Different Computations of Parametric Roll Level 2 Criterion

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ABSTRACT

The second generation intact stability criteria are currently under development and validation at the IMO. These criteria are organized in 5 failure modes and 3 levels of assessment in each failure mode. The level 2 for parametric roll failure mode consists of two checks marked C1 and C2. The C2 check is based on the computation of the maximum roll angle of the ship in both head and following sea by solving the differential equation of parametric roll through a probabilistic approach. The future regulation proposes an analytical solution of the maximum roll angle. It also allows a numerical one-degree-of-freedom simulation for solving the differential equation and finding the maximum roll angle without specifying any method or parameter. During the latest International Conference on the Stability of Ships and Ocean Vehicles, experts in the field proposed a method and some parameters for this numerical solving: initial roll angle, simulation duration (in terms of number of ship's natural roll periods) and non-linear GZ. This paper deals with the influence of these parameters used to compute the C2 check on the resulting KG_{max} curve. Results show that the simulation duration has a major influence on the KG_{max} while the initial roll angle has a limited influence. As expected, linearizing GZ is not relevant.

Keywords: *Parametric Roll, Differential Equation, KG_{max} curve*

1. INTRODUCTION

The second generation intact stability criteria are currently being developed and validated at the IMO. They have been presented in detail by Umeda (2013). This paper deals with their version amended in February 2015 and January 2016 by the Sub-Committee on Ship Design and Construction of the IMO (SDC 2/WP.4 and SDC 3/WP.5). These new criteria are organized in 5 failure modes: parametric roll, pure loss of stability, dead ship condition, surf-riding/broaching and excessive acceleration. In each failure mode, 3 levels of assessment are defined. The first level requires simple calculations and ensures large safety margins. The second level is based on more complex computations associated with probabilistic approaches of the phenomena. It ensures medium safety margins. The third level consists of a direct assessment using numerical simulations and ensures optimized safety margins. The second level of parametric roll considers two verifications. The first check (C1) considers the GM variation in waves and the reference speed corresponding to the parametric resonance using a probabilistic approach based on a table of 16 weighted waves. This paper deals with the second check of parametric roll failure mode (C2). This check considers the maximum roll angle in each of the 197 non-zero-weighted waves of the IACS Wave Scatter Diagram (IACS, 2001) for 7 different ship speeds corresponding to head and following seas. Although both checks are embedded in the same criterion, C2 is considered as a separate criterion in this paper. Thus, a KG_{max} curve can be associated with it for any ship. The maximum roll angle is calculated as the maximum absolute value of the function $\Phi(t)$ solution of the differential equation of parametric roll. The new regulation (SDC 2/WP.4 and SDC 3/WP.5) proposes to calculate the maximum roll angle from an analytical solution of the differential equation. It also allows a one-degree-of-freedom numerical simulation. During the 12th International Conference on the Stability of

Ships and Ocean Vehicles, Peters *et al.* (2015) proposed to solve this equation with a simulation time equal to 15 natural roll periods of the ship and an initial roll angle equal to 5 degrees. They also recommended considering a non-linear GZ. These proposals have been included in the explanatory notes of the new regulation (SDC 3/WP.5). The goal of this paper is to study the influence of each of these proposals on the KG_{max} curves associated with the C2 criterion for several ships chosen for their variety of behavior with regard to parametric roll.

2. GENERAL PRINCIPLES

Differential Equation

The differential equation to be solved is established as follows:

$$J_{44}\ddot{\Phi} + B_{44}\dot{\Phi} + WGZ(\Phi, t) = 0 \quad (1)$$

J_{44} denotes the roll moment of inertia, including added inertia. B_{44} denotes the non-linear damping coefficient. In this paper, it is computed according to Kawahara *et al.* (2009) and Ikeda *et al.* (1978) for the lift component. W denotes the ship's weight. $GZ(\Phi,t)$ is the righting arm, as a function of the roll angle Φ and the time t, varying with the wave encounter frequency. In this study, GZ is computed in calm water and "modulated" by the GM in waves, as proposed by Belenky *et al.* (2011), Peters *et al.* (2015) and SDC 3/WP.5. The solving of the differential equation provides the maximum roll angle, which is used to calculate the coefficient C2. Since the number of non-zero-weighted waves is large, Grim's effective wave height concept (1961) is used to render the computation faster. The method used to compute C2 and the associated KG_{max} is detailed by Grinnaert *et al.* (2016).

Ships

The KG_{max} curves associated with the C2 criterion are computed for 4 different ships chosen for their different behavior with regard to parametric roll. The main particulars of all ships are listed by Grinnaert, *et al.* (2016).

The first ship is the well-known C11 container ship. She is vulnerable to parametric roll (France, *et al.* 2001).

The second ship is a 319 m container ship. An extreme-roll accident occurred on this ship (Kaufmann, 2009). She is assessed as possibly vulnerable to parametric roll by the level 2 criterion (Grinnaert, *et al.*, 2016) although neither the test in the towing tank nor direct assessment computation have proven this yet.

The third ship is a roll-on roll-of vessel presented by Garme (1997). She is assessed as non-vulnerable to parametric roll by the level 2 criterion although parametric roll may occur in some conditions in some lightly-weighted waves (Grinnaert, *et al.*, 2016).

The last ship is a tanker. The wall-sided shape of her hull from bilge to deck makes her clearly non-vulnerable to parametric roll (Grinnaert, *et al.*, 2016).

3. INFLUENCE OF SIMULATION DURATION

Since parametric roll is a resonance phenomenon due to the repetition of the encounter of waves, attaining the steady state roll amplitude is essential to determine the vulnerability to this failure mode. Thus, the duration of the simulation is important. The KG_{max} curves associated with the C2 criterion are computed for the four ships previously presented for 6 different simulation durations, given as a number of the ship's natural roll period. The following durations are tested: 3, 4, 6, 10, 15 and 20 natural roll periods. Peters *et al.* (2015) and SDC 3/WP.5 recommend a simulation duration equal to 15 roll periods.

Figure 1 and Figure 2 show the results for both container ships. We observe that the KG_{max} significantly varies with the time duration, but the curves associated with 10, 15 and 20 roll periods are fully coincident for both ships. This proves that the steady state roll amplitude has been attained between 6 and 10 roll periods.

Figure 3 shows the results for the Ro-Ro vessel. We observe that all curves are close together. The KG_{max} is slightly affected by the simulation duration. The curves associated with 10, 15 and 20 periods are fully coincident.

Figure 4 shows the results for the tanker. We observe that all curves are coincident and correspond to zero-GM. This proves that the tanker is not vulnerable to parametric roll: parametric roll never occurs, regardless of the wave and speed (the C2 coefficient is set to 1 if the average value of GM in waves is negative, see Grinnaert, *et al.* 2016).

The simulation duration has no effect on KG_{max} curves.

This first test shows that:

1) The more the ship is vulnerable to parametric roll, the more the simulation duration has an influence on the KG_{max} curve associated with the C2 criterion.

2) The relevance of the simulation duration equal to 15 natural roll periods of the ship proposed by Peters, *et al.* (2015) is confirmed.

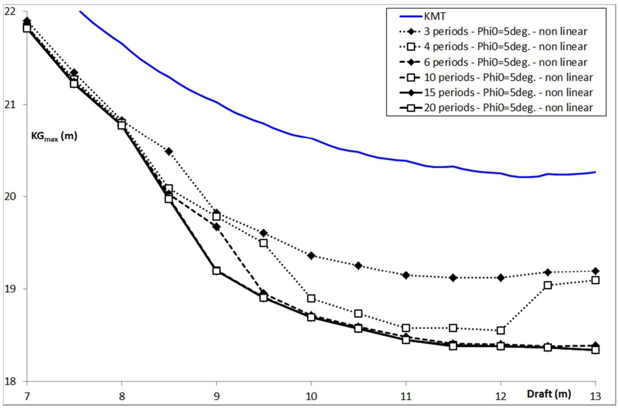

Figure 1: Influence of simulation duration on KG_{max} curves associated with the C2 criterion for the C11 container ship.

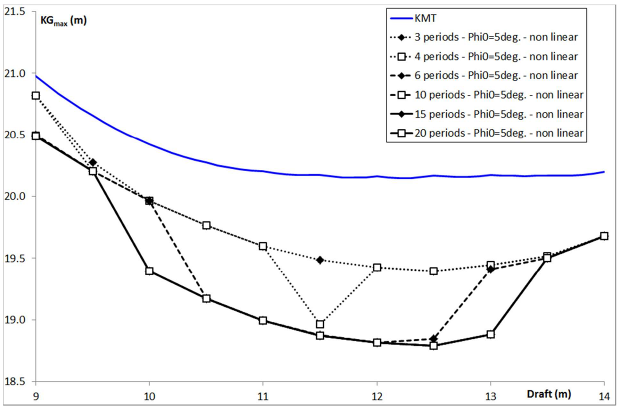

Figure 2: Influence of simulation duration on KG_{max} curves associated with the C2 criterion for the 319 m container ship.

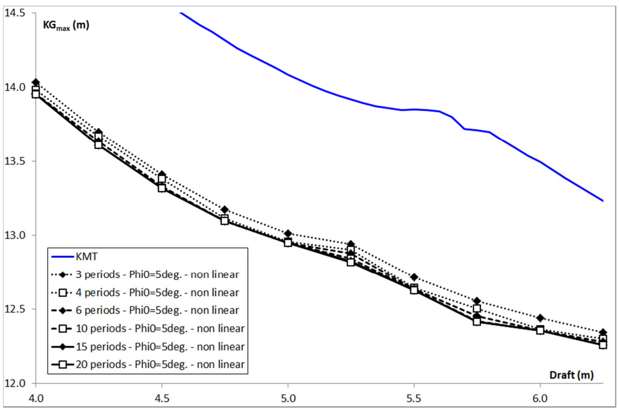

Figure 3: Influence of simulation duration on KG_{max} curves associated with the C2 criterion for the Ro-Ro vessel.

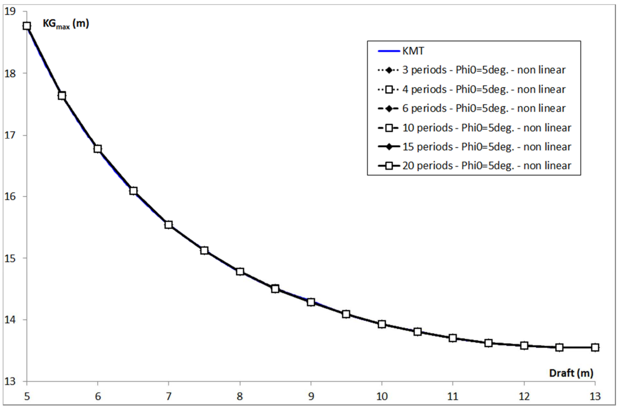

Figure 4: Influence of simulation duration on KG_{max} curves associated with the C2 criterion for the tanker (all curves are coincident).

4. INFLUENCE OF INITIAL ROLL ANGLE

The right term in equation (1) is equal to zero because there is no transverse excitation in parametric roll. The ship is assumed to sail in pure head or following seas. Thus, a non-zero initial roll angle (or a non-zero initial roll speed) must exist to initialize the numerical phenomenon during the simulation. Peters *et al.* (2015) and SDC 3/WP.5 recommend an initial roll angle equal to 5 degrees. Since the C2 coefficient increases if the maximum roll angle exceeds 25 degrees (see SDC 2/WP.4), it may be interesting to start the simulation with an initial roll angle larger than 5 degrees, in order to reduce the number of natural roll periods of the ship needed to attain the steady state roll amplitude. Computations performed with an initial roll angle equal to 10 degrees show that the steady state roll amplitude is attained between 6 and 10 roll periods, as if the initial roll angle were 5 degrees. Computations with other durations between 6 and 10 roll periods would probably prove that the initial roll angle has an influence on the duration needed to attain the steady state roll amplitude. However, the initial roll angle has no major influence on this duration.

Even if the influence of the initial roll angle on the duration needed to attain the steady state roll amplitude is limited, the initial roll angle may also have an influence on the KG_{max}. This should be limited, but not zero. KG_{max} curves are computed for the ships previously presented with initial roll angles equal to 5 and 10 degrees. The results are shown in Figure 5 to Figure 8 respectively for the C11 container ship, the 319 m container ship, the Ro-Ro vessel and the tanker. As expected, we observe that the initial roll angle has no influence on the KG_{max} curves of the tanker since she is not vulnerable to parametric roll (Figure 8). On the three other ships, the initial roll angle has a light influence on the KG_{max}. Only one point differs significantly for the 319 m container ship (Figure 6, draft equal to 9.5 m, difference of approx. 0.5 m between both KG_{max}).

To conclude this second section, we can note the following:

1) The initial roll angle has no major influence on the duration needed to attain the steady state roll amplitude.

2) Since the initial roll angle has a limited influence on the KG_{max} associated with the C2 criterion, it is wise to clearly specify its value in the future regulation.

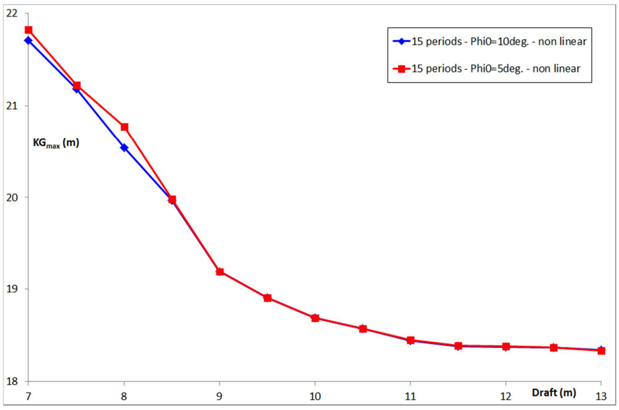

Figure 5: Influence of the initial roll angle on KG_{max} curves associated with the C2 criterion for the C11 container ship.

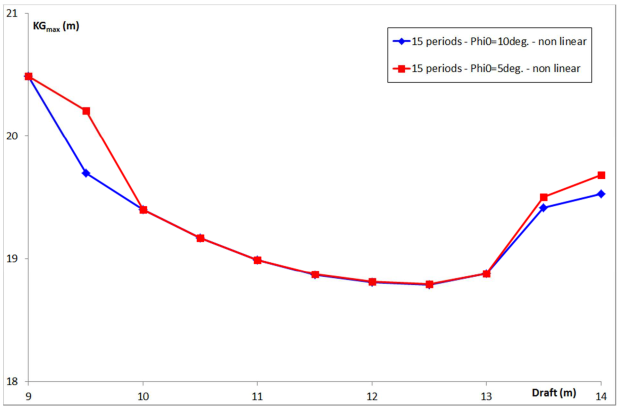

Figure 6: Influence of the initial roll angle on KG_{max} curves associated with the C2 criterion for the 319 m container ship.

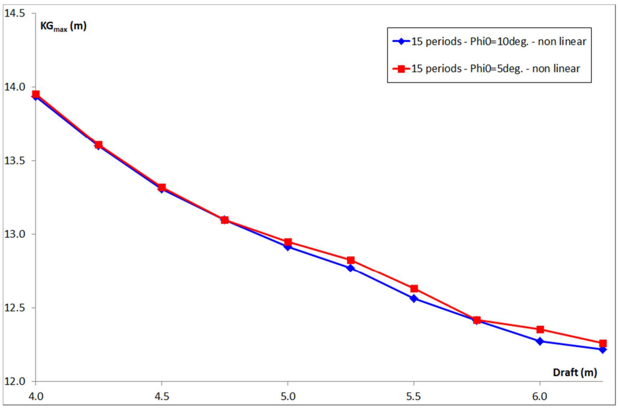

Figure 7: Influence of the initial roll angle on KG_{max} curves associated with the C2 criterion for the Ro-Ro vessel.

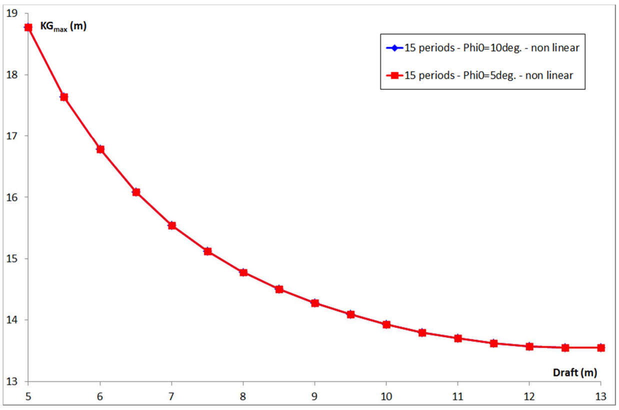

Figure 8: Influence of the initial roll angle on KG_{max} curves associated with the C2 criterion for the tanker (both curves are fully coincident).

5. INFLUENCE OF LINEARIZED GZ

Parametric roll is a failure mode that could cause capsizing. Thus, it seems logical to study it at large roll angles with a non-linear GZ which is recommended by Peters *et al.* (2015) and SDC 3/WP.5. However, the C2 coefficient increases if the maximum roll angle exceeds 25 degrees (see SDC 2/WP.4). Thus, an error on GZ at angles larger than 25 degrees has no influence on the result. Since many ships have a linear GZ up to an angle equal to 25 degrees, it is interesting to compare KG_{max} associated with the C2 criterion computed with linear and non-linear GZ. GZ curves are computed in calm water for the four ships previously presented at full load draft and KG equal to KG_{max} given by the C2 criterion (except for the tanker where the KG has been chosen for GM equal to 0.175 m since her GM_{min} associated with C2 is zero). They are shown in Figure 13 to Figure 16. All configurations of GZ versus GM are presented: the non-linear GZ is significantly larger than the linearized GZ ($GZ_{lin} = GM \times \Phi$) for both the 319 m container ship and tanker (Figure 14 and Figure

16). The non-linear GZ is lower than the linearized GZ for the Ro-Ro vessel (Figure 15) and the GZ of the C11 container ship is relatively linear (Figure 13). The non-linear GZ and linearized GZ are used to compute the KG_{max} curves associated with the C2 criterion. The results are shown in Figure 9 to Figure 12.

As expected, the linearized GZ reduces the KG_{max} of the 319 m container ship (Figure 10). This reduction is so large that considering the linearized GZ instead of the real GZ would probably be an error.

It would be logical to expect a similar result on the tanker (Figure 12) since her GZ curve has the same configuration, but the linearized GM has no influence on KG_{max} at a full load draft (11 m). However, KG_{max} is reduced by the linearized GZ at lower drafts: the tanker is assessed as vulnerable to parametric roll if her GM is lower than 50 centimeters. The “jump” of KG_{max} between drafts equal to 10 m and 10.5 m is a characteristic of the KG_{max} curves associated with the C2 criterion. These KG_{max} curves are the lower envelope of the restricted zones in the surface formed by both draft and KG (where C2>0.06, see Grinnaert, *et al.*, 2016). Lesser jumps are observed in Figure 10 and Figure 11.

The result on the Ro-Ro vessel is unexpected (Figure 11): at full load draft (5.5 m), the KG_{max} given by the linearized GZ is more conservative than that given by the real GZ although the linearized GZ is larger than the real GZ. This is due to the highly non-linear behavior of the parametric roll differential equation.

The result on the C11 container ship is as expected (Figure 9): since the non-linear GZ and linearized GZ almost overlap up to an angle of 25 degrees, linearizing the GZ has a very limited influence on the KG_{max} associated with C2.

To conclude this last section, we observe that, as expected, linearizing the GZ is not relevant, unless the real GZ is linear up to 25 degrees for all drafts scanned by the KG_{max} curve.

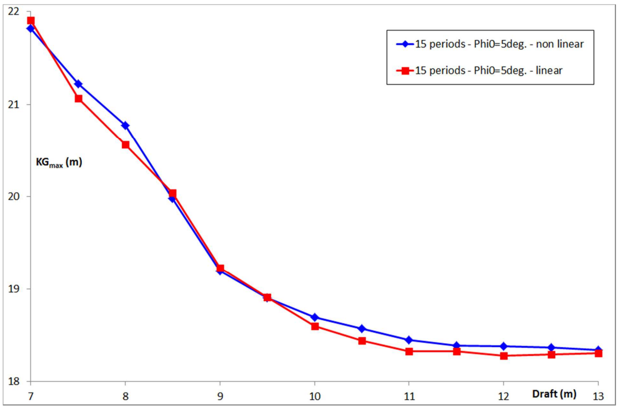

Figure 9: Influence of the GZ linearity on KG_{max} curves associated with the C2 criterion for the C11 container ship.

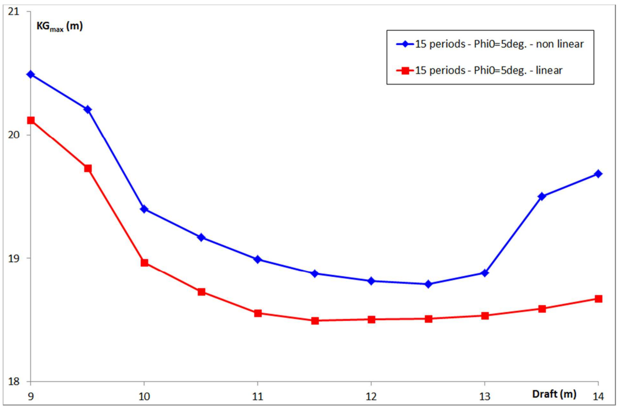

Figure 10: Influence of the GZ linearity on KG_{max} curves associated with the C2 criterion for the 319 m container ship.

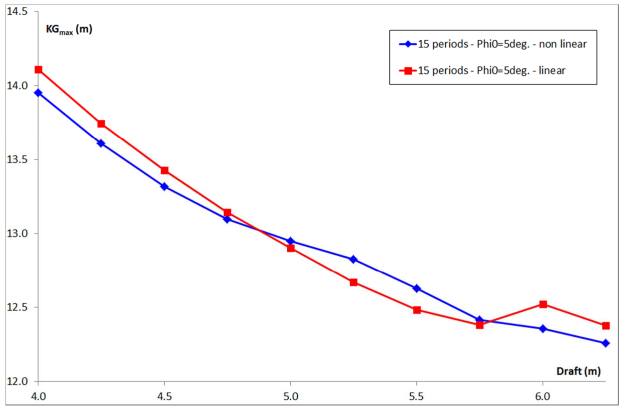

Figure 11: Influence of the GZ linearity on KG_{max} curves associated with the C2 criterion for the Ro-Ro vessel.

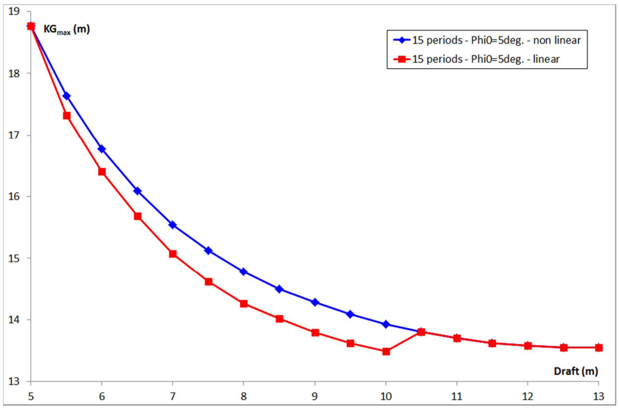

Figure 12: Influence of the GZ linearity on KG_{max} curves associated with the C2 criterion for the tanker.

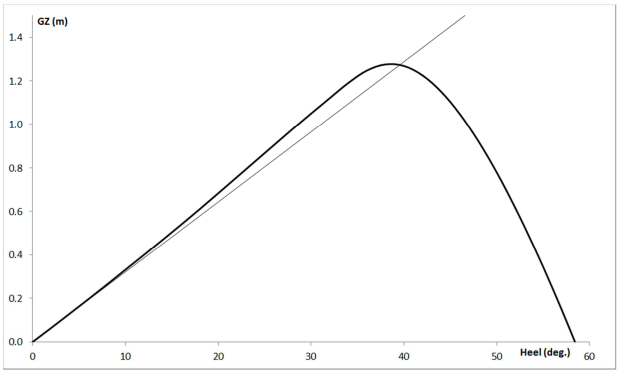

Figure 13: GZ curve of the C11 container ship.

Figure 14: GZ curve of the 319 m container ship.

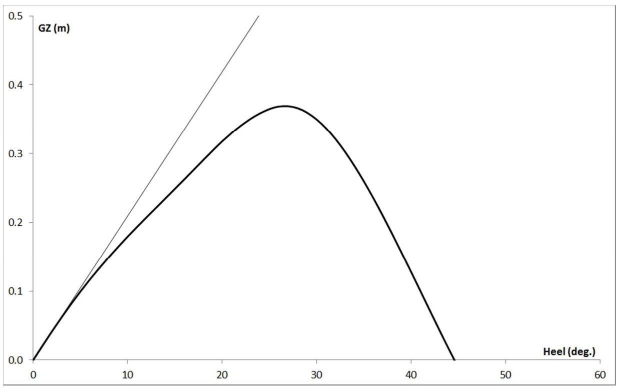

Figure 15: GZ curve of the Ro-Ro vessel.

Figure 16: GZ curve of the tanker.

6. CONCLUSION

KG_{max} curves associated with the C2 criterion have been computed for four different ships chosen for their variety of behavior with regard to parametric roll. The influence of the one-degree-of-freedom simulation duration, the initial roll angle and of linearizing the GZ has been assessed.

The results of these sensitivity tests clearly show that the more the ship is vulnerable to parametric roll, the more the simulation duration has an influence on the KG_{max} associated with the C2 criterion. A simulation duration equal to 15 natural roll periods of the ship guarantees the attainment of the steady state roll amplitude for a ship known as highly vulnerable to this failure mode. The initial roll angle has no major influence on the duration needed to attain the steady state roll amplitude, but its influence on the KG_{max} exists. In the latest amendment of the new regulation (SDC 3/WP.5), the values of both the simulation duration and initial roll angle are clearly specified in order to avoid any possible interpretation of the rule. As expected, except in special cases, linearizing the GZ is irrelevant.

7. REFERENCES

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