CAPSIZING OF VESSELS IN FOLLOWING SEAS

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Abstract

Capsizing in following seas is a highly non linear phenomenon, with the forces and moments dependent on the longitudinal position of the vessel in the waves. A four degree of freedom mathematical model which can be used to describe the behaviour of vessels in following seas has been developed. Although this model includes heel/yaw and yaw/heel coupling, required to determine the vessel's behaviour, it does not include the full non linear heel restoring moment required to study vessel capsizing.

The object of research into vessel capsizing is to determine guidelines for both designers and operators to assist them to avoid capsizing occurring.

Guidelines which can be used by masters to avoid dangerous situations in following and quartering seas are being developed by IMO. A proposal which is easy to use has been developed by the Japanese delegation, however it does not include the effect of wave height, or any reference to the stability of the vessel.

Making use of a wide range of model experiments, and predictions from a mathematical model developed by Hamamoto et al (1992) it is possible to conclude that vessels that meet the IMO stability criteria are not likely to capsize in following seas if they have a metacentric height significantly greater than 0.2 times the wave height.

It is proposed that the operators of vessels with a metacentric height of less than 0.2 times wave height should take great care in following and quartering seas. They should adopt the proposed IMO guidelines.

Introduction

Capsizing of small vessels in severe seaways has been the subject of research for many years. It is one of the few areas of ship hydrodynamics that is very unlikely to be able to claim validation from full scale results - at least in the foreseeable future!

The principal aim of research into vessel capsize is to try and develop guidelines to prevent it which can also be presented in an easy to apply form. As capsizing is a very extreme event, involving substantial non-linearities, it is difficult to model the process mathematically. As a consequence, models are often simplified to enable particular phenomena to be investigated, with the resulting focus on one mode of capsize only.

Physical model testing has also been carried out, although again often only one mode of capsize is investigated at a time. Recently, a range of free running model experiments have been conducted by a range of authors, such as Kan et al 1990 and 1994, and these have enabled a range of capsize modes to be investigated, albeit for a limited number of hull shapes.

Modes of capsize in following seas

It is well established that there are three principal modes of capsize in following seas:

1. pure loss of stability;
2. low cycle resonance; and
3. broaching.

Pure loss of stability and low cycle resonance can occur in direct following seas and in this case can be investigated using a one or two degree of freedom mathematical model. The critical issue in investigating these modes of capsize is in determining the change in stability in the wave and it is generally accepted this can be calculated using fairly straight forward hydrostatic calculations.

To investigate the third of these capsize modes, broaching, a four degree of freedom model in surge, sway, yaw and roll is required. Pitch and heave can be neglected if the quasi steady assumption is invoked and all the coefficients in the equations of motion are taken to be functions of longitudinal position of the vessel in the wave.

Mathematical model of behaviour in following seas

In order to investigate the behaviour of vessels in following seas, a four degree of freedom mathematical model was developed as follows (Renilson and Tuite, 1995):

Surge

$$m\left(1-X_{\dot{u}}''\right)\dot{u} = X_{hull} + X_{prop} + X_{rud} + X_{wave} \qquad (1)$$

Sway

$$m\left(1-Y_{\dot{v}}''\right)\dot{v} = Y_{hull} + Y_{prop} + Y_{rud} + Y_{wave} \qquad (2)$$

Yaw

$$mL^2(I_{zz} - N_{\dot{r}}'')\dot{r} = N_{hull} + N_{prop} + N_{rud} + N_{wave} \qquad (3)$$

Roll

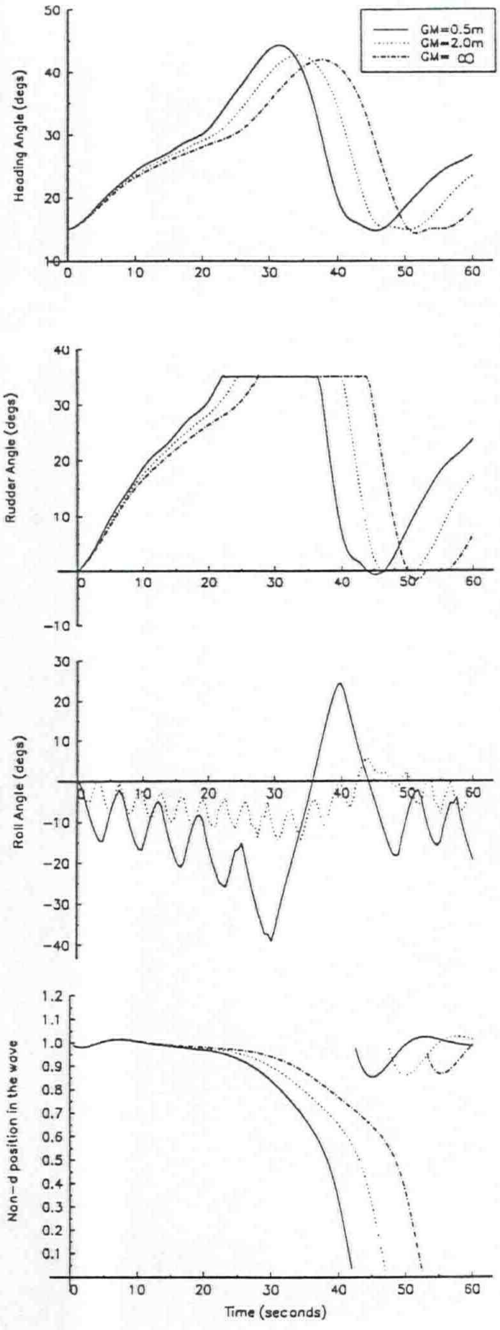
$$mL^2\left(I_{xx} - K_{\ddot{\phi}}''\right)\ddot{\phi} = K_{hull} + K_{rud} + K_{wave} + K_{prop} \qquad (4)$$

In equations 1 - 4 it is assumed that the forces and moments on the right hand side are functions of the vessel's longitudinal position in the wave. It is also assumed that the encounter frequency is low enough such that the vessel is in a quasi steady position in the wave and the forces and moments are independent of frequency.

The inclusion of the roll equation, and the coupling from roll into yaw and sway which is present in the *hull* terms is important as the large heel angles can cause significant yawing moments, and hence can influence the lateral behaviour.

Typical results from this simulation for a 25m Australian trawler are given in figures 1 and 2 where the results for three different metacentric heights in two wave conditions are given. In both figures roll can be seen to have a strong influence on the yaw behaviour of the vessel. The coupling between yaw-roll and sway-roll influences the relative motion (yaw and sway) which in turn effects the vessel's position in the wave, dictating its behaviour.

A similar mathematical model has been developed by Hamamoto et al (1992) and used to investigate the capsizing of a 115m containership in regular following and quartering waves. A sample of the results is given in figure 3 where the effect of the metacentric height on the wave height to wave length ratio causing a capsize for two wave lengths and three heading angles is shown. It can be seen from these results that, in general, a wave length to ship length ratio of 1.5 at an initial heading angle of 30° gives the most critical condition.



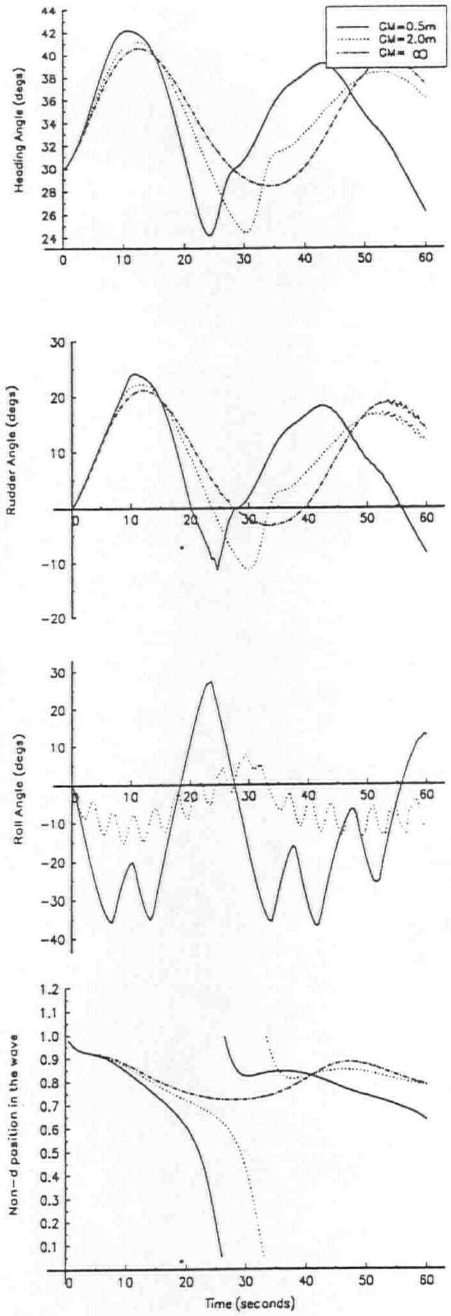
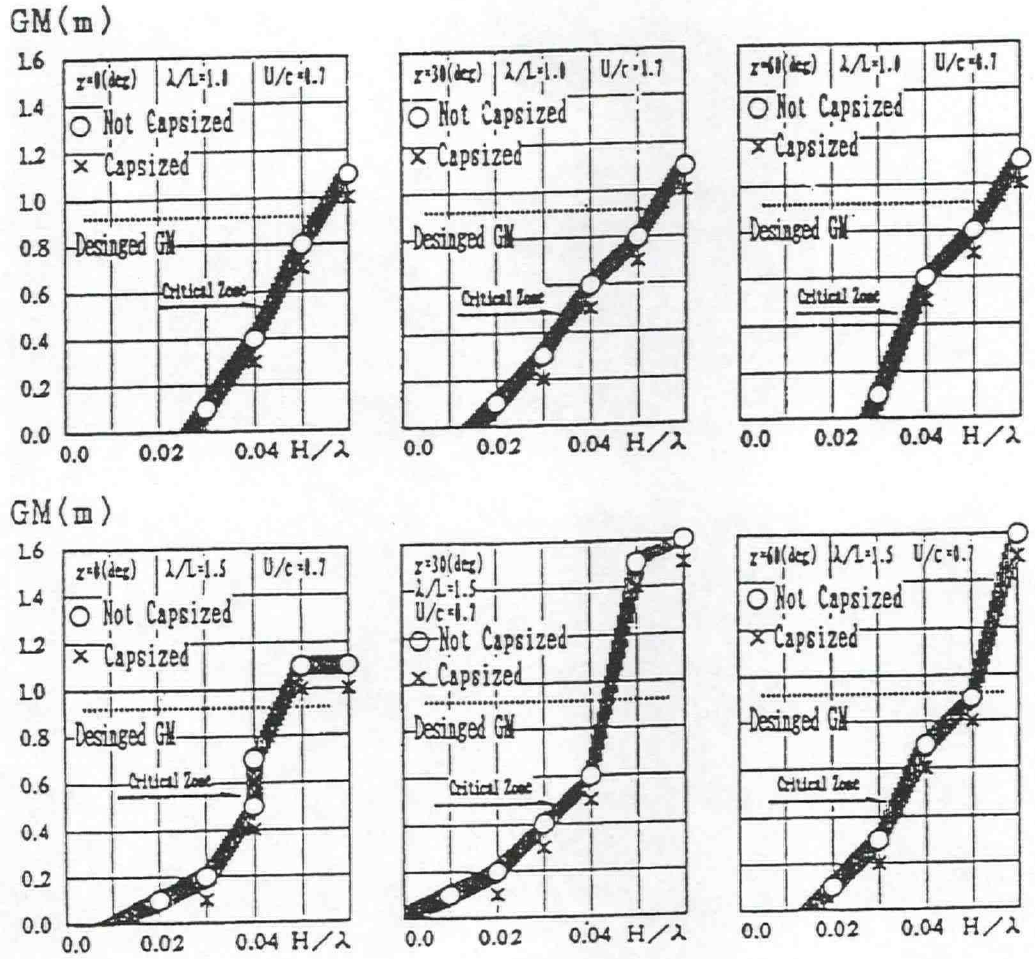


Figure 1. Condition 1

Figure 2. Condition 2

Wave length = 30m
Wave steepness (H/λ) = 0.133
Wave encounter angle = 15°
Nominal speed = 12 knots

Wave length = 30m
Wave steepness (H/λ) = 0.133
Wave encounter angle = 30°
Nominal speed = 12 knots



Critical metacentric height leading up to capsize versus H/λ

Figure 3 (Taken From Hamamoto et al 1992)

Guidelines for vessels in following seas

In order to give guidance to ship operators in following seas, IMO has developed a simplified procedure for alerting ship operators to the fact that they may be operating in a dangerous condition, and to give them guidance for avoiding this condition. One of the recent proposals, submitted by the Japanese group is described by Takaishi (1994).

This is best summarised in figure 4 taken from reference 4. The procedure is to follow the diagram from the top down. As can be seen, this is determined to be valid for wavelengths greater than half ship length, and for headings between 0° and ± 45°.

The mariner estimates the wave length, period and heading angle. $V/\sqrt{L}$ is then calculated and the vessel's position on the speed/heading diagram obtained. Speed and/or heading angle are to be altered if the vessel is in the so called 'Surf-riding zone'.

Next, V/T is plotted with heading angle. Now, if the vessel is in the 'dangerous zone', speed and/or heading have to be altered.

Finally, if the encounter period is nearly equal to either the natural roll period for the vessel, or to half the natural roll period for the vessel, the speed has to be reduced to avoid this.

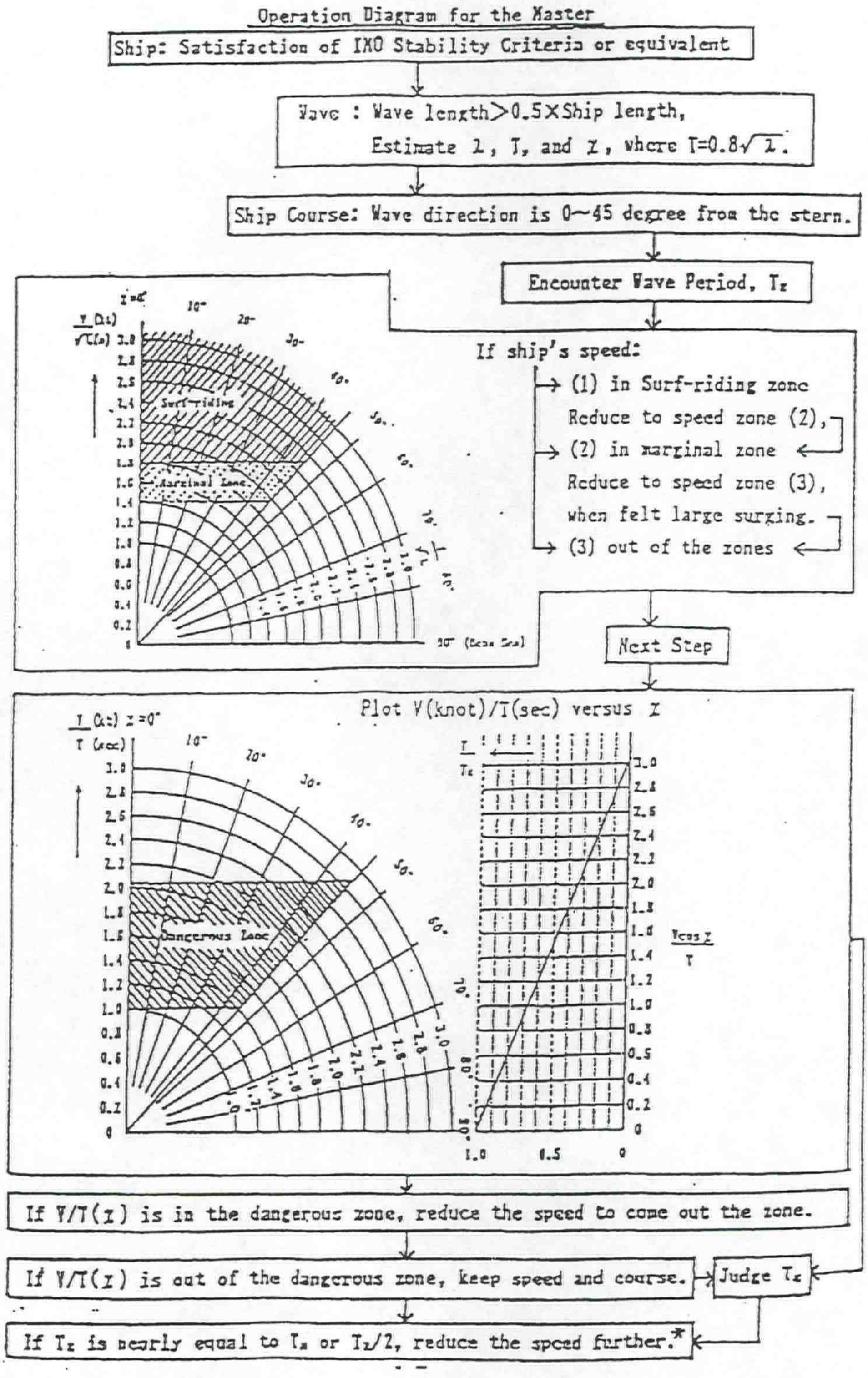
This procedure is simple to apply and easy to understand, however it does not take the wave height, or the vessel's stability into account. For example, a vessel with a GM of 3m would have to adopt these guidelines when travelling in a following sea with a wave height of only 0.1m. This is too strict, and is not what is really intended.

What is required is a method for relating the stability of the vessel to the wave size where problems may occur. In order to do this, a survey of all known free running model experiments in regular waves was carried out.

Model experiment data from a wide range of different sources covering about 250 capsize events on 10 different hull shapes in regular waves were obtained. (References 1, 2, 5, 6, 7, 8, 9, 10, 11, 13.)

The models tested ranged from fishing vessels to containerships covering a range of 'normal' hull forms. All the tests were carried out in regular following or quartering seas at a variety of different wavelengths, wave steepnesses, Froude numbers and headings.

Both wave height and metacentric height were non dimensionalized by dividing by ship length. The resulting plot is given in figure 5. Here, all capsizes in following and quartering seas are indicated, regardless of their cause and of the values of wavelength, vessel heading and vessel speed. In addition, the prediction from Hamamoto et al (1992) given in figure 4 is included in this figure.



*Keep in consideration the minimum speed for maintaining course control of ship.

Figure 4 (Taken From Reference 4)

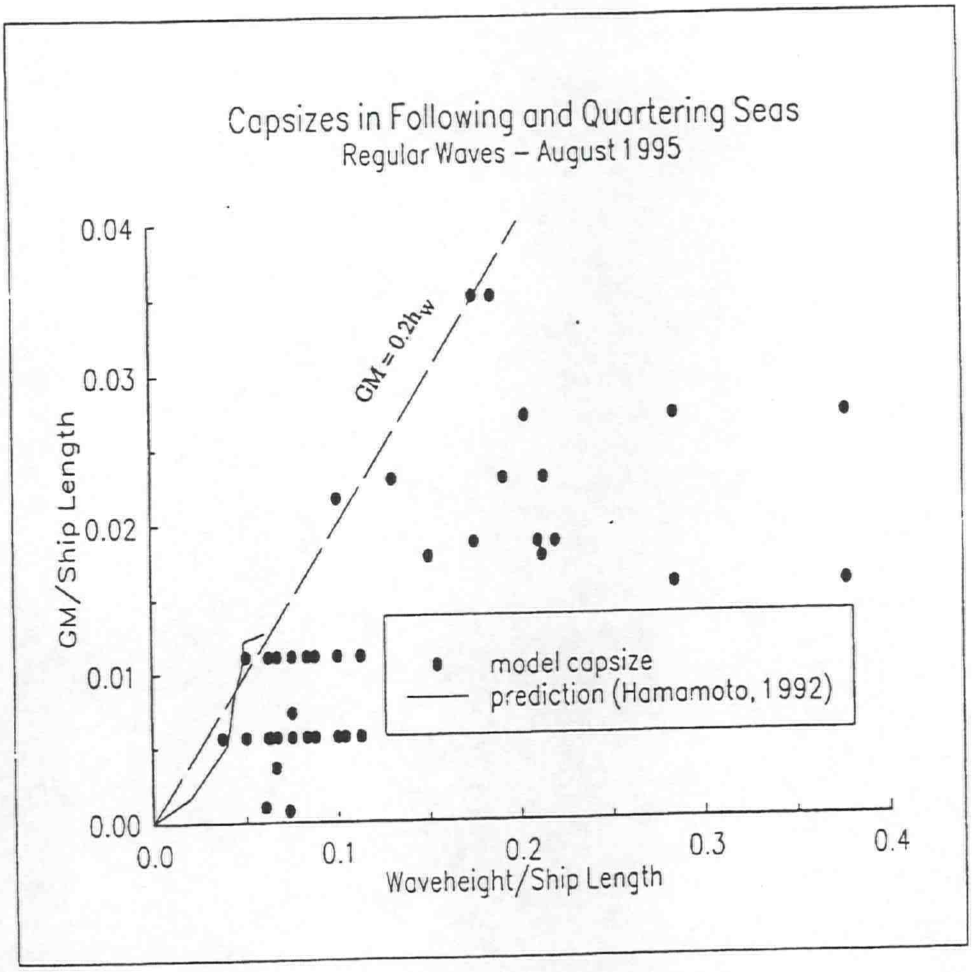


Figure 5 Capsizes in Following and Quartering Seas

As can be seen, capsizes do not occur at a metacentric height greater than about 0.2 times the wave height. Of course, there are also many conditions where the metacentric height is less than $0.2h_w$ and a capsize does not result. These occur when the combination of wavelength, vessel heading, and vessel speed give a situation which does not cause a capsize, regardless of the fact that the metacentric height is less than $0.2h_w$.

The prediction by Hamamoto et al (1992) of the capsize boundary for a 115m containership is also included on this figure. As can be seen, this also shows that capsizes do not occur when the metacentric height is above about $0.2h_w$.

As capsizes do not occur when the metacentric height is greater than about $0.2h_w$, it should not be necessary to apply the proposed new guidelines for vessels in following and quartering seas when the metacentric height significantly exceeds this value.

It is therefore suggested that the proposed procedure for a vessel travelling in following and quartering seas should be as follows:

1. determine whether the vessel meets IMO stability criteria - if not, this should be rectified immediately;

2. determine whether the metacentric height is significantly greater than $0.2h_w$ - if not, great care should be taken and the proposed new guidelines for vessels in following seas applied.

If the vessel meets the IMO stability criteria and the metacentric height significantly exceeds $0.2h_w$ the vessel should be safe and it should only be necessary to adopt normal good seamanship procedures.

Concluding remarks

A simple guideline has been developed by the Japanese delegation at IMO to assist mariners to avoid a capsize in following and quartering seas. Although this is easy to use it does not contain any parameter relating to wave height or vessel stability.

The results of a wide range of free running model experiments, together with predictions from a mathematical model for a 115m containership, indicate that all capsizes occur when the GM is less than $0.2h_w$. It is therefore proposed that when GM is significantly greater than $0.2h_w$ it is not necessary to apply this guideline - provided the vessel meets the usual IMO stability criteria.

Further work

It is recommended that the results of additional free running model capsizes, together with those from mathematical models, be obtained and plotted on figure 5 to verify that capsizes do not occur when GM is significantly greater than $0.2h_w$.

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