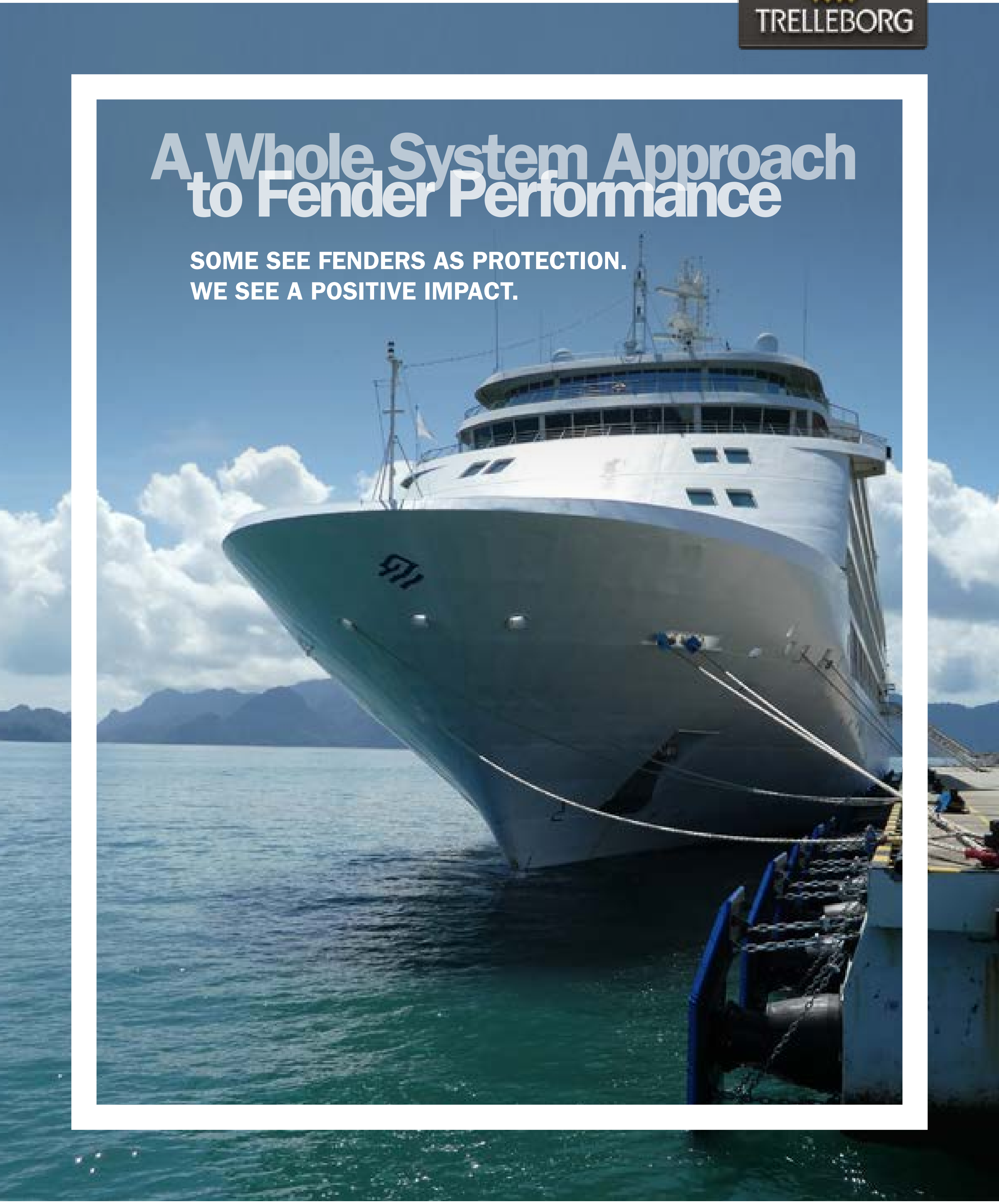
A Whole System Approach to Fender Performance

**SOME SEE FENDERS AS PROTECTION.
WE SEE A POSITIVE IMPACT.**



A Whole System Approach to Fender Performance: Why it Matters

With larger vessels, increased cargo volume, improved safety awareness and tougher environmental regulations, today's ports face significant challenges. To accommodate regional compliances and the rapidly changing nature of the shipping industry, ports must find ways to upgrade and future-proof their infrastructure, doing so safely, efficiently, cost-effectively and sustainably.

Fender systems are a critical part of port infrastructure. The systems are mission-critical equipment, and are essential to the safety and efficiency of port operations, protecting vessels and terminals alike. Taking a whole system approach ensures high-quality fender systems optimize vessel throughput and port operations efficiently and safely over the long term. That's because a whole system approach to fenders – one that includes engineering, design, manufacturing and maintenance – will reduce construction costs, downtime and operating expenditure. This is in addition to contributing to more efficient berthing operations by improving turnaround times, while improving overall operational efficiencies and reducing operational safety risks.

In short, a fender system that lasts longer and offers enhanced reliability – and that requires less maintenance – is both a better investment and better for the environment.

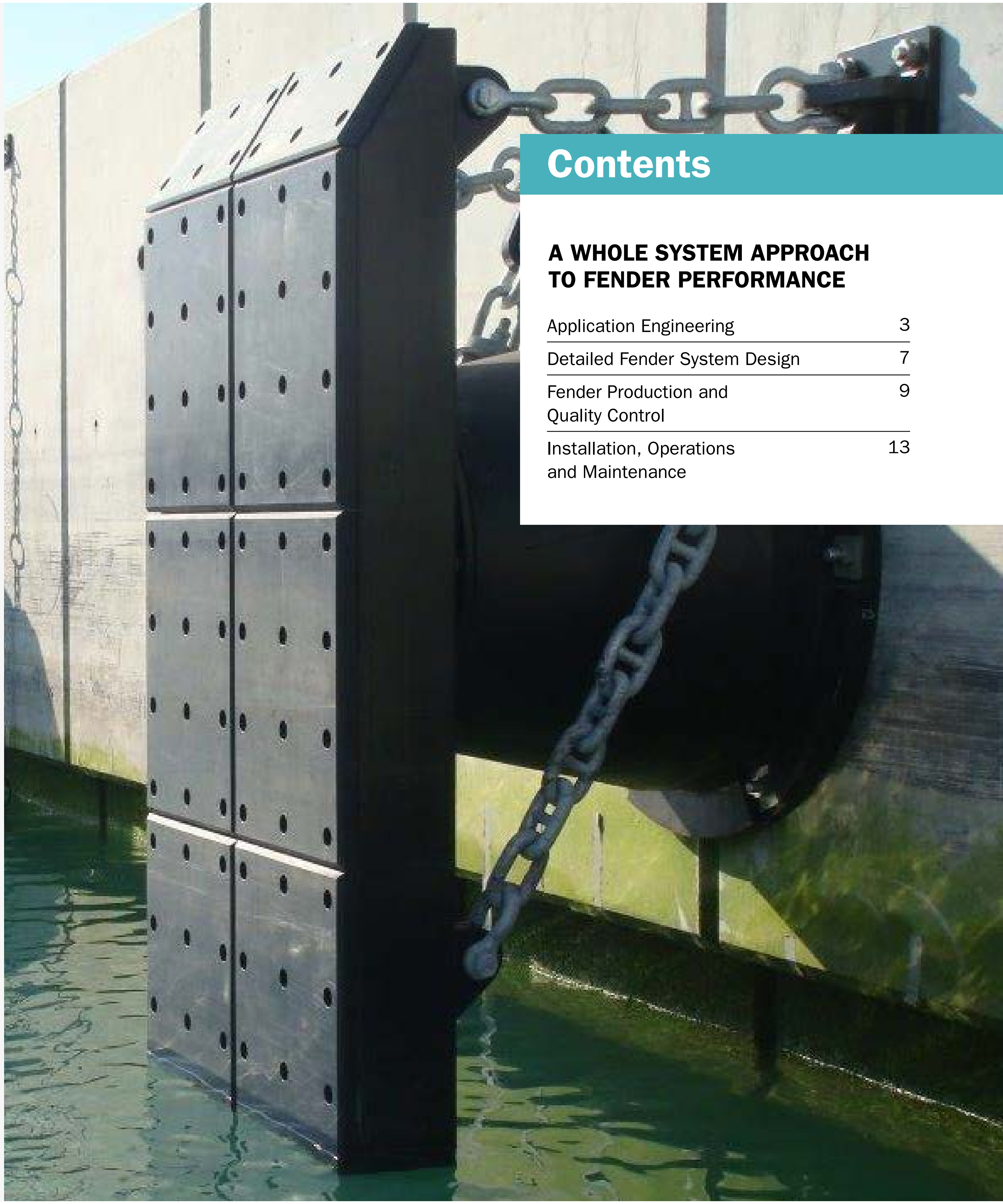
THE FOUR ELEMENTS OF A WHOLE SYSTEM APPROACH

A high level of technical expertise and experience is required to select the most suitable fender system to safeguard berths, vessels and port operations.

There are four key elements that are needed for a best-practice fender system. Suppliers should have a proven track record in all of these elements, in order to guarantee enhanced safety and efficiencies.

- Application Engineering
- Detailed Fender System Design
- Fender Production and Quality Control
- Installation, Operations and Maintenance

This whitepaper discusses these four elements and the role each plays in a superior fender system.



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A WHOLE SYSTEM APPROACH TO FENDER PERFORMANCE

Application Engineering

A high level of technical expertise and application engineering is required when it comes to the design and selection of fender systems, which must be able to protect modern ports and terminals, a wide range of vessels and high-value cargo.

FUNCTIONAL AND OPERATIONAL REQUIREMENTS OF FENDER SYSTEMS

During application engineering, information such as berthing data, site conditions and environment needs to be collected. These are assessed alongside other design criteria – such as local standards, desired service life, maintenance cost and frequency – to determine a project's unique requirements.

Functional requirements

A fender system's main function is to ensure the safe berthing of a vessel and protection of port infrastructure. It must be able to absorb the kinetic energy of all specified vessels under all possible site environmental conditions, in order to prevent structural or vessel damage.

Operational requirements

Berth frequency

Operational requirements of a port include facilitating frequent berthing as efficiently as possible to prevent downtime and to make sure all arrivals and departures occur as seamlessly as possible.

Environmental conditions

Berthing occurs in a wide variety of operating conditions, including extreme weather such as heavy wind and tide action – as well as different temperatures. These environmental factors can significantly affect the performance of a fender system.

A fender in arctic conditions, operating at -30°C, behaves and performs very differently to one in the United Arab Emirates at +50°C. Taking these factors into consideration is critical to designing and manufacturing a fender system that will perform optimally once installed.

Accommodating a wide range of vessels

A port and its fender systems must also balance the berthing needs of a wide range of vessels with different hull configurations – such as maximum allowable hull pressure, different hull angles, freeboard variations and flat hull to belted hull. Each kind of vessel or configuration has its own challenges which need to be considered when designing a fender system.

APPLYING PERFORMANCE CORRECTION FACTORS

Once all the functional and operational design parameters are determined, accurate and comprehensive application of berthing energy calculations, along with performance correction factors, should be made to engineer the best-fit fender solution.

The kinetic energy of a berthing vessel needs to be absorbed by a suitable fender system. To ensure the fender system absorbs the required amount of energy in actual conditions, the fender performance correction factors should be considered.

When it comes to fender selection at the application engineering stage, there are two fundamental criteria:

- The energy capacity of the fender under the worst operating conditions must be greater than the abnormal design berthing energy.
- The reaction force exerted by the fender onto a vessel/structure must be less than the vessel's hull pressure limit and fender mounting structure capacity.

DETERMINATION OF BERTHING ENERGY

All of the following berthing factors need to be considered during the selection of a fender, and data should be backed up with testing documents and published in a catalog. Applying the right performance correction factors is vital to overall fender performance and enhances the lifetime of the fenders, reduces maintenance costs and lowers operational risk.

Angular factor (AF)

Fender energy absorption capacity depends on how the fender mass is compressed – parallel or angular. There are many factors affecting fender compression, including vessel hull angle and berthing approach angle. Angular compression can lower the energy absorption capacity of a fender. It is important to correct the base energy considering the worst fender compression angle to avoid damages to vessels or structures.

Temperature factor (TF)

Different locations experience significant temperature variations throughout the year. The constant exposure of fenders to temperature affects their hardness, for example, at a low temperature, a rubber fender will become hard, while at a high temperature, a fender will become soft – both variations directly impact fender performance. TF must therefore be accounted for during fender selection.

Velocity factor (VF)

Velocity factor is key in the selection of fenders. VF at normal design berthing speeds affects fender performance characteristics (reaction force and energy absorption), as well as the design of fender system components, such as frontal frames, wharf structure, chains and anchors.

When comparing catalog figures from different manufacturers, it is essential to ensure VFs are accurately applied to calculate the performance at the designed berthing speed.

VF, TF and AF should all be considered in the fender system design process to ensure that the fenders are safe and efficient.

Manufacturing tolerance

Tolerance is a defined range of measurements or limits in which a fender system can function properly. The industry standard tolerance is +/-10% of a fender's catalog performance level, but it is important to consider how different levels of tolerance impact fender selection and the fender system design process.

To guarantee fenders perform as intended, they must be independently tested to ensure the required tolerance level is met, so that the safety of the berthing structure is not at risk. And while it is possible to produce fenders under tight tolerance, manufacturers should be consulted if less than 10% of manufacturing tolerance is needed for projects.

Providing this information at the outset of the project ensures the best fender solution for its intended environment is developed. A supplier with proven application engineering expertise will establish a dialogue at this stage, identifying missing information and making recommendations to ensure all relevant data is captured.

BEST-PRACTICE SPECIFICATION

To ensure fenders are fit for purpose, they must be produced in accordance with the specifications of a project. When supplying fenders for a project, a range of application details and fender component information, such as panels and chains, must be specified. Fender specification should be carried out right at the very start of a project to ensure that the right fender system is selected – one that will function as required in its intended environment.

A data-driven approach

Taking a data-driven approach to fender design can improve accuracy, reduce costs and enhance port safety. Combining internal data on fenders and external data from the ports, such as berthing speeds, gives port authorities, terminal operators and consultants a clear view of how to improve the design of marine structures.

Meeting current guidelines

British Standard BS6349

The British Standard recently launched the BS6349-1-4 providing clear guidance on material requirements for all relevant fender components, such as the rubber, steel panel and UHMW-PE-facing steel panels.

PIANC Guidelines

PIANC working group WG211 is currently updating the PIANC's 2002 Guidelines for the Design of Fender Systems. We expect the updated guidelines to be published in the near future.

Installation

The installation of fender systems should also be considered early in the design process. This is because the accessibility for maintenance, wear allowances and protective coatings will all affect the design and selection of the final fender system.

A GOOD SPECIFICATION SHOULD COVER:

- Design conditions and requirements
- Wharf and vessel details
- Energy requirements or clear requirements for energy calculations
- Use of correction factors
- Material and testing requirements
- Supplier qualifications

Detailed Fender System Design

OPTIMIZATION OF A FENDER SYSTEM DESIGN

Fender panels are just as important as the rubber units on high-performance systems. That's why every panel is purpose-designed using structural analysis programs and 3D CAD modeling for optimum strength.

Fender panels distribute reaction forces to provide low hull pressures and to cope with large tidal variations. They can also be designed to resist line loads from belted ships, or even point loads in special cases. Optional lead-in bevels reduce the snagging risk, while brackets (where required) provide highly secure connection points for chains.

Once a fender has been selected, the detailed design of the system must be executed and optimized by the fender supplier. This is an essential part of the four-step whole system approach. Key considerations in best-practice design are:

Maximum reaction force

To ensure an optimal fender system design, it is critical to find out the maximum design reaction force of a fender. Maximum reaction force considers (national) design codes for partial load factors and performance correction factors like AF, TF, VF and manufacturing tolerance.

Fender components

Suppliers must understand that all the components, including accessories, in a fender system are equally important in ensuring optimal performance. All components in a fender system are designed based on the reaction force created by the compression of the fender during berthing operations.

As with the berthing energy calculation and fender selection process, globally standardized design guidelines for fender systems are available, but they are not always complete or adopted. The final design of a fender system depends on the designer's experience, data input and the load cases considered during the design process.

Front panel design

The front panel is a crucial part of a fender system that withstands and transfers loads from vessels to energy absorption units. Front panels and rubber units are equally important, and their design should consider many factors. These include how a vessel will make contact with the panel (such as full-face contact or double contact), critical stresses (such as bending, shear and torsion loads), rubber fender and chain connections, maintenance and more.

Once the detailed design is complete, all relevant design checks should be done. These include bending of the panel, local buckling of the inner webs, shear and weld checks. Compliance with local design codes such as the EN1993 (Eurocode 3) for Europe, AS4200 for Australia or AISC for America should also be ensured.

Low-friction facing pads

Low-friction facing pads reduce friction during vessel berthing operations and provide a wear function, which helps to determine the lifetime maintenance costs of a fender installation.

The quality and thickness of the materials are important, and the right material selection of facing pads is essential to ensure spark-free contacts with low abrasion and high impact strength. UHMW-PE is the best material available for fender systems as it uniquely combines low friction, impact strength, non-marking characteristics and resistance to wear.

Restraining chain design

Some fender systems need chains to help support heavy components or to control the deflection and shear during impact. Chains are important components in fender systems as they restrict the excessive displacement of a fender and ensure hassle-free serviceability. When an improperly engineered chain is applied to a fender system, the chain system is at risk of a catastrophic failure.

The dimension and angle of installation – as well as the chain material – are critical for effective design. Chains are also often supplied with compatible accessories like tensioners, shackles, brackets and U-anchors.

Fastening system

Fender systems must be properly fixed to perform as intended. The improper design of a fastening system may not only lead to the failure of an entire fender system, but it can potentially damage a fender system's mounting structure. Improper selection of fastening material could lead to corrosive threads during the service life of a fender system. Corroded fasteners make replacing the fender system a very challenging task. The concrete in which the anchoring system is positioned should also be checked to avoid concrete failure due to anchor pull out.

Corrosion protection

Fender systems usually operate in corrosive environments – sometimes made worse by high temperature and humidity. Corrosion of fender accessories can be reduced with specialist paint coatings, by galvanizing or with selective use of stainless steels. ISO EN 12944-5:2019 and ISO EN 12944-9 are widely used international standards defining the durability of corrosion protection systems in various environments.

Design checks

It is important that once the fender system design is complete and has been checked by the supplier, it is also externally reviewed by an independent third party or the commissioning design engineer. This ensures all the correct design checks have been performed to the standards specified – with no shortcuts such as lighter panels and accessories or less welding – to make sure the fender system meets all requirements and in turn, performs over its intended lifetime.

Fender system architecture

A fender's design should follow manufacturers' recommendations as typically published in their catalogs to ensure the fender performs as intended and avoid early failure of the system. At first glance, different manufacturers' fenders might look similar, but in reality there are significant differences among the fenders in overall dimensions and rubber compound used. Manufacturers typically provide guidance on clearances, minimum concrete edge distance, weight support (and the need of chains) and suitable fender orientation. For example, some manufacturers do not recommend cone fenders to be installed in the reversed direction (with the smaller diameter oriented toward the structure), whereas others take the approach that installing a cone fender in the reversed direction can result in significant savings on the structural costs. With the right cone fender design and the right compound composition, fender performance and durability will not be compromised.

Fender Production and Quality Control

If the right fender system is selected during application engineering and correctly designed during detailed engineering, the fender that is procured will need to meet the expectations that have been set.

This means all parts of the fender system must be produced according to their relevant manufacturing standards to ensure the fender system performs in its intended environment.

Fender systems should be tested in accordance with PIANC guidelines 2002, the ASTM F2192 or the British Standard Code of Practice for Maritime Structures: BS 6349, and be subject to performance and material verification testing, as well as fatigue/durability tests, where applicable. These tests ensure design criteria are met and that a fender system and its components will perform as intended.

BEST-PRACTICE MANUFACTURING AND QUALITY ASSURANCE

To guarantee the performance and durability of a fender system over a lifetime, there are three crucial factors that must be considered in relation to production:

- Quality of materials
- Manufacturing process
- Independent quality and performance verification

HIGH-QUALITY MATERIALS

Choice of materials impacts performance

The quality and composition of the materials used in the manufacturing of fenders and accessories have a significant impact on the performance and longevity of the fender system. For example, fenders manufactured from rubber compounds with no recycled rubber have a lifespan of almost 10 times longer than those made with a high content of recycled rubber.

Similarly, manufacturing low-friction fender panel facing pads from virgin UHMW-PE will increase the life of the facing pads due to increased resistance to wear and tear.

Understanding how the material composition impacts the quality and durability of a fender system is critical. If poorly designed or made from low-grade materials, the performance and longevity of the whole fender system will be compromised, including the fender, the front panel, the low-friction pads and accessories. Comprehensive materials testing is therefore needed to ensure the accuracy of compounds used throughout the manufacturing process.

Accurate compound testing

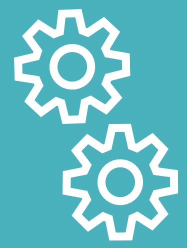
As a best-practice approach to product verification, the manufacturer should perform Thermo-gravimetric analysis (TGA) testing/FTIR/Ash analysis during the production of a rubber fender system.

TGA test results of rubber compound samples and samples drawn from the final fender product should be compared to identify if the right material is used. This provides the customer with guarantees around product quality and batch consistency. The TGA test also enables consultants to verify that the chemical composition of the rubber compound they have specified is actually supplied to their clients in the final product.

FTIR is a simple and rapid test to prove the identity of polymer or rubber chemicals. It is useful to determine the type and percentage of polymers in a rubber fender. Ash analysis, meanwhile, could be used to determine the amount of ‘fillers’ used in a rubber product, which are inorganic materials that can be added to a rubber product, causing a negative effect on durability and performance.

Accurate compound testing also ensures that the rubber components meet the required standards according to BS6349-1-4.

MANUFACTURING PROCESS



Building and curing

Building and curing processes have a significant impact on the final performance of rubber fenders and therefore the overall fender system. It is important to determine a manufacturer’s expertise and capabilities in these areas and to understand how the different processes affect fender performance.

Building

The building process is dependent on the type and size of the fenders, and the application they will be used in. For example, large cone fenders are produced through the wrapping process, whereas small cone fenders are produced by extruding the rubber compound into the mold. The building process used to manufacture the fender will significantly impact the properties of the rubber compound and subsequently the performance of the final fenders.

Most fenders are produced either by extrusion into a mold, by filling up molds with rubber blanks, or wrapping of a rubber sheet on a mandrel. Filling up the mold with extruded block or wrapping process provides better performance than direct extrusion into the mold.

Curing

When the building process is complete, curing is the next step in fender manufacturing. It is a critical step as curing is the process that converts raw compounded rubber to a finished, usable fender for the application it is designed for. The sulfur to accelerator ratio selected in the formula impacts fender performance and should be adjusted based on the local environmental factors and system requirements of each project. It is therefore important to be aware of the curing process and how ingredients impact the strength and durability of the final fender.

For more detailed information on the manufacturing process, read our *Manufacturing Methods Matter* whitepaper here.

BEST-PRACTICE INDEPENDENT TESTING

With the critical role that fenders play in port operations, it is essential to verify the authenticity and performance of fenders with independent testing. However, suppliers are often responsible for the current testing protocols which may result in unreliable data and flawed practices.

Performance verification testing

Performance verification testing is usually performed in a large press or test frame with either load cells or pressure transducers measuring load, and a displacement transducer measuring deflection. There are, however, a limited number of publicly available test frames around the world that are capable of testing rubber fenders. This means performance verification testing is almost always performed at the manufacturer's facility, and this is unreliable as the data is not independently certified.

Unreliable testing practices

The industry has commonly relied on factory testing with witnessing by either a third party or a consultant involved in the project's specifications. However, there is no easy way for witnesses to verify the results independently to prove the manufacturer's claim. The inspection agencies are not in any way guaranteeing the validity of the data they are endorsing. Supplier results and certificates based on factory testing, even if witnessed by a third party, should therefore not be accepted as truly independently verified.

True independent testing

Fender system projects involve sizable contracts and budgets – there is too much at stake to allow manufacturers to serve as their own regulators.
In order to ensure objective, trustworthy results for marine fenders, performance verification testing must be conducted in an independent laboratory or by an independent company with its own testing equipment, which works independently of the manufacturer.
This will remove any uncertainty from the results and enable end users to have confidence that the lifecycle and performance of the fenders meet the specification, and that the fenders are therefore fit for purpose.

For more details on material selection, read our *Mixing It Up* whitepaper here.

OTHER TESTING CONSIDERATIONS

Panels

A fender panel is a critical component in a fender system. The panel might be well-designed, but it may experience catastrophic failure or may not reach its intended design lifespan if the panel is not fabricated properly.

Fender panels must be manufactured according to the project's requirements and design specification. The steel panel manufacturer should be ISO9001-certified and have certified welding processes in place as per relevant international standards (i.e. EN1090 and ASME). A detailed steel fabrication specification and inspection and test plan (ITP) should also be available at the pre-production stage (ready for the client's approval), and should describe every critical step in the process, including how the project requirements are achieved and controlled during fabrication.

Special attention should be given to the painting process. A fender panel is mostly used in seawater, and as a result, a badly applied paint system will reduce the panel's design life drastically. A dedicated and conditioned paint workshop with qualified workers working strictly according to the ITP is essential.
For the ITP inspection, points for surface preparation such as degreasing, surface cleanness, blasting, dedusting, surface profile and soluble salts should be considered. For paint inspection, the environmental conditions, dry film thickness and visual testing should be covered, and additionally a holiday detection and pull-off test can be considered.

These measures prevent the pitfalls of poor fender panel performance such as weld failure, severe corrosion, extreme wear due to poor quality, paint failure and panel bending – which all contribute to operational downtime, increased maintenance and shorter overall product lifetimes.

UHMW-PE

UHMW-PE is often a first-choice material for facing steel fender panels and other heavy-duty applications. Various grades of UHMW-PE with different molecular weights are available in the market with significant differences between wear resistance and impact strength, resulting in significant differences in expected operational lifetime.

The manufacturer should be ISO9001-certified.
A detailed, project-specific ITP – as well as regular audits by specialists – should be in place to accurately verify that the required UHMW-PE material properties are met.

The recently published BS6349-1-4 provides recommendations for relevant material specification and testing. The standard refers to relevant well known ISO test methods of which density, wear resistance, Charpy impact strength and melt flow index can be easily tested on the pads by the fender system supplier, or by the client with help of a third-party testing laboratory.

Accessories

Quality assurance checks on other parts of the fender system including plates, chains and fixings as well as any welding should be conducted. ITPs should also be put in place for accessories, and should include measures to ensure that material certificates meet the design requirements, while spares should be procured for randomized testing, for example, HDG thickness on fixings and shackles.

Installation, Operations and Maintenance

Installation and commissioning

Making sure that the fender system is installed properly is critical in ensuring that it performs as intended. When installation is considered early – as part of a whole system approach to fender design – fender systems can be produced to perform optimally in a specific environment. This increases the lifetime of the fender system, reduces downtime and maintenance and supports safe, continuous operations.

Installation and commissioning support should be provided by the fender supplier. This includes installation, training, manuals, oversight and supervision.

Operations and maintenance

Inspection and maintenance guidelines should be provided by the supplier, as part of a best-practice approach. These guidelines determine the maintenance scope of the installed fender system and must include detailed inspection points and intervals.

Suppliers may have the experience and skills to provide support with on-site supervisions, as well as regular fender system inspection, if requested.

Trelleborg is able to carry out regular inspections and make recommendations on maintenance. Regular inspection and maintenance increases a fender's longevity, reduces operating expenditure and ensures the fender system performs as intended over its full product lifetime.

Sustainability matters

Sustainability is an increasingly important consideration. A low-cost fender – made from low-quality materials – will have a shorter lifespan than a high-quality fender. Since rubber is still hard to recycle, the selection and design of rubber fenders can have a significant environmental impact on a port's sustainability credentials. High-quality products with a longer lifetime significantly reduce replacement and recycling to support sustainability.

After-sales support

To help address the challenges of the demanding environments, in which fender systems operate, the supplier should offer clients a full range of after-sales services. High-quality after-sales support incorporates repair services, tailored inspection and maintenance programs, access to spare parts, timely technical support, on-site service and even customized training programs that enable ports to invest in their people.

Trelleborg provides a commissioning service and certifies fender system installation.

Summary

Effective and reliable fender systems are mission-critical equipment. They have a direct impact on the safety, efficiency and sustainability of port operations.

Trelleborg's fender systems are designed and manufactured based on a deep understanding of every aspect of the port ecosystem, providing you with a solution tailored to your environment that guarantees quality, performance and longevity.

Our end-to-end solution includes research and development, expert fender design, high-quality materials, manufacturing, testing, stringent quality control and after-sales services.

We apply industry-leading thinking in fender systems to develop the most effective, efficient and safe solution for our customers – no matter how demanding the working and environmental conditions.

Take a look at our proven track record and discover how our fender systems are protecting port and marine infrastructure across the world.

EXPLORE CASE STUDIES

DISCLAIMER

Trelleborg AB has made every effort to ensure that the technical specifications and product descriptions in this whitepaper are correct.

The responsibility or liability for errors and omissions cannot be accepted for any reason whatsoever. Customers are advised to request a detailed specification and certified drawing prior to construction and manufacture. In the interests of improving the quality and performance of our products and systems, we reserve the right to make specification changes without prior notice. All dimensions, material properties and performance values quoted are subject to normal production and testing tolerances. This whitepaper supersedes the information provided in all previous editions.

If in doubt, please check with Trelleborg Marine and Infrastructure.

Trelleborg is a world leader in engineered polymer solutions that seal, damp and protect critical applications in demanding environments. Its innovative solutions accelerate performance for customers in a sustainable way.

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Blog: Thesmarterapproachblog.trelleborg.com

Trelleborg Marine and Infrastructure
Email: marine_infra@trelleborg.com