PARALLEL MOTION FENDERS; SOME DESIGN CONSIDERATIONS, INCLUDING THE IMMERSION OF FENDER CONES

by

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MOTS-CLEFS

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1. INTRODUCTION

Parallel motion or 'PM' fenders are a relatively recent development in fender technology and there is currently no published guidance for their design. PM fenders offer a number of advantages but are significantly more complicated in their mode of operation than conventional fender systems; PM fenders can be less tolerant of exceptional berthing events outside the design envelope. The loadings within the PM mechanism can be difficult to define, especially when an angled berthing is combined with sliding frictional forces. A number of PM fender installations have experienced structural problems; this article considers how some of these problems might be avoided.

2. WHAT IS A PARALLEL MOTION FENDER?

2.1 Conventional fenders

In locations where there is little tidal range single level fendering systems can be used; a simple fender may consist of a rubber unit fixed to or suspended from a quay edge but for larger vessels where it is necessary to spread the fender reaction force over a larger area of the vessel's hull plating a fender panel is usually provided; the panel will typically be backed by energy absorbing rubber fender units. A wide range of fender units of various shapes is available but cellular units, and particularly cones, are popular because they are stable and efficient in that they provide large energy absorption for their size. Where there is little tidal range the fender panel and rubber unit are unlikely to ever be immersed in the water.

In locations with larger tidal ranges, such as the UK, a fender panel on a single fender unit is often insufficient and a ship, or her belting if she has one, might get beneath the fender panel at low tide. The solution is to use a taller panel to provide a contact surface throughout the tidal range. This tall panel will require at least two fender units behind it, one near the top and one near the bottom. The bottom unit will inevitably be immersed at high tide.

The tall fender panel is effective but it has a number of disadvantages. For an impact near the top or bottom of the panel only the upper or lower fender unit (assuming there are just two) will be compressed so each fender unit has to be designed to be capable of absorbing all the ship's berthing energy. When a berthing occurs at mid tide the energy is shared between both fender units which are compressed more or less equally; as a result the overall fender reaction is stiffer than during a top or bottom impact and the reaction force on the ship and the support to the fender unit is greater. This increased reaction force may not be of much consequence when the fender is mounted on a solid structure such as a quay wall but if it is mounted on a piled dolphin the reaction force can have a significant impact on the dolphin's design and therefore its cost.

A further disadvantage with the tall panel is that when a ship with a belting contacts the panel near the bottom the panel angles outward so that the top of the panel can strike the ship at high level. This has caused difficulties for vertically sided ships with windows or vents at high level which have been damaged by fender panels. It is also a difficulty for lightweight ships built of aluminium which can only accept fender loads on their beltings.

2.2 PM Fenders

PM fenders were conceived to overcome these shortcomings of conventional fenders. A PM fender consists of a fender panel, similar to a conventional panel but backed by only a single fender unit (or pair of units mounted together) at its centre. To support the fender panel and to restrain it so that it is always vertical, it is mounted on a pair of arms which project from a torsion tube. The connection between the arms and the panel is hinged and the torsion tube itself is mounted on hinges. Figure 1 shows the arrangement of a typical PM fender although a number of different geometries have been used including some double arm scissor arrangements. In practice the panel does not remain truly vertical due to deflection of the PM mechanism and play in the hinges.

The articulation of the hinges in the system permits the panel to rotate in plan and to move backwards from the berthing line compressing the fender unit

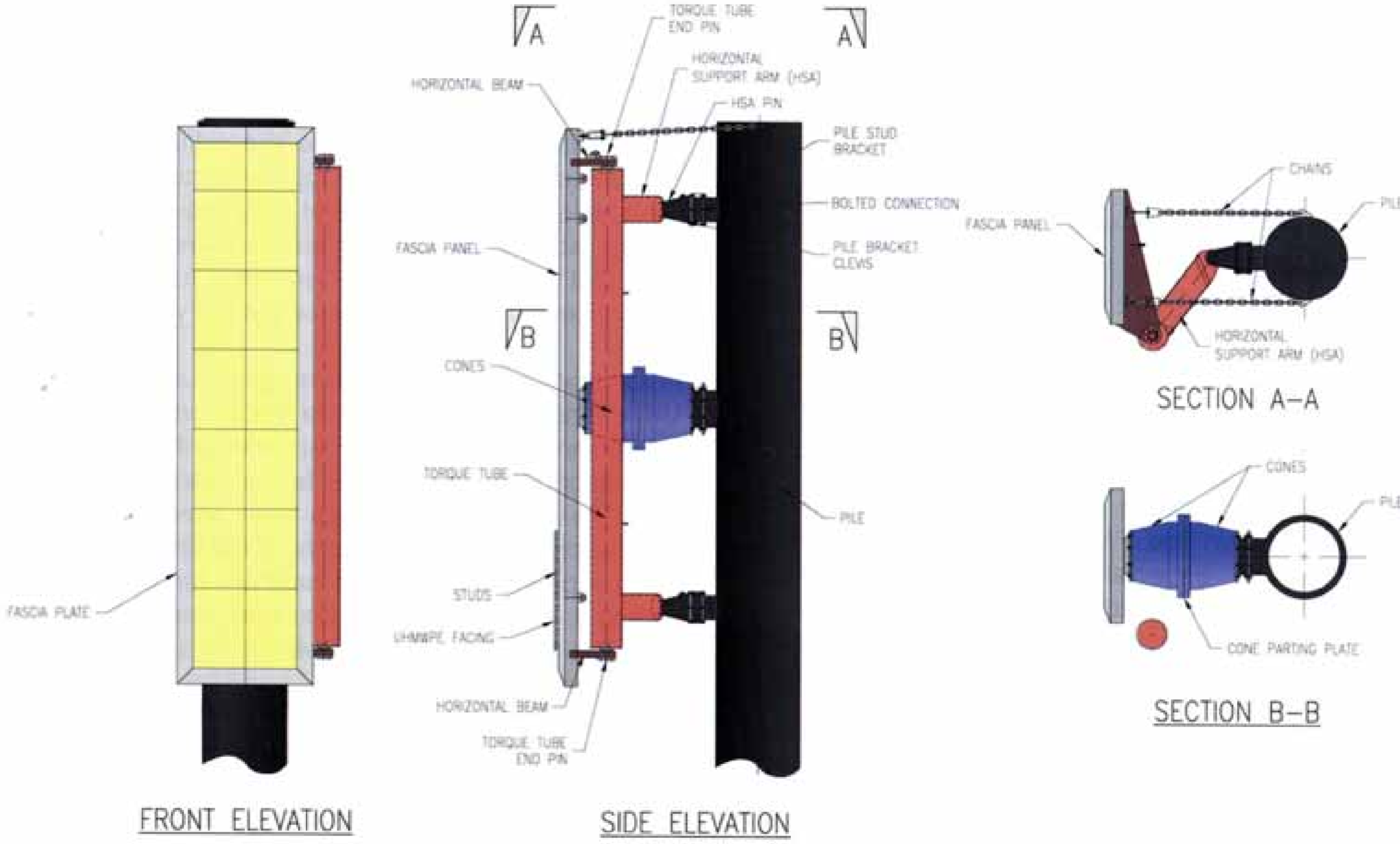

Figure 1: General arrangement of typical parallel motion fender (drawing courtesy of Tony Gee & Partners)

but the mechanism does not allow the panel to move vertically or longitudinally.

If a vessel impacts the PM fender panel at mid height then the load is transferred directly into the rubber units. If the impact is near the top of the fender panel then the reaction force is transferred into the upper arm which in turn applies a torsion to the torsion tube which is resisted by a moment applied by the lower which pulls the bottom of the fender panel away from the ship. The panel is therefore moved away from the berthing line by a combination of the ship impact at the top and the torsion arm tension at the bottom. Resisting the action is the rubber unit in the centre of the panel. Under the influence of these three forces the fender panel is subject to a bending moment. If the ship contact is near the bottom of the panel then the action is similar but the force in the arms and the torsion in the torsion tube is reversed.

This relatively simple load path becomes more complex when secondary forces are taken into account. Because the fender panel is mounted on radial arms it does not move back from the berthing face perpendicularly but in an arc. This radial movement imparts a forced shear into the rubber fender units as they are compressed which needs to be taken into account in the calculation of the unit's performance.

The radial motion also causes the fender panel to slide horizontally along the ship's side as it compresses which, through friction at the contact surface, imparts a horizontal force into the fender panel. Typically fender panels will be faced with a low friction facing such as UHMW-PE panels but the actual coefficient of friction very much depends upon the condition of the ship's side or belting and an uneven belting can significantly increase the horizontal load in the panel's support mechanism. The effect can be exacerbated if the vessel is moving along the berth while the fender is being compressed. Unlike conventional fenders which will tend to deflect to shed loads which are not applied perpendicular to the berthing line, a parallel motion fender has no such ability, due to its inbuilt geometry.

2.3 Fender edges

Fender panels are generally fitted with top and edge chamfers. The top chamfer is to protect against a belting over-riding the panel and then bearing down on the panel's top edge as the ship rolls. If this happens to a conventional fender it can usually deflect sufficiently on its rubber supports to absorb the impact. If it happens to a PM fender then there is no give in the support mechanism other than by deflection of the steelwork. The top flare needs to be large enough to accommodate the largest belting and the panel support mechanism needs to be designed to carry the vertical component of the fender reaction when applied to the angled flare.

The side flares are required to accommodate angled berthing and irregularities in the ship's side as she moves longitudinally along the berth. Most PM fender systems are asymmetrical in their design with the fender reacting differently to an angled berthing on one side to the other. This difference is partly the result of the shear on the rubber fender unit being either ameliorated or compounded depending upon which way the panel is angled. However the asymmetry becomes a more significant factor if an angled berthing is combined with horizontal friction from longitudinal movement of the ship. Under this combination of effects the horizontal force either works with the support mechanism's movement or, if the first contact is on the torsion tube side of the panel, the friction can work to prevent the free movement of the mechanism which will greatly increase the axial load in the torsion arms.

Compared to a conventional fender the design of a PM fender involves the consideration of very many more variables and the interaction between these variables is complicated. PM fenders are generally bespoke in that they are purpose designed for each installation. So while they can offer cost savings on the design of their supporting dolphins this is to a degree offset by the increased design complexity and therefore design cost. More concerning for clients is perhaps the absence of design guidance for PM fenders and the high maintenance cost which can result from an inadequately designed PM fender.

3. SOME PM DESIGN DEFECTS

3.1 Failure history

PM fenders have been in use for over ten years and in this time they have experienced a number of failures; as with any fender system some of these failures can be attributed to abnormal events and abuse but other failures are the result of the relative complexity of the PM system and a lack of appreciation of the interaction of the various forces in their design. All the examples of defects that follow have occurred early in the life of the fenders, generally within the first two years of use.

3.2 Torsion arms

The most common structural failure on PM fenders is to the torsion arm to torsion tube joint; typically this manifests itself in the heat affected zone of the joint weld and in most cases the cracking starts at the 3 o'clock and 9 o'clock positions which indicates that it is the normal operation of the fender rather than a top edge loading that has caused the failure. The failure is indicative of inadequate design of the joint and remedial work has been done to a number of PM fenders by adding gusset plates to the joint. Figure 2 shows one of these joints with a cracked weld.

Figure 2: A torsion arm to torsion tube joint with cracked weld

3.3 Bearings

The bearings of a PM fender are critical to its performance; there are typically four bearings, two at high level and two at low level. The low level bearings can spend much of their life under water and can therefore be difficult to inspect and maintain; they need to be designed accordingly.

Manufacturers of PM fenders offer 'sealed for life' bearings consisting of a stainless steel pin within spherical composite bearings within a sealed housing. Some manufacturers offer a remote greasing facility as an optional extra. The life of a sealed bearing is very much dependent upon the functioning of its seal and whether a seal can be relied upon for the 15 year or so design life of a fender system is questionable. Figure 3 is a photograph of a 'sealed for life' bottom bearing from a PM fender after only two years in service; the bearing was not fitted with a greaser. Externally the bearing showed no defect but when it was disassembled it was found to be full of silt and corrosion product. Remote greasers are an additional cost but they do improve the chances of keeping silt out of the bearings, provided they are combined with a proper maintenance regime.

Apart from seal failure PM fenders have also experienced failures of the bearing pin in bending although whether this is the result of inadequate design or other factors is still to be determined.

Figure 3: Inside a PM bottom bearing after two years in service

3.4 Panel facings

Inadequate facing panel fixings is a defect which occurs on all types of fenders but the consequences of the resulting increase in friction forces has greater significance for a PM fender than for a conventional fender. Loss of UHMW-PE panels can occur where the panel fixing relies upon studs welded to the panel face; if the studs are of inadequate diameter or the stud welds are inadequate the studs shear off under the friction load. Figure 4 shows an example of the failure of stud welds on a PM fender panel. An improved detail is to weld shear bars to the panel face so that the transfer of shear force does not rely on the studs alone.

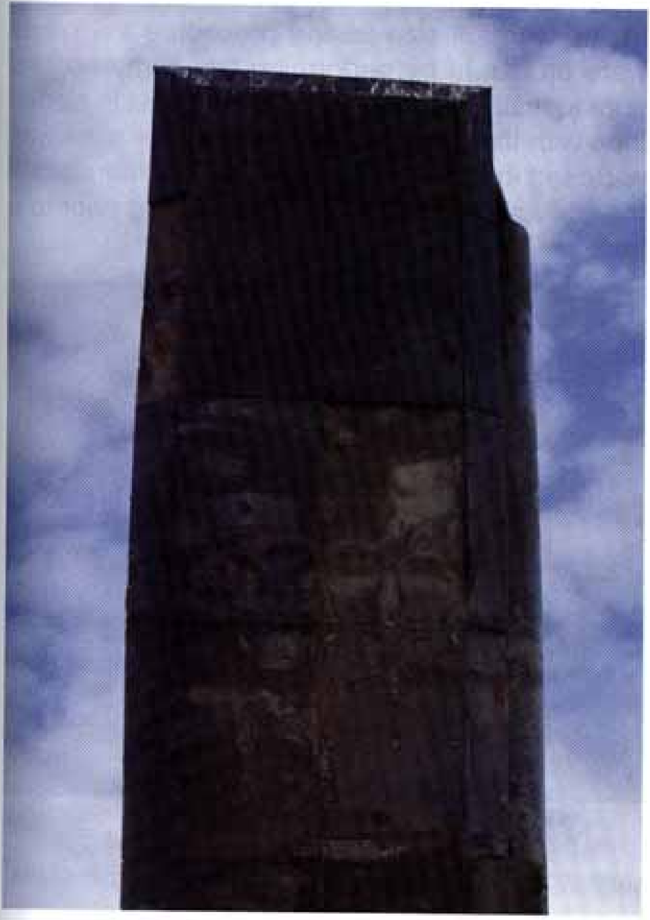

Figure 4: Loss of facings due to failure of fixing stud welds

3.5 Fender Cones

On many PM fenders the energy absorbing unit is a rubber fender cone, or pair of cones, mounted back to back in series. In this case the outer cone is usually a softer rubber compound than the inner one in order to provide a more progressive reaction force. On a PM fender the cones will be mounted at around mid tide and therefore will be immersed in water at high tide. The effect of the immersion of cones is not unique to PM fenders but the significance of cone immersion has only been appreciated as the result of PM fender failure analysis.

Cellular fenders such as cones and cylinders contain a void space which is normally filled with air; as the unit is compressed it buckles and the volume of the void is reduced. The fender units are provided with grooves or flutes cast into their bases to enable the air trapped within the unit to escape. The cross-sectional area of the flutes on some manufacturer's cones do appear small in relation to the size of the void within the cone.

Fender manufacturers publish fender performance data which is derived from tests carried out on their fender units in air. To my knowledge no manufacturer publishes performance data for their fenders when immersed in water. Furthermore I am unaware of any manufacturer or technical standard that advises designers that the performance of an immersed cellular fender can be very different from one in air.

Intuitively one would expect water within a unit such as a cone to have the effect of stiffening the cone and increasing its reaction force; air within the cone is compressible but water is not so, with a restricted exit via the flutes, the pressure within the cone can be expected to be higher when an immersed cone is compressed. The flutes that manufacturers mould into their cones are designed only for use in air; they are typically the size of a small barnacle and when the unit is mounted at mid tide the flutes can become rapidly blocked by marine growth. Figure 5 shows cone flutes filled by barnacles while Figure 6 shows a damaged cone where it can be seen that the barnacle growth extends the full length of the flute. The effect of this marine growth is to reduce the effective cross section of the flute to a small fraction of its original dimension.

Figure 5: Barnacles filling fender vent flutes

Figure 6: The barnacle growth extends the full length of the flutes

There are practical difficulties in carrying out full scale tests on immersed fender units especially if the effect of blocked flutes is also to be tested; the risk of a burst cone is probably not one that any testing laboratory would be willing to bear. Tests on model cones are less hazardous and City University carried out a series of model tests in 2007 as part of an investigation into the cause of a PM fender failure; the following summary of their findings is reproduced with their consent.

City University's tests were carried out on a pair of model rubber fender cones with a 288 mm diameter at the base and 178 mm diameter at the top, the internal depth of the cones was 157 mm. The cone under test was mounted base up in a 250 kN capacity test rig sitting on a spacer plate to enable a 70 % deflection of the cone to be achieved. A stiff circular plate was fitted to the upper (open) end of the cone through which the load from the test rig was applied. The circular plate was fitted with a pressure transducer to enable the internal pressure within the cone to be measured during the test.

Into a threaded hole in the circular plate could be screwed plugs with orifices of different sizes to simulate different degrees of blockage of the flutes. The initial orifice size was chosen as 5 mm diameter as this size was calculated to match the Reynolds number through the flutes of the full sized cones. The other plugs had a 4 mm and a 3 mm diameter orifice. A 3 mm orifice represents a 64 % reduction in cross-section area compared to a 5 mm orifice which is much less of a reduction in area than that shown in figures 5 & 6, but City University feared that using a smaller orifice would risk bursting the cone.

Tests were carried out measuring the cone reaction force against deflection at three different rates of compression, 10 mm/s, 15 mm/s and 20 mm/s. In line with full size testing procedure the cones were broken in by performing two compressions prior to testing. The tests were done first in air and then with the cone filled with water; the cone was enclosed in a perspex box to contain the ejected water. Figure 7 shows a cone in the rig prior to a test.

Figure 7: A cone mounted in the test rig; the digital readout shows cone internal pressure

3.6 Test results

A number of tests in air were carried out first and after 10 full compressions it was found that the reaction/displacement curve was essentially unaffected by the compression rate within the 10-20 mm/s test range. A further 9 tests were then carried out at the three speeds for the three sizes of orifice. The combined results of these tests is shown on the graph at Figure 8 with the solid red line being the result of the test in air.

In the early stages of the cone's compression there is little change in its internal volume so up to around 30 % compression water within the cone has negligible effect. As the compression increases further the effect of water becomes marked, especially for the smaller orifice and faster compression

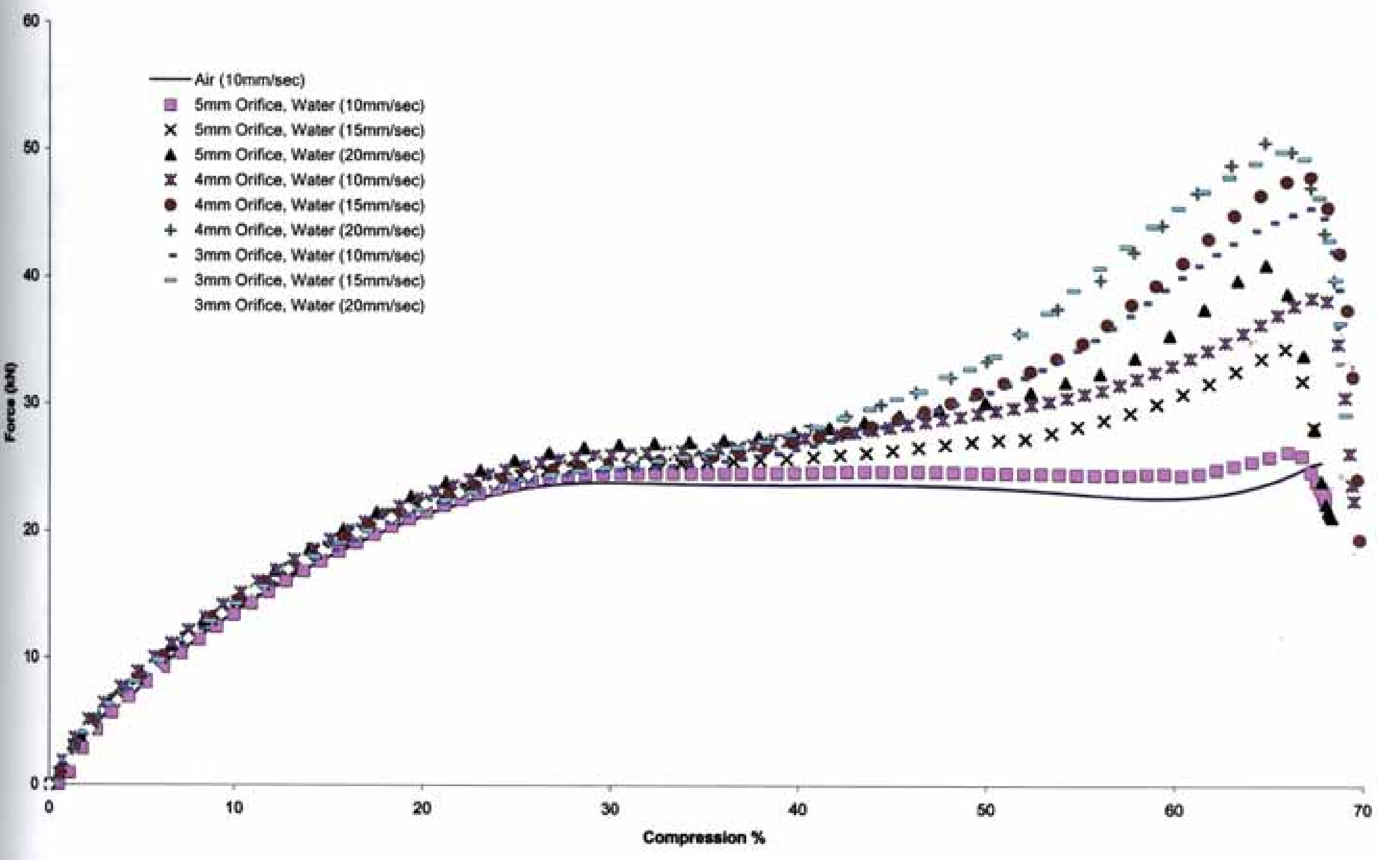

Figure 8: Model fender cone laboratory test results

speeds. While scale effects mean that the results need to be treated with caution the indication is that water within a cone might increase the cone reaction force by around 100 %, particularly if marine growth is present. Further testing, ideally at full scale, would be desirable to verify these findings but in the meantime designers should consider providing alternative means of venting for cellular fenders mounted below high tide level.

4. CONCLUSIONS

Parallel motion fenders are a useful addition to the range of fender designs available to a port designer; they are particularly useful in locations with a large tidal range where it is necessary to prevent the top of a fender panel contacting a ship's upperworks during a low tide berthing. Selecting a PM fender design on account of its ability to provide a lower reaction force on a supporting dolphin than a conventional fender panel requires caution. A PM fender is subject to significantly more complicated forces than a conventional fender and a well designed and constructed PM fender will inevitably be significantly more expensive than a conventional one.

In most applications a PM fender will need to be purpose designed for that location; as such it will be a 'bespoke' rather than a 'proprietary' design. Clients and specifiers should ensure that any PM design is adequately checked by an organisation experienced in PM fender design.

In situations where a PM fender's benefits of panel verticality and lower reaction force are not a necessity then a simpler conventional fender system may be a more appropriate solution.

Cellular fenders installed below high tide level should be provided with vent holes large enough to enable the free escape of water, even when the vent is fouled by marine growth.

SUMMARY

Parallel motion (PM) fenders are a relatively recent development in fender technology. PM fenders have two significant advantages over conventional fender units in that they remain close to vertical when compressed by an off centre berthing impact and they produce a reduced reaction force on their supporting structure. PM fenders are however significantly more complicated in their structural form than conventional fender systems and the loading within a PM mechanism can be difficult to determine. Perhaps as a result of this complexity PM fenders have experienced a number of structural failures in service. This article considers the reasons for some of these failures. The use of cellular rubber fender units below water level is one possible cause of fender failure and results from tests on model fender cones immersed in water are reported. These test results have significance for the design of any fender system where cell units are installed below high tide level.

RÉSUMÉ

Les défenses d'accostage à translation (défenses PM) sont un développement relativement récent de la technologie des défenses d'accostage. Les défenses PM ont deux avantages significatifs sur les défenses d'accostage traditionnelles : elles restent proches de la verticale quand elles sont comprimées par le choc d'un accostage décentré et elles provoquent une force de réaction réduite sur l'ouvrage qui les supporte. Les défenses PM sont néanmoins significativement plus compliquées dans leur forme structurelle que les systèmes de défense traditionnels et les efforts dans leur mécanisme peuvent être difficiles à déterminer. Peut-être en raison de cette complexité, les défenses PM ont connu nombre de ruptures en service. Cet article étudie les raisons de certaines de ces ruptures. L'utilisation de défenses alvéolaires en caoutchouc en dessous du niveau de l'eau est une cause possible de la rupture de défense et des résultats d'essais sur des modèles de cônes immergés sont publiés. Ces résultats d'essai peuvent être utilisés pour la conception de tout système de défense d'accostage dans lequel des éléments alvéolaires sont installés en dessous du niveau des plus hautes eaux.

ZUSAMMENFASSUNG

Parallel verlaufende („Parallel motion", PM) Fendersysteme sind eine relativ neue Entwicklung in der Fendertechnologie. PM Fendersysteme haben gegenüber konventionellen Fendersystemen zwei bedeutende Vorteile: sie bleiben nahezu senkrecht, wenn sie durch einen dezentralen Stoß auf den Anleger zusammengedrückt werden, und sie erzeugen eine verminderte Reaktionskraft auf das sie stützende Bauwerk. PM Fendersysteme sind jedoch in ihrer Struktur komplizierter als konventionelle Fendersysteme und die Belastungen innerhalb eines PM Fendersystems können schwierig zu bestimmen sein. Vielleicht haben PM Fendersysteme als Ergebnis dieser Komplexität eine Reihe von strukturellen Versagensfällen im Betrieb erfahren. Dieser Artikel betrachtet die Gründe für einige dieser Versagensfälle. Die Verwendung von Zellkautschuk-Fendern unterhalb des Wasserspiegels ist ein möglicher Grund für ein Versagen der Fender und es wird über Ergebnisse von Versuchen mit im Wasser eingetauchten Modell-Kegel-Fendern berichtet. Diese Versuchsergebnisse sind für die Gestaltung aller Fendersysteme, bei denen die Zelleinheiten unterhalb Tidehochwasser installiert sind, von Bedeutung.