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Floodable length analysis of a container vessel using computer aided design

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Abstract

The floodability of a container vessel is investigated to determine the maximum volume of compartments that can be flooded without causing the container vessel to capsize. In this project, Maxsurf modeler was used for the hull design and Maxsurf stability enterprise for the floodable length analysis of a container vessel at several displacements, number of transverse water tight bulkheads and its positions from AP to FP and a constant permeability value for the compartments. Floodable length is the preliminary check on damage survival. It is used at the initial concept design phase because it is faster than a full damage stability analysis, it checks if the vessel has sufficient buoyancy to sustain damage and stop from sinking straight to the bottom. Maxsurf Enterprise marine design software is used to determine the results. The output of the analysis shows a floodable length curve and the curves that represent different displacements, if a displacement line is below the allowable floodable length of a compartment then the vessel will not survive damages but if the line is above the allowable floodable length then the vessel will survive damages. The result also shows that it is easier for the vessel to survive heavily loaded conditions with more compartments.

Keywords: Floodable Length; MAXSURF; Container vessel; CAD; Damage Stability

1. Introduction

The container ship is vessel structured specifically to hold huge quantities of cargo compacted in different types of containers. One of the most potent methods of transporting goods is done by container ships. These ships have made it convenient to transfer high quantities of cargo at a time and have changed the global trade efficaciously. Container ships are the cargo ships that carry most sea going non bulk cargoes. In today's world, container vessels carry around 90% of the world's non bulk cargoes; one of the main ways of carrying goods worldwide is through container vessels and because of how important the container ship is to the world's economy it is important to prevent flooding and sinking of the vessel while at sea [1], [2].

Flooding is the result of water ingress onboard and can affect the watertight integrity and the stability of the vessel Flooding control is really important, 50% of vessels lost at sea sink because of uncontrollable /uncontrolled flooding. Floodable length is an approach to calculating the damage stability of any ship and it is used by ship designers. Floodable length is the length of the compartment which if flooded will cause the ship to sink up to the margin line. The floodable length is usually paired with factor of subdivision. If a ship is damaged, water will come in, it will flood but water is restricted due to the watertight bulkheads and bulkhead decks, to calculate how many watertight bulkheads are needed in a ship the floodable length is used [3], [4].

A floodable length analysis is done at the beginning of concept design, to determine the beginnings of vessel compartmentation. The vessel is carefully divided to consider damage stability. Each ship has its own unique floodable length and most are designed such that the spacing of bulkheads will allow two adjacent watertight compartments to be flooded without submerging the margin line and endangering the ship. The sinking of vessels due to insufficient

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compartments (watertight bulkheads) in the ship's hull is caused when large compartments are flooded, and there is no enough buoyancy available to keep the vessel afloat, then the ship may sink. The aim of the study is to use computer aided design (CAD) to analyze a container ship's floodable length. This will enable us fulfil several objective; to know the maximum length of the vessel that can be flooded and still allow the vessel to pass stability criteria test; the typical stability criteria we use are an equilibrium criteria such as margin line emission, to ensure the vessel can pass criteria at both a lightly loaded and heavily loaded condition at several displacements and to define the proposed location of bulkheads so as to see how the length between bulkheads compares with the allowable floodable length at each point along the vessel. Similarly, to amplify knowledge of methods of hull analysis using computer tools to increase the accuracy and decrease the time expenditure required to rapidly access the preliminary floodable length of the hull design [5], [6], [7]

A ship's construction is said to be "floodable" if it is susceptible to floods. The ability to intentionally flood specific areas of the hull for damage control purposes or to increase stability is also mentioned. This is crucial for combat vessels because they frequently risk serious hull breaches as a result of enemy action and depend on skilled damage control personnel to equalize and then stop flooding of the hull. Floodability is decreased by using a double bottom (or double hull), separating the capacity of the hull into watertight compartments with decks and bulkheads (which also increase the strength of ships), and other techniques. Any flooding caused by a hull breach can be contained in the compartments where the flooding occurs if a ship's hull is separated into watertight compartments. The watertight compartments are typically equipped with an automatic door system that can be activated locally or remotely as soon as flooding is detected. Watertight hatches between compartments are a common feature of smaller boats and submarines; these hatches are manually closed to prevent water from escaping the flooded compartment. A ship may be able to maintain enough buoyancy to stay afloat as long as the flooding is localized, but if many compartments are left open to the water, the ship will still likely sink. If a ship has longitudinal bulkheads (going fore and aft) in addition to transverse bulkheads, flooding one of the sides of the ship might seriously list the ship and make it potentially capsize. Damage control personnel can then purposefully flood the matching compartment on the opposite side to balance the list in these circumstances [8],[9],[10],[11],[12].

The term damage stability deals with the ability of a ship to float in water and regain its upright equilibrium position when some sort of structural damage has occurred. Generally, following an accident, the damage is hull fracture leading to flooding of ship compartments. If so many compartments are flooded that there is not enough buoyancy available to keep the vessel afloat, the ship may sink. Prior to the development of digital computers, the floodable length curve procedure could not be repeated since it was time-consuming. To give you an idea, manually calculating floods for a single compartment combination could take three hours. Because most Naval Architects used slide rules, adding machines, and planimeters, the calculations were rarely strictly manual. However, accelerating the task was not feasible. Naval architects created ingenious, incredibly elegant techniques to boost efficiency; one of them creates the curve of floodable lengths as shown in figure 1 [13],[14],[15],[16]

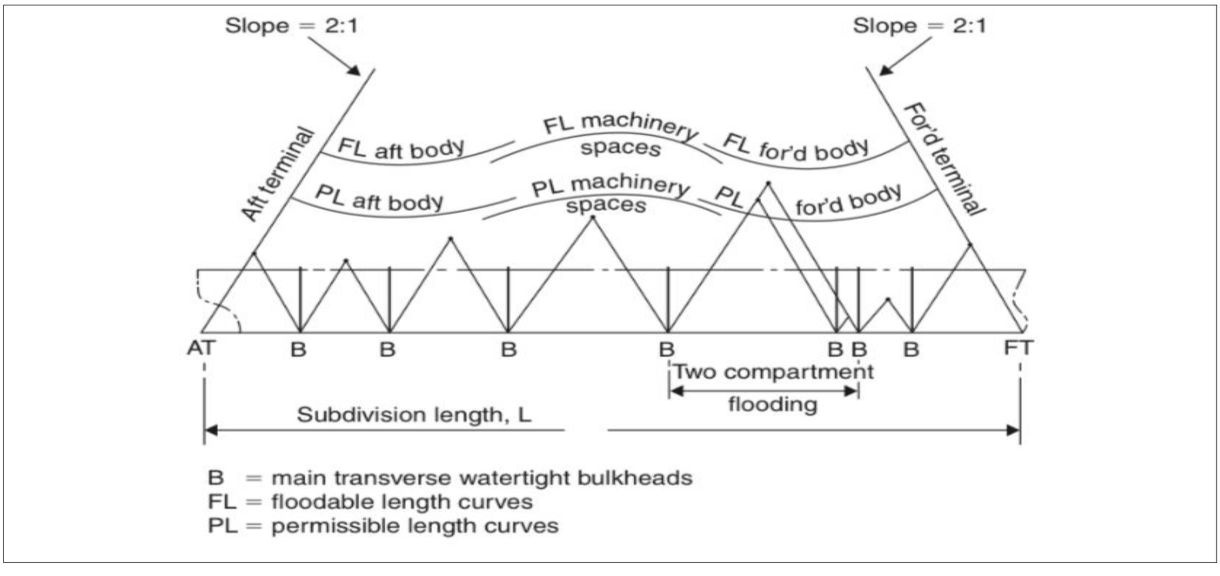

Figure 1 Floodable length curve [17]

The concept behind constructing the floodable length curve of the vessel is that a ship should not sink if any compartment is breached and flooded. Since flooding of the midship compartments is accompanied by parallel sinkage while flooding of the end compartments is accompanied by sinkage and trim, which increases the likelihood that the waterline will touch the vessel's margin line, the floodable length is near the midship area than it is at the ends. As a result, the floodable length changes throughout the length of the ship, and its variation is determined by vertically charting the floodable length along the length of the ship. Additionally, the permeabilities of each compartment affect how much of the ship can flood throughout its length. The permeabilities of each compartment affects the length of the ship that is floodable along its length. If the compartments are more permeable, more water will enter them in the event of a hull breach, which will reduce the floodable length at that location along the ship's length. [18],[19], [20].

2. Material and methods

The model is designed using MAXSURF software. MAXSURF is a naval architecture software ideal for the design of marine vessels. MAXSURF includes capabilities for hull modeling, stability, motions and resistance prediction, structural modeling, structural analysis and export to vessel detailing. MAXSURF operates from a single parametric 3D model in order to ensure smooth communication and coordination across variable involved in the project. Once a design has been modeled using Modeler, its stability and strength characteristics can be assessed during the stability analysis module. Stability provides the MAXSURF user with a range of powerful analysis capabilities to handle all types of stability and strength calculations [21].

The design analysis of this vessel starts with the purpose and choice of the vessel to be designed. The first step in conceptualizing this work’s goal, which is to determine the floodable length analysis of a container vessel, is to choose an existing container vessel with cited parameters. The specifications of the vessel were obtained from a vessel that flooded in 2013 as shown in Table 1. Knowing some parameters such as the length, breath, draught and form coefficient of the existing vessel can be used to determine any vessel’s dimensions using repetitive approach method the new vessel’s dimension can then be replicated by a small increase or decrease in size [22]

Table 1 Ship parameters [23]

Name of vessel	**EMMA MÆRSK**
Type of vessel	Container ship
Year built	2005
Length overall	397.71 m
Breath overall	56.40 m
Gross tonnage	170,794
Dead weight	156, 907 t
Draught max	16.02 m
Engine rating	80,080 kW at 102 RPM
Service speed	24.50 knots
Hull material	Steel

2.1. Determining the floodable length curve

The basic feature that affects the floodable length curves for a ship is the block coefficient, sheer ratio, freeboard ration and permeability

$$\text{Block co-efficient} = \frac{Moulded\ displacement}{L \times B \times d} \quad \text{.....................(1)}$$

$$\text{Sheer ratio} = \frac{Sheer\ aft\ or\ forward}{d} \quad \text{.....................(2)}$$

$$\text{Freeboard ratio} = \frac{Freeboard\ to\ margine\ line\ @\ midship}{d} \quad \text{.....................(3)}$$

$$\text{Permeability}= vol\ of\ compartment \times 100 \quad \text{……….(4)}$$

2.2. Floodable length calculations

Let's say we calculate the volume of a compartment from its dimensions and we obtain the value, v, and usually the volume of the compartments cannot be fully flooded because there are almost always objects in the compartments and if we subtract the volume of these objects from the volume, v, we obtain the volume of the water that can flood the compartment, let it be v_f

$$\text{The ratio } \mu = \frac{v_f}{v} \quad \text{………………(5)}$$

Where μ is the Permeability

2.2.1. Damage Stability Regulations According To SOLAS

Regulation 5 of the SOLAS convention shows how to calculate the permeabilities to be considered in the calculations and permeability is usually in percentage

$$85 + 10\left(\frac{a-c}{v}\right) \text{……………….(6)}$$

Where a is the volume of passenger spaces under the margin line within the limits of the machinery space.

c is the volume of between deck spaces, v is the volume of the machinery space below the margin line

The percent permeability of spaces forward or abaft of the machinery space is

$$\mu=63 + 35\frac{a}{v} \text{…………..(7)}$$

Where a is volume of passenger spaces under the margin line in the respective zone and v is the whole volume under the margin line in the same zone.

Then the maximum permissible length of a compartment having its center at a given point of the ship's length is gotten from the floodable length by multiplying the floodable length by an appropriate number called the factor of subdivision. For example, a factor of subdivision equal to 1 means that the margin line should not submerge, if one compartment of submerged, while a factor of subdivision equal to 0.5 means that the margin line should not submerge when two compartments are flooded.

Regulation 6 of the convention shows how to calculate factor of subdivision as a function of the ship's length and nature of the ship's service. First SOLAS defines the factor, A, is applicable for ships primarily engaged in cargo transportation

$$A = \frac{58.2}{L-60} + 0.18 \quad \text{……………….(8)}$$

For L=131, A = 1

Then factor, B, is applicable for ships primarily engaged in passenger transportation

$$B = \frac{30.3}{L-42} + 0.18 \quad \text{…………………(9)}$$

For L = 79, B = 1.

A is criterion of service numeral,

Cs, is calculated as function of the ship length

L is the volume of machinery and bunker spaces

M is the volume of passenger spaces below the margin line, P is the number of passengers for which the ship is certified, N, and the whole volume of the ship below the margin line, V.

There are two formulas for calculating Cs; their choice depends upon the product

P_1 = KN, where K = 0.056L.

If P_1 is greater than P,

$$\text{Then } C_S = 72 - \frac{M+2P_1}{v+P_1-P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

But if P_1 is less than P then we have

$$C_S = 72 - \frac{M+2P}{V} \quad \ldots\ldots\ldots\ldots\ldots(11)$$

For ships of length 131 m and above, having a criterion numeral C_S<23 the subdivision abaft the forepeak is governed by the factor A if C_S> 23

The Hull Model and the Analysis Using MAXSURF

Using the principal parameters from table 1 and Maxsurf modeler, I was able to design the container vessel with the aid of the control points in the software to manipulate the shape of the vessel to get the desired results. The design of the vessel and lines drawings will be shown in the results and discussions.

To run the analysis using Maxsurf stability enterprise a desired number of transverse watertight bulkheads and bulkhead spacing in meters is required and a range of displacement in tonnes. It is important to note the parameters of the vessel before attempting to include the transverse watertight bulkhead positions.

In the simplest form, the input can consist of offsets, bulkhead positions and compartment permeabilities. Then, it is possible to check in a few seconds what happens when certain compartment combinations are flooded. If the results do not meet the criteria relevant to the project, we can change the positions of bulkheads and run flooding and damage stability calculations for the newly defined subdivision. Before the advent of digital computers, the above procedure took a lot of time; therefore, it could not be repeated many times. Just to give an idea, manual flooding calculations for one compartment combination could take something like three hours. Usually, the calculations were not purely manual because most Naval Architects used slide rules, adding machines and plan meters. Still it was not possible to speed up much of the work to improve efficiency [5].

3. Results and discussion

3.1. The Lines Drawing

This is the graphical representation of the hull in the form of lines from the cited parameters in table 1. The hull's shape is depicted in the lines drawing by three separate views: the profile plan, the body plan, and the plan (or half breadth plan).

3.2. The Body Plan View

On a grid, the cross sections are arranged. The cross sections of the hull's forward and middle portions are shown on the right side. The cross sections of the hull's aft section and forward to middle are shown on the left side. Now look at the grid's horizontal lines. The base line is the final result. The base line will be visible on the profile plan. All vertical measurements are collected along this line. Other horizontal lines with equal spacing are visible above that. These are the waterlines that we observed in both the profile plan and the half breadth as straight and curved lines. Notable are the vertical lines as well. The centerline, which we observed in the half breadth, is the one from which all horizontal measurements are obtained. Vertical lines are evenly spaced out from the centerline. These are the buttock lines that we could make out in the profile plan as both curved and straight lines. Curved lines that go along the cross sections will also show you the deck's and the railing's lines shown on figure 2.

3.3. The Plan (Half Breadth) View

There is a central line along which all horizontal measurements are made. A number of curved lines radiate from the centerline. The only difference is that we can now observe the waterlines from the bottom up rather than from the side, just as we did with the profile plan view. Some straight lines that are positioned evenly spaced outside the centerline of the half breadth are also present. The buttock lines visible in the sheer profile are the same ones that are shown here as curving lines. The deck and railing lines will also appear as curved lines in the half-breadth, resembling waterlines. In the upper part of the hull, these are crucial for creating the cross-section shapes shown on figure 3.

3.4. The Profile Plan View

Figure 4 shows the hull's overall outline is seen in this side shot, but there are other significant architectural lines to discuss. There are the waterlines, which run horizontally along the hull and should not be confused with the load waterline of the hull. These are sometimes referred to as lift lines or level lines, depending on whether the model has a solid hull. Then there are several curving lines known as buttock lines that run the length of the hull. The secret to a drawing like this is that these lines are present in all three of them; they only seem differently due to the various drawing elements in each.

3.5. The model of the container vessel

Figure 5 shows the profile plan view of the 3D model which was gotten from the lines plan. Using Maxsurf modeler

3.6. Analysis output for heavily and lightly loaded conditions

Table 2 and 3 show the Floodable length table for condition 1 and 2 respectively, the table is a representation of the floodable length curve showing the range of displacement used, LCG value, permeability values and the floodable length at different stations in the vessel.

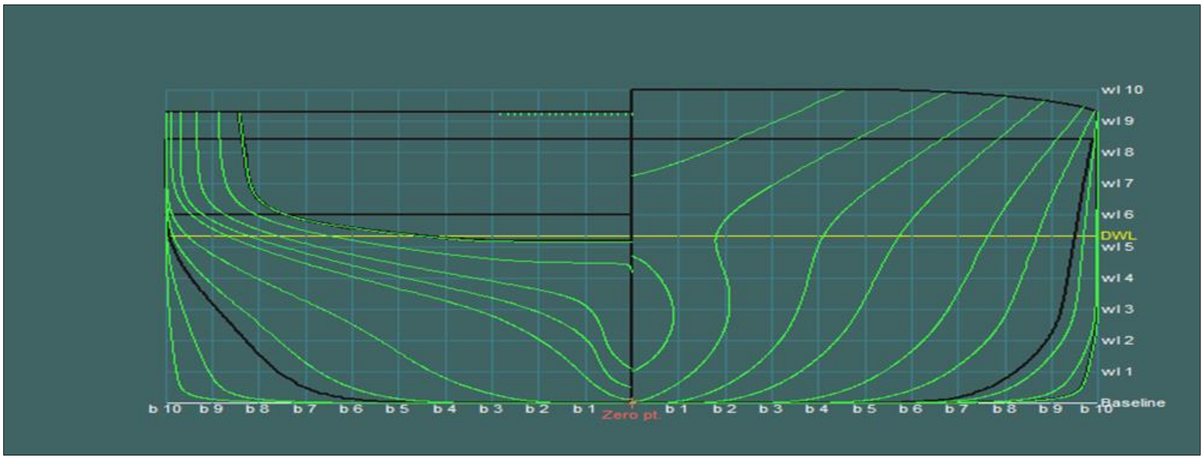

Figure 2 Body plan of the lines drawing

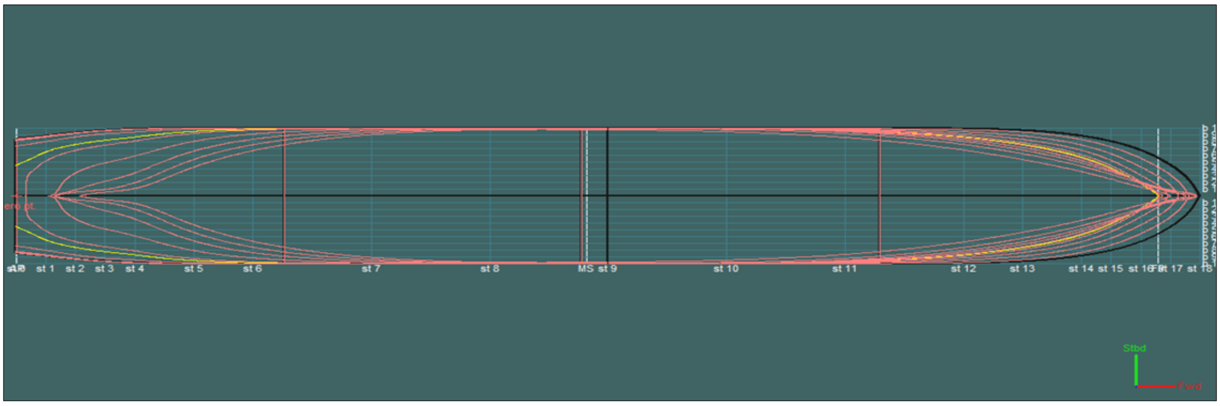

Figure 3 Half breathe plan of the lines drawing

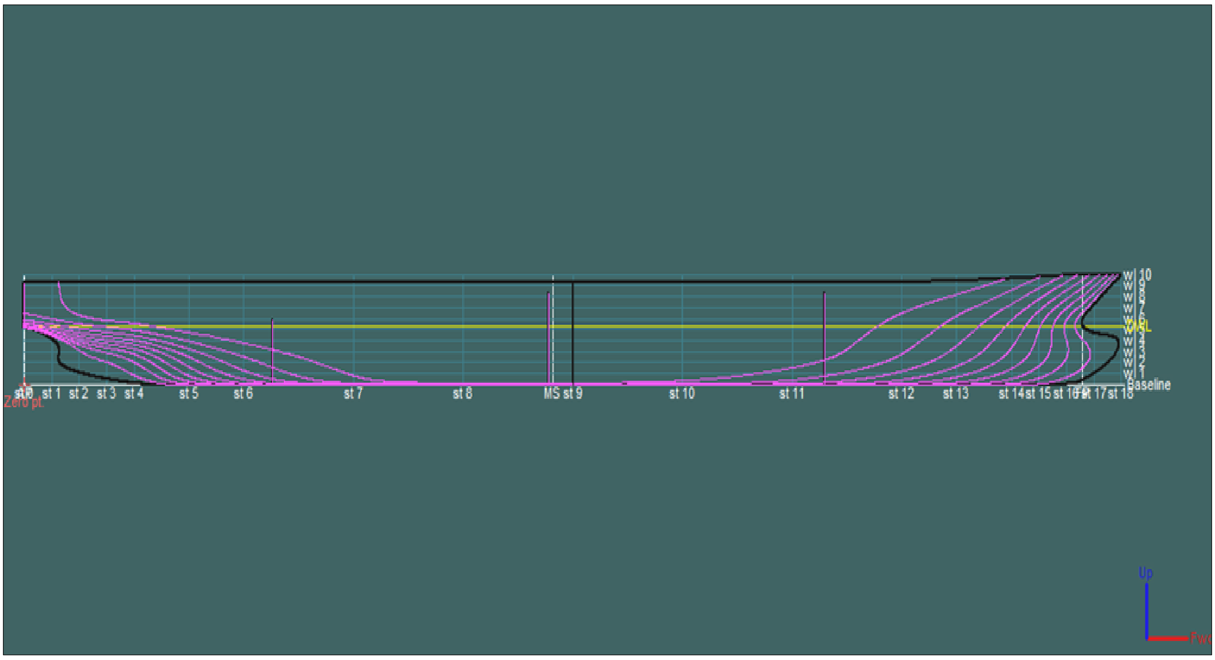

Figure 4 Profile plan of the lines drawing

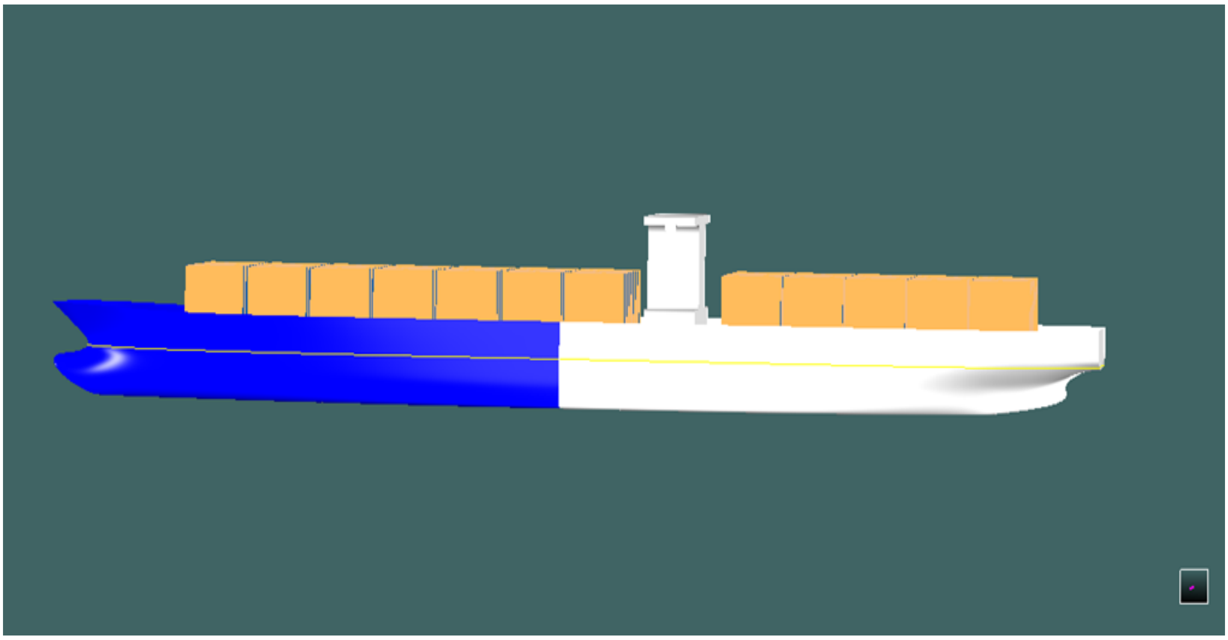

Figure 5 The profile view of the 3D model

3.7. Analysis output for heavily and lightly loaded conditions

Table 2 and 3 show the Floodable length table for condition 1 and 2 respectively, the table is a representation of the floodable length curve showing the range of displacement used, LCG value, permeability values and the floodable length at different stations in the vessel.

Table 2 Floodable length table for condition 1

Name	**Long. Pos. m**	**Flood. Len m**	**Flood. Len m**	**Flood. Len m**
Displacement t		180000	215000	250000
LCG m		202.509	201.168	199.446
Permeability %		100	100	100
st 0	0.000	0.92	0.92	0.92
st 1	9.943	20.80	20.80	20.80
st 2	19.885	40.69	40.69	40.69
st 3	29.828	60.57	60.57	60.57
st 4	39.771	80.46	80.46	78.21
st 5	59.657	98.95	84.58	70.86
st 6	79.542	98.53	83.21	69.90
st 7	119.313	115.48	98.91	82.67
st 8	159.084	156.00	135.24	113.84
st 9	198.855	176.55	160.71	137.05
st 10	238.626	130.18	116.56	94.96
st 11	278.397	99.01	85.31	73.81
st 12	318.168	85.36	75.09	66.60
st 13	338.053	92.86	84.97	71.08
st 14	357.939	79.53	79.53	79.53
st 15	367.882	59.65	59.65	59.65
st 16	377.824	39.76	39.76	39.76
st 17	387.767	19.88	19.88	19.88
st 18	397.710	-0.01	-0.01	-0.01

Table 3 Floodable length table for condition 2

Name	**Long. Pos. m**	**Flood. Len m**	**Flood. Len m**	**Flood. Len M**
Displacement t		65000	82500	100000
LCG m		203.459	203.603	203.668
Permeability %		100	100	100
st 0	0.000	0.92	0.92	0.92
st 1	9.943	20.80	20.80	20.80
st 2	19.885	40.69	40.69	40.69
st 3	29.828	60.57	60.57	60.57
st 4	39.771	80.46	80.46	80.46

st 5	59.657	120.23	120.23	120.23
st 6	79.542	149.56	147.33	129.86
st 7	119.313	182.83	170.31	158.54
st 8	159.084	236.83	221.18	206.78
st 9	198.855	285.56	267.22	241.43
st 10	238.626	213.84	200.41	186.52
st 11	278.397	158.00	150.51	138.84
st 12	318.168	130.50	122.72	116.40
st 13	338.053	119.31	119.31	119.31
st 14	357.939	79.53	79.53	79.53
st 15	367.882	59.65	59.65	59.65
st 16	377.824	39.76	39.76	39.76
st 17	387.767	19.88	19.88	19.88
st 18	397.710	-0.01	-0.01	-0.01

The figures 6 and 7 show the Floodable length curves for condition 1 and 2. The modeled container vessel has 3 transverse watertight bulkheads at positions 100m, 200m and 310m from AP to FP and 4 compartments. All conditions are at 100% permeability, assuming no extra volume in either of the compartment for the running of this analysis. For the heavily loaded condition (condition 1). At displacements from Figure 6.

180000t: The vessel passed the stability criteria at all the bulkhead positions, which mean when flooded the vessel will not be damaged 210000t: At this displacement only the second and last compartment from the AP to FP passed the criteria and if each of the other compartments get flooded it will cause damage to the vessel 250000t: The second compartment passed the criteria, the last compartment barely passed and the other compartments did not pass the criterion, which means if flooded it will cause damage to the vessel. For the lightly loaded condition (condition 2). At displacements from Figure 7,

65000t, 82,500t, 100000t: At these displacements, if flooded all the compartments

will pass the criteria that means if any one of the compartments is flooded it will not cause damage to the ship or let it sink below the margin line.

3.8. Analysis output for mildly loaded condition

Table 4 shows the Floodable length table of condition 3, the table is a representation of the floodable length curve showing the range of displacement used, LCG value, permeability values and the floodable length at different stations in the vessel.

Table 4 Floodable length table for condition 3

Name	**Long. Pos. m**	**Flood. Len M**	**Flood. Len m**	**Flood. Len M**
Displacement t		100000	140000	180000
LCG m		203.668	203.426	202.509
Permeability %		100	100	100
st 0	0.000	0.92	0.92	0.92
st 1	9.943	20.80	20.80	20.80

st 2	19.885	40.69	40.69	40.69
st 3	29.828	60.57	60.57	60.57
st 4	39.771	80.46	80.46	80.46
st 5	59.657	120.23	116.77	98.95
st 6	79.542	129.86	116.08	98.53
st 7	119.313	158.54	136.20	115.48
st 8	159.084	206.78	181.14	156.00
st 9	198.855	241.43	227.33	176.55
st 10	238.626	186.52	155.89	130.18
st 11	278.397	138.84	115.93	99.01
st 12	318.168	116.40	101.28	85.36
st 13	338.053	119.31	111.81	92.86
st 14	357.939	79.53	79.53	79.53
st 15	367.882	59.65	59.65	59.65
st 16	377.824	39.76	39.76	39.76
st 17	387.767	19.88	19.88	19.88
st 18	397.710	-0.01	-0.01	-0.01

For the mildly loaded condition (condition 3) as shown in figure 8:

At displacements values 106000t, 140000t, 180000t: At these displacements, if any of the compartment's floods, it won't cause the ship any harm or cause it to sink below the margin line, hence each compartment will meet the criterion.

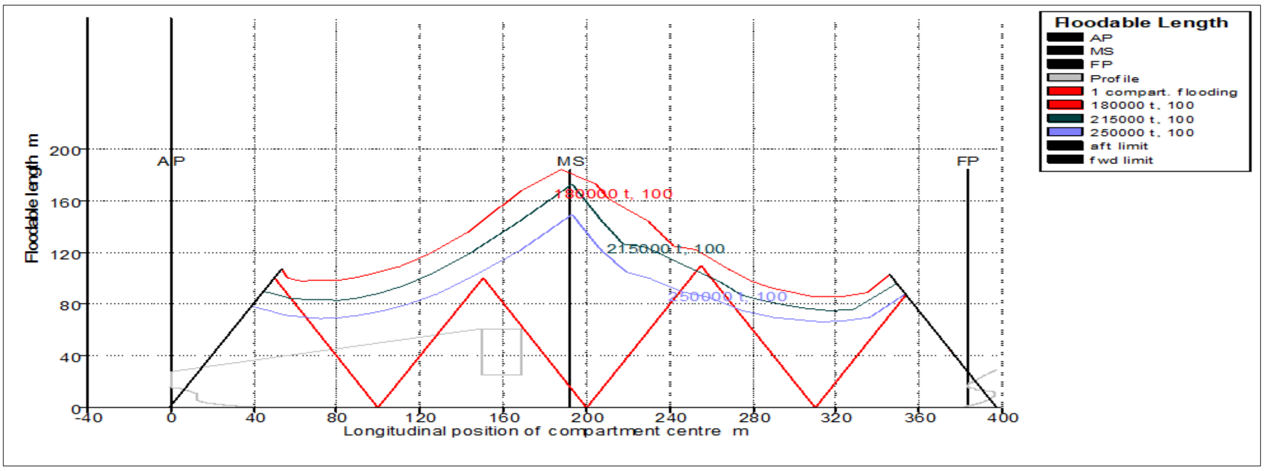

Figure 6 Floodable length curve for condition 1

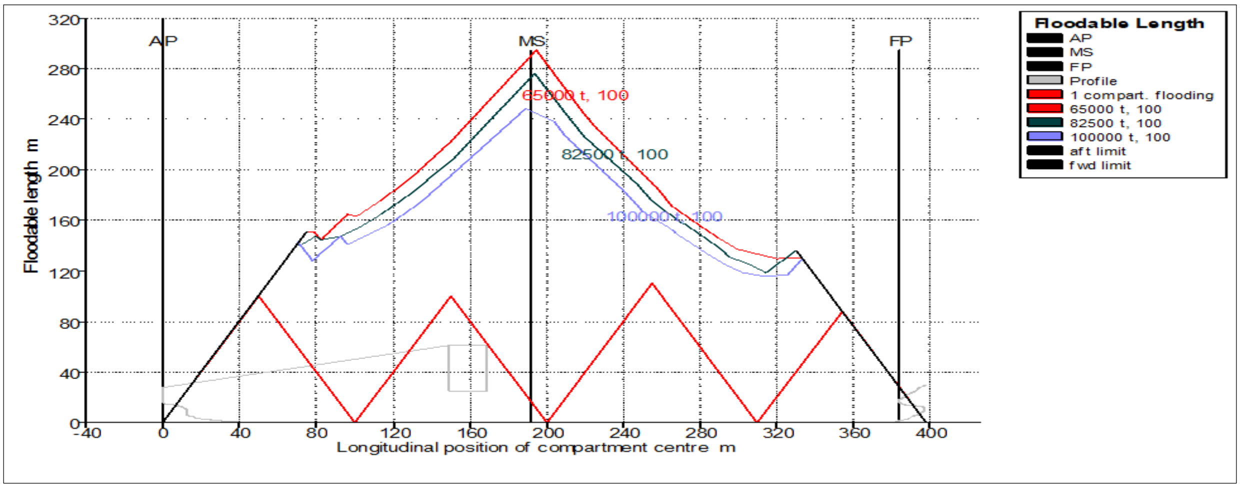

Figure 7 Floodable length curve for condition 2

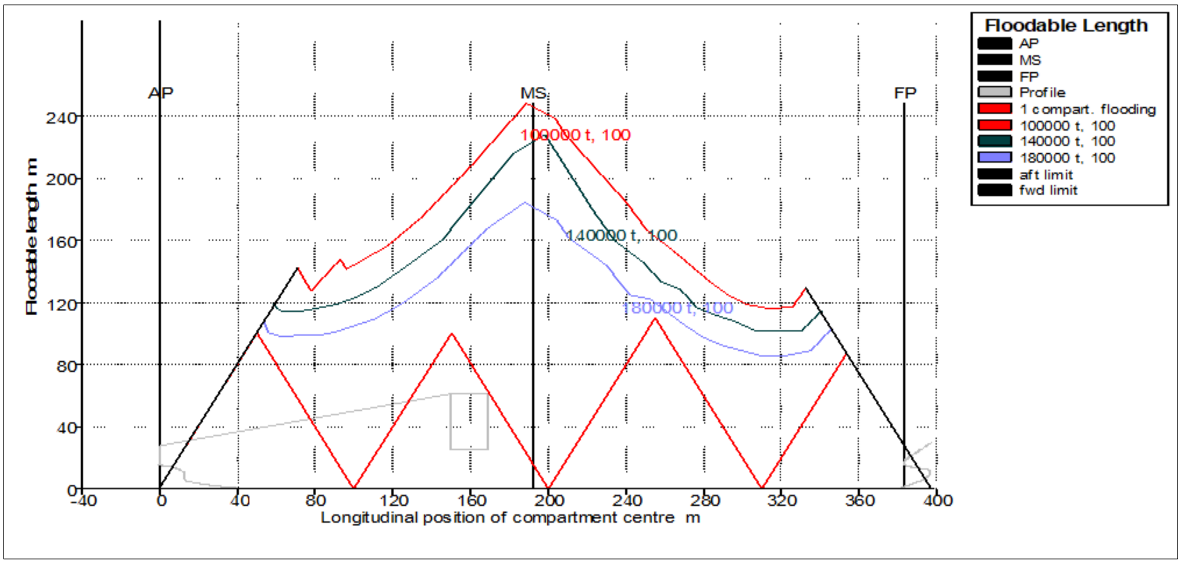

Figure 8 Floodable length curve for condition 3

3.9. Analysis output 2

3.9.1. Analysis output for heavily and lightly loaded conditions

Table 5 and 6 shows the Floodable length table for condition 4 and 5 respectively, the table is a representation of the floodable length curve showing the range of displacement used, LCG value, permeability values and the floodable length at different stations in the vessel.

Table 5 Floodable length table for condition 4

Name	**Long. Pos. m**	**Flood. Len m**	**Flood. Len m**	**Flood. Len m**
Displacement t		200000	250000	300000
LCG m		201.795	199.446	196.724
Permeability %		100	100	100
st 0	0.000	0.92	0.92	0.92

st 1	9.943	20.80	20.80	20.80
st 2	19.885	40.69	40.69	40.69
st 3	29.828	60.57	60.57	60.57
st 4	39.771	80.46	78.21	56.78
st 5	59.657	91.17	70.86	51.18
st 6	79.542	89.72	69.90	50.18
st 7	119.313	105.93	82.67	59.61
st 8	159.084	143.80	113.84	82.49
st 9	198.855	161.19	137.05	112.83
st 10	238.626	123.24	94.61	71.69
st 11	278.397	92.91	73.81	58.45
st 12	318.168	79.81	66.60	53.40
st 13	338.053	87.91	71.08	58.34
st 14	357.939	79.53	79.53	76.20
st 15	367.882	59.65	59.65	59.65
st 16	377.824	39.76	39.76	39.76
st 17	387.767	19.88	19.88	19.88
st 18	397.710	-0.01	-0.01	-0.01

Table 6 Floodable length table for condition 5

Name	**Long. Pos. m**	**Flood. Len M**	**Flood. Len m**	**Flood. Len m**	**Flood. Len m**	**Flood. Len m**
Displacement t		80000	105000	130000	155000	180000
LCG m		203.587	203.670	203.545	203.165	202.509
Permeability %		100	100	100	100	100
st 0	0.000	0.92	0.92	0.92	0.92	0.92
st 1	9.943	20.80	20.80	20.80	20.80	20.80
st 2	19.885	40.69	40.69	40.69	40.69	40.69
st 3	29.828	60.57	60.57	60.57	60.57	60.57
st 4	39.771	80.46	80.46	80.46	80.46	80.46
st 5	59.657	120.23	120.23	119.98	109.73	98.95
st 6	79.542	143.41	131.46	119.67	109.21	98.53
st 7	119.313	172.11	155.86	141.38	127.39	115.48
st 8	159.084	222.45	203.95	186.42	170.35	156.00
st 9	198.855	257.85	247.79	227.33	205.94	176.46
st 10	238.626	201.50	183.89	164.57	148.23	129.63
st 11	278.397	150.97	137.32	123.89	111.11	99.01
st 12	318.168	125.77	114.37	102.47	93.68	85.36

st 13	338.053	119.31	119.31	118.18	105.97	92.86
st 14	357.939	79.53	79.53	79.53	79.53	79.53
st 15	367.882	59.65	59.65	59.65	59.65	59.65
st 16	377.824	39.76	39.76	39.76	39.76	39.76
st 17	387.767	19.88	19.88	19.88	19.88	19.88
st 18	397.710	-0.01	-0.01	-0.01	-0.01	-0.01

Figures 9 and 10 show the modeled container vessel has 9 transverse watertight bulkheads at positions 25m, 52m, 91m, 120m, 154m, 200m, 230m, 280m and 340m from AP to FP and 10 compartments that will be flooded for the analysis. All conditions are at 100% permeability, assuming no extra volume in either of the compartment for the running of this analysis.

For the heavily loaded condition (condition 4): At displacements from Figure 9

200000t: All the compartments at this displacement passed the stability criteria and will not cause damage to the vessel if breached. 250000t: At this displacement if any compartment is breached it will not cause the vessel to sink.

300000t: If the 9th compartment gets flooded it will cause damage to the ship as it did not pass the criteria like the other compartments did.

For the lightly loaded condition (condition 5): At displacements from Figure 10

80000t, 105000t, 130000t, 155000t and 180000t: At these displacements, if flooded all the compartments will pass the criteria that means if any one of the compartments is flooded it will not cause damage to the ship or let it sink below the margin line.

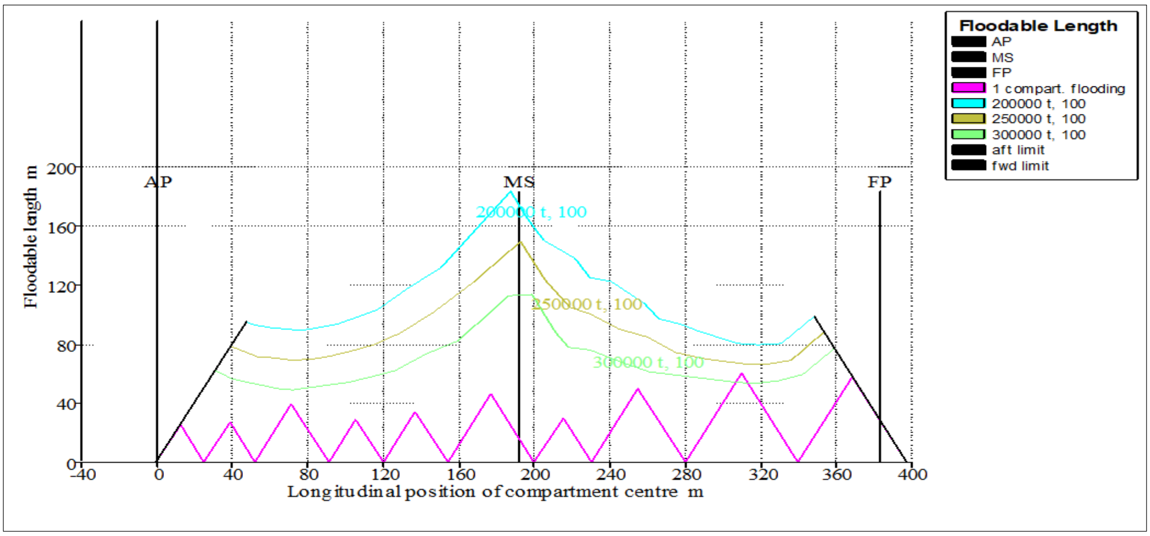

Figure 9 Floodable length curve for condition 4

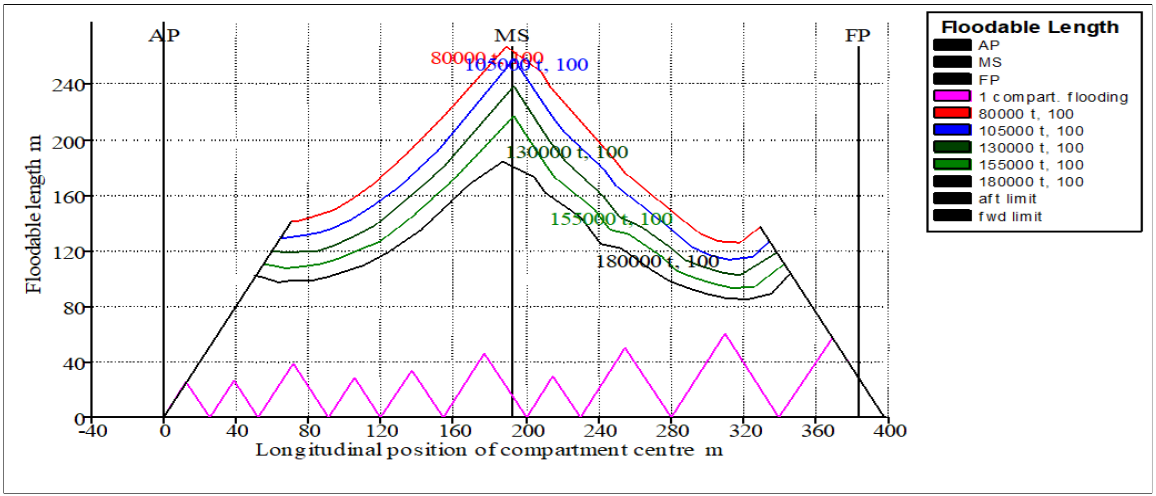

Figure 10 Floodable length curve for condition 5

4. Conclusion

When the ship's structural integrity is not properly inspected, it will not only endanger the environment, but also our lives, if not inspected. The ability of ships to withstand any damage incurred during their voyages on the open seas is crucial. Understanding the damage stability and what it entails for us is the first step in adhering to it. In conclusion the more the number of transverse watertight bulkhead the safer it is for the vessel but then again having too much transverse watertight bulkhead has its disadvantages for example it is not cost effective and the bulkheads take much spaces meant for other volumes in the vessel, that is why the analysis was done. From my results the compartments mainly passed the stability criteria at several loading conditions and will not cause damage to the vessel if said compartments are breached.

Compliance with ethical standards

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Disclosure of conflict of interest

There is conflict of interest amongst the authors.

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