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SHIP'S SAFETY HAZARDS DURING REPLACEMENT OF BALLASTS AT SEA

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Abstract

The sequential replacement of ballast water at sea during the ship voyage is commonly used on board the ships. However, the successive emptying and filling of ballast tanks causes the occurrence of hazards to ship's safety. The article presents hazards to ship's safety and the calculations have been performed of the most dangerous hazards in respect of ship operation, for the m/v „Orla" ship on calm water. The obtained service conditions of the ship during replacement of ballasts shall be the basis for calculating the ship's safety hazards on waves.

Key words: *Ship ballasting, ship's safety hazards during replacement of ballasts, sequential method of ballast water replacement*

1. Introduction

There occur such periods during ship operation and service in which water ballast is carried on board the ship. Such situations occur when the ship is sailing without any cargo, or if it is only partly loaded and the ballast taken on board is intended for improving or ensuring the ship's safety, mainly in respect of stability. In a situation when the ship is [to be] unloaded it takes on board the water ballast for safe voyage. In the port of destination, when the ship is loaded with a new cargo, the ballast taken on board earlier has to be removed. So as to avoid translocation of live organisms in ballast water from one point to another, the ballasts waters removed in harbour have to be cleaned / purified with physical or chemical methods. These methods are expensive and applied rather reluctantly, so what remains is the replacement of ballasts during the ship's voyage at sea, in areas specified by the relevant rules.

2. Replacement of ballasts at sea

There are three basic methods of replacing ballast waters:

- The sequential method in which ballast tanks are successively emptied and filled with sea water,
- The flow-trough method in which ballast tanks are filled with sea water, which in turn forces out the water previously taken into the tanks from these tanks,

- The dilution method, in which a ballast tank is filled from the top and at the same time water is pumped out of its bottom part so as to maintain the constant level in the ballast tank.

The first one of the methods described above is the most commonly used by the ships. It is the quickest and the least energy-consuming method of all and it does not need the use of additional technical solutions in the ballast system existing on board the ship. However, the successive emptying and filling of tanks results in periodical worsening of stability conditions and other characteristics of the ship, having an impact on its safety. In the sequential method particular operations make up the so called sequences (sequence of emptying and filling) on particular tanks. The sequential method is used when replacement of ballasts requires removal of rather big volumes of water at the moment of ship's voyage duration, followed by refilling of tanks with sea water from a given place of the ship's voyage. It is a new procedure, different from the ballasting technology applied at harbour, because at sea the probability of different hazards occurrence is much higher, especially during waves and wind effects acting on the ship.

The following procedure is applied when determining the sequences of emptying and filling of ballast tanks in the process of ballasts replacement. The ship's service characteristics are specified, such as: trim, draught, values of shearing forces and bending moments occurring in the hull. These calculations are carried out at the filling and emptying of the successive ballast tanks. Thus calculated values are compared with the criterial values. Such calculations are repeated for subsequent tanks. The evaluation of safety conducted in such a way concerns only the ship service parameters as if it was on calm water without waves. In accordance with the Conwention [5] the ballasts replacement sequence should be demonstrated at least for typical loading conditions derived from the approved Information on Stability. The description of the sequence of ballast waters replacement should be split into particular steps where each of them is summed up with the following information items:

- the water volume in each of the tanks,
- the pumps used,
- the approximate time of operation,
- the longitudinal strength of the hull, as the function of permissible values,
- the information on stability, taking into acccount free surface areas of liquid during the emptying or filling operations,
- the values of draughts at forward and after perpendiculars,
- other information items (ballast replacement location in geographic coordinates, etc.).

The sequence of ballast waters replacement may be different for different ships and for other loading conditions, one should be guided first of all by the ship's safety. Unballasting of tanks arranged along one ship's side shall be avoided (it involves the risk of the ship capsizing), as well as simultaneous emptying of neighbouring sections of tanks located in vicinity (high shearing forces and bending moments arise). Establishing the sequence of ballasts replacement occurs taking into account valid provisions of law and restrictions. The sequential method for a given ship is prepared in form of the Ballast Water Management Plan. This Plan is prepared individually for each ship and approved by a Classification Society.

During the ballast waters replacement the ship must by located at an appropriate distance from the shore and at a depth [draught] specified by relevant regulations. It is, respectively: 200 miles and 200 m [5].

3. Ship's safety hazards during replacement of ballasts

Depending on the ship size (number and size/capacity of ballast tanks) and also depending on delivery values of the pump used, the smaller-size ships need c.a. 24 hours for full replacement of

water in tanks and bigger-size ships (with a large amount of ballast) even up to more than 2 days. The obligatory duty of the ballast waters replacement causes that the replacement process must often take place during waves and wind effects acting on the ship. The ship has no option to wait for the end of severe weather conditions, and during the operation the weather conditions may get worse. Following the obligatorily imposed distance from the shore and the depth of the water area, where the replacement of ballast water can take place, the ballast replacement area may be very narrowed.

Hence one can assume that from the point of view of the ship's safety in terms of stability the process of ballast water replacement shall be rather hazardous; in addition, the intensification of hazards shall have growing tendency in unfavourable weather conditions.

The hazards arising during the ballast water replacements using sequential method in which ballast tanks are successively emptied and filled with sea water are presented in table 1.

Tab. 1. Kinds of hazards to ship's safety in selected methods of ballast water replacement [3], [6]

Item.	Kind of hazard to the ship	Flow-through method	Sequential method
1.	Reduction of stability of ships with ballast in cargo spaces	x	x
2.	Excessive bending moments and shearing forces in hull binding and lashing	-	x
3.	Excessive torsional stresses in the hull	x	x
4.	Damages of tank constructions	x	x
5.	Construction damages due to vacuum pressures in tanks during their emptying	x	x
6.	Construction damages due to excess pressures during their filling	x	x
7.	Stresses in constructions or troubles with maintaining stability at incorrect sequence of filling	x	x
8.	Construction damages of bottom bracings in forward part	-	x
9.	Loss of ship manoeuvrability and its abillity to move	-	x
10.	Loss of visibility from the bridge due to big trims	-	x
11.	Overloading with stresses in cargo lashing and securing systems	-	x
12.	Difficulties in operating the equipment by the crew. Reduced efficiency of the whole operation, in particularly adverse weather conditions.	x	x
13.	Emergence of propeller	-	x
14.	Slamming	-	x
15.	Sloshing in ballast tanks	x	x
16.	Excessive heel of the ship	x	x
17.	Excessive increase of ship motions, especially roll motions	-	x

Kinds of hazards occurring during ballast water replacements at sea may be different for different types of ships which has been emphasized i.a. in [3].

Based on analyses included in various publications it is emphasized that the most important causes of the hazards occurrence are as follows:

- too long time of ballast replacement duration,
- wrong sequence tanks of emptying and filling of ballast tanks,
- unfavourable weather conditions (wind, high waves).

On the other hand, out of different hazards, the following ones are considered as the most dangerous in respect of the ship operational aspects:

- loss or considerable worsening of ship stability,
- increase of ship motions, especially roll motions,

- propeller emergence, at insufficient stern draught which causes worsening of propulsion characteristics and manoeuvrability,
- bow emergence which results in slamming occurrence and worsening of visibility from the navigating bridge (occurrence of the so called blind sector before the ship's bow).

For estimating the ship's safety during the operation of replacement of ballasts the following criteria or recommendations are applied:

- in case of ship stability – the criteria included in regulations of the Classification Societies or in provisions of IMO [4],
- for evaluating the visibility from the navigating bridge– The SOLAS Convention [2],
- minimum bow draught – DnV Rules [8],
- minimum stern draught – being of the value preventing the propeller emergence.

4. The ballast system of the m/v „Orla" ship

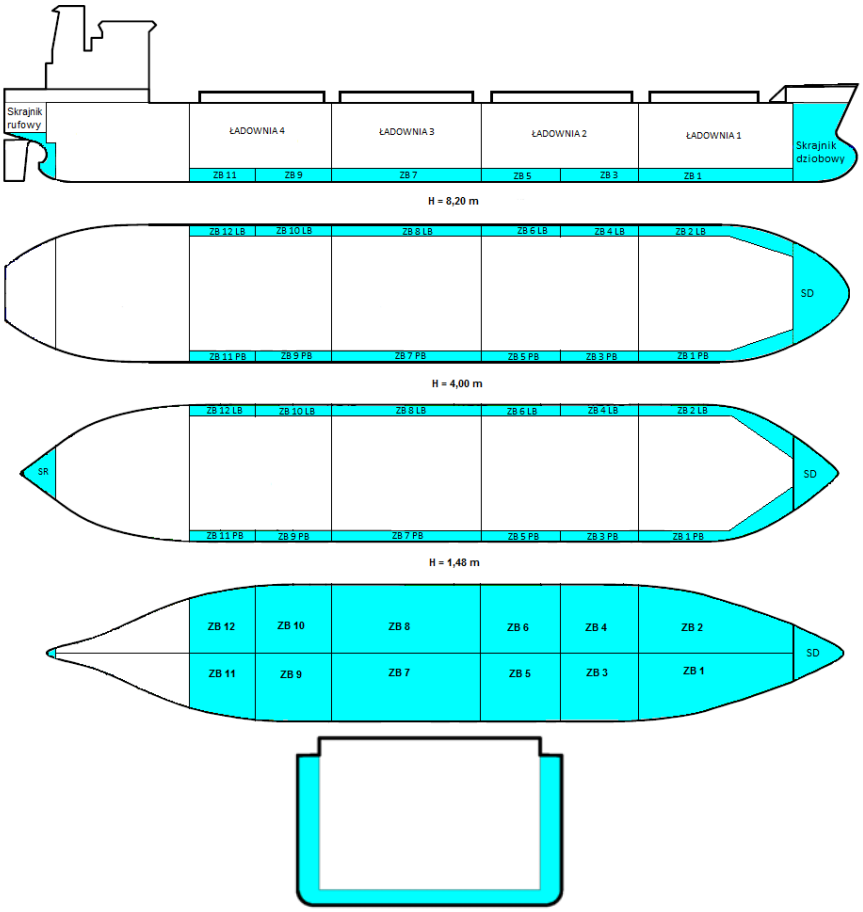
The calculation of the hazards to ship's safety during ballast water replacements have been performed for the m/v „Orla" ship, and the relevant parameters are presented in tables 2 and 3. In drg 1 the plan of placing the ballast tanks is presented and in table 4 - parameters of these tanks.

Tab. 2. Characteristics of the m/v „Orla" ship [1]

Name	-	Orla
Owner	-	PŻM [Polish Steamship Company]
Ship type	-	Universal bulk carrier
Rules (classifying authority)	-	PRS [Polish Register of Ships]
The ship service speed	V [kn]	7,08 (13,77 kn)
Length overall	L_{OA} [m]	149,4
Length between perpendiculars	L_{pp} [m]	138,0
Breadth	B [m]	23,11
Side height	H [m]	12,10
Draught to summer load waterline	Ts [m]	8,55
Displacement	D [T]	220150
Deadweight capacity	DWT [t]	17033

Tab. 3. Characteristics of the m/v „Orla" ship ballast system [1]

Total number of ballast tanks	14
Bottom tanks	14
Max. capacity of bottom tanks [m^3]	7650,7
Max. volume ballast water [m^3]	7650,7
Number of ballast pumps	2
Delivery of ballast pump[m^3/h]	650
Max delivery of ballast pumps [m^3/h]	1200
Time of ballast removal [h]	7,08
Time of ballast filling [h]	7,08



Drg. 1. Plan of the ballast tanks arrangement on board the m/v „Orla" ship

Tab. 4. Ballast tanks included in the ballast system of the m/v „Orla"ship [1]

Tank name	Number of frame [-]	Tank capacity V_Z [m^3]	Water mass in tank M_Z [t]	Coordinates of tank location			Moment of tank surface area MH_Z [m^4]
				XG_Z [m]	ZG_Z [m]	YG_Z [m]	
Forepeak	173-187	674	690,85	133,34	7,33	0	1618
Tank nr 1 PB	141-173	901	923,53	117,64	5,47	7,21	1728
Tank nr 2 LB	141-173	901	923,53	117,64	5,47	-7,21	1728
Tank nr 3 PB	126-141	422,4	432,96	98,38	4,32	8,63	1146
Tank nr 4 LB	126-141	422,4	432,96	98,38	4,32	-8,63	1146
Tank nr 5 PB	110-126	452,3	463,6	86,0	4,31	8,64	1240
Tank nr 6 LB	110-126	452,3	463,6	86,0	4,31	-8,64	1240
Tank nr 7 PB	78-110	838,4	855,26	67,69	4,11	8,49	2480
Tank Tank nr 8 LB	78-110	838,4	855,26	67,69	4,11	-8,49	2480
Tank nr 9 PB	63-78	418,6	429,06	48,04	4,35	8,61	1108
Tank nr 10 LB	63-78	418,6	429,06	48,04	4,35	-8,61	1108
Tank nr 11 PB	47-63	399,4	409,3	35,79	4,66	8,35	800
Tank ik nr 12 LB	47-63	399,4	409,3	35,79	4,66	-8,35	800
After-peak	8-19	110,7	113,46	4,14	6,88	0,4	435
Total	-	**7650,7**	**7841,3**	**84,4**	**4,88**	**0,01**	-

5. Impact of ballast replacement on the ship service parameters on calm water

Calculations of the ship's safety hazard occurring during replacement of ballasts were carried out for the sequence of emptying and filling of ballast tanks applied on board the ship – table 5.

Tab. 5. The sequence of emptying and filling of ballast tanks in the sequential method for the m/v „Orla" ship [7]

Replacement step	Operation name	Ballast weight [t]	Replaced ballast [t]	Replacement time [h]
0	Initial condition – ship in ballast	7841,9	0	0^h0^m
1	Emptying, tanks nos: 7, 8, forepeak, after-peak	5318,8	2523,1	2^h20^m
2	Filling, tanks nos: 7, 8, forepeak, after-peak	7941,9	0	2^h10^m
3	Emptying, tanks nos: : 1, 2, 11, 12	5173,5	2668,4	2^h30^m
4	Filling, tanks nos: 1, 2, 11, 12	7941,9	0	2^h15^m
5	Emptying, tanks nos: 3 i 4	6976,9	865	0^h50^m
6	Filling, tanks nos: 3 i 4	7941,9	0	0^h45^m
7	Emptying, tanks nos: 5 i 6	6914,7	927,2	0^h55^m
8	Filling, tanks nos: 5 i 6	7941,9	0	0^h50^m
9	Emptying, tanks nos: 9 i 10	6983,7	858,2	0^h50^m
10	Filling, tanks nos: 9 i 10	7941,9	0	0^h45^m
				14^h10^m

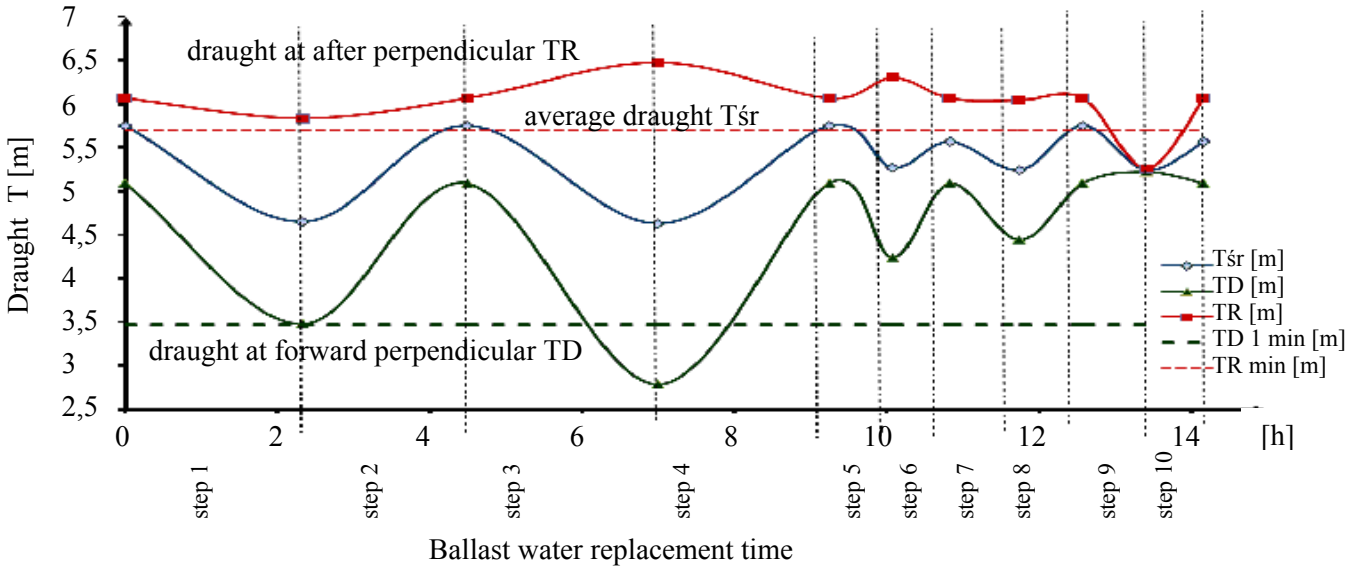
The calculated ship service parameters during the emptying and filling of ballast tanks are presented in table 6 and in drgs 2 ÷ 6. In the drawings also the criterial values are shown on the basis of which one can estimate in which stage (replacement step) specific hazards arise.

Tab. 6. The service and stability parameters of the m/v „Orla" ship during the emptying and filling of ballast tanks in particular replacement steps [7]

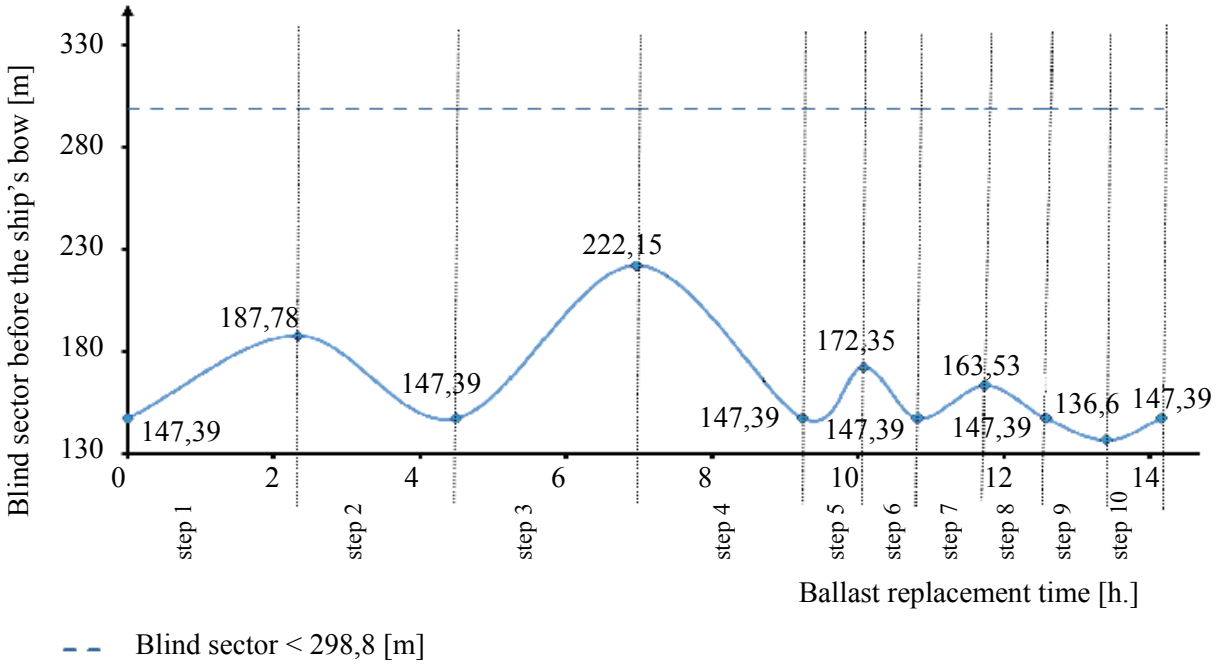
Step	D [T]	t [m]	T_S [m]	T_A [m]	T_F [m]	BM [%]	SF [%]	Propeller immersion draught [m] <456,7	Propeller draught [%]	GM [m]	KG [m]	KM [m]	GZ max [m]	GZ Range [°]	ΔGM [m]
0	13961,6	-0,96	5,57	6,06	5,09	70	27	147,39	106,7	3,77	6,49	10,32	2,86	> 60	0,06
1	11438,5	-2,35	4,65	5,83	3,48	79	28	187,78	102,2	4,32	6,8	11,19	2,85	> 60	0,07
2	13961,6	-0,96	5,57	6,06	5,09	70	27	147,39	106,7	3,77	6,49	10,32	2,86	> 60	0,06
3	11293,2	-3,68	4,63	6,47	2,79	50	27	222,15	113,0	4,39	6,79	11,29	2,87	> 60	0,07
4	13961,6	-0,96	5,57	6,06	5,09	70	27	147,39	106,7	3,77	6,49	10,32	2,86	> 60	0,06
5	13096,6	-2,07	5,27	6,30	4,24	70	30	172,35	110,6	3,86	6,64	10,55	2,81	> 60	0,06
6	13961,6	-0,96	5,57	6,06	5,09	70	27	147,39	106,7	3,77	6,49	10,32	2,86	> 60	0,06
7	13034,3	-1,61	5,24	6,04	4,44	79	28	163,53	106,1	3,86	6,65	10,57	2,91	> 60	0,06
8	13961,6	-0,96	5,57	6,06	5,09	70	27	147,39	106,7	3,77	6,49	10,32	2,86	> 60	0,06
9	13103,4	-0,04	5,24	5,26	5,22	76	33	163,60	92,9	3,86	6,63	10,55	2,81	> 60	0,06
10	13961,6	-0,96	5,57	6,06	5,09	70	27	147,39	106,7	3,77	6,49	10,32	2,86	> 60	0,06

where:

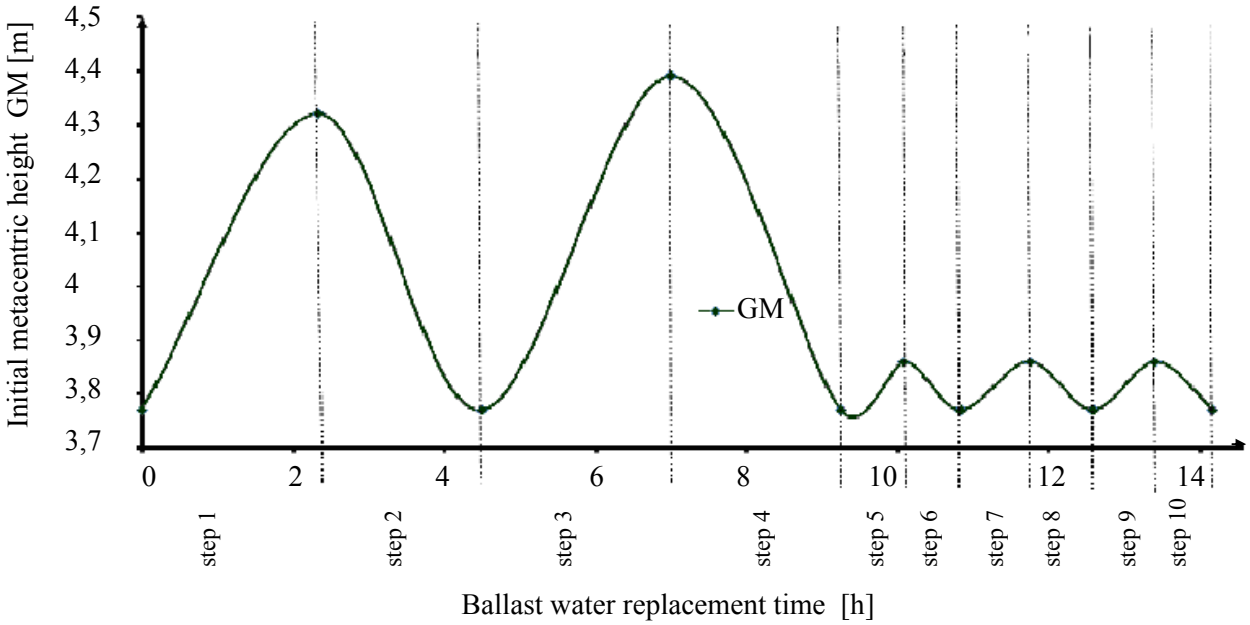
D – ship buoyancy,
t – ship trim,
T_S – average draught,
T_A – draught at after perpendicular,
T_F – draught at forward perpendicular,
BM – value of bending moment in hull in % of maximum value,
SF – value of shearing force in hull in % of maximum value,
GM – initial metacentric height,
KG – rise of of the centre of gravity of the ship,
KM – rise of the metacentre,
GZ – maximum value of righting arm,
ΔGM – correction for free surface areas of liquid .



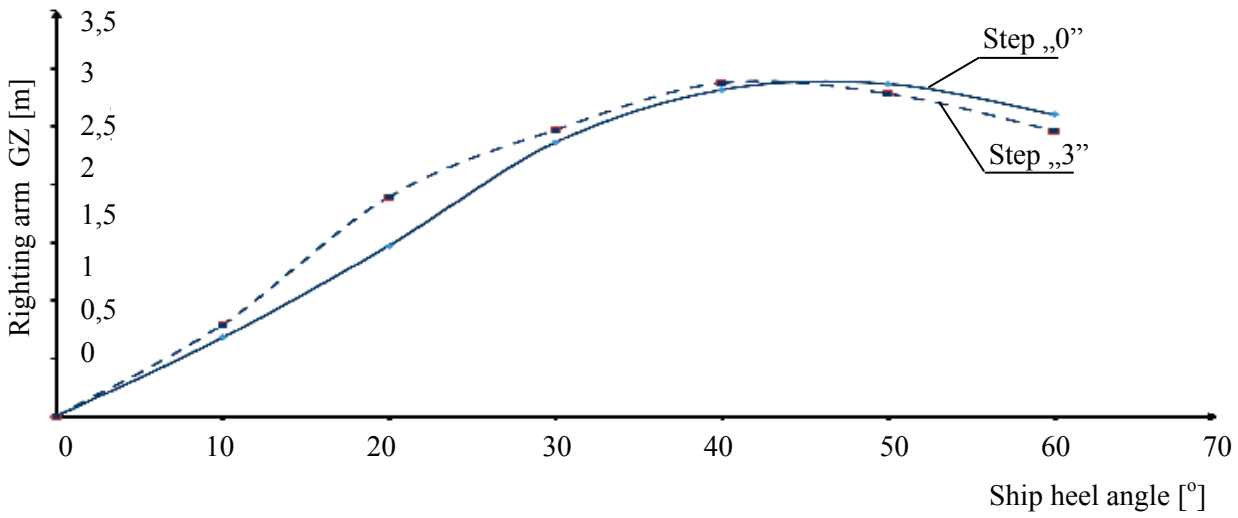
Drg. 2. Change of the m/v „Orla" ship draughts during the ballast water replacements



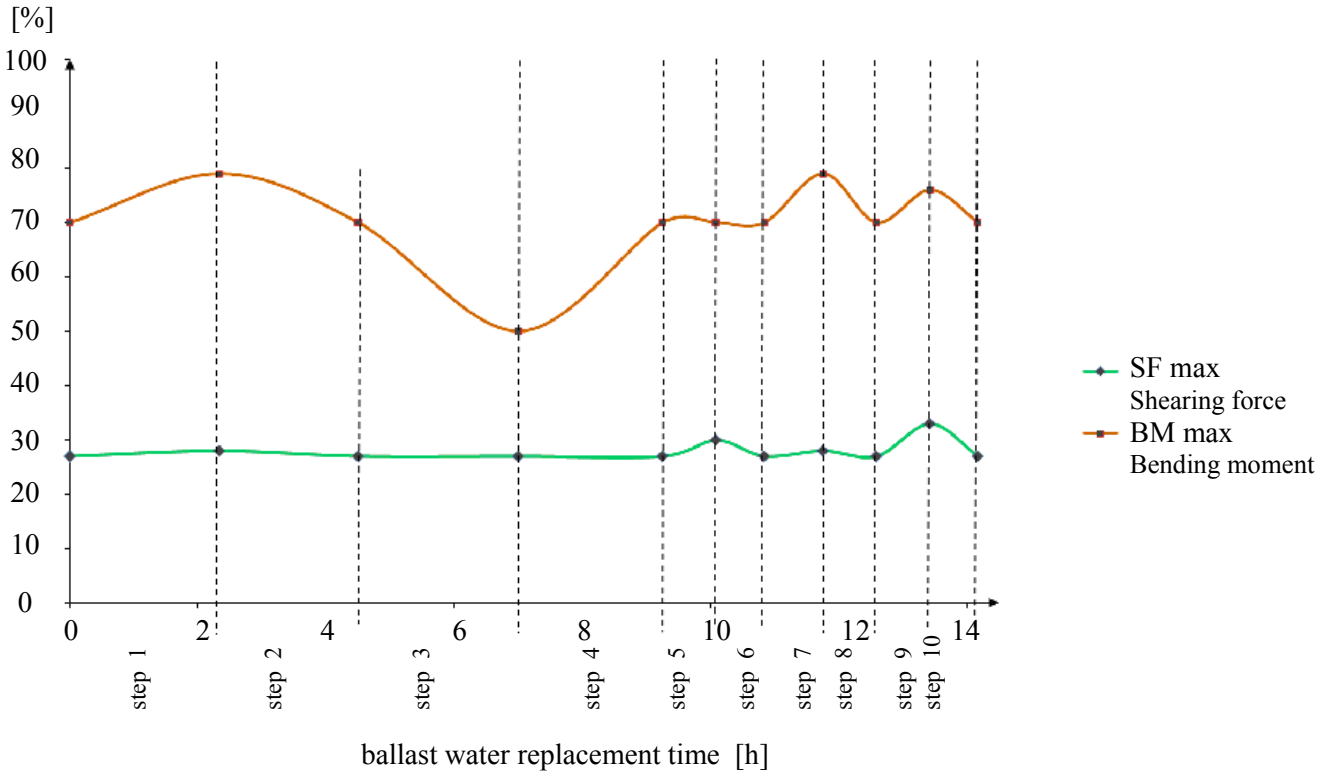
Drg. 3. Change of the blind sector before the m/v „Orla" ship bow during the ballast water replacement



Drg. 4. Change of the initial metacentric height of the m/v „Orla" ship during the ballast water replacements



Drg. 5. Curve of righting moment lever of the m/v „Orla" ship for selected stages of the ballast water replacements



Drg. 6. Diagram of maximum values of the shearing forces and bending moments in the ship hull initial during the ballast water replacements – the m/v „Orla" ship

6. Evaluation of the ship's safety during replacement of ballasts on calm water

On the basis of the obtained calculation results it was found out that:

- the bow and stern draught is minimum, it is exceeded in the middle and final stages of ballast replacement, which during the ship navigation on waves shall result in slamming and the propeller emergence,
- the initial transverse metacentric height is very high,
- the range of curves of statical stability is very good.

General conclusions

The Plan of Ballast Replacement prepared and used on board the ship does not guarantee full safety even on calm water.

As regards the ship's safety in respect of stability it does not occur on calm water. For the ship the emptying of the ballast tanks does not cause worsening of the curves of statical stability or reduction of the initial metacentric height – it is quite the other way round, during the emptying of the ballast tanks the initial metacentric height rises. However, the initial metacentric height being too high is not a good solution, either, because on waves the ship has low [small] period of motions – it becomes too "rigid".

The performed analysis of changes in selected ship service parameters has proved that replacement of ballasts on calm water is a difficult procedure being hazardous to the ship. The level of ship's safety gets changed with the change of the service parameters values in relation to criterial values.

In the next article there shall be conducted the ship safety analysis during ballast replacement at waves and wind effects acting on the ship.

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