WEATHER CRITERION FOR INTACT STABILITY OF LARGE PASSENGER VESSELS

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SUMMARY

The application of intact stability Weather Criterion to the new large passenger ships leads to more stringent requirements than the application of current subdivision and stability rules for damage ships. A critical analysis of Weather Criterion in its hystorical development and in the present version has thus been conducted. In this paper, the calculation method of the rolling amplitude is examined with the aim of identifying weak points needing further studies and to propose some interim modification of existing procedure. It appears that the formulas or graphs used to compute the relevant quantities for the evaluation of ship safety on the base of Weather Criterion appear to overestimate roughly the environmental action. A proposal to correct the evaluation formula for the factor "r" is provided.

NOMENCLATURE

ϕ_0 heeling angle under the action of steady wind
ϕ_1 rolling amplitude
ϕ_2 limiting angle for area computation
lw_1 lever of steady wind
lw_2 lever of wind gust
d , T ship draught
B ship beam
C_B block coefficient
s wave steepness
X_1 factor expressing the roll damping dependence on B/T
X_2 factor expressing the roll damping dependence on C_B
k factor expressing the effect of bilge keels on roll damping
r effective wave slope coefficient
T_ϕ rolling period
OG=KG-d height of centre of gravity on waterline
KG height of centre of gravity on keel
GM initial metacentric height
N coefficient of quadratic roll damping
I' virtual moment of inertia of ship
Δ ship displacement
GZ righting arm
ϕ_{syn} peak roll amplitude

1. INTRODUCTION

In the present version of the Weather Criterion, the ability of the ship to withstand the combined effects of beam wind and rolling should be demonstrated, for each standard condition of loading, with reference to Fig. 1, as follows:

- the ship is subjected to a steady wind pressure acting perpendicular to the ship's centreline which results in a steady wind heeling lever lw_1;
- from the resultant angle of equilibrium ϕ_0, the ship is assumed to roll owing to wave action to an angle of roll ϕ_1 to windward. Attention should be paid to the effect of steady wind so that excessive resultant angles of heel are avoided;
- the ship is then subjected to a gust wind pressure which results in a gust wind heeling lever lw_2;
- under these circumstances, area b should be equal to or greater than area a;
- free surface effects should be accounted for in the standard conditions of loading.

The IMO Recommendation then specifies the methodology that *must* be used to calculate all the relevant quantities.

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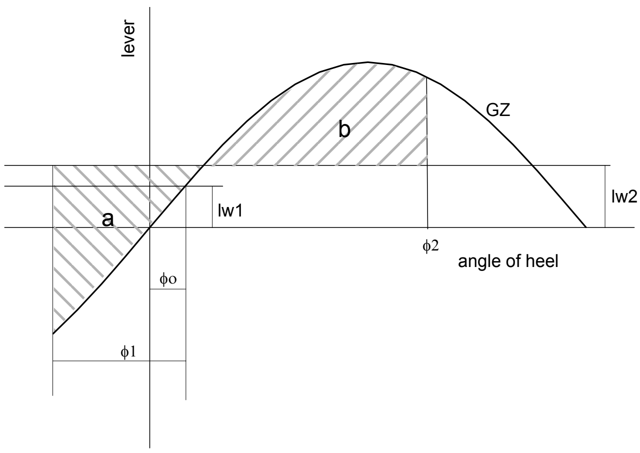

Fig. 1. Illustrating the Weather Criterion

The application of the IMO Weather Criterion (IMO Res. A.562) for intact stability, based on the effects of a severe wind and rolling, to modern large passenger vessels can result in requirements more stringent than those corresponding to the application of general intact stability criteria of intact stability code (IMO Res. A.167 as amended by Res. A.206 and successive) and of current damage stability rules (SOLAS'90). In Fig. 2 the GM limit curves of a large passenger ship are reported as an example. The fact that intact stability requirement in terms of GM (or KG) is more stringent than damage stability rules including both subdivision *and* stability is contradictory. On the other hand, SOLAS'90 is generally considered as a good safety rule, so that the problem is really that of a better tuning of Weather Criterion to ships of the considered size.

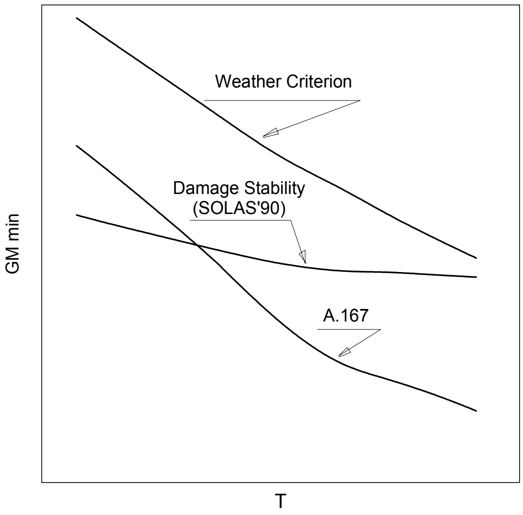

Fig. 2. GM Limit curves for a 77,000 GRT passenger ship with B/T=3.98÷4.27 and OG/T=0.9÷1.15. The even keel condition is indicated.

The matters related to the basic formulation of the weather criterion have thus been reviewed tracing back to the original documents [1]. They are connected with:

- mathematical modelling of roll motion equation. The analysis of large campaigns of experiments by means of powerful parameter identification techniques, applied to the entire roll resonance curve in regular beam waves, indicates that the effective wave slope coefficient can be overestimate especially for ships with OG/T greater than zero. At the same time, the influence of linear damping can be underestimated;
- the evaluation of roll period is based on a regression formula which is not reliable for modern ship forms. In this case, it can lead to an overestimation of the wave steepness.

Some actions to be taken to extend the weather criterion to modern ship forms are envisaged and at the same time it is suggested that appropriate experiments should be conducted for the evaluation of some of the characteristic quantities related to the weather criterion or the satisfaction of the criterion as a whole.

2. ANALYSIS OF WEATHER CRITERION PROCEDURE

The basic physical mechanisms on which the Weather Criterion is based are globally sound and represent pionieristic work done in this field by several researchers, mainly in Japan and Russia. The introduction of Weather Criterion as an additional stability requirement together with the Res. A.167 really improved the safety of navigation. Many issues contained in Weather Criterion however appear to be questionable in themselves and other when extending the range of applicability beyond the original limits. In the following we try to give a global view with some hint for improvement.

2.1 EVALUATION OF ROLL MOTION AMPLITUDE ϕ_1

The roll motion amplitude ϕ_1 in Weather Criterion is calculated through the expression:

$$\phi_1 = 109\,k\,X_1\,X_2\sqrt{r\,s} \tag{1}$$

The square root is a consequence of the (questionable) assumption of purely quadratic damping made following Bertin. The k and X_2 factors are not relevant to present discussion and can be found in tabular form whereas the factors r and X_1 are very important and will be discussed in detail.

The factor X1, expressing the effect of B/T ratio on roll damping is reported in Fig. 3.

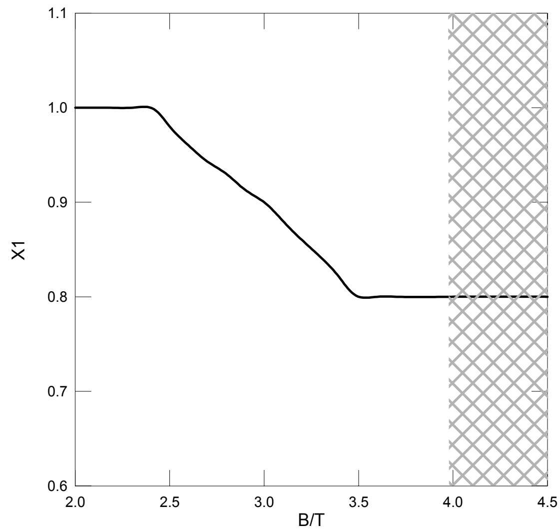

Fig. 3 Effect of B/d on roll damping factor X_1. The shaded area represents the values of B/T typical of modern large passenger ships.

As one can see, the region of interest for large passenger ships (dashed in the figure) is all outside the interval corresponding to the original sample of ships used to evaluate the effect of B/T on damping and the last available value of X_1 is thus used. Due to the high slope of the curve, the assumed extrapolation entails a huge underestimation of damping. Further work in this field is needed, based on roll damping measurements or calculations.

The following choices made-up formula 1:

- 30% reduction of ϕ_{syn} due to the irregular waves;

- $r = 0.73 + 0.6\dfrac{\overline{OG}}{d}$ (2)

Eq. 2 worths also particular attention, especially for high values of OG/d as it is usual both in very small and very large passenger ships. A research conducted on a sample of very small ships indicated overestimates the wave action by several times. A research conducted on a specimen of conventional ships confirms this overestimate by an average factor 1.5 (Fig. 4). The values originally used to obtain Eq. 2 were in the range -0.4<OG/d<0.6.

It is clear at this point that the influence of the two factors r (from Fig. 4) and X_1 (from Fig. 3) can contribute to a reduction of ϕ_1 for large passenger ships. An additional effect is conncted with the effective wave slope s.

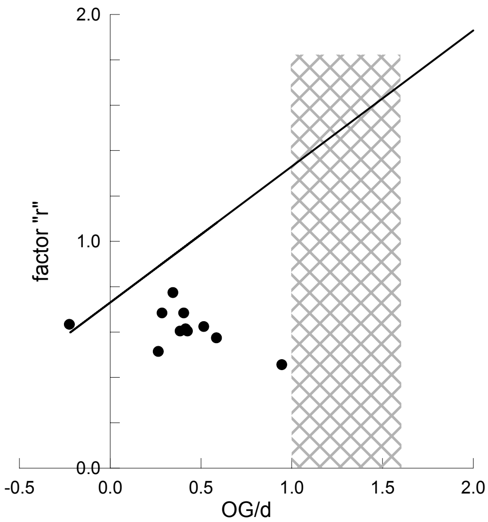

Fig. 4. Effective wave slope coefficient as resulting from Eq. 2 and from experiments. The dashed area represents the interval of values typical of modern large passenger ships. The experimental points are taken from [2,7].

2.2 EVALUATION OF WAVE STEEPNESS

This is based on the theory of Sverdrup-Munk, which was criticised in recent time. On the other hand, the proposers of Japanese original rule assumed a lower limit of 0.038 which is sensibly higher than the tendency limit, as is evident from Fig. 5. For comparison, the wave heights assumed in alternative formulations of height dependence on period (through wavelenght) for "significantly large" waves are presented [8]

In addition the effect of the roll natural period computation is to be considered. The ships we are taking in consideration have indeed quite large rolling periods, over 20 s. The regression formula assumed in Weather Criterion appears not suitable for the evaluation of T_ϕ, since it conducts to an underestimate with the effect of moving the roll peak towards the peak of energy spectra.

3. CONCLUSIONS

From the above presentation we can draw the conclusions that for large passenger ships several formulas or graphs to compute the relevant quantities for the evaluation of ship safety on the base of Weather Criterion appear to overestimate roughly the environmental action

- To coordinate actions aimed to provide new knowledge where this is laking and a tuning of some expressions;

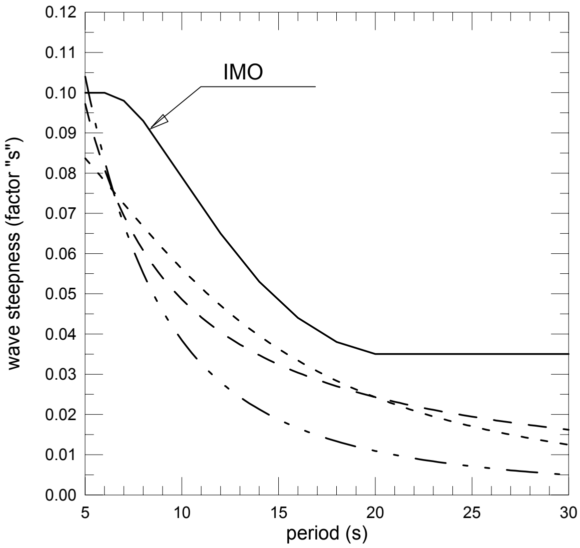

Fig. 5. Wave steepness as a function of roll period T_ϕ assumed in Weather Criterion (solid curve). The modern large passenger ships fall in the assumed flat zone. The dashed curves represent "significantly high waves" assumed in several alternative formulations [8]

- To introduce the possibility to provide direct evidence of fulfillment of the Weather Criterion, or at least to evaluate some relevant quantities connected with, through ad hoc tests or reliable computations;

- To promote a standardisation of testing methodologies provided by some relevant body (for example the ITTC Specialist Committee for Extreme Ship Motions and Capsizing), operating in strict connection/on behalf of IMO;

- As an interim action, to modify the expression (2) given for the computation of the factor r for large passenger ships as follows:

$$\begin{cases} r = 0.73 + 0.6\dfrac{\overline{OG}}{d} \\ \text{but not greater than 1 (one)} \end{cases}$$

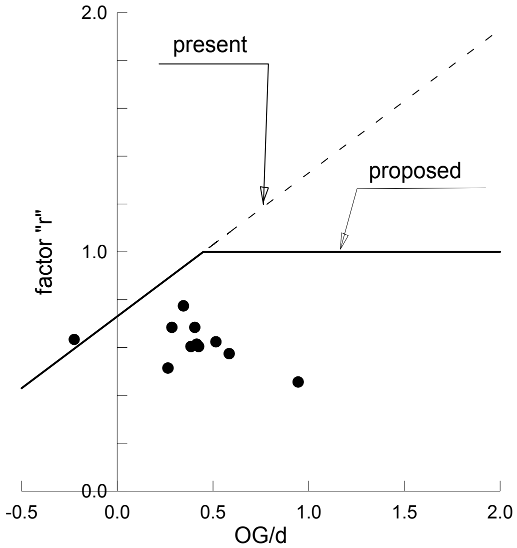

Fig. 6. Proposed dependence of effective wave slope coefficient on center of gravity height on waterline.

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