THE SHIPS IMPACT IN GROUND OF PORT WATER AREA

Galor Wiesław

Maritime University of Szczecin, Poland

Keywords

navigational risk, ship impact in the bottom, port water area

Abstract

The existing ports are expected to handle ships bigger than those for which they were designed. The main restriction in serving these ships is the depth of port waters, which directly affects the safety of a manoeuvring ship. The under keel-clearance of a ship in the port water area should be such that a ship moves safely. In some specific conditions it happen the ship strike the sea bottom. The undesired impact against the ground can damage the ship hull. The paper presents the algorithm of ships movement parameters during contact with the ground

1. Introduction

The world fleet tends to expand in terms of total capacity, with vessels growing in size, while their number is maintained on a similar level. The building of new ports is restricted on the one hand by natural conditions of sea areas, and necessary large financial effort on the other hand. As economic and geopolitical conditions change, directions of cargo transport (bulk in particular) also change, sometimes in a cycle lasting a few years. This in turn, makes building new ports a risky enterprise for investors, as the invested capital return amounts to at least twenty years. Therefore, a need arises to use the existing ports for handling ships larger than those the ports are designed for.

This objective can be achieved through changes in operating conditions within ports and the modernization of certain components of port basins and areas. These measures should results in ports handling ships as large as possible on condition that specified safety level is maintained.

Safe manoeuvring of a ship within a given area requires that the manoeuvring area of a ship with a specific draft is comprised within available port water area having a required depth.

There are two undesired types of events [2] that can lead to a navigational accident within a port area:
- impact on the shore (or another port structure),
- contact with the area bottom.

In the former case the area depth is sufficient, whereas the horizontal dimension is too small. In the latter case the ship's draft is too deep in comparison with the basin depth. This relation is defined by the distance of the lowest point of the ship bottom to the basin bottom, usually referred to as the under keel clearance or water depth under ship's keel.

2. Under keel clearance

The under keel clearance (UKC) is used for the description of the criterion of safe manoeuvring in a port area [3]. This criterion is most often expressed in this way:

$$H - T \geq R_{min} \qquad (1)$$

where:

H – water area depth,
T – ship's maximum draft,
R_{min} – safe under keel clearance.

R_{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 [5]. This clearance is also called the required or safe water clearance.

The objective function can be written as:

$$UKC= R_{min} \rightarrow min \tag{2}$$

with the restrictions

$$R \leq R_{dop} \tag{3}$$

where:

R – risk of manoeuvring in an area,
R_{dop} – admissible navigational risk defined at an acceptable loss level,

where:

$$R_{dop}= P[Z_c(t) \leq R_{min} \; / \; 0 \leq t \leq t_p] \; \text{ for } C \leq c_{min} \tag{4}$$

where:

$Z_c(t)$ – the list distance between ships hull and bottom during manoeuvring
R_{min} – under keel clearance
C – losses,
c_{min} – acceptable level of losses.

There are cases where a ship's hull harmlessly penetrates the bottom up to 40 cm. obviously it is possible only if the bottom ground is properly loose (sand, mud etc.). Therefore, it is possible to predict the minimum value of UKC for a certain risk level. It should be emphasized here that the adoption of such assumptions can have another effect, namely certain ships will not be allowed to enter the port due to environmental conditions (mainly water level and waves). The ship will have to wait for the conditions to improve. In tidal ports whether a ship may enter or leave a port depends on the so-called tidal window with waiting time amounting to several hours. The losses arising from the fact that a ship hits the ground while moving, such as hull damage or, possibly, loss of cargo (particularly liquid cargo, which may pollute the marine environment) depend on a number of factors, which can be expressed by a variety of measures. The one of these is maximum ship hull load less than admissible value caused damage of its.

3. The probability of ship damage

As research shows [6], situations when a ship's hull touches the sea bottom do not often result in serious damage. Only incidents in which the ship's hull is damaged are regarded as accidents. The damage may be of various kinds:
- tearing of bottom plating,
- crushing of deck,
- folding of web frames,
- stretching of shell plating.

The kind and degree of hull damage depends mainly on the energy absorbed by the hull when hitting the bottom. The measure of hull damage used for the
assessment of the impact is the volume of damaged hull material. The relationship combining the absorbed energy and the degree of damage has been empirically worked out [6]:

$$E = 47.2 \cdot R_T - 37.2 \tag{5}$$

where:

E - energy absorbed by the hull during impact
R_T - degree of damage of hull material.

This empirical relation has been determined from the observations of the effects of numerous collisions and is used for the assessment of collision effects.

The relation shows that the degree of damage increases in direct proportion with the energy absorbed by the ship's hull during the impact against an obstruction. This is, undoubtedly, a simplified approach as the quantity of absorbed energy depends on a lot of factors, but mainly on the structure of the ship's hull bottom, material properties and the type of damage. Therefore, further research is carried out to determine as accurately as possible the relation between the absorbed energy and the hull material damage, which would account for the above conditions. The energy absorbed by the ship's hull hitting the bottom is equal to the work done by the ship during the impact. The energy mainly depends on the force appearing between the hull and the bottom. It is difficult to define the force and its curve as the function of time by analytical methods. Therefore, simpler methods based on empirical research data are used. The empirical equation given below presents the energy of impact dependent on ship's mass and the velocity at the moment of impact. The vertical component of ship's velocity should be taken into account in these calculations:

$$E_v = m_s V_v{}^2 / 2 \qquad (6)$$

where:

E_v - energy absorbed during impact;
m_s - ship's mass
V_v - vertical components of ships velocity.

The consequences arising from the fact that a ship hits the ground while moving, such as hull damage or, possibly, loss of cargo (particularly liquid cargo, which may pollute the marine environment) depend on a number of factors which can be expressed by a variety of measures [1].

The maximum ship hull load for such a case can be defined as:

$$P_k(t) = 1 - \exp(- t(t_c)) \qquad (7)$$

where:

t_c – period in which the pre-set hull load will be exceeded during the hull impact against the bottom.

$$t_c = [P/1 - P_k(P_u)]^{-1} \qquad (8)$$

where:

$P_k(P_u)$ – probability of the hull load higher than admissible during its impact against the bottom.

$$P_k(P_u) = P[Q_{sgr} \geq Z_G] \qquad (9)$$

where:

Q_{sgr} – admissible pressure on ship's hull,

Z_G – passive earth pressure.

While determining the probability of ship hull damage during the impact one should take into account that not every such impact ends in a serious accident. Therefore:

$$P_{uw} = P_u \cdot P_k(P_u) \qquad (10)$$

where:

P_{uw} – probability of an accident during ship's manoeuvres,
P_u – probability of a ship's touching the bottom.

The probability of ship's impact against the bottom may be assumed as a criterion for the evaluation of the safety of ship manoeuvres within port waters.

From statistical data displaying the number of damaged hulls against the number of impacts against the bottom (damage indicator), the probability of hull damage can be replaced by the hull damage indicator. Then the probability of an accident will be equal to:

$$P_{uw} = P_u \cdot w_w \qquad (11)$$

where:

w_w –   hull damage indicator.

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

$$P_{A(N)} = N \cdot p_A = I \cdot T \cdot p_A \qquad (12)$$

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 [4]. Because accidents are infrequent events thus it can be used recurrent models. One of them is geometrical distribution:

$$P_{A(N)} = 1 - (1 - p_A)^N \qquad (13)$$

Figure 1 presents the probability of navigation accident for linear and geometrical distributions in function of ships transit numbers.
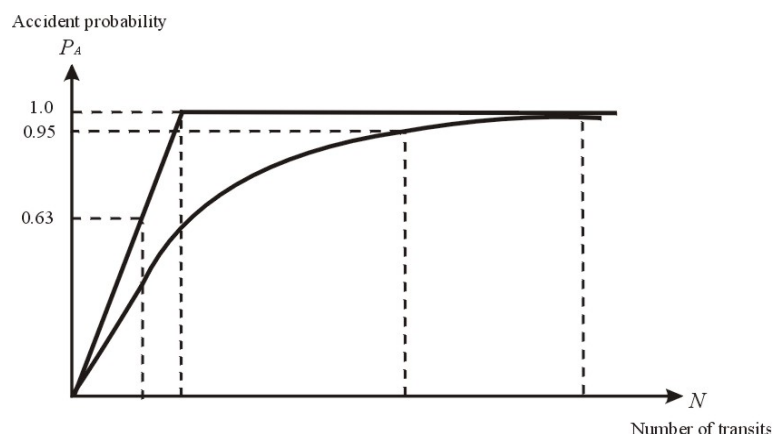

Figure 1. Probability of accident in function of transits number for linear and geometrical distributions

The probability of the ship's hull damage can be taken as an assessment criterion of safety and used to improve port functioning. The probability of arise the ship hull damage can be taken as an assessment criterion of safety and used to improve of port functioning.

4. The ship impact on the ground

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 [4] 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' 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. 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. During a vessel's striking the bottom of an area built of sandy or argillaceous ground, for a ship in progressive movement, there occurs a gradual sinking of the hull into the ground (until the vessel stops). The mechanism of the vessel's striking the area's bottom depends on the vessel's draft, namely whether the ship 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. A similar phenomenon will occur in the case of being trimmed by the stern.
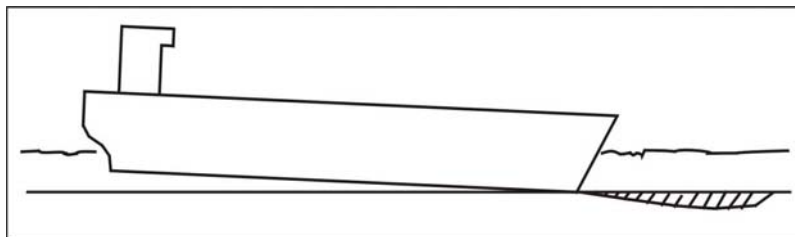
Figure 2. Penetration of the ships hull into the bottom

The penetration of the vessel into the ground depends on the relation between the horizontal and vertical components of the ship's speed. The ship will stop in a certain distance from the point of the hull's first contact with the bottom and the penetration to a particular depth. In the initial stage of the vessel's penetration into the ground, the ship's movement is mainly affected by horizontal forces. Stopping of the vessel takes place on a horizontal plane until the vessel stops, which is described as stopping distance from the first contact point to the stopping of the ship. During plough-in there are also vertical forces causing penetration of the ground. 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.

On the basis of considerations presented there has been prepared an algorithm of calculating vessel movement parameters when striking the port water area ground and of forces impacting on the ship's hull. It has been applied in a computer simulation model of the vessel's movement in the area. The model works in real time and serves the purpose of preparing navigational analyses. This permits risk determination of the vessel striking the area bottom and its results (likelihood of hull damage). In successive steps ship movement parameters during contact with the ground are calculated, which permits the determination of its results. There are the following steps of calculating of:

- – initial kinetic energy.
- – pressure of the ship on the area bottom, to decrease the water level or the vessel's draft.
- – checking whether passive earth pressure (the ground's reaction) does not exceed the permissible value.

- − the friction force of the bottom part of the ship's hull against the ground, taking into account the friction coefficient.
- − the depth of the ship's penetration into the ground.
- − work performed for overcoming friction force of the hull's bottom part.
- − work performed for overcoming the resistance of friction of the lateral parts of the hull for a specified depth of the ship's penetration into the ground.
- − work performed for overcoming soil wedge.
- − the decrease of the ship's kinetic energy caused by contact with the ground.
- − the decrease of the ship's speed components.

5. Conclusion

The keel clearance should warrant the safe manoeuvring of a ship in the port water area. Its value depends on many elements, in the midst of which the sea water level is very important. If keel clearance is great then the safety of ship is major but the admissible ship draft is less. It can cause:
- − limited quantities of cargo loaded and unloaded, which means lower earnings for the port and stevedoring companies;
- − lower ship-owners' profits as the ship's capacity is not used to the full or longer turnaround time due to necessary lighter age at the roads, before the ship's entrance. port charges are smaller as they depend on the ship's tonnage (berthing, towage etc.);
- − in many cases large ships resign from using services of a port where they are not able to use their total cargo capacity.

It is possible to predict of maximum sailing draft for entering ships into the port by proper method of calculation. Such predictions enabled increases in maximum drafts in relation to UKC defined by port low as a fix value. It can translate into cargo increases ranging up to several thousands tonnes per ship. In particular it refers to the Polish ports (Gdańsk, Gdynia, Świnoujście). UKC requirements should be determined with a much higher degree of certainty allowing the manoeuvring of ship to be made more safely. A ship can touch the bottom of a navigable area due to the reduction of its keel clearance. The mechanism of ship's impact against the bottom basically differs from grounding or hitting a port structure (berth) and is not sufficiently described in the literature on the subject. Phenomena such as ship's pressure on the bottom ground and its reaction (passive earth pressure) are essential in the assessment of the impact effects. The kind and degree of hull damage mainly depend on the energy absorbed by the hull during its impact against the sea bottom. The results of the research permits to assess of navigational risk and thus to improve the safety of ship manoeuvring in port water areas.

References

[1] Galor, W. (2005). *The managing of the navigational safety of ships in port water areas.* Editors C.A. Brebbia At all. WITPRESS Southampton, Boston.
[2] Galor, W. (2005). The movement of ship in water areas limited by port structures. *Annual of Navigation no 10*, Gdynia.
[3] Galor, W. (2005). Analiza określania zapasu wody pod stępką. *Materiały XI Międzynarodowej Konferencji Naukowo –Technicznej „Inżynieria Ruchu Morskiego". Szczecin, 2005.*
[4] Galor, W. (2005). Wybrane problemy bezpieczeństwa żeglugi na akwenach portowych. *TRANSPORT* pod redakcją Z. Strzyżakowskiego, Prace Naukowe nr 3(23) 2005 Politechniki Radomskiej, Radom.
[5] Mazurkiewicz, B. (2006). *Morskie budowle hydrotechniczne. Zalecenia do projektowania i wykonania Z1-Z41.* Wyd. FPPOiGM, Gdańsk.
[6] Pedersen, T.P. & Zhang, S. (2000). Absorbed energy in ship collision and grounding, Revision Minorsky's Empirical Method, *Journal of Ship Research,* Vol.44, No.2.