Contributions on Roll Damping Coefficient for Fishing Vessels

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ABSTRACT

Roll damping coefficient is one of the main parameters that characterize the performance of a ship in a seaway and, consequently, it is the most influential factor in certain stability criteria failure modes. This article applies the approved Dead Ship Condition failure mode to a trawler fishing vessel using two different damping coefficients; one determined applying the Ikeda's Method and the other determined empirically by forced roll tests. Both results will be compared, analysed and discussed.

Keywords: *Roll damping, forced roll tests, Ikeda's method, ship stability, ship safety, fishing vessels.*

1. INTRODUCTION

Roll damping coefficient is one of the main parameters that characterize the performance of a ship in a seaway and the corresponding operability and safety.

It has been the great unknown for many years and possibly still is (Falzarano et al., 2015). Recently, and specially during the development of the Second Generation Intact Stability Criteria (SGISC), described in (Peters et al., 2011) and (Umeda et al., 2016), emphasis has been placed on it as it influences the majority of the failure modes considered. In fact, the damping coefficient is a determining parameter in three of the five established failure modes, namely parametric roll, dead ship condition and excessive acceleration. This parameter has been studied extensively for passenger and cargo vessels, however, fishing vessels have been left out of most of the studies, (Bačkalow et al., 2016). The main reason is that there are significant differences between hull forms depending on the country and the type of fishing gear.

In the present article, a trawler fishing vessel is used to evaluate if the accepted semi-empirical method by the IMO (IMO, 2016a), the so-called Simplified Ikeda's method (Kawahara et al., 2009), properly estimate the damping coefficient for this particular fishing vessel. Moreover, the dead ship condition (DSC) failure mode is applied to this vessel, considering both the semi-empirical damping coefficient and the one obtained by forced roll test experiments. Evaluating, therefore, the influence of the roll damping coefficient on the DSC failure mode.

2. SHIP DESCRIPTION

A trawler fishing vessel of 41.7 LOA has been used. A profile view of the vessel is shown in Figure 1 and Table 1 shows the main characteristics of the ship. In Figure 2 the righting arm curve in calm water of the loading condition under analysis is shown.

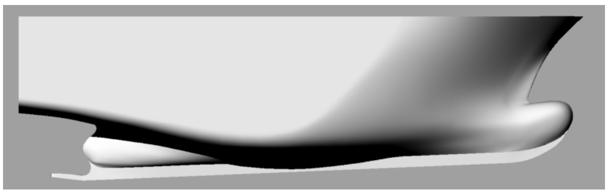

Figure 1: Profile view of the trawler fishing vessel.

Table 1: Trawler fishing vessel characteristics.

Parameter	Value
Length overall, LOA (m)	41.700
Length at the waterline, LWL (m)	40.111
Moulded Breath, B (m)	11.500
Draught, D (m)	4.072
Trim, t (m)	0.000
Displacement, Δ (t)	997.900
Block coefficient, C_B (-)	0.424
Midship coefficient, C_M (-)	0.736
Corrected metacentric height, GM_C (m)	0.774
Lateral windage area, A_L (m^2)	248.020
Vertical distance from the centre of A_L to D/2, Z (m)	5.300
Natural roll frequency, w_0 (rad/s)	0.592
Service velocity, V_S (kn)	12.000

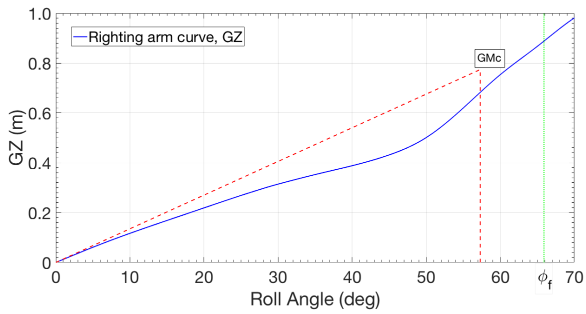

Figure 2: Righting arm curve of the trawler fishing vessel (ϕ_f, represents the down-flooding angle)

This vessel was tested at the ETSIN towing tank, whose dimensions are 100m length, 3.8m breath and 2.2m depth. The scale used for the ship model is 20.666.

3. DETERMINATION OF THE ROLL DAMPING COEFFICIENT

Simplified Ikeda's method

The Ikeda's method is based on the assumption that the damping coefficient can be split in different independent components, such as the frictional and eddy damping components (Himeno, 1982). The Simplified Ikeda's method is a set of regression formulas for each independent damping coefficient component obtained applying the Ikeda's method to a series of parametric hull shapes (Kawahara et al., 2009).

Each regression formula has applicable ranges which depend on the block coefficient, the midship coefficient, the breath to depth ratio and the vertical position of the centre of gravity to depth ratio. As these formulas were obtained considering cargo vessels, the trawler fishing vessel used in the present work is outside the applicable ranges, namely the block coefficient and the midship coefficient. However, as it is currently recommended in (IMO 2016b), if a vessel parameter exists outside the applicable range, the Simplified Ikeda's method may be applied only keeping as the parameter value the one corresponding to the limited value. Therefore, instead of using the coefficients shown in Table 1, the following coefficients have been considered for the Simplified Ikeda's method:

- $C_{B,ikeda} = 0.500$
- $C_{M,ikeda} = 0.900$

As a result of applying the Simplified Ikeda's method to a range of roll angle values from 0 to 25 deg, the following damping coefficients have been obtained:

- $\mu = 0.0020$ [1/s]
- $\beta = 0.1898$ [-]
- $\delta = 0.0000$ [s]

Forced roll tests

Apart from obtaining roll damping coefficients by semi-empirical or theoretical methods, it may be obtained experimentally.

One of the most relevant experimental technique is the forced roll test (Handschel et al., 2014). In these kind of experiments, the ship rolls due to an external moment or force. The most common way is to exert a roll moment to the model applying beam sinusoidal waves or by generating a sinusoidal moment using contra-rotating masses. From forced roll tests results, the roll response curves are obtained. Each roll response curve represents the mean roll amplitude that the ship experiences per each wave slope (or, not being the current case, each wave height) and per each wave frequency. Taking into account the peak amplitude and frequency values, the damping coefficient components may be obtained.

In the present work, the moment was generated using an internal moving mass which moves transversally through a linear rail.

The internal moving mass is placed at the centre of the linear guide and is allowed to move, from the centre, 90 mm on each side. This internal mass moves thanks to an electrical engine controlled by an encoder, as shown in Figure 3.

As the internal mass in motion not only produces a roll moment but also other forces and moments, to avoid these negative effects, as far as feasible, the linear guide is placed inside and near the centre of gravity of the ship model. The linear guide position in the trawler fishing vessel model is shown in Figure 4.

The roll motion and the other rotations and translations are measured using an optical trackable system, namely the OptiTrack. The trackable panel position is shown in Figure 4.

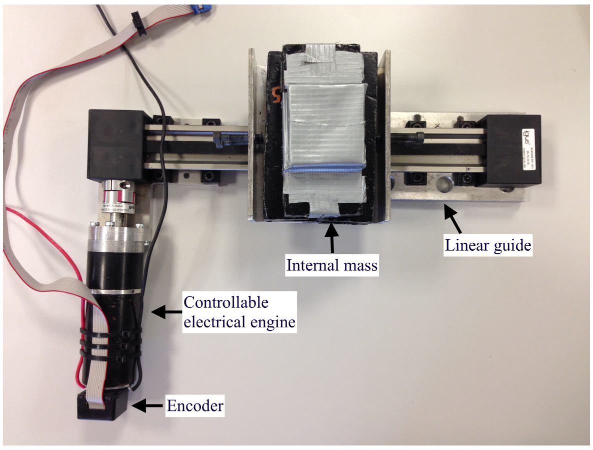

Figure 3: Linear rail components.

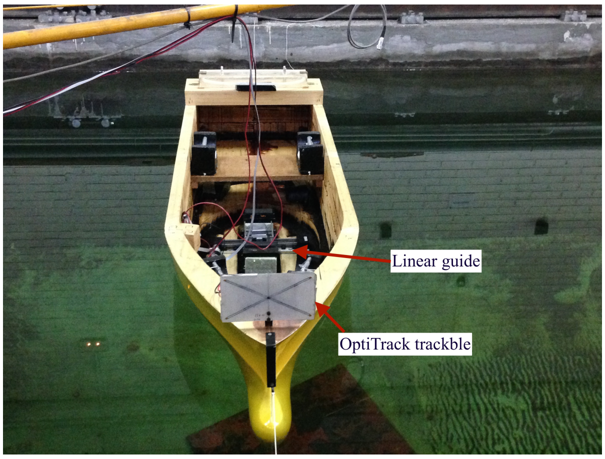

Figure 4: Linear guide and trackable panel position.

The internal moving mass weight is such that a specific wave slope is simulated. The moving weights values are deducted from the equilibrium between the static moment generated by the moving mass located at its maximum amplitude position and the ship righting moment, as Equation 1 shows:

$$m\, y_{m,max} \cos\phi = \Delta\, GZ(\phi) \tag{1}$$

Where:

- m, represents the moving mass weight.
- $y_{m,max}$, represents the maximum mass amplitude.
- ϕ, represents the roll angle.
- $GZ(\phi)$, represents the righting arm value for a specific roll angle.

Three wave slopes (α) were considered, namely 0.5, 1.0 and 1.5 deg, thus, three different roll response curves were obtained. The experimental values are shown in Figure 5.

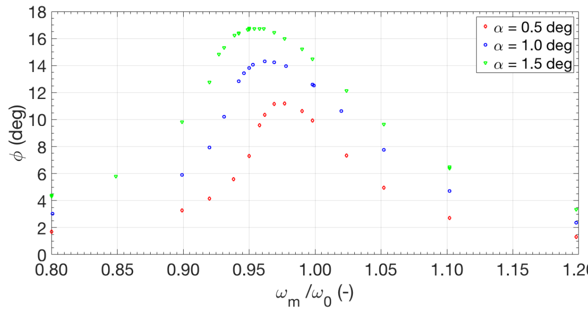

Figure 5: Experimental roll response curves

The peak amplitude and frequency values are shown in Table 2.

Table 2: Peak frequencies and amplitudes values per each wave slope

Wave slope, α (deg)	Peak frequency, ω_{peak} (rad/s)	Peak amplitude, A_{peak} (deg)
0.5	2.63	11.2
1.0	2.59	14.3
1.5	2.56	16.8

The damping coefficients are obtained fitting the equivalent linear damping coefficient, $\mu_{eq}(\omega_{peak}, A_{peak})$, to the following Equation (Bulian et al., 2009):

$$\mu_{eq}(\omega_{peak}, A_{peak}) = \mu + \frac{4}{3\pi}\beta(\omega_{peak}\, A_{peak}) + \frac{3}{8}\delta(\omega_{peak}\, A_{peak})^2 \tag{2}$$

Where $\mu_{eq}(\omega_{peak}, A_{peak})$ is obtained from Equation 3:

$$\mu_{eq}(\omega_{peak}, A_{peak}) = \frac{m\, y_{m,max}}{\Delta GM}\,\frac{\omega_0^2}{2\, A_{peak}\omega_{peak}} \tag{3}$$

Equation 3 has been deducted from the one degree of freedom (1-DoF) roll equation, shown in Equation 4, assuming that the effect of the internal moving mass can be represented simply by an external forcing term and knowing that the actual mass motion is sinusoidal.

$$\phi'' + 2\mu_{eq}\phi' + \omega_0^2 \frac{GZ(\phi)}{GM} = \omega_0^2 \frac{m\, y_{m,max} \sin \omega_m t}{\Delta GM} \quad (4)$$

As the moving mass motion is sinusoidal, it is considered that the response of the ship is sinusoidal too. Thus, at resonance:

$$\phi = A_{peak} \sin \omega_{peak} t$$
$$\phi' = A_{peak}\, \omega_{peak} \cos \omega_{peak} t \quad (5)$$

And knowing that at resonance the damping and the external moment components are in phase and opposed to each other, as stated in Equation 6. Therefore, Equation 3 is deducted from Equation 6.

$$2\mu_{eq} A_{peak}\, \omega_{peak} = \omega_0^2 \frac{m\, y_{m,max}}{\Delta GM} \quad (6)$$

From the fitting of the equivalent linear damping coefficient obtained in Equation 6 with Equation 2, the following damping coefficients for the trawler fishing vessel have been obtained:

- μ = 0.0038 [1/s]
- β = 0.0000 [-]
- δ = 0.5951 [s]

Comparison

In Table 3 the damping coefficients obtained using both Simplified Ikeda's method and forced roll tests are shown.

Table 3: Roll damping coefficients obtained

Method used	μ [1/s]	β [-]	δ [s]
Simplified Ikeda's Method	0.0020	0.1898	0.0000
Forced Roll Tests	0.0038	0.0000	0.5951

As can be seen in Table 3, the Simplified Ikeda's method characterize the roll damping of the trawler fishing vessel as being linear-quadratic, while the forced roll tests experiments characterize it as being linear-cubic. It is a considerable difference which will definitely influence the DSC evaluation.

4. EVALUATING THE DEAD SHIP CONDITION FAILURE MODE

The fishing vessel under analysis complies with the Level 1 criterion for the DSC failure mode but it does not complies with the Level 2.

The Level 2 criterion for the DSC failure mode has been evaluated for the trawler fishing vessel using a code developed by the authors.

The code has been verified analysing the robustness of the results but it has not been validated as no complete sample calculations have been available. For instance, in the example of application of the Level 2 DSC Criterion shown in the Explanatory Notes (IMO, 2016c) some input data is missing.

In Table 4, the results of the DSC Level 2 evaluation using both damping coefficients are shown considering the long-term probability index denoted as C:

Table 4: Dead Ship Condition Level 2 evaluation.

Method used	C
Simplified Ikeda's method	0.124
Forced Roll Tests	0.174

As can bee seen in Table 4, the trawler fishing vessel does not comply with the DSC Level 2 criterion as both C values are above 0.06 or 0.04, which are the two standard values under consideration.

Despite not complying with the criterion, it is worth mentioning that the C values obtained differ to each other by 40%, which is a considerably high difference. Also, even if the C value obtained using the forced roll tests damping coefficient is ship-specific, no scale effects have been considered. Therefore, the DSC Level 2 criterion has a large sensibility to the roll damping, as also emphasized in (Míguez et al., 2015).

5. CONCLUSIONS

The Level 2 criterion for the DSC failure mode has been applied to a trawler fishing vessel considering two different damping coefficients.

Each method has some drawbacks. The first method used to obtain the damping of the current fishing vessel has been the Simplified Ikeda's method, which has the inconvenience of being determined considering cargo vessels, besides being the ship under consideration outside some applicable ranges. The second method used is forced roll tests, which has the advantage of being ship-specific although no scale effects are considered. However, the latest method is expensive and time consuming.

The results obtained either considering both damping coefficients show that the fishing vessel considered does not comply with the Level 2 criterion. The most relevant fact is that the long-term probability index obtained (C) differ by 46% between both methods, which is a considerable and non-insignificant difference.

Consequently, the difference of the C values between both cases needs to be further analysed. Despite of this, it is an indicator of the great influence that the damping coefficient has in the Dead Ship Condition Level 2 criterion.

6. QUESTIONS TO BE FORMULATED

During the development of the present work, some questions have emerged.

Referring to the damping coefficient determination:

- Although it is known that the Simplified Ikeda's method may be used for cargo vessels and that it is recommended to use it when inside all the application ranges, it is of common understanding that the use of this method outside the application ranges is conservative. However, from the results obtained it seems to be the opposite. Therefore, have the consequences of being outside the application ranges of the Simplified Ikeda's method been analysed?
- Otherwise, when using experimental tests, there are many points that can be raised due to the lack of standard. Moreover, depending on the experimental technique used, the damping coefficients may differ considerably as the hydrodynamic scenario is different. Is it necessary to develop standard procedures for decay tests and forced roll tests?
- Also, regarding experimental tests, there are still many uncertainties regarding the damping scale effects. Do the scale effects have to be taken into account? If so, how?

Referring to the Level 2 Criterion for the Dead Ship Condition failure mode:

- It is not possible to validate the codes as there is not a complete sample calculation or example. Should it be a high priority issue for the finalization of the SGISC?
- As seen in the present work, depending on the damping coefficient used, considerable differences may be obtained in the C value. Therefore, it may be determinant when checking the compliance with the criteria. Has the influence of the damping coefficient on the DSC Level 2 criterion been studied?

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