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Introduction

Marine rubber fenders provide a critical role in the operations of ports. They allow several thousand tonne vessels to berth against vital infrastructure without damaging the wharf or the vessel. Use of fenders also allows the structural engineer to know the expected berthing loads which are critical to the design of the wharf as they are the products which turn vessel kinetic energy into known reactions when they absorb the vessel's energy.

Prior to PIANC publishing the document "Guidelines for the Design of Fender Systems" in 2002 [PIANC 2002] there was a lack of uniformity in how fender systems were designed, specified, and tested. Extensive reference to this publication will be made throughout this paper.

For a fender system to be designed and procured properly the consultant must perform each the following steps.

1. Determine the expected normal berthing energy of the vessel and then apply an appropriate factor of safety to establish the abnormal berthing energy requirement.
2. Select an appropriate fender inclusive of all correction factors that affect the nominal performance of the fender.
3. Verify from testing that the fenders produced for the project actually meet the performance requirements specified.

While most consultants understand the first step in this process many have only a vague understanding how to address the last two steps. Probably no other subject results in more

requests for assistance from fender manufactures than how to properly apply correction factors. Without a doubt there is no more misunderstanding or lack of oversite than of performance verification testing. This paper attempts to clarify each of these steps with a focus primarily on the topic of verification testing.

Why Use fenders?

It is important that the user have a clear understanding of why marine fenders are even used if the selection and verification process is to be performed correctly. There is one primary reason fenders are used and several secondary reasons.

- Absorb vessel kinetic energy (primary reason for using fenders)
- Provide a known reaction load for the design of the wharf
- Protect the vessel as well at the wharf
- Provide an easily replaceable component between the vessel and the wharf

Selection of Fenders

After a fender designer determines the estimated abnormal berthing energy it is time to select a fender equal to or greater than that energy. While doing so would seem straightforward it can be confusing for consultants or owners who are not specialist in fendering. Prior to PIANC 2002 the only factors typically considered in the fender selection process were the effects compression angle had on the fender's performance and sometimes the manufacturing tolerance, usually +/-10% of a fender's catalog performance. Two other important factors were being ignored, that being the speed at which the fender was being compressed and the temperature of the rubber fender at that time.

How to Select the Right Fender

The following equations can be used to determine a fender's corrected performance. The manufacturing tolerance is assumed to be +/-10%. Additional details can be found within the published whitepaper "Applying the right correction factors" [Trelleborg 2015].

Energy

$$(E_{nom})(AF)(VF)(TF_{High})(0.9) >= Ed \times Cab$$

Where:

E_{nom} is the nominal catalog energy capacity of the fender, or RPD if following PIANC methods.

AF is the manufacturer specific angular correction factor for the effective angle at which the vessel is berthing, or in the case of multiple fender contact, the highest angle at which any single fender is being compressed.

VF is the manufacturer specific velocity correction factor for the speed at which normal berthing occurs.

TF_{High} is the temperature correction factor at the highest expected service temperature.

Ed is the nominal calculated berthing energy (PIANC 2002 Section 4.2.1)

Cab is the factor of safety used to determine the "abnormal energy". (PIANC 2002 Section 4.2.5)

Reaction

$(R_{nom})(VF)(TF_{Low})(1.1) = R_{des}$

R_{nom} is the nominal catalog reaction of the fender selected that meets the E_{nom} calculated above.

VF is the manufacturer specific velocity correction factor for the speed at which the berthing occurs.

TF_{Low} is the temperature correction factor at the lowest expected service temperature.

R_{des} is the design reaction after accounting for all modifications to the fender's nominal performance. This is the estimated reaction used in the design of the wharf structure. It is also the suggested reaction used to design the fender panel system and its components.

PIANC 2002, Appendix D details two cases that demonstrate in more detail how to calculate the resulting energy and reaction values when using correction factors.

Performance Verification Testing

Performance verification testing, sometimes referred to as a Factory Acceptance Test, is a test performed on the actual fenders produced for a project. Rubber fenders are almost always manufactured to order as there are too many models, sizes, and grades to stock. To ensure the fenders were produced correctly and according to the particular specification of the intended project, some quantity are tested, usually 10%. These tests differ from the scale model testing performed to establish catalog rated performance values, RPD, or for determining the various correction factors which are described in PIANC 2002, Appendix A, sections 1 through 5. Verification testing is testing of "your" fenders, not prototype fenders. This is described in Appendix A, section 6.

How to Perform the Verification Test

Performance verification testing is usually performed in a large press or test frame with either load cells or pressure transducers, which are installed in the hydraulic circuit of the press, measuring the load and a displacement transducer for measuring the deflection. Consideration must be given to the sheer size of even a mid-sized rubber fender. Besides the large specimen size, testing or rubber fenders requires more stoke, or deflection capability, than most frames can produce. There are a limited number of publically available test frames around the world capable of testing rubber fenders. For this reason performance verification testing is almost always performed at the manufacturer's facility. There are significant reasons that should cause pause with the user when he elects to test their fenders at the manufacturer's factory. These reasons will be discussed later.

Break-In Cycles

Before a fender's performance can be verified it must first be subjected to a number of break-in cycles. When the fenders were molded a number of weak or temporary bonds are formed in the rubber that must be broken so that the fenders performs in a repeatable fashion. The first two or three deflection cycles on a newly molded fender are not indicative of the fender's performance in service. The first cycle in particular can be as high as 30% greater than its actual performance. Once the fender is broken in it will never achieve these high levels of reaction again.

Constant Velocity vs. Decreasing Velocity

PIANC 2002 allows for performance verification testing to be performed using either the Constant Velocity, CV, or Decreasing Velocity, DV methods noted in PIANC 2002 Appendix A, section 4. A few manufacturers have built full scale dynamic test frames that can simulate actual berthing speeds during the testing of fenders, but most have not. This is not a problem as PIANC 2002 was written specifically to address the fact that most manufacturers can only perform verification testing using the CV method. If available, testing using the DV method has the advantage that the results do not need to be velocity corrected which leads to more accurate results.

How Correction Factors Apply to Verification Testing

The correction factors mentioned earlier actually serve another purpose [Figure 1]. They may be necessary to correct the performance established during performance verification testing if the fender is tested outside of the required test speed or temperature range.

Correction factors used to specify the fender are to account for site conditions such as temperature and berthing velocity that vary from the nominal performance of the fender. Correction factors applied to the performance varication tests are to account for testing conditions that exist at the time of the test. These are usually limited to the effects of temperature and velocity during testing. Few fender test frames are located in climate controlled facilities. Even fewer are capable of testing at the actual velocities used to determine the berthing energy.

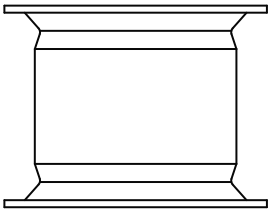
- When selecting a fender correction factors are used to account for the conditions under which the fender must operate that differ from the nominal catalog rated performance.
- When performing verification testing of a fender the correction factors are used to modify the test results so that the fender's nominal performance can be determined.

PIANC 2002 requires that performance testing using the CV method be performed at a speed of 2 to 8 cm/min and with a temperature range of 23°C +/-5°. If the performance verification test is completed outside of either of these parameters then the results must be corrected so that the results reflect the fender's nominal performance. How the test results are corrected depends on how the fenders were rated.

If the fender's catalog rated performance is published using PIANC RPD values based on the recommended 150 mm/s compression speed then the results must be velocity corrected to determine the catalog rated nominal performance within tolerances. If the fender's catalog

rated performance is based on CV test results, then no velocity correcting is necessary as long as the verification test velocity was between 2 to 8 cm/min. If the corrected performance verification test results meet the nominal performance of the fender within manufacturing tolerances then the fender is assumed to have passed the test.

Fender selection and performance verification test procedure based on CV catalog rating and CV performance verification testing



Selecting a fender for use

- Calculate berthing energy
- Use VF based on berthing velocity to correct both Reaction and Energy values
- Use TF based on site low temperature to correct Reaction value
- Use TF based on site high temperature to correct Energy value
- Use AF based on the effective berthing angle to correct Energy value
- Use +10% manufacturing tolerance to correct reaction value
- Use -10% manufacturing tolerance to correct energy value
- If corrected fender reaction is below allowable for the structure AND the corrected fender energy is above calculated abnormal berthing energy THEN the selected fender is acceptable for the design

Performance verification testing

- Stabilize fender temperature as recommended by PIANC 2002
- Break-in fender with a least 3 cycles to design deflection or greater
- Wait a minimum of one hour
- Test fender and record load vs. deflection data
- If fender test speed is outside of 2 to 8 cm/min. use VF to correct both Reaction and Energy values
- If fender test temperature is outside of 23°+/-5° use TF to correct Reaction and Energy value to standard test temperature
- Test at 0° angle so no angular correction necessary
- After correcting for test speed and test temperature fender Reaction shall be less than 110% of catalog reaction
  Energy shall be greater than 90% of catalog energy

Figure 1 - Fender Selection and Verification Testing Workflow.

Ramifications of Out of Specification Fenders

Little thought is given by the fender designer as to the consequences of installing an out of specification fender. There are two primary concerns if the fender specified is not the one being installed.

Energy absorption below specified value

> When the fender is incapable of absorbing the specified energy it is very likely the wharf will experience loads much higher than anticipated. The kinetic energy of the vessel must go somewhere, it can't simply disappear. When a fender does not have adequate energy capacity it will undergo an extreme increase in reaction with very little additional deflection. Since energy is defined by the product of reaction and deflection, the additional energy absorbed is very little when the fender is compressed beyond its design reaction. In that instance something else must deflect, either the vessel hull or the wharf itself, to absorb the excess energy. Since neither the vessel hull nor the wharf itself is intentionally designed to deflect there is little chance they will do so in the elastic range.

Reaction above specified value

> When the fender being installed is above the specified reaction there is the possibility that the wharf will see unacceptable reactions. A high stiffness fender can have as much as twice the reaction of a low stiffness fender of the same size. Given that live load factors are usually 1.6, it is quite easy for the fender to produce reactions far in excess than that anticipated. This has very serious consequences for load sensitive structures such as fenders installed on monopiles.

The Problems with Current Industry Testing Practices

There are several serious concerns with the way fender performance verification testing is currently performed. Some of these concerns mainly involve the authenticity of the reported performance as very little thought is given to the need for independent certification of the reported test results.

Why Verification Testing Cannot Be Left to the Manufacturer

When testing is performed at the factory the fender being tested can easily be selected especially for the test and not randomly selected. Manufacturers can build special test fenders that will pass the test and build the remaining production run with substandard materials.

Testing results can also be manipulated for commercial reasons. It is much less expensive to build a low quality fender that does not meet performance requirements and just manipulate the test results than to build it to the requirements.

An Inconvenient Truth About Witnessed Testing

Common practice in the industry has relied on factory testing with witnessing by either a 3rd party or by the consultant. There are several reasons why this is inadequate with the primary reason being there is no easy way for a witness to verify the results independently of what

the manufacturer is reporting. Modern data acquisition methods rely on computers to interpret the data and produce a report. The witness rarely has any understanding of how the data acquisition system functions. There is little difficulty in manufacturer adjusting the recorded data inside the computer without the witness's knowledge.

Many project specifications require a 3rd party inspection agency witness the test. It should be absolutely clear that they are indeed only doing just that, witnessing a test. They do provide any oversight on how the test data was acquired or if the report they are asked to stamp is even from the test they just witnessed. The inspection agencies are not in any way guaranteeing the validity of the data they are stamping. If the data being stamped and presented to the customer for acceptance cannot be guaranteed then what useful purpose does the test serve?

Independent construction materials testing is a common practice in the construction business. Why is it not standard practice in the verification of fender performance when it has such a critical effect on safety and protection and valuable assets?

"Trust But Verify" But how?

Independently verifying fender performance during the performance verification test is not easy, but it is critical if the intended performance of the fender is to be guaranteed.

Independent verification testing is possible with one of two methods.

- Testing at an independent structural laboratory
- Testing at the manufacturer's factory using their test frame but independently recorded performance data.

Each of the two methods has its advantages and disadvantages

Independent Laboratory

Testing at an independent structural laboratory is the easiest method to verify performance. These laboratories have large test frames capable of generating high loads on large specimens.

The advantages of independent laboratory testing include:

- The laboratory is a 3rd party testing laboratory that has no incentive to manipulate the results.
- No purchase of additional equipment is usually needed to perform the test.
- The laboratories are often located in climate controlled buildings eliminating the need to accommodate changing temperature conditions or having to deal with weather. Therefore, no temperature correction of the results is necessary.
- The results, including raw data, can be available for review by the consultant or the end user.
- Laboratories are often nationally accredited

The disadvantages of independent laboratory testing include:

- There are a limited number of these test laboratories available around the world.

- Time must be allowed in the schedule for the fender test specimens to be delivered to the testing laboratory which may be some distance from the jobsite.
- The fenders to be tested should be from the full lot delivered to site to avoid the manufacturer attempting to prepare special fenders for testing purposes.
- There is a cost associated with testing, but the costs for a reasonably size project are usually only 2% to 4% of the value of the fender contract.
- There is a limit to the amount of stroke on any test frame and fenders, with their unusually high deflection requirements, can exceed the abilities of even the largest test frames.

Manufacturer's Facility

Manufactures are accustomed to the specific needs for fender testing and they are already setup to easily test fenders at their factories.

The advantages of factory testing include:

- The large test frame needed to compress the fender is available.
- Convenient in that the fenders are usually made in the same factory, so no logistics to consider.
- Other inspections of the fenders such as build quality and dimensions can occur during one inspection visit.

The disadvantages of factory testing include:

- The consultant or independent inspector has no way to verify that the data being generated during the test is authentic. There are numerous ways in which a manufacturer can manipulate the results without raising any suspicion.
- The factories are almost all located in faraway foreign countries where even getting there can be problematic. There is potential foreign language difficulties to deal with including the specific language on each of the pieces of equipment used for the test as well as the computer used to collect the data.

It is time for the fender industry to accept that performance verification testing needs to be done independently, or at least outside of the manufacturer's control. There is simply too much an incentive for the manufacturer to just "make it pass" when such large contracts at high dollar amounts are at stake.

Ways the Industry Could Offer True Independent Testing

While the industry moves towards true independent testing and not just witnessed testing the simplest way to get trustworthy results is to use an independent laboratory. This is assuming there is one convenient for your use available and you dedicate the funds and time to carry out the test at an independent laboratory.

The long term goal for the industry should be for manufacturers to offer testing at their own facilities but with results guaranteed to be independently recorded and guaranteed by an inspection agency. Doing this will require the industry to adopt standards and methods that are easy to implement, cost effective, and easy to understand by independent inspectors and consultants.

The industry should develop a PIANC or ISO working group to write a specification on how 3rd party inspection companies can verify performance, not just witness it.

Recommendations

It is recommended that the user not rely on simple witness testing to determine performance. The person witnessing the performance verification test probably knows less about fenders than you.

A way needs to be established to verify the load vs. deflection data outside of the control of the fender manufacturer. The real time data should be shown on an external display and the results printed in real-time so the witness has direct access to the data. This method is only useful if the load sensing system is calibrated by an independent agency just prior to the performance verification testing.

PIANC needs to establish methods and procedures that give confidence in the performance verification results being reported.

Consult with well-known 3rd party inspection agencies to determine the feasibility of offering certified inspectors that understand how to use the independent test equipment that will be made available for performance verification purposes. The agency should be able to certify the results, not just serve as a witness to the testing.

Summary and Conclusions

The subject of specifying fender systems and verifying performance is not a difficult subject to master if proper attention is given to the subject. Given the importance of fenders in protecting the wharf and vessel it is difficult to understand how little attention some users give to the procurement of fenders. No matter how well the designer understands the fender specification process it will hardly matter if the performance verification testing is not independently verified.

References

PIANC 2002, *Guidelines for the Design of Fender Systems: 2002, Report of Working Group 33 – MARCON, PIANC, Brussels, Belgium.*

Trelleborg 2015, *Applying the Right Correction Factors, Trelleborg Marine Systems, www.trelleborg.com/marine.*