Waldemar UCHACZ[1], Wiesław GALOR[2]

WYBRANE PROBLEMY OPTYMALIZACJI WODY POD STĘPKĄ W TRANSPORCIE TOWARÓW DROGĄ MORSKĄ

Streszczenie. Akwen portowy jest określony wymiarami w poziomie i pionie, które są dostosowane do obsługi statków o określonych wielkościach. Podczas eksploatacji portu może wystąpić potrzeba obsługi statków większych niż te, dla których port został zaprojektowany. Szczególnie może to dotyczyć zanurzenia statku. Problem ten może być rozwiązany poprzez zmniejszenie zapasu wody pod stępką (ZWPS), lecz to powoduje zwiększenie ryzyka uderzenia statku w dno akwenu portowego i w rezultacie straty finansowe, wynikające z uszkodzenia kadłuba statku. W artykule przedstawiono założenia obliczeń optymalnego zapasu wody pod stępką w aspekcie zwiększenia zanurzenia statku i zysku armatora oraz potencjalnych strat.

Słowa kluczowe. Transport morski, zapas wody pod stępką, optymalizacja

SOME PROBLEMS OF SHIP UNDER KEEL CLEARANCE OPTIMIZATION IN THE TRANSPORT OF CARGO

Summary. Port water area is described by horizontal and vertical dimensions, that are designed to service of ships given size. During port exploitation it can happen of needs to service the ship greater than those was designed. Especially it regards the ships drought. This problem can be solve by reduction of under keel clearance (UKC). But it caused increasing of risk of ships strike into the ground of port water area, and in result the consequence of financial losses caused by damage of ship's hull. The paper presents assumption of calculation of optimization of ships under keel clearance in aspect of increase of ships draught expected benefits and potential losses.

Keywords. Sea transport, ships under keel clearance, optimization

[1] ZITM, Akademia Morska w Szczecinie; ul. Wały Chrobrego 1-2, 70-500, Szczecin, tel. +48 91 4809391, fax. +48 91 48 09 466, e-mail: w.uchacz@am.szczecin.pl.

[1] IIRM, Akademia Morska w Szczecinie; ul. Wały Chrobrego 1-2, 70-500, Szczecin, tel. +48 91 4809514, fax. +48 91 48 09 523, e-mail: w.galor@am.szczecin.pl

1. INTRODUCTION

Many ports built in previous decades, are facing a need operation of ships larger than those for which it was designed. Construction of new port is associated with very high costs, are affected by, among other natural environmental conditions. In view of changing economic conditions, as well as geopolitical, in relatively short periods of time are changing the directions of transport. Due to the economics of building new ports, where the return on investment is very long, there is a high risk of investment profitable cost effectiveness. World fleet is characterized by a division into different groups of vessels, one of the marker is their size. An example might be a type “Baltimax” ships with maximum overall dimensions allow navigation through the Danish Straits. Type of these ships size is limited by fairway depth of at 15.4 m. Port water area is specified dimensions in the horizontal plane, and depth. Support for larger ships than originally planned, the port water area needs to be modernized through the reconstruction of individual building elements of port structure. However, there remains a serious problem of the depth of the basins, which for a given port is maintained at a fixed level, and the change (increase depth) is very expensive. Moreover, the deepening is not always acceptable, because it might hazard the stability of hydro technical constructions. This raises the problem of maximum exploit of an existing depth. Examples of ports with insufficient depth to handle of "Baltimax" ships, are the main Polish ports (Świnoujście, Gdynia and Gdańsk), where more and more ships call at more than planned for the port [6]. Maximum draft of these ships is more than acceptable for a given port. This raises the need to reduce their draft, in order to fit up to a maximum depth of the ports, and this makes this type of ship capacity is not fully utilized.

2. OWNERS PROFIT

Owners profit associated with the operation of ships is the difference between the ships freight expense being charged for the carriage of cargo by sea and the cost of transportation services. The total cost associated with the operation of ships is divided into three elements [5]:

- costs of maintaining the ship, which are relatively stable and reflect the need to ship in constant operational stand by,
- costs of load and ships movement, depending on the size of the production of transport,
- administration costs (fixed coasts).

$$D = F - K \tag{1}$$

where:

D – owners profit,

F – freight,

K – ship’s operating costs.

For bulk cargo the freight is depended on carried cargo volume.

$$F = F_j V \tag{2}$$

where:
F_j – freight unit cargo,
V – volume of cargo.

The volume of cargo for the type of vessel is dependent on the possibility of a ship loading. In the case of limitations due to insufficient depth of the port water area, the vessel can be loaded up to the draft resulting from the restrictions by under keel clearance.

Hence:

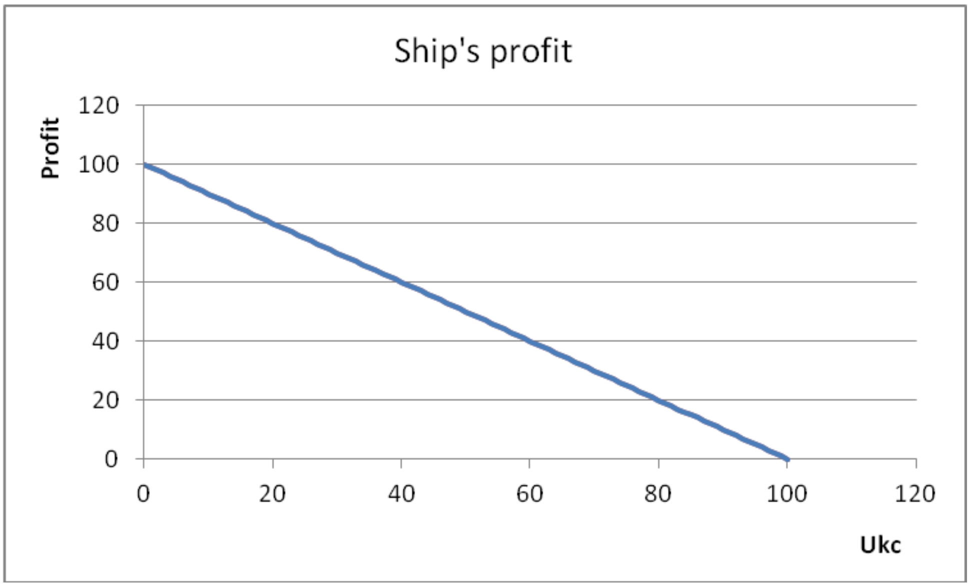
$$V = T_s \Delta V \tag{3}$$

where:
T_s – admissible ships drought resulting the depth of port water and ships under keel clearance,
ΔV – cargo volume for given change of drought ship (i.e. for 1cm)

Therefore, the owners profit D increases for bulk cargo ships due to increasing of ships draught as result of under keel water decreasing- linear dependence (Fig.1).

$$D(x) = D_p - \Delta V x \tag{4}$$

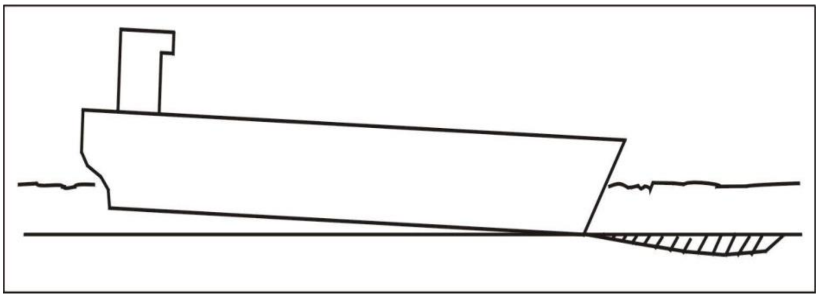
where:
D – owners profit,
D_p – profit for maximal ships drought,
ΔV – cargo volume for given change of draught ship,
x – ships under keel clearance.



Rys. 1. Zysk armatora statku z tytułu przewozu ładunku
Fig. 1. Owners profit as result of volume carriage cargo

3. THE COST OF THE SHIP HITS THE BOTTOM OF THR GROUND

When a ship hits the bottom (Fig. 2), 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. The kind and degree of hull damage depends mainly on the energy absorbed by the hull when hitting the bottom.



Rys. 2. Uderzenie statku w dno akwenu
Fig. 2 . The ships hit the ground

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 by [4]:

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

where:

E - energy absorbed by the hull during impact MNm],
R_T - degree of damage of hull material [m^3].

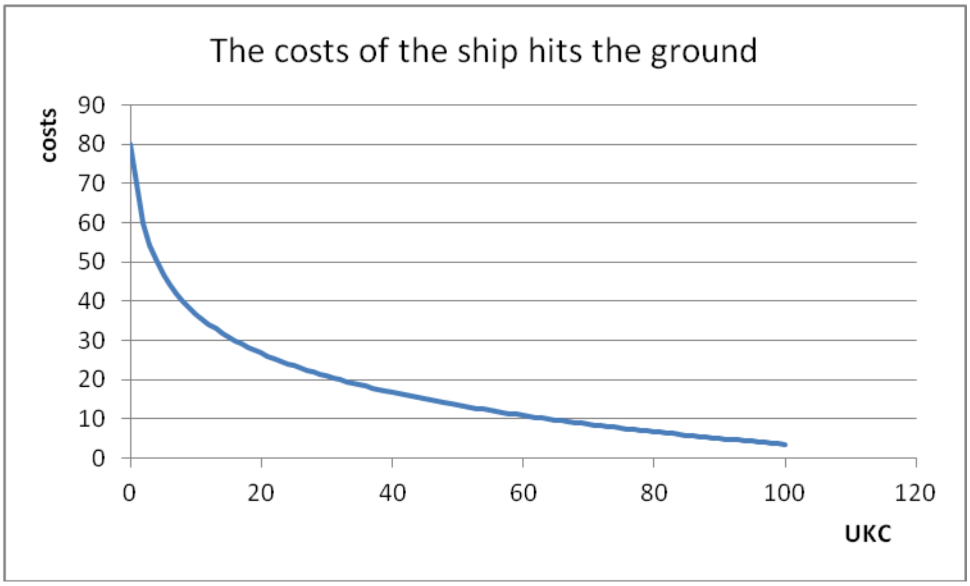
This empirical relation has been determined from the observations of the effects of numerous collisions and is used for the assessment of collision effects. The relation shows that the degree of damage increases in direct proportion with the energy absorbed by the ship's hull during the impact against 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.

The value of the energy E_u can be determined from this relation [2]:

$$E_u = m\frac{V_w^2}{2} \quad (6)$$

where:
E_u - value of the energy,
m - ships mass,
V_w - vertical component of ships speed.

Thus, the costs associated with the ship hit the sea bottom of port water area can be dependent on the energy impact of a ship in the ground. The possibility of hitting the ground increases with decreasing under keel clearance. It can be assumed that the costs of hit (and resulting the coast of damage the hull) depending on ships under the keel clearance, is a logarithmic (Fig. 3):



Rys. 3. Koszty uderzenia statku w dno
Fig. 3. The costs of the ship hits the ground of sea bed

$$K_u(x) = a_u - c_{K_u} log_2 x \quad (7)$$

where:
K_u – cost of the ship hit the bottom of the ground,
a_u - time of ship waiting on entrance to the port,
c_{K_u} – correctional coefficient,
x – under keel clearance.

4. LOSSES DUE TO SHIPS WAITING FOR AN APPROPRIATE LEVEL OF WATER

The requirement of port entering by loaded ship up to given draught is keeping the proper of under keel clearance UKC. As a result of the impact of various factors (mainly related to the state of water level), this condition cannot be met. Then the ship must wait for the right conditions under which UKC be a sufficient. On the one hand, in order to reduce the possibility of waiting to load a ship less, and thus increase UKC, which, however, on the other hand reduces the owners profit. However of UKC (increase the profit), it should be you must reckon with the possibility of waiting for the port entrance, and thus the losses due to ships downtime. They result from the so-called fixed costs (administration coasts) that are incurred by the owners, regardless of whether the ship is carrying cargo (profit), or waiting to loading or waiting enter the port (loss-making). With some simplification it can say that these costs are fixed.

Hence:

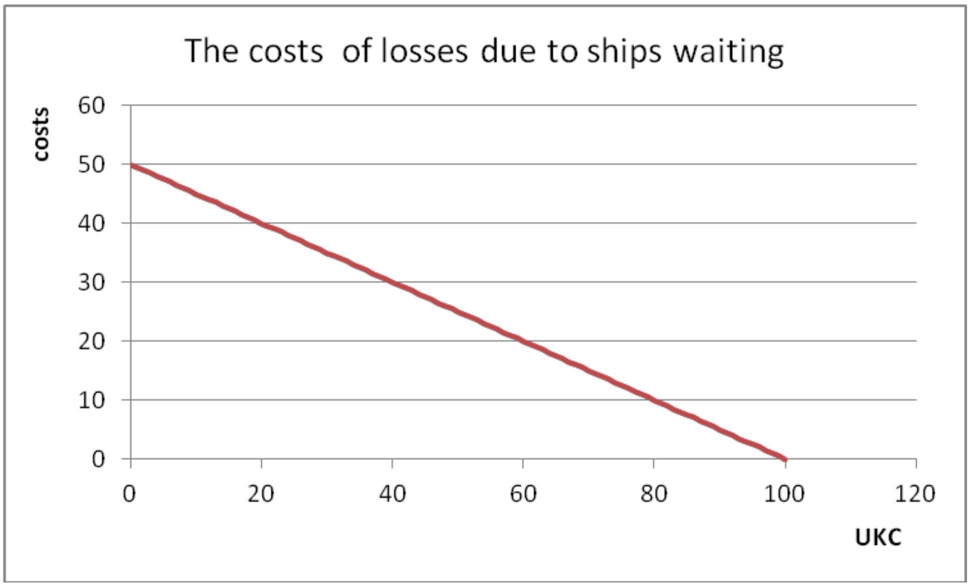
$$K_o = T_o \Delta k_s \tag{8}$$

where:
T_o - time of ship waiting on port enter (hrs, days),
Δk_s – unit fixed costs (per hour, day).

The fluctuations of water level at the entrance to the port, on the one hand, and the condition of loading a ship on the other hand, can cause losses due to waiting to enter port. The kind of the expectations costs due to proper of UKC(ship draught loading), will be strongly dependent on the nature of changes in water level at the entrance to the port. Determination of this relationship depends on the given port water area and requires statistical research. It can be simplified hat this relationship is linear. Thus the costs K_o of losses due to ships waiting for an appropriate level of water is following (Fig.4):

$$K_o(x) = C_o - a_o x \tag{9}$$

where:
C_o - constant value
a_o – unit fixed coasts
x – UKC (under keel clearance).



Rys. 4. Koszty oczekiwania statku na odpowiedni poziom wody
Fig. 4. The costs of losses due to ships waiting

5. OPTIMIZATION OF SHIP UNDER KEEL CLEARANCE (UKC)

The owners profit is connected with the operation of ship as carrying the cargo, in results and achieved the freight is achieved, and coasts of carriage that cargo (formula 1).

The natural aim of owners s to maximize profit. Therefore, the objective function optimization problem can be formulated as follows [1,3]:

$$FC = \max\{D(x) - c_u K_u(x) - c_o K_o(x)\} \tag{10}$$

where:

c_u, c_o – weighted coefficients of costs function respectively to function of costs of ship hits the ground and costs of ships waiting for enter the port.

It can therefore write:

$$calculate\ x : \max\left(D_p - \Delta V x - c_u\left(a_u - c_{K_u} log_2 x\right) - c_o(C_o - a_o x)\right) \tag{11}$$

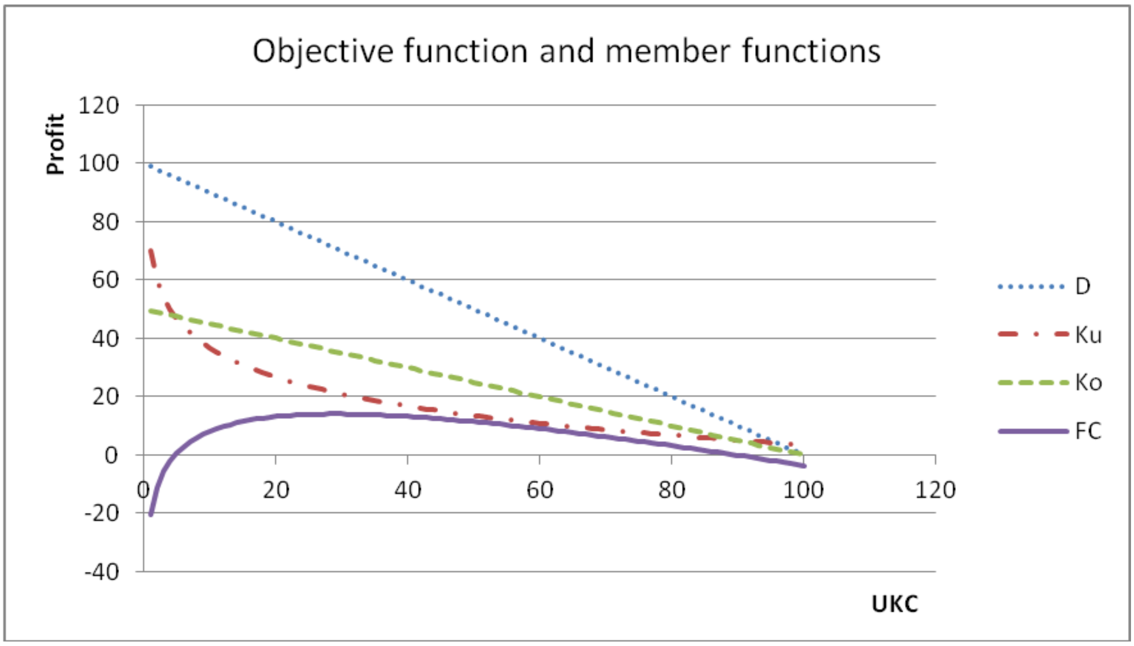
Equating derivative of equation (11) to zero, we obtain:

$$x = \frac{c_u}{ln2(\Delta V - a_o)} \tag{12}$$

Supposed exemplary dates:

$D_p = 100$ $\Delta V = 1$ $a_u = 1$ $c_{K_u} = 10$ $C_o = 50$
$a_o = 0.5$

the following results for member function and objective function is achieved, that are presented in Table 1 and on diagram (Fig. 5).



Rys. 5. Funkcja optymalizacji oraz funkcje składowe
Fig. 5. Objective function and member functions

Table 1

The value of optimization criterion UKC

x	D	K_u	K_o	$FC = D - K_u - K_o$
1	99	70	49,5	-20,5
2	98	60	49	-11
3	97	54,15037	48,5	-5,65037499
4	96	50	48	-2
5	95	46,78072	47,5	0,719280949
6	94	44,15037	47	2,849625007
7	93	41,92645	46,5	4,573549221
8	92	40	46	6
9	91	38,30075	45,5	7,199250014
10	90	36,78072	45	8,219280949
11	89	35,40568	44,5	9,094316186
12	88	34,15037	44	9,849625007
13	87	32,9956	43,5	10,50439718
14	86	31,92645	43	11,07354922
15	85	30,93109	42,5	11,56890596
16	84	30	42	12
17	83	29,12537	41,5	12,37462841
18	82	28,30075	41	12,69925001
19	81	27,52072	40,5	12,97927513
20	80	26,78072	40	13,21928095
21	79	26,07683	39,5	13,42317423
22	78	25,40568	39	13,59431619
23	77	24,76438	38,5	13,73561956
24	76	24,15037	38	13,84962501
25	75	23,56144	37,5	13,9385619
26	74	22,9956	37	14,00439718
27	73	22,45112	36,5	14,04887502
28	72	21,92645	36	14,07354922
29	**71**	**21,42019**	**35,5**	**14,07980995**
30	70	20,93109	35	14,06890596
31	69	20,45804	34,5	14,0419631
32	68	20	34	14
33	67	19,55606	33,5	13,94394119
34	66	19,12537	33	13,87462841
35	65	18,70717	32,5	13,79283017
…	…	…	…	…
…	…	…	…	…
…	…	…	…	…
90	10	5,081469	5	-0,08146904
91	9	4,922054	4,5	-0,4220536
92	8	4,76438	4	-0,76438044
93	7	4,608412	3,5	-1,10841189

cont. table 1

94	6	4,454111	3	-1,45411148
95	5	4,301444	2,5	-1,80144392
96	4	4,150375	2	-2,15037499
97	3	4,000872	1,5	-2,50087158
98	2	3,852902	1	-2,85290156
99	1	3,706434	0,5	-3,2064338
100	0	3,561438	0	-3,5614381

Source: Own study

The maximum value of the objective function is numerically calculated with FC 14.07980995 for x = 29. The maximum value of the objective function FC calculated analytically (14) is 14.07999427, for x = 28.8539. This confirms the compliance of analytical and numerical approaches to assumptive form of functions.

6. CONCLUSIONS

This article attempts to determine the optimal ships under keel clearance , taking into account such factors as:

- freight ships,
- the costs of the ship hit the bottom of the ground of port water area,
- the costs of the ship waiting for an appropriate level of water.

Assuming a simplified form of the function describing the above mentioned factors, obtained the optimal form of the objective function - the maximum profit of the ship. The study is exemplified by analytical and numerical calculations and diagrams. The authors found that the study method is appropriate for solving a basic problem. Further research is required to determine the function describing the factors considered, especially in the direction to take account of random factors in the function describing the cost of the ship waiting for an appropriate water level.

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