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Fender System Selection in PIANC WG211

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The PIANC Guidelines for the Design of Fender Systems: 2002 (WG33) is to be replaced by an updated document, PIANC Fender Guidelines 2024 (WG211). With the preparation and development of PIANC WG211, the issues that should be considered when selecting a fender system deserve as much attention as the design of any other element of the structure of which it is a part. This paper describes the fender selection process as outlined in Chapter 6 of PIANC WG211. The guideline provides background information on the range of factors influencing fender system selection, including estimating key aspects of vessel geometry, assessing multiple fender system contacts, and determining how the design vessel(s) is likely to interact with the proposed fender system. PIANC WG211 introduces the term ‘Base Fender Performance’, and this paper includes an overview of the detailed guidance now provided on the method to calculate and apply the relevant correction factors. It includes a new correction factor associated with accounting for the effect of multiple fender system contacts and the application of partial resistance factors now adopted for the selection of fenders, related to determining fender design performance. This paper also provides details on the updates to design guidance associated with factors affecting hull pressure, including the effect on the selection of fenders and the sizing of fender panels. This paper will provide designers, and others involved with the selection of fenders and fender systems, with a comprehensive overview of the revised and updated guidance, considerations and methodologies now included within WG211.

Keywords: PIANC WG211, fender selection, hull pressure.

Introduction

This paper presents an outline of the fender and fender system selection process, providing background information on the issues that should be considered.

The fender, the type of fender system and the supporting structure are interlinked. Therefore, the selection of a fender system deserves as much consideration as the design of any other element of the structure of which it is a part.

The selection of a fender system should take a common-sense approach and follow the general process as outlined below:

- Determine the functional requirements,
- Determine the operational criteria,
- Assess the site conditions,
- Establish the design criteria,
- Calculate the berthing energy to be absorbed by the fender during berthing and/or when moored,
- Select a suitable fender and fender system based on the berthing energy and design criteria,
- Determine the fender reaction force and related friction forces,
- Confirm that the supporting structure and vessel hull can accommodate the calculated forces.

The above process may have to be repeated several times to select the optimal fender and/or fender system for a particular situation.

There are numerous fender systems available, and it is the task of the designer to pragmatically select the most suitable and economical fender system which satisfies the design requirements and specified characteristics. Before designing a fender system, a comprehensive evaluation of all of the project specific criteria that the fender system must satisfy should be undertaken. A sound understanding of the principles behind the use of the correction factors is also needed to prevent a potentially significant over- or under-design of the resulting fender system.

The fender should be selected based on the calculated design berthing energy of the design vessel(s), the vessel type and berth use, or based on the permanent mooring / ‘lean-on’ load(s), whichever is greater.

Fender System Selection

Every type and size of fender has different performance properties. Whatever type of fender is selected, the fendering system should have sufficient capacity to absorb the energy of the berthing design vessel(s). When selecting fenders, many factors need to be considered, including (but not limited to):

- Differences in vessel size, shape, and hull form,
- Berthing velocity at moment of fender contact,
- Berthing angle at moment of fender contact,
- Single or multiple fender contact,
- Angular compression of the fender,
- Temperature range,
- Berthing frequency,
- Fender efficiency,
- Asset manager / owner preference,
- Tidal range.

The selection of a suitable fender is largely based on carrying out calculations to confirm that the energy absorption capacity of the fender system is greater than the berthing energy of the vessel(s). In addition, the associated compressed fender hull contact pressure should be less than the allowable vessel hull pressure and the structural capacity of the supporting structure.

Fender selection relies on the experience and judgement of the designer to make reasoned and pragmatic decisions as to which fenders and fender systems may function best in the circumstances unique to each project. In conjunction with this experience, the designer can seek advice from fender suppliers in identifying suitable fender solutions.

At the project conception, specific site-based design criteria may not be available and may need to be estimated. A sensitivity analysis may be required to determine the effect of changes to the assumed design criteria on the required size and performance properties of the selected fender. This may include an iterative assessment of a range of different fender types and sizes. The design process is therefore likely to identify several different fender types and sizes that could accommodate the required range of vessels and conditions.

The selection of a suitable fender system may need to consider a wide range of potentially limiting conditions or restrictions. These may include, but are not limited to, specific types of vessels, matching replacement fender systems to an existing fender system, large vessel stand-off distances, accommodating vessel gangways, vessels with belting, etc.

The range of vessel sizes using the berth will also need to be carefully considered as this may influence the fender type, spacing (pitch) and the size(s) (heights) of the fenders selected. Sometimes there may be one primary overriding criterion which may dictate the whole fender system selection process.

Having determined the characteristic berthing velocity of the governing design vessel(s) and calculated the design berthing energy, the types of fenders and fender systems that are most likely to satisfy the project design criteria for the project should be identified.

Each potential solution should then be assessed against the project specific criteria to determine the optimal combination of efficiency, robustness, and cost-effectiveness. All permanent and temporary conditions associated with the operation of the berth (e.g. crane offload) should also be considered, to ensure that the most suitable fender type and fender system is selected.

Using the calculated design berthing energy, the fender performance data for each type, size and possible rubber grade of the fender is identified, as published in the fender supplier's catalogues. This is to identify the Base Performance (previously known as CV performance in WG33) properties for each type, size, and rubber grade of the fender.

To determine the Characteristic Performance of the selected fender, the applicable correction factors need to be determined, using the project specific design criteria. The Base Performance of the fender is then multiplied by these correction factors, to determine the fender Characteristic Performance.

The Design Performance of the selected fender requires the applicable partial resistance factors to be determined and applied to the fender characteristic berthing energy and reaction force.

This design process is repeated until all possible fender solutions have been assessed and/or the optimum solution has been identified. It should be noted that the most effective and efficient energy absorbing fender may not be the most suitable fender for the required application.

Factors Influencing Fender System Selection

Fender systems can be designed to function as single stand-alone fender systems (e.g. berthing dolphins) or they can function as part of a combined multiple fender system arrangement (e.g. on a continuous berth). A range of factors and variables should be considered including (but not limited to):

- Bow radius,
- Bow flare,
- Fender system pitch,
- Single fender system contact,
- Multiple fender system contact,
- Vessel hull structure,
- Vessel belting and double hull contact,
- Type of supporting structure,
- Flexible dolphins,
- Fender system elevation,

- Pneumatic and foam fenders,
- Number, size, and orientation of fenders,
- Shear of fenders,
- Submerged fenders,
- Ageing effects on fenders,
- Non marking fenders,
- Mooring analysis,
- Permanent mooring.

Multiple Fender System Contact

Whilst vessels may attempt to approach parallel to a berth, in practice, given the number of variables influencing the vessel approach and the vessel hull geometry, true parallel berthing is difficult to achieve. Nonetheless, multiple fender system contacts can and do occur at small berthing angles. For continuous berths, depending on the approach angle of the vessel, the bow radius and the fender system pitch, vessels may contact multiple fender systems sequentially and by varying amounts when berthing.

Multiple fender system contacts will provide the greatest berthing energy absorption capacity, which is proportionally larger than for single fender contact. Consequently, multiple reaction forces will be induced onto the supporting structure. The supporting structure should therefore be capable of resisting the cumulative sum of these multiple fender reaction forces.

The total berthing energy absorption capacity of multiple fender systems equates to the sum of the energy absorbed by all the compressed fenders. If one fender system is initially contacted, closely followed by the adjacent fender systems, the energy will be absorbed by all the fenders that are contacted by the vessel. The energy absorbed by each individual fender system will vary depending on the degree to which each fender system is compressed. The fender at the initial point of contact will have the largest deflection and the largest associated reaction force, refer to Figure 1.

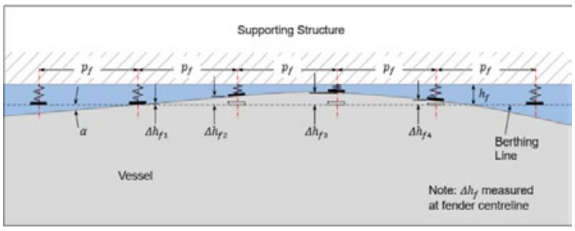

Figure 1 Contacted fenders at larger berthing angles (with contact on bow flare)

For vessels with approach angles that are almost parallel to the berth, this can result in many more fenders being contacted, with each contacted fender being compressed by varying amounts, refer to Figure 2.

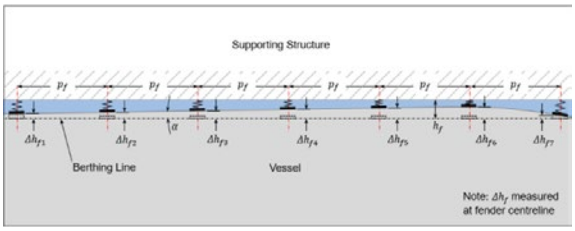

Figure 2 Contacted fenders at smaller berthing angles (almost parallel to the berth)

For all cases of multiple fender contact, the cumulative energy absorption capacity of the multiple fenders that are compressed is therefore greater than that for a single fender contact. For multiple fender contacts with buckling fenders, the non-linear force deflection characteristics of the fender will result in larger overall reaction forces on the structure compared with single fender contact.

The range of design berthing velocities associated with the range of design vessels should also be considered. The differences in berthing velocity, in combination with the vessel approach angle and vessel geometry, will result in numerous berthing scenarios that may all need to be considered to identify the optimum fender system solution.

Changes in the selected fender pitch, the fender type and fender height will also influence the number of fenders that are compressed for a multiple fender contact scenario. The smaller the pitch, the more fenders are likely to be contacted.

If the range of design vessel sizes is large, it is generally not economical or practical to position the fender systems sized for the largest vessels using the pitch calculated for the bow radius of the smallest vessels. In such cases, smaller alternative secondary fenders can be considered for placement between the primary fender systems that are provided to accommodate the largest vessels.

Both single and multiple fender system contact scenarios should be assessed for a range of vessel approach angles. Contact with multiple fender systems during berthing increases the potential berthing energy absorption capacity, potentially enabling a smaller fender to be selected and/or larger vessels to be accommodated on the same berth.

Should the initial berthing contact be made by the stern quarter of a vessel and, as the hull radius is typically considerably much smaller at this location, the designer should consider whether single fender contact is also a possibility in this scenario.

Base Fender Performance

The performance of a fender depends predominantly on its type, size, and the material grade. Several other factors, including the amount of angular compression, ambient temperature, speed of compression and the number of fenders contacted during berthing, also influence the performance of the fender. The Base Fender performance represents the mean value of fender performance and is a reference value for testing of the fender. The Base Fender performance for the selected fenders should be determined from the fender supplier's catalogues.

To determine the Base Fender performance properties, fender suppliers undertake slow Constant Velocity (CV) compression testing for each fender type and rubber grade. These CV fender compression tests typically determine the base energy absorption (E_{base}) and base reaction force (R_{base}) properties. The E_{base} and R_{base} performance characteristics are then published by fender suppliers for use in the first stage of the fender selection process.

Correction Factors

Fender selection and the design of buckling rubber type fender systems requires the E_{base} and R_{base} to be adjusted by correction factors that are directly applicable to the project specific conditions and design criteria. These correction factors consist of the following:

- Velocity factor (C_v)
- Temperature factor (C_t)
- Angular factor (C_{ang})
- Multiple fender contact factor (C_{mult})

The characteristic values of the vessel berthing velocity, ambient temperatures at the project site, and vessel approach angle, are used to determine these correction factors. Whilst WG211 provides detailed guidance on the selection of all of these factors, determining in particular the velocity and multiple fender contact correction factors is discussed further in this paper. Correction factors are not applicable to pneumatic fenders.

Velocity Factor

Ideally, fender suppliers would test fenders at the actual or design berthing velocity to determine the required performance of the fenders and enable fender selection. However, in practice this is very difficult to achieve given the size and complexity of the testing equipment required and the range of fenders to be tested. Consequently, fender suppliers typically determine the Base Fender performance properties using slow, CV compression tests at velocities of between 0.33 to 1.33 mm/s (or a strain rate (V_o) of between 0.01 to 0.3 %/s where the strain rate is calculated by dividing the design berthing velocity by the height of the fender).

To account for the difference in the velocity between the base performance tests and the actual, real-life design berthing velocity, fender suppliers determine and publish velocity factors (C_v) for a range of compression times using either the Constant Velocity (CV) or Decreasing Velocity (DV) methods. (Note, in WG33 [4], the DV performance for a berthing velocity of 15 cm/s was known as the Rated Performance Data (RPD) fender performance. This is no longer applicable in WG211 as the berthing velocity is now selected on a case-by-case basis. The fender supplier should specify in their catalogue whether the CV or DV method has been used to derive C_v).

The C_v factor depends on the fender size, strain rate and the type of fender and is determined from the compression time. The fender's maximum reaction force will occur at the greatest berthing velocity and the lowest temperature. Failure to apply C_v could lead to an underestimation of the forces acting on the fender system and supporting structure.

To determine the characteristic value for $C_{v,c}$ the designer should first determine the fender compression time by dividing the design deflection by the characteristic berthing velocity. Fender suppliers may also provide $C_{v,c}$ factors for a range of different rubber compounds. A natural rubber fender is less prone to high velocity effects when compared to a synthetic rubber fender, when tested at the same compression velocity.

Multiple Fender Contact Factor

A berthing approach that is almost parallel to the berthing line, (i.e. a characteristic berthing angle (α_c) of ≤ 2°), will typically result in the vessel contacting multiple fenders. The characteristic berthing angle of the vessel therefore determines the number of fender systems that contribute to absorbing the berthing energy. For larger berthing angles (i.e. with α_c of ≥ 2°), the number of contacted fenders is primarily influenced by the geometry of the vessel's bow.

To account for the influence of contacting several fenders in the design and selection of the fender, and to prevent over design, the multiple fender contact correction factor C_{mult} has been introduced.

Depending on the length of the design vessel, and the number of fenders contacted, the characteristic value of $C_{mult,c}$ can be in the region of 1.5 to 3.0. The corresponding increase in the total energy absorption capacity enables a potentially smaller fender to be selected. Lower reaction forces per fender are then required to be accommodated by the supporting structure. Conversely, multiple compressed fenders can also simultaneously create a much greater total reaction force on the whole supporting structure.

$C_{mult,c}$ can be calculated manually using a geometric analysis of the vessel alongside the berth, refer to Figure 3.

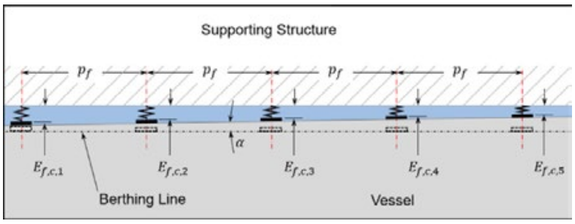

Figure 3 Calculation of $C_{mult,c}$ for multiple fender contact

- $C_{mult,c}$ can be calculated using Equation *(1)*:

$$C_{mult,c} = \frac{E_{f,c,1}+E_{f,c,2}+E_{f,c,3}+\cdots+E_{f,c,n}}{E_{base}} \tag{1}$$

Where: $E_{f,c,n}$ = Characteristic berthing energy absorbed by n^{th} fender of the partially compressed fenders [kNm]

The calculation of $C_{mult,c}$ can also be undertaken using simulations to replicate the berthing approach, enabling the efficient assessment of numerous variations in vessel dimensions, berthing approaches, and berth configurations.

An iterative approach is always required when considering multiple fender contacts to identify the optimum fender solution. Variations in fender pitch and the fender size will change the overall energy absorption characteristics. The parameters of several different design vessels may also require a comparative geometrical assessment to determine the critical design case.

Determining Fender Design Performance

The fender design performance is derived by applying partial resistance factors of safety to the characteristic performance values. The design fender performance largely depends on the project reliability requirements for the fender system.

To determine the fender design performance, partial resistance factors related to the energy absorption of a single fender (γ_f) (which includes the variable effects of the manufacturing process), the effect of a single or multiple fender contact (γ_{mult}) and a partial load factor (γ_R) must be considered.

Fender Performance Partial Resistance Factor

Differences in the variety of the components and processes that are part of the manufacturing of fenders can lead to variations in the properties of a fender. Such components include:

- Raw materials and rubber compounds,
- Manufacturing process of the rubber or fender element,
- Moulds,
- Curing process,
- Storage temperature and humidity,
- Testing equipment.

The partial resistance factor (γ_f) replaces the manufacturing tolerance factor in WG33 [4] that was applied to take account of variances in fender production. The γ_f factors are based on the mean performance of the fender as published by the fender suppliers.

Multiple Fender Contact Partial Resistance Factor

For scenarios involving multiple fender system contacts, the energy absorption capacity is affected by variations in the berthing angle of the approaching vessel. A particularly low characteristic berthing angle (α_c of ≤ 2°) may result in a high value of $C_{mult,c}$, increasing the overall berthing energy absorption capacity of the berth.

To manage uncertainties arising from small berthing angles, coupled with multiple fender system contacts, a partial resistance factor for multiple fender contacts (γ_{mult}) is introduced to ensure compliance with reliability requirements and to prevent the under estimation of the capacity of the selected fender system.

Load Partial Resistance Factor

For some types of fenders, a comparatively small fender deflection results in the maximum reaction force of the fender (e.g. cell or cone fender). For other fender types, this occurs only at the maximum deflection of the fender (e.g. cylindrical, foam or pneumatic fenders). When a fender exceeds its maximum design deflection, the associated reaction force typically increases rapidly. In addition, some fender types demonstrate hardening effects over time, whereas others indicate softening. This can result in significantly greater forces being imparted onto both the supporting structure and the vessel hull structure.

The type of fender selected therefore influences the frequency of the occurrence of the maximum reaction force. The potential frequency of the occurrence of $R_{f,c}$ should be assessed to ensure that the appropriate reaction force is applied to the design of the fender system.

The Partial Load Resistance factor (γ_R) is generally used to design all the components of the fender systems (e.g. the fender panel, restraint chains, anchor bolts, etc.). The use of γ_R should not be considered when assessing fender induced berthing impact loads acting on the support structure, since recommendations for load factors and combination factors are generally prescribed within national codes and standards.

γ_R is applied to the characteristic reaction force $R_{f,c}$ to determine the design reaction force $R_{f,d}$ for fender system component design. $R_{f,d}$ is also used to assess the load distribution on the vessel hull structure. $R_{f,d}$ is not used for the design of the support structure.

Application of Partial Resistance Factors

The design energy absorption capacity $(E_{f,d})$ is determined by dividing the characteristic energy absorption capacity $(E_{f,c})$ by the partial material factor (γ_m). γ_m can be calculated from the partial resistance single fender performance factor (γ_f) and the partial resistance multiple fender contact factor (γ_{mult}), refer to Equation *(2)*. The product of these partial factors is applied to $E_{f;c}$ to determine $E_{f,d}$, as presented in Equation *(3)*.

$$\gamma_m = \gamma_f \ \gamma_{mult} \qquad (2)$$

$$E_{f,d} = \frac{E_{f,c}}{\gamma_m} = \frac{E_{f,c}}{\gamma_f \, \gamma_{mult}} \qquad (3)$$

To determine $R_{f,d}$, the performance curves for the selected fender type(s) are used to identify the applicable values of the reaction force $(R_{base,c}$ or $R_{base,max})$, as the value of $R_{f,d}$ may be different for linear and non-linear fender compression. Refer to Figure 4 and Figure 5, where $R_{f,d1}$ applies to R_{base} and $R_{f,d2}$ applies to $R_{base,max}$. The maximum value of either $R_{f,d1}$ and $R_{f,d2}$ is used as the design reaction force, $R_{f,d}$.

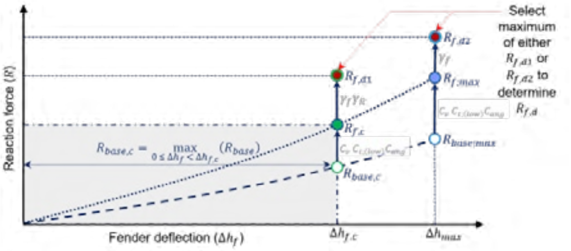

Figure 4 Identification of $R_{f,c}$ and calculation of $R_{f,d}$ for linear force-deflection curves

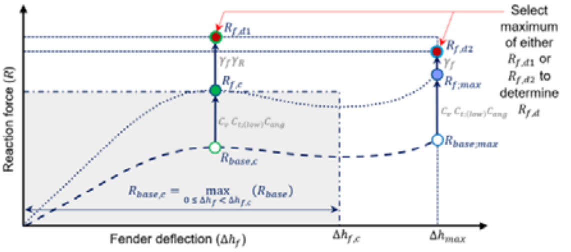

Figure 5 Identification of $R_{f,c}$ and calculation of $R_{f,d}$ for non-linear force-deflection curves

To determine $R_{f,d1}$, the deflection of the selected fender $(\Delta h_{f,c})$ at the characteristic energy absorption capacity $(E_{f,c})$ must first be determined. The maximum value of $R_{base,c}$ is then identified within the characteristic fender deflection range, as noted in Equation *(4)*, Figure 4, and Figure 5.

$$R_{base,c} = \max_{0 \le \Delta h_f < \Delta h_{f,c}} (R_{base}) \qquad (4)$$

For linear fenders, $R_{base,max}$ is defined as the maximum reaction force generated by the fender at the fender's maximum compression. The applicable values of $R_{base,c}$ and $R_{base,max}$ are then multiplied by the appropriate correction factor values to determine $R_{f,c}$ and $R_{f,max}$.

To determine $R_{f,d1}$, $R_{f,c}$ is multiplied by γ_f and γ_R as noted in Equation *(5)*. To determine $R_{f,d2}$, $R_{f,max}$ is multiplied by only γ_f, refer to Equation *(6)*.

$$R_{f,d1} = R_{f,c} \ \gamma_f \ \gamma_R \qquad (5)$$

$$R_{f,d2} = R_{f,max} \ \gamma_f \qquad (6)$$

For berthing events that involve multiple fender contacts, the cumulative sum of the fender reaction forces acting on the supporting structure may be greater than the design reaction force $R_{f,d}$. Careful consideration of this issue should be undertaken in the design of a fender supporting structure with multiple fender systems.

As the characteristic energy absorption and reaction force of a fender represents a conservative estimate of the mean fender performance properties, the partial resistance factors are applied to determine the design fender performance. These partial resistance factors account for the rarest, extreme design events that may occur based on the assessed consequence class.

Uncontrolled, accidental berthing events or collisions are not accounted for within the fender design performance properties, as these are extreme design conditions and are defined as accidental limit state events. The requirement to design for accidental berthing events is a unique client requirement and should be based on a residual assessment of the capacity of the selected fender systems, with all partial factors of safety set to 1.0.

Hull Pressure

While absorbing the berthing energy of a vessel, the fender will exert a reaction force on both the vessel and supporting structure. Under normal berthing conditions, no plastic deformation of the vessel's hull structure is accepted. Forces induced by wave impacts continue to be amongst the governing criterion for hull design. Typically, vessel designers and builders will only consider additional reinforcement to the vessel fender contact area if required by the vessel owners and/or to fulfil specific port requirements. With vessel sizes continuing to increase, hull plate thicknesses continue to be optimised with increasing spacing between web frames. This has the potential to result in lower hull pressure limits.

Factors Affecting Induced Hull Pressure

Several factors influence the magnitude of the hull pressure induced by fenders. These include, but are not limited to, the following:

- Vessel approach velocity,
- Vessel approach angle,
- Vessel hull profile (e.g. bow flare),
- Fender pitch,
- Fender contact area,
- Multiple simultaneous fender contacts,
- Fender panel stiffness, facing shape and orientation.

Arguably, the most significant is the vessel approach velocity, but there may also be other port or vessel specific influencing factors. When establishing the fender design criteria and assessing the operational parameters of the port their significance should not be forgotten.

Recent Hull Pressure Research

Historically, fender panels were dimensioned using a maximum allowable hull pressure to spread the design reaction force in a safe way over the vessel hull. Theoretically this means that cylindrical fenders cannot be used as these typically generate a high peak hull pressure. However, based on recent observations and experience it is acknowledged that vessels of all sizes can and do berth safely on cylindrical fenders. The Port of Rotterdam has undertaken research that demonstrates the safe use of cylindrical fenders for container vessels (Lloyd's, 1989), oil and LNG carriers, (Broos, Rhijnsburger, Vredeveldt & Hoebee, 2018) and on all general classes of vessels (TNO, 2019) [3].

As part of the work undertaken by WG211 [5], additional research was undertaken (Berendsen E. A., 2022) [1]. The FEM analyses of a fender (allowing for fender buckling with various panel sizes) and hull structure interaction, indicated that when using large fender panels or contact areas, the stated load capacity of the vessel hull can be exceeded (refer to Figure 6). In addition, very small fenders (e.g. cylindrical and arch fenders) have hull pressures significantly greater than the recommended hull pressures stated in WG 33 [4].

For fender systems that utilise fender panels, increasing the size of the fender panel makes it possible to increase the reaction force from the fender onto the vessel hull, up to a maximum point that represents the upper limit of the capacity of the hull. In such cases, the stress concentration in either the vessel web frame or deck becomes critical. Therefore, simply increasing the contact area of the fender panel does not necessarily ensure that these larger reaction forces can be accommodated by the vessel hull, as can be seen in Figure 7.

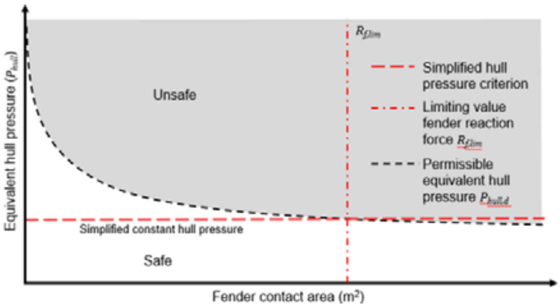

Figure 6 Equivalent hull pressure limits (Berendsen et al., 2024) [2].

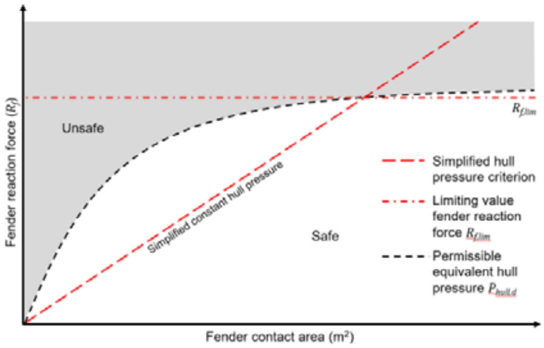

Figure 7 Maximum fender reaction force (Berendsen et al., 2024) [2].

It was concluded by Berendsen, Roubos, Williams, Walters & Broos, 2024 [2] that:

- Contact pressures between the fender panel and vessel are not uniformly distributed. Elastic deformation of the vessel hull will result in comparatively small, direct contact areas close to the edges of the fender panel with the vessel hull, often referred to as 'line loads'.
- For larger vessels, wide fender panels are typically considered to be more efficient when compared to taller fender panels. However, in tidal ports, fender panels are likely already to be comparatively tall (to accommodate the variance in water levels) and it may therefore be more efficient to engage with a vessel's deck structure.
- Design codes used to assess the pressure on the parallel hull of the vessel assume a constant hull pressure criterion. Constant hull pressure can overestimate the structural capacities of the vessel hull and a limiting value for the total fender-induced reaction force is recommended to be included for the design of fender systems.

For buckling fenders, typically fitted with fender panels and when the fender panel contact area is small, the generated hull pressures can result in the maximum stress in the hull plate being reached. However, as the vessel hull plate redistributes the fender panel forces into the vessel stiffeners and web frames, these loads are generally not critical for small fender contact areas. For larger fender panel contact areas, the fender forces are distributed over a greater number of stiffeners and/or web frames within the vessel hull structure.

For non-buckling fenders (e.g. pneumatic, foam or cylindrical fenders), the contact area of the fender on the vessel hull increases as the fender is compressed and does not initiate local force concentrations on the hull.

Typical Hull Pressure Capacities

Ideally, the permissible hull pressure limits of the design vessel(s) that the fender system is required to accommodate should be readily available. In practice, permissible hull pressure limits are difficult to obtain and as such, reasonable assumptions on the size the required fender panel or contact area are needed.

It is acknowledged that most berths are required to be designed to accommodate a wide range of vessels and to provide the operator of the facility with the greatest degree of operational flexibility. Calculation of the maximum equivalent permissible hull pressure for every vessel type is not practical or cost-effective and the use of general guidance, as provided in WG211, is considered to be sufficient.

General guidance for a range of applicable hull pressures in the absence of vessel specific information is provided in WG211 [5]. These values include the factors of safety normally used by Classification Societies. The $R_{f,d}$ of the selected fender and the fender panel contact area is used to determine the applicable load acting on the hull structure of the berthing vessel and to verify that the allowable hull pressure limit is not exceeded.

The equivalent maximum permissible hull pressure $(P_{hull,d})$ should therefore be greater than the average hull pressure $(P_{hull,av})$ or the maximum allowable hull pressure $(P_{hull,max})$ as given in Equation *(7)*.

$$P_{hull,d} \geq \max\left(P_{hull,av}\ ;\ P_{hull,max}\right) \qquad (7)$$

Certain operators may require a berth and associated fender system to accommodate a specific, unique vessel type. In such cases, if details of the vessel side plating, longitudinal stiffeners and side transverse frame separation information is provided, the permissible hull pressure can be calculated.

Summary

WG211 represents the up-to-date fender system design and selection process.

The selection of a fender system deserves as much attention as the design of any other element of the structure of which it is a part. The selection of the fender, the type of fender system and the supporting structure are therefore interlinked.

The Base Fender performance represents the mean value of fender performance and is based on slow Constant Velocity (CV) compression testing for each fender type and rubber grade.

To account for the influence of contacting several fenders, the multiple fender contact correction factor C_{mult} and partial resistance factor γ_{mult} have been introduced.

General guidance for a range of applicable hull pressures in the absence of vessel specific information is provided in WG211.

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