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Stability Aspects of Bulk Carriers

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ABSTRACT

Bulk carriers are one of the three dominating merchant ship types together with grain and container vessels. Today, bulk carriers comprise about one third of the world fleet in tonnage terms. The demand for raw materials like coal, iron, copper, …etc., has increased considerably since the turn of the millennium. Moreover, the bulk carrier has specific nature due to the loaded bulk cargo's parameters which may slosh, liquefy, shift...etc.

The intact stability of bulk carriers is investigated, with respect to the latest regulations developed by IMO. The effect of loading conditions and types of cargoes on ship stability and cargo earning capacity are studied. It is found that in some cases of loading conditions with certain types of cargo we have to use ballast water to satisfy the new grain regulations. This will lead to a reduction in the cargo earning capacity of the ship. The study under consideration is very important from the economic point of view of the vessel's operation. Ship's owners and charters must know which type of bulk cargoes is more profitable in case they have a choice to carry different types of bulk cargoes.

A computer program is developed to carry out the stability calculations. Firstly we should get the vessel's lines plans drawings, then using these drawings to prepare the vessel's tables of offsets. Using these tables of offsets and Model Maker Program, full model of ship's sections at different stations and the general arrangement can be obtained.

Take this model in the Auto Hydro program to do the different loading conditions calculations. A programing code is written and to be run to check the compliance with the intact stability criteria.

Keywords— Bulk carriers- stability- Bulk cargo

Abbreviations and notations:

DWT	: Deadweight in (ton)
GM_o	: The initial metacentric height in (m)
HM	: Heeling Moment in (ton.m)
IMO	: International Maritime Organization
K	: Correction multiplier factor
KG	: The vertical vessel's center of Gravity (height above the keel) in (m)
R	: Angle of Repose in (degree)
MSC	: Maritime Safety Committee of IMO
S.F.	: Stowage Factor (m^3/ t)
SOLAS	: Safety Of Life At Sea
SSC	: Statical Stability Curve
TSM	: Volumetric Transverse Shifting Moment (m^4)
Δ	: Displacement in (ton)
ρ	: Density in (t /m^3)
θ	: Heel angle in (degree)
ϕ_f	: Angle of flooding in (degree)
φ_h	: Ship's angle of heel due to cargo shifting in (degree)
ϕ_m	: Angle of the maximum difference between righting arm and heeling arm in (degrees)
λ_o	: Heeling arm at zero degrees in (m)
λ_{40}	: heeling arm at 40 degrees in (m)

1. INTRODUCTION

1.1 Bulk Carrier's Definition

The strict technical definition of a bulk carrier has been adopted by the SOLAS in 1999 [1], and it defines a bulk carrier as a ship which has a single deck, top side tanks and hopper side tanks in cargo spaces, as shown in Figure1, and intended to primarily carry dry cargo in bulk (e.g. ore, cement, corn, grain, coal….etc.), [2].

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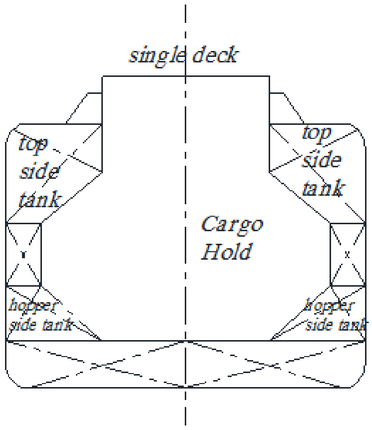

Figure 1: Typical cargo hold structural configuration for a single side skin bulk carrier

1.2 Types of Bulk Carriers

Bulk carriers can be divided on the basis of their loading/unloading facilities or their cargo carrying capacity as shown in Table 1:

Table 1: Categories of bulk carrier

On the basis of the loading/ unloading facilities:	*Geared Carriers*	This is a ship which has got its own gear (or equipment) to load or unload cargo. This gear is in the form of cranes or derricks.
	Gearless Carriers	Some ships go away with the cranes and derricks but depend on the equipment available at shore to load/discharge cargo and these are known as gearless carriers.
On the basis of the cargo carrying capacity:	*Mini bulk carriers or MBCs*	Are relatively small bulk carriers usually have capacity less than 10,000 DWT.
	Handy size carriers and Handy max carriers	Are general purpose ships in nature, [3]. These two segments represent 71% of all bulk carriers over 10,000 DWT and also have the highest rate of growth [4]. Handymax ships are typically 150–200 m in length and 52,000 – 58,000 DWT.
	Panamax carriers	The size of a Panamax vessel is limited by the Panama canal's lock chambers[5], which can accommodate ships with a beam of up to 33.53 m, a length overall up to 320.04 m, and a depth up to 12.56 m[6]. The capacity of this type is 60,000–99,999 dwt, [7].
	Capesize carrier	Capesize ships are too large to traverse the Panama Canal and must round Cape Horn to travel between the Pacific and Atlantic oceans, a standard Capesize bulker is around 175,000 DWT, [8].
	Very large bulk carriers	Very large bulk carriers are a subset of the capesize category reserved for vessels over 200,000 DWT, [9].

2. BULK CARRIER’S STABILITY

Solid bulk cargoes are usually loaded by pouring directly into a ship’s cargo holds. If a solid bulk cargo is poured onto one spot, it naturally forms a conical pile with distinctive slope angle, called the *Angle of Repose* ‘R’[10].

This is determined by the friction between the individual particles of the stow, which, in turn, depends upon the cargo commodity, its moisture content and the size and shape of the individual particles; see Figure2 and Table 2.

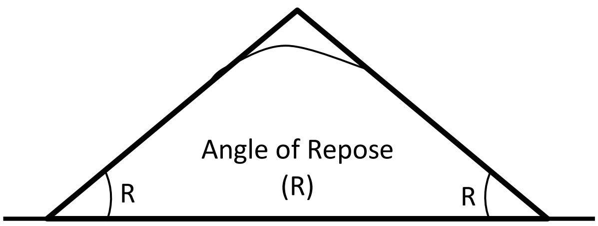

Figure 2: Angle of Repose for a solid bulk cargo [11]

If a particularly heavy roll heels a vessel beyond the cargo's angle of repose, then the stow becomes unstable, as in condition 3, as shown in Figure 3. If the shift of cargo occurs, then the ship will roll about an angle of list so the return roll is unlikely to restore the cargo to the level state. Further rolling will produce even greater angles of heel towards the side of shifted cargo. This, in turn, can lead to further shifts of the stow which causes the list to progressively increase. The process will either capsize the ship or reach a stable listed state, depending upon the vessel's transverse stability characteristics.

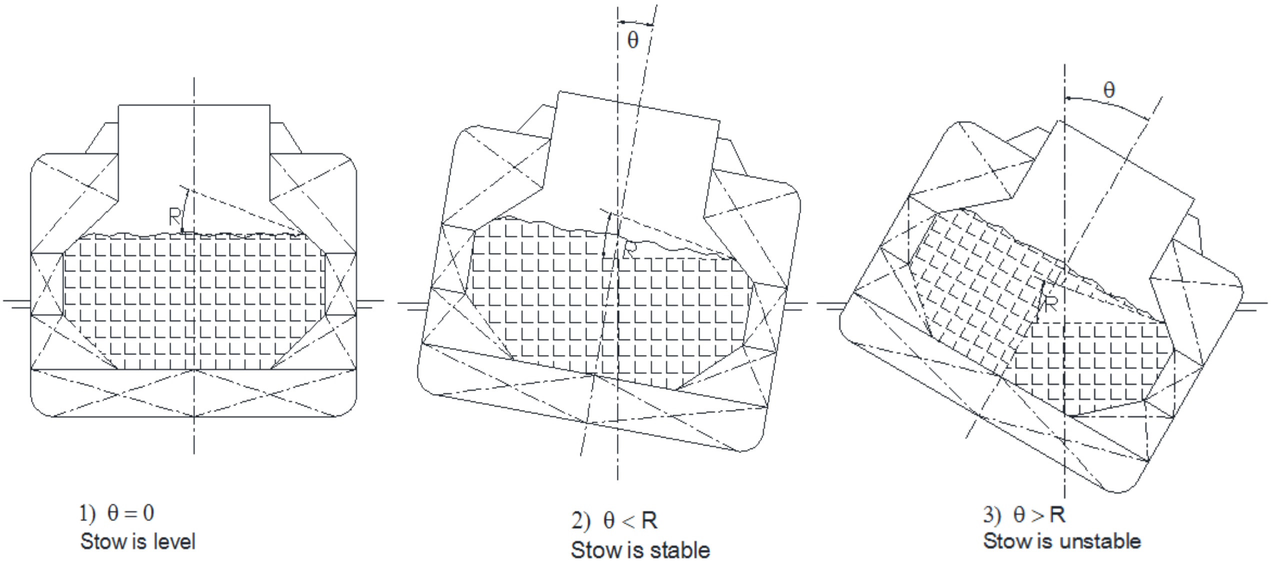

Figure 3: Behavior of a trimmed bulk cargo with angles of heel "θ"

Table 2: Examples of the angle of repose (R) and stowage factor (S.F.) of some different solid bulk cargoes in m^3/t [12]

Solid Bulk Cargoes	**S. F. (m^3/t)**	**Angle of Repose**
Ammonium Nitrate UN 1942	1	27°to 42°
Ammonium Sulphate	0.95 to 1.06	28° to 35°
Monoammonium Phosphate	1.0 to 1.21	35° to 40°
Potash	0.77 to 1.03	32° to 35°
Potassium Chloride	0.81 to 1.12	30° to 47°
Superphosphate	0.81 to 1.00	30° to 40°

3. FORMULATION of BULK CARRIER STABILITY PROBLEM

The angle of the heel due to solid bulk cargo shift (ϕ_h) can be determined. Any bulk carrier, must have data, regarding the hold spaces, so that the KG and volumetric heeling moment for each stow can be calculated. TSM called simply the Moment of Water plane Inertia or, more correctly, the Second Moment of Area and this moment indicates the rate at which the underwater hull shape changes with angle of heel and it is an important factor in determining the hull form's resistance to rolling [13]. It is the moment caused by the shift in the Centre of Buoyancy per radian of water plane area rotation. This information is supplied by the shipbuilder in the form of tables or diagrams, for each cargo space, as shown in Figure4. Figure4 shows typical variations of volumetric heeling moment (curve No.1), stow's height of VCG from the keel (curve No.2) and volumetric capacity (curve No.3) with hold ullage.

The fluid KG of loaded vessel in the upright condition is calculated in the normal way by taking moments of individual weights about the keel and allowing for free surface effects of any slack tanks. Heights of cargo stows in the holds are obtained by measuring their ullages (i.e. the depths of the stow's top surface from the hatch top). The ullage values are used to obtain the KG, volume and volumetric heeling moment of each grain stow. The weight of each stow is calculated as follows:

Weight of cargo stow (ton) = Volume of stow/Stowage factor (1)

The value of the stowage factor, S.F. is generally used instead of bulk density, 'ρ' and should be supplied by the grain shipper, prior to loading.

S.F. = 1/ ρ (m^3/t) (2)

Values of KG and volumetric heeling moments must be corrected for all partially filled holds with the appropriate factors of 'K', as shown below, before being used in the KG calculation.

The calculations' steps of the angle of heel due to solid bulk cargo shift (ϕ_h) are as follows:

a. Find out the Volumetric Transverse Shifting Moment (TSM) in (m^4) for each cargo hold corresponding to the loaded cargo's volume (m^3) from the vessel's tables.

b. In order to take into account the adverse effect of vertical shift of grain/bulk cargoes surfaces in "partially filled compartment", Volumetric Transverse Shifting Moment has to be multiplied by "K" where multiplier "K" is given by; according to [14];
   - 1.06 For "fully filled compartments".
   - 1.12 For "partly filled compartment".

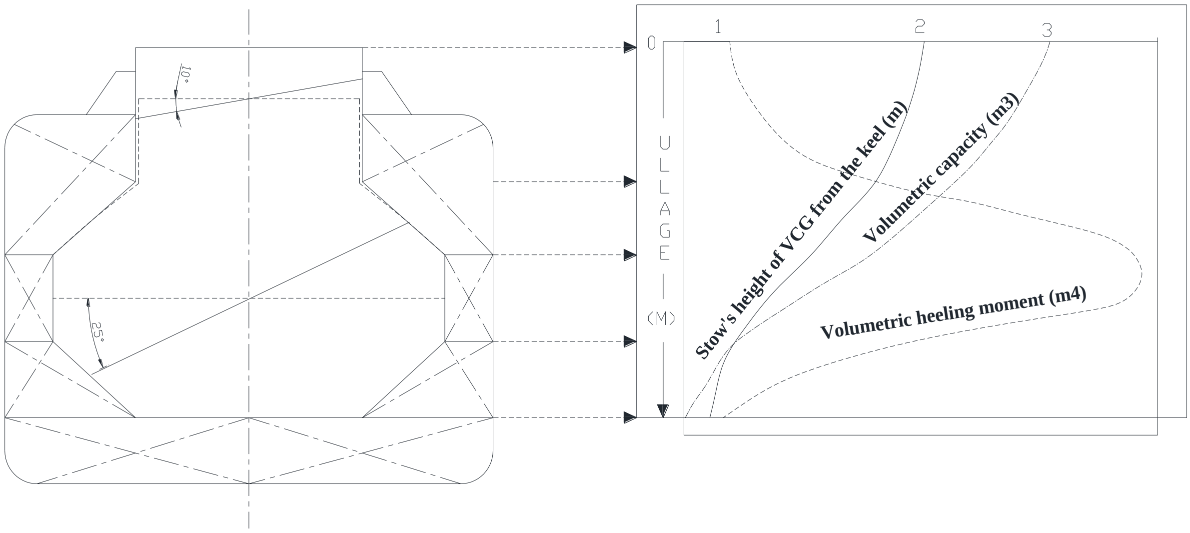

Figure 4: Grain Characteristics for a hold [11]

c. Transform Volumetric Transverse Heeling Moment (TSM) in (m^4) into Heeling Moment (HM) (t.m) from the following formula, [14]:

HM = K. TSM (m^4)/ S.F. (m^3/t) in (t.m) (3)

d. Find the value of heeling arm (λ_o) at zero and the value of heeling arm (λ_{40}) at 40 degrees, respectively, by the formulae, [15]:

$$\lambda_0 = \frac{Total\ Heeling\ Moment\ (t.m)}{Displacement(ton)} \quad (4)$$

And

$$\lambda_{40} = 0.8 * \lambda_0 \quad (5)$$

Draw the heeling arm curve due to transverse grain shift which may be approximately represented by the straight line A-B where A and B are the ordinates. 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 Figure 5.

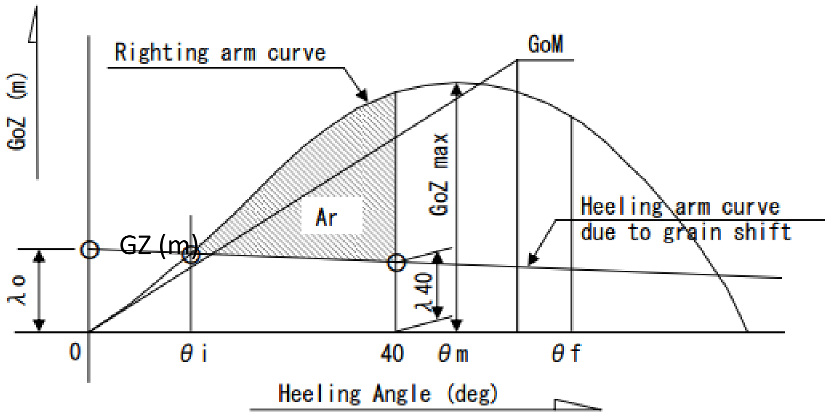

Figure 5: Determination of the angle of the heel due to solid bulk cargo shift (ϕ_h)

4. THE STABILITY CRITERIA REQUIRED BY THE GRAIN REGULATIONS, [16]

The intact stability criteria as per the Grain Regulations A.749 (18), [17], Maritime Safety Committee MSC.23(59), [18] and Chapter VI, SOLAS 1974, [19] according to the intact stability characteristics of any ship carrying bulk cargoes should meet, throughout the voyage, at least the following criteria after taking into account the heeling moments due to dry bulk cargo shift:

i. In the statical stability flow chart, see Figure 5, the net residual area between the heeling arm curve due to transverse grain shift and the righting arm curve up to the angle of heel of maximum difference between the ordinates of the two curves, (ϕ_m), or 40 degrees or the "angle of flooding", (ϕ_f), whichever is the least, shall in all conditions not be less than 0.075 meter-radians; i.e,

Residual Dynamical Stability ≥ 0.075 (meter-radians) (i)

ii. The angle of heel due to shift of grain, ϕ_h, shall not be greater than 12 degrees i.e,

$\phi_h \leq 12^o$ (ii)

iii. The initial metacentric height, after correction for the free surface effects of liquids in tanks, shall not be less than 0.3 meters, i.e,

$GM_o \geq 0.3$ m (iii)

5. APPLICATION OF PROPOSED PROCEDURE

In what follows an illustrative example given to show the procedure to be followed to investigate the stability problem of bulk carriers at different conditions of loading with different types of bulk cargo.

5.1 Bulk Carrier's Specifications

Table 3 summarizes the candidate vessel's principal particulars.

Table 3: Vessel Principal Particulars M/V "Gold Stone"

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
Net Tonnage	1822
Engine Type	6320 ZCD-6
Engine Power	1545 K.W
Frame spacing	600 mm
Longitudinal Center of gravity (LCG)	-5.313 m (fore)
Vertical center of gravity (KG)	5.70 m
Number of cargo holds	2
Year of Built	2007

5.2 Stability Calculations Flow Chart

A computer program is developed to carry out the stability calculations. The following flow chart, see Figure 6, explains the steps to meet the above mentioned criteria.

Table of offsets was developed and from these tables a model for the vessel was developed using Model Maker software. This model was used to carry out some loading conditions for the candidate vessel using AutoHydro software. Then the stability criteria for every loading condition were checked and analyzed as follows in the next sections of this paper.

5.3 Loading Conditions

Stability calculations are carried out at the following loading conditions:

a) Full load departure condition:

The ship is fully loaded with cargo homogenously distributed through all cargo holds and with full stores and consumables, [20].

In this case:

Ship's displacement (Δ) = 6164.563 Ton
Cargo weight = 4184.283 Ton
Draft = 6 m
No ballast water onboard

b) Half load (50%) departure condition:

In this case:

Ship's displacement (Δ) = 4072.4215 Ton
Cargo weight = 2092.1415 Ton
Draft = 6 m
No ballast water onboard

c) 25% load departure condition:

In this case:

Ship's displacement (Δ) = 3026.351 Ton | Draft = 6 m
Cargo weight = 1046.0708 Ton | No ballast water onboard

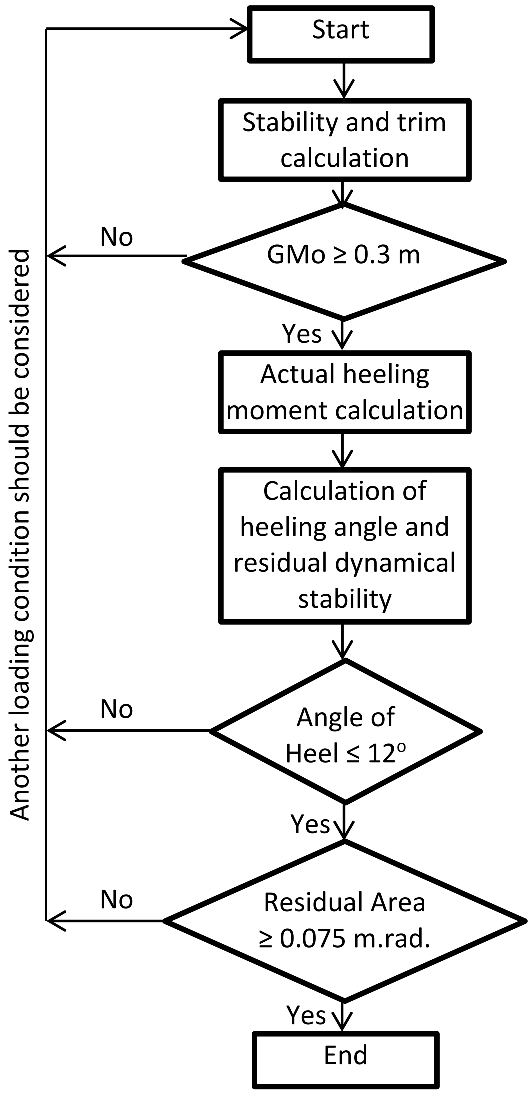

Figure 6: Stability diagram flow chart

5.4 Different Types of Bulk Cargo

The types of bulk cargo are represented by what so called stowage factor (S.F.) in (m^3/ton).

Bulk carriers usually designed to carry different types of bulk cargo with different stowage factors as given in Table 2.

This means that a bulk carrier must meet the stability grain regulations at all types of bulk cargo for which the ship is designed to carry. In this study the stability calculations for the vessel under consideration were carried out at different stowage factors, namely, 1.5, 1.25, 1.0, 0.8, and S.F. 0.667 m^3/t, to study the effect of the type of cargo on ship's stability for different loading condition (full load, half load,….etc.).

6. RESULTS and DISCUSSION of THE PROCEDURE

Figure 7 shows GZ – curve for full load departure with cargo onboard of 1.25 m^3/t stowage factor while Table 4 gives the stability checkup for the same loading condition as an example of the obtained results for different loading conditions mentioned above.

Figure 8 shows GZ – curves for full load departure with different types of cargo (i.e. different values of S.F.). Also these results are given in Table 5.

It is clear from the figure that there are two areas, one of them is stable area where all stability criteria are satisfied (for S.F. ≥ 1.25 m^3/t), while the second area is unstable (for S.F. ≤ 1.0 m^3/t).

This means that the vessel under consideration is designed to carry light bulk cargo with S.F. ≥ 1.25 m^3/t.

In order that this vessel can carry safely heavy bulk cargo with S.F. ≤ 1 m^3/t, it must have onboard certain quantity of ballast water in certain ballast tanks located in the double bottom and this will reduce the cargo earning capacity of the ship.

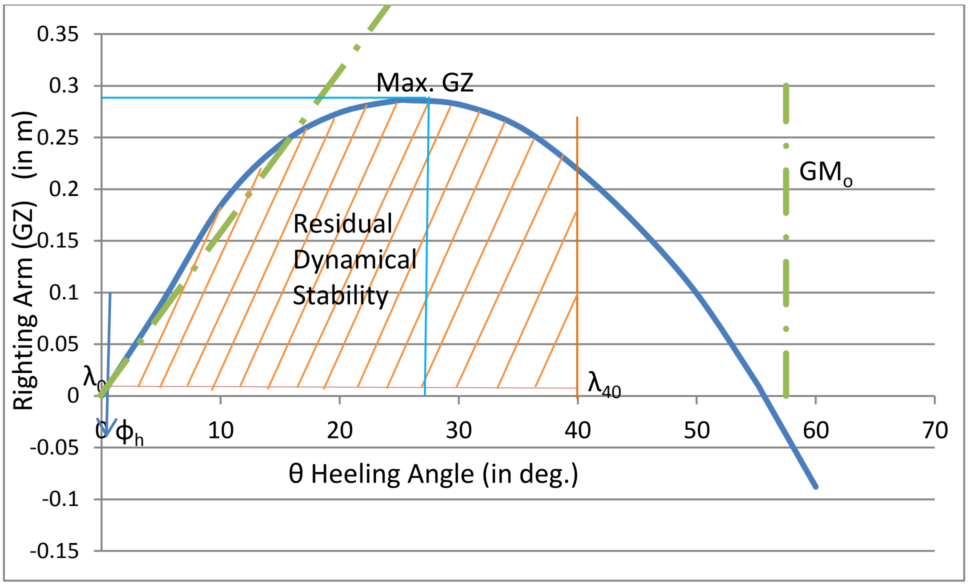

Figure 7: statically stability curve (SSC) for full load departure (S.F. 1.25 m^3/ton) as an output of the Autohydro software

Table 4: Stability checkup for full load departure (S.F. 1.25 m^3/ton) as an output of the Autohydro software

	Min/Max	Actual	Margin	Pass
(1) Area from 0 deg. to 30	≥ 0.055 m-R	0.107	0.052	Yes
(2) Area from 0 deg. to 40or Flood	≥ 0.09 m-R	0.152	0.062	Yes
(3) Area from 30 deg. to 40 or Flood	≥ 0.03 m-R	0.045	0.015	Yes
(4) Righting Arm at 30 deg.	≥ 0.2 m	0.282	0.082	Yes
(5) Absolute Angle at Max. R.A.	≥ 25 deg.	27.31	2.31	Yes
(6) GM at Equilibrium	≥ 0.15 m	0.903	0.753	Yes
(7) Area from 0 deg. to 40 or Flood	≥ 0.075 m-R	0.152	0.077	Yes
(8) GM at Equilibrium	≥ 0.3 m	0.903	0.603	Yes

This was done and the results are shown on Figure 9. It was found that in the case of S.F. equals to 0.8 m^3/t, we have to carry an amount of 535.2 tons of water as a ballast to satisfy all stability criteria (see Table 5 and Table 6). As a result of ballasting operation the quantity of cargo to be carried onboard is reduced from 4184.283 tons to 3649.083 tons i.e. cargo earning capacity is reduced by 12.79%.

For other loading conditions (i.e. 50% and 25%) the results are shown on figure 10 (and table 7) and figure 11 (and table 8), respectively. It is clear that for these load conditions the vessel meet all grain stability criteria when loaded with different cargoes without need to carry ballast onboard.

It should be noted that one can say that for the same vessel and for the same loading condition, when the S.F. value increases (i.e. light cargo) the value of KG increases. In fact, in our case study, this is not usually true for all cases, since the cargo distribution in cargo holds as well as water ballast is not the same in all cases of loading conditions.

7. CONCLUSIONS

Bulk carriers comprise about one third of the world fleet in tonnage terms. Due to the nature of the bulk cargoes, bulk carriers face some stability problems.

For safe operation of such vessels IMO developed special stability criteria, which must be satisfied.

This paper gives a brief discussion of such regulations and a computer program was developed to carry out stability calculations for such vessels.

The effects of loading conditions as well as the type of bulk cargo carried onboard were examined. It was found that in some cases of loading conditions with certain type of cargo we have to use ballast water to satisfy the new grain regulations. This will lead to a reduction in the cargo earning capacity of the ship. The study under consideration is very important from the economic point of view of the vessel's operation. Ship's owners and charters must know which types of bulk cargoes are more profitable in case they have a choice to carry different types of bulk cargoes.

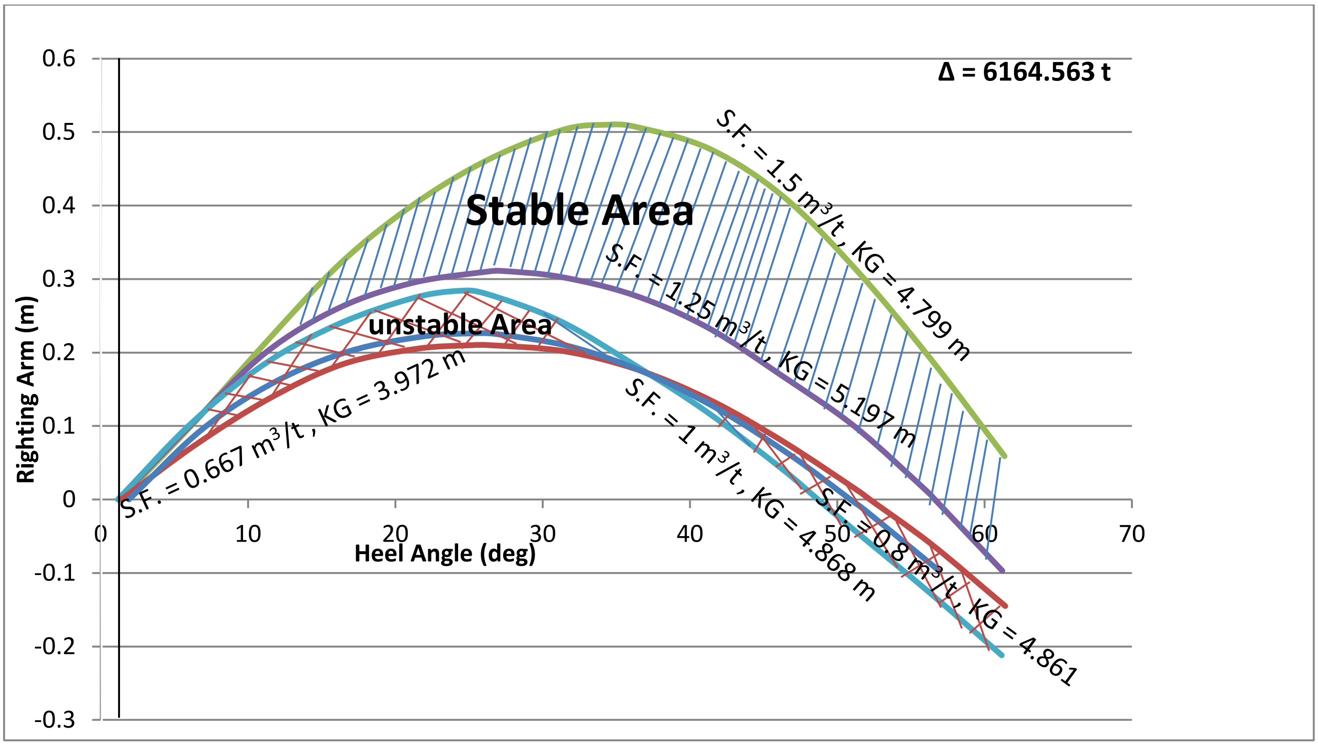

Figure 8: Righting Arm Curves (GZ Curve) in the Full Load Condition

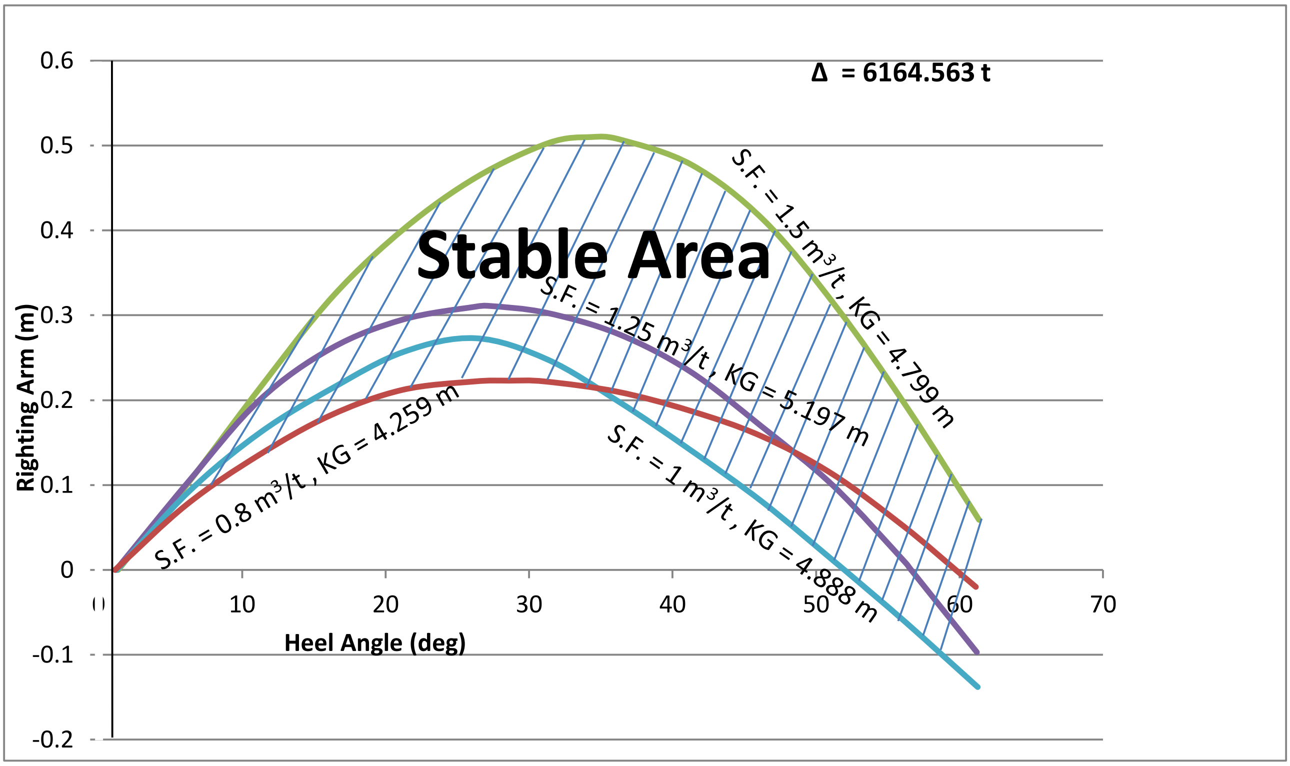

Figure 9: Righting Arm Curves (GZ Curve) in the Full Load Condition

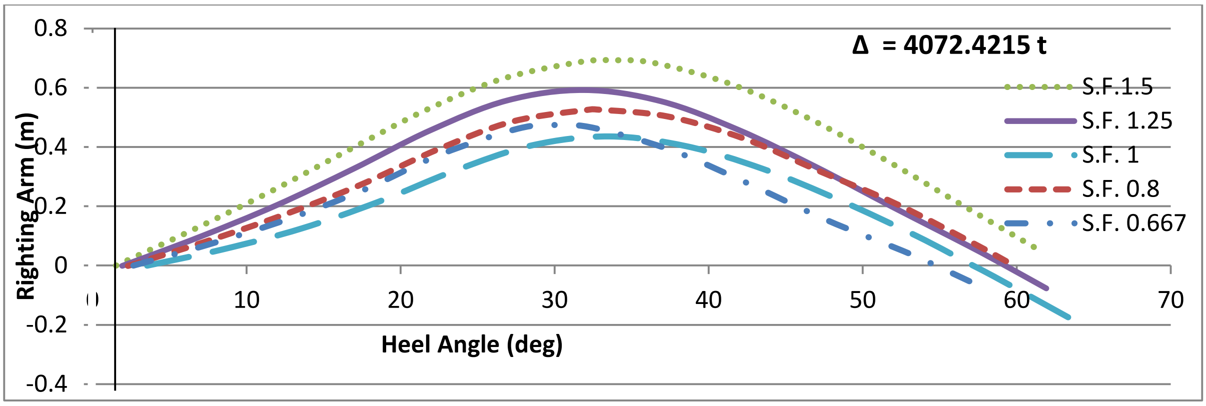

Figure 10: Righting Arm Curves (GZ Curve) in the Half Load (50%) Departure Condition

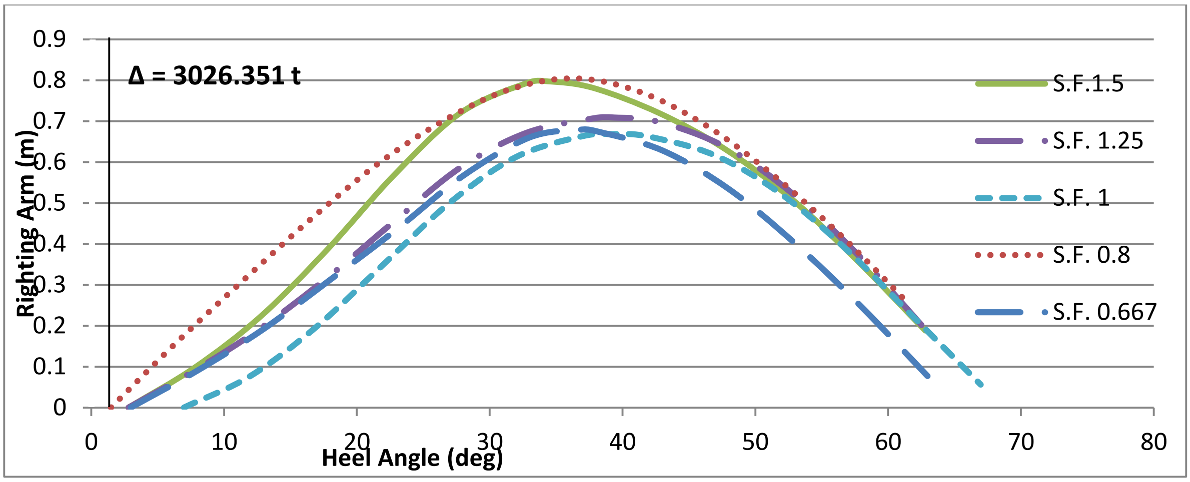

Figure 11: Righting Arm Curve (GZ Curve) in 25% Loading Departure Conditions

Table 5: Stability criteria for candidate ship in full load departure when loaded with bulk cargoes with different S.F.

Item / Loading condition / Stowage factor	Full load departure (condition No.1)									
	S.F. = 0.667		S.F. = 0.8		S.F. = 1		S.F. = 1.25		S.F. = 1.5	
Summer draft (m)	6									
Light ship weight (ton)	1,674.57									
Fixed weight (ton)	3.5									
Cargo in Hold (1) (ton)	1683.4		697.056		1,301.26		1840.212		1531.905	
Cargo in Hold (2) (ton)	2500.883		3487.227		2,880.56		2281.455		1899.084	
Consumables (ton)	302.21									
Deadweight (ton)	4489.99									
Ballast onboard (ton)	70		No ballast		No ballast		62.616		753.2	
Displacement (ton)	6164.563									
VCG (KG) (m)	4.861		3.972		4.868		5.197		4.799	
Stability criteria	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**
(1) Area from 0 deg. to 30 ≥ 0.055 m-R	0.041	No	0.050	No	0.104	Yes	0.107	Yes	0.145	Yes
(2) Area from 0 deg. to 40 or Flood ≥ 0.09 m-R	0.013	No	0.063	No	0.135	Yes	0.152	Yes	0.220	Yes
(3) Area from 30 deg. to 40 or Flood ≥ 0.03 m-R	-0.028	No	0.014	No	0.030	No	0.045	Yes	0.075	Yes
(4) Righting Arm at 30 deg. ≥ 0.2 m	-0.035	No	0.107	No	0.242	Yes	0.282	Yes	0.417	Yes
(5) Absolute Angle at MaxRA ≥ 25 deg	16.92	No	22.62	No	23.82	No	27.31	Yes	40.21	Yes
(6) GM at Equilibrium ≥ 0.15m	0.725	Yes	0.579	Yes	1.217	Yes	0.903	Yes	1.076	Yes
(7) Area from 0 deg to 40 or Flood ≥ 0.075 m-R	0.013	No	0.063	No	0.135	Yes	0.152	Yes	0.220	Yes
(8) GM at Equilibrium ≥ 0.3 m	0.725	Yes	0.579	Yes	1.217	Yes	0.903	Yes	1.076	Yes
(9) The angle of heel due to cargo shift, $\phi_h \leq 12^o$	7.7	Yes	4.6	Yes	3.6	Yes	2.1	Yes	2	Yes

Table 6: Stability criteria for candidate ship in full load departure when loaded with bulk cargoes with different S.F.

Item / Loading condition	Full load departure (condition No.1 with ballast water added)							
Stowage factor	S.F. = 0.8		S.F. = 1		S.F. = 1.25		S.F. = 1.5	
Summer draft (m)	6							
Light ship weight (ton)	1,674.57							
Fixed weight (ton)	3.5							
Cargo in Hold (1) (ton)	697.056		1335.658		1840.212		1531.905	
Cargo in Hold (2) (ton)	2952.027		2565.23		2281.455		1899.084	
Consumables (ton)	302.21							
Deadweight (ton)	4489.99							
Ballast onboard (ton)	535.2		283.4		62.616		753.2	
Displacement (ton)	6164.563							
VCG (KG) (m)	4.259		4.888		5.197		4.799	
Stability criteria	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**
(1) Area from 0 deg. to 30 ≥ 0.055 m-R	0.083	Yes	0.099	Yes	0.107	Yes	0.145	Yes
(2) Area from 0 deg. to 40 or Flood ≥ 0.09 m-R	0.119	Yes	0.133	Yes	0.152	Yes	0.220	Yes
(3) Area from 30 deg. to 40 or Flood ≥ 0.03 m-R	0.036	Yes	0.034	Yes	0.045	Yes	0.075	Yes
(4) Righting Arm at 30 deg. ≥ 0.2 m	0.222	Yes	0.248	Yes	0.282	Yes	0.417	Yes
(5) Absolute Angle at MaxRA ≥ 25 deg	28.61	Yes	26.27	Yes	27.31	Yes	40.21	Yes
(6) GM at Equilibrium ≥ 0.15m	1.030	Yes	1.060	Yes	0.903	Yes	1.076	Yes
(7) Area from 0 deg to 40 or Flood ≥ 0.075 m-R	0.119	Yes	0.133	Yes	0.152	Yes	0.220	Yes
(8) GM at Equilibrium ≥ 0.3 m	1.030	Yes	1.060	Yes	0.903	Yes	1.076	Yes
(9) The angle of heel due to cargo shift, $\phi_h \leq 12^o$	3.1	Yes	2.8	Yes	2.1	Yes	2	Yes

Table 7: Stability criteria for candidate ship in half load departure when loaded with bulk cargoes with different S.F.

Item / Loading condition / Stowage factor	Half load departure (condition No.3)									
	S.F. = 0.667		S.F. = 0.8		S.F. = 1		S.F. = 1.25		S.F. = 1.5	
Summer draft (m)	6									
Light ship weight (ton)	1,674.57									
Fixed weight (ton)	3.5									
Cargo in Hold (1) (ton)	2092.142		2092.142		1161.505		929.4		774.55	
Cargo in Hold (2) (ton)	0		0		930.6365		1162.742		1317.592	
Consumables (ton)	302.21									
Deadweight (ton)	2397.85									
Ballast onboard (ton)	No ballast		No ballast		No ballast		No ballast		No ballast	
Displacement (ton)	4072.4215									
Stability criteria	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**
(1) Area from 0 deg. to 30 ≥ 0.055 m-R	0.136	Yes	0.145	Yes	0.117	Yes	0.169	Yes	0.197	Yes
(2) Area from 0 deg. to 40 or Flood ≥ 0.09 m-R	0.203	Yes	0.231	Yes	0.186	Yes	0.264	Yes	0.314	Yes
(3) Area from 30 deg. to 40 or Flood ≥ 0.03 m-R	0.067	Yes	0.086	Yes	0.069	Yes	0.095	Yes	0.117	Yes
(4) Righting Arm at 30 deg. ≥ 0.2 m	0.463	Yes	0.526	Yes	0.436	Yes	0.592	Yes	0.686	Yes
(5) Absolute Angle at MaxRA ≥25 deg	30.20	Yes	32.74	Yes	33.55	Yes	31.93	Yes	33.83	Yes
(6) GM at Equilibrium > 0.15m	0.813	Yes	0.908	Yes	0.610	Yes	1.078	Yes	1.362	Yes
(7) Area from 0 deg to 40 or Flood ≥ 0.075 m-R	0.203	Yes	0.231	Yes	0.186	Yes	0.264	Yes	0.314	Yes
(8) GM at Equilibrium ≥ 0.3 m	0.813	Yes	0.908	Yes	0.610	Yes	1.078	Yes	1.362	Yes

Table 8: Stability criteria for candidate ship in 25% load arrival when loaded with bulk cargoes with different S.F.

Item / Loading condition	25% load arrival (condition No.5)									
Stowage factor	S.F. = 0.667		S.F. = 0.8		S.F. = 1		S.F. = 1.25		S.F. = 1.5	
Summer draft (m)	6									
Light ship weight (ton)	1,674.57									
Fixed weight (ton)	3.5									
Cargo in Hold (1) (ton)	1046.071		1046.071		696.903		557.64		774.55	
Cargo in Hold (2) (ton)	0		0		349.1678		488.4308		271.5208	
Consumables (ton)	302.21									
Deadweight (ton)	1351.78									
Ballast onboard (ton)	No ballast		No ballast		No ballast		No ballast		No ballast	
Displacement (ton)	3026.3508									
Stability criteria	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**	**Actual**	**Pass**
(1) Area from 0 deg. to 30 ≥ 0.055 m-R	0.168	Yes	0.197	Yes	0.181	Yes	0.173	Yes	0.209	Yes
(2) Area from 0 deg. to 40 or Flood ≥ 0.09 m-R	0.284	Yes	0.322	Yes	0.295	Yes	0.295	Yes	0.344	Yes
(3) Area from 30 deg. to 40 or Flood ≥ 0.03 m-R	0.116	Yes	0.126	Yes	0.114	Yes	0.122	Yes	0.135	Yes
(4) Righting Arm at 30 deg. ≥ 0.2 m	0.660	Yes	0.726	Yes	0.663	Yes	0.672	Yes	0.793	Yes
(5) Absolute Angle at MaxRA ≥25 deg	36.72	Yes	35.19	Yes	39.37	Yes	39.37	Yes	34.40	Yes
(6) GM at Equilibrium > 0.15m	0.994	Yes	1.208	Yes	0.696	Yes	1.037	Yes	1.065	Yes
(7) Area from 0 deg to 40 or Flood ≥ 0.075 m-R	0.284	Yes	0.322	Yes	0.295	Yes	0.295	Yes	0.344	Yes
(8) GM at Equilibrium ≥ 0.3 m	0.994	Yes	1.208	Yes	0.696	Yes	1.037	Yes	1.065	Yes

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