THE MODELLING OF BUCKLING FENDERS TO PROTECT THE SHIP BERTHING PROCESS

Wiesław Galor

Maritime University of Szczecin
Institute of Marine Traffic Engineering
Waly Chrobrego 1/2, 70-500 Szczecin, Poland
tel.: +48 91 4880568, e-mail: irm@wsm.szczecin.pl

Abstract

The berthing of ship to the quay is the last stage of navigation process in marine shipping. During the ships berthing the impact in berth can occur and in result the appearing of energy in ship – fender device – berth system. The exceeding of admissible value of this energy leads to damage of one of these elements and in effect causes the accident. The accident can happen as unwanted event connected with negative consequences (damage of ship and port structure). It can be connected with ship's strike in quay. The fenders are devices to protect the port structures and ships bulk while berthing to the quay. Design and choice of fender system should contain selection suitable devices answering of existing or planning construction of structure, which select system should be protected. The buckling type of fenders (arch, conical shape) are the newest generation combining excellent absorbing energy with reaction forces of ship berthing. The paper presents the study of fenders designing based on analytical, experimental and numerical considerations. The paper presents an example of fenders designing. The buckling type of fenders achieved by carrying out of laboratory research was made. The Portowców Quay in Port of Świnoujście real research of ships berthing was carried out.

***Keywords**: safety of navigation, berthing of ship, impact energy, buckling fenders, polyurethane elastomers*

Introduction

The manoeuver of berthing a ship to a port structure (a quay, a pier) is the final stage of the navigational process. An ideal manoeuver would be consisted in a total loss of speed at the moment the ship makes contact with the berth. However, in reality, a dynamic ship's interaction takes place that causes a deformation and stress of the hull and the fender (when applied). If these magnititudes surpass boundary values damage will be suffered by one of the parts of the system that includes the ship, the berth and the fender. Fenders improve the safety of berthing operations by partially absorbing the kinetic energy of the ship. It consists in an elastic deflection (shape elasticity) of the material the ship is made of, and the energy of berthing turns into work of deflection.

The fender absorbs a part of ship's kinetic energy. The remaining part of the energy is absorbed by the hull structure and the port structure. The conditions of ship's safe berthing are as follows:

$$E \leq E_d \quad dla \quad p \leq p_{dop}\,, \tag{1}$$

where:

- E - ship's maximum kinetic energy absorbed by the berth-fender-ship,
- E_d - ship's admissible kinetic energy absorbed by the berth-fender-ship,
- p - maximum pressure of individual fender on ship's hull plating,
- p_{dop} - admissible pressure of individual fender on ship's hull plating.

Admissible pressure of an individual fender on the ship's hull depends on her size and design. And according to the type of vessel (a general cargo carrier, a container ship, a tanker, a bulk carrier, a gas carrier) it can range from 200 - 700 kN/m^2. It is determined on the basis of the analysis of deflections during the stresses of the shell plating structure which takes into account an adequate distribution of fender pressure on the shell, longitudinal girders, and frames. At the same time a phase of elasticity of ship's shell structure is assumed. There are situations in which work of deflection of a given part of the shell plating is taken into consideration and where a plastic strain in the form of dents of the shell is accounted for. However, the deflection twice exceeding the thickness of the shell plating or those above 25mm are to be considered as damage (fault) [5]:

Berth fenders are special devices used for protecting port or offshore structures as well as vessels t stay alongside such structures. The vessel affects fenders statically and dynamically, which causes deformations and stresses of the vessel hull as well as the berth structure. The correct selection of type and parameters of a fender should ensure that elastic stresses in an admissible range will be created in the structure of the vessel and the protected object. The design and choice of the fenders should correlate with the construction of quay to be protected. This choice depends substantially on the ship size and operational conditions in which the berthing manoeuvre is performed [4]. These conditions consist of:

- hydro-meteorological restrictions (wind, current),
- ship's manoeuvring properties (as a power of main propulsion, thrusters),
- tugs service (number of tugs, their power),
- tactics of manoeuvring (captain's or pilot's skills).

Ship's berthing kinetic energy

The amount of kinetic energy of a ship's approach to a port structure can be generally expressed as dependence [2]:

$$E_k = 0.5 \cdot m_v \cdot V_s^2 \;\; [m/s], \tag{2}$$

where:

m_v - Ship's virtual (total) mass,

$$m_v = m_s + m_w \;\; [kg], \tag{3}$$

where:

m_s - Ship's mass,

m_w - Mass of added water,

or

$$m_w = C_m \cdot m_s \;\; [kg], \tag{4}$$

where:

C_m - Added water mass coefficient.

Added water mass coefficient C_m can be determined according to many dependencies. The most frequent are [3]:

$$C_m = 1 + 2 \cdot T / B, \tag{5}$$

where:

B - breadth of the ship [m].

When determining ship's kinetic energy to be absorbed by the fenders the following factors should be taken into account:

- ship's canting when approaching the berthing line,
- location of the hull contact point with fender in relation to the ship's centre of gravity,
- elasticity properties of the fenders, the shell and the port structure,
- resistance of water between the ship and the port structure,
- surface friction in way of contact point between the shell plating and the fender.

The above factors cause the kinetic energy of the ship to decline and as a result the fender is forced to absorb part of the entire energy which is understood as the effective energy. The effective energy while berthing the ship to a port structure (knocking into the fenders) will equal:

$$E = E_K \cdot C \quad [J], \tag{6}$$

where:

C - Total coefficient of energy loss (the product of coefficients of partial loser, which take account of particular vector).

The choice of type of fender

When selecting a fender, it is necessary to identify all limitations connected with preliminary choice of fender, from the vantage point of reaction force value transmitted from ship to wharf, by means of fenders and their number. The protective action of fenders on the hull of ship and the wharf depends on absorbing parts of ship kinetic energy [1]. These devices take over the struck energy at the moment when the ship touches the fender. During this process, the fender absorbs reaction of ship impact power which is transmitted to wharf construction. It means that fender transforms the overtaking energy of ship which transmits its energy to wharf construction. The fenders play a great role in safety assurance during ship berthing manoeuvre. Reduction of the damage risk of the ship or quay depends on the proper selection of fenders. Basic parameters of berth fenders are as follows:

- reaction force as a function of deflection,
- energy absorption as a function of deflection,
- admissible deflection.
- There are additional parameters:
- fenders hardness,
- fender – ship hull area contact,
- fender dimensions (length, breadth, depth),
- method of fixing to the berth.

Basic parameters depend on the size, shape and sort of material used in fenders making (Figure 1). If the material has clear properties, then the fender parameters depend only on size and shape. An efficient berth fender should be characterized by possibly high absorption of the energy of a mooring ship and low pressure on the hull and on the berth structure. In this respect the most effective are devices using elements of high elasticity. Materials used previously, comprising wood, solid rubber, used tires and rubber cylinders do not satisfy these requirements. Fenders of the latest generation are manufactured of properly chosen rubber and polyurethane elastomers that have exceptionally elastic properties and feature high parameter repeatability.

Nowadays, the most frequently used substances absorbing energy are rubber or plastic (mainly polyurethane elastomers). Fenders made of these materials can be used in full sections and combination of small elements in whole units (buckling units). Buckling fender consists of specifically joint elements that give us a fender with proper characteristics. It depends on obtaining quick growing reaction at not large deflection, and then on maintenance of almost constant reaction at further deflection.

The buckling effects are achieved by changing of part of fenders elements. In first phase of doing force pressure to fender the fast increasing of reaction force to great value is observed.

This force overdo some value caused the buckling some part of fender. Then reaction force keep the fix level and even little decreasing (phase 2).This state maintain up to achieved of moment of maximal deflection. The third phase deflection is so great that fender work like fixed section material. Thus reaction force is fast increasing up to admissible value.

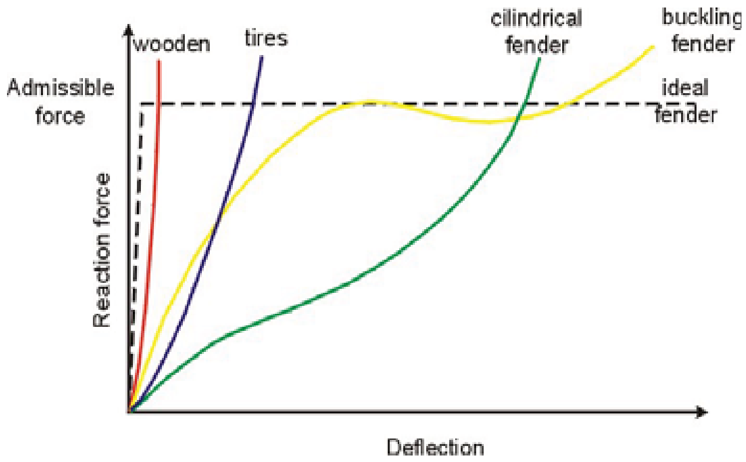

Fig. 1. The types of fenders

By proper choose of components of fender elements, their shape and quantity it can achieved the fenders with adequate parameters (characteristic). There is the resilience of material property additionally can changed. Buckling fender consists of specifically joint elements that give us a fender with proper characteristics. It depends on obtaining quick growing reaction at not large deflection, and then on maintenance of almost constant reaction at further deflection.

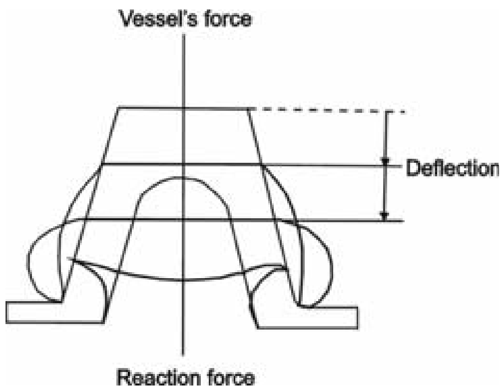

Fig. 2. The phases of buckling fenders deflection

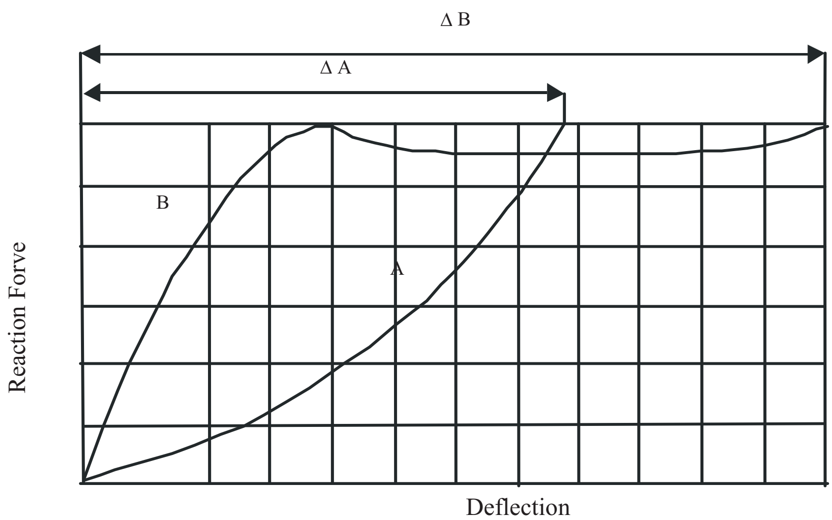

Fig. 3. Reaction forces to different types of fender

Effectiveness of such devices is more considerable then other types of fenders. Figure 3 presents curve A which showings characteristics of full sections fender, and curve B - that of buckling fender. Both types of fenders achieve the same reaction in different deflection. It means that the absorbed energy is greater for buckling fender and, thus, it is more efficient. Polyurethane elastomer is one of used plastics in production of fenders and it is known for its high level of energy absorption and high durability on extension and compression. To analyzing of fenders progress it can say that their shape and also parameters was depended on possibility of their performance. The rubber using restricted that shapes by problems of vulcanization of hem. Hence initially there were cylindrically fenders as rubber strengthened cylinder with inner whole. The using of rubber modification or directly of polyurethane materials permit to presume of other shapes. Effectiveness of such devices is more considerable then other types of fenders. Figure 1 presents curve A which shows characteristics of full sections fender, and curve B - that of buckling fender. Both types of fenders achieve the same reaction in different deflection. It means the absorbed energy is greater for buckling fender and, thus, it is more efficient.

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The modelling of fenders

Fenders consisting of buckling elements are connected in a manner assuring its desired characteristic. This generally features rapid growth of reaction force at small deflection, and then the reaction remains more or less the same although deflection increases. Examining strength characteristics of fender materials, engineers attempt to obtain possibly small elasticity constant with possibly large relative elongation. Such material should have high level of maximum admissible stresses. Other desired properties of fender material are small water absorbability, high abrasion resistance and a required working temperature range. The main strength parameter of fenders is elasticity constant, expressed by this quotient:

$$S = \frac{F}{h} \qquad \left[\frac{kN}{h}\right], \tag{7}$$

where:

F - vessel impact force *[kN],*

H - elastic deflection [m.].

The vessel loses its speed and kinetic energy by deforming a fender along a certain distance. The vessel and accompanying water have a certain mass when berthing at a certain speed and hitting the fender. Therefore, it can be said that the measure of fender elasticity is the length of elastic deflection caused by a certain force. In practice, relative deflection (percentage) is used, and this term is used hereinafter. The relative deflection is the ratio of deflection to its height (thickness):

$$\Delta = \frac{h}{H}, \tag{8}$$

where:

h - elastic deflection [m]

H - height (thickness) of a fender.

The choice of a proper polyurethane elastomer and fender profile goes together with the determination of the dimensions of single elements and their mutual relations based on theoretical findings in the field of material strength. This is followed by making a few draft designs of a given fender type. The choice of an optimal profile requires empirical examination of the designed devices. This practical examination is conducted on models generally made to 1:10 scale, with the use of a testing machine that allows specifying variant fenders depending on the load applied [6]. Thus reaction force is defined, then the value of absorbed energy. Each model is affected by forces that increase linearly. Analysis of test results enables determination of the optimal shape and dimensions of the fender being designed. To these end specific parameters of individual models are examined. After the choice of the optimal profile, fender models to 1:1 scale are made in order to determine its real parameters (reaction forces and energy absorption).These models are examined using a testing machine. Laboratory tests provide a basis for computer-aided modelling by the finite elements method. This is aimed at selecting proper materials and optimized profiles of fenders, which, in turn, aims at maximizing the absorbed energy. The use of computer simulation allows to shorten laboratory tests and accelerates the process of establishing parameters for the whole series of a given fender type. The presented procedure of designing provides a basis for manufacturing berth fenders adjusted to the system of fixing to the berth. When a fender system is fixed in a particular port, in the initial stage of operation real observations are made to see how ships get berthed alongside wharves. Such procedure permits to design different types of buckling fenders. Figure 4 presents the following types: cylindrical, arch, modular and cone fenders.

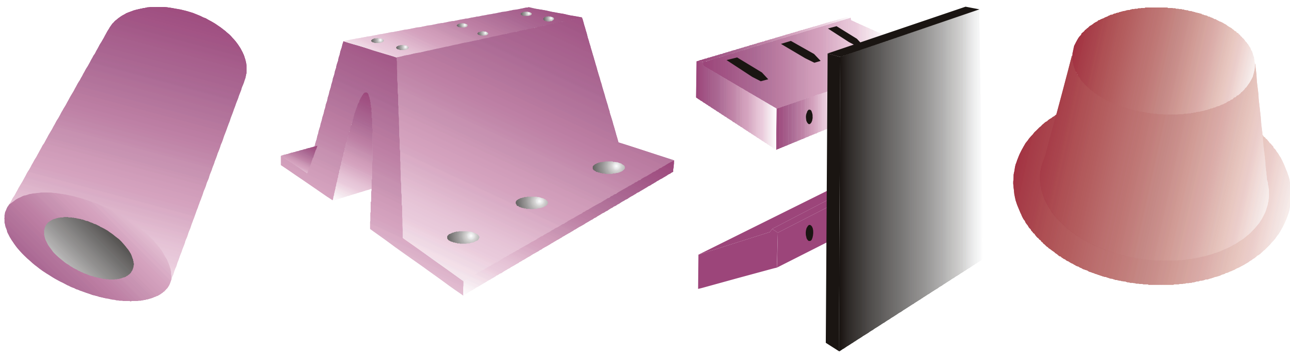

Fig.4. The cylindrical, arch, modular and cone buckling fenders

Such types of buckling fenders were made by ZPTS MILANÓWEK factory based on carried out research. As an example of application buckling fenders (arch type) is Portowców Quay in Swinoujscie port, which is one of the deepest quays found in this port (figure 5).

Fig. 5. The berthing manoeuvres of ship to Portowców Quay in Port of Świnoujście equipped in arch fender

Most frequent trans-shipment loads on this quay are mass-loads. Therefore the mooring crafts are large ships transporting mass - loads. The maximum size of mooring ships (called “Świnmax”) can attain length of 275m and about 100000 DWT of capacity (bulk carriers). This quay was equipped in 48 fenders of ZPTS Milanówek type made of polyurethane. Standard size of these devices is 600 x 1,700mm (height, length). Fenders were installed vertically in five groups: 18, 6, 6, 6 and 18 segments. Distance between each fender is about 2.8m and between groups of fenders is about 22m. Division of the installed fenders into 5 groups originated from researches qualifying points of first contact approaching of ship to quay. The researches were carried out on the basis of observation and real measurements of fenders installed on this quay. The figure 5 presents the berthing manoeuvre of ship to Portowców Quay in Port of Swinoujscie.

Summary

The manoeuver of berthing a ship to a port structure (a quay, a pier) is the final stage of the navigational process. During the ships berthing the impact in berth can occur and in result the appearing of energy in ship – fender device – berth system. The exceeding of admissible value of this energy leads to damage of one of these elements and in effect causes the accident. Berth fenders are special devices used for protecting port or offshore structures as well as vessels to stay alongside such structures. Fenders improve the safety of berthing operations by partially absorbing the kinetic energy of the ship. It consists in an elastic deflection (shape elasticity) of the material the ship is made of, and the energy of berthing turns into work of deflection. An efficient berth fender should be characterized by possibly high absorption of the energy of a berthing ship and low pressure on the hull and on the berth structure. Fenders of the latest generation are manufactured of properly chosen rubber and polyurethane elastomers that have exceptionally elastic properties and feature high parameter repeatability. By proper choose of components of fender elements, their shape and quantity it can achieved the fenders with adequate parameters (characteristic). Fenders made of these materials can be used in full sections and combination of small elements in whole units (buckling units). Buckling fender consists of specifically joint elements that give us a fender with proper characteristics. It permits to achieve near 4 times better parameters (energy absorbed) from the same quantity of plastic material (polyurethane elastomers). The results of carried out researches fully confirm such thesis.

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