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Intact stability of a bulk carrier

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Abstract

Due to the accelerating demand for transporting raw materials around the world over the last century, bulk carriers are being constantly developed in order to maximise their capacity and efficiency whilst maintaining safety and durability of the vessels. With regards to safety, the International Maritime Organisation (IMO) and the International Association of Classification Societies (IACS) recurrently issue regulations and technical standards for the design and construction of ships, in order to safeguard the crew and other people on board. In light of these regulations, three issues concerning the properties of a bulk carrier are investigated. Firstly, the floodability of a bulk carrier is researched, to determine the largest possible volumes of compartments which can be flooded without causing the bulk carrier to capsize. Results were determined both manually and by means of marine design software, *Maxsurf Enterprise*; results generated by the two methods are compared. Additionally, a series of loadcases, each consisting of a different cargo and ballast configuration, are sought to reveal their effect on both the still water bending moment and the intact stability of the vessel. The results are analysed in relation to the IMO's criteria.

Introduction

Bulk carriers are, and have always been, the workhorses of the sea, designed to carry large amounts of cargo and operating worldwide. As the demand for iron ore, coal and other raw materials accelerated in the last century, seaborne trade stood out as the most convenient way to transport cargo and, therefore, the necessity for larger, more refined bulk carriers has grown (Rawson & Tupper, 2001).

Regarding today's maritime transportation, the foremost challenge lies in designing a vessel which is safe and which adheres to the relevant classification society's standards whilst being capable of meeting the specific requirements of its owner. The International Maritime Organisation (IMO) and the International Association of Classification Societies (IACS) frequently issue conventions and codes concerning the technical standards for the design and construction of ships in order to safeguard the crew and other people on board (International Maritime Organization, 2014).

Intact stability

An intact stability test must be undertaken for each loadcase. The test can be completed automatically by *Maxsurf Stability*; in this case, however, a procedure will be used to calculate the intact stability for loadcase L-01 which will serve as a representative solution that can be followed for all other loadcases. The procedure followed is with respect to the IMO's IS Code. For each loadcase, nine criteria need to be met by the bulk carrier: six of which concern the properties of the righting lever and the remaining three concern the severe winds and rolling (Barrass & Derrett, 2012).

Righting Lever Properties

The curve of righting levers is calculated with the Large Angle Stability module in *Maxsurf Stability* and is displayed in Figure 1.

The first three intact stability criteria concern the area under the GZ curve. *Maxsurf Stability* outputs

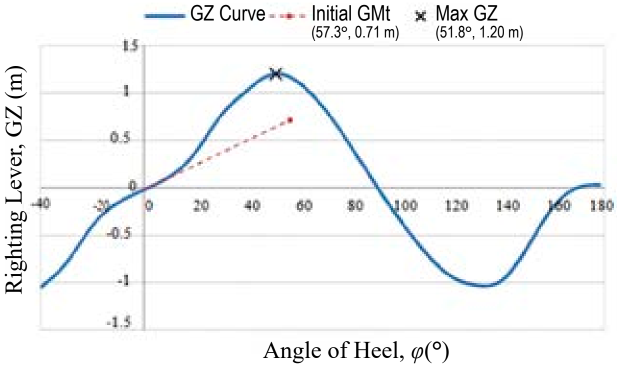

Figure 1. GZ curve for L-01

the value of the area under the graph from angle 0° to any other angle. In order to find the area under the curve between 30° and 40°, the total area under the curve at angles below 30° was subtracted from the total area under the curve at angles below 40°. The requirements for each criterion, along with the results for loadcase L-01 are presented in Table 1. Each of the criteria was met as shown by a reading of "Pass" in the "Status" column.

Table 1. Intact stability criteria 1–3 for L-01

IS Code	Criteria	Units	Requirement	Value	Status
2.2.1	Area (0° to 30°)	m·deg	≥ 3.1513	**8.057**	Pass
2.2.1	Area (0° to 40°)	m·deg	≥ 5.1566	**16.958**	Pass
2.2.1	Area (30° to 40°)	m·deg	≥ 1.7189	**8.901**	Pass

The maximum righting lever, GZ_{max}, for loadcase L-01 is shown in Figure 1 at a value of 1.199 m and a heeling angle of 51.8°. The initial metacentric height, GM_0, is also shown in Figure 1. A tangent to the GZ curve at 0° is drawn and its intersection with 57.3° (1 radian) heeling angle is the initial transverse GM value, its value is 0.71 m. These properties all conform to the Intact Stability criteria as shown in Table 2.

Table 2. Intact stability criteria 4–6 for L-01

IS Code	Criteria	Units	Requirement	Value	Status
2.2.2	Max GZ	m	≥ 0.2	**1.199**	Pass
2.2.3	Angle of max GZ	deg	≥ 30	**51.8**	Pass
2.2.4	Initial GM	m	≥ 0.15	**0.71**	Pass

Severe Wind and Rolling Criterion

When a vessel is subjected to a steady wind pressure perpendicular to the centreline, the bulk carrier rolls to an equilibrium angle, φ_0. To find φ_0, the wind heeling lever, l_{w1}, must be calculated by equation (1), where the displacement and the projected lateral area of the ship above the waterline are calculated by performing an equilibrium test in *Maxsurf* for loadcase L-01 (Isbester, 2014).

$$A_{\text{lat}} = 1128.5 \text{ m}^3 \quad \text{and} \quad \Delta = 25478\ t \tag{1}$$

z_m in equation (1) is the vertical displacement between the centre of A_{lat} and the centre of the underwater lateral area. The distance between the waterline and the centre of A_{lat} is approximately equal to ½×(A_{lat}/L_{BP}) and the distance between the waterline and the centre of the area underwater is approximately equal to $T/2$, where T is the draught which in the centre of the vessel has a value of 9.244 metres.

$$z_m \approx \frac{T}{2} + \frac{A_{\text{lat}}}{2L_{BP}} = \frac{9.244}{2} + \frac{1126.7}{2(149.4)} = 8.393 \text{ m} \tag{2}$$

$$l_{w1} \approx \frac{504 \cdot 1128.5 \cdot 8.4}{1000 \cdot 9.81 \cdot 25478} = 0.0191 \text{ m} \tag{3}$$

Figure 1 is used to find the corresponding heeling angle at this righting lever:

$$\varphi_0 = 3.72° \tag{4}$$

The large angle stability analysis performed by the software also outputs a value for the angle of downflooding, meaning the angle at which the vessel's deck touches the waterline. For loadcase L-01 the downflooding angle (φ_d) has a value of 22.1°. The first two severe wind and rolling criteria are met as displayed in Table 3.

Table 3. Intact stability criteria 7–8 for L-01

IS Code	Criteria	Units	Requirement	Value	Status
2.3.1.2	φ_0	deg	≤ 16	**3.72**	Pass
2.3.1.2	φ_0/φ_d	%	≤ 80	**16.83**	Pass

The last criterion requires the areas, a and b, as displayed in Figure 2, to be found for the L-01 GZ curve. To calculate these areas, φ_1, φ_2, φ_c and the righting lever, l_{w2}, caused by a gust wind pressure must be calculated.

$$l_{w2} = 1.5\ (0.0191) = 0.0286 \text{ m} \tag{5}$$

The corresponding heeling angle, φ_c, is found from Figure 2:

$$\varphi_c = 90.69° \tag{6}$$

Since $\varphi_c > 50°$, φ_2, as shown in Figure 2 is taken as 50°.

$$\varphi_2 = 50° \tag{7}$$

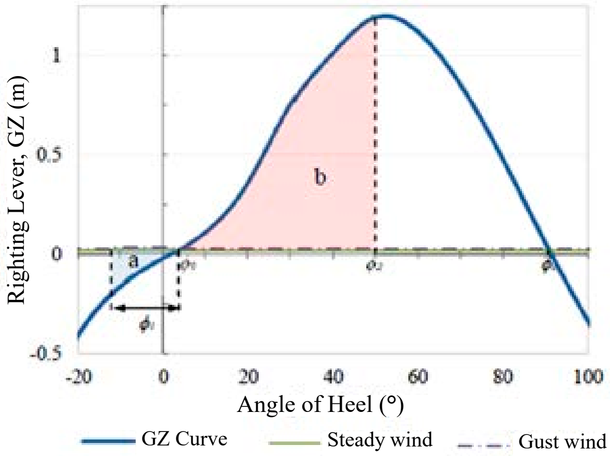

Figure 2. Severe wind and rolling GZ curve for L-01

Since l_{w2} is approximately zero, the area, A_b, can be read from the graph as the area underneath the graph between 0° and φ_2. The area is calculated using *Maxsurf* and it has a value of:

$$A_b = 28.11 \text{ m}^2 \quad (8)$$

$$\varphi_1 = 109 k X_1 X_2 \sqrt{rs} \quad (9)$$

The parameters for φ_1 were calculated and are shown in Table 4.

$$\varphi_1 = 109 \cdot 1 \cdot 0.98 \cdot \sqrt{0.645 \cdot 0.035} = 16.05° \quad (10)$$

Similarly, since l_{w1} and l_{w2} are approximately zero, the area, A_a, can be read from the graph as the area underneath the graph between φ_0 and $-\varphi_1$. *Maxsurf* was used to calculate the area under the graph as:

$$A_a = 2.305 \text{ m}^2 \quad (11)$$

The final criterion is also adhered to as shown Table 5.

Table 4. Calculation of parameters of φ_1

		Value
X_1	B / T =23.11 / 9.244 = 2.5	**0.98**
X_2	C_B = 0.8239	**1**
k	The bulk carrier has no bilge keels therefore A_k = 0	**1**
r	The *KG* value is obtained automatically from *Maxsurf* [1] and has a value of 7.934 m. *T* has been previously found to be 9.244 m. *OG* = *KG* – *T* = 7.934 – 9.244 = –1.31 m *r* = 0.73 + 0.6 (–1.31/9.244) = 0.645	**0.645**
s	$T_{time} = 2CB / (GM)^{1/2}$ GM is obtained from *Maxsurf* [1] and is equal to 0.178 m. *C* is found by equation where L_{wl}, the length of the vessel at the waterline, is obtained automatically by *Maxsurf* [1] and is equal to 153.934 m. *c* = 0.373 + 0.023 (2.5) – 0.043 (1.5393) = 0.364 Therefore, $T_{time} = 2 \cdot 0.364 \cdot 23.11/(0.178)^{1/2}$ = 39.9 s.	**0.035**

Table 5. Intact stability criteria 9 for L-01

IS Code	Criteria	Units	Requirement	Value	Status
2.3.1.4	A_b/A_a	%	≥ 100	**1220**	Pass

Results

Each loading condition was tested for intact stability; the results are presented in Table 6.

Conclusions

All loadcases, except the lightship loadcase, pass the intact stability criteria. The lightship loadcase (L-00) fails the angle of maximum GZ criterion, as shown in Table 6. In reality, the vessel will never travel under lightship conditions as it will always have either cargo or ballast inside the tanks. The lightship condition was tested since it is common practice to test all loading cases for intact stability (Biran & López-Pulido, 2014); however, it is not

Table 6. Intact stability results for L-00 to L-08

Criteria		Units	L-00	L-01	L-02	L-03	L-04	L-05	L-06	L-07	L-08
Area (0° to 30°)	**≥ 3.1513**	m·deg	56.43	8.06	9.42	22.16	31.10	18.84	24.75	15.67	19.67
Area (0° to 40°)	**≥ 5.1566**	m·deg	76.92	16.96	19.29	42.23	56.58	35.57	46.18	30.14	36.47
Area (30° to 40°)	**≥ 1.7189**	m·deg	20.5	8.9	9.9	20.1	25.5	16.73	21.43	14.46	16.8
Max GZ	**≥ 0.2**	m	2.32	1.20	1.32	2.40	3.04	2.08	2.6	1.67	1.96
Angle of max GZ	**≥ 30**	deg	21.8	51.8	52.7	51.8	49.1	53.6	54.5	44.5	47.3
Initial GM	**≥ 0.15**	m	10.91	0.71	0.79	2.60	3.61	2.19	2.79	1.80	2.13
φ_0	**≤ 16**	deg	0.9	3.7	1.4	1.4	0.6	1.4	0.5	1.7	0.2
φ_0/φ_d	**≤ 80**	%	1.57	16.98	5.72	4.58	1.75	5.14	1.78	5.35	0.55
A_b/A_a	**≥ 100**	%	111	1295	1307	555	524	556.6	542.9	644.4	593.2

obligatory that a vessel passes the intact stability criteria under lightship conditions.

As a result of the ship meeting the intact stability criteria, the vessel is deemed seaworthy. For every loadcase during which the ship is forced to heel to an angle, there is a sufficient righting lever (GZ) which returns the ship to its original upright position. Taking, for example, loadcase L-01, as shown in Figure 1, the righting lever remains positive until a heel angle of 92° is reached; this implies that the vessel can be heeled to an angle of 90° of heel and still be capable of returning to an upright position.

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