 | 6.6 | 6.4 | 1.57 | Mixture | Mixture | High | Mixture | Mixture |

1) Dataset is a subset of all sheltered

1. **RESULTS**

**4.1 Extreme berthing velocities**

In this study the characteristic and design berthing velocities were derived by direct interpolation of a Weibull distribution fit to large datasets of Table 3, and hence the associated partial factors were determined. The results are given in Table 4.

**Table 4: Extreme berthing velocities individual vessel classes and partial factors in accordance with reliability classes of EN1990 [15]**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | ***kDWT*** | | | ***n***1 | ***max***2 | | **Extreme berthing velocities[ cm/s]** | | | | | | | | | | | **Partial factors [-]** | | |
| ***Reliability class*** |  | |  | | |  | | ***vk*** |  |  | |  | ***RC1*** | | ***RC2*** | ***RC3*** | | ***RC1*** | ***RC2*** | ***RC3*** |
| ***TR* [Years]** |  | |  | | |  | | **50** | **100** | **475** | | **1000** | **4750** | | **12,500** | **38,250** | |  |  |  |
| All tankers ○ | 60-319 | 932 | | | | 12 | | 11.5 | 11.8 | | 12.6 | 12.9 | | 13.5 | 13.9 | | 14.3 | 1.17 | 1.20 | 1.24 |
| All sheltered ∆ | 7-365 | 713 | | | | 13 | | 12.6 | 13.1 | | 14.0 | 14.4 | | 15.2 | 15.7 | | 16.3 | 1.21 | 1.25 | 1.29 |
| All exposed □ | 7-195 | 1235 | | | | 26 | | 26.4 | 27.7 | | 30.4 | 31.6 | | 34.1 | 35.6 | | 37.2 | 1.29 | 1.34 | 1.41 |
| All data | 60-319 | 1948 | | | | 26 | | 25.0 | 26.3 | | 29.1 | 30.4 | | 32.9 | 34.4 | | 36.2 | 1.31 | 1.38 | 1.44 |

1) Number of field observations

2) Maximum measured berthing velocity

Figure 3 shows that the Weibull distribution fits to the datasets of ‘all tankers’ and ‘all sheltered’ navigation conditions slightly underestimate low probability berthing velocities. This was considered acceptable, because the highest measured berthing velocities were caused by fairly conservative measurements, for example small seagoing tankers and large seagoing bulkers [14]. The dataset ‘All exposed’ contains numerous berthing velocities just below 20 cm/s [7], as well as two higher berthing velocities of 25 and 26 cm/s (Figure 3) [15].



**Figure 3: Probability of exceedance plot large datasets [15]**

**4.2 Sensitivity analysis**

When assessing design values for berthing velocity in accordance with equation (6), the effect of alternative target reliability indices, reference periods and berthing frequency could be taken into consideration. In this section the influence of these aspects on the design value for berthing velocity is presented in the next figures. Figure 4 shows the influence of the number of berthings *n*. When the number of berthings per years is equal to 10 instead of earlier assumed 100 a reduction of 7-12% in the design value was found. In accordance with NEN8700 [11] the assessment of existing structures is generally performed using an alternative reference period and target reliability index. For the reliability level for disapproval in accordance with reliability class RC1 an alternative reference period of 15 years is suggested for variable loads in combination with a target reliability index of 2.5. Figure 5 shows that a change in reference period from 50 to 15 years leads to a 5-7% decrease in the design value for berthing velocity and a change in target reliability index from 3.3 to 2.5 leads to a 4-7% decrease (Figure 6).

Figure 4: Influence of number of berthing’s per year n compared to n=100, tref=50 years and βd=3.3

Figure 5: Influence alternative reference periods tref compared to n=100, tref=50 years and βd=3.3

Figure 6: Influence alternative target reliability indices βd compared to n=100, tref=50 years and βd=3.3

Example: Suppose that the original design of a marine structure in sheltered navigation conditions is based on a berthing frequency of n=100, a reference period tref=50 years and a target reliability index of βd=3.3. During the service life the actual berthing frequency of the design vessels appeared to be n=10. If a reference period of 15 years is considered in combination with a reliability index of 2.5, the design value for the berthing velocity is approximately 20% lower compared to the original design (tref=50 years and βd=3.3). In case of exposed navigation conditions the same analysis leads to a decrease of approximately 30%.

1. **DISCUSSION**

**5.1 How to use berthing velocity records and partial factors in the design**

This section discusses how to implement field observations of berthing velocity and partial factors in structural assessments of marine structures subject to berthing impact loads. The process to derive a design berthing impact load is illustrated in Figure 7. On the left side the partial factor *γv* is applied to the characteristic berthing velocity *vk* and on the right side to characteristic berthing impact load using the suggested partial factor *γQ*by design codes and standards, such as EN 1990. The flowchart starts with the determination of a characteristic berthing velocity *vk* by using field observations.

Determine design berthing impact load ***FS= γSd Fv***

Determine characteristic berthing velocity ***vk*** based on berthing velocity records

Determine design berthing velocity ***vd = γv vk***

Determine characteristic berthing impact load ***Fk***

Determine design berthing impact load ***FQ= γQ Fk***

Determine associated berthing impact load ***Fv***

Assess characteristic berthing energy ***Ekin;k***

Assess design berthing energy ***Ekin;d***

Assess governing design berthing impact load ***Fd*** with maximum effect on marine structure

**Figure 7: Global flowchart assessing berthing impact on a marine structure [15]**

The derivation of partial factor *γv* was based on a statistical examination of comprehensive datasets of representative field observations. However, *γv* does not take uncertainty in modelling the effects of loads into account, while *γQ* complies with design codes and standards - such as EN 1990 [10], ROM [12] or BS2394 [3] - and already includes model uncertainty. In analogy with the Eurocode Standard, equation 6.2 of EN1990, an additional partial factor *γSd* ≈ 1.05 for berthing impact load *Fv* needs to be applied. It should be noted that the governing berthing impact load *Fd* depends on the type of berthing structure [15] and the values of partial factors *γv*, *γSd* and γQ. Typical values for γQ  are 1.35, 1.5 and 1.65 for RC1, RC2 and RC3, respectively.

Table 5 presents generalised partial factors for berthing velocities *γv* as concluded in this study for large seagoing vessels. It should be noted that *γv* is proportional to. For the dataset of sheltered navigation conditions, lower partial factors were found compared to the dataset of exposed navigation conditions (strong tidal currents). The use of berthing aid systems resulted in even lower design velocities and lower partial factors.

**Table 5: Partial factor *γv* for berthing velocity (*vk*) and abnormal berthing factor *Cab* for berthing energy (*Ek*) given well-organised navigation conditions**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Navigation conditions** | **Pilot assistance** | **Symbol** | **Reliability class EN 1990** | | |
| **RC1** | **RC2** | **RC3** |
|  |  |  |  | | |
| *Sheltered and monitored*1 | *Yes* | *γv* | 1.15 | 1.20 | 1.25 |
|  |  | *Cab* | 1.35 | 1.45 | 1.55 |
|  |  |  |  |  |  |
| *Sheltered* | *Yes* | *γv* | 1.20 | 1.25 | 1.30 |
|  |  | *Cab* | 1.45 | 1.55 | 1.70 |
|  |  |  |  |  |  |
| *Exposed*2 | *Yes* | *γv* | 1.30 | 1.35 | 1.40 |
|  |  | *Cab* | 1.70 | 1.80 | 2.00 |

1) Pilots are aware of the allowable berthing velocity and use berthing aid systems, such as portable pilot units.

2) Strong tidal currents.

It should be noted that Table 5 assumes the berthing impact load to be a dominate design variable (*αs*=0.7), and hence can be used in the design of quay walls, jetties and flexible dolphins. However, if berthing loads are not dominant a lower importance factor (*αs*=0.4) could be taken into consideration or for instance combinations factors in case of multiple design loads.

Another finding is that higher extreme berthing velocities were observed for manoeuvres subject to high tidal currents. However the associated berthing angels at the moment of impact were very low [7], and hence the amount of energy transferred was lower compared to the original design.

**5.2 Evaluation of partial factors**

Although existing design guidelines do not differentiate between sheltered and exposed navigation conditions, the partial factors listed in Table 5 are in the range of the recommended values in literature (see Table 6). BS 6394-4 [4] recommends using *Cab*=1.5 for situations with a low risk profile, such as berths facilitating general cargo vessels, and *Cab*=2.0 for situations with a high risk profile, such as marine structures for LNG, LPG and ferry terminals.

PIANC [17] and EAU 2012 [6] recommend applying lower abnormal berthing factors, approximately *Cab=1.25,* for large seagoing tankers and bulkers. In this study, higher abnormal berthing factors were found. PIANC seems to be aware of this fairly low reliability level and recommends using a higher confidence level for normal berthing (section 4.2.8.4 of PIANC 2002 [17] ) for berths with very low approach velocities. The higher abnormal berthing factors could be explained by an increase in target reliability index, a longer reference period and the use of shore-based docking systems in all the measurement data used by Brolsma [2]. However, the results of this study show that one should be very careful using *Cab<1.5* for flexible dolphins equipped with buckling fender systems, because almost all berthing manoeuvres result in the maximum reaction force.

PIANC 2002 and EAU 2012 suggest that there is a correlation between vessel size and abnormal safety factor *Cab*. Although berthing policy (e.g. use of berthing aid systems, pilot and tug assistance) was to some extent related to vessel size, in this study no correlation between type and size of vessel and partial factor *γv* was found.

BS 6349 [4] also recommends applying an additional partial factor to the resulting berthing impact load. The partial factors representing normal (characteristic) and design situations given in the code are 1.35 for persistent and 1.2 for transient situations. The values found were quite similar to the partial factor of exposed and sheltered navigation conditions. Although without accounting for non-linear softening, a design following BS 6349 could result in a conservative design.

1. **CONCLUSION**

This paper provided guidance on the use of field observations and partial factors for berthing velocity and loads on marine structures. However, it should be noted that the results of this study are based on observations at different ports having typical navigation conditions, i.e. Rotterdam being fully sheltered from waves and currents and Bremerhaven exposed to strong currents and slightly by waves. Fully exposed berths ‒ high swells, strong currents and winds ‒ have not been considered. The results of the research were used to evaluate existing design guidance for similar navigation conditions. The most important conclusions are:

* Partial factors for berthing velocity are not fixed values, as they are influenced by the prescribed probability of failure during a reference period and variation of the berthing velocity.
* The partial factors found did not show a correlation with vessel size. Higher partial factors were found for exposed navigation conditions (strong tidal currents) and lower partial factors when berthing aids were applied.
* The existing design guidelines were considered to be safe for most situations. Applying the British Standards [4] could result in a conservative design. When using the recommendations of PIANC [17] and EAU [6], applying an abnormal berthing factor *Cab* lower than 1.5 should be done with great care.

The presented methods for deriving characteristic and design values for berthing velocity are easy to apply and could be beneficial for assessing new and existing marine structures. It is recommended to use a characteristic value of berthing velocity with a return period of 50 years. This return period in combination with a berthing frequency of 100 berthings of the design vessel per year resulted in a close correlation with existing recommendations for the design of new marine structures. However, when assessing existing marine structures, the effect of lower target reliabilities, alternative reference periods and berthing frequency could be taken into consideration. This will generally result in lower design berthing velocities up to 10%-30%.

It is highly recommended to further study the risk of the fairly high berthing velocities found for navigation conditions subject to strong tidal currents. In particular, the effect of a second berthing impact could reduce the amount of energy transferred if berthing angles are quite low. Sophisticated datasets and partial factors for berthing velocity of inland barges and smaller seagoing coasters are still lacking. It is recommended to collect field observations of smaller vessels in order to better account for the human influence, which is believed to be stronger when berthings are not assisted by well-trained pilots.

1. **ACKNOWLEDGEMENTS**

On behalf of Port of Bremerhaven, Port of Rotterdam, Delta Marine Consultants and Inros Lackner the authors would like to thank all companies involved for their support, funding and hospitality. Special thanks Mr M. Gaal, who, on behalf of Trelleborg, was really one of the main driving forces in accomplishing this research by providing the SmartDock® portable laser during the field measurements. Prof. dr. S.N. Jonkman, Prof. dr. R.D.J.M Steenbergen and Dr. D.J. Peters are gratefully acknowledged their contribution on behalf of the TU-Delft, TNO and RH-DHV. Finally, the cooperation with PIANC WG 145 was of great importance in sharing and developing knowledge. Also the support of Prof. S. Ueda contributed to the interpretation of the collected data. The port authorities of Bremerhaven and Rotterdam express their appreciation of the partnership with all the companies involved.

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