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Intact Stability Analysis of a Container Ship Due to Containers Stowage on Deck

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Abstract. Nowadays, the container transportation service increases rapidly and then this condition emphasizes the container ship growth. The containers stowage only on deck can cause a serious problem subjected to ship stability. The objective of present study is to analyze the stability of a container ship due to containers stowage on deck. Also, twelve cases based on weight conditions C1 to C2 were simulated in order to distinguish the impact of the weight on stability parameters KG, GZ, vanishing stability angle, and stability range. The results show the weight condition affects on the magnitude of KG and LCG wherein the position of centre of gravity point is behind amidship and the decrease of LCG due to the decrease of consumable weight ≥ 50% is average 2.06%. The effect of the decrease of consumable weight ≥ 50% can make stern trim condition (C3, C5, C6, C8, C9, C11, and C12). The containers stowage on deck impacts on reducing the KG as well the magnitude GZ becomes small. In addition, the vanishing stability and stability range become small. Nevertheless, the stability parameters due to the containers stowage on deck fulfil the requirement of Intact Stability Code. Overall KG values due to the weight condition (C1 to C12) are significantly lower than the limiting KG. This means that overall KG due to weight conditions fulfill the stability criterion.

1. Introduction

Since 1970s, containerized shipping has been continuously increased [1] and then it implies significant on the container ship growth. Recently, the big carrying capacity of the container ship reaches more than 21000 TEUS [2]. In fact, the number of containers on the deck is sometimes large and for this condition the distribution of containers on deck is an important problem that can cause week ship stability and ship in dangerous condition. Therefore, a stowage plan of containers must be prepared properly to ensure a balance containers weight distribution on ship.

Several studies have been carried out subjected to the container stowage plan associated with ship stability. An efficient heuristic for solving the stowage problem using the genetic algorithm technique incorporation of ship stability constraints was developed [3]. A 0-1 linear programming model was proposed in order to maximize space utilization while minimize the operation cost from upload and download of different types containers at each port of a multi-port journey, with vessel stability, industry regulations and customized rules as the constraints [4]. An effective algorithm for generating basic stowage plans of large container ship was developed based on critical measurements such as the number of re-handles, crane intensity and ship stability [5]. A prototype stowage planning system was developed wherein the study mainly focuses on the stability adjustment module [6]. A model of a representative problem of the computational complexity of stowage planning into A2-phase hierarchical decomposition associated with the modelling of vessel stability was introduced and improved [1, 7]. Moreover, the ships' behaviour in partially loaded conditions and carrying ballast water in the double bottom tanks was analyzed in order to emphasize the critical level of loading condition which triggers the uptake of ballast water in the double bottom tanks, due to metacentric height variation [8].

Merely, the containers stowage on deck only can cause seriously problem. One cause of this condition is that a ship has less stable [9]. Also, this condition is presumed that the centre of gravity point (CoG) is above deck or high distance between keel to gravity centre point (KG) and then it can cause the GZ becomes small and the stability range is also small.

In this present study, the intact stability of the container ship due to containers stowage on deck has been analyzed by using Maxsurf stability application [10]. Several weight conditions have been simulated in order to distinguish the impact of the weight on stability parameters KG, GZ, vanishing stability angle, and stability range. The stability parameters that were obtained have been verified using the requirement of the Intact Stability Code [11]. Also, the KG on each ship mass due to weight condition has been analyzed by comparing with the limiting KG.

2. Methods

The intact stability of the container ship in several weight conditions due to containers stowage on deck was analyzed by using the Maxsurf Stability [10]. The main dimensions of the container ship are provided in Table 1 and the body plan is shown in Figure 1. Here, the influence of weight condition on righting lever (GZ) was investigated, therefore, the weight conditions of the container ship were considered into twelve cases (C1 to C12) and each weight condition is described as shown in Table 2. These weight conditions are almost experienced by a container ship in actual sea condition. In addition, these weight condition cause trim condition. The weight of the ship container consists of two components as given:

$$W = LWT + DWT \tag{1}$$

$$LWT = W_{st} + W_{eng} + W_{oe} \tag{2}$$

W is total weight of ship, LWT is light weight of ship, DWT is dead weight ton of ship, W_{st} is construction weight, W_{eng} is the weight of machinery installation, and W_{oe} is the weight of equipment and outfitting. The weight of the container ship was calculated by component per component which is obtained from the collected data. In addition, the vertical gravity centre point from keel (KG) of the container ship in light weight condition was obtained from the inclining test. Then, it is as initial KG that is used for analysing the intact stability due to the change of KG caused by the weight conditions.

The hydrostatic parameters of the container ship were investigated in order to describe the position of the centre of gravity point (G) caused by weight condition. Then, the change of the position of centre gravity of gravity point in longitudinal direction (LCG) impacts on trim condition. Therefore, the limiting KG was calculated by using Maxsurf Stability [10] and the combined KG and weight condition was analyzed associated with Intact Stability Code [11]. Then, the limiting KG was compared with the KG of each weight condition.

Moreover, the GZ curve of each weight condition in increasing the heeling degree was made and then the stability parameters for each weight condition were verified using the requirement set by the International Maritime Organization (IMO) namely Intact Stability Code [11].

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Table 1. The main dimensions of the container ship

Length Over All (LOA)	74.05 m
Length Between Perpendicular (LBP)	69.20 m
Breadth (B)	17.20 m
Depth (H)	4.90 m
Draft (T)	3.50 m

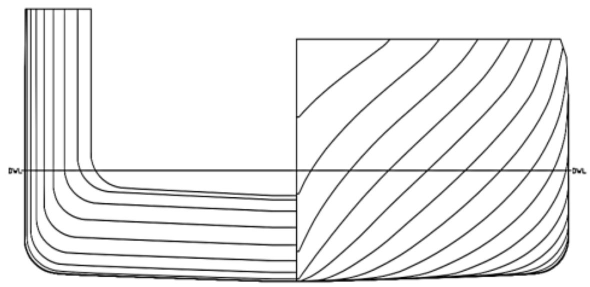

Figure 1. Body plan of the container ship

Table 2. The description of the weight condition

Case	Description
C1	Full Loaded condition
C2	Payload 100% and consumable 50%
C3	Payload 100% and consumable 10%
C4	Full loaded container in tier 82 and 84, and consumable 100%
C5	Full loaded container in tier 82 and 84, and consumable 50%
C6	Full loaded container in tier 82 and 84, and consumable 10%
C7	Full loaded container in tier 82 only and consumable 100%
C8	Full loaded container in tier 82 only and consumable 50%
C9	Full loaded container in tier 82 only and consumable 10%
C10	Consumable 100% with full water ballast
C11	Consumable 50% with full water ballast
C12	Consumable 10% with full water ballast

3. Results and Discussion

The intact stability of the container ship due to containers stowage on deck was analyzed successfully using Maxsurf Stability and then the results are discussed accordingly. For the weight calculation by referring the empirical formula 1 and 2, the light weight of the container ship was obtained approximately 1313.930 ton and the KG is obtained approximately 4.642 m. Figures 2 to 5 show the weight arrangement based on the case of weight condition (C1 to C12).

3.1. The effect of weight condition on KG and LCG

The weight, KG, and longitudinal center of gravity (LCG) of each condition were obtained as shown in Table 3. The LCG is measured from after peak to centre of gravity point. For grouping the weight condition, the cases of C1, C2, and C3 are the same full pay load condition and these are small different in comsumable weight. The cases of C4, C5, and C6 are the same full loaded container in tier 82 and 84 and their different are in in comsumable weight. The cases of C7, C8, and C9 are the same full loaded container in tier 82 only their different are in in comsumable weight. Also, the cases of C10, C11, and C12 are the same unloaded condition and full water ballast wherein their different are in in comsumable weight. Based on these grouped cases, Figures 6 to 7 show the weight related to KG and LCG. The KG and LCG decrease in decreasing the consumable weight. In overall case, the position of center of gravity point is behind amidship and the decrease of LCG due to the decrease of comsumable weight ≥ 50% is average 2.06%. The effect of the decrease of comsumable weight ≥ 50% can make stern trim condition (C3, C5, C6, C8, C9, C11, and C12).

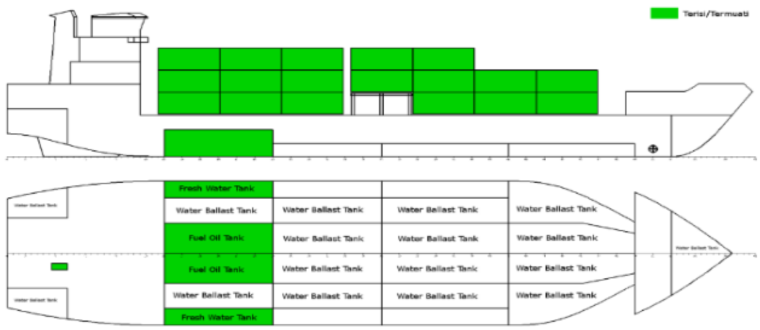

Figure 2. Condition 1, 2, and 3

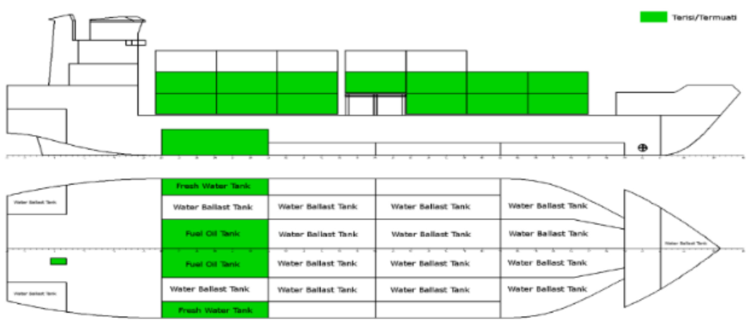

Figure 3. Condition 4, 5, and 6

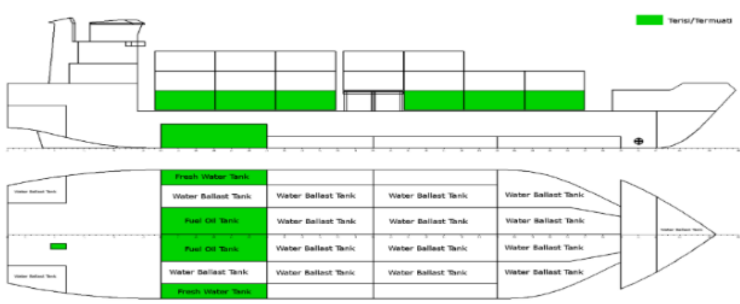

Figure 4. Condition 7, 8, and 9

Figure 5. Condition 10, 11, and 12

Table 3. The weight, KG, and LCG of each case

Case	Weight (ton)	KG (m)	LCG (m)
C1	3324,929	6,077	29,719
C2	3146,267	6,312	30,323
C3	3003,337	6,561	30,857
C4	2940,723	3,454	29,686
C5	2762,061	3,553	30,371
C6	2619,131	3,688	30,987
C7	2673,449	4,988	29,43
C8	2494,787	5,208	30,17
C9	2351,857	5,458	30,843
C10	3324,985	5,735	30,535
C11	3146,323	5,951	31,185
C12	3003,393	6,183	31,76

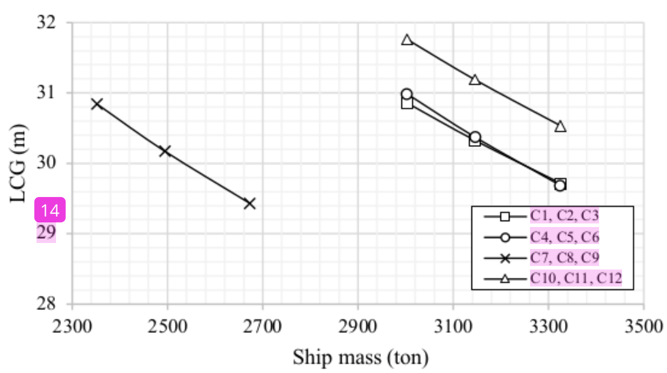

Figure 6. The ship mass related to LCG due to weight condition

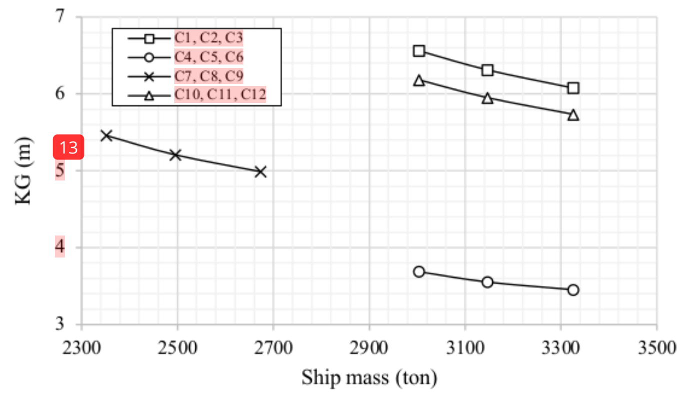

Figure 7. The ship weight mass related to KG due to weight condition

Meanwhile, the center of gravity point of each weight condition is vertically above water level and three grouped weight conditions has the center of gravity point above deck (Figure.7). The vertical position of the centre of gravity point (KG) affects on the value of GZ and then this is dicussed in intact satbility analysis as well the KG of each case related to the limiting KG is discussed in next section.

3.2. Intact Stability Analysis

The righting lever (GZ) on each heeling angle for every weight condition is provided in Table 4, Figures 8 to 11 show GZ curve of each weight condition in increasing the heeling angle.

Table 4. The GZ value in increasing the heeling angle for each weigth condition

Angle / Case	Righting arm (GZ) in meter									
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
C1	0.00	0.60	1.19	1.23	0.89	0.32	-0.36	-1.06	-1.76	-2.41
C2	0.00	0.62	1.22	1.24	0.85	0.24	-0.47	-1.22	-1.96	-2.64
C3	0.00	0.62	1.23	1.21	0.79	0.14	-0.62	-1.41	-2.17	-2.89
C4	0.00	0.66	1.30	1.40	1.11	0.58	-0.06	-0.74	-1.42	-2.07
C5	0.00	0.68	1.34	1.42	1.09	0.52	-0.16	-0.88	-1.60	-2.28
C6	0.00	0.68	1.36	1.40	1.03	0.43	-0.29	-1.05	-1.80	-2.51
C7	0.00	1.01	1.98	2.22	2.00	1.53	0.90	0.19	-0.56	-1.31
C8	0.00	1.06	2.01	2.24	1.97	1.46	0.80	0.04	-0.75	-1.53
C9	0.00	1.09	2.02	2.21	1.89	1.35	0.65	-0.14	-0.97	-1.78
C10	0.00	1.18	2.33	2.81	2.82	2.55	2.10	1.54	0.90	0.22
C11	0.00	1.23	2.41	2.88	2.87	2.58	2.10	1.51	0.84	0.12
C12	0.00	1.26	2.45	2.91	2.87	2.56	2.06	1.43	0.73	-0.01

Based on those figures, the high KG affected by the weight condition results the small angle of vanishing stability as well small GZ maximum. The maximum GZ of the C2 approximately 1.304 m is higher than C1 and C3 and the difference of the maximum GZ is average 1.18%. Also, the maximum GZ is on the same heeling angle 25 degrees. For the comparison between C4, C5, and C6, the maximum GZ is on the same heeling angle 25 degrees and then the maximum GZ of the C6 is higher than C4 and C5 wherein the difference is given an average 1.54%. The maximum GZ of the C8 is higher than C7 and C9 and the difference is average 0.78%. The maximum GZ of the C7 and C8 is on the same heeling angle 30 degrees whereas the maximum GZ of the C9 is at 25 degrees. Moreover, the maximum GZ of the C12 is higher than C10 and C11 and then the difference is obtained on average 1.54% wherein these are on the same heeling angle 35 degrees. Therefore, the small angle of vanishing stability implies on range of stability and then the decrease of KG can make a ship in a vulnerable condition.

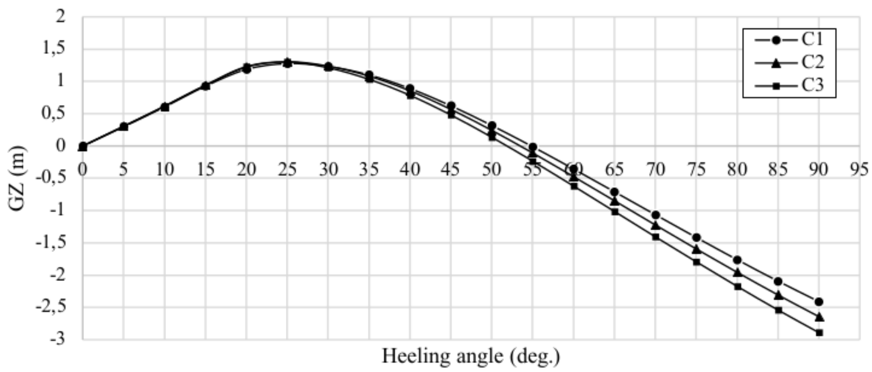

Figure 8. The GZ curve of C1, C2, C3

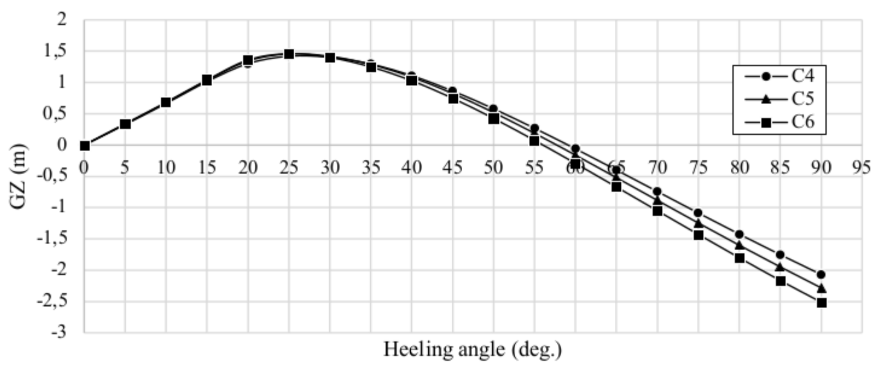

Figure 9. The GZ curve of C4, C5, C6

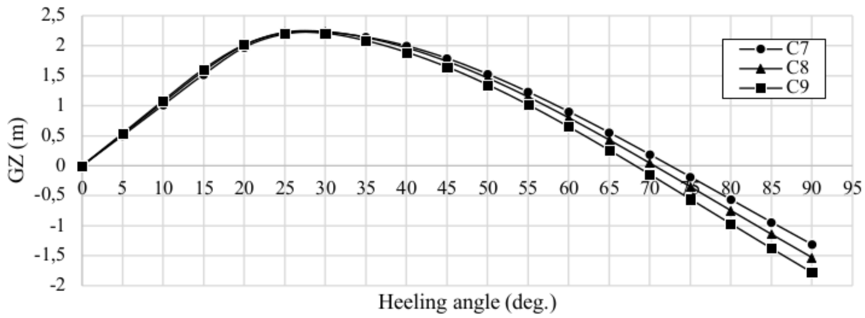

Figure 10. The GZ curve of C7, C8, C9

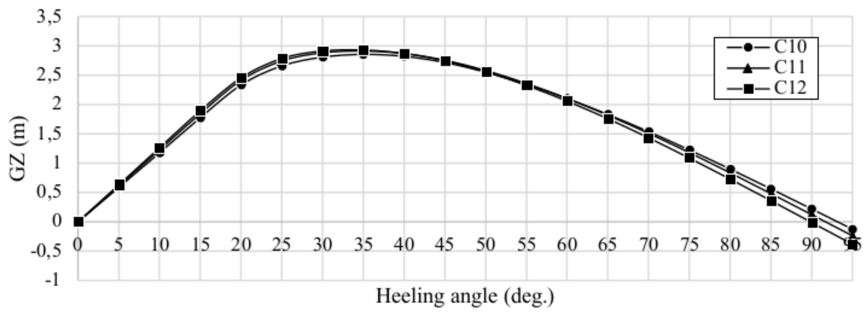

Figure 11. The GZ curve of C10, C11, C12

The GZ of the grouped weight condition C1, C2, C3 is greatest. Similarly, the KG due to the weight condition C1, C2, C3 is also greatest. This means the greater KG results the greater GZ as well the range of stability becomes large.

The stability parameters for overall weight conditions (C1 to C12) were verified and the overall stability parameters fulfil the requirement of Intact Stability Code. The ratio of B/T of the container ship is 4.9 and this value is greater than 2.5. For this reason, the additional criteria provided on Explanatory Notes to the International Code on Intact Stability 2008 are needed and then the stability parameters are greater than the criteria value. This means the overall stability parameters fulfill also the requirement of the Explanatory Notes to the International Code on Intact Stability 2008.

3.3. The analysis of KG related to the limiting KG

The KG on each ship mass due to weight condition was analyzed by comparing with the limiting KG as shown in Figure.12. The maximum KG on each ship's mass condition was analyzed from 1314 tons to 3325 tons. As a resulted, the maximum KG (limiting KG) on each ship mass condition which meets the stability criterion was obtained as shown in Figure.12

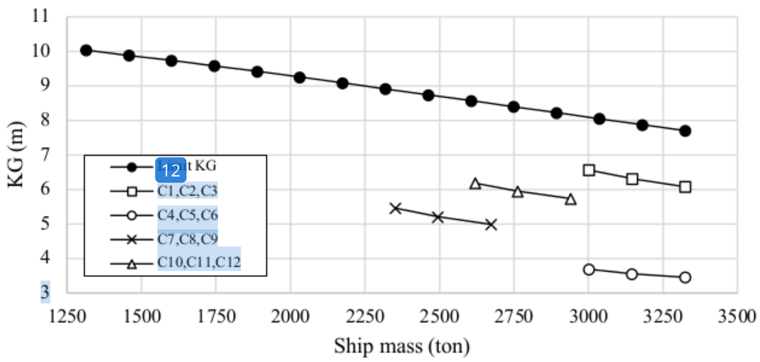

Figure 12. Limiting KG due to ship mass

The limiting KG tends to decrease in increasing the ship mass. Nevertheless, overall KG values due to the weight condition (C1 to C12) are significantly lower than the limiting KG. This means that overall KG due to weight conditions fulfill the stability criterion.

Conclusions

The effect of the weight condition on KG and LCG, intact stability, and limiting KG of the container ship due to containers stowage on deck was analyzed successfully using Maxsurf Stability and then several interpretations are concluded accordingly.

The weight condition affects on the magnitude of KG and LCG. The containers stowage on deck impacts on reducing the KG as well the magnitude GZ becomes small. In addition, the vanishing stability and stability range become small. Nevertheless, the stability parameters due to the containers stowage on deck fuilfil the requirement of Intact Stability Code. However, the increase of the container tier numbers on deck can make the container ship in vulnerable condition. Moreover, the containers stowage on deck can make the container ship that has not in trim condition. The KG of the container ship due to containers stowage on deck is lower than the limiting KG. Therefore, this condition also fulfil the stability criterion.

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