A Study of the Roll Motion in Small Supply Boats Operating in Zero Forward Speed

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ABSTRACT

This paper presents a study, carried out by PROJEMAR about the roll motion of small supply boats designed to operate in Brazilian coast. These boats work during great part of the time in zero or very small velocities, being susceptible to large roll motion amplitude when excited by beam sea waves. The study had the objective to improve the hydrodynamic behaviour of these boats, for application in future designs.

Keywords: *Projemar, Roll, Small Boats, Bilge Keel*

1. INTRODUCTION

Small vessels with overall length under 100m are more susceptible to the action of waves than ships. This can be explained due to many reasons. The first is the fact that the natural periods for first order motions (heave, pitch and roll) of these boats are in a range of 5 to 10 seconds, near of the most energetic region of the spectrum in many seas around the world. So the resonance normally occurs causing the increase of the motion amplitude.

Another unfavourable situation is when the boat is under of the action of waves whose length is close to one of its dimensions. In this case undesirable oscillations are experienced too.

Furthermore, the design requirements, in most of the cases, are faced to speed performance and the hull form is defined to minimize the ship water resistance. For that reason, when in small velocity or stopped, the potential and viscous damping became insufficient to keep the motions in reasonable levels.

In case of Roll motion this lack of damping results in large motions amplitude and sickness of the crew.

These situations are not interesting for supply boats designed to operate giving support to offshore platforms. Depending on the sea state, the operation can be interrupted and the work postponed.

The strategies used to improve the seakeeping performance include the improvements on hullform and increase of the bilge keel efficiency. Both has influence in the wave resistance and has to be tested carefully.

Another way to reduce the large roll motions is by implementation of anti-roll stabilization tanks. This alternative depends on the loading condition and is very useful for boats in zero speed.

This paper presents studies about these two alternatives. The potential and viscous damping aspects are briefly described. Means how to increase both in a vessel and the consequences of this are discussed too.

The most used types of anti-rolling tanks are presented and their more common aspects and main advantages are discussed.

A case analysis is presented to illustrate the ideas.

2. MOTION DAMPING

The total damping of a vessel is obtained by summing up the wave radiation and viscous effects. In terms of roll damping, it cannot be calculated just based on theoretical methods, as the viscous effect is a very important component of the total damping and can only be estimated by semi-empirical methods.

The potential damping is obtained from the potential theory being generated when the ship, excited by waves, starts to move and to produce waves, dissipating the energy absorbed. In roll motion this effect is governed by the shape of the cross section of the boat and is strongly related to the breadth-draft ratio.

For a breadth-draft ratio of about 2.5, the submerged part of the vessel has almost a circular cross section, and a circular cylinder rotating about its centre does not produce waves and the potential roll damping is reduced. Lower or greater breath-daft ratios take the wave damping component to higher values.

In Journee & Massie (2001) is proposed a curve, presented in the figure 1, with the relation between the wave damping and the breadth-draught ratio.

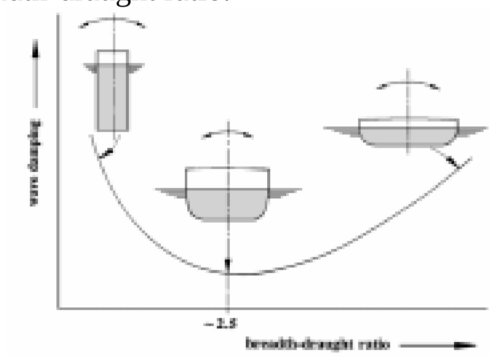

Figure 1 Roll Damping as Function of Breadth-Draught ratio.

The viscous damping is originated on the hull and its appendages by friction and eddy making effects. Its estimation is not easy using conventional methods, being usually estimated by experiments or semi empirical methods that are based on analysis of the experimental data.

Bilge keels can strongly increase the roll viscous damping of vessel, but its utilization must be analysed. In square body ships the bilge keel position is obvious. But in small boats this has to be investigated to find out the more efficient position.

Another aspect is to reduce the effect of the bilge keel in the resistance of the vessel. A streamline study is required to obtain a position where the drag force is reduced and the resistance limited to the frictional.

3. ANTI ROLLING TANKS

A passive anti-rolling tank can be a good alternative to reduce the roll motion at zero speeds. These tanks can be as effective as the bilge keel but its application is more complex due to the working characteristics, volume required etc.

In Lewison & Williams (1971), is described the performance of passive roll stabiliser instalations in thirteen vessels of widely differeing type, ranging from a pilot cutter to a 151m container ship, and discusses the extent to wich model experiments were successful in predicting the performance of the instalations at sea.

The main idea behind of these tanks, known as stabilization tanks, is to have them working as dynamic vibration absorbers, whose mathematical model is described in Rao and illustrated in figure 2.

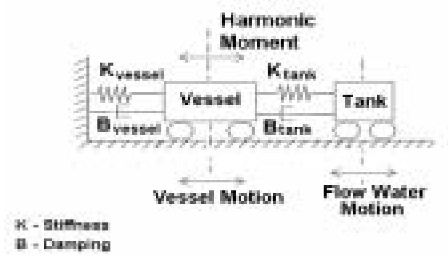

Figure 2 Dynamic Absorber Model

The moment generated by the water inside the tank, has to counterbalance the roll exciting moment induced by waves on the vessel. This is done designing the tank in order to have the natural period of the flow water inside the tank equal to the roll motion natural period. Doing this, the moment generated by the water in the tank and the moment of the vessel roll motion will be in opposite phase, cancelling themselves.

The passive stabilization tanks work at the natural roll period of the vessel, if the natural period of the tank is different of this period a contrary effect can occur increasing the roll motion amplitude. The natural period of the vessel has to be measured or calculated carefully. An accurate weight control is useful, since it lets a better estimation of the longitudinal radius of gyration, necessary for this calculation.

According to Bhattacharyya (1978) anti-rolling tanks can be divided in flume tanks and U-tube tanks. The flume tank, or free surface tank, is shown in the figure 3. This type of anti-roll stabilizer is an open tank that can have baffles/nozzle plates to provide internal damping. The response period of the tank can be changed to match the natural period of the vessel by simply changing the liquid level.

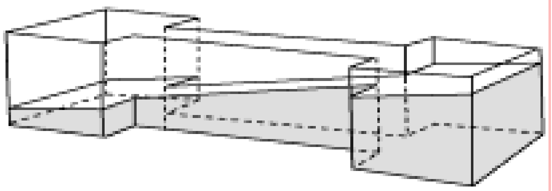

Figure 3 Free Surface Tank.

The U-tube tank is shown in figure 4. This type of stabilizer is more complex than the flume. It consists of two tanks partially filled with liquid, with the air spaces connected by a duct and a crossover duct at the tank bottom. The response period can be adjusted by means valves or nozzles in the duct. Another aspect is the fact that this kind of tank does not obstruct the fore-aft passage.

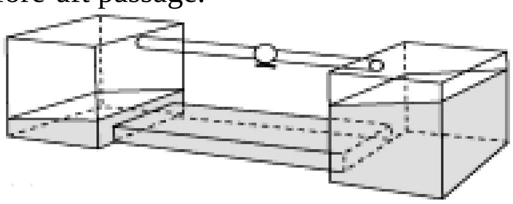

Figure 4 U-Tube Tank

The loading conditions have to count with the necessary load at the tank, which varies generally from 1% to 5% of the vessel's displacement. Another characteristic is the reduction of the metacentric height by as much as 25%.

4. CASE ANALYSIS

The case analysis presents the main aspects of the studies carried out to improve the roll motion response of a small supply boat.

The vessel analyzed has the following main characteristics.

Table 1 Vessel Main Characteristics

LBP	31,90m
B	8,40m
T	3,50m
D	4,0m
Displacement	512t
Wetted Area	361.3m^2

Based on figure 1 can be noted that the hull is located in a region of low potential damping since the breath/draft ratio is 2.4.

During the conception of the hull form a first study is to compare a round bilge hull with a chinned bilge. This preliminary calculation has the objective to verify the potential and viscous damping of these hulls. The chinned hull presents one knuckle. No appendages were taken into account in the bilge hull.

Two hydrodynamic models were constructed to calculate the responses. Figure 5 presents the chinned bilge hull. Figure 6 presents the round bilge hull.

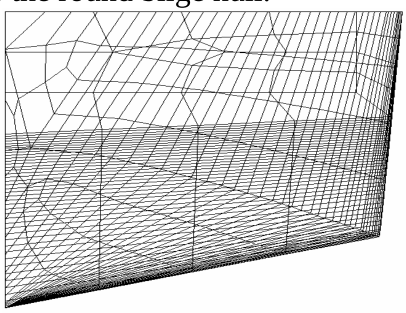

Figure 5 Chinned Bilge Hull Form

Each hydrodynamic model is composed by two parts. A panel model used to calculate the potential damping, and a strip model used to calculate the viscous damping.

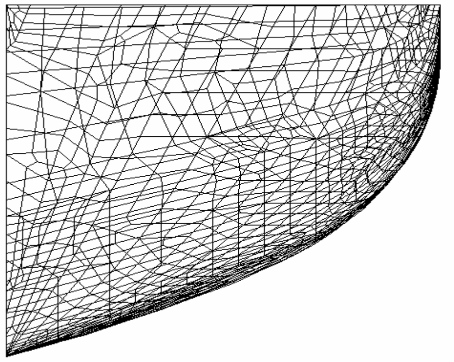

Figure 6 Round Bilge Hull Form

The SESAM system, developed by Det Norske Veritas, was used to carry out the analysis. The potential damping is calculated based on potential theory. The viscous damping is calculated based on called "Ikeda method" that estimates viscous roll damping contributions due to forward speed, skin friction, eddy making, lift and bilge keels. More information can be found in Ikeda & Himeno (1978).

The responses were calculated for incidences varying from 0 to 180 degrees with 45 degrees of range. The seastate was represented by a Pierson Moscovitz spectrum with 1m of significant height and mean period varying from 3 to 7 seconds. The vessel responses presented are the mean values, corresponding to 1.25 times the standard deviation.

Figure 7 presents the result obtained for the beam sea case which was the critical.

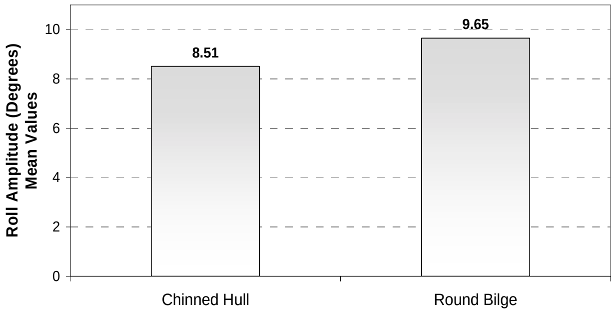

Figure 7 Hull Form Comparison

5. BILGE KEEL STUDY

The first result showed that the chinned bilge hull presents amplitude 12% lower than the round bilge hull. This result was already expected since the bilge keel was not included and its effect in viscous damping is very important to the round bilge hull form. So is important check the effect of the bilge keel in the round bilge hull before starting the stabilization tank study.

The design of the bilge keel required improvements in the analysis. Measurements on site of the rolling motion amplitude and period were carried out in a very similar hull form. This result was used to verify the accuracy of the roll damping model used. The vessel had a bilge keel with 9m of length and 0.208m of width installed.

Based on the on site results the hydrodynamic model was recalculated considering the same loading condition of the vessel, and received a bilge keel with same dimensions. The environmental condition considered was the same measured on site. Pierson-Moskovitz spectrum was used to represent the sea state.

The difference between measured and calculated values was 2.5% as can be seen in figure 8.

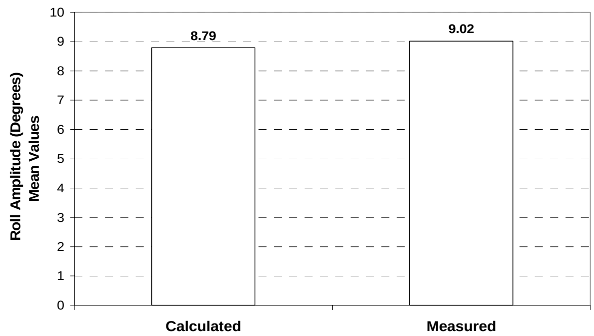

Figure 8 Comparison Between Measured and Calculated Values

The next step was to define the bilge keel to be used in the vessel analysed.

Firstly, the better position for the bilge keel has to be found. A streamline study was carried out on the region where the bilge keel would be located.

This study has the intention to minimize the form resistance from bilge keel restraining its effect to the frictional component.

Three possible elevations were selected. These elevations relative to bottom are presented in table 2.

Table 2 Streamline Elevations

Streamline 1	0.5m
Streamline 2	1.0m
Streamline 3	2.0m

Figures 9 to 11 show these streamlines.

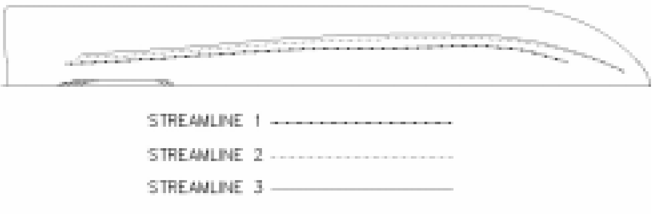

Figure 9 Streamlines Plan View

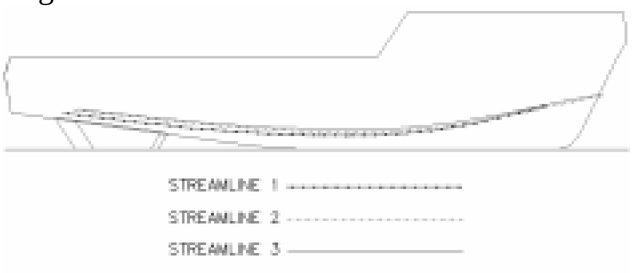

Figure 10 Streamlines Profile View

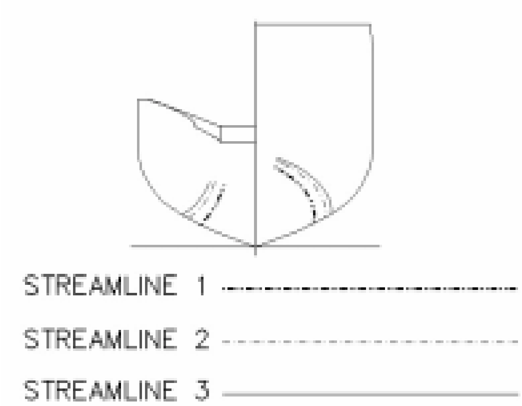

Figure 11 Streamlines Section View

The second step is to verify the reduction of roll amplitude as the width of bilge keel increases in the three elevations. A standard length of 9m was used and the width calculated to the values presented in the table 3.

Table 3 Widths Evaluated

Width(mm)
208
308
408
508
608
708
808
908

The results showed that when the bilge keel is positioned on streamline 1 its effectivity increases more than the other options whose results are very close themselves. These results, presented in figure 12, were calculated for an irregular sea with 1m of wave height and mean period varying from 3 to 7 seconds. Pierson Moskovitz spectrum was used to represent the sea state.

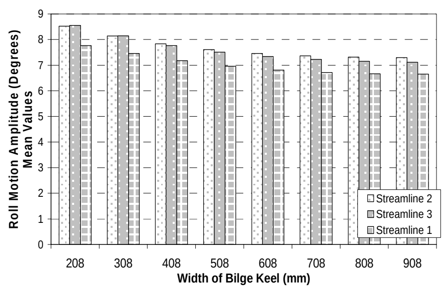

Figure 12 Variation of Width and Elevation of Bilge Keel

Figure 13 shows the percentage of reduction of the roll motion amplitude as the width of bilge keel increases. Can be noted that the rolling motion amplitude is 31.1% lesser than that obtained for the bare hull. It is very clear the tendency of the curve to a constant value as the width increase.

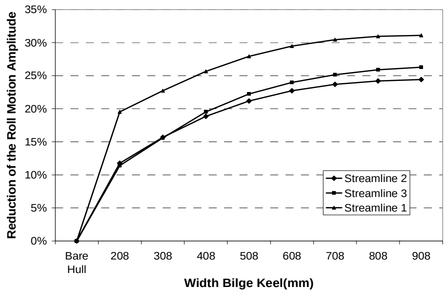

Figure 13 Reduction of Roll Motion

A third step is to select the correct width and increase the length of bilge keel. To carry out this part of the study was chosen the width of 408mm. At a length of 9m the expected reduction on the roll motion is 25.7%.

The lengths evaluated are present in the table 4.

Table 4 Lengths Evaluated

Length(m)	Length(%Lpp)
9	28.2
10	31.3
12	37.2
14	43.9
15	47.0
16	50.1
17.5	54.9

The results are in figure 14. The same environmental condition was used.

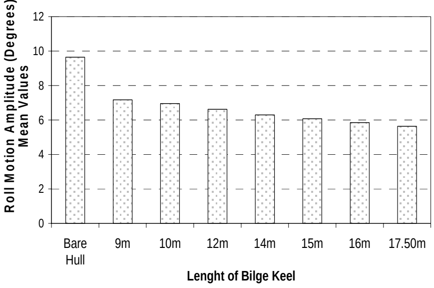

Figure 14 Percentage of Reduction of Roll Motion

Figure 15 shows the percentage of reduction of the roll motion amplitude as the length of bilge keel increases.

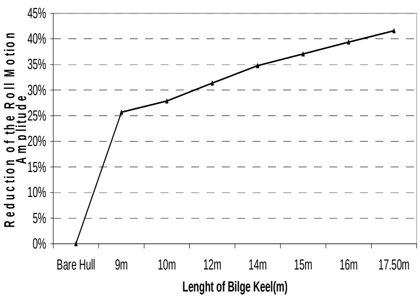

Figure 15 Percentage of Reduction of Roll Motion

The results show that the maximum rolling motion amplitude is 41.6% lesser than that obtained with bare hull, considering a bilge keel whose length is 17.50m (55% of lbp).

The choice of the reasonable length takes into account, besides the motion performance, constructive aspects and resistance effect. Being this last the more important. In this study the 15m of length was chosen.

Figure 16 and 17 show the bilge keel in the hull.

Figure 16 Bilge Keel Positioned in Profile Plan

Generally the total area of a bilge keel should vary from 1% to 5% of the Hull's wetted area. The chosen bilge keel has 6.8% of wetted area. Since it is been positioned in a streamline, the accretion in the resistance tends to be minimum.

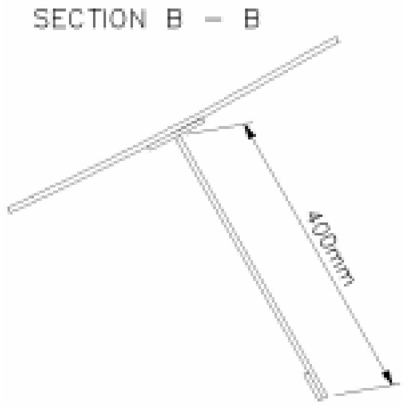

Figure 17 Bilge Keel Positioned in Section Plan

The decreasing of roll motion obtained is 37% in relation of bare hull, bringing the motion amplitude from 9.65 to 6.08 degrees. Figure 18 compares the bilge hull, including the bilge keel, compared with the chinned bilge hull. As can be noted the round bilge hull presents a better motion response.

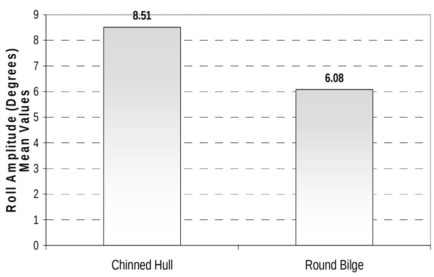

Figure 18 Hull Form Comparison Bilge Keel Included

6. STABILIZATION TANK STUDY

In this vessel, two tanks are available to be used as stabilization tanks. The Figure 19 shows these tanks.

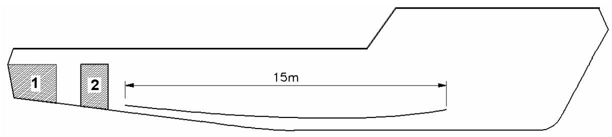

Figure 19 Stabilization Tanks

These tanks were chosen because they have already been designed to water storage. In this case, this water is used to compensate the cargo weight during the operations of the vessel. Therefore the vessel capacity was not affected.

Tank 1, shown in figure 20, is a free surface tank located at the stern of the vessel.

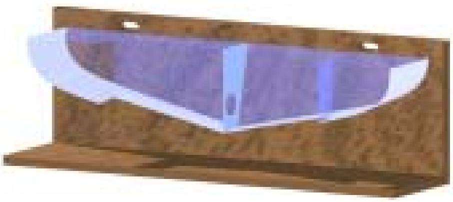

Figure 20 Stabilization Tank Number 1

The tank 2, presented figure 21, is a U-tube tank, located forward tank 1.

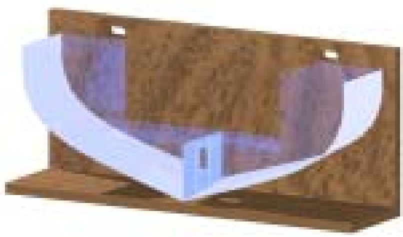

Figure 21 Stabilization Tank Number 2

The oscillation period of the water inside the tanks shall be investigated before its application as stabilization tanks. In spite of the evolution of the mathematical computation, the model test is still the more reliable tool for this kind of design.

This model test can be done using the device presented in figures 22 and 23.

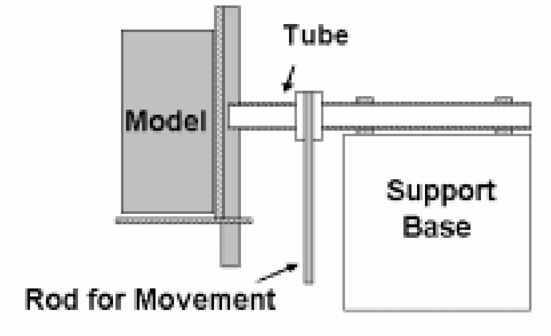

Figure 22 Stabilizer Test Device profile View

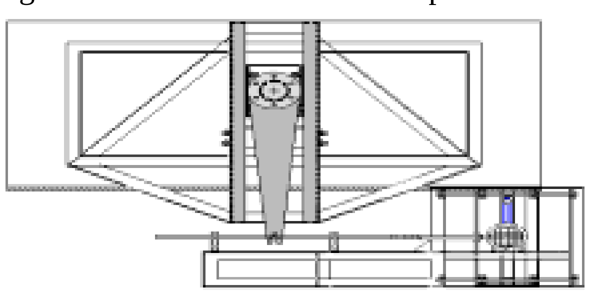

Figure 23 Stabilizer Test Device Stern View

In the device, an engine simulates the rolling motion of the vessel. Using a modulator, it is possible to roll the tank in several periods simulating the real sea state. A strain gauge between the engine axis and the model has to be installed.

When the tank is excited in periods below of the natural period of the flow water inside it, the deflection on the strain gauge tends to be minimal because the flow water moment is not counteracting the moment generated by the engine.

When the excitation periods are on or near of the natural period of the flow water, it will be out phase with the rolling motion induced by the engine. Consequently a restoring moment will be generated counteracting the engine moment. In this case the deflection on the strain gauge will be greater. For excitation periods above the resonance the deflection on the strain gauge tends to be minimal again.

The figure 24 shows a curve of this result.

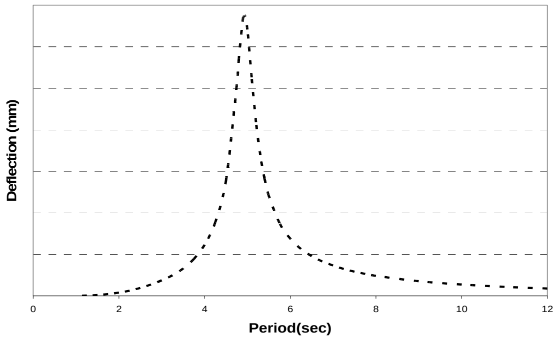

Figure 24 Strain Gauge Deflection

During the test it may be necessary to change the internal space of the tank, to include obstacles or bulkheads, increasing the internal damping and taking the fluid motion to the vessel natural period. In this work the internal spaces were not changed, just the variations on the water level were tested.

The water level is another factor that should be investigated. In these tanks, which form is not common, 50% of the capacity could not result in the maximum moment. Therefore, before start varying the periods, the volume and consequently the level of water should be changed, in order to define the level where the stabilizer is more effective.

For the vessel studied in this analysis, the calculations and the measurements showed that the natural period of the vessel is about 5s. Its response amplitude operator (RAO) is presented below in the figure 25. This result considers just the bilge keel effect.

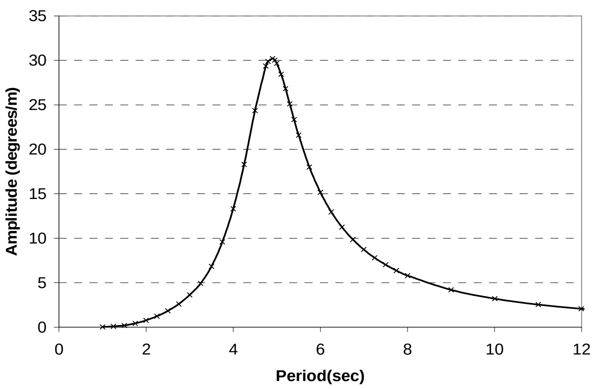

Figure 25 Roll Response Amplitude Operator

Figure 26 presents the response amplitude operators of the vessel including the stabilizer effect of the anti-rolling tanks.

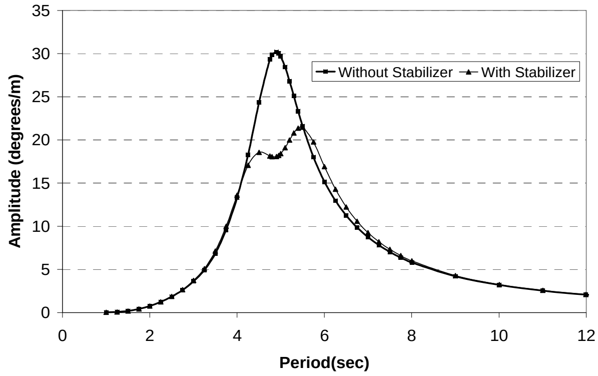

Figure 26 Roll RAO Stabilizer Tanks Included

The anti-rolling tank effect works as a restoring moment in the equation of motion, more details can be obtained on Bhattacharyya (1978), Journée, & Massie (2001) and Vasta & Giddings(1961).

Table 5 presents the volume of water used in the two stabilizer tanks.

Table 5 Volume of water in the Stabilizers

Stabilizer	Volume(m^3)	% of total
1	8.12	50.00
2	9.10	49.97

The reduction obtained in the RAO curve is about 30%. Figure 27 presents a comparison of the responses for bare hull, hull with the bilge keel and hull with bilge keel and stabilizer. The environmental condition used to obtain this last, is the same used in the bilge keel calculations.

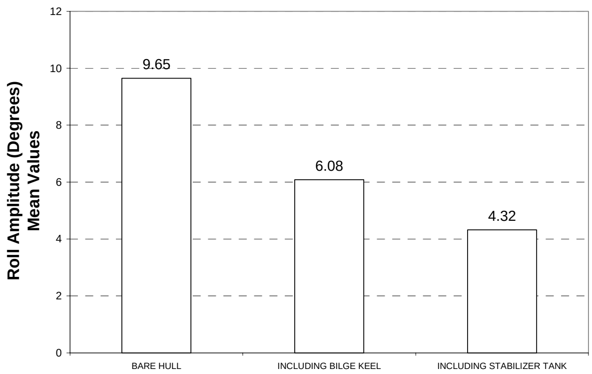

Figure 27 Roll Response Evolution

The total reduction achieved on the roll motion amplitude was about 55%. From this 67% is due to the bilge keel and 33% comes from the stabilizer tanks.

7. CONCLUSIONS.

The design of a vessel should not be focused in just one direction or concerning a specific design factor. All of them have to be carefully investigated.

Low potential damping is expected in small supply boats. As a consequence, the viscous damping has greater importance in reduction of motions, especially in the roll motion problem.

Extended bilge keels are indicated for situations where a large amount of damping is required, and a small penalty on the service speed accepted. When the reduction of the motion required is smaller a bilge chinned hull can be the best alternative.

The bilge keels have to be designed to minimize the resistance and the seakeeping performance. Both problems have to be carefully studied.

The case study presented showed the real necessity to look into this problem. Three positions were studied for the bilge keel. In the location near the bottom the best result was obtained. This is not a general rule and another vessel would demand a different study.

The other alternative discussed in this paper is the anti-rolling tanks. These tanks can be a good alternative to reduce the rolling motion. However its utilization is limited by the compartimentation and capacity of the tanks, being it difficult to fit in small boats.

The rolling motion always will be critical to small boats, but an accurate hydrodynamic analysis, composed by a bilge keel study an anti rolling tank study and a model test can minimize its effects improving the operability of the vessel.

8. ACKNOWLEDMENTS

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