Application of IMO Second Generation Intact Stability Criteria for Dead Ship Condition to Small Fishing Vessels

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ABSTRACT

This work analyses the applicability of the Second Generation Intact Stability Criteria (SGISC) to small fishing vessels. The stability performance of a set of ten small fishing vessels in dead ship condition is analysed in relation with the degree of fulfilment of the same vessels of the IMO Weather Criterion. The results obtained show that the vessels which present better stability regarding the SGISC in general show less stability margin under the IMO Weather Criterion. These inconsistencies suggest that SGISC in dead ship condition could require further development for its application to small fishing vessels.

Keywords: *Second generation intact stability criteria, dead ship condition, small vessel, fishing vessel, weather criterion*

1. INTRODUCTION

It is widely recognized that the current stability framework can be improved, being necessary to explore new approaches to develop new intact stability criteria which could capture the complexity of the dynamics experienced by seagoing vessels. The IMO Sub-Committee on Stability and Load Lines and Fishing Vessels at its 45th meeting in 2002 (SLF 45) established a working group with the long-term aim to redefine the Intact Stability Code according to a performance standards approach (Francescutto, 2004). In its current status, the Second Generation Intact Stability Criteria (SGISC) framework contemplates five failure modes: Pure loss of stability, parametric roll, surf-riding / broaching, dead-ship condition; and excessive accelerations. This SGISC is intended to substitute or at least complement to some extent the current stability framework. Regarding the current status of the SGISC in dead ship condition, the IMO weather criterion is proposed to be the 1st tier criterion for the dead ship condition. The 2nd tier criterion is based on the calculation of the probability of capsizing in certain conditions. Therefore, homogeneity in the trends observed by the application of both stability standards to the same vessels would be expectable.

Focusing in the application of the SGISC for dead ship condition to small fishing vessels, the authors have undertaken a research to study the influence of a specific fishing effort control regulations on the accident rates of part of the Spanish fishing fleet (Mata-Álvarez-Santullano and Souto-Iglesias, 2014, 2012). In the course of this investigation the stability performance in rough weather of ten small fishing vessels under IMO weather criterion and SGISC for dead ship condition was studied.

The current work presents the results of this part of the investigation: the comparison of the stability performance of ten small fishing vessels under these two mentioned stability criteria.

2. VESSELS STUDIED

Ten small fishing vessels have been studied. They are grouped in two sets: five fishing vessels which were lost in stability related accidents, and the five vessels which where decommissioned for building the lost ones. These two sets of vessels are referred to as "lost vessels" and "predecessors", and are given the codes F1 to F5 and P1 to P5, respectively. The ten vessels are presented in Table 1.

Boat	SFFR[1] code	Gear type	Year of build	Length overall (m)	Tonnage (GT)	Notes
F1	25057	Seines	2001	17	34.18	Lost vessel
F2	24593	Hook and lines	1999	16.02	29.97	Lost vessel
F3	24391	Seines	1999	18	44.83	Lost vessel
F4	24358	Gilnets / entangling nets	1999	20.5	87.03	Lost vessel
F5	24199	Seines	1999	19.4	59.01	Lost vessel
P1	16060	Seines	1989	15	17.11	Predecessor to 25057
P2	11830	Hook and lines	1963	11.3	5.86	Predecessor to 24593
P3	5969	Seines	1978	14.1	28.7	Predecessor to 24391
P4	251	Gilnets / entangling nets	1983	16	47	Predecessor to 24358
P5	5154	Seines	1959	15.75	29	Predecessor to 24199

Table 1 Fishing vessel case studies

[1] SFFR: Spanish fishing fleet register

The ships in this table are referred to using the SFFR code. The European equivalent to such code is obtained adding to it the country code (ESP). This database may be accessed at http://ec.europa.eu/fisheries/fleet/index.cfm?lg=en.

Images of the ten vessels are included in Figure 1.

Vessels	Lost vessel	Predecessor
F1-P1		
F2-P2		No photography available
F3-P3		
F4-P4		

F5-P5		

Figure 1. Images of the ten vessels studied

It has not been possible to obtain precise information about all predecessors, for the following reasons:

- Some documents are missing in the ship file or there is not ship file in the Spanish Maritime Administration, as some vessels are quite old.

- Some documents were not compulsory by the regulation that was in force when some of the predecessors were built (e.g. hullform plan, stability book…)

- The shipyards where some boats were built do not exist nowadays or do not keep files of those boats.

Due to these reasons, not all the main dimensions and characteristics of these are available. Some of them have been estimated according to the following procedures:

- Hullforms were obtained by affine transformation of known similar fishing vessels. The vessels from which the studied ones were obtained had similar dimensions, the same type of fishing gear, hull material, and hull type (stern and bow). When possible, ships built in close years and from the same areas of operation were chosen.

- Unknown main dimensions were estimated by linear regression of databases of fishing vessels, similar in size, type of fishing gear, year of built, hull material and area of operation.

For each of the ten fishing studied a characteristic loading condition is established. Each vessel has been studied in one loading condition only, chosen from the information available, normally the full load condition. In the case of vessels for which no stability booklets were available (most predecessors) a loading condition close to the full load is estimated, with the best information available.

3. METHODOLOGY FOR THE ANALYSES

The Weather Criterion is one of general provisions of the IMO 2008 Intact Stability Code. This criterion was originally developed to guarantee the safety against capsizing for a ship losing all propulsive and steering power in severe wind and waves, which is known as a dead ship condition. This criterion is well known and explanatory notes have been developed by IMO explaining the fundamentals behind the criterion (IMO, 2008), the underlying physical laws and the implicit assumptions.

A graphical representation of this criterion is shown in Figure 2.

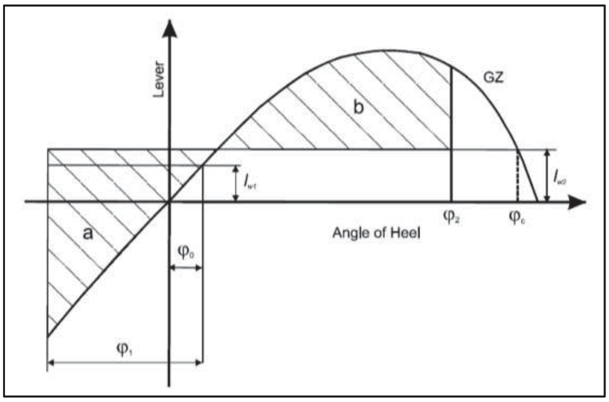

Figure 2 Graphical representation of the weather criterion

The basic principle of the weather criterion is an energy balance between the beam wind heeling and righting moments with a roll motion taken into account. The underlying physical ideas behind the criterion are:

- The ship is assumed to be heeled under the action of a steady beam wind providing a constant, heel independent, heeling moment;
- In addition, the ship is assumed to roll (mainly due to the action of waves) around the equilibrium angle under the action of constant beam wind with amplitude determined according to the criterion.
- When the ship is at the maximum heel to the windward side, a gust occurs leading to a wind heeling moment that is 50% higher than the heeling moment due to the steady wind.
- The ship is required to have sufficient dynamic stability to survive the considered scenario. This will occur if ‘b’ (Figure 2) is larger than ‘a’. Otherwise the vessel will reach the capsizing angle.

It is worth to mention that, under the Spanish regulations, Weather Criterion is not required to be complied with if the area below the stability curve up to a heel angle of 30º is over 0.065 rad x m.

The Weather Criterion is based on partially semi-empirical approaches. To overcome the inherent limitations to this criterion, a Second Generation Intact Stability Criteria (SGISC) for dead ship condition is under development by IMO. Some authors (Bulian and Francescutto, 2006) have proposed a methodology to assess the ship vulnerability to the failure mode “dead ship condition”. Under this approach vulnerability is assessed by estimating the short term probability of capsizing by calculating the roll motion under the combined action of stochastic wind and waves. This is the basis of the methodology agreed by the IMO SLF sub-committee for the 2nd tier vulnerability criteria for the dead ship condition (IMO, 2013).

In this paper the probability of capsizing is estimated following the methodology by Bulian and Francescutto with some modifications which are explained hereinafter. Most of the text and formulae included in this section is taken directly from these references. This section is not intended to be a thorough description of the methodology, and further details and explanations may be found in the referenced documents by Bulian and Francescutto (Bulian and Francescutto, 2006, 2004) and IMO.

3.1 Roll model

The objective of this analysis is obtaining a short-term capsize index Cs by means of a simplified calculation methodology which takes into account the roll dynamics in given environmental conditions. The roll motion of the ship can be described by the following 1-dof non-linear model:

$$(J_{xx}+J_{add})\cdot\ddot{\varphi}+D(\dot{\varphi})+\Delta\cdot\overline{GZ}(\varphi)= M_{wind,tot}(\varphi,t)+M_{waves}(t) \quad (1)$$

where

- J_{xx} is the ship dry moment of inertia
- J_{add} is the added moment of inertia

- D(ϕ') is the general damping moment
- Δ is the ship displacement
- GZ(ϕ) is the restoring lever
- $M_{wind,tot(\phi,t)}$ is the total instantaneous moment due to wind taking
- $M_{waves(t)}$ is the total instantaneous moment due to waves

For simplicity, a linear roll damping model is chosen, therefore D(ϕ') = 2•μ•ϕ', with

$$\mu = k \cdot \sqrt{(J_{xx} + J_{add}) \cdot GM \cdot \Delta} \qquad (2)$$

where GM is the transversal metacentric height and k a non-dimensional damping coefficient. Following Tello et al. (Tello et al., 2011) the coefficient k may be taken constant for fishing vessels similar to the studied, equal to 0.12.

The spectrum of wave moment is estimated according to the methodology by Bulian and Francescutto. Under this assumption, the excitation moment due to waves M_{waves} is assumed to be a Gaussian process, whose spectrum, $SM_{waves(\omega)}$ is estimated from the sea wave slope spectrum Sαα(ω):

$$S_{M_{waves}}(w) = (\Delta \cdot \overline{GM} \cdot f_{r,waves}(w))^2 \cdot S_{\alpha\alpha}(w) \qquad (3)$$

Where $f_{r,waves(\omega)}$ is the effective wave slope function and the spectrum of the wave slope $S_{\alpha\alpha}$ is to be calculated as

$$S_{\alpha\alpha}(w) = \frac{\omega^4}{g^2} \cdot S_{zz}(w) \qquad (4)$$

3.2 Wave moment spectrum

Spectrum of wave moment has been obtained by two different methods:

1. Moment of waves is directly computed by state-of-the-art linear seakeeping software that calculates wave loads and vessel motions in regular waves, on the basis of three dimensional potential theory. To avoid problems associated with roll-sway-yaw coupling in the 1-dof roll model only Froude-Krylov moments are considered for the calculations.

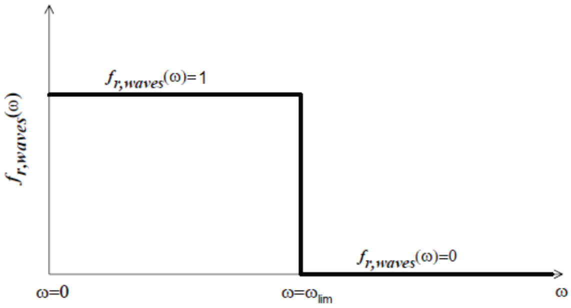

Figure 3 Simplified effective wave slope function

2. A very simplified form for $f_{r,waves(w)}$ is used (Figure 3): a step function that takes value 1 for frequencies lower than w_{lim}, and takes value 0 for values higher than w_{lim}, being w_{lim} the frequency corresponding to a wave having a length equal to one half of the ship breadth:

$$w_{lim} = \sqrt{\frac{2\pi \cdot g}{B/2}} \qquad (1)$$

3.3 Roll spectrum

Assuming wind and waves moments to be Gaussian processes, locally uncorrelated, the spectrum of the total roll moment can be computed as the sum of the non-dimensional wind and waves moment spectra.

$$S_m(w) = S_{\delta m_{wind}}(w) + S_{m_{waves}}(w) \qquad (6)$$

The final roll spectrum $S_{x(\omega)}$ can be obtained as follows:

$$S_x(w) = \frac{w_0^4 S_m(w)}{[w_e^2(\varphi_s) - w^2]^2 + [2 \cdot \mu \cdot w]^2} \qquad (7)$$

Where ϕ_s is the static equilibrium heel angle under the action of the static wind with velocity V_w and ω_e is the modified roll natural frequency close to the equilibrium angle ϕ_s, given by the equation

$$w_e = w_0 \cdot \sqrt{\frac{GM_{res}(\varphi_s)}{GM}} \quad (8)$$

Where $GM_{res(\phi s)}$ is the derivative of the righting lever curve at ϕ_s.

The linear roll damping model chosen allows us to compute directly the spectrum as all terms in the right side of the above equation are known.

3.4 Capsize index and mean capsize time

The capsizing event is defined as the up-crossing of a certain "equivalent area virtual capsize" angle. In order to take into account the actual shape of the righting lever, two virtual capsize angles to leeward and windward are defined, in such a way that the area under the actual residual righting lever and under the linearized residual righting lever are the same. Such "equivalent area" virtual capsize angles are to be calculated by equations 9 and 10.

windward: $$\varphi_{cap,EA-} = \varphi_s - \sqrt{\frac{-2}{GM_{res}(\varphi_s)} \cdot \int_{\varphi_{cap,-}}^{\varphi_s} GZ_{res}(\xi)d\xi} \quad (9)$$

leeward: $$\varphi_{cap,EA+} = \varphi_s + \sqrt{\frac{-2}{GM_{res}(\varphi_s)} \cdot \int_{\varphi_s}^{\varphi_{cap,+}} GZ_{res}(\xi)d\xi} \quad (10)$$

$$\begin{cases} CI = 1 - \exp(-\lambda_{EA} \cdot T_{exp}) & (11) \\ T_{cap} = 1/\lambda_{EA} & (12) \\ \lambda_{EA} = \frac{1}{T_{z,C_s}} \cdot \left[\exp\left(-\frac{1}{2 \cdot RI_{EA+}^2}\right) + \exp(-\frac{1}{2 \cdot RI_{EA-}^2})\right] & (13) \end{cases}$$

$$\begin{cases} RI_{EA+} = \frac{\sigma_{C_s}}{\Delta\varphi_{res,EA+}};\ \Delta\varphi_{res,EA+} = \varphi_{cap,EA+} - \varphi_s & (14) \\ RI_{EA-} = \frac{\sigma_{C_s}}{\Delta\varphi_{res,EA-}};\ \Delta\varphi_{res,EA-} = \varphi_s - \varphi_{cap,EA-} & (15) \end{cases}$$

Where $GZ\varphi = GZ(\varphi)\text{-}l_{wind,tot}$ and $l_{wind,tot}$ is the heeling moment lever due to the action of the mean wind.

From this point, the mean capsize time T_{cap} and the capsize index CI can be estimated. These magnitudes are given by the expressions in equations 11 and 12.

The exposure time T_{exp} is taken equal to 3600 s, and the quantities σ_{Cs} and $T_{z,Cs}$ are to be determined:

$$\begin{cases} \sigma_{C_s} = \sqrt{m_0} & (16) \\ T_{z,Cs} = 2 \cdot \pi \cdot \sqrt{\frac{m_0}{m_2}} & (17) \end{cases}$$

For a more complete description of the methodology and the process to obtain CI and T_{cap}, the work under development by IMO (IMO, 2013) should be consulted.

3.5 Conditions of the analysis

For the ten vessels studied, Tcap and CI have been calculated in two sea states defined by the significant wave height and modal wave period according to the standardized scale adopted by NATO (Military Agency for Standarization, NATO, 1983). For all vessels, SSN4 and SSN5 have been studied, corresponding to significant wave heights of 1.88m and 3.25m with modal periods of 8.8s and 9.7 s respectively. The Bretschneider wave spectrum and exposure time of 1 hour have been considered.

4. RESULTS

4.1 Weather Criterion

Table 2 presents the degree of compliance of the ten vessels studied with the Weather Criterion. Only two vessels (F1 and F2) fail to comply with the criterion, although it must be remarked that none of the case studies had to comply with Weather Criterion, as in all cases the area under the GZ curve up to 30º is larger than 0.065 m.rad.

Vessel	b / a (%)	Heel angle due to steady wind moment (deg)
F1	15.1	9.8
F2	63.2	6.3
F3	143.1	7.1
F4	348.0	5.1
F5	125.6	5.9
P1	147.7	6.6
P2	193.4	5.9
P3	293.0	3.0
P4	306.9	3.4
P5	337.2	1.7

Table 2 Summary of the weather criterion results for the ten vessels studied

4.2 SGISC. Vulnerability in dead ship condition

For the ten vessels studied, Capsize Index (CI) and Mean Capsize Time (T_{cap}) have been obtained according to the methodology explained previously. Results of the analyses are presented in tables 3 to 6.

SSN4 – wave moment calculated by linear seakeeping program

Vessel	Static heel angle (º)	CI	Tcap (hours)
F1	0.8	5.33E-04	1875
F2	0.6	3.96E-07	2526427
F3	0.7	8.07E-08	12393879
F4	0.5	8.11E-12	1.23E+11
F5	0.6	5.43E-05	18407
P1	0.8	4.14E-03	241
P2	0.6	1.59E-05	63087
P3	0.3	8.06E-09	124132802
P4	0.4	5.60E-10	1.78E+09
P5	0.2	1.46E-07	6847793

Table 3 CI and T_{cap} in SSN4. Wave moment calculated by linear seakeeping program

SSN5 – wave moment calculated by linear seakeeping program

Vessel	Static heel angle (º)	CI	Tcap (hours)
F1	1.7	0.898827	0.44
F2	1.3	0.060066	16.14
F3	1.5	0.034321	28.63
F4	1.1	0.000404	2477.51
F5	1.3	0.498709	1.45
P1	1.6	0.986700	0.23
P2	1.2	0.271029	3.16
P3	0.6	0.008210	121.30
P4	0.7	0.002221	449.67
P5	0.4	0.030468	32.32

Table 4 CI and T_{cap} in SSN5. Wave moment calculated by linear seakeeping program

SSN4 – wave moment calculated by simplified effective wave slope function			
Vessel	Static heel angle (º)	CI	Tcap (hours)
F1	0.8	0.012652	78.5
F2	0.6	0.000141	7105.5
F3	0.7	0.000098	10170.0
F4	0.5	0.000002	464736.8
F5	0.6	0.011733	84.7
P1	0.8	0.075432	12.8
P2	0.6	0.007261	137.2
P3	0.3	0.001136	879.9
P4	0.4	0.000049	20328.1
P5	0.2	0.019307	51.3

Table 5 CI and T_{cap} in SSN4. Wave moment calculated by simplified effective wave slope function

SSN5 – wave moment calculated by simplified effective wave slope function			
Vessel	Static heel angle (º)	CI	Tcap (hours)
F1	1.7	1.00	0.119
F2	1.3	0.5790	1.155
F3	1.5	0.5464	1.265
F4	1.1	0.1099	8.586
F5	1.3	0.9992	0.140
P1	1.6	1	0.060
P2	1.2	0.9949	0.189
P3	0.6	0.8766	0.478
P4	0.7	0.3702	2.163
P5	0.4	0.9997	0.125

Table 6 CI and T_{cap} in SSN5. Wave moment calculated by simplified effective wave slope function

5. RESULTS ANALYSIS

Regarding the Weather Criterion, it is interesting that, while under the Spanish stability regulations in force, Weather Criterion was not required to be checked for F1 and F2, these two vessels failed to pass it.

It is to be noted a very low b/a ratio of about 15% for F1. When comparing the lost vessels with their predecessors, it can be seen that, in general, predecessors have more margin with respect to the criterion limits. Except F4, all the lost vessels have lower b/a ratio than any of the predecessors. Regarding the heel angle due to steady wind, in all cases predecessors have lower values, which is indicative of better stability.

The main result of the SGISC analysis is that in general predecessors present worst stability in dead ship condition, except for the pair F3-P3 and F5-P5, for which the trend is not so clear.

One outcome observed looking at tables 3 to 6 is that in general higher CI’s are obtained when using the simplified effective wave slope function for estimating the wave moments than the CIs obtained using the linear seakeeping Froude-Krylov roll moments. This is an expectable result, as in general the simplified effective wave slope function reaches higher values in the frequency calculation domain than the effective wave slope estimated by the seakeeping program.

The comparisons between F3-P3 and F5-P5 provide different results depending on which roll moment calculation method is chosen. For instance, comparing vessels F3 and P3 in SSN5, if roll moment is obtained by linear seakeeping calculations, P3 results to have lower CI (that is to say, better stability performance). On the contrary, if the wave roll moment is estimated by the simplified effective wave slope, F3 results with better stability. This suggests that in some cases the simplified effective wave slope may not provide the needed accuracy at estimating wave roll moment for the intended regulatory use.

Except for the pairs of vessels F3-P3 and F5-P5, in general, the lost vessels seem to have better behaviour in dead ship condition than the predecessors.

According to the results obtained, it seems the two methods used for comparing the stability in rough weather (IMO standard Weather Criterion, and 2nd Generation Stability Criteria dead ship condition) does not correlate. While according to Weather Criterion predecessors show in general better performance, in dead ship condition the lost vessels tend to have smaller capsize indexes.

6. CONCLUSIONS

The analysis conducted has not thrown consistent results in regards to pointing to the lost vessels as less secure from the point of view of these rough weather criteria.

Considering the variability in the results obtained, it is guessed that further validation work might be needed for ensuring that Second generation intact stability criteria (SGISC) in dead ship condition is providing a robust methodology to quantitatively determine capsizing probabilities for regulatory purposes. The large sensibility of short term capsize index CI and capsize time T_{cap} formulation to small input parameters variations may indicate that further validation is needed in order to ensure the methodology it suitable for early design stability assessment or regulatory purposes, as in design stages many vessel parameters are still uncertain or may have a large variability which would affect the values of CI and T_{cap}.

At this stage, this methodology is believed to provide good guidance at design stages when comparing different design options or comparing vessels.

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