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THE DESIGN OF FENDERS AS ELEMENT OF NAVIGATIONAL SAFETY MANAGING

Abstract: Basic aim of marine navigation is to handle the ship to port of destination by safely and efficiently manner. The maneuver of berthing to port structure is a final stage of navigational process. An ideal maneuver would be consisted in total loss of ship's speed in moment in contact to the berth. However, a dynamic ship's interaction takes place the impact of ship to the berth. It can cause the damage the ship hull or port structure. But using the fenders may improve the berthing by absorbing the kinetic impact energy of ship. The paper presents the method of fenders designing in aspect of managing of safety process of navigation.
Keywords: managing of navigational safety, designing of fenders some keywords

1. INTRODUCTION

The basic goal of inland navigation is to handle the ship to point of destination by safety and efficiently manner.Ship handling is first and foremost supposed to be safe so that will not bring about a navigational accident, which an unwanted event is resulting in losses. The losses may be different kinds like a loss of human health or life, damage or loss of cargo and ship, the pollution on environment, damage to a port structure or financial losses due to the port or its part being blocked. The safety level is most often determined by risk measure. There are many ways of risk to be defined. Generally risk is identified with possible effect (losses) of an unwanted event (accident). A more exact definition says that it is the probability of losses due to accident, which may arise in a particular part of the man-technique-environment system. In practice it means the necessity of mailing conception of risk reduction measures and calculation the risk reduction achieved and the associated value of losses. The risk concept used to be defined in different of way. Mainly the risk referred to as navigational risk may be expressed as:

$$R_N = P_A \cdot C \qquad (1)$$

where:

R_N - navigational risk,
P_A - frequency of accident,
C - consequence of accident in relevant units (losses).

The losses may be different kinds like a loss of human health or life, damage or loss of cargo and ship, the pollution on environment, damage to a port structure or financial losses due to the port or its part being blocked. Because the losses can be result different events [8], the following criterion of safety assessment will be used:

1. Safety under keel clearance (SUKC)
2. Safety distance to structure (SDS)
3. Safety distance of approach (SDA)
4. Safety air drought (SAD)
5. Safety of berthing (SOB)

Thus, there are many categories of risk due to ship movement in water area. In each case the accident rate (probability) is determined for each of the accident categories. The overall risk of ship movement in water area in then the sum of these single, independents risks [5]:

$$R_o = R_g + R_n + R_c + R_{ad} + R_b \tag{2}$$

where: R_o =. overall risk of ship movement in water area,
R_g - risk of grounding,
R_n -risk of collision with navigations obstructers,
R_c -risk of collision with other ships,
R_{ad} -risk of impact the object over the ship,
R_b-safety of berthing.

2. SAFETY OF BERTHING

The berthing of ship to quay is the last stage of navigation process in inland shipping. An ideal maneuver 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 magnitudes 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 accident can happen as unwanted event connected with negative consequences (losses of ship and port structures damage). It can be connected with ship's strike in quay. Thus it is necessarily to quantity determine of risk while ship berthing. Condition of the safety of the maneuvre while berthing the ship to the quay can be as follows [3]:

$$E(t) \leq E_k^{berth} \quad or \quad E(t) \leq E_k^{ship} \tag{3}$$

where:

E(t) - maximum kinetic energy of the ships impact absorbed by the system berth – fender – ship,

E_k^{berth} - admissible kinetic energy absorbed by the system berth - fender ,

E_k^{ship} - admissible kinetic energy, near which the formed strengths of the reaction of t system berth – fender do not cause the durable deformation of the ship's hull yet.

Factors which have the influence on the size of the maximum kinetic energy of the ship's impact against the berth construction are as follows:

- ship manoeuvrability (kind and the power of the propulsion, thrusters),
- hydro meteorological conditions (wind, current),
- tugs service (the number of tugboats, their power),
- the manoeuvring tactics (captain's or pilot's skill).

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.

$$E \leq E_d \quad for \;\; p \leq p_{dop} \tag{4}$$

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) [8].

3. THE KINETIC ENERGY OF SHIP'S BERTHING

An important phenomenon during the operation of ship's berthing is energy damping in water as a result of ship's turning. At a certain moment the ship touches the fender and its deformation takes place. Part of the kinetic energy changes then into work of reaction force related to a normal of the berth. For a maximum deformation the speed of ship's contact with the fender drops to zero. That part of energy which as a result has been formed during the deformation of the fender begins to change into a turn motion in relation to the contact point (Fig.1).

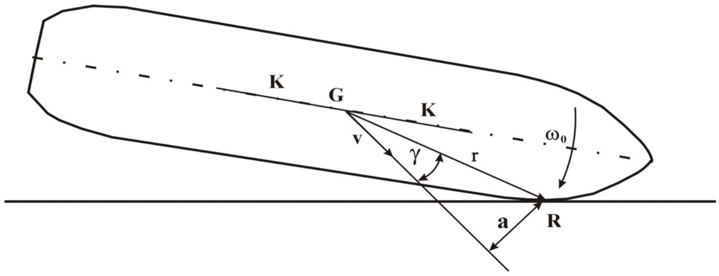

Fig. 1. Ship's impacting against the berth [3]

It is expressed by gaining the angular velocity in relation to contact point, reaching the top value at the maximum deformation of the fender. Energy absorbed by the fender can be estimated from the difference of energy for the ship moving freely, prior to the first contact with the fender and the energy after the impacting (maximum deformation of the fender).The work done on the fender system from the beginning of contact until maximum deflection is reached can be evaluated as difference between the kinetics energy before and after impact. The dependence has been shown by F. Vasco Costa [9]:

$$E = \frac{m \cdot V^2}{2}\left(1 - \frac{a^2}{K^2 + r^2}\right) - m \cdot V \cdot \omega_{0.} \cdot \frac{K^2}{K^2 + r^2} + \frac{m \cdot \omega_0^2}{2} \frac{K^2 \cdot r^2}{K^2 + r^2} [J] \qquad (5)$$

where:

- V - ship's linear velocity (translation),
- a - the arm of ship's linear movement vector in relation to the point of contact R,
- K - radius of moment of ship's mass inertia in relation to the point of gravity G,
- r - distance between the point of gravity and the point of contact R,
- ω_0 - ship's velocity of rotation before the impact.

This equation gives the amount of kinetic energy of ship to be absorbed by fenders as function of velocity of linear movement of ship and velocity of rotation of the ship impacting mass of the ship. The energy of berthing permits to choose of parameters of fenders to ensure the safety of ship's manoeuvre.

4. THE BERTH FENDERS

Berth fenders are special devices used for protecting port or offshore structures during berthing manoeuvres as well as during vessel or boat stay alongside such structures [4]. 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 (fig.1). The fender reaction consists in absorbing part of the kinetic energy of the ship when they get in contact. Fenders used at present all over the world make use of elastic elements. When their elastic deflection (deformation) takes place, the berthing energy is converted into elastic work. During that work the fender takes over the reaction of ship impact forces and transfers these forces onto the berth structure. This means that the absorbed energy from the ship is changed into the work of elastic elements of the fender system itself.

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:

- fender hardness,
- area of fender – ship hull contact,
- fender dimensions (length, breadth, depth),
- method of fixing to the berth.

The basic parameters of a fender used depend on the material it is made of, its shape, design and dimensions. 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 (fig.2). Fenders of the latest generation are manufactured of properties and feature high parameter repeatability. Thanks to the possibility of properly chosen rubber and polyurethane elastomers that have exceptionally elastic [7] Wharf fender is a device that protects port structure and sailing craft during its berthing and mooring to the structure. Ship's berthing manoeuvre is actually the last stage of navigation process based on safe guidance of the craft from the starting to the point of destination.

There is a dynamic affect of ship on fenders at berthing, causing deformation and tension of the device, ship and wharfs. The proper selection of fender assures that tensions are resilient in admissible range. The design and choice of the fenders should correlate with the construction of wharf to be protected. This choice depends substantially on the ship size and operational conditions in which the berthing manoeuvre is performed. 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).

Fig. 2. The reaction force of various type fenders [5]

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 [6]. The protective action of fenders on the hull of ship and the wharf depends on absorbing parts of ship kinetic energy. These devices take over the struck energy at the moment when the ship touches the fender. Then the fender undergoes a resilient deformation and ship's energy bounding changes in work of resilience. 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 fender transforms the ship’s energy to work on resilient units of the fender. The fenders play a great role in safety assurance during ship berthing manoeuvre. Reduction of the damage risk of the ship or wharf depends on the proper selection of fenders.

The basic parameters characterising fenders are by reaction force, energy absorbed and admissible deflection. There are also dimensions of fender (length, width, height) and sorts of fastening as additional parameters. Basic parameters depend on the size, shape and sort of material used in fenders making. If the material has clear properties, then the fender parameters depend only on size and shape.

5. DETREMINATION OF OVERALL PROBABILITY OF ACCIDENT

The probability of arise the ship hull damage can be taken as an assessment criterion of safety and used to improve of port functioning [2]. Knowing the number of entries of ships in a year (annual intensity of traffic), one can determine the probability of ship’s impact against the quay for one ship transit.

$$p_A = \lambda / I_R \cdot t \tag{6}$$

where:

p_A – probability of ships impact for one ship transit,

λ – accident frequency,
I_R – annual traffic intensity,
t – given period.

Determinate the probability of accident for given number of ship transits it can used the following formula [3]:

$$P_{A(N)} = N \cdot p_A = I \cdot T \cdot p_A \quad for \quad N \cdot p_{A..} \rightarrow 0 \tag{7}$$

where:
$P_{A(N)}$ – probability of accident for given ship transit number,
p_A – probability of accident in one transit,
N – number of transits.

This relationship is linear because implies proportional growth of probability to considered of ship number transit. More adequate manner is use the statistical models described the accident probability. Because accidents are infrequent events thus it can be used recurrent models. One of them is geometrical distribution:

$$P_{A(N)} = 1 - (1 - p_A)^N \tag{8}$$

Figure 3 presents the probability of navigation accident for linear and geometrical distributions in function of ships transit numbers.

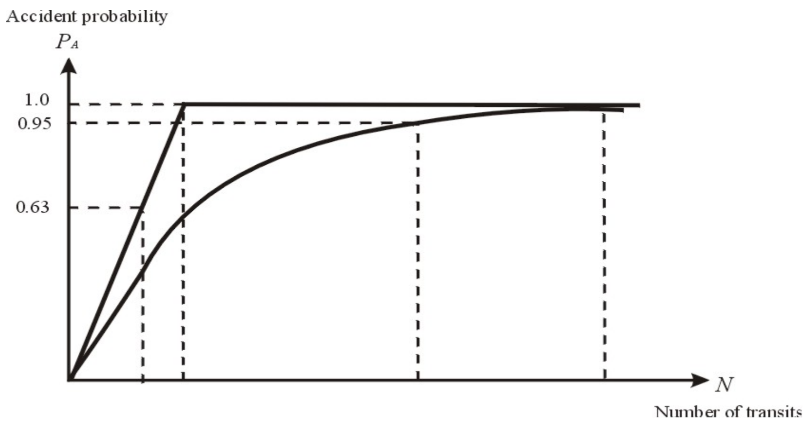

Fig. 3. Probability of accident in function of transits number for linear and geometrical distributions [2]

These models enable to assessment the safety of ship berthing and used to improve of port functioning [1]. Next step of research will be use to practical assessment of navigational safety.

SUMMARY

1. The basic goal of inland navigation is to handle the ship to point of destination by safety and efficiently manner.

2. The safety level is most often determined by risk measure generally dentified with possible effect (losses) of an unwanted event (accident).
3. The following criterion of safety assessment will be used: safety under keel clearance, safety distance to structure, safety distance of ship approach, safety air drought and safety of berthing.
4. The berthing of ship to quay is the last stage of navigation process in inland shipping. The energy of berthing permits to choose of parameters of fenders to ensure the safety of ship's manoeuvre.
5. Berth fenders are special devices used for protecting port or offshore structures during berthing manoeuvres as well as during vessel or boat stay alongside such structures.
6. Select the fenders depends on proper choose of basic parameters- reaction force, energy absorbed and admissible deflection.
7. Overall probability of accident by ship stuck in quay depends on numbers of transit. Most useful manner is applicants the statistical models described the accident probability.
8. Linear and geometrical distributions in function of ships transit numbers to assess of the probability of navigation accident.

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PROJEKTOWANIE URZĄDZEŃ ODBOJOWYCH JAKO ELEMENT ZARZĄDZANIA BEZPIECZEŃSTWEM NAWIGACJI

Streszczenie: Podstawowym celem nawigacji morskiej jest prowadzenie statku do portu przeznaczenia w sposób bezpieczny i efektywny. Manewr dobijania statku do nabrzeża jest końcowym etapem procesu nawigacji. Urządzenia odbojowe ułatwiają cumowanie poprzez absorbowanie energii uderzenia statku. Idealny manewr cumowania polega na całkowitym wytraceniu prędkości statku w momencie kontaktu z nabrzeżem. Jednak, ze względu na dynamikę oddziaływania statku, należy się liczyć z uderzeniem statku w nabrzeże. Może to spowodować uszkodzenie kadłuba statku budowli portowej. Lecz zastosowanie urządzeń odbojowych może ułatwić manewr dobijania poprzez absorbowanie energii kinetycznej uderzającego statku. Artykuł przedstawia metodę doboru urządzeń odbojowych w aspekcie zarządzania bezpieczeństwa procesu nawigacji.

Słowa kluczowe: zarządzanie bezpieczeństwem nawigacji, projektowanie urządzeń odbojowych