THE ANALYSIS OF ELEMENTS DECIDED OF SHIP'S MOVEMENT DURING STRIKE ON GROUND

ANALIZA CZYNNIKÓW WPŁYWAJĄCYCH NA RUCH STATKU PODCZAS UDERZENIA W DNO AKWENU

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Abstract: The main goal of navigation is to handle the ship in accordance with the basic aim, which should be executed. The port water areas are one of especially, where risk of navigation accident is high. The safety of manoeuvring ship on port water area depends mainly on under-keel clearance (UKC). The paper presents the analysis of elements, which determine the movement of ship during strike on ground.

Keywords: safety of navigation, under keel clearance, ship's strike on sea bottom

Streszczenie: Podstawowym celem nawigacji jest prowadzenie statku zgodnie z postanowionym celem, który ma być zrealizowany. Akweny portowe są szczególnymi, gdzie ryzyko wypadku (awarii nawigacyjnej) jest wysokie. Bezpieczeństwo statku manewrującego po akwenach portowych zależy głównie od zapasu wody pod stępką statku (ZWSP). Artykuł przedstawia analizę czynników, które mają wpływ na bezpieczeństwo nawigacji statku w przypadku uderzenia w dno akwenu pływania.

Słowa kluczowe: bezpieczeństwo nawigacji, zapas wody pod stępką, uderzenie statku w dno akwenu

1. Introduction

The marine navigation is the process of planning and leading the safe movement of ship from one place to another (port of destination). The main goal of navigation is to handle the ship in accordance with the aim of their movement when required parameters of this process should be retained. Realization of this goal depends on assurance of suitable level of ships safety during their manoeuvring in water area. This is achieved by controlling ship movement along a planned trajectory. However, various factors may affect ship motion. Port areas are a particular type of navigable waters because manoeuvring is limited by a number of factors [6]. An analysis of marine accidents shows, that a large number of such accidents occur within port waters. The port approach and port areas are characterised limited depth (shallow water) and various port structures.

The restricted area is characterized by a great number of factors being present at the same time. It caused that possibility of navigational accident in these areas is more than in other ones. The ship during process of navigation has to implement the following safety shipping conditions:

- keeping the under keel clearance,
- keeping the proper distance to navigational obstruction,
- keeping the proper air draught,
- avoid of collision with other ships.

To assessment and analyse the safety, especially in the quantitative manes, the necessary to select values that can be treated as a safety measures. It permits to determine the safety level by admissible risk [5]:

$$R_a = P_A [d(t)_{max} < d_{min} (0 < t < T_p)] \text{ for } c < C_{min} \quad (1)$$

where:

- $d(t)$ - distance of craft hull to other objects during manoeuvring,
- d_{min}^{max} - permissible distance of craft hull to other objects,
- T_p - time of ships manoeuvring,
- c - losses as result of collision with object,
- C_{min} - the acceptable level of losses.

Because the losses can be result different events, the following criterion of safety assessment will be used:

- Safety under keel clearance (SUKC),
- Safety distance to structure (SDS),
- Safety distance of approach (SDA),
- Safety air drought (SAD).

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:

$$R_o = R_g + R_n + R_c + R_{ad} \quad (2)$$

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.

There are three undesired types of events that can lead to a navigational accident within a port area:

- impact on the shore (or another port structure),
- contact with the area bottom,
- collision with other ships.

For first case, the area depth is sufficient, whereas the horizontal dimension is too small. In the second case the ship's draft is too great in comparison with the port water area depth. This relation is defined by the distance of the lowest point of the ship keel to the sea-bottom, usually referred to as the under-keel clearance (UKC) or water depth under ship's keel. The under-keel clearance is used for the description of the criterion of safe manoeuvring in a port area. This criterion can be expressed in this way:

$$H - D_{max} \geq UKC_{min} \quad (3)$$

where:

- H - water area depth;
- D_{max} - ship's maximal draft,
- UKC_{min} - safe under-keel clearance.

UKC_{min} is the value of minimum under-keel clearance of a ship manoeuvring within a given area that is to assure the ship safety that is no contact of ship's hull with the bottom should occur. The main limitation of handling the ships is the depth of port waters. The size of UKC in ports is defined by maritime administration, port authorities or ship masters [1, 4]. The interests in this field are contradictory. Maritime administration responsible for the safety of navigation wants the UKC to be relatively high. This, in turn, reduces the possible use of ships' capacity to the full, which for both ship owners and charterers is far from advantageous. In extreme cases a ship's owner or charterer may give up using port's services. The determination of permanent value of UKC was connected with decade-long observations and restrictions in sufficiently accurate determination of its components [2].

$$UKC_{min} \geq (H - \delta_H) - (D - \delta_T) \quad (4)$$

where:

- δ_H - errors in the determination of area depth,
- D - ship's draft,
- δ_T - error in the determination of ship's draft.

The overall error in depth determination is connected with errors done in:

- inaccurate soundings,
- determining the navigational reserve,
- determining water level,
- an error due to muddy bottom.

The error of ship draft determination is affected by errors done in:

- determining the change of draft in fresh water,
- estimated ship's list,
- draft determination due to waves,

- assessment of proceeding ship's squatting.

Situations when a ship hits the ground obviously are due to erroneous determination of keel clearance when its assumed value is too low. However, the excessive value of keel clearance leads to lower probability of ship's impact against the bottom on the one hand and decreased admissible ship's draft on the other hand.

2. The ship strikes in ground

The risk of accident arise in situation when under keel clearance is insufficient, what depend on many factors. Furthermore, the type of accident is taken into account different than generally descript in literature as grounding or striking the edge of coast. It regards of ships impact the bottom of ground with fixed vertical ordinate.

During a ship's striking the bottom of an area built of sandy or argillaceous ground, for a vessel in progressive movement, there occurs a gradual sinking of the hull into the ground (until the ship stops). The mechanism of the ship's striking the area's bottom depends on the ship's draft, namely whether the vessel is trimmed by the bows, the stern or if it is loaded on an even keel. During a ship's striking the bottom of an area of fragmented ground, for a vessel in progressive movement, there occurs gradual sinking of the hull into the ground (until the vessel's stoppage). During this process there can be distinguished the plough-in phase bound with longitudinal motion and the penetration (sinking) in a vertical direction.

Figure 1 presents this movement in the case of a vessel being trimmed by the bows. A similar phenomenon will occur in the case of being trimmed by the stern.

Fig 1. Penetration of the ship's hull into the bottom

The penetration of the ship into the ground depends on the relation between the horizontal V_H and vertical V_v components of the ship's speed V_S . The ship will stop in a certain distance I_P from the point of the hull's first contact with the bottom and the penetration to a particular depth Z_K . In the initial stage of the ship's penetration into the ground, is mainly affected by horizontal forces. Stopping of the ship takes place on a horizontal plane until the ship stops, which is described as stopping distance I_P from the first contact point to the stopping of the vessel. During ploughing there are also vertical forces causing penetration of the ground with initial angle β . The exceeding the permissible value of hull strength may cause damage to the hull. These stages are affected by the kind of ground of the area bottom.

When a ship hits the bottom, its hull presses on the ground which results in the passive ground pressure. That pressure is the ground reaction to the hull pressure on the bottom. The passive ground pressure increases with the pressure of the hull. When the maximum admissible value is exceeded, the area of ground is formed and the blocks of ground begin to move aside from under the hull. An increase in the passive earth pressure (for non-cohesive grounds) along with the increase of hull pressure takes place due to structural changes in the ground [3] occur in both granular system and in particles of the ground. Initially, the elastic soil becomes elastic-plastic, then plastic. This is a state in which all the grains and particles are in the state of boundary equilibrium, which corresponds to the boundary value of passive pressure of the ground. The ship's pressure on the ground causes the hull to penetrate into the bottom ground. When the boundary passive pressure (reaction) is reached the expulsion of ground block and the ship's bottom penetrates the ground. That phenomenon takes place in both non-cohesive grounds, such as gravels and sands and their mixes, and in cohesive grounds, including clay gravels and sand-gravel mixes, clay sands, clay and silt. An analysis of the ship hull action on the ground when the bottom is hit shows that there are similarities to the action of fenders. This means that the ground is a medium absorbing the energy of the impact [6]. The magnitude of energy absorption mainly depends on the ground properties. Ships penetrating a non-cohesive ground to a certain depth will not have their hull damaged.

3. Ground reaction on hull strikes on ground

When a ship strike the sea bottom, its hull presses on the ground which results in the passive ground pressure. That pressure is the ground reaction to the hull pressure on the bottom. The passive ground pressure increases with the pressure of the hull. When the maximum admissible value is exceeded, the area of ground is formed and the block of ground begins to move aside from under the hull. An increase in the passive earth pressure (for non-cohesive grounds) along with the increase of hull pressure takes place due to structural changes in the ground. The changes occur in both granular system and in particles of the ground. Initially, the elastic soil becomes elastic-plastic, then plastic. This is a state in which all the grains and particles are in the state of boundary equilibrium, which corresponds to the boundary value of passive pressure of the ground.

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of passive pressure of the ground. Figure 2 illustrates that process. The ship's pressure on the ground causes the hull to penetrate into the bottom ground. When the boundary passive pressure (reaction) is reached the expulsion of ground block and the ship's bottom penetrates the ground. That phenomenon takes place in either non-cohesive grounds, such as gravels and sands or their mixes, and in cohesive grounds, including clay gravels and sand-gravel mixes, clay sands, clay and silt.

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Fig. 2. Ship penetration in ground depends of ship pushing

Additionally, when there is ship's hull impact against the ground there may also occurs shearing forces and bending moments; if these are exceeded, the hull can be damaged. These factors will occur if the hull is supported on an underwater obstacle of small size. The ship proceeding within the dredged port waters should not encounter such obstacles. Nevertheless, one may expect the following situations to happen:

- part of ship's hull hits the ground (particularly when the ship is trimmed),
- the hull hits brought in earth (a bump) caused by a natural water current or propeller streams.

4. The elements determined of ship's strike on ground

On the basis of considerations presented there can be prepared an algorithm of calculating vessel movement parameters when striking the port water area ground and of forces impacting on the vessel's hull. The following components decided about ships movement [5]:

- friction force of the hull's bottom part,
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- overcoming soil wedge.

Thus the stopping of ship will be fulfill when the initial kinetic energy (in moment of first contact with sea-bed) became completely lost, i.e. will be change to following components:

$$mV_{Ho}^2/2 - \int P_{RT}dl - \int P_Bdl - \int P_{RK}dl = 0 \quad (5)$$

where:

- m - ships mass and water added mass,
- V_{Ho} - horizontal component of ships velocity in moment of contact with sea-bed,
- $\int P_{RT}dl$ - work performed for overcoming friction force of the hull's bottom part,
- $\int P_Bdl$ - work performed for overcoming the resistance of friction of the lateral parts of the hull,
- $\int P_{RK}dl$ - work performed for overcoming soil wedge.

In results of above consideration, it possible can be prepared an algorithm of calculating vessel movement parameters when striking the port water area ground and of forces impacting on the vessel's hull. There is possible to determine of results of ship impact in sea bed. It permits to assess of navigational risk and thus to improve the safety of ship movement when strike the ground.

5. Conclusions

The under keel clearance (UKC) should ensure ship's safe manoeuvring in a port area on the one hand, and the maximum ship's draft on the other hand, particularly in port areas.

A ship can touch the bottom of a port water area due to the reduction of its keel clearance. Such event no has to necessaribily results of damage of ship's hull.

There is possible to determine of results of ship impact in ground. It permits to assess of navigational risk and thus to improve the safety of ship movement in port water areas.

The next step of searching is further study to prepare of algorithm of calculating vessel movement parameters when striking the port water area ground

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