CHAPTER 203

An Adjustable Marine Fender System programmed with the Aid of Numerical Models in order to minimize Berthing and Mooring Loads

Tj. J. Risselada M.Sc.*
&
C. Deelen M.Sc.**

1. Introduction

An adjustable marine fender system, programmed with the aid of mathematical models, can substantially contribute to safer berthing and mooring of ships with various water displacements, operating at high or at low speed under varying wind, wave and current conditions. This doesn't only imply a reduction of risks to vessel and terminal structures but also in case of exposed sites or of unruly waters, a - possible substantial - reduction of ship's costly down-time.

2. The adjustable fender system

2.1. Why an adjustable fender?

Fenders as an interface between ship and rigid or resilient structure (viz. flexile dolphin) are an indispensable protective element both when berthing and when moored. More and more one has become aware that fenders designed to take a certain amount of energy fail to actually dissipate this energy and instead return it to the ship again (the recoiling effect) like the billiard ball against the table frame. Even in a sheltered port like Rotterdam with only modest tidal currents and with ample tug assistance the occurrence of such recoiling effect is not only known but at times even felt as a potential source of risk. This is illustrated in Fig.1 where a ship's movements fore and aft during berthing are rendered, Ref(1).

Also cases are known where the velocity of the far end of the vessel markedly increased or where the velocity during the second approach considerably exceeded that of the first.

This recoiling effect can be observed both when berthing and when mooring alongside. With regard to berthing the fenders are designed to take a certain amount of energy generated by a ship with a certain water displacement hitting them at a certain speed.

Other design specifications, apart from the area of the protective panel, hardly ever are given, primarily so because such specifications thusfar hardly were computable.

* Risselada & Partners, Consulting Engineers, Rotterdam.
** Nautical Research Engineer, Port of Rotterdam Authority.
(former Project Engineer, "Delft Hydraulics").

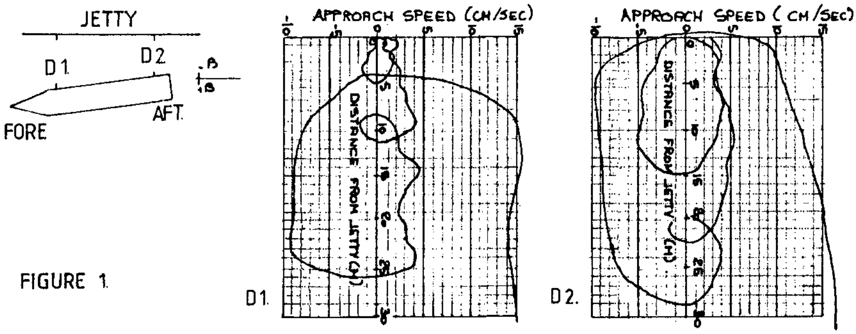

FIGURE 1.

Ships moored alongside an offshore terminal and subject to certain types of waves, or ships moored in a protected harbour and subject to long period waves or seiches might show a very unruly behaviour. In case of swaying and sometimes in case of rolling ships's motions are aggravated instead of dampened when the fenders are not capable of dissipating a sufficient amount of energy or don't possess the required resilience. Also here pertinent specifications lack, be it that a good deal of investigation has been conducted into the functioning of mooring systems as a whole wherefrom it was established that soft fenders perform better.

Basically the problem of recoiling, irrespective whether in case of berthing or of being moored alongside, depends on the degree of hysteresis that occurs in the fender.
None of the current types of fenders is able to meet the demand of economically absorbing a large amount of energy without attaining an excessive compression force and at the same time possesing a high degree of hysteresis, (see reaction force compression and decompression diagrams of Fig.2a, 2b and 2c). Therefore, if not dictated by the outcome of a tender, the as most suitable selected fender(system) can at the best be a compromise on basis of experience.
A universal fender system capable of simultaneously meeting the often conflicting requirements of providing both smooth berthing and quiet mooring facilities under varying wind, wave and current conditions to larger as well as to smaller ships, fully laden or light, can only be achieved by resorting to an adjustable type of fender.
The load/(de)compression relation can now be established more or less arbitrarily, whilst the maximum height of the compression curve is confined by the permissible inside overpressure and the depth of the decompression curve is determined at zero overpressure (see Fig. 2d).
The application of such a universal system implies that first suites of fender characteristics, dealing with every possible situation, must be determined, which necessitates.

a) to thorougly know the wind, wave, and current climate;
b) to have an overview of the type and loading condition of all ships that are going to use a terminal and of the conditions whereunder;
c) to be familiar with the devices and aids for efficiently and reliably accomplishing the successive adjustments to the fender system.

The reguired characteristics can be determined by means of a whole series of scale model tests in a laboratory, but this actually would be prohibitive in view of time and cost.

2.2. The role of numerical models.

However since "Delft Hydraulics" has developed special numerical models to expedite this kind of research, there is no justification any longer for not drawing up more extensive and precise specifications. This in particular applies to terminals off shore or in exposed areas and to sheltered basins where long period waves or swell can penetrate. Thanks to the computer programs "BOTS" and "BAS" fender loads can be quintified more readily, thus enabling to quickly and rather inexpensively determine the required characteristics.

The program "BOTS" applies to ships hitting a resilient body, viz. a flexible dolphin or a rigid structure fitted with fenders. An extrensive description of this program can be found in Ref(2). The phenomena governing these collision processes are highly complicated. Conventional design methods often based on the energy to be absorbed during berthing manoeuvres fail to produce reliable results. A proper mathematical description includes the memory effect in hydronamic forces during the entire collision. This memory effect can be described by impulse reponse theory.

The fluid reactive forces are accounted for by means of frequency dependent hydrodynamic coefficients with regard to the added mass and to the damping, dependent on the ship's hull, water depth, and frequency and direction of motion. By integrating the impulse response functions the behaviour of the total ship-fluid-fender system can be determined. Hence for any specific case it can be computed how the characteristics (viz. kinetic capacity, spring stiffnes and damping power) should be in order to optimize the berthing procedure.

The computer program "BAS" (see Ref(3)) enables to calculate the motion response of the moored ship and the resulting hawser and fender forces for ships subject to every combination of external wind, wave and current forces.

As due to non-linear characteristics of the fender system, the classical solution of cumputing transfer functions by transformation of the equations of motion to frequency domain can not be used, these equations are solved here in the time domain. The main restriction of many mathematical models is that the calculation of the wave exciting forces makes use of linear first order diffraction theory. Present development at "Delft Hydraulics", however, also deals with the calculation of second order slowly varying drift forces.

Once all typical characteristics being known one can thus in conjunction with nautical experts specify for every situation the requirements the fender system has to meet. In case of computer controled operation this means that an all comprehensive program can be drawn up by feeding for every situation of berthing and subsequent mooring the relevant data into the processor. These data can be collected in advance from records together with site observations. But the quickest and most reliable way is to obtain them by means of a wave rider of similar device with respect to wave characteristics, and direction, a current meter for the velocity and direction of the current at the site and an anemometer for the wind. All these data can be automatically recorded in the computer and instantaniously fed into the specific program.

The value of the approach velocity -the most important variable- constitutes a problem apart. Figuring to the square in the calculation it namely can unlike the other variables not be determined in advance but must be instantly decided on it the very last moment when the ship is going to hit the fender. In event - as more and more is to be a rule with important terminals - this velocity is measured by means of special electronic "berthing aids" working either on basis of radar or sonar, this value can together with the angle of approach be directly input in the computer so that the fender further is automatically adjusted.

2.3. Implementation.

The present state of the art enables to devise hollow side or axially loaded compressible pneumatic of hydraulic cylindrical elements fitted with an adjustable valve for regulating the required, computer dictated, internal pump generated pressure. In contrast to current types of rubber fenders, which have heavy walls and consequently a compressibility in the order of 50%, this adjustable type will have much lighter walls consisting of neoprene rubber in a particular way reinforced with a specially designed fabric of aramide fibers, hence a compressibility of some 75%.

Both valve and pum are remote controled and follow exactly the commands from the program selected on the computer. Thus the fenders just can be precisely given those subsequent characteristics which are required

a) to take the amount of energy of a berthing ship with regards to the permissible compression at a varying internal pressure
b) hence to lower that pressure at the end of the travel thus generating sufficient hysteresis to minimize recoiling to the ship
c) to raise the pressure again to such a value that the fender dampens the motions of the moored ship in an optimum way.

As is clear this system entirely roots in the numerical modeling of a whole suite of possible situations with respect to fender characteristics and ship's reactions.

For any situation the appropriate program(s) must be selected, wherein the exogeneneous variables some way or other must be entered.

2.4. Typical fender characteristics.

The first generation fenders, as they may be designated, principally served to prevent direct contact between ship and quay, viz. brushwood bundles, old tyres, timber strips.

The majority of current types of (second generation) fenders consists of side or axially loaded predominantly hollow elements of neoprene rubber or similar material. Requirements as to energy absorption and maximum load to take underly the decision on their dimensions. The selection of the make often is the outcome of a tender, it being thus the price that rules.

It can be distinguished between the "soft" type marked by a convex load compression diagram, secondly the shear type ones which like bending piles habe a nearly linear load compression relation and thirdly the popular buckling types which are characterized by an initially strong concave diagram that conseguently runs horizontal and at the end bends steeply upward.

The shaded area of the typical load/(de)compression diagrams (Fig.2a, 2b, 2c) is indicative for the degree of hysteresis of the above mentioned types, whilst the shaded area of these diagrams (Fig.3a, 3b, 3c) renders their energy absorption capacity at egual ultimate load. In Fig.2d and 3d the same is depicted for a (third generation) adjustable fender, rendering the highest possible compression curve. Actually it can be programmed that the wanted load compression curve takes any random shape within the shaded area shown in Fig.2d. It should be noted that the ultimate compressibility of the current types is assumed to lie around the 50%, and that of the adjustable fenders at about 75%.

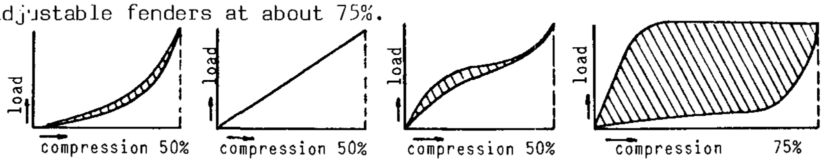

Figure 2. load compression/decompression diagrams and degree of hysteresis of various fender types

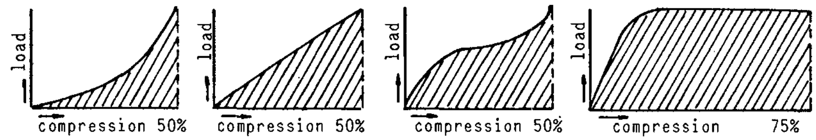

Figure 3. load compression energy absorption diagrams

In case such a fender(cluster) in conjunction with a flexible dolphin is applied a high degree of energy efficiency can be attained, which is greatest when the ultimate reaction forces of the dolphin and of the fenders are equal. In view of theri favorable energy/maximum load relation the buckling type and in particular the adjustable type excel.

2.5. Field of application and cost aspect.

In spite of its higher energy efficiency it is evident that such a custom-designed system is much more expensive than a system by means of one of the current "from the shelf" type fenders. Actually one should not evaluate the adjustable system im comparison with the existing ones solely on basis of the direct cost but also take the indirect returns duely into account.

Apart from a seizable risk reduction in event of unruly wheather conditions, the reduction of ship's downtime might provide sufficient compensation for the higher investment. The application of such a system even lead to bolder and from an operational view point eventually more economical lay-outs, thus (more than) offsetting the extra cost as compared to a traditional fender system fitted to a less exposed lay-out.

In this context it should be noted that such a system ofcourse will have no particular effect on heaving and surging motions.

3. Conclusions.

3.1. The present fenders are inadequate in so far that they more temporarely absorb energy rather than dissipate it and consequently rebound the vessel (recoiling effect), sometimes even aggravating the ship's motions instead of dampening them.

3.2. No current fender at present is universal enough to deal in an optimum way with larger as well as with smaller ships, with fully laden as well as light ones, approaching at higher as well as at lower velocity and operating under varying sea and wind conditions.

3.3. For designing a fender perfectly suited for every possible situation first a set of all the characteristics required hereto must be determined. Theoretically these can be found from scale model laboratory tests, but this actually is prohibitive in view of time and cost.

3.4. The numerical models "BOTS" and "BAS" developed by "Delft Hydraulics" now enable us to compute the desired characteristics in an expeditious and economic way and to compile them in one comprehensive computer program.

3.5. The only way to make a fender meet the many, sometimes conflicting, demands is to make it adjustable.

3.6. With the help of a valve and a pump one can regulate the pneumatic or hydraulic pressure inside a hollow element. viz. cylinder.
Inputting the ad hoc vriable data in a computer allows through said program to adjust the fenders by remote control to the

needs of the moment.

3.7. In exposed sites and in unruly harbour basins better berthing and quieter lying alongside will reduce risks and shorten ship's downtime, hence paying partly or wholly for the higher fender cost.

Appendix

4. References

1) Proceedings of "Ship Handling" symposium, Wageningen, the Netherlands, November 1973.

2) de Vrijer, A., Fender Forces caused by Ship Impacts, Delft Hydraulics Laboratory, publication 309, July 1983.

3) Mynett, A.E., Keuning, P.J., and Vis, F.C., 1985 The dynamic behaviour of moored vessels inside a harbour configuration; Int. Conf. Numerical and Hydraulic Modelling of Ports and Harbours, Birmingham, England, pp 211-220.