Mitigation manoeuvres to reduce parametric roll on a naval ship

Vivien Luthy, *CMA CGM*, France, vivien.luthy@supmaritime.fr
François Grinnaert, *Ecole Nationale Supérieure Maritime*, francois.grinnaert@supmaritime.fr
Jean-Yves Billard, *Ecole navale*, jean-yves.billard@ecole-navale.fr

ABSTRACT

Parametric roll is a serious operational issue leading to undesired heavy roll motion. Weather routing permits to avoid the worst conditions. However, unexpected weather conditions may appear. Consequently, real time solutions have to be proposed to the officer of the watch. Several methods to identify parametric roll based on the ship motions are available and provide alerts informing the officer of the watch of the existing danger. Following this alert, the officer of the watch may decide to manoeuvre to avoid high roll motions and secure cargo safely. This paper proposes to assess different possible manoeuvres in real sea states after parametric roll is detected, such as course or speed modification. Therefore, simulations in six degrees of freedom are conducted on a large naval ship using the time domain solver Fredyn. When parametric roll is observed, an identical simulation is rerun with a manoeuvre ordered after the parametric roll detection with a slight delay corresponding to the crew reaction time. Simulations are compared and the efficiency of each manoeuvre is assessed. The results show that a significant course alteration permits to reduce high roll motions after parametric roll is detected.

Keywords: *Parametric roll, Time domain simulation, Real sea state, Real time evaluation, Manoeuvres*

1. INTRODUCTION

Parametric roll is a stability failure in waves which can lead to severe roll motions. Recent accidents have been or may be imputed to this phenomenon (France, 2001, Carmel, 2006, ATSB, 2020, MAIB 2020, Theillard 2020, DMAIB 2022). Those accidents have got the attention of the community, leading to extensive studies on this topic and to new intact stability criteria (IMO, 2020). The physic of the phenomenon is nowadays well understood. However, this phenomenon is hardly operationally avoided due to the complexity of the sea state estimation and to operational constraints. Real time evaluation methods of the appearance of parametric roll based on inertial unit data exist (Galeazzi, 2009, Galeazzi 2015). When those evaluation methods are implemented onboard (Acomi, 2016), they permit to inform the officer of the watch of the existing risk of parametric roll. However, most of the time the officer of the watch does not have the culture and sufficient information to execute the most adequate manoeuvre to reduce this risk. Operationally naval ships are more likely to be engaged in heavy weather than merchant ships. However, even if some naval ships are identified as less subject to this phenomenon due to their hull shape (frigates), some other naval ships present a hull shape close to the one usually observed on merchant ships. Therefore, naval officers are not used to encounter this phenomenon on their ships. The aim of this paper is to present the impact of different manoeuvres on the roll motions in real sea state when parametric roll is observed on a large naval ship. First the time domain solver used to simulate the ship motions is presented and a brief description of the method used to detect parametric roll is exposed. Then the manoeuvres to avoid parametric roll are presented. Finally, a significative case demonstrating the efficiency of each manoeuvre on a real sea state is presented and discussed.

2. TIME DOMAIN SIMULATION

Time domain solver

The seakeeping and manoeuvring time-domain solver Fredyn Version 16 (MARIN, 2021) from CRNAV (more information on https://www.marin.nl/en/jips/networks/crnavies) is chosen to conduct this study. Such solver permits to realize simulations in 6 degrees of freedom. The Frigate Dynamics (Fredyn) solver is fully adapted to naval ships (MARIN, 2011). Here, hydrodynamics forces acting on the hull are computed using a partially non-linear strip theory. Excitation forces and motion response in waves are considered in detail and validated. The naval ship selected for this study presents a hull shape similar to the one of large merchant ships.

Time domain simulations in 6 DoF permits to simulate rare stability failures such as parametric roll.

Parametric roll detection

The parametric roll detection method used throughout this paper has not yet been published. A brief description of it is proposed hereafter. However, the method to detect parametric roll is not the topic of this paper. The detection method does not influence the results. Galeazzi method (Galeazzi, 2009, Galeazzi 2015) or Octopus method (Acomi, 2016) would lead as well to the detection of parametric roll.

Method

The method used to detect parametric roll throughout this paper is based on the roll and pitch time series, and on the physics of the phenomenon. It considers that the pitch time series is the direct image of the encountered waves. Therefore, the encounter period is assumed to be equal to the pitch period (no matter the wave direction). The ratio of the roll over pitch period is considered. The shape of the roll time series is analysed to characterize the development of parametric roll. Finally, the coupling between pitch and roll motions is studied to detect the appearance of the phenomenon. Operationally, parametric roll detection is realized only if the roll amplitude is greater than a threshold to reduce the alarm rate (even if parametric roll is detected).

Validation

This detection method has been validated on simulations in head and following seas permitting to evaluate the parametric roll response detection rate. As well, the method has been tested in beam seas to evaluate the parametric roll false response detection rate. Results show that the detection of parametric roll is correctly realized.

3. AVOIDANCE MANOEUVRE

Manoeuvre mitigation

In heavy weather, captains keep sharp attention to the ship motions, weather forecast and crew reaction. When large roll motions appear “A prudent captain would come to head sea and reduce speed” (DNV 2005). During both well documented stability failure involving the C11 class container ships APL China (France, 2001) and the one involving Panamax G-class container ship Maersk Carolina (Carmel, 2006) the masters altered course toward head sea and reduced speed. However, the variation the transverse stability in waves is the most important in longitudinal seas, leading to the greatest probability of appearance of parametric roll. Reducing speed permits to reduce wave encounter frequency, allowing captains to assume that more time is available to select the most suitable route. However, reducing speed decreases the ships roll damping and therefore it may increase the roll amplitude.

This study focuses on two types of manoeuvres, either a course alteration or a speed modification to reduce such heavy roll motions. With the aim to select the most relevant manoeuvre to be executed when parametric roll appears. Thus, in this study the ship initially sails in head seas to maximise the probability of appearance of parametric roll.

Simulations are conducted in those conditions in real sea states. When parametric roll is detected, the time series are closely analysed. If the parametric roll alarm rises, warning the officer of the watch of the appearance of the phenomenon, 20 seconds are left to the crew to select and begin a manoeuvre (t_{start}). The simulation is conducted once more in the exact same conditions and the selected manoeuvre is executed at t_{start}. The part of the simulation prior t_{start} is strictly identical (same wave seed). The comparison of the effect of each manoeuvre on the roll time series permits to select the most relevant manoeuvre.

Course alteration

The turn ratio is validated prior to simulate course alterations. The course alterations are realized by modifying the heading setting in the auto-pilot at t_{start}. Table 1 presents the selected course alterations to be tested and the required time to execute this manoeuvre in calm water at 7 knots relatively to the time required to execute a course alteration of 15 degrees at same speed.

Table 1: Course alterations

Short Name	Course alteration [deg]	Relative course alteration time in calm water
C+15	15	100%
C+22.5	22.5	110%
C+30	30	117%
C+45	45	126%
C+67.5	67.5	160%
C+90	90	186%

Speed modification

Speed modification is realized by modifying the speed setting in the auto-pilot at t_{start}. The propeller rotational speed (in revolutions per minute) is consequently automatically adjusted. The engine loading sequence is not considered. However, the speed resistance curve triggers the speed variations. Table 2 presents the selected speed modifications to be tested.

Table 2: Speed modifications

Short Name	Speed modification [m.s^{-1}]	Comments
V+1	+ 1	Increases speed roll damping component
V-1	- 1	Reduces speed roll damping component

4. RESULTS AND DISCUSSION

Results and validations

The results are obtained for a large naval ship. The ship's roll damping coefficients are calculated using Ikeda's method (Ikeda, 1978, Kawahara, 2009) as the hull shape is close to the one of merchant ship. The simulations are conducted on a sea state modelled with a Pierson-Moskowitz spectrum of significant height 5 metres and of peak period 9.856 seconds. A "cos^8" spreading function is considered (Bureau Veritas, 2019) and a spreading angle of ± 45 degrees to simulate real sea state.

Each simulation is one hour long. The simulation begins with the autopilot set to head seas and the speed adjusted at 7 knots. A first simulation without any manoeuvre is performed, during which parametric roll is observed (hereafter denoted reference simulation). The first parametric roll detection alarm rises at 548.7 seconds (t_{Alarm}). The crew reaction time is added to calculate the time of the beginning of the manoeuvre ($t_{start} = t_{Alarm} + 20 = 568.7$ s). The simulation is run again several times to assess the effects of all manoeuvres presented in Table 1 and Table 2.

Figure 1 presents the reference simulation and two manoeuvres with a course alteration of respectively 15 and 30 degrees. Figure 2 presents the reference simulation and two manoeuvres with a course alteration of respectively 30 and 90 degrees. Figure 3 presents the reference simulation and two manoeuvres with a speed modification of respectively + 1 and - 1 m.s^{-1}.

Table 3 presents dimensionless results of the roll amplitudes reached for each manoeuvre. Three roll amplitudes are assessed. The first roll amplitude represents the maximum roll amplitude reached during the entire one-hour simulation (ΦSim). The second one represents the roll amplitude reached around t_{start} (ΦPR). The third one is the maximum roll amplitude reached once the manoeuvre is completed on the final part of the simulation (Φ2ndPart). All results are provided as a fraction of the one observed on the roll time series of the reference simulation. On this reference time series ΦSim, ΦPR and Φ2ndPart are respectively denoted ΦSimRef, ΦPRRef, Φ2ndPartRef and are represented on Figure 1. The right column of Table 3 compares the roll amplitude reached on the final part of the simulation (Φ2ndPart) with the roll amplitude reached around t_{start} on the reference time series (ΦPRRef).

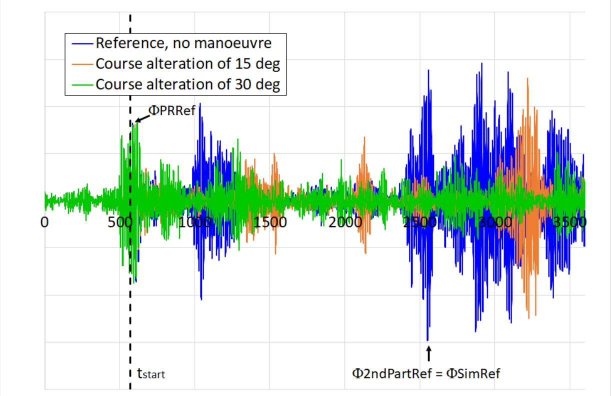

Figure 1: Manoeuvre, effect of limited course alterations on the roll motion

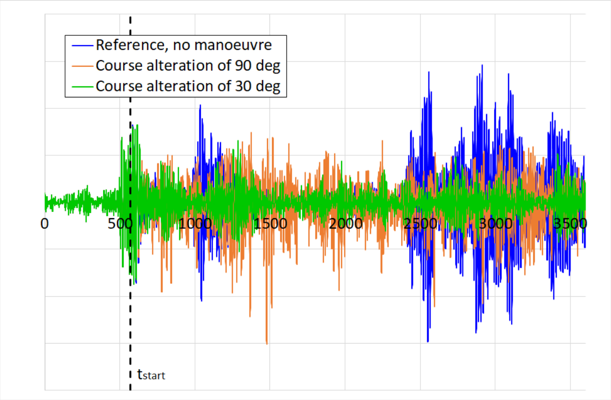

Figure 2: Manoeuvre, effect of large course alterations on the roll motion

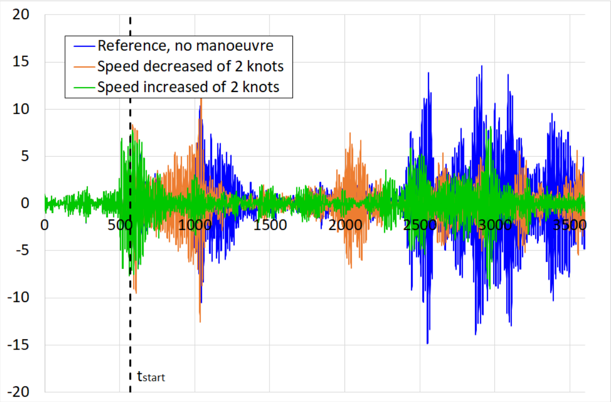

Figure 3: Manoeuvre, effect of speed modification on the roll motion

Table 3: Roll amplitudes comparison

Sim	ΦSim / ΦSimRef	ΦPR / ΦPRRef	Φ2ndPart / Φ2ndPartRef	Φ2ndPart / ΦPRRef
Ref	100%	100%	100%	172%
C+15	88%	100%	88%	151%
C+22.5	70%	101%	70%	121%
C+30	58%	100%	44%	76%
C+45	58%	100%	51%	87%
C+67.5	87%	100%	87%	150%
C+90	101%	100%	101%	174%
V+1	60%	90%	60%	104%
V-1	90%	110%	90%	155%

Discussion

The results presented in Figure 1 to Figure 3 and in Table 3 for this loading and environmental condition are discussed hereafter. Figure 1 shows that a course alteration of 15 degrees is not sufficient to avoid parametric roll to appear once more. The roll amplitude reached after the manoeuvre is 12 % smaller than the one reached on the reference simulation. However, the roll amplitude reached after the manoeuvre is 1.5 time greater than the one reached around t_{start}.

For a course alteration of 22.5 degrees, the roll amplitudes globally decrease. However, parametric roll still occurs after the manoeuvre, and the associated roll amplitude is still larger than the one encountered on the reference time series.

In this study, a course alteration of at least 30 degrees permits to avoid the appearance of severe roll motion due to parametric roll. The roll amplitude reached after the course alteration decreases significantly and no roll amplitude larger than the one reached at the time of the manoeuvre is observed.

Figure 2 shows that a course alteration of 90 degrees leads to heavy roll motions, as important as in head seas. A slight modification of the roll period is observed. Therefore, those heavy roll motions are not a consequence of parametric roll since the ship is sailing in beam sea. They may be due to the phenomenon of synchronous roll. A course alteration of 67.5 degrees leads to large roll amplitudes, similar to the one observed after a course alteration of 15 degrees. This may be due to synchronous roll.

Therefore, a course alteration may permit to avoid large roll amplitudes. A limited course alteration does not permit to avoid the appearance of parametric roll and a large course alteration may lead to synchronous roll (the ship initially sails in head seas). Therefore, in this case, a course alteration between 30 and 45 degrees permits to significantly reduce the roll motions.

Figure 3 shows that a speed reduction of 1 m.s^{-1} leads to roll amplitudes equivalent to the one of the reference (without manoeuvre). Even if the speed reduction alters the encounter period, the phenomenon of parametric roll still appears and leads to large roll motions, probably due to the roll damping reduction. In this case, when the ship increases her speed, it does still encounter parametric roll. However, the roll amplitude is lower than the one observed when no manoeuvre is engaged. The encounter period is modified, and the roll damping is increased. This leads to maximum roll amplitudes equivalent to the one encountered at the time of the manoeuvre.

Therefore, a speed modification permits to modify the encounter wave period. However, a modification of 1 m.s^{-1} does not seem sufficient to alter the encounter period sufficiently to avoid the appearance of parametric roll. When the ship speed is reduced, the roll damping decreases, amplifying the roll motions. Thus, a speed reduction should be avoided. When the ship speed is increased, the roll damping increases consequently, limiting the ship roll motions. These results should be handled with care as the speed reduction and increase are simulated faster than in reality. Therefore, this speed increase would in reality present a longer transient state, during which the roll motion may be closer to the one of the reference simulation.

The effects of each manoeuvre have been separately assessed. This study concludes that for the presented cases the most effective manoeuvre is a course alteration between 30 and 45 degrees.

5. CONCLUSION

Parametric roll is a rare phenomenon leading to unexpected large roll motions in head and following seas. Methods to warn the officer of the watch on the existing risk of parametric roll exists (IMO, 2007). Some of those warning methods are available onboard. This paper studies the effects of a course alteration or a speed modification on the roll motion of a large naval ship after parametric roll is detected. Six course alterations and two speed modifications have been assessed through 6-DoF simulations in a real sea state after parametric roll is detected in head seas. Speed modifications as well as course alterations modify the encounter wave period, key parameter of the appearance of parametric roll. Results show that a course alteration smaller than 30 degrees is not sufficient to avoid parametric rolling. When course is altered to beam seas, the risk of synchronous roll is significantly increased, leading to roll amplitudes as large as in head seas. When the speed is reduced, the roll damping is reduced as well, leading to larger roll amplitudes than expected. When the speed is increased, the roll damping is increased as well, leading to smaller roll amplitudes.

Therefore, the statement that “A prudent captain would come to head sea and reduce speed” (DNV, 2005) in heavy weather does not always permit to avoid dangerous situations. This typical manoeuvre may lead to large roll motions due to parametric roll, as experienced by some masters (France 2001, Carmel, 2006). This study concludes that in this case a course alteration between 30 and 45 degrees is the most efficient manoeuvre.

The authors propose to extend this study to several ships, loading conditions and environmental conditions to define statistically the most relevant manoeuvre to execute in case of unexpected heavy roll motions in head or following seas. Such study would lead to define the safest manoeuvre.

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