CHAPTER 220

FENDER SELECTION CRITERIA

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ABSTRACT

Fenders are to be selected taking into account two quite distinct functions they have to fulfill:

- During berthing manoeuvres fenders have to avoid damage to the ship and to the berthing structure;

- After ships are already berthed and moored, fenders have to keep them quiet during loading and unloading operations.

To fulfill the first function fenders have to be able, while deflecing, to absorb a very large amount of energy.

To fulfill the second function fenders need to be able, while recovering their form, to dissipate a large amount of energy. Besides, they have to contribute to reduce or to increase the natural period of oscillation of already moored ships, depending on their tendency to oscillate in phase or out of phase with waves reaching the berths.

INTRODUCTION

The dimensions of ships have increased very rapidly in the last thirty years. The power of tugboats and the strength of ropes needed to assist the ships during berthing manoeuvres did not increase as fast as the dimensions of the ships. Besides, because they are larger, ships have now, at least in some harbours, to be moored in where ships will possibly be brought to move in ressonance with very stable long waves reaching such berths.

For these reasons fenders nead to be selected taking into account that they will have not only to be able to absorb large amounts of energy during risky berthing operations but, as well, to be able to oppose, working as dash-pots, the tendency of moored ships to oscillate in ressonance with waves reaching their berths.

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Just by passing ashore several strong ropes and keeping them tight, it is possible to keep small ships quiet at their berths, independently of the periods of the waves reaching the berths. But to prevent large ships from starting to move in ressonance with long waves it is preferable, in most cases, to just use a few soft long mooring ropes passed not very tightly, so as to bring the natural periods of oscillation of the moored ships well above the periods of the waves reaching the berths.

THE FIRST IMPACT DURING A BERTHING MANOEUVRE

Berthing manoeuvres are very risky operations, especially when the ships are to be berthed in locations exposed to the action of waves, of currents and of wind.

A sudden change in the magnitude or in the direction of the wind or current, a rope that breaks, a deficient evaluation of the velocity of the point of the ship about to contact the first fender, an order to a tugboat which is not well understood or not promptly obeyed, and the ship will hit the fender moving at a too high velocity (Fontijn 1987, Svensen 1970 and Tryde 1987).

The cost of a fender is just a small fraction of the cost of a repair in the ship's hull or in the berthing structure. Preference is therefore to be given to fenders that are not only able to absorb a large amount of energy without being damaged but that, in case of something going wrong during the berthing manoeuvre,will keep absorbing an extra amount of energy while being damaged and having afterwards to be substituted.

Fenders that just "bust" in case of being overloaded, are to be avoided.

Berthing manoeuvres, which must always be planned and performed with the greatest care, are usually accomplished in the following phases:

- Placing the ship in front of the berth in a position parallel to the berth;

- Bringing the ship by a rotation, or a translation at a small angle, into contact with a first fender;

- Rotation of the ship around the first point of contact until she touches a second fender at the other end, becoming again parallel to the berthing surface.

In case of the velocity and the direction of the translation being known, the amount of the energy to be absorbed during the impact of the ship with the first contacted fender can be evaluated by the expression (see fig. 1)

$$E = \frac{mu^2}{2} \times \frac{k^2+r^2 \cos^2\gamma}{k^2+r^2} \tag{1}$$

where

m is the mass of the ship plus the added mass;

u is the ship's velocity of translation;

r is the ship's radius of gyration;

k is the distance from the center of mass of the ship to the point of contact;

γ is the angle of the velocity direction with the line connecting the center of mass of the ship with her point of contact with the fender.

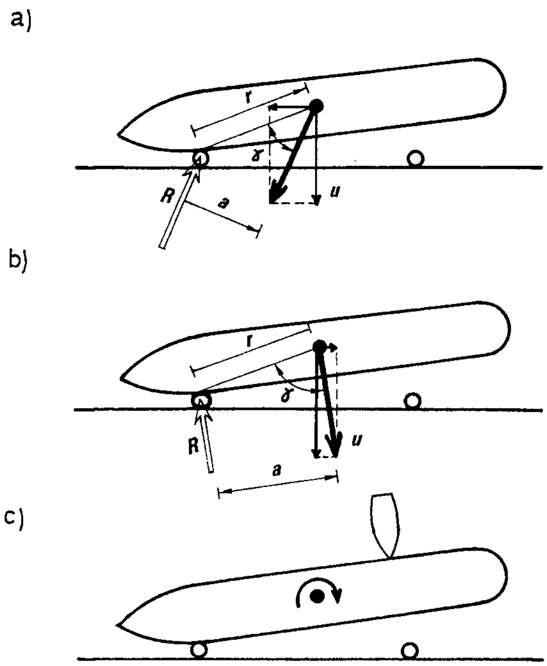

Fig. 1 - The berthing manoeuvre

In order to render the first impact of the ship as smooth as possible, the ship has to be moved in such a way as to render both the distance r and the angle γ as large as possible (Vasco Costa, 1964).

In case of $r/k = 1,6$, the making of $\gamma = 90°$ instead of $\gamma = 70°$ will permit the amount of energy to be absorbed by the fender during the first impact to be halved.

The bringing of the ship not in a perpendicular but in an oblique direction towards the berth will imply the risk of her hull sliding on the fender surface. If this happens, part of the ship's kinetic energy will be dissipated overcoming the friction between hull and fender. If the fender is not damaged in the process, nor the neighbouring ships affected, the sliding contributes to the reduction of the amount of energy to be absorbed by the deflection of the fender.

What is to be avoided is the bringing of the ship to berth moving in a direction with a tangential component oriented towards the point of contact, as indicated in the British Standard Code of Practice for Maritime Structure BS 6349, Part 4, and in fig. 1a. The bringing the ship as represented in fig. 1b, will not only imply a reduction on the amount of energy to be absorbed by the fender but, as well, a reduction on the magnitude of the fender reaction on the ship's hull. The only inconvenient of the recomended procedure is the increase on the amount of energy to be absorbed later, when a second fender is contacted at the other end of the ship.

If the ship enters in contact with the fender while moving in a simple rotation, instead of a translation, the amount of energy to be absorbed can still be evaluated by expression (1) by making $\gamma = 0$. The rotation permits, therefore, the minimization of the energy to be absorbed for a given velocity of the point of the ship's hull entering into contact with the first fender.

THE SECOND IMPACT

When a ship about to contact a first fender is moving at an excessive velocity, there is a tendency to apply on her, through ropes or tugboats, a force at the other end of the ship, in order to reduce the velocity of the point about to hit the first fender (see fig. 1c). In this way the risk of an accident during the first impact is, no doubt, reduced, but at the cost of increasing the amount of energy to be absorbed at the other end of the ship during the second impact (see fig. 1c). This must be the reason why second impacts are usually harder than the first (Jamm and Russman 1966). As second impacts take place after the motion of the ship is already under control, serious accidents never happen during the second impact.

The bringing of the ship to berth moving in a direction with a tangent oriented as represented in fig. 1b, and applying on a berthing ship torques that will reduce the velocity of the point of the hull about to contact the first fender, are practices to be recomended. Although implying an increase on the amount of energy to be absorbed during the second impact, they will permit to reduce the risk of accidents during the first impact.

It is customary practice to assume, in the evaluation of the energy to be absorbed by the fender, that a certain amount of water, to be denoted as added or hydrodynamic mass, is moving solidary with the ship, contributing to increase the amount of energy to be absorbed by the fender. In fact most of the water in the vicinity of the ship has to move in a direction opposed to that of the ship, not in the direction the ship is moving, in order to give room for the ship to move.

Much has been written about the elusive concept of added mass. For the purpose of fender selection the suggestion is advanced to evaluate the mass to be decelerated just by multiplying the mass of the ship by a coefficient

$$1 + 2\ D/B$$

where D is the draught and B the beam of the ship (Vasco Costa, 1964).

To reduce the influence of the added mass, and therefore the amount of energy the fenders will be required to absorb, the suggestion is advanced to stop the ship, or at least to reduce her velocity, just before the ship contacts the fender. In this way the inertia of the water will keep for a while the water moving faster than the ship. When the ship is brought again into motion, the water that has overtaken the ship will contribute to reduce her velocity during the impact with the fender.

MOORED SHIPS AS OSCILLATING SYSTEMS

It has been found in some harbours, by trial and error, that the most convenient way to keep moored ships quiet at some berths is by reducing the number of mooring lines and making them longer and slacker, while at some other berths it is better to make them shorter and to keep them very tight (Khanna and Bert 1977, Kilner 1960, Vasco Costa 1983 and Wilson 1970).

Why does it so happen?

Just because some waves, of so small height as to pass unnoticed, but of such great length as to render them very stable, succeed in reaching berths far inside harbours and in bringing the ship to oscillate in ressonance with the periodic forces they exert on the ship.

These long waves, with periods of 30 seconds and longer, may have been generated by long/lasting violent storms in far-off places, or be the result of the interference of distinct trains of shorter waves.

If the basins they reach inside a harbour happen to have good reflective walls, and natural modes of oscillation coincident with any of the periods of the incoming waves, stationary waves will be formed inside the basins, their height possibly becoming larger than that of the waves in the open seas (Martinez and Naverac 1988, Oortmerssen 1987, and Portela 1970).

The periods of the distinct modes of oscillation of a closed rectangular basin can be evluated by the expression

$$T = \frac{2\ \ell}{n\ \sqrt{gd}} \tag{2}$$

where

l is the length of the basin;
d is the depth of the water;
n is an integer defining the mode of oscillation.

In table 1 are given the natural periods of oscillation of closed basins with rectangular form. For the evaluation of periods of oscillation of basins with other simple geometrical forms see Wilson (1970).

The natural period of oscillation of a moored ship of mass m being held at berth, without clearances, by mooring lines and fenders that deflect proportionally to the forces to which they are submitted, is to be evaluated by the expression

$$T = 2\ \pi\ \sqrt{m/k} \tag{3}$$

where

K is the spring factor of the moorings (see table 2).

The smaller the mass of a ship, the stiffer the fenders and shorter her mooring lines, the shorter will be her natural period of oscillation. The larger the mass of a ship the softer the fenders and the longer her mooring lines, the longer will be the natural period of oscilla-tion of the moored ship.

Small ships, namely pleasure and fishing boats, have nat-ural periods of oscillation that are in general much shorter than the natural periods of oscillation of the basins in which they are moored. For that reason they oscillate in phase with the periodic forces exerted on their hulls by the waves. To reduce the amplitude of their motions after being moored, the spring factors of

TABLE 1
Periods of oscillation of closed basins

$$T = \frac{2l}{n\sqrt{gh}}$$

Dimensons of basin		Periods of oscillation				
Length	Depth	Uninodal	Binodal	Trinodal	Quadri-nodal	Quinqui-nodal
500 m	5 m	2min23s	1min12s	48s	36s	29s
	8 m	1min53s	56s	38s	28s	23s
1 000 m	8 m	3min46s	1min53s	1min15s	56s	45s
	15 m	2min45s	1min22s	55s	41s	33s

TABLE 2
Periods of oscillation of ships moored without clearences

$$T = 2\pi\sqrt{m/K}$$

Mass of ship m	Spring factor of moorings K				
	200 kN/m	500 kN/m	1000 kN/m	2000 kN/m	5000 kN/m
100 t	4.4s	2.8s	2.0s	1.4s	0.9s
500 t	9.9s	6.3s	4.4s	3.1s	2.0s
1 000 t	14.0s	8.9s	6.3s	4.4s	2.8s
5 000 t	31.4s	19.9s	14.0s	9.9s	6.3s
10 000 t	44.4s	28.1s	19.9s	14 s	8.9s
50 000 t	1min40s	1min3s	44.4	31.4s	19.9s
100 000 t	2min20s	1min29s	1min3s	44.4s	28.1s
500 000 t	5min14s	3min19s	2min20s	1min40s	1min3s

their moorings are to be increased by resort to a large number of shorter, stiffer and tighter ropes, as well to stiffer fenders.

Large ships, especially if moored in basins of relatively small dimensions, present natural periods of oscillation that are larger than the natural periods of oscillation of such basins. As a consequence, they will tend to oscillate out of phase with the periodic excitation forces exerted in them by the waves. To reduce the amplitude of their movements after being moored it is convenient to increase their natural periods of oscillation by holding them with just a few very long ropes, to be kept not too tight, and by resort to soft fenders.

Unfortunately, large moored ships never have well-defined natural periods of oscillation. This is not only because surge, sway, yaw, heave, pitch and role motions interfere with each other but, besides, because mooring ropes, instead of having elongations proportional to the forces to which they are submitted, become stiffer when the forces applied on them increase in magnitude, the same happening to some types of fenders. When mooring ropes and fenders become stiffer, the natural period of oscillation of the moored ship decreases, this implying a greater risk of her starting to move in ressonance with shorter waves.

The places where the consequences of moored ships starting to move in ressonance with stationary waves in a basin can be more serious are the nodes of such waves. At the anti-nodes a moored ship will only be made to move up and down a few centimeters, while at the nodes the vertical movements will be almost non-existent, but the slope of the water surface will keep changing all the time. The larger the slope of the water surface the larger will be the force tending to bring the ship to slide down the water surface.

A stationary wave with a length of 1 500 m and a height of 0.5 m will cause the water slope to reach every half period a value of

$$\pi \frac{H}{L} = \pi \frac{0{,}5\,\mathrm{m}}{1500\ \mathrm{m}} \cong \frac{1}{1000} \qquad (4)$$

Such slope will pass unnoticed to visual observation. Notwithstanding, a ship with a displacement of 300 000 t will be submitted to an horizontal force of 300 t, which every half period will change direction (see fig. 2).

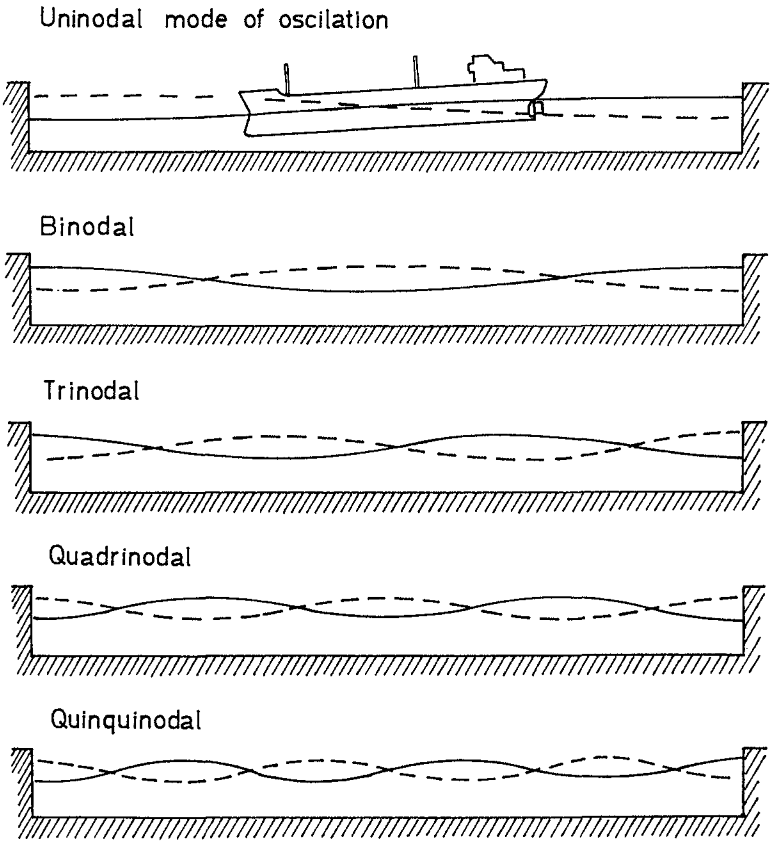

Fig. 2 - Modes of oscillation of a closed basin

Such periodic force will bring the moored ship to have oscillatory motions whose amplitude will increase from motion to motion if the natural period of oscillation of the moored ship happens to be coincident, or near coincident, with that of the wave. In such case not only loading and unloading operations will have to be suspended but the ship will possibly break her mooring ropes or damage the fenders.

What can be done to avoid such situations?

Confronted with the difficulty of keeping ships quiet at their berths, some entities just prefer to ignore the nature of problem. This is the reason why, in the book "Guidelines and Recomendations for the Safe Mooring of Large Ships at Pier Piers and Sea Islands", published by the Oil Companies International Marine Forum, is stated on page 3: The design mooring conditions do not include wave conditions able to cause significant dynamic loadings in mooring.

Let us present some considerations on how to deal with the oscillation of moored ships in ressonance with long waves reaching their berths.

First of all the possible modes of oscillation of the water in front of the berth must be identified. Just by throwing a few pieces of cork along a quay berth it will be possible to find out if stationary waves are present, which are their periods, and where are located their nodes and anti-nodes. But equipment is already available to study the motion of the water in front of a berth. In case of basins with simple geometrical forms, it will be possible to find the main forms of oscillation of a basin just by resort to simple analytical expressions (Kubo et al, 1988).

Once the periods of stationary waves in the basin and the natural periods of oscillation of the moored ship have been found, an option has to be made between two alternative ways of reducing the risk of the ship starting to move in ressonance with the waves. Are the stiffnesses of mooring ropes and of fenders to be increased in order to reduce the natural period of oscillation of the moored ship, or are their stiffnesses to be decreased in order to increase her natural period of oscillation?

In general, as referred, small ships are to be held by stiff mooring cables and stiff fenders while large ships, especially when berthed in small basins, are to be held by just a few, soft, long mooring cables and relatively soft fenders.

It must be pointed out that the avoidance of ressonance by increasing the natural period of oscillation of a moored ship implies the risk of the ship starting to move with undetected longer waves, that can be the occasional result of the superposition of trains of long waves with different lengths. For such reason, resort to soft moorings and soft fenders should only be adopted when the occurence of very long waves is not to be feared.

When selecting fenders having in view the keeping of moored ships quiet at berth, one has to take into account that fenders, besides contributing to increase or decrease their natural periods of oscillation, will also have to act as dash-pots, dissipating as much energy as possible while recovering their form after deflection (see fig. 3).

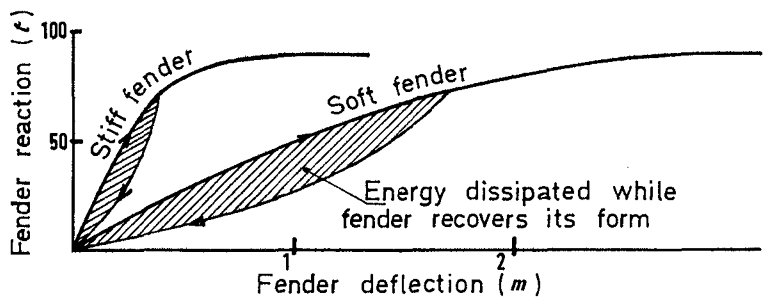

Fig. 3 - Stiff versus soft fenders

RECOMENDATIONS

In order to reduce not only the frequency of accidents during berthing manoeuvres but also their consequences, fenders need to be able to absorb very large amounts of energy when something goes wrong during such operations. Preference is to be given to fenders that, instead of just "busting" when overloaded, will keep absorbing energy while being damaged.

In order to reduce "down time" during loading and unloading operations, the fact has to be faced that moored ships are oscillating systems, and that the problems they pose are to be studied and solved, just as similar systems have been studied and solved, namelly the suspension of automobiles. For such purpose the modes and periods of oscillation of the water inside harbour basins and the location of nodes and anti-nodes of stationary waves have to be identified. Spring factors of mooring ropes and fenders and of their combinations are to be evaluated, in order to find out if the natural periods of oscillation of the moored ships are to be increased or decreased.

When selecting fenders having in view the quitness of moored ships, preference has to be given to fenders which present deflections proportional to the forces they are being submitted to, because such fenders permit moored ships to present well defined natural periods of oscillation. Preference has also to be given to fenders that dissipate a large amount of energy while recovering their original form after being deflected.

Great progress is the study of modes of oscillation of water basins and of moored ships has been made in the last twenty years.

In the Procedings of the NATO-ASI on "Advances in Berthing and Mooring of Ships and Offshore Structures", held in 1987 in Trondheim, reference is made to most recent publications on the subject.

ACKNOWLEDGEMENTS

Tanks are due for valuable comments by Eugene H. Harlow and by Bela Komman, both of Soros Associates, on the original version of this contribution.

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