**DETERMINATION OF DYNAMIC UNDER KEEL
CLEARANCE OF MANEUVERING SHIP**

**DYNAMICZNE OKREŚLANIE ZAPASU WODY POD
STĘPKĄ MANEWRUJĄCEGO STATKU**

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Abstract: The safety of navigation of a ship manoeuvring within port waters mainly depends on its under keel clearance (UKC). Mainly UKC depends on water level change, squatting of moving ship and heeling and wave response. The effect of these components will be determined currently than such UKC is called as dynamic under keel clearance. The paper presents an analysis of certain components of UKC to maximise of ship draft and thus to achieve the economic benefit to port and ships owner.

Keywords: safety of navigation, under keel clearance

Streszczenie. Bezpieczeństwo statku manewrującego po akwenach portowych zależy głównie od zapasu wody pod stępką statku (ZWSP). ZWSP zależy głównie od zmian poziomu lustra wody, osiadania statku w ruchu, przechyłów statku oraz oddziaływania fal. Rezultat oddziaływania tych czynników może być określany na bieżąco podczas manewrowania statku. Artykuł przedstawia analizę czynników w celu maksymalizacji zanurzenia statku i stąd uzyskania optymalnych zysków dla portu i armatora.

Słowa kluczowe: bezpieczeństwo nawigacji, zapas wody pod stępką

1. Introduction

The main goal of navigation is to handle the ship in accordance with aim of their movement when required parameters of this process should be retained. Realisation of this goal depends on assurance of suitable level of ships safety during their manoeuvring in water area. The ship, however, may be affected by various factors during that process, which sometimes make it difficult. This means that in certain conditions just any trajectory cannot be planned for the ship, and on the other hand, steering the traffic on a properly planned trajectory is not always possible. An important element of the ship's environment, is a water area where the ship moves. 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 [3]. Another significant factor is the standardisation of new buildings ships. In the case of bulk carriers this means that ship's parameters have to be adjusted to restrictions existing throughout the world. One example is "Panamax" size ships, the breadth of which is adjusted to pass through the Panama Canal. Therefore, ships' statistics in terms of size show that in certain size ranges there are far more vessels than in others. 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 modernisation of certain components of port basins and areas [1]. 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. Safe movement of a ship in a certain area can be described as a state in which its hull will not touch the sea bottom. The condition that has to be met is as follows:

$$R_B \geq (H_i - \delta_H) - (T - \delta_T) \quad (1)$$

where:

- R_B – safe keel clearance,
- H_i – depth of the area,
- δ_H – errors in the determination of area depth,
- T – 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; and
- 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.

2. Methods of the determination of under keel clearance

The size of UKC in ports is defined by:

- maritime administration (maritime offices, harbour master's offices),
- port authorities,
- ship masters.

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. However, advances in the field, i.e. scientific methods enable the optimisation of the UKC value as a altering value depended on local conditions. Conclusions from analyses of selected methods [4] are that UKC is mostly determined by the coefficient method of summed components.

The coefficient method consists in determining the value R_{min} as part of ship's draft:

$$R_{min} = \eta Tc \quad (2)$$

where:

- Tc – maximal draft of the hull,
- η – coefficient (0.05-0.15).

The values of coefficient η used in practice range from 0.03 do 0.15 [5].

In the other method the value R_{min} is determined as an algebraic sum of component reserves [3], where in addition errors of the particular components are taken into account:

$$R_{min} = \sum_{i=1}^n R_i + \delta_r \quad (3)$$

where:

- R_i – component reserves of depth,
- δ_r – sum of errors of components determination.

The under keel clearance is divided into a static and dynamic component. This division reflects the dynamics of particular reserves. The static component includes corrections that change little in time. This refers to a ship lying on calm waters. The dynamic component consists of the reserve for the squatting of a moving ship and wave action. It should be noted that in this division the dynamic component should also include the reserve for listing caused when a ship turns.

Therefore, the UKC can be defined as:

$$R_{min} = R_S + R_D + \delta_r \quad (4)$$

where:

- R_s – static component,
- R_d – dynamic component,
- δ_r – errors of component determination.

$$R_S = \sum_{i=1}^6 R_i \quad (5)$$

where:

- R_1 – reserve for sounding error,
- R_2 – navigational reserve,
- R_3 – reserve for water silting up,
- R_4 – reserve for water level change,
- R_5 – reserve for tide determination error,
- R_6 – reserve for ship draft determination.

$$R_D = \sum_{i=7}^9 R_i \quad (6)$$

where:

- R_7 – reserve for heeling on curve waterway,
- R_8 – reserve for squatting of a moving ship,
- R_9 – reserve for waves affecting.

The determination of all the components is burdened with calculating or estimating errors. Considered as incidental errors, they can be defined as [4]:

$$\delta_r = \left(\sum_{i=1}^9 \delta_{ri} \right)^{\frac{1}{2}} \quad (7)$$

3. Optimization of ship's draught

As far as the officially determined UKC is concerned, there is a conflict of interests between maritime administration and port authorities. The former, being responsible for the safety of shipping tends to set up a relatively deep UKC, while the latter want to handle ships with as deep draft as possible [2]. This in turn imposes restrictions on the full use of ship capacity, cutting down the profits of ports and cargo carriers. In extreme cases a ship /its owner or charterer/ may choose not to use the services of a port with such restrictions. Therefore, the optimization of the UKC in a given port is desirable and feasible by the application of the right methods.

The objective function can be written as follows:

$$UKC = R_{min} \rightarrow \min \quad (8)$$

With these restrictions:

$$\text{a.} \quad R \leq R_{dop} \quad (9)$$

where:

- R_{min} – minimum safe value of UKC
- R – risk of ship's manoeuvring in the area,
- R_{dop} – admissible navigational risk defined at an acceptable loss level,

$$\text{b.} \quad T_o \leq T_{akc} \quad (10)$$

where:

- T_o - time of waiting for entry into or departure from the port
- T_{akc} - accepted waiting time.

4. Safety of a ship moving in port waters

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 kind:

- tearing of bottom plating,
- folding of web frames,
- stretching of shell plating.

That is why the evaluation of ship's movement safety should allow for its impact against the bottom, on condition that the effects of the impact (losses) do not exceed the accepted level (hull damage). That incident can be described as follows:

$$P_u \left[z_c(t)_{\max} \leq R_B / 0 \leq t \leq T_p \right] d\alpha \quad C \leq c_{\min} \quad (11)$$

where:

- P_u – probability of ship's impact against the bottom,
- $z_c(t)_{\max}$ – closest distance of ship hull from the bottom during maneuvers,
- R_B – safe keel clearance,
- C – losses due to the impact against the ground,
- $c_{\min}$ – acceptable level of losses.

The risk of hull damage due to ship's hitting the bottom in port waters may be accepted as a criterion of safety assessment of ship's manoeuvring in a port area.

The effects of the moving ship hull impact onto the bottom such as hull damage and, possibly, cargo loss (plus environmental pollution by liquid cargo) depend on a number of factors and can be expressed by various measures.

It is assumed that a ship may hit the ground on condition that the effects (losses) will not exceed a certain acceptable level of hull damage.

5. Water level fluctuations

The restriction of the time of ship's waiting for a port entry or departure is due to the fact that the present water level may not allow for ship manoeuvring with a preset underkeel clearance. A ship will have to wait regardless of the method applied for the determination of UKC. At present in Polish ports while determining the UKC as a constant value, a safety margin for low water is set up taking into account the difference between multi-year average water level and multi-year average low water level [3]. This margin for the largest Polish ports is as follows:

- Gdańsk – 0.60 m,
- Gdynia – 0.60 m,
- Szczecin – 0.50 m.
- Świnoujście – 0.80 m

Decreasing the UKC one should bear in mind that the changing sea state may force a ship to wait for the proper conditions, i.e. for the sufficient water level. The waiting time should not exceed the time an owner or charterer is willing to accept. It should be underlined that ships waiting for the proper water level is a normal practice in tidal ports where the water level changes at half-daily or daily cycles. In non-tidal ports as Polish ports are the lower water level may last longer, hence more detailed investigation is necessary. One of the basic factors affecting the UKC is a margin for low water levels [7]. While planning vessel entries, their laydays and departures one has to be familiar with short-term forecasts of water level, particularly its drops. Ships generally lie in ports for a few days. Arriving and departing manoeuvres in the port of Świnoujście take about six hours. The

knowledge of sea level forecasts for the next few hours allows a ship to proceed safely through a restricted area of accessible depth. On the other hand, the knowledge of forecasts for the next few or several days allows to plan vessel callings, stays and necessitated sailings if the sea level is known to decrease.

When the sea level in the port is below the average measured water level, admissible draft is decreased by the correction, that is the present water level difference. If the water level in the port is above the average, the harbour master may give permission for an entry or departure of a ship drawing deeper than the set maximum draft. Each time the correction should be defined on the basis of the water level analysis, its drop or rise trend along the entire planned track of the ship. In practice, the harbour master does not make a decision on raising the admissible draft as there is no appropriate method for determining the changes in water level during the ship entry, laytime and towing out of the port.

Presented below is an analysis of the water level in the port of Świnoujście below 470 cm, occurring in the years 2001-2008. The average time of drops below the 470 cm level shows that December and March were the least favourable months for maximum size ships the port could accept. The mean time of the drop duration in those months is almost twice higher than in the other months. The duration times of water level drops vary substantially from year to year. Besides, it is characteristic that there is no drop below 470 cm in summer months from June to September. The durations of water level drops, shown in Figure 1, range greatly, lasting from one hour to more than 100 hours. One hour drops amounted to 21.8%, drops to six hours had a 48.3% share, 12-hour drops made up 66.7%, and the drops lasting to 24 hours amounted to 81.6% of the total time. The occurrence of drops longer than 24 hours made up 12.4%.

6. 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:

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. It can be claimed that the UKC may sometimes assume negative values (the bottom can be penetrated) in the case of fine loose bottoms. The basic condition of such a contact is that the ship's hull does not get damaged during its contact with the bottom. Therefore, it seems necessary to do research aiming at the development of a method allowing determining the

minimum keel clearance with the safety level being maintained. Then decisions whether a ship can manoeuvre within port waters will be taken at the acceptable risk. It permits to manage of ships safety. Additional taking into account the possibility of serious damage of ship hull the method can be used to choice of optimal ships draft.

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