Optimizing ships’ behaviour when sailing in following seas

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Abstract. Ships are built for sailing and transporting cargo on seas and oceans in weather conditions that are not friendly all the time. Even if the weather forecast is transmitted to vessels, the way of acting is a matter of officers’ judgement, based on their knowledge and experience. The subject of this paper is to analyse the behaviour of a port container vessel in different weather conditions. The method consists in using a specially developed software which takes into account the main particulars, the actual stability and the dynamic characteristics of the individual ship in the real voyage conditions, in order to obtain the Dangerous Zone Diagram. In order to avoid surf-riding and broaching the master should reduce speed to less than the critical speed. The results of the study are presented in a diagram that allow us to analyse the situation and to determine the ways for avoiding dangerous conditions by changing the course or the speed. The study should be regarded as a supporting tool during the decision making process.

1. Introduction

The ship’s behaviour certainly depends on the type of ship and the weather conditions. Nevertheless, we have to consider that having one type of vessel sailing on the same weather characteristics, the vessel will behave differently, subject to particular stability situation. The International Maritime Organization addressed this situation by developing an instrument that could be used by the captain of the vessels navigating in severe water conditions, in order to decide about actions to be taken to avoid dangerous situations.

The International Maritime Organization, through Maritime Safety Committee, has synthetized and approved this instrument, published as Guidance to the Master for Avoiding Dangerous Situations in Adverse Weather and Sea Conditions [1, 2]. These guidelines define the severe weather conditions and the situations that might occur while vessels operate under different conditions. There are studies addressing these situations through designing against parametric instability in following seas using analytical predictions [3, 4, 5].

The concept of following and quartering seas refers to the situation when the direction of the wave relative to the course of the ship, takes values between 0° and 45° from the stern of the ship. The dangerous situations that could occur when the vessels are sailing in severe weather conditions are:

- Surf-riding and broaching;
• Reduction of intact stability caused by riding on the wave crest at mid-ship;
• Synchronous rolling motion;
• Parametric rolling motion or
• A combination of dangerous phenomena, which may lead to vessel’s capsizing.

The reaction of a ship to dangerous situations depends on the actual stability parameters, hull geometry, ship size and ship speed. This implies that the vulnerability to dangerous responses, including capsizing, and its probability of occurrence in a particular sea state may differ on a case to case basis.

2. Case study
When the vessel sails in following seas its behaviour will be much different than in head seas, existing the possibility for the above mentioned dangers to occur. The case studies a model ship of a Panamax port-container vessel sailing in severe following and quartering seas. According to the Guidance to the Master for Avoiding Dangerous Situations in Adverse Weather and Sea Conditions [1], there are two critical conditions of encountered waves:

The first critical condition is (equation (1)), when the component of the ship speed in the wave direction approaches the speed of the waves, the ship can be accelerated to reach surf-riding and broaching. There is a marginal zone (equation 2)) where a large surge motion may occur.

\[ V_{\text{critical}} = 1.8 \cdot Lpp^{1/2} \text{[kn]} \]  
(1)

\[ V_{\text{marginal}} = (1.4...1.8) \cdot Lpp^{1/2} \text{[kn]} \]  
(2)

where:

- \( V \) – the speed of the vessel [kn]
- \( Lpp \) – length between perpendiculars [m]

The second critical condition is related to the component of the ship speed in the wave direction that approaches the group velocity of the wave system; in this situation the ship may be overtaken by large waves, which may be twice the height of the observed significant wave height.

![Figure 1. Critical Conditions [1].](image-url)
When the speed of the vessel approaches the speed of the waves, the ship can be accelerated to reach surf riding. In that situation the ship will experience a surge motion and may lose steerage and thereby lose control of the ship. Figure 2 presents the stages for the ship model’s speed to approach the constant value of wave speed.

Figure 2. Model ship speed / Wave speed.
To avoid surf-riding and broaching the Captain of the vessel have to reduce speed to less than the critical speed as resulted from equation (1). The critical speed causing surf-riding and broaching are determined upon the length of the vessel and are presented in the table 1.

| Ship length [m] | 10  | 20  | 50  | 70  | 100 | 150 | 200 | 300 |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Critical speed [kn] | 6   | 8   | 13  | 15  | 18  | 22  | 25  | 31  |
| Marginal speed [kn]  | 5   | 6   | 10  | 12  | 14  | 17  | 20  | 24  |

The figure 3 was elaborated by Maritime Safety Committee [1] to provide the officers of the vessel assistance on their decision on navigation, to avoid dangerous phenomena.

This study considered a Panamax containership travelling at 18 knots in stern quartering sea with a wave angle of 30 deg. The ratio of ship speed to length is calculated (equation (3)):

\[ \frac{V_s}{L_{1/2}} = \frac{18 \text{[kn]}}{284.7 \text{[m]}} \approx 1.1 \]

From the diagram (figure 4) it can be noticed that the speed is not critical, and there is no need for future actions to be taken.
However, in case of large surge accelerations and surge motions, precautions must be taken as regards speed and heading. It should be noted the group velocity of the wave system is less than the velocity of the dominant waves speed.

Dangerous situations occur when a ship is sailing in rough seas that involve irregular waves with sudden serial high wave attacking the ship regularly from aft. It is seen that the sea becomes more regular in following seas, and high waves emerge continuously.

This means that when a ship is sailing in the same direction and at the same speed as the high wave group, the ship may be constantly hit by severe high waves. This phenomena is called Dangerous Encounter Wave Grouping. Figure 5 presents the wave data observed from a fixed point (a), and Wave data observed from a travelling point in following and quartering seas (b).

![Figure 5](image)

**Figure 5.** Sailing in rough seas involving irregular waves. a) wave data observed from a fixed point, b) wave data observed from a travelling point in following and quartering seas.

The International Maritime Organization through Maritime Safety Committee, and Revised Guidance to the Master for Avoiding Dangerous Situations in Adverse Weather and Sea Conditions [2], suggests to avoid the dangerous zone as defined by the relationship between the ship speed and the wave period within following and quartering sea. The ratio is defined by equation (4) and should be placed in the range from 0.8 to 2.0.

\[
\text{The}_\text{ratio} = \frac{V}{T} = 1.5
\] (4)
where \( T \) – the period of waves [s]

3. Results
The study was conducted for a Panamax containership travelling at 16 knots in stern quartering seas with a wave angle of 30 deg. The considered weather conditions: the height of the swell \( H_s = 10 \text{ m} \) and the period of the waves of approximately 15 sec.

It resulted that in order to avoid dangerous phenomena, it is important that the ship’s officer to adjust the speed of the vessel or to change the course. The calculated ratio of the ship’s speed to the waves’ period:

\[
\text{The ratio } = \frac{V}{T} = \frac{16[\text{kn}]}{15[\text{s}]} \approx 1.1
\]  

(5)

From the diagram shown in figure 6 it is seen that the speed of the vessel is in the lower part of the dangerous zone, and, the speed should be slightly reduced or the course should be altered towards the beam sea.

![Figure 6. Critical Conditions [1].](image)

4. Conclusions
Synchronous and Parametric Rolling highly depend on the encountered wave period and the natural roll period of the ship. Synchronous Rolling occurs when the encountered wave period is nearly equal to the natural roll period frequency and Parametric Rolling occurs when the encountered wave period is nearly equal to the half of the natural roll period frequency. In order to avoid these two phenomena each situation has to be analysed individually. Considering the results of this study, that surf-riding and broaching may occur even at lower speeds, the Captain have to adjust the speed of the vessel or to change its course in case of large surge accelerations.

References
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