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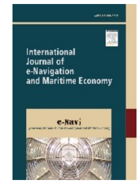

Original article

A Proposed Method for Ship Safety Enhancement After Flooding☆

Nourhan I. GHONEIM[a*], Mohamed SHOUMAN[b], Kambiz MOKHTARI[c]

[a*] Dept. of Maritime Studies, International Maritime College Oman, Oman, norhan@imco.edu.om, Corresponding Author

[b] Dept. of Marine Engineering Technology, Arab Academy for Science, Technology and Maritime Transport, Shouman85@aast.edu.

[c]Dept. of Maritime Studies, International Maritime College Oman, Oman, kambiz@imco.edu.om

Abstract

Bulk carrier ship type is one of the three dominant types of merchant vessels along with container ships and tankers. Recently, in terms of tonnage, bulk carriers constitute about the world's fleet third. The stuff materials indigence such as grains, fertilizers, ores, etc. Since the turn of the millennium, the number has increased considerably. Recently, a growing variance in bulk cargo which has transported by sea, represents now a large part of international commercial exchange shipped by sea. Every year there are huge number tons of cargoes like steel, coals, livestock feed, copper and minerals that are transported by sea in bulk. While most of those shipments are made without accidents, a number of serious injuries have occurred which have resulted not only in the ship's loss, but also in lives loss. In this paper, there is an existing bulk carrier vessel, a computational case study, is made to investigate the different loading conditions effects and bulk cargoes' types on ship's stability, in case of damaged conditions, in addition to the effect on the ship's hull longitudinal strength. A proposed method is suggested to improve the level of safety of the ship past flooding by the usage of air bag (cushion). The candidate vessel consists of two cargo holds. In this paper there are three investigated damage scenarios, the first one is checking the stability in case of damage of cargo hold No.1. The second one is checking the stability in case of damage of cargo hold No.2 and the third scenario is checking the stability in case of flooding of both of the two cargo holds. There's a modelling software, Auto Ship, is used here to model the vessel, simulate the different scenarios and to run the stability code to check the stability criteria.

Finally, after performing the above mentioned three damage scenarios, the result was that the ship will still float in case of scenario one or two but in case of the third scenario, it will sink. So, this study has suggested a way to keep the vessel floating in case of the third scenario until reaching the nearest port without sinking. This proposed method is by using air cushions to open directly in case of existing alarm in the bulk carrier work to fill all the space inside the cargo hold instead of filling with the water.

Keywords: Bulk carrier, damage stability, survival, safety.

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1. INTRODUCTION

In this paper there is a case study of an existing bulk carrier that has detailed data like tank capacity plan, body plan lines, drawing of deadweight scales, general arrangements, line plan and section drawing of mid-ships (M/V Gold Stone) [1]-[2]. Nevertheless, there is a very significant aspect that hasn't taken into consideration in any research which is the effect of damage stability due to the unique nature of this type of vessels. In this study, the candidate ship's stability in damaged condition has been investigated and to ensure more level of safety in case of flooding, a proposed procedure has been developed.

It has been found from all the above-mentioned researches that the bulk carrier is the type of vessel that is very important. It has therefore studied from a different perspective, such as the damage stability, liquefaction, longitudinal strength and corrosion...etc. Also, it has been noticed from all the below mentioned researches that all of them were analyzed and investigated the different causes of damage and the results of these damage. In this study the main reason is to try to find a proposed way to avoid the sinking which may happen because of any reasons which will enable the vessel to keep floating until reaching the nearest port that will keep all the lives onboard, the ship and the remaining cargo. The bulk carriers already have alarm system which rings in case of water ingress and reach to 10 cm level in the cargo hold. Once the alarm rings, the responsible checks the most suitable cargo holds to give the order for the air cushion to open. When the air cushion opens, all the empty volume which may be filled by water will be occupied by these cushions that will prevent the water ingress from continuing. To check the possibility of these air cushions and also the efficiency of its usage, there is a modelling software, Auto Ship, which should be used firstly to simulate the ship model then try the three damage scenarios and finally to check the stability criteria in each scenario. Finally, some calculations are done to specify the remaining empty volume that leads to the cushion size.

Regarding to the latest bulk carriers damage stability researches, Skjong et al (2) examined generic bulk carriers damage stability after a collision. Calculations of average survivability and the damage stability has been evaluated for the bulk carriers' fleet of the world by analysis the data from the project of HARDER. It is evaluated that the result of using of the double side skin in bulk carriers shall improve the bulk carriers' survivability of about 5 – 7.5 %, [3].

At the end of discharge, the heavy grabs may cause damage for the tank top plating, which may result in the steel structure's damage and affect the speed of the corrosion. The new steel surfaces are exposed as scales fall off, [4]. Captain Tugsan et al (3) discussed the causes of bulk carriers' loss totally with the cargo, reason of stability loss due to liquefaction of cargo and responsibilities for loading of the crew and Master and within the voyage under the Regulations of SOLAS 74 and IMSBC Code, [5]. Senior Surveyor Odd Olufsen et al (1) focused in the relation between the requirements of damage and intact stability and the deck loads' securing. All calculations' basis of the main forces acting on deck freight is the transverse accelerations which occur due to rolling, including components of gravity. The accelerations depend upon the vessel's shape, the sea condition, the ship's main dimensions and the loaded ship metacentric height (GM), [6]. Burakovskiy et al (4) suggested three scenarios of sinking for M/V "Derbyshire", Including ship's conduct in stormy conditions. The gradual flood scenarios of the hold after damage to the hatch cover the waves associated with the wave run-up of the bow, resulting in the ship deck being under the influence of significant hydrodynamic forces and a loss of stability due to the wave run-up of the bow. The main cause of the loss is not the low strength of the hatch covers, but instead the flat bow deck, which allowed the development of a large hydrodynamic force, that result in ship's bow wave run-up, followed by GM zeroing and the ship's overturn, [7]. A. Campanile et al (2) investigated the bulk carrier's time-variant reliability analysis in damage conditions after the event of collision. There have been applied two different models of the collision. The analysis of Time-variant reliability is carried out for examination the happening of the applied models of collision damage on the probabilities of annual failure of the hull girder in hogging and sagging conditions, [8]. Ozgur- Ozguc et al (2) have been investigated the residual strength and collision resistance of bulk carriers' types of double side skin (DSS) and single side skin (SSS) affected by collision damage. The safety of the vessels was calculated in damaged condition as a ratio of the bending moment to the hull girder's ultimate strength. It is noted as a result of the calculations that it is expected that the possible collapse may be happened in sagging state for both DSS and SSS bulk carriers following collision damage, [9]. A.Campanile et al (2) investigated an analysis of corroded bulk carrier's Time-variant reliability in damage and intact conditions and is carried out by Importance Sampling simulation and First-Order (FORM), Second-Order (SORM) Reliability Methods. Time-varying sensitivity analyzes are also conducted for damage and intact conditions to examine the occurrence of random variables uncertainties on the achieved failure probability, [10]. A. Campanile et al (2) Considering the IACS deterministic model against the GOALDS / IMO database statistics on collision occurrences, the incidence of collision damage models on bulk carrier reliability was investigated, supporting the probabilistic model. Consistency analysis has been performed to examine the occurrence of collision depth of penetration and the statistical height properties on the probabilities of hull girder hogging / sagging failure. Additionally, the prevalence of corrosion on residual strength and reliability of hull girder net and local net scantlings are also discussed, respectively, [11].

2. CASE STUDY (M/V GOLD STONE)

2.1 Candidate vessel's principal particulars

Table I displays the vessel main particulars.

2.2 Tanks and holds capacities

TABLE I CANDIDATE VESSEL PRINCIPAL PARTICULARS

Length Over All (LOA)	91.0 m
Length between Perpendiculars (LBP)	83.0 m
Breadth (B)	15.0 m
Depth to main Deck (D)	7.3 m
Summer Draft (T)	6.0 m
Light Ship Weight	1674.57 Ton
Gross Tonnage	2827 Ton
Net Tonnage	1822 Ton
Engine Type	6320 ZCD-6
Engine Power	1545 K.W
Frame spacing	600 mm
Vertical center of gravity in design condition (KG)	5.7 m
Ship speed	11 knots
Year of Built	2007

Figure 1 shows the vessel general arrangements and tank's arrangement onboard the ship under consideration. Table II gives the capacity of all cargo holds and tanks together with their longitudinal and vertical center of gravity and moment of inertia.

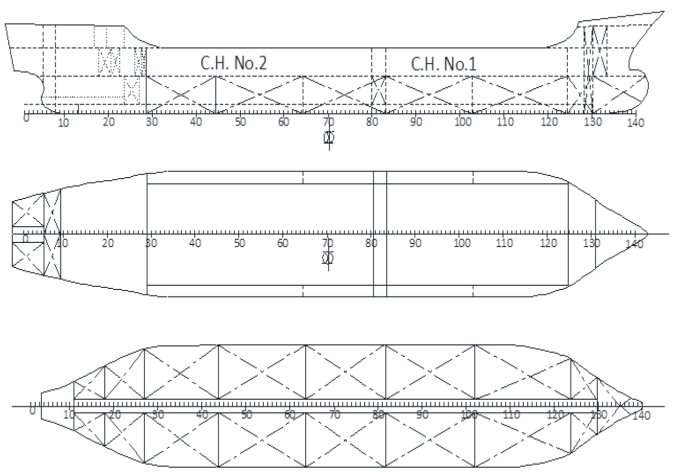

Fig.1 General arrangements and tank plan

2.3 Types of solid cargoes

The types of bulk cargo are represented by what so called stowage factor (S.F.) (cubic meter per ton (m^3/ton)), i.e. S.F. is the reciprocal of density. Bulk carriers usually are designed to carry different types of bulk cargo with different stowage factors. This means that a bulk carrier must meet the stability grain regulations for all types of bulk cargo for which the ship is designed to carry.

Where:

LCG: is the Longitudinal Center of Gravity expressed in meters from Mid-ship

TCG: is the Transverse Center of Gravity expressed in meters from ship's longitudinal axis "x".

VCG: is the Vertical Center of Gravity expressed in meters above the molded Base Line

2.4 Software package

A computer program, Auto Ship (Auto ship 9.2) [12] is used to carry out the stability calculations. The Auto Ship hull design/surface modeling program combines the graphical user interface of Windows with the dexterity of NURBS (Non-Uniform Rational B-Spline) mathematics, the high-end CAD standard for surface modeling, to give the tools to quickly and efficiently create any hull shape from a racing yacht to a super tanker, including the superstructure and appendages. Firstly, we should get the vessel's lines plans, then using these drawings to prepare the vessel's tables of offsets. Using these tables of offsets and Model Maker module, full model of ship's sections at different stations and the general arrangement can be obtained.

Take this model in the Auto Hydro module to do the different loading conditions calculations. To use Auto Hydro Software, the following input data are required:

i. Light Ship
ii. Fixed Weights
iii. Specific Gravity of cargo (1/S.F.)
iv. Weight of cargo in holds
v. Vessel's tanks capacity
vi. A programing code is written and to be run to check the compliance with the following Damage Stability criteria:

1. GZ (max.) ≥ 0.1
2. List Angle, $\theta_E^o \leq 17^o$.
3. Range of positive stability between θ_E^o and $\theta_F^o \geq 20^o$.
4. Where: θ_F is angle of flooding
5. Dynamic stability ≥ 0.0175 meters-radians

Where:

GZ: is the Righting arm corrected for the actual location of the center of gravity

Note:

If the deck edge is immersed, then $\theta_E^o \leq 15°$

The Calculations' steps for candidate vessel are as follows:

Input data for candidate vessel:

i. Light Ship

The light ship condition data, as shown in Table III, are to be submitted as first step.

ii. Fixed Weights

All Fixed Weights with its data such as LCG, TCG and VCG, as shown in Table IV, to be input as second step:

iii. Specific Gravity of cargo (1/S.F.)

The Specific gravity "Sp.Gr." which is calculated in (ton /m^3) from the Stowage Factor (S.F.) of the loaded cargo should be defined.

3. DAMAGE STABILITY OF CANDIDATE SHIP

3.1 Statutory Requirements

Both intact stability criteria as per IMO resolutions A.749 (18) and MSC23 (59) are used for the vessel under investigation.

3.1.1 IMO A.749(18) criteria

TABLE II TANKS' CAPACITIES OF CANDIDATE SHIP

Tank Name	Location		Level from B.L.		Center of Gravity			Capacity	Inertia
	Starting	End	Top	Bottom	LCG	TCG	VCG		
	Frame	Frame	(m)	(m)	(m)	(m)	(m)	(m^3)	(m^4)
Cargo Holds (CH)									
Cargo Hold No.1(CH1)	82	124	9.3	1.1	20.383	0	5.016	2323.01	
Cargo Hold No.2(CH2)	27	79	9.3	1.1	-9.3	0	5.067	2803.79	
Ballast Water Tanks (BWT)									
BWT7/No.7	79	82	4.5	1.1	6.8	3.4	2.8	32.39	23.63
BWT6/No.6	27	43	4.5	1.1	-19.64	4.65	1.58	84.85	165.24
BWT5/No.5	43	63	4.5	0.01	-9.605	5.027	1.537	129.49	299.04
BWT4/No.4	63	82	4.5	0.01	2.001	5.068	1.531	125.57	297.29
BWT3/No.3	82	102	4.5	0.01	13.697	5.068	1.531	132.13	312.75
BWT2/No.2	102	124	4.5	0.01	25.444	4.75	1.47	120.72	277.73
BWT1S/No1	124	128	4.5	0.01	33.965	2.883	2.491	43.39	25.77
BWT1P/No1	124	130	4.5	0.01	34.48	-2.756	2.509	59.95	33.48
Fore Peak Tank (FPT)	130	144	4.5	0	38.806	0	2.583	104.58	88.34
Diesel Oil Tanks (DOT)									
DDOT1/No1	25	27	7.7	4.5	-25.9	1.23	6.1	9.26	1.49
DDOT2/No2	25	27	7.7	4.5	-25.9	1.23	6.1	9.26	1.49
DDOT1P/o1	18	25	1.1	0.01	-28.33	-1.96	0.672	9.88	17.6
DDOT1S/o.1	18	27	1.1	0.01	-27.48	2.123	0.661	14.22	29.49
Fuel Oil Tanks (FOT)									
DFOT1/No.1	17	19	7.7	4.5	-30.35	5.172	6.262	7.84	3.25
DFOT2/No.2	16	17	7.7	4.5	-31.43	5.09	6.304	7.23	2.96
FOST	19	21	7.7	4.5	-29.48	5.249	6.219	11.49	4.78
FOT1P/No.1	22	25	7.7	1.1	-27.13	-5.004	4.791	41.43	9.52
FOT1S/No.1	21	25	7.7	1.1	-27.29	5.036	4.928	48.47	11.99
Lubricating Oil Tanks (LOT)									
LOCT	12	17	1.1	0.02	-32.58	-1.177	0.72	3.22	2.21
LOST	10	14	7.9	4.5	-34.07	-5.475	6.862	7.93	1.83
SOWT	12	17	1.1	0.02	-32.57	1.177	0.72	3.22	2.21
Fresh Water Tanks									
CWT	3	7	4.5	0	-37.37	0	2.68	10.3	4.95
AWT3	-7	3	8.1	6.15	-42.01	3.169	7.249	24.98	18.43
AWT2/No.2	-7	3	6.15	3	-41.63	1.213	5.632	11.74	17.29
AWT1/No.1	3	7	8	4.5	-38.39	2.405	6.575	35.12	44.86

TABLE III LIGHT SHIP DATA

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Light Ship	1,674.57	5.313a	0.000	5.700

TABLE IV FIXED WEIGHTS DATA

Item	Weight (MT)	LCG (m)	TCG (m)	VCG (m)
Crew & effects	1.50	31.300a	0.0	10.0
Provisions	2.00	41.500a	0.0	9.0

The following general stability criteria as are inspected for the candidate vessel:

i. The area under the GZ curve $\geq$ 0.055 m-rad. up to angle of heel,"ϕ"= 30º.

ii. The area under the righting GZ curve $\geq$ 0.09 m-rad. up to ϕ = 40º or the angle of down flooding ϕ_f if this angle < 40º.

iii. The area under the GZ curve between the angles of heel of 30º and 40º or between 30º and ϕ_f, if this angle < 40º, should $\geq$ 0.03 m-rad. Where ϕ_f is an angle of heel at which openings in the hull, superstructures or deckhouses which can't be closed weather tight immerse. In applying this criterion, small openings through which progressive flooding can't take place and need not to be considered as open.

iv. The righting lever GZ should be $\geq$ 0.20 m at an angle of heel $\geq 30^o$.

v. GZ_{max} should occur at an angle of heel preferably exceeding 30^o but not less than 25^o .

vi. The initial metacentric height $GM_o > 0.15$ m.

3.1.2 MSC.23 (59) criteria:

a) Trimming of bulk cargoes

All the reasonable and necessary trimming shall be performed to level all the free grain surfaces and to minimize the grain shifting effect.

In any "filled compartment ", the bulk grain shall be trimmed so as to fill all the spaces under the decks and hatch covers to the maximum extent possible.

After loading, all free grain surfaces in "partly filled compartments", shall be trimmed level and the ship shall be upright before proceeding to sea.

b) Intact Stability Requirements

The intact stability characteristics during the voyage of any bulk carrier should meet at least the following criteria after taking into consideration the heeling moments due to dry bulk cargo shift:

i. The angle of heel due to grain shift, $\phi_h < 12^o$. which is calculated by drawing the heeling arm curve due to transverse grain shift which may be approximately represented by the straight line A-B which are the λ_o and of λ_{40} respectively. Where $\lambda_{40} = 0.8\ \lambda_0$. Then find the intersection point between this curve and the righting arm curve. This point represents the angle of heel due to shift of grain (ϕ_h), see Fig.2.

$\phi_h < 12^o$ ……….. (i)

ii. In the statically stability diagram, see Fig.2, the net residual area between the heeling arm curve and the GZ curve up to the angle of heel of maximum difference between the ordinates of the two curves, (ϕ_m), or 40^o or the "angle of flooding", (ϕ_f), whichever is the least, shall in all conditions not be less than 0.075 m-rad.

Residual Dynamical Stability > 0.075 …….…... (ii)

iii. The initial metacentric height, after correction for the free surface effects of liquids in tanks, shall not be less than 0.30 meters.

$GM_c > 0.3$ ……………. (iii)

3.2 Damage scenario No. (1)

In this condition the Cargo Hold No. 1 is flooded completely by sea water (SpGr 1.025), see Fig.3

3.3 Damage scenario No. (2)

In this condition the Cargo Hold No.2 is completely flooded by salt water (SpGr 1.025), see Fig.5.

Figure 6 Shows the GZ – curve for the above mentioned scenario No. (2).

Figure 4 Shows the GZ – curve for the above mentioned scenario No. (1).

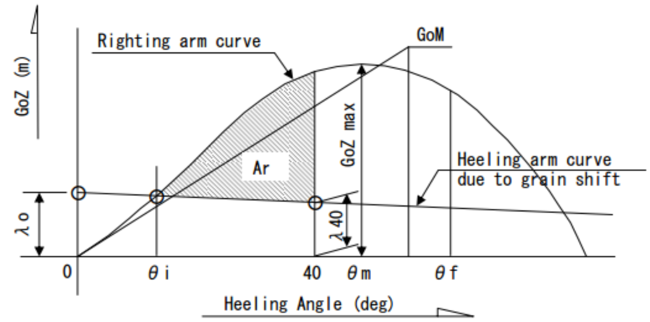

Fig. 2 Calculations of the angle of the heel due to solid bulk cargo shift (ϕ_h)

3.4 Damage scenario No. (3)

In this condition the vessel's two Cargo Holds are completely flooded by salt water (SpGr 1.025), see Fig.7.

Figure 8 shows the GZ – curve for the above mentioned scenario No. (3).

Where:

MaxRA : is the Maximum Righting Arm in (m)

It is clear from the results that the ship under consideration complies with the stability criteria in case of flooding of only one compartment (Cargo Hold No.1 or No.2), i.e. the ship is one – compartment type as required by the regulations. However, if the two holds No.1 and No.2 are flooded simultaneously the ship will sink (scenario No.3).

Of course scenario No.3 is beyond the requirements of the regulations. However, in the following section we suggest a method to avoid the sinking of such ship in case of scenario No.3. Hoping that this can be implemented as future requirement to enhance ship survivability in case of damage.

4. THE PROPOSED METHOD TO INCREASE THE SAFETY LEVEL OF A SHIP AFTER FLOODING

The proposed concept is to provide the vessel's holds of the bulk carrier with an Air Bag (Cushion) which will work in case of the flooding of two adjacent holds in the B-60 type of vessels and in case of the flooding of three adjacent holds in the B-100 type of vessels.

The function of the air bags is to limit the volume of the entering water to permit the ship to be still float at a waterline tangential to the margin line of the ship.

The air bags will come into action using the alarm system which is already exists onboard of bulk carriers. The air bags will be embedded under the main deck.

In this section ,the idea of using air bags to change the candidate vessel from one compartment ship to two compartments ship in order to increase the chance of survivability of the ship during flooding, without any extra construction fitting or design changes, has been demonstrated in the next section.

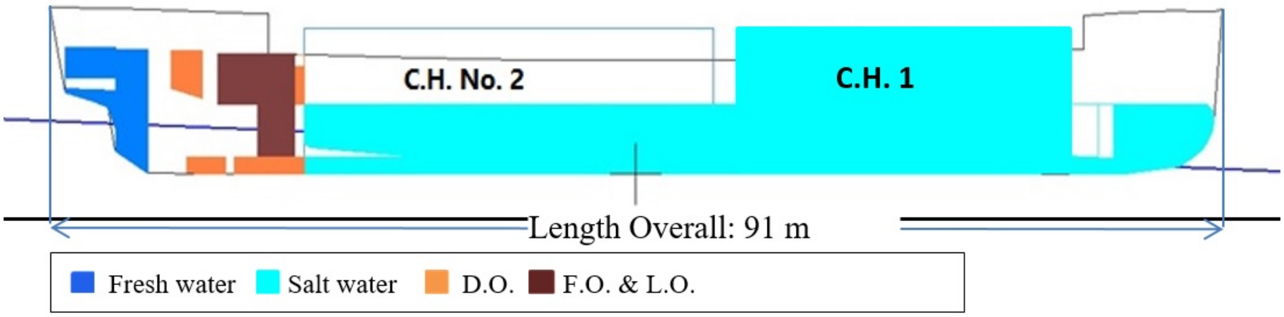

Fig.3 Profile view for damage scenario No. (1)

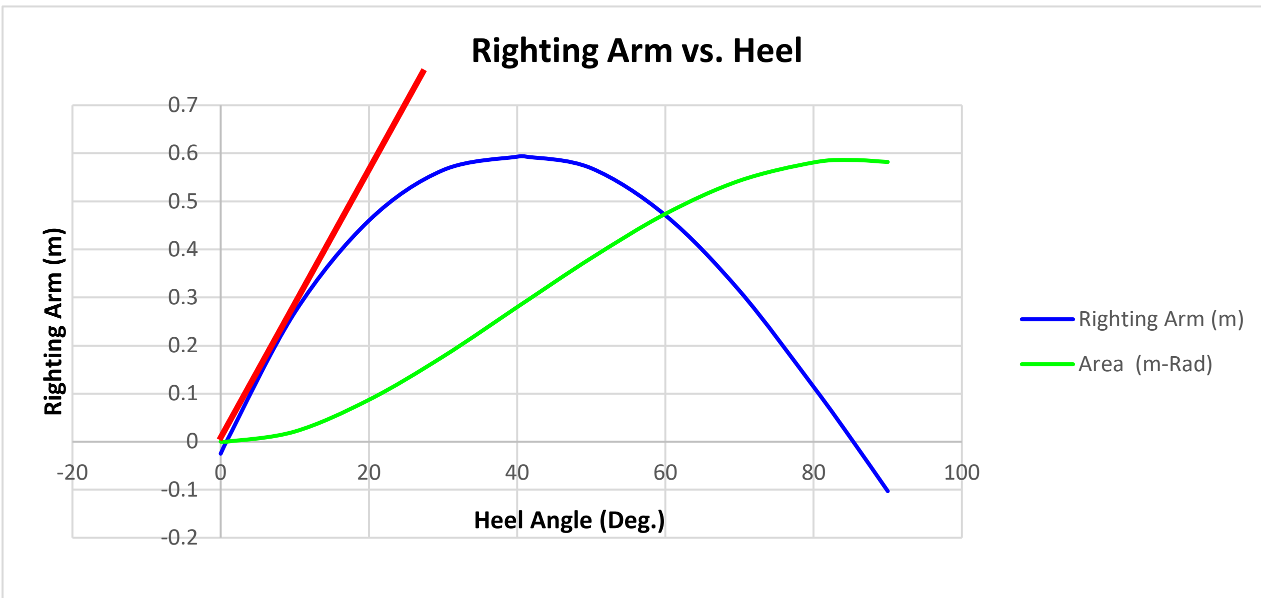

Fig.4 Righting Arms vs. Heel Angle for damage scenario No.(1)

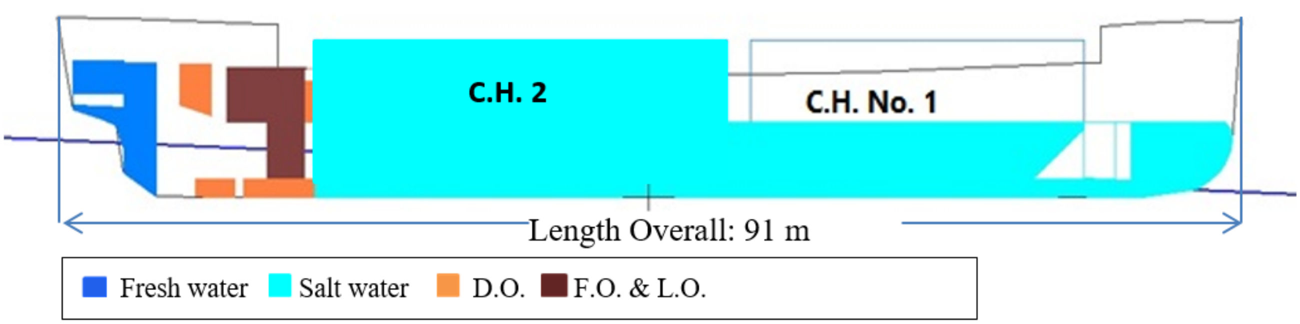

Fig.5: Profile view for damage scenario No. (2)

The calculations will be carried out for the candidate vessel in ballast condition (i.e. the worst condition, where the two cargo holds are empty and the volume of water which can enter the holds, in case of flooding of the two holds, will be maximum, the matter which causes ship sinking). The calculations are started by determining the quantity of ingress water which is required to make the ship float on waterline tangent to margin line.

This can be done in two ways:

i. First method:

- Calculate the margin line draft ($d_{margin\ line}$)

D margin line = depth – 0.76 m

= 7.3 – 0.76 = 6.54 m

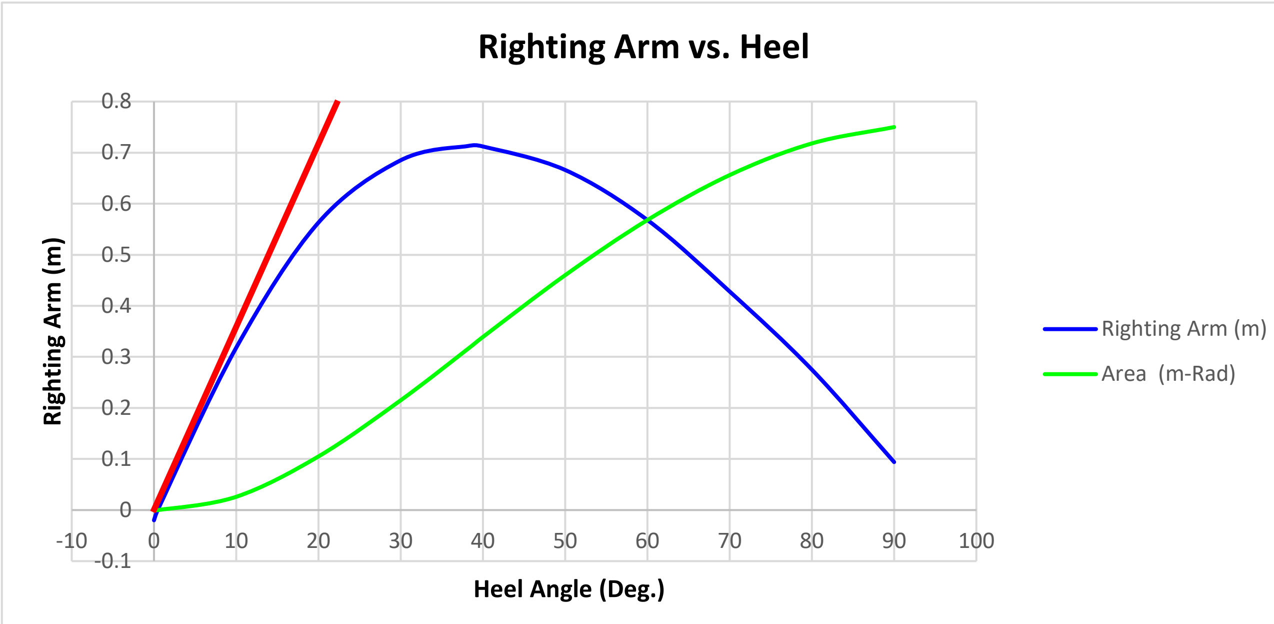

Fig.6 Righting Arms vs. Heel Angle for damage scenario No. (2)

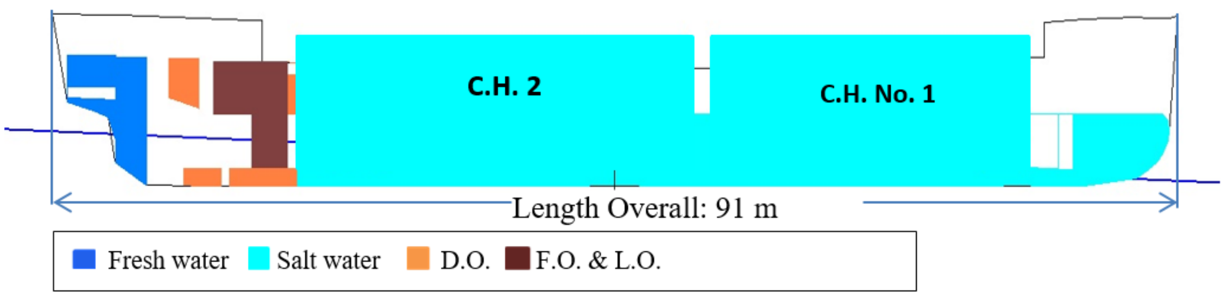

Fig.7 Profile view for damage scenario (3)

- Find the displacement at ($d_{margin\ line}$) from hydrostatic data of candidate vessel (Δ_m).
- Calculate the flooding water amount (Q_m) which will make the ship float on margin line draft ($d_{margin\ line}$)

$Q_m = \Delta_m$ – (light ship weight +consumables)

- Run the developed program by filling the two cargo holds by an amount of water equals approximately to Q_m to make sure that the draft of the ship will not more than $d_{margin\ line}$ ($d_{margin\ line}$ =6.54 m).

The results of the above mentioned steps are as follows:

Tank Name	Load (%)	Actual Volume m^3	Max. Volume of cargo holds m^3
CH 1	62.00%	1405.444	2266.859
CH 2	62.00%	1742.371	2810.302
Totals:		3,147.81	5,077.16

Volume of required air bags is equal to the maximum volume of cargo holds minus the volume of flooded water, i.e.
Volume of required air bags = 5077.16-3147.81 = 1829.35 m^3

ii. Second method:

In this method the Tons per Centimeter immersion in sea, "TPC value", in the ballast condition will be obtained from the hydrostatic data of the candidate ship and then the water ingress volume will be calculated.

TPC in ballast condition at departure = 10.95 ton/cm
Margin line draft ($d_{margin\ line}$) = 6.54 m
Mean draft in ballast condition at departure (d_m) = 3.556 m

Weight of water ingress (flooded water)=($d_{margin\ line}$ -d_m)*TPC
= (654-355.6) * 10.95
= 3267.48 Ton

Volume of water ingress (flooded water) = (Weight of water ingress (flooded water))/ρ = (3267.48)/1.025 = 3187.78537 m^3

Calculate the needed volume to be occupied with the air cushion =
= Total max. volume of the cargo holds – the flooded volume

$= 5{,}077.16 - 3187.78537 = 1{,}889.3746\ m^3$

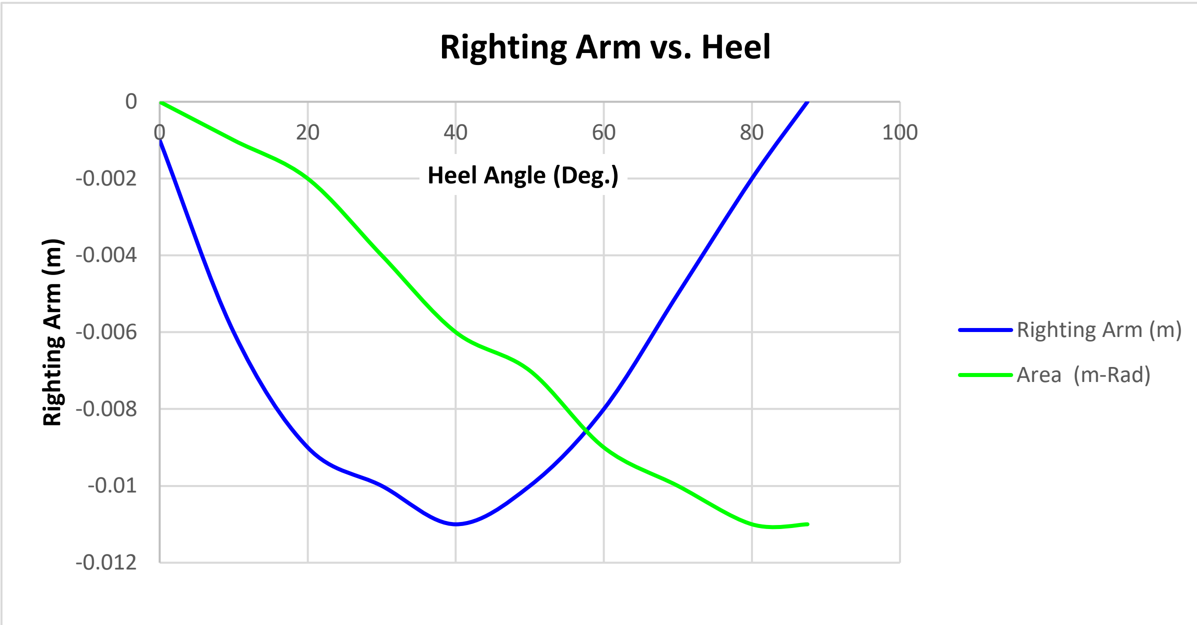

Fig.8 Righting Arms vs. Heel Angle for damage scenario (3)

TABLE V DAMAGE STABILITY CRITERIA

Stability criteria		Scenario No.1		Scenario No.2		Scenario No.3	
		Actual	Pass	Actual	Pass	Actual	Pass
(1) Area from 0 deg. to 30	≥ 0.055 m-R	0.188	Yes	0.219	Yes	-0.004	No
(2) Area from 0 deg. to 40 or Flood	≥ 0.09 m-R	0.291	Yes	0.339	Yes	-0.006	No
(3) Area from 30 deg. to 40 or Flood	≥ 0.03 m-R	0.103	Yes	0.121	Yes	-0.002	No
(4) Righting Arm at 30 deg.	≥ 0.2 m	0.574	Yes	0.675	Yes	-0.010	No
(5) Absolute Angle at MaxRA	≥ 25 deg.	40.52	Yes	37.99	Yes	87.50	Yes
(6) GM at Equilibrium	≥ 0.15 m	1.848	Yes	1.917	Yes	*Undefined*	No

By comparing the results of both methods, a difference is noted of a value:
1,889.3746 - 1829.35 = 60.0246 m^3
The difference between the two methods is very small (~ 3.28%).
Where:
ρ: is the Density in (kg/m^3).

5. DIFFERENT TYPES OF AIR BAGS USED IN MARINE FIELDS

There are some existing examples of air bags which may help in finding some standards or parameters in the required air cushion.

5.1 The Various Types of Airbags used in different fields

5.1.1 Heavy Lifting Airbags

High-pressure heavy lifting airbags are the stiffest large pneumatic lifting bags for the gigantic structure, for the lifting and moving of concrete caissons, has been updated based on airbags launched from the ship. This update makes heavy lifting airbags more suitable for heavy lifting work. The maximum lifting capacity of each heavy lifting airbag can be more than 1,000 tons, [13].

Having the different structure with the ship launching airbags, high pressure and heavy duty are its advantages where they use the special synthetic-tire-cord, which is stronger than the material that is used for the ship launching airbags, flexible, super high lifting capacity and cost effective, [14].

A further application of ship launching marine airbags after updating is marine salvage and re-floatation.

5.1.2 Ship Launching Airbags

It's known also as Ship Launching Balloon or Roller Bags, are manufactured of heavy-duty synthetic-tire-cord layers with inner and outer rubber layers in a shape of cylindrical long balloon. May be utilized for the launching of the ship or ship landing of tanker, barges or tugboat, carrier, carrying vessel, ferry and other special vessels. The largest vessel has been launched by ship with airbags of up to 85,000 DWT, [15].

Launching of the ship, based on ship launch airbags, is an innovative technology for ship launch, compared to "float-out", "side launch" or "end-on launch". This technology to launch a ship overcomes the constraints on fixed side-launch launch tracks. A lot of shipyards worldwide have accepted ship launching airbags because of its advantages of flexible, time saving, safety, investment saving.

5.2 The existing similar applications

In the Bladder-tank system, after a few years, the rubber bag inside the pressure tank may become responsive. May also be damaged if filling isn't taken care of, [16].

6. CONCLUSION and RECOMMENDATIONS

Three scenarios of flooding were made: flooding of hold No.1 (fore hold), flooding of hold No.2 (after hold), and finally flooding of the two holds simultaneously which led to the sinking of the ship. However, Attempts are made to prevent sinking. A suggested solution is created using air bags (cushions) that may come into operation at any point in order to prevent water from reaching the two holds to be no more than the quantity needed to make the vessel float at a water line tangent to the margin line as described.

A software package AUTOSHIP was used in order to conduct the above mentioned damage stability calculations.

The choice of suitable air bags to be used in our case that needs more investigation concerning cost effectiveness, installation and operation. These items will be recommendations for further works about the overall survivability of ships after damage. These can be determined by using models in experiments or by simulation for damaged models to find accurate and specific results for using these air bags. Also, if the previous bulk carriers' causalities will be investigated as if they were fitted with this arrangement and study , they couldn't be lost or in other words could be survived. Finally, the analysis of these recommendations after execution to decide if it will be effective or not.

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