ROLL MITIGATION OF SMALL FISHING BOAT

A. A. M. Ayob,[a] O. Yaakob,[a,*]

[a] Marine Technology Centre (MTC),
Universiti Teknologi Malaysia,
81310 UTM Skudai, Malaysia.

Article history
Received
08 May 2015
Received in revised form
09 July 2015
Accepted
20 August 2015

*Corresponding author
omar@fkm.utm.my

Abstract

Heavy rolling motions experienced by small vessels give rise to many problems and disadvantages to the vessel and crew. This is undesirable especially during resonance when the encounter wave frequency coincides with the vessel natural frequency. Onboard activities, especially fishing, are affected because of difficulties due to the rolling motion. Heavy motion may lead to loss of personnel overboard or damage to onboard equipment, and also to structural failure and capsize phenomenon. The objective of this project is to develop and improve method for roll reduction and assess its performance. A Tsunami 22' Fishermen boat and device to reduce the rolling motion have been selected for case study. The performance of the device has been analysed and tested on a model of the boat. The selected roll reduction device is a moving mass device. The moving mass device has been fabricated and evaluated its effectiveness by calm water roll decay test. It is found that the moving mass device is capable of reducing the rolling motion of the boat. The roll decay coefficient has been found increased up to 85.87%.

Keywords

Roll stabilization; anti-roll device; moving mass device

Introduction

Commercial fishing is the one of the most dangerous occupations in Malaysia today, with fatality rate continuously and widely documented in the specialized literature [1]. One of the factors that endanger the fishermen is motion from the vessels. A ship that is subjected to wind and wave may perform motions in six degrees of freedom, which are surge, sway, yaw, heave, pitch and roll whereas all angular degrees of freedom (pitch, yaw, and roll) are undesirable for any ship. [2] Excessive motion of a ship can seriously degrade the performance of machinery and also the personnel. [3] The excessive motions also may interfere with the recreational activities of passengers on cruise ships. [4]

As mentioned above, rolling motion is an undesirable motion for most vessels. The rolling motion can be quite dangerous because roll motion has a very small damping and therefore prone to dynamic magnification, which can lead to capsizing. Disruption of performance of seagoing surface vessels limits the effectiveness of the crew, and operation of on-board equipment, as well as damages cargo [5]. As for combat ships, too much rolling can degrade the combat readiness of its crew and adversely affect the performance of its weapons systems. Offshore platform, pipe-laying ships and drill ships require only small motions to perform many of the individual operations [4].

Generally, small fishing boats are used to catch fish at seas, lake or river. The length of small fishing boats is usually less than 15-30 meters, and installation of their equipment depends on operations. These small vessels are usually operated nearby the coastline because of their small capacity, and the equipment on board also limits them from long navigation. In addition, the small fishing boats operations are dependent on the sea weather. In certain conditions, waves can reach more than 0.5m (>0.5m) in height, which can reduce the stability of the vessels or boats.

Since most severe roll motion occurs at resonance, or known as synchronous rolling, increasing the damping is the one of the best ways to reduce roll motion. [6] Roll is certainly the most severe angular motion experienced by a ship, often exceeding the “small angle” range of 10 to 15 degrees. Operating the ship would be difficult, and can lead to motion sickness because of the large angle of rolling.

Small roll damping is easily generated especially at beam seas. When roll damping occurs, some activities need to stop such as fishing, leisure. This is because it might lead to loss overboard or endanger the motion of the equipment. There are a lot of devices to reduce roll motion that have been used previously in UTM such as bilge keels, U-tube tank, and passive tank stabilizer. This research paper proposes a novel method of utilizing the existing moving mass system [8].

Suitable anti-rolling device needs to be added to vessels to reduce the amplitude and the acceleration of the rolling angle to ensure the comfort and safety of passengers.

Ship motions are generally divided into six components; in which three of them are labelled as linear motion and the rest are rotational around the major axes, as shown in Figure 1. The figure illustrates that the motion at x-axis surges, as the ship moves backwards and forwards. Meanwhile, the y-axis is an athwartship motion of the vessels, referred to as swaying. Heaving motion occurs at z-axis, defined as vertical up and down motion. The angular motion about the longitudinal axis is called as rolling motion. This roll motion is known to be crucial because it has very small damping, thus extreme roll might lead to capsizing. [2][7] The angular motion for the transverse and vertical motion is called as pitching and yawing, respectively.

In real situation, ships that move in seaways experience six kinds of motion simultaneously, as stated earlier. This study focuses only on the rolling motion, and coupling between motions is neglected to simplify the problem. Therefore, mathematical equation and the ship motion had been simplified into mathematical model, which is the damped linear mass-spring system.

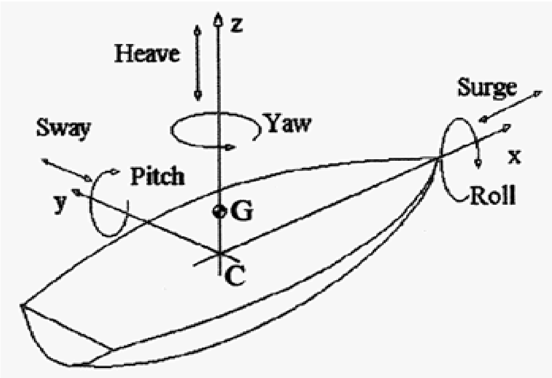

Figure 1: The principal x, y, and z-axes of a ship

The equation of uncoupled rolling motion is stated in Equation 1 below [7]:

$$a\frac{d^2\phi}{dt^2} + b\frac{d\phi}{dt} + c\phi = M_o cos\omega_e t \qquad (1)$$

where $\frac{d^2\phi}{dt^2}$ is the inertial moment, $\frac{d\phi}{dt}$ is the damping moment, c^{ϕ} is restoring moment and M_o cos $\omega_e t$ is the exciting moment. The exciting moment occurs because of the moment produced by the wave or external forces, which can be described in cosine form and encountering frequency.

Meanwhile, each component at the left consists of coefficients is vital in roll motion. The symbols ‘a’, ‘b’, and ‘c’ represent the virtual mass moment of inertia for rolling, damping coefficient, and restoring moment coefficient, respectively. $\frac{d^2\phi}{dt^2}$, $\frac{d^2\phi}{dt^2}$, and ϕ represent the angular acceleration, angular velocity, and angular velocity for rolling, respectively. Knowing each component from rolling equation can ease solving the problem.

Methodology

Fishing Boat Selection

A 7.2 m fishing boat (Figure 2) was selected for this research work, which was built in 2005 at Tanjung Dawai, Kedah. The main particulars of the fishing boat at full and experimental model scale can be seen in Table 1.

Figure 2: Fishing boat

Table 1: General particulars of 7.2m fishing boat

Parameters	Full Scale	Model
Scale Factor	1	2.88
Length Overall (LOA) (m)	7.20	2.50
Beam (m)	1.64 m	0.57
Draft (m)	0.3	0.10
Long. Ctr of Bouyancy (LCB) Fwd Amidship (m)	0.96	0.33
Long. Ctr of Gravity (LCG) Fwd Amidship (m)	0.97	0.34
Displacement (kg)	1800	75.35
Speed	12 Knots	3.63 m/s

Design Consideration

Before the designing of the moving started, some criteria needed to be considered, as listed below:

i. The moving weight needs to be designed based on the design load condition.
ii. Next, the moving weight should be in range of 0.5 to 2% boat displacement as recommended [9].
iii. The location of the moving weight device should be located between bulkhead 3 and 4 at distance 3.61m from aft of the boat. This location is basically to avoid trimming condition.

Moving Mass Device Design

To begin the design, the natural frequency of the fishing vessels needed to be known, by using simple calculation as follows:

$$T_{\phi} = \frac{2\pi}{\omega_{\phi}} = 2\pi\sqrt{\frac{I'_{xx}}{\Delta GM_T}} \tag{2}$$

Meanwhile, metacentric value was obtained from the formulation of $GM_T = KM_T - KG$, whereas KM_T was obtained from hydrostatic table provided by the Maxsurf Pro software, while the KG value was obtained from the loading calculation. Then, the value of the virtual mass moment of inertia was calculated, based on the formula in literature review, as follows:

$$\alpha = I'_{xx} = \frac{\Delta'}{g}k^2{}_{xx} \tag{3}$$

Consequently, the natural period of the vessel could be calculated.

Table 2: Estimation of natural period of the vessel

Parameters	Value
Vertical Center of Gravity, KG	0.646 m
KM_T@ 1.744 Tonnes	0.853 m
GM_T	0.2071 m
Displacement	1.744 Tonnes
K''_{xx}	0.5904 m
I_{xx}	0.061971 Tonnes-^{2} - m
Natural Period, T_{φ}	2.60 s

The weight of the moving object was estimated as suggested by Miller et al.; within 0.5% - 2% displacement of the ship [9]. For the value of spring stiffness or spring constant, k, it was determined from the natural frequency equation as in Equation 4.

The natural frequency of the model from the previous experiment was 4.68448 rad/s. The needed length of the device was similar to the beam on waterline which was 1.41m. Thus, the dimension of the model and full scale could be determined, as shown in Table 3.2. The dimension of the moving mass is shown below.

Table 3: Moving mass device dimension

Parameters	Actual Size	Model Size
Moving Weight, m	2% x 1.744tonnes = 0.035 tonnes	1.5 kg
Length, l	1.41 m	48 cm
Spring Constant, k	133 N/m	16 N/m

Spring constant, k, of the moving mass device was calculated by using the formula below with reverse method calculation. This is because the natural period of the vessel and mass were already known.

$$\omega_n = \sqrt{\frac{2k}{m}} \quad (4)$$

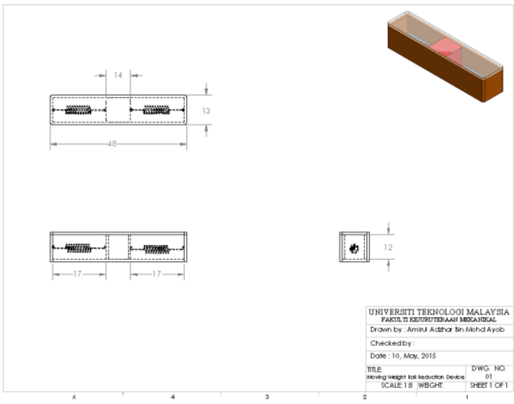

Figure 3: Orthographic drawing of moving mass device

Result and Discussion

Result of Roll Decay Test

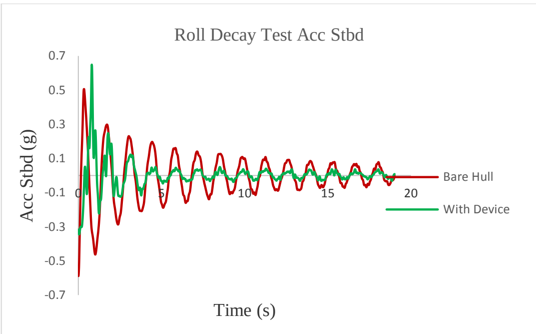

Figure 4: Result of roll decay test with and without moving mass device for starboard side

Figure 4 and Figure 5 show that the roll acceleration of the fishing boat model reduced after providing the model hull with the anti-rolling device (moving mass device).

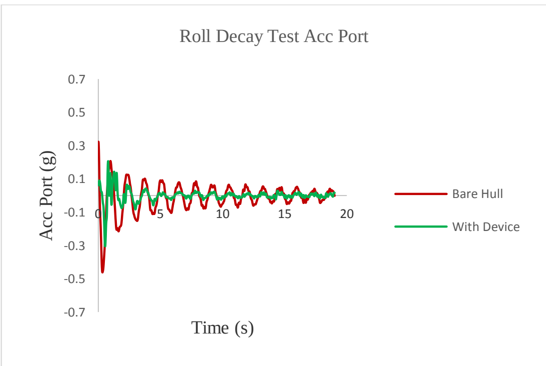

Figure 5: Result of roll decay test with and without moving mass device for port side

Table 4 shows the results from the analysis of bare hull without installation of anti-rolling device.

Table 4: Roll decay analysis results of bare hull

	Roll Decay Analysis Results	Bare Hull		
		Port	Starboard	Average
1	Damping Coefficient, b	0.0134	0.01072	0.01206
2	Critical Damping, b_c	0.3371	0.3371	0.3371
3	Non-dimensional Damping Factor, κ	0.0397	0.0318	0.03575
4	Natural Period Model, T_{nM}	1.36	1.36	1.36
5	Natural Frequency Model, ω_{nM}	4.62	4.62	4.62
6	Natural Period Ship, T_{nS}	2.31	2.31	2.31
7	Natural Frequency Ship, ω_{nS}	2.72	2.72	2.72
8	Damping Ratio, γ	0.0398	0.0318	0.0358

Table 5 shows the results of the bare hull after installing the anti-rolling device (moving mass device). The data showed that the calculated value of non-dimensional damping factor for bare hull was 0.03575.

Meanwhile, the value of non-dimensional damping factor for bare hull with moving mass device was 0.06645. Based on these two values, the percentage of improvement could be calculated by using the simple formula below.

$$= \frac{0.06645 - 0.03575}{0.03575} x100\%$$

$$= 85.87\%$$

Table 5: Roll decay analysis results of bare hull with moving mass device

Roll Decay Analysis Results		Bare Hull with Moving Mass Device		
		Port	Starboard	Average
1	Damping Coefficient, b	0.0222	0.0245	0.02335
2	Critical Damping, b_c	0.3470	0.3557	0.35135
3	Non-dimensional Damping Factor, κ	0.0640	0.0689	0.06645
4	Natural Period Model, T_{nM}	1.32	1.29	1.305
5	Natural Frequency Model, ω_{nM}	4.76	4.87	4.815
6	Natural Period Ship, T_{nS}	2.24	2.19	2.215
7	Natural Frequency Ship, ω_{nS}	2.80	2.87	2.835
8	Damping Ratio, γ	0.0640	0.0689	0.06645

Conclusion and Recommendation

It can be concluded that the roll decay test had been successfully done to achieve the objective of this project, which is to reduce the roll motion for small fishing boats by using moving mass device. The results of this experiment show that 85.87% roll motion can be reduced after installing this device. Thus, the moving mass device is efficient to reduce the rolling motion for small boats. The results showed that the damping moment coefficient was increased from 0.01206 tonnes-m^2/s to 0.02335 tonnes-m^2/s. Besides, the amplitude of the rolling motion decreased after the moving mass device was installed on the small fishing boat model. Furthermore, as the damping coefficient, b, increased due to the installation of moving mass device, the value of non-dimensional damping coefficient also increased from 0.03575 to 0.06645.

In order to improve the roll reduction device, some aspects can be taken into considerations:

i. **Conduct the experiment at the beam sea**
Beam seas test should give more reliable prediction to the effectiveness of the moving mass device.

ii. **Reduce the weight of moving mass**
Moving mass that was used to slide along the rail in the model scale weighed 1.5kg. If it were to be converted into ship scale or the actual scale, it would weigh around 35kg. The size of the moving mass in actual scale is too big and not suitable as fishing boat because it may reduce the cargo in the vessel.

iii. **Increase the spring stiffness, k**
Reducing the weight of the moving mass will increase the spring coefficient directly because the mass is inversely proportional to the spring constant.

References

[1] *Mata-Alvarez-Santullano, F. and Suoto-Iglesias, A., 2014. Stability, safety, and operability of small fishing vessels. Journal of Ocean Engineering 79 (2014). Page 81-91.*

[2] *Marzouk, O.A. and Nafyeh, A.H., 2009. Control of ship roll using passive and active anti-roll tanks. Journal of Ocean Engineering 36 (2009). Page 661-671.*

[3] *Moaleji, R. and Greig, A.R., 2005. On the development of ship anti-roll tanks. Journal of Ocean Engineering 34 (2007). Page 103-121.*

[4] *Beck, R. F., Cummins, W. E., Dalzell, J.F., Mandel, P. and Webster, W.C., 1989. Motions in waves In. Edward V. Lewis. Principles of Naval Architecture Volume III. Jersey City: The Society of Naval Architects and Marine Engineers. Page 126-136.*

[5] *Perez, T. and Blanke, M., 2012. Ship roll damping control. Journal of Ocean Engineering 36 (2012). Page 129-147.*

[6] *Ahmed, F., Gawad, A., Saad, A.R., Nafyeh., A.H., Mook, D.T., 2001. Roll stabilization by anti-roll passive tank. Journal of Ocean Engineering 28 (2001). Page 457-469.*

[7] *Bhattacharya, R., 1972. Dynamic of Marine Vehicles. 1st Edition, Toronto: A Wiley Interscience Publication. Page 75-95, Page 278-297.*

[8] *Maimun, A. Priyanto, A. Wong, K.S. Pauzi, M. and Rafiqul, M. 2009. Effect of Side Keels on Patrol Vessel Safety in Astern Waves. Ocean Engineering. Vol. 36. Pg 277-284.*

[9] *Eugene, R.M., Slager, J.J. and Webster, W.C., 1974. Development of Technical Practices for Roll Stabilization System Selection, Hydronautics, Inc, Technical Report 7401.06-1.*