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THE WAITING TIME OF THE SHIP ON PORT ENTRANCE AT REQUIRED WATER LEVEL

Summary. The safety of a ship which manoeuvres within a port area depends to a large extent on the underkeel clearance (UKC). Ports have been built to handle ships of specific maximum parameters. In many cases, however, the existing ports face the need to accept ships larger than those they were designed for. The construction of new harbours is limited by both natural conditions and exceedingly high estimated costs. The main restriction for handling larger ships is the depth of port basins, directly affecting the safety of the manoeuvring ship. The minimum underkeel clearance is most often specified by port regulations as a constant value. However, depending on the prevailing conditions, mainly water level, this required UKC value can be reduced. Thus, ships of larger draft will be allowed to enter. This article / paper present a method of UKC optimization with two restrictions: maximum permitted navigational risk and the time of waiting for sufficient water level. An example has been given in reference to ship's waiting time probability for the port of Świnoujście.

CZAS OCZEKIWANIA STATKU NA WEJŚCIE DO PORTU PRZY ODPOWIEDNIM POZIOMIE WODY

Streszczenie. Bezpieczeństwo statku manewrującego po akwenie portowym zależy od wielkości zapasu wody pod stępką (UKC). Porty są budowane do obsługi statków o określonych maksymalnych parametrach. Jakkolwiek w wielu przypadkach istniejące porty stają wobec potrzeby obsługi statków większych niż te, dla których zostały zaprojektowane. Budowa nowych portów jest z jednej strony ograniczona przez warunki naturalne, zaś z drugiej strony przez wysokie koszty. Głównym ograniczeniem w obsłudze większych statków jest głębokość akwenów bezpośrednio wpływających na bezpieczeństwo manewrującego statku. Minimalny zapas wody pod stępką statku jest często określony przez przepisy portowe jako stała wartość. Jednak w rzeczywistości zależy ona od wielu czynników, z których przeważający jest poziom wody, co pozwala w określonych warunkach na zmniejszenie UKC. Stąd można osiągnąć większe zanurzenie wchodzącego statku. Referat przedstawia metodę optymalizacji UKC dla dwóch ograniczeń: maksymalnego dopuszczalnego ryzyka i czasu oczekiwania na odpowiedni poziom wody. Podano przykład określania prawdopodobieństwa czasu oczekiwania dla portu Świnoujście.

1. INSTRODUCTION

Many ports built decades ago today are forced to accommodate vessels larger than those they were designed for. New port projects are restricted due to local sea and land conditions as well as high financial effort. As the economic and geopolitical conditions change, established directions of cargo flows also change, which sometimes may take less than a decade. Therefore, to build a new harbour is a risky business as the investment return period is about twenty years or more. If we take a look at statistics of the global fleet, we will find there are groups of ships in terms of size that include considerably large numbers as compared to other size ships. One such example is the Panamax size vessel whose maximum breadth is 33.53 m. The draft of these vessels well exceeds ten metres. Manoeuvring a ship within port waters also calls for certain requirements to be fulfilled.

For ship manoeuvres to be safe, two conditions have to be met:

- proper size of the manoeuvring area,
- underkeel clearance (UKC).

In most cases the port water area is described by its horizontal parameters given for an assumed depth. Generally, the horizontal dimensions do not change as the water level changes. Sometimes the extension of port's ability to serve larger ships requires certain feasible modifications. There always remains a serious problem of the port basin or area depth, which is maintained in a given port at the same level. However, increasing the depth is generally so costly that port authorities do not take it into account. Besides, in some cases deepening a basin might threaten the stability of port shore structures.

Polish sea ports - Świnoujście, Gdynia and Gdańsk - are among those of insufficient depth to freely handle Panamax ships, but nevertheless, ships of that size call at those ports. As the draft of Panamax ships is too deep for these ports, to be accepted such ships have be to lightened so that their decreased draft will fit the maximum depth of port basins. Needless to say, the cargo capacity of those ships is not fully used.

The survey of callings at the port of Świnoujście in the years 2001-03 shows that in that period 156 not fully laden ships called at the port. Their maximum draft to the load line was deeper than the port's maximum draft of 12.8 m. The average yearly number of incompletely laden ships calling at the port of Świnoujście was 52. Although last year changes in the port regulations allow to accept ships drawing to 13.3 m, which increases the use of maximum size ship cargo capacity, an analysis has shown that the maximum permitted draft can still be increased (naturally, depending on the prevailing conditions).

2. CONDITIONS FOR SHIP'S SAFE MANOEUVRING IN A PORT AREA

An accessible port area (with an assumed depth) ensures safe manoeuvres, if these conditions are satisfied [1]:

$$\omega \in \Omega \qquad dla \;\; H = const \tag{1}$$

where: ω - required ship manoeuvring area, Ω - accessible area, H - assumed area depth

Another condition ensuring a safe manoeuvre of a ship in a given area is this one:

$$H_i \geq T + SUKC \tag{2}$$

where: H_i - depth at i-th point of the area, T - ship's draft, *SUKC* - safe underkeel clearance (*SUKC*)

The safe underkeel clearance (*SUKC*) should be such that it will ensure ship's manoeuvres in an area that will not result in hull damage. An accident risk exists when the underkeel clearance is insufficient.

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. This in turn imposes restrictions on the full use of ship's 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:

$$UKC = R_{min} \rightarrow min \tag{3}$$

With these restrictions:

a.
$$R \le R_{dop} \tag{4}$$

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

b.
$$T_o \le T_{akc} \tag{5}$$

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

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.

$$P_u \left\lfloor z_c(t)_{\max} \le R_B / 0 \le t \le T_p \right\rfloor \quad dla \quad C \le c_{\min} \tag{6}$$

where: P_u - probability of ship impact on the bottom, $z_c(t)_{\max}$ - least distance of ship hull from the bottom while manoeuvring, R_B - safe underkeel clearance, C - losses due to ship's hull hitting the bottom, $c_{\min}$ - acceptable level of losses

While determining the possibility of hull damage when a ship hits the bottom one should take into account the fact that not always the hull-bottom contact results in a serious accident. Therefore, we should take into consideration the effects of only such events that will cause hull damage [2].

This can be described by the risk:

$$R = P_u \cdot P_k \tag{7}$$

where: R - risk of hull damage during ship manoeuvring, P_u - probability of ship hull-bottom contact, P_k - probability that hull loads occurring when the ship hits the bottom will exceed admissible values.

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 [4].

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 are 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.

3. WATER LEVEL FLUCTUATIONS

One of the basic factors affecting the UKC is a margin for low water levels. 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 2001-2003. 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. Figure 1 shows a total time of low water below the 470 cm level in particular months and years.

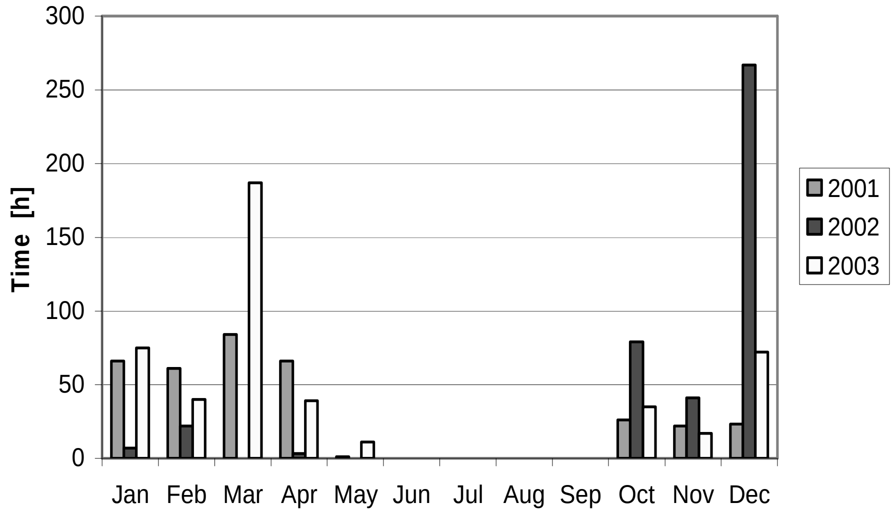

Fig. 1.Duration of water level drops below 470 cm in Świnoujście in the years 2001-2003
Rys. 1. Czas spadku poziomu wody poniżej 470 cm w Świnoujściu w latach 2001-2003

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%.

4. PROBABILITY OF SHIP'S WAITING FOR A PORT ENTRY OR DEPARTURE

Various phenomena that occur in the sea are of random character, therefore an attempt to determine the course of these phenomena can be made by the probability calculus. There are several definitions of random event probability, each having both advantages and disadvantages.

The classical definition of probability defines the probability as the ratio of the number *k* of cases favourable to an occurrence of a random event *A*, to the total number *N* of all equally probable cases:

$$p_o = k / N \tag{8}$$

where: p_o– probability of a random event, *k* – number of elementary events favourable to a random event, *N* – number of all random events in the examined period.

In spite of the given reservations, this definition according to Jednorał [3] can be applied in an analysis of marine phenomena.

One such analysis was focused on the water level drops below 470 cm that were observed in Świnoujście in the years 2001-2003. On this basis the probability of the water level drop in the examined three year period was determined (Fig.2).

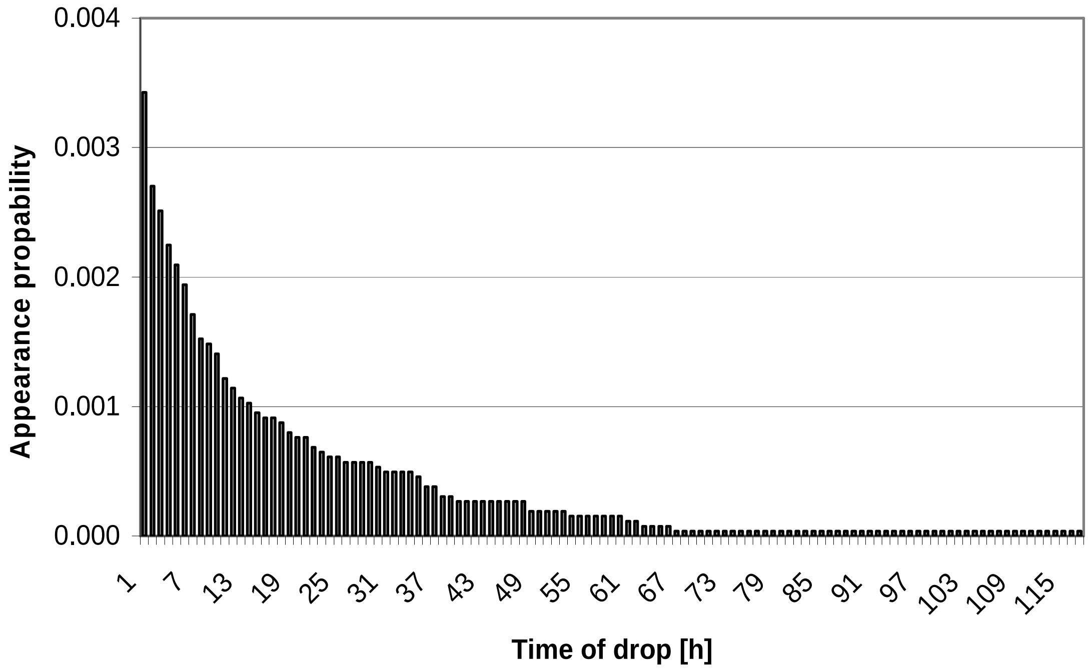

Fig. 2. Probability of water level drop below 470 cm in Świnoujście in the years 2001-2003
Rys. 2. Prawdopodobieństwo spadku poziomu wody poniżej 470 cm w Świnoujściu w latach 2001-2003

The probability of a water level drop lasting up to one hour in Świnoujście within a three year period is 0.0034, six hours – 0.0019, 12 hours – 0.0011 and 24 hours – 0.0006. The probability of drop times has a form of exponential distribution.

These data allow to determine for a preset period the probability that a ship with a specific draft will have to wait, due to a water level drop, for entering or leaving the port.

As these phenomena occur relatively rarely, recurrent models [2] can be used as statistical models for probability estimation. Quite common are geometric and Poisson distributions.
The geometric distribution assumes this form:

$$P_{o(N)} = 1 - (1 - p_o)^N \tag{9}$$

where: $P_{o(N)}$ - probability of ship's waiting for a specific number of ships' manoeuvres, p_o probability of an event for one manoeuvre, N - number of ship's manoeuvres

The Poisson distribution allows to consider the process as a function of time for which the probability of an event (state of water level drop below a preset value, corresponding to the ship's waiting time) are expressed by this relationship:

$$P_o\ (x=n)=\frac{\lambda^n}{n!}e^{-\lambda} \tag{10}$$

where: P_o - waiting time probability, λ - intensity of water level drop below an assumed value, n - number of drop periods

This distribution allows to determine the probability of ship's waiting or a specific number of such events x. The probability of such event is:

$$P_o(x>0) = 1 - P_o\ (x=0) = 1 - e^{-1} \tag{11}$$

For a given intensity λ in the time t we can determine the period of time T_W , in which such event can occur:

$$T_W = t/\lambda \tag{12}$$

where: T_W - time in which one accident can happen, λ - accident intensity, t - examined period of time

The above considerations allow to determine the probability of ship's time of waiting for a sufficient water level that will ensure safe manoeuvres during the ship's entry or departure. As not all water level drops will be assumed, further research will take into consideration water drop ranges. These will be adopted as an absolute value (e.g. as a difference between the average level and a drop by a specific value). Another method can consist in specifying the allowed water level drop for a preset probability of the time of waiting for favourable water level conditions.

5. CONCLUSION

The underkeel clearance is one of the basic criteria for the assessment of navigational safety of manoeuvres in port waters. This parameter determines the maximum permitted draft of a vessel. In many cases the present depth of a port area restricts ship's draft. In this way the ship cargo capacity cannot be fully utilized. This restriction in the largest ports of Poland applies to the handling of deep-drawing ships, mainly Panamax ships. As in these harbours the underkeel clearance is adopted as a constant value, it turns out that in many cases it is too large as it does not account for external factors, mainly water level fluctuations. For that reason the ports have been seeking ways to increase their competitiveness by optimizing the underkeel clearance, i.e. its minimization with maintaining certain restrictions, namely navigational safety (minimum navigational risk) and acceptable time of waiting for port entry or departure. In this approach the underkeel clearance is individually determined for each event – entry or departure manoeuvres. Such practice, already in use in many ports worldwide, assuming the method of variable or dynamic underkeel clearance, can definitely be introduced in Polish ports. First attempts have already been made in the port of Świnoujście where the previously mandatory UKC was reduced by 50 cm.

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