A Standard Method For Presentation of Capsize Data

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ABSTRACT

One of the major difficulties involved in investigating vessel capsizing in following and quartering seas is in presenting the results in a systematic manner. The difficulty is in how to show the results of the variation of the five critical variables (λ/L; h/λ; χ; KG; and Fn) in a simple presentation. A method is proposed which allows straightforward comparison between different vessels, and with the existing IMO regulations which are based on statical stability concepts only.The capsize boundaries obtained in regular waves are distilled into a single plot of maximum permissible KG' (=KG/B) to avoid capsize in waves as a function of Froude Number.It is shown that the maximum KG' which will allow the vessel to meet the existing IMO regulations applicable to the vessel type can also be included on this plot.

NOTATION

B	Vessel beam
Fn	Froude number
G_FM	Metacentric height
G_FZ	Righting lever
h	Wave height
KG	Vertical centre of gravity position
KG'	Non-dimensional vertical centre of gravity position (=KG/B)
L	Vessel length
θ	Heel angle
θ_f	Angle of downflooding
λ	Wavelength
χ	Vessel heading to waves ($\chi = 0°$ represents following seas)

INTRODUCTION

Existing IMO regulations for the intact stability of vessels are based purely on statical concepts utilizing the G_FZ curve and the G_FM value as follows:

Criterion	IMO minimum
Area under the G_FZ curve between 0° and 30°	3.15m-deg
Area under the G_FZ curve between 0° and 40° (or 0° and θf, whichever is less)	5.16m-deg
Area under the G_FZ curve between	

30° and 40° (or 30° and θ_f, whichever is less)	1.72m-deg
G_FZ at 30° or greater	0.20m
Angle for maximum G_FZ	25degrees
G_FM	0.15m (0.35m for fishing boats)

Although these criteria do take the non-linear restoring moment into account they are based on statical stability alone and do not consider the dynamics of the behaviour of the vessel in the waves. IMO has adopted criteria to take into account the effect of the wind etc, however all existing criteria are still based on statical rather than dynamical concepts. (IMO 1995)

With the recent advances in knowledge of the behaviour of ships in rough seas and the advent of modern computing the time has come to develop new criteria based fully on dynamical concepts.

BACKGROUND

Studies of capsizing in following and quartering seas have been conducted over a number of years by a range of investigators. In each case they have had to cope with the following variables for every vessel type investigated: λ/L; h/λ; χ; KG; and Fn. The difficulty is in conducting experiments or time domain simulations with a systematic variation of each of these variables, and in presenting the results in a standard manner that enables ready comparison with other investigations.

In addition, the results are often not of use to designers who need to assess the safety of their proposed designs.

PROPOSED METHOD

A method is proposed for analysing and displaying capsize data in a manner which allows ready comparison with other vessels and with the existing IMO regulations. It is suggested that once experience with this method has been gained, criteria based on it could be developed and used for future stability regulations.

Results in regular waves are used, as being 'deterministic' they are easier to obtain than those in irregular waves, allowing for ready comparison between different vessels. It has often been demonstrated that in following and quartering seas the results are very similar for regular and irregular waves. (Takaishi, 1982)

To simplify the process it is desirable to conduct all the investigations at a constant wave steepness. In order to investigate the relative safety of a vessel it is reasonable to investigate its behaviour in steep waves. A number of existing investigations have utilised different wave steepnesses, making it impossible to compare the results. To overcome this it is proposed that a standard wave steepness of $h/\lambda = 1/15$ be used for all studies of capsizability in future. If this value is adopted as a standard by all investigators in the field then it will be possible to compare different designs on an equal basis. This is necessary to be able to develop standard stability regulations based on rational dynamical concepts.

The first step in the proposed method is to determine the maximum KG value that the vessel can have without capsizing for a fixed λ/L value and Froude Number at the wave steepness of $h/\lambda = 1/15$. This process is repeated for a range of heading angles and the resulting capsize boundary can be represented on a plot of heading angle, χ, against KG as shown for a fictitious vessel in figure 1.

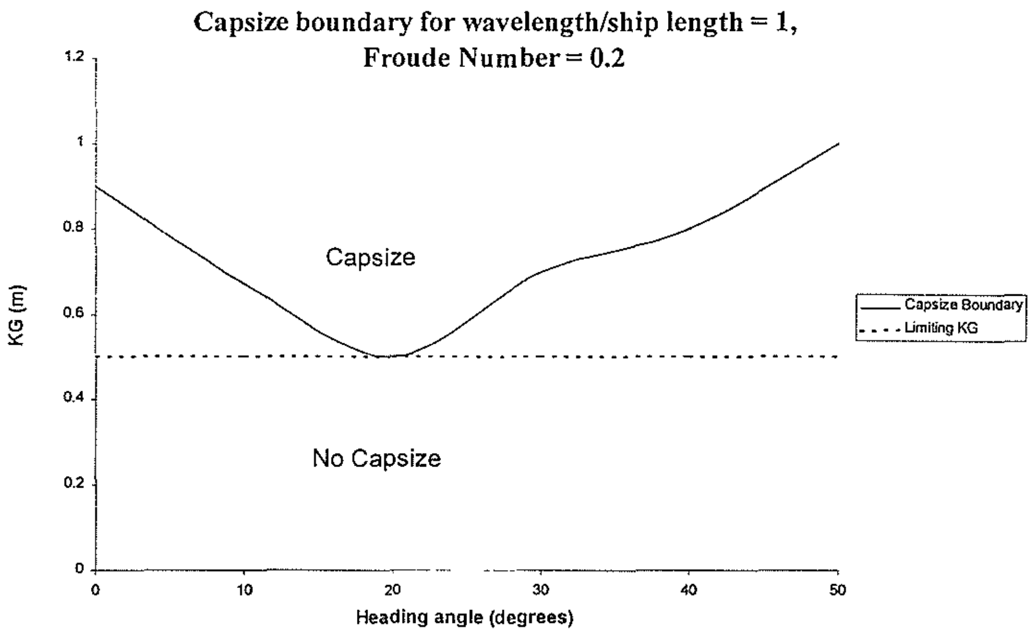

Figure 1: Example of capsize boundary for single λ/L and Fn

For a given heading angle, if the vessel is loaded with a KG value higher than the boundary shown in figure 1 it will capsize in waves of steepness $h/\lambda = 1/15$ or above, whereas if it has a KG value lower than the boundary it is safe in waves with this steepness.

As it is clearly necessary to load the vessel in such a way that it does not capsize at any heading, the important aspect of this boundary is its minimum value, and this can be considered the limiting KG value for the vessel in this λ/L and at this Froude Number.

As can be seen from figure 1, the limiting value of KG for this case is 0.5m. If the vessel has a greater KG value than this it will capsize at headings other than 20°.

Of course, as it is possible to encounter waves with different lengths this exercise must be repeated for a range of wavelengths and in each case the limiting KG value can be obtained as before. These limiting KG values can then be plotted against λ/L as shown in figure 2.

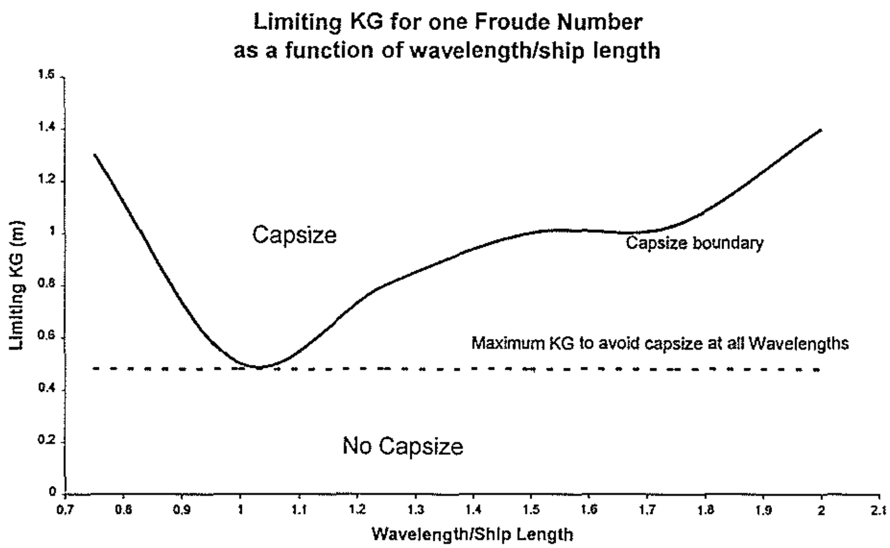

Figure 2: Example of limiting KG for one Froude Number

In figure 2 the capsize boundary indicates the maximum KG which the vessel can be loaded to without capsizing in waves of steepness $h/\lambda = 1/15$ at any heading at that one Froude number. The wavelength/ship length ratio most likely to cause a capsize in waves of steepness $h/\lambda = 1/15$ can easily be determined from this figure. In the case of this fictitious vessel this is 1.03, and at that wavelength/ship length ratio the maximum KG value that the vessel can have without capsizing is 0.48m.

As the ship may encounter waves of any length this means that it is necessary for the KG to be less than 0.48m to guarantee against capsize. This then is the maximum permissible KG for this vessel to travel in following and quartering seas at a Froude number of 0.2.

This can be non-dimensionalised by dividing by the vessel's beam, B, to give KG' (= KG/B).

This process can then be repeated for the range of speeds, as shown in figure 3. Here the curve is the boundary of the maximum KG' that the vessel can sustain without capsizing at any heading and any wavelength combination in waves of steepness $h/\lambda = 1/15$. What this means is that if the KG' value is greater than this for a particular Froude number then there will be at least one combination of heading and wavelength which will cause the vessel to capsize in waves of steepness $h/\lambda = 1/15$. Conversely, if the KG' value is less than this for a particular Froude number then it will not capsize at any heading in any wavelength in waves of steepness $h/\lambda = 1/15$. This value of KG' can then be termed the limiting KG' to prevent capsize at that Froude number.

The maximum KG' permitted for this fictitious vessel to meet the IMO stability regulations is also shown on figure 3, and it can be seen that at the lower Froude numbers the IMO regulations may be considered too conservative, whereas at the higher Froude numbers they allow a higher KG' than that permitted by the dynamic approach.

As the dynamic approach is based on the behaviour of the vessel in a wave steepness of $h/\lambda = 1/15$, which was chosen relatively arbitrarily as a 'typical' steep wave, considerable experience will be required with this comparison before it will be possible to discard the statical approach which has been built up over many years. However, if the proposed approach is adopted as uniform by researchers in this field, and the results regularly compared with those from the statical approach then it will be possible to develop the correlation between the approaches. Once this has been done, the dynamical approach can be adopted in favour of the statical approach, and the assessment of vessel stability will be greatly improved.

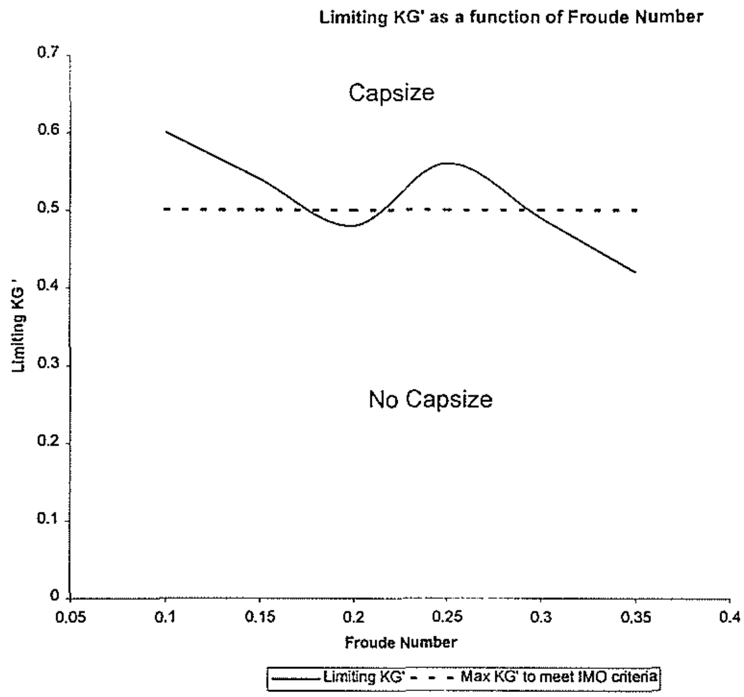

Figure 3: Limiting KG′ as a function of Froude Number

The final plot, shown in figure 3, is therefore a very good guide to the likelihood of a given vessel capsizing in following and quartering seas, and can reasonably be used to compare the stability of different vessels in a standard manner.

CONCLUDING REMARKS

A simple but comprehensive method for analysing capsize data has been demonstrated.

With this method a vast array of data is distilled into a single plot of limiting KG′ as a function of Froude Number, allowing for straightforward comparison between different vessels, and enabling the designer and operator to easily assess the likelihood of capsize for a given vessel. It is also possible to include the maximum KG′ that will allow the vessel to meet the IMO criteria on this plot for reference.

It is suggested that this method now be used as standard to compare the likelihood of capsize for different vessel types, and that the results be compared with the maximum KG′ obtained from the existing IMO regulations in each case. Once experience with this approach has been developed it will be possible to use it rather than the existing statical methods to assess vessel stability in future.

REFERENCES

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