

## MARPOL 25A: IS IT SAFETY OR ABSURDITY?

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### Abstract

This paper deals with the implementation and immediate impacts of MARPOL Regulation 25A which was adopted recently regarding the intact stability of tankers. Principally, the above-mentioned regulation considers the cargo density corresponding to the available cargo deadweight at the displacement at which transverse KM reaches a minimum assuming full departure consumables and 1% of the total ballast capacity. It further requires the maximum free surface moments in all ballast tanks. Although it is supposed to take into account the worst possible loading scenarios that a ship may encounter during service, it seems that it is far from being realistic, with unacceptable consequences. The regulation may appear to impose more stringent rules on tankers in terms of stability at the first glance. However, its thorough evaluation and application necessitate irrelevant complexity during the design, construction and operation, especially the need to have excessive GM values to satisfy the requirement. This translates into crew discomfort, sophisticated ballast piping and equipment, excessive motions, higher probability of cargo sloshing, and ultimately higher initial and operational costs without a true safety gain. There is a fine line between safety and absurdity. It is strongly believed that this current regulation steps beyond the acceptable safety margins and crosses the line. A few logical interpretations such as considering real free surface moments instead of maximum ones may rectify the drawbacks.

### 1. INTRODUCTION

The desire and relentless efforts to increase level of safety at sea have gained speed recently. Environmental concerns and awareness also added extra momentum to these efforts. Tremendous amount of research has been going on to find solutions to existing problems or to eliminate risk factors in ship stability and survivability. Tankers and passenger vessels are the prime target of these studies due to the nature of their payload. As a result, international institutions either update the existing rules and regulations or come up with new ones. In the past, issue of new regulations was extremely slow which might

have frustrated many researchers. However, the recent regulations, which are mostly produced as a response to incidents, are not well investigated and may result in the deterioration of true safety. Although it is relatively easier to comply with the new rules for new designs, they may have far-reaching consequences on safety, operability and profitability of the ship.

Safety is believed to be extremely important not only in ship design but also in our daily lives without any doubt. However, it should be optimized by taking into account other parameters within the system such as functionality, practicality and profitability. When the balance between these parameters is

destroyed, the entire system will not function properly. If an excessive emphasis is put on safety, other indispensable elements would have to suffer to some extent. It is not always easy to estimate the immediate and long-term impacts of a new regulation until it is put into effect. The recent MARPOL Regulation 25A is thought to fall into the category where safety measures violate standard naval architectural and financial principles, without adding anything to the actual safety. Furthermore, the regulation seems to assert more theoretical rules rather than operational ones.

In this study, a midsize product tanker is considered as an example just to demonstrate aforesaid claims. Extensive intact and damaged stability analyses are carried out for various loading conditions. Alternative structural arrangements for the double bottom are investigated to comply with the rules. Difficulties are tried to be overcome by usage of fixed ballast in combination with partially watertight double bottom design. In order to investigate the influence of ship motions on free surface effect in ballast tanks, seakeeping characteristics in typical sea states are determined. Local motions resulting from movement of liquid cargo and ballast are also calculated. Results are supplied comparatively in tables and graphs. Based on these results, the problems created by the existing regulation are detailed and more realistic suggestions are made towards immediate improvement to avoid potential future problems.

## 2. SAMPLE VESSEL

In order to reveal the implementation of Regulation 25A, a 29500 DWT oil tanker is chosen as an example. The tanker has seven cargo tanks (port and starboard) and the same number of L shaped ballast tanks (port and starboard). The main particulars are given below and general arrangement of the tanker is shown in Figure 1.

### Main particulars

Length overall	$L_{OA}$	= 182.14 m.
Length between per.	$L_{BP}$	= 168.18 m.
Maximum breadth	B	= 25.30 m.
Depth	D	= 18.0 m.
Summer draft	T	= 11.35 m.

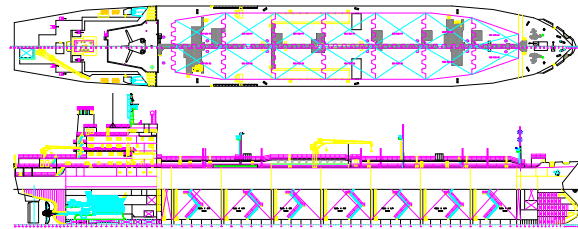


Fig.1. General Arrangement.

In order to reveal advantages and/or disadvantages of the new regulation, the most critical loading conditions have been selected from her stability booklet. The tanker is designed to carry liquid cargo densities ranging from  $0.70 \text{ t/m}^3$  to  $1.54 \text{ t/m}^3$ . As the regulation demanded, among the possible cargo densities, the cargo density corresponding to the available cargo deadweight at the displacement at which transverse KM reaches a minimum value must be taken into account. Full departure consumables and 1% of the total ballast capacity with maximum free surface moments are also considered for the loading conditions, as per the rule. It was found that the worst case, which is also defined by the regulation, was the full load departure condition for the lowest density. However, various loading scenarios have been taken into account within the analysis.

The tanker without Regulation 25A has more than adequate intact and damaged stability for every feasible loading condition and for all cargo densities intended to be carried. The intact stability analysis for the original loading condition with no ballast for four different cargo densities namely  $0.70 \text{ t/m}^3$ ,  $0.81 \text{ t/m}^3$ ,  $0.93 \text{ t/m}^3$  and  $1.54 \text{ t/m}^3$  are given below in Table 1 and Figure 2.

Table 1. Stability analysis for various cargo densities.

Loading	$\Delta$ (tons)	DWT	T (m)	KM (m)	KG (m)	GM (m)
0.70 t/m <sup>3</sup>	37845	24312	10.657	10.504	9.903	0.206
0.81 t/m <sup>3</sup>	40640	27108	11.358	10.637	9.732	0.488
0.93 t/m <sup>3</sup>	40659	27126	11.359	10.639	9.058	1.296
1.54 t/m <sup>3</sup>	40675	27143	11.363	10.640	7.332	2.455

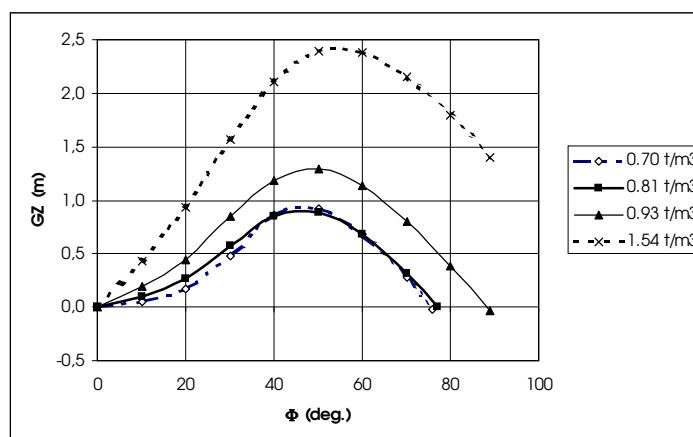


Fig. 2. Stability of original form for various cargo densities.

From the stability output, despite having the least stability among others, the full load condition with full load consumables and no ballast for 0.70 t/m<sup>3</sup> cargo still satisfies the conventional stability criteria. In other words the vessel would have been considered safe in terms of stability before the due date February 1, 2002. It should be noted that throughout the calculations, all cargo tanks are regarded as slack creating a great amount of free surface moments.

### 3. ADOPTION OF REGULATION 25A

Since Regulation 25A has been in effect for more than a year, the stability of the tanker needs to be re-evaluated based on the requirements of the rule. Following the regulation, 1% of the total ballast capacity should be accounted for the unpumpable ballast water. This part sounds logical and rational in

view of the fact that it could happen during loading and unloading operations at port. Naturally, this much of left over ballast water will cause some reduction in GM values. It is expected that this reduction should be limited to a maximum value of the sum of real free surface moments of each individual tank in question. In reality, due to the surface permeability of the bottom longitudinals and due to the fact that the water will only be transferred from scallops, the free surface effect will be much less. However, the regulation imposes to consider maximum free surface moments for each tank, although only a very small fraction of the tank contains water. This is where one starts to question the logic and the rationale behind the action and integrity of the regulation. Undoubtedly, no one could deny an innocent desire for an extra safety margin for the unpumped ballast water. The margin must be compatible with the risk

Let's now look at what happens to the stability of the tanker under the new regulation. Full load condition with  $0.70 \text{ t/m}^3$  cargo density is selected having the lowest KM value. First, 1% ballast water is taken into account with its real free surface moment (actual FSM of the liquid present). It should be noted that the real free surface moments are calculated when the double bottom is partitioned watertight through

longitudinal girders up to 0.30 m. manhole heights. Then same condition is considered with maximum free surface moment (maximum FSM of the tank regardless the quantity of liquid present). The results are given in Tables 2, 3, 4 and 5 comparatively and graphical representation is supplied through Figures 3, 4, 5 and 6 respectively.

Table 2. Stability comparison with real and maximum FSM for  $0.70 \text{ t/m}^3$ .

	$\Delta(\text{tons})$	DWT	T (m)	FSM (t.m)	KG (m)	GM (m)
Real FSM-div.	37888	24287	10.668	2619	9.884	0.159
Max. FSM	37888	24287	10.668	35500	9.884	-0.709
Real FSM	37888	24287	10.668	16575	9.884	-0.209

Table 3. Stability comparison with real and maximum FSM for  $0.81 \text{ t/m}^3$ .

	$\Delta(\text{tons})$	DWT	T (m)	FSM (t.m)	KG (m)	GM (m)
Real FSM-div.	40626	26789	11.352	2619	9.619	0.550
Max. FSM	40662	27062	11.362	35500	9.714	-0.366
Real FSM	40662	27062	11.362	16575	9.714	0.099

Table 4. Stability comparison with real and maximum FSM for  $0.93 \text{ t/m}^3$ .

	$\Delta(\text{tons})$	DWT	T (m)	FSM (t.m)	KG (m)	GM (m)
Real FSM-div.	40657	26819	11.357	2619	8.991	1.081
Max. FSM	40660	27060	11.358	35500	9.067	0.166
Real FSM	40660	27060	11.358	16575	9.067	0.631

Table 5. Stability comparison with real and maximum FSM for  $1.54 \text{ t/m}^3$ .

	$\Delta(\text{tons})$	DWT	T (m)	FSM (t.m)	KG (m)	GM (m)
Real FSM-div.	40656	26818	11.358	2619	7.323	2.465
Max. FSM	40659	27058	11.360	35500	7.317	1.597
Real FSM	40659	27058	11.360	16575	7.317	2.062

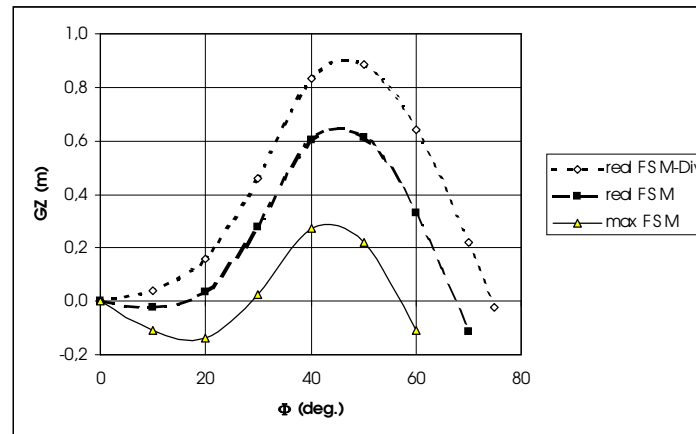


Fig. 3. Effect of FSM for 0.70 t/m<sup>3</sup> cargo density.

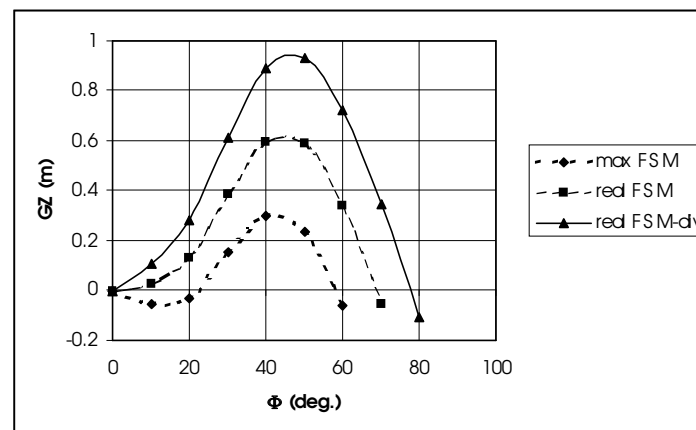


Fig. 4. Effect of FSM for 0.81 t/m<sup>3</sup> cargo density.

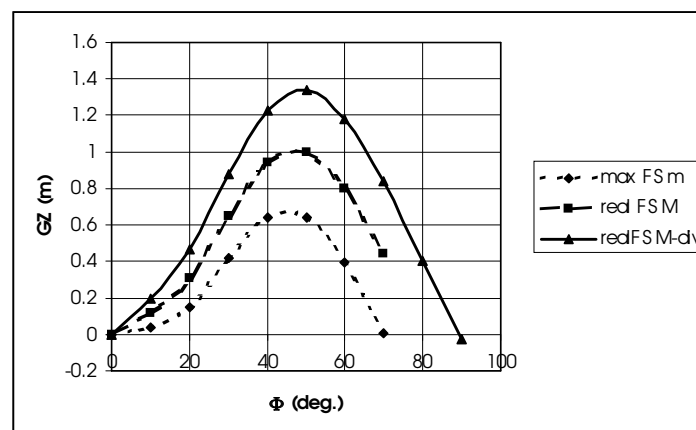


Fig. 5. Effect of FSM for 0.93 t/m<sup>3</sup> cargo density.

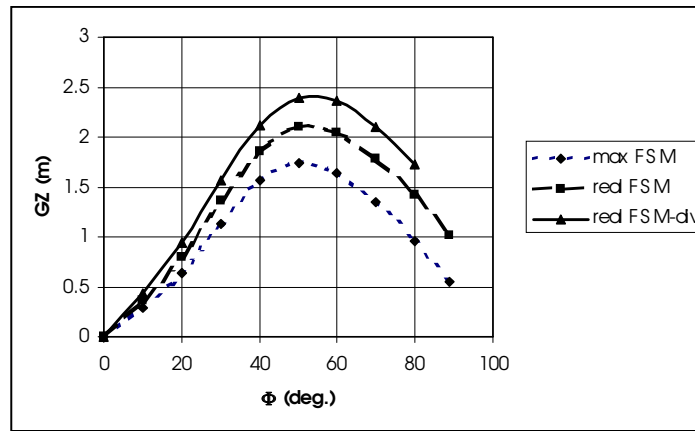


Fig. 6. Effect of FSM for 1.54 t/m<sup>3</sup> cargo density.

As can be seen from the above tables, with 1% ballast water if the real FSM is used in the calculations, the tanker would still comply with Regulation 25A, however when the maximum FSM is considered, she even fails to satisfy the GM condition of the conventional stability criteria, although it still has sufficient dynamic stability.

Similar results would be obtained if 0.81 t/m<sup>3</sup> density were used instead. Compliance with the regulation is realized for 0.93 t/m<sup>3</sup> and 1.54 t/m<sup>3</sup> cargo densities. That means, the tanker complies with the regulation in its original form for cargo densities higher than 0.93 t/m<sup>3</sup>. An indirect restriction would be imposed on the ship in terms of type of payload, and her earning potential. Since the ship has ample ballast capacity, the requirements could easily be met by appropriate ballasting of the ship.

#### 4. SOLUTION ALTERNATIVES

Obviously, the original design does not satisfy the regulation for especially lower cargo densities. The simplest or trivial solution would

be to restrict cargo type that ship could carry. But this would have a negative impact on profitability of the ship greatly.

Another way to satisfy the regulation is to use fixed ballast in order to lower center of gravity. The amount of required fixed ballast for the lowest cargo density was found to be 2750 tons for maximum free surface moments. The amount of fixed ballast is reduced more than by half if real free surface moments are used instead. This much of extra fixed ballast means the same amount of reduction from the deadweight, which approximately amounts to 8% of total DWT. Moreover, application of fixed ballast causes other problems such as crew discomfort due to increased GM etc. for higher cargo densities. A comparative stability analysis for different cargo densities in question has been performed and results are depicted in Table 6 and Table 7 for maximum and real free surface moments respectively. The effect of free surface moments (maximum and real) along with watertight double bottom having real free surface are shown in Figures 7, 8, 9 and 10 comparatively.

Table 6. Stability after fixed ballast for maximum FSM.

Loading	$\Delta$ (tons)	DWT	T (m)	KM (m)	KG (m)	GM (m)	$A_{\phi v}$ (rad.m)	$T_{\phi}$ (sec)
0.70 t/m <sup>3</sup>	40601	24250	11.349	10.626	9.227	0.157	0.410	51.1
0.81 t/m <sup>3</sup>	40656	24304	11.356	10.642	8.597	0.707	0.816	24.1
0.93 t/m <sup>3</sup>	40641	24290	11.352	10.641	8.064	1.154	1.240	18.8
1.54 t/m <sup>3</sup>	40658	24307	11.357	10.641	6.670	2.247	2.468	13.5

Table 7. Stability after fixed ballast for real FSM.

Loading	$\Delta$ (tons)	DWT	T (m)	KM (m)	KG (m)	GM (m)	$A_{\phi v}$ (rad.m)	$T_{\phi}$ (sec)
0.70 t/m <sup>3</sup>	40601	24250	11.349	10.626	9.227	0.623	0.758	25.6
0.81 t/m <sup>3</sup>	40656	24304	11.356	10.642	8.597	1.172	1.333	18.7
0.93 t/m <sup>3</sup>	40641	24290	11.352	10.641	8.064	1.620	1.840	15.9
1.54 t/m <sup>3</sup>	40658	24307	11.357	10.641	6.670	2.713	3.489	12.3

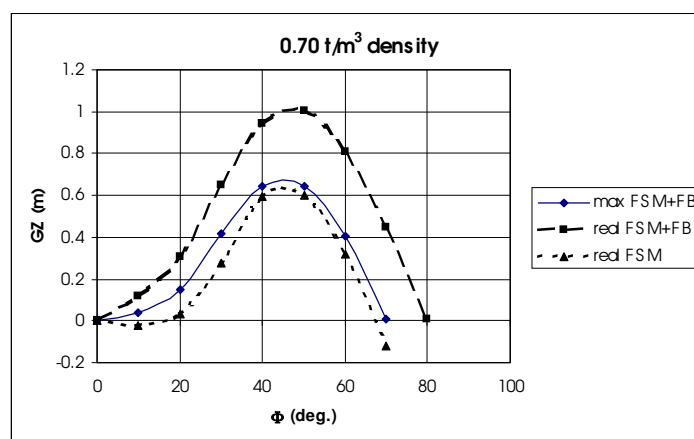


Fig. 7. Effect of max. and real FSM for 0.70 t/m<sup>3</sup> density.

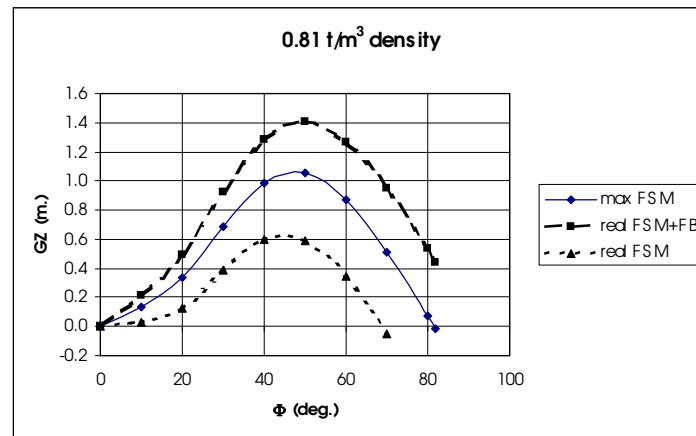


Fig. 8. Effect of max. and real FSM for 0.81 t/m<sup>3</sup> density.

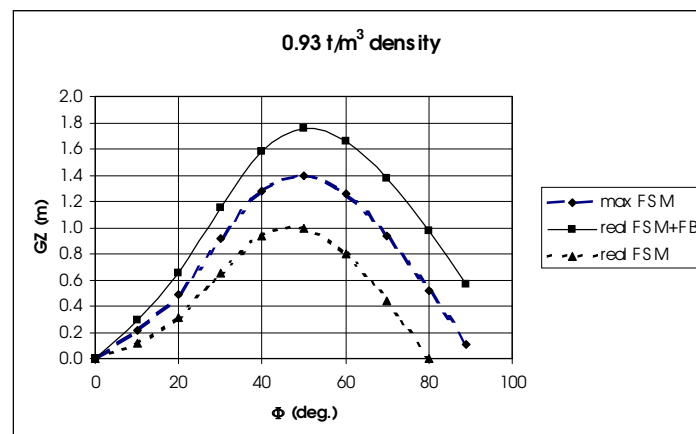


Fig. 9. Effect of max. and real FSM for 0.93 t/m<sup>3</sup> density.

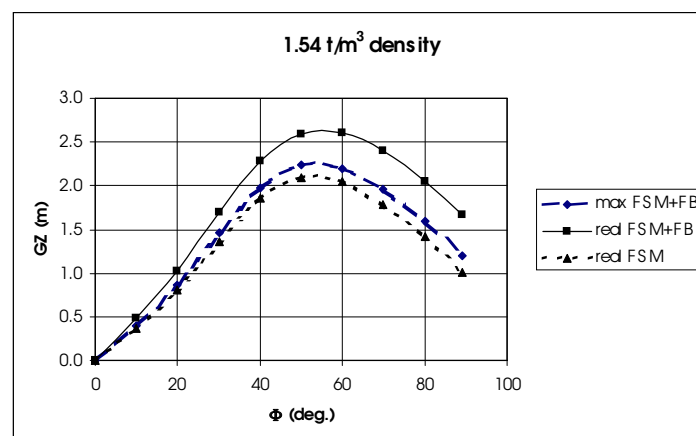


Fig. 10. Effect of max. and real FSM for 1.54 t/m<sup>3</sup> density.



Other alternative is to modify the structural design of double bottom ballast tanks. Originally, the double bottom part of the ballast tanks are divided by two longitudinal girders at 2.8 m. and 7.0 m. from the centerline. The height of the double bottom measures to 1.7 m. whereas the height of the lowest point of manholes is 0.30 m. from the baseline. It has been found that ensuring watertight integrity along the girders with raised manholes (0.80 m. from baseline) and application of adequate amount of fixed ballast would solve the

problem. This of course forces the designer to modify the ballast pumping system as well. Scuppers may be fitted with remotely controlled automatic valves to sustain watertightness. About 227 tons of fixed ballast was placed in the double bottom port and starboard close to LCG. Having divided the double bottom ballast tanks, stability of the tanker was examined again for the maximum (up to the manhole height) and real FSM of the partitioned tanks. The results are shown in Tables 8 and 9.

Table 8. Subdivision and partial fixed ballast with max. FSM.

Loading	$\Delta$ (tons)	DWT	T (m)	KM (m)	KG (m)	GM (m)	$A_{\phi v}$ (rad.m)	$T_{\phi}$ (sec)
0.70 t/m <sup>3</sup>	37864	24026	10.653	10.519	9.806	0.170	0.540	49.1
0.81 t/m <sup>3</sup>	40626	26789	11.352	10.637	9.619	0.478	0.625	29.3
0.93 t/m <sup>3</sup>	40657	26819	11.357	10.641	8.991	1.008	1.072	20.2
1.54 t/m <sup>3</sup>	40656	26818	11.358	10.640	7.323	2.393	1.422	13.1

Table 9. Subdivision and partial fixed ballast with real FSM.

Loading	$\Delta$ (tons)	DWT	T (m)	KM (m)	KG (m)	GM (m)	$A_{\phi v}$ (rad.m)	$T_{\phi}$ (sec)
0.70 t/m <sup>3</sup>	37864	24026	10.653	10.519	9.806	0.248	0.600	40.6
0.81 t/m <sup>3</sup>	40626	26789	11.352	10.637	9.619	0.550	0.680	27.3
0.93 t/m <sup>3</sup>	40657	26819	11.357	10.641	8.991	1.081	1.143	19.5
1.54 t/m <sup>3</sup>	40656	26818	11.358	10.640	7.323	2.465	1.516	12.9

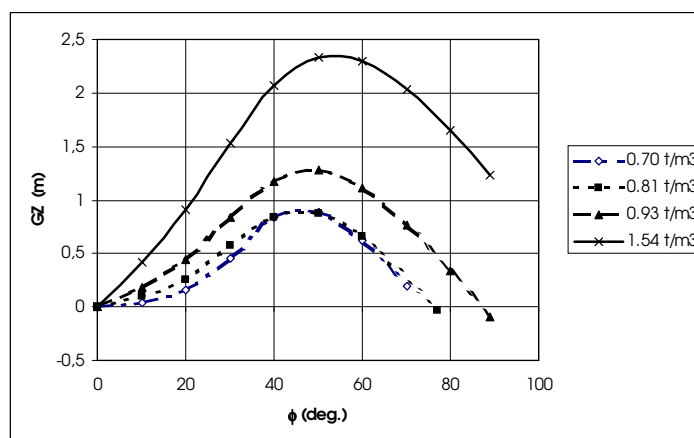


Fig. 11. Subdivision and fixed ballast with max. FSM.

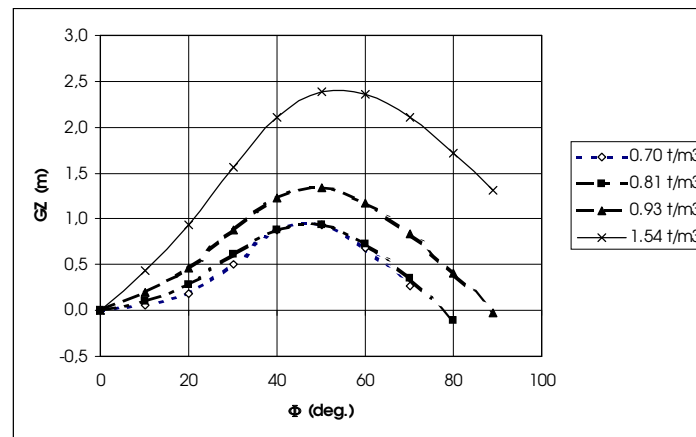


Fig. 12. Subdivision and fixed ballast with real FSM.

## 5. EFFECT ON MOTION CHARACTERISTICS

The radical variations in stability characteristics of the tanker due to Regulation 25A result in changes in lateral motion and seakeeping characteristics of the tanker as well. Since GM values increase tremendously, due to reduction in free surface moments between the maximum and real values, significant lateral accelerations, for example, will approximately triple between the lowest and highest GM values for a significant wave height of 7.5 meters. Here, a range of extreme GM values were considered namely 0.16 m., 0.5 m., 2.4 m. and 2.71 m. whereas significant wave height varied between still water and 7.5 m. The same analysis has been carried out for roll motion under the same environmental conditions and GM data. Once again, similar trend was

observed for significant roll amplitudes: for a 7.5 m. significant wave height, significant roll is about 8 degrees for the lowest GM and about 33 degrees for the highest GM.

The above analysis reveals that, increasing GM results in excessive motions. Therefore the tanker becomes extremely stiff causing an unpleasant environment for the crew. High frequency roll motion triggers inevitable crew fatigue. Even scheduled ship operations may be affected in the aftermath. Another unwanted consequence of this ordeal is the excessive slosh loads in cargo tanks. They not only contribute to the overall extreme ship motions, but also impose extra loads on the structural members of the relevant regions. Figures 13 and 14 reveal the effect of GM on lateral accelerations and significant roll amplitudes with changing significant wave height.

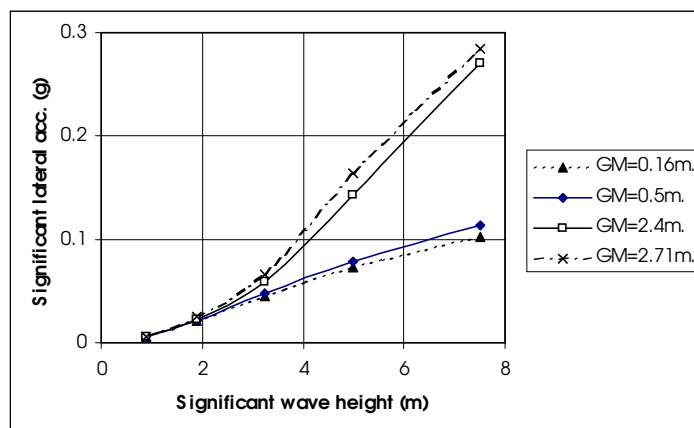


Fig. 13. Significant lateral acceleration.

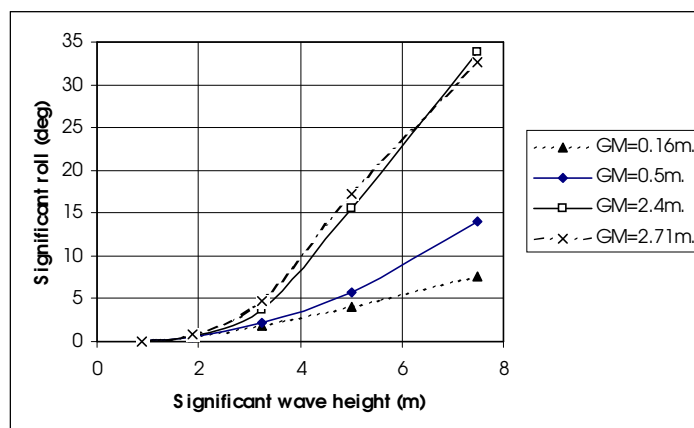


Fig. 14. Significant roll amplitudes.

## 6. DISCUSSION OF RESULTS

Extensive stability analysis of a midsize product tanker under the new regulation revealed important outcomes from various points of view. First of all, Regulation 25A compels naval architects to design intolerably so-called “safer” ships. Let’s now take a look at some of the facts in the aftermath:

If the first solution alternative is chosen, that is carrying limited cargo densities; the tanker will be in difficulty to find suitable cargo to carry in this competitive market. It would definitely,

lose market share and money in her service life. This selection would not go further than being a trivial solution.

Second alternative has also a number of drawbacks itself. 2750 tons of fixed ballast has to be carried regardless within the margin of deadweight. As was mentioned earlier, it would cause the ship to sacrifice 8% of her deadweight each and every trip. In other words, she loses 8% of her profit every leg of her journey. Furthermore, as far as the intact stability is concerned, there is a vast difference between the lowest and highest cargo densities.

For example, GM increases approximately 15 times from the required value between the extreme cargo densities. The range of stability and area under the GZ curve also jumps up about 1.5 and 6 times respectively. Another eye striking change can be observed in the natural periods: for 70 t/m<sup>3</sup> density the period is 51 seconds whereas for 1.54 t/m<sup>3</sup> density it drops down to 13.5 seconds. That means our ship becomes four times stiffer. This in turn may create a great discomfort for the crew and may even hinder their work. The above stability evaluation depicts that we are building extremely safer ships beyond acceptable limits.

Finally, combining structural changes in the double bottom tanks with a certain amount of fixed ballast seem to pose another solution towards satisfying the regulation. However, the above-mentioned side effects do not subside at all, and acceptance of this solution requires a positive interpretation of the rules.

Assessing overall stability qualities of this tanker, one has to keep in mind that she has very robust damage stability characteristics as well. In the severest bottom raking damage (40% of the ship's length), she manages to satisfy damaged stability criteria in full along with all other damaged scenarios required by MARPOL.

## 7. CONCLUSIONS

In this study, intact stability of a midsize tanker has been investigated under the requirements of MARPOL 73/78 Regulation 25A. It was found that, although the regulation seems to ensure ship stability during loading and unloading by taking into account small amounts of left over liquids especially in ballast tanks, it harms basic stability characteristics of a tanker resulting in stiffer tankers and crew discomfort and profitability of the tanker.

No one in the right mind would object safety of life at sea and environmental consciousness.

However there is fine line between safety and absurdity. When taking preventive measures against casualties at sea, we shall also keep our goals and reality in perspective. Otherwise, it would be very easy to cross the line.

As stated in the rule, consideration of unpumpable liquid in ballast tanks sounds reasonable, however considering maximum free surface moments in calculation of liquid GM appears to be unrealistic. One percent of total ballast capacity amounts to a several centimeters of liquid in the double bottom tanks when the vessel is upright, which is well below the height of the bottom longitudinals. If the vessel is heeled to a side, the role played by the watertight longitudinal girders up to the manholes is no different than longitudinal bulkheads obstructing the water. It should also noted that after a few degrees of heel to a side, parts of the double bottom partitions will become dry and this will remain so even after the water ingress between partitions. As a result, free surface moments will reduce greatly as the heel increases. Table 10. shows the change of free surface moments with changing heel angle.

Table 10. Change of FSM with heel.

	0°	5°	10°	20°	30°
FSM	16575	1105	498	271	256

In reality, during loading and unloading the vessel would not be upright most of the time. Therefore considering maximum free surface moments will only multiply the safety margin theoretically.

As to the Regulation 25A, as stated by many experienced designers, one has to say that it is an ill conceived development which will create a new generation of very stiff tankers with their ensuing problems on crew discomfort and excessive slosh loads on internal subdivision. Furthermore, efforts to increase GM will most likely result in a reduction of dynamic stability,

$GZ_{\max}$  and  $\phi_{\max}$  as most designers will opt to increase the beam and reduce the depth.

If the slack water in ballast tanks is really a problem in tanker safety, which we do not believe, then this can be catered for in the ship loading manual with the true FSM and on-board loading and stability calculation system may warn the crew for the need of additional ballast water to satisfy the regulation. When so much of ship safety depends on crew response, a regulation considering the crew as ignorant and yet creating unnecessary fatigue on the crew performance cannot be right.

Finally, it is strongly believed that these type of regulations should be evaluated within the context of SOLAS as it is concerned with safety of life at sea not within MARPOL, which is concerned with pollution avoidance. It is strongly suggested that before issuing new rules, the outreaching consequences have to be assessed thoroughly by experts utilizing past and present experiences of designers and operators.

## 8. REFERENCES

- [1]. MARPOL 73/78 Regulation 25A, Consolidated edition 2002.
- [2]. PC-SHCP User manual, Tremblay and Associates, Canada, 2001.
- [3]. 29500 DWT tanker blue prints and Stability Booklet.

## 9. ACKNOWLEDGMENTS

The authors wish to thank Dr. Kadir Sarioz for his help in the ship motions and seakeeping analysis.

## 10. APPENDIX

### 10.1. MARPOL 73/78 Regulation 25A

1. This regulation shall apply to oil tankers of 5,000 tons deadweight and above:
  - a. for which the building contract is placed on or after 1 February 1999, or
  - b. in the absence of a building contract, the keels of which are laid or which are at a similar stage of construction on or after 1 August 1999, or
  - c. the delivery of which is on or after 1 February 2002, or
  - d. which have undergone a major conversion:
    - i. for which the contract is placed after 1 February 1999; or
    - ii. in the absence of a contract, the construction work of which is begun after 1 August 1999; or
    - iii. which is completed after 1 February 2002.

2. Every oil tanker shall comply with the intact stability criteria specified in subparagraphs (a) and (b) of this paragraph, as appropriate, for any operating draught under the worst possible conditions of cargo and ballast loading, consistent with good operational practice, including intermediate stages of liquid transfer operations. Under all conditions the ballast tanks shall be assumed slack.

- a. In port, the initial metacentric height  $GM_0$ , corrected for free surface measured at  $0^\circ$  heel, shall be not less than 0.15 m;
- b. At sea, the following criteria shall be applicable:
  - i. the area under the righting lever curve (GZ curve) shall be not less than 0.055 m.rad up to  $\Phi = 30^\circ$  angle of heel and not less than 0.09 m.rad up to  $\Phi = 40^\circ$  or other angle of flooding  $\Phi_f$  if this angle is less than  $40^\circ$ . Additionally, the area under the righting lever curve (GZ curve) between the angles of heel of  $30^\circ$  and  $40^\circ$  or between  $30^\circ$  and  $\Phi_f$ , if this angle is less than  $40^\circ$ , shall be not less than 0.03 m.rad;
  - ii. the righting lever GZ shall be at least 0.20 m at an angle of heel equal to or greater than  $30^\circ$ ;
  - iii. the maximum righting arm shall occur at an angle of heel preferably exceeding  $30^\circ$  but not less than  $25^\circ$ ; and
  - iv. the initial metacentric height  $GM_0$ , corrected for free surface measured at  $0^\circ$  heel, shall be not less than 0.15 m.
3. The requirements of paragraph (2) shall be met through design measures. For combination carriers simple supplementary operational procedures may be allowed.
4. Simple supplementary operational procedures for liquid transfer operations referred to in paragraph (3) shall mean written procedures made available to the master which:
  - a. are approved by the Administration;
  - b. Indicate those cargo and ballast tanks, which may, under any specific condition of liquid transfer and possible range of cargo densities, be slack and still allow the stability criteria to be met. The slack tanks may vary during the liquid transfer operations and be of any combination provided they satisfy the criteria;
  - c. will be readily understandable to the officer-in-charge of liquid transfer operations;
  - d. provide for planned sequences of cargo/ballast transfer operations;
  - e. allow comparisons of attained and required stability using stability performance criteria in graphical or tabular form;
  - f. require no extensive mathematical calculations by the officer-in-charge;
  - g. provide for corrective actions to be taken by the officer-in-charge in case of departure from recommended values and in case of emergency situations; and
  - h. are prominently displayed in the approved trim and stability booklet and at the cargo/ballast transfer control station and in any computer software by which stability calculations are performed.

## 10.2. Intact stability

The vessel should be loaded with all cargo tanks filled to a level corresponding to the maximum combined total of vertical moment of volume plus free surface inertia moment at  $0^\circ$  heel, for each individual tank. Cargo density

should correspond to the available cargo deadweight at the displacement at which transverse KM reaches a minimum value, assuming full departure consumables and 1% of the total water ballast capacity. The maximum free surface moment should be

assumed in all ballast tanks. For the purpose of calculating  $GM_o$ , liquid free surface corrections should be based on the appropriate upright free surface inertia moment. The righting lever curve may be corrected on the basis of liquid transfer moments.

