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Sample calculations using a draft method for assessment of the vulnerability to pure loss of stability of a fishing vessel

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Abstract

The paper presents sample calculations concerning the assessment of the vulnerability to pure loss of stability of a fishing vessel. Calculations were performed for level 1 and level 2 of the method under consideration. In the summary the author discusses the results of calculations. The paper describes the results method for assessment of the stability criteria for a fishing vessel. Calculations were performed by software MAXSURF after the implementation of the algorithm. The result of the calculation are measure the phenomenon criteria of pure loss of stability of a fishing vessel.

Introduction

Relatively small dimensions of a fishing vessel hull and the marine environment with its wave impact are two significant safety factors worth to be considered. Particular attention should be paid to stability-related safety of fishing vessels. Major operational risks include:

- decreased or lost stability, particularly when ship's hull is on the wave crest;
- low freeboard and possible shipping of green water;
- accumulation of green water on deck;
- ship's relatively high centre of gravity resulting from specific operations of the vessel;
- constant angle of loll due to outboard fishing gear.

This study, dealing with the phenomenon of pure loss of stability of a fishing vessel, aims at discussing a calculation algorithm based on the proposal of correspondence groups presented at a forum of IMO's *Ship Design and Construction Sub-Committee* [1].

The calculation procedure and the results presented in the following chapters refer to the pure loss of stability on the wave crest. This phenomenon is one of five stability failure modes that this work focuses on to implement new standards of ship stability safety assessment – so called second-generation intact stability criteria. The pure loss of stability affects mainly ships with small hulls, that is why a fishing vessel was chosen for the analysis. Notably, the calculations are of theoretical nature and are supposed to test the proposed algorithm.

Second generation intact stability criteria

The basic novelty of second generation criteria is that they take into account both the characteristics of ship motions in waves for the assessment of stability safety (more accurate model of physical phenomena) as well as specific character of hull shape. Present standards refer to a ship in calm water. However, as ship's behaviour in waves may lead to dangerous situations, naval architects should take it into account at the designing stage, so that the ship should have comprehensive operational guidelines in this respect. To date, five scenarios have been identified as dangerous situations (their number may change as the work is still in progress):

- pure loss of stability failure mode;
- parametric rolling stability failure mode;
- dead ship stability failure mode;
- excessive acceleration stability failure mode;
- surf-riding/broaching stability failure mode.

An important assumption made in the draft criteria is a three level evaluation that a vessel can be

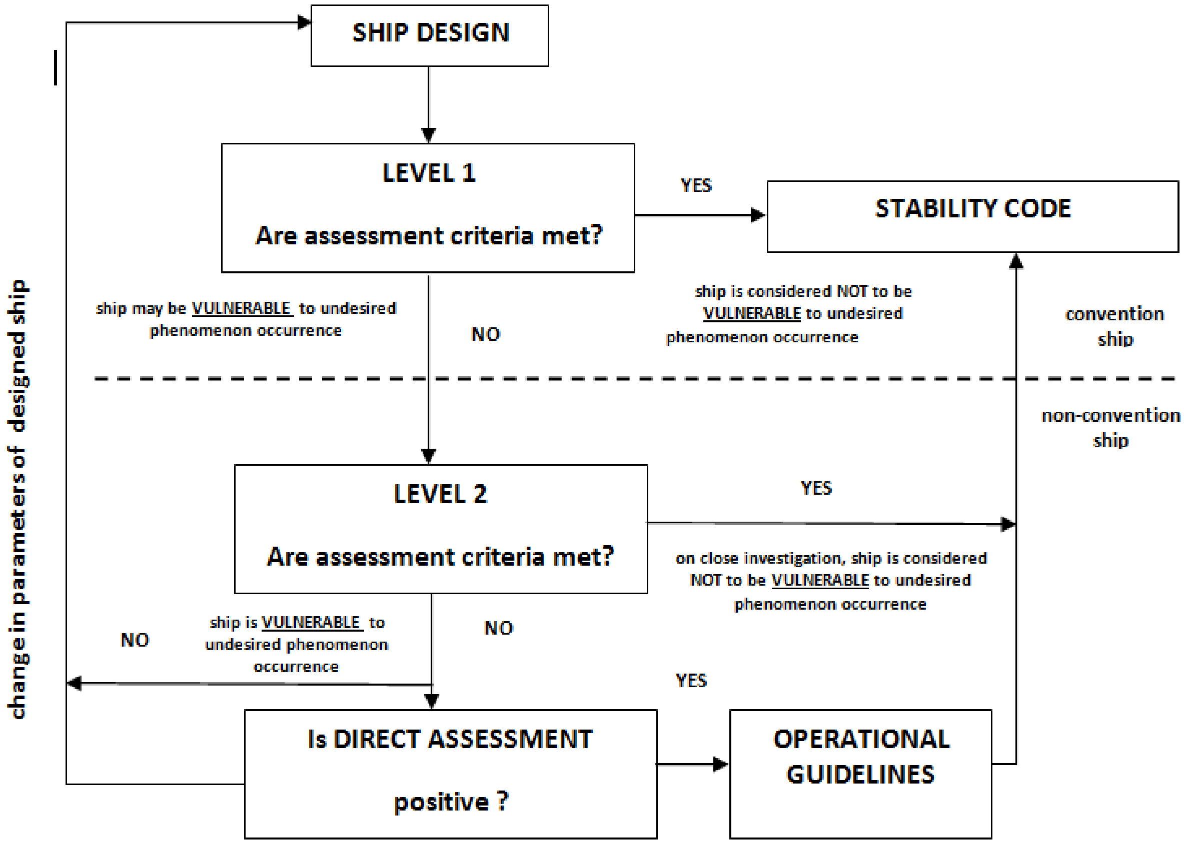

Fig. 1. Three-level evaluation of ship vulnerability to stability failure modes [2]

subject to (Fig. 1). The three-level division allows to separate convention vessels from non-convention vessels. According to the method, a ship being evaluated will go subsequently through three levels of evaluation. To qualify for the next level the ship must receive a negative assessment to set standards at the given level, i.e. must be recognized as vulnerable to the tested stability failure mode. If a ship meets criteria at level 1, it will be qualified as a convention vessel. If, in turn, it fails to meet the criteria, is will be evaluated at the higher level and be qualified as non-convention vessel. This will impose more detailed analysis resulting in amendments to the ship design or operational guidelines specific to a particular ship. A detailed procedure is illustrated in figure 1, while more comprehensive information on second generation stability criteria can be found in these publications: [1, 3, 4].

Pure loss of stability

According to the International Stability Code 2008 the basic parameters used in assessing intact stability are the righting lever GZ and the initial metacentric height GM. These parameters are strictly related to the vertical position of the ship's centre of gravity, and whether the statutory criteria are met during operation depends mainly on the position of the centre of gravity KG. These parameters are calculated for a ship in calm waters, i.e. when the waterplane can be represented as a non-deformed plane. In reality, when a moving ship is affected by waves which alter its position of equilibrium, it alternately finds itself on the wave crest and in the trough (and, naturally, some transitory states when the wave passes along the ship's hull). In such situation, the actual underwater part of the hull changes instantaneously, which leads to changes in the current waterplane. Consequently, changes also occur in the moment of inertia of the waterplane, waterplane area, position of the centre of buoyancy and other parameters connected with the shape of underwater part of the hull. All in all, movement in waves significantly affects the values of GZ and GM. The least favourable is a situation when a ship is on the wave crest and the wave length is comparable to ship's length [5]. An undesired change of the GZ value (decrease) is roughly proportional to the height of a wave in which a ship hull rests. The reduction of the righting lever value and of the initial metacentric height is called the pure loss of stability of a ship in waves. In an analysis of this phenomenon we usually consider the most disadvantageous situation for ship's stability safety in conditions where:

– direction of wave propagation conforms with ship's movement (following or head waves);

– ship's speed is equal to wave speed – for the following waves;
– wave length is equal to ship's length;
– significant wave height is actually considerable.

The proposed method of evaluating the ship vulnerability to pure loss of stability (still being developed and discussed) applies to ships 24 meters long or more, and the tested ship's speed expressed by Froude number meets this relation:

$$F_N > F_{NCL} \tag{1}$$

$$F_N = \frac{V_S}{\sqrt{gL}} \tag{2}$$

where:
F_N – Froude number corresponding to ship's speed [–];
F_{NCL} – Froude number corresponding to service speed; as assumed in the method, F_{NCL} = 0.2;
L – ship's length [m];
g – acceleration due to gravity, 9.81 [m/s^2].

The herein presented levels of evaluation as adopted in document [1] assume assessment of the initial metacentric height *GM* on the wave crest (and transitory states) and the value of righting lever *GZ* affected by several regular waves, whose model is shown in table 1. Level 1 refers to the evaluation of initial *GM* when a ship is on the crest of a wave equal in length to ship's length and having a specific steepness described by the coefficient S_W. A ship is qualified as vulnerable to pure loss of stability at Level 1 when thus calculated $GM_{\min}$ is less than the standard value at this level.

Level 2 of the vulnerability to pure loss of stability refers to parameters concerning the shape of righting levers curve of the ship for its various positions relative to the wave. The examined parameters include:
– range of positive righting levers – ship's angle of loll for which negative GZ values occur;
– angle of loll caused by a negative initial GM;
– maximum value of the righting lever.

The wave model used for the analysis (Table 1) consists of 16 regular waves of specific parameters (length, significant height, steepness) and the weight coefficient attributed to each wave, which in a way expresses the probability that a given wave will occur and that the ship will be affected in given circumstances by the stability failure mode. Apart from the weighting factors, this inference is based on logical values 0 and 1 qualifying or rejecting a ship as vulnerable to the evaluated risk (for a given wave). Such approach, incorporating weighting factors, is probabilistic in a sense. Calculations at Level 2 should take into account various positions of the wave crest relative to the ship hull (every 0.1 ship's length *L*), and free trim and sinkage (determination of ship's balanced position for its hull various positions relative to wave crest). A ship is qualified for Level 3 evaluation (identification of vulnerability to the examined phenomenon) when the sum of weight factors (the greatest value of the three mentioned parameters) is greater than the standard value for Level 2.

Level 1 criterion for the vulnerability to pure loss of stability

As assumed in the method, at this level a ship is considered not to be vulnerable to the pure loss of stability failure mode if the following inequality is satisfied:

$$GM_{\min} > R_{PLA} \tag{3}$$

where:
R_{PLA} – factor for the assessment of a criterion at Level 1, (Level 1 standard);
$GM_{\min}$ – minimum value of the initial metacentric height of the ship in waves.

According to the method, the standard R_{PLA} is assumed to be equal to 0.05 m or is calculated by the formula below, whichever value is lower.

$$R_{PLA} = \min\begin{cases} 1.83d(F_N)^2 \\ 0.05 \end{cases} \text{[m]} \tag{4}$$

where:
d – drafts due to the loading condition;
F_N – Froude number calculated for ship's present speed.

The value of initial metacentric height $GM_{\min}$ can be determined from numerical calculations for a full passage of a wave along the ship hull or from formula (5), when the condition for the shape of ship sides is satisfied, as expressed by formula (6).

$$GM_{\min} = KB + \frac{I_L}{V} - KG \tag{5}$$

$$\frac{V_D - V}{A_w(D-d)} \geq 1.0 \tag{6}$$

where:
d – draft corresponding to the loading condition under consideration;
I_L – transverse moment of inertia of the waterplane at the draft d_L – formula (7);
KB – height of the vertical centre of buoyancy corresponding to the loading condition under consideration;

V – volume of underwater hull (displacement) corresponding to the loading condition under consideration;
D – ship's depth;
V_D – volume of underwater hull (displacement) at waterline equal to D;
A_W – waterplane area at the draft corresponding to the loading condition under consideration.

$$d_L = d - \delta d_L \tag{7}$$

$$\delta d_L = \min\left(d - 0.25 d_{\text{full}}, \frac{LS_W}{2}\right) \tag{8}$$

where:
S_W – wave steepness parameter assumed in the method as a value 0.0334 [–];
d_L – draft for calculation of transverse moment of inertia of the waterplane [m];
δd_L – draft difference to be deducted due to ship's loading condition; smallest value of the two presented in formula (8) [m];
L – ship length [m].

Numerical calculations of $GM_{\min}$ can be made for the full passing of a longitudinal wave taking into account ship's new balanced positions due to the varying positions of ship's hull relative to the wave crest. The wave crest will be centred at the longitudinal centre of gravity and at each 0.1L forward and aft thereof.

Level 2 criterion for the vulnerability to pure loss of stability

At this level a ship is considered not to be vulnerable to the pure loss of stability failure mode if the greatest value of parameters CR_1, CR_2, CR_3 (formula (11)) resulting from the shape of righting level curve is less than the criterion R_{PLO} – formula (8). According to the method assumptions, R_{PLO} has a value as indicated in formula (10).

$$CR_{\max} < R_{PLO} \tag{9}$$

$$R_{PLO} = 0.06\,[\text{m}] \tag{10}$$

$$CR_{\max} = \max\begin{cases} CR_1 \\ CR_2 \\ CR_3 \end{cases} \tag{11}$$

In the method, CR parameters are calculated as follows:

$$CR_1 = \sum_{i=1}^{N} W_i C1_i - \text{weighted criterion 1} \tag{12}$$

$$CR_2 = \sum_{i=1}^{N} W_i C2_i - \text{weighted criterion 2} \tag{13}$$

$$CR_3 = \sum_{i=1}^{N} W_i C3_i - \text{weighted criterion 3} \tag{14}$$

where:
W_i – weighting factor for a given wave model obtained from table 1;
i – number assigned to each wave described in table 1;
N – number of waves under consideration as per table 1;
CR_1 – criterion 1 resulting from formula (15);
CR_2 – criterion 2 resulting from formula (16);
CR_3 – criterion 3 resulting from formula (17).

Criterion $C1_i$ concerns an angle of loll at which we observe vanishing stability, and which corresponds to a loading condition for a specific wave model (Table 1). Calculation results should be analyzed for each wave crest centred at the longitudinal centre of gravity and at each 0.1L forward and aft thereof. Criterion $C1_i$ is calculated from formula (15) and assumes logical values 0 or 1. The criterion is equal to 1 when the least of angles of loll at which values of righting lever are negative is smaller than the criterion R_{PL1} value obtained from formula (16). The value of angle φ_v is determined for a full passage of a longitudinal wave at each 0.1 ship length.

$$C1_i = \begin{cases} 1 & \varphi_V < R_{PL1} \\ 0 & \text{otherwise} \end{cases} \tag{15}$$

$$R_{PL1} = 30\,[°] \tag{16}$$

where:
φ_v – angle of loll at which the righting lever assumes negative values;
R_{PL1} – criterion parameter 1.

Criterion $C2_i$ (formula (17)) concerns an angle of loll φ_{loll} caused by a negative value of the initial metacentric height. It assumes the logical 1 value if the value of angle of loll exceeds the value expressed by R_{PL2} provided by formula (18). Conditions for obtaining the value of φ_{loll} (passage of a longitudinal wave) should be the same as for criterion CR_1.

$$C2_i = \begin{cases} 1 & \varphi_{\text{loll}} > R_{PL2} \\ 0 & \text{otherwise} \end{cases} \tag{17}$$

$$R_{PL2} = 25\,[°] \tag{18}$$

where:
φ_{loll} – angle of loll due to a negative value of GM;
R_{PL2} – criterion 2 parameter.

The criterion for $C3_i$ refers to the least value of ship's maximum righting lever $GZ_{\max}$. The value of parameter $C3_i$ is calculated from formula (19) and assumes the logical value 1 if $GZ_{\max}(m)$ is smaller than parameter R_{PL3} calculated by formula (20). The conditions for determining $GZ_{max}(m)$ (longitudinal wave crest passing along ship's hull) are the same as for the description of parameters $C1_i$ and $C2_i$.

$$C3_i = \begin{cases} 1 & GZ_{max}(m) < R_{PL3} \\ 0 & \text{otherwise} \end{cases} \quad (19)$$

$$R_{PL3} = 8\left(\frac{H_i}{\lambda_i}\right) dFn^2 \ \text{[m]} \quad (20)$$

where:

H – significant wave height;

λ – wave length;

d – draft corresponding to the loading condition;

F_N – Froude number corresponding to ship's service speed, formula (2).

Table 1. Wave parameters used in the evaluation of ship's vulnerability to the pure loss of stability

Regular wave number	Weighting factor	Wave length	Wave height	Wave steepness	Reversed wave steepness parameter
	W_i	λ_i [m]	H_i [m]	S_{wi} [–]	$1/S_{wi}$ [–]
1	1.300 E–05	22.574	0.700	0.0310	32.2
2	1.654 E–03	37.316	0.990	0.0265	37.7
3	2.091 E–02	55.743	1.715	0.0308	32.5
4	9.280 E–02	77.857	2.589	0.0333	30.1
5	1.992 E–01	103.655	3.464	0.0334	29.9
6	2.488 E–01	133.139	4.410	0.0331	30.2
7	2.087 E–01	166.309	5.393	0.0324	30.8
8	1.290 E–01	203.164	6.351	0.0313	32.0
9	6.245 E–02	243.705	7.250	0.0297	33.6
10	2.479 E–02	287.931	8.080	0.0281	35.6
11	8.367 E–03	355.843	8.841	0.0263	38.0
12	2.473 E–03	387.440	9.539	0.0246	40.6
13	6.580 E–04	422.723	10.194	0.0230	43.4
14	1.580 E–04	501.691	10.739	0.0214	46.7
15	3.400 E–05	564.345	11.241	0.0199	50.2
16	7.000 E–06	630.684	11.900	0.0189	53.0

Level 3 criterion for the vulnerability to pure loss of stability – direct evaluation

According to the schematic procedure shown in figure 1 the tests of ship's vulnerability to pure loss of stability failure mode takes place in three stages. The first and second stages are discussed over. When a ship qualifies to level 3 assessment, (after obtaining a negative vulnerability evaluation at both level 1 and 2), it is subject to direct stability assessment. The direct assessment is to be understood as additional model test and/or numerical calculations by a mathematical model that broadly describes, in this case, pure loss of stability. The outcome of such calculations or simulations will include:

1) design recommendations for, e.g., hull shape;
2) guidelines for the master, i.e. a manual specifying the circumstances (weather situation, loading conditions) under which the ship may experience the pure loss of stability;
3) information on the scope of personnel training on possibilities of stability failure mode occurrence;
4) other operational recommendations that may make the ship vulnerable to the pure loss of stability.

Calculations using the MAXSURF software

For the verification of calculations presented below a model of the fishing vessel *Trawler Pro* was used, available in the data base of Maxsurf software [6] storing a variety of ship hull models. Main particulars of the ship are given in table 2.

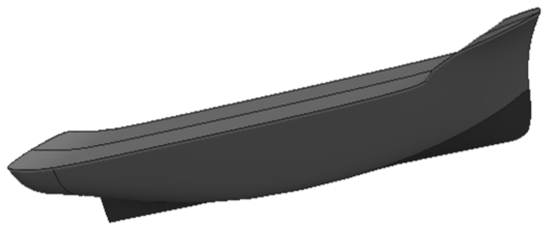

Fig. 2. A model of ship hull used in the calculations [6]

Table 2. Ship's main particulars [6]

Length L [m]	25	Displacement [m^3]	172
Breadth B [m]	5.7	Service speed V_S [kn]	10
Draft d [m]	2	Depth D [m]	3.2

The calculations of the initial metacentric height GM and righting lever GZ were made using Hydromax / Maxsurf software [6] and taking into account a typical loading condition, calm water and various positions of the wave relative to ship's hull. The results are collected in table 3.

The ship condition for the calculations also included the condition of no list or trim, and vertical position of the centre of gravity KG = 2 m.

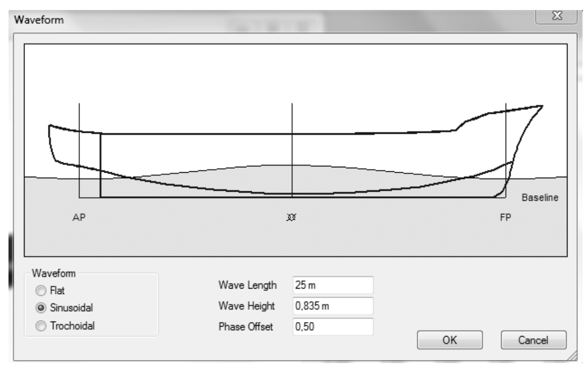

Fig. 3. Module of the Hydromax program for modelling the regular wave and its position relative to the ship hull [6]

Table 3. Values of the righting arm in calm water and in regular waves

Angle of loll φ	10°	20°	30°	40°	50°	60°	70°	80°	90°
GZ calm water	0	0.055	0.124	0.217	0.298	0.275	0.194	–0.087	–0.04
GZ – wave 1	0	0.04	0.095	0.174	0.232	0.215	0.143	–0.04	–0.084
GZ – wave 2	0	0.042	0.097	0.179	0.24	0.215	0.137	–0.031	–0.094
GZ – wave 3	0	0.043	0.099	0.183	0.246	0.219	0.139	–0.032	–0.095
GZ – wave 4	0	0.045	0.103	0.188	0.254	0.228	0.148	–0.04	–0.086
GZ – wave 5	0	0.047	0.107	0.194	0.265	0.239	0.159	–0.051	–0.075
GZ – wave 6	0	0.048	0.11	0.198	0.271	0.246	0.166	–0.058	–0.068
GZ – wave 7	0	0.049	0.112	0.201	0.276	0.251	0.172	–0.064	–0.062
GZ – wave 8	0	0.051	0.115	0.204	0.281	0.256	0.176	–0.069	–0.058
GZ – wave 9	0	0.051	0.116	0.207	0.284	0.26	0.18	–0.072	–0.054
GZ – wave 10	0	0.052	0.118	0.209	0.287	0.263	0.183	–0.075	–0.051
GZ – wave 11	0	0.053	0.119	0.21	0.289	0.265	0.185	–0.077	–0.049
GZ – wave 12	0	0.053	0.12	0.212	0.291	0.267	0.187	–0.079	–0.047
GZ – wave 13	0	0.054	0.121	0.213	0.292	0.268	0.188	–0.081	–0.046
GZ – wave 14	0	0.054	0.121	0.213	0.293	0.27	0.189	–0.082	–0.045
GZ – wave 15	0	0.054	0.122	0.214	0.294	0.271	0.19	–0.083	–0.044
GZ – wave 16	0	0.054	0.122	0.215	0.295	0.271	0.191	–0.083	–0.043

Example calculations

First, we have to specify a loading condition and set ship's speed. The speed taken for the calculations is 10 kn, equivalent to 5.14 m/s. Then we calculate the Froude number and compare it with the minimum value at which the method may be used.

$$F_N = \frac{V_S}{\sqrt{gL}} = 0.32 \ [–] \tag{21}$$

$$0.32 > 0.2 \ [–] \tag{22}$$

The above inequality shows that the requirement is satisfied.

Level 1 criterion of the vulnerability to the pure loss of stability

As a next step of calculations, we determine a minimum initial metacentric height $GM_{\min}$ and establish the standard criterion R_{PLA}. Further, we compare these values to check whether the ship is not vulnerable to the pure loss of stability at level 1. Using formula (4) we calculate R_{PLA} as proposed by the method and compare it with the option resulting from the formula, taking the smaller value. The calculations yield $R_{PLA} = 0.36$ m. Thus for further calculations the value $R_{PLA} = 0.05$ m is chosen. Then $GM_{\min}$ we calculate:

$$\begin{aligned} GM_{\min} &= KB + \frac{I_L}{V} - KG = \\ &= 1.18 + \frac{239.3}{176} - 2.5 = 0.039 \, [\text{m}] \end{aligned} \tag{23}$$

$$d_L = d - \delta d_L = 2 - 0.41 = 1.59 \, [\text{m}] \tag{24}$$

$$\begin{aligned} \delta d_L &= \min\left(d - 0.25 d_{\text{full}}; \frac{LS_W}{2} \right) = \\ &= \min\left(2 - 0.8; \frac{25 \cdot 0.0334}{2} \right) = \min(1.2; 0.41) \, [\text{m}] \end{aligned} \tag{25}$$

We make use of formulas (5), (7) and (8); the positive result of the verified condition described by formula (6) – the condition is satisfied as shown by relation (26).

$$\frac{337.5 - 172}{121(3.2 - 2)} > 1.0 \tag{26}$$

$$GM_{\min} = 0.039 < R_{PLA} = 0.05 \, [\text{m}] \tag{27}$$

The calculations indicate that the ship assessed at level 1 is vulnerable to the pure loss of stability. Level 2 calculations are presented below.

The value $GM_{\min}$ calculated by the Hydromax program requires some extra remarks. The value of initial metacentric height as calculated by the program for a suitable wave model $\lambda = L$ (wave length equal to ship length) and $Hs = S_w L$ (significant wave height equal to the product of ship length and wave steepness parameter) was $GM_{\min} = 0.205$ [–]. The method provides the wave steepness parameter $S_w = 0.0334$ [–]. On the other hand, using the steepness parameter for the built-in wave model of such length, ($S_w = 0.075$ [–]) the minimum metacentric height on the wave crest $GM_{\min} = 0.17$ m. In both cases the values significantly differ from the results calculated by formula (23). In a situation where the $GM_{\min}$ is taken from the program calculations and referred to the standard value R_{PLA}, the ship can be considered not to be vulnerable to the pure loss of stability.

Level 2 criterion of the vulnerability to the pure loss of stability

For the level 2 criterion the following formulas are used:

– results collected in table 4, formulas (15) and (16);

– results collected in table 5, formulas (17) and (18);
– results collected in table 6, formulas (19) and (20).

Table 4 contains the calculated criterion $C1$ for values of the angle of vanishing stability (loss of positive righting levers) compared to the criterion for a series of regular waves with parameters given in table 1. The angle of loll φ_V value was obtained by calculations using the Hydromax program for the previously specified ship model and a loading condition assigned to it. The sum value of particular components in the criterion $\Sigma C1 = 0$ [–].

Table 4. Calculated components of the criterion CR_1

Wave number	Angle of loll φ_v [°]	Parameter R_{PL1} [°]	Logical state	Weighting factor W [–]	Value of the criterion $C1$ [–]
1	> 70	30	0	1.300 E–05	0
2	> 70	30	0	1.654 E–03	0
3	> 70	30	0	2.091 E–02	0
4	> 70	30	0	9.280 E–02	0
5	> 70	30	0	1.992 E–01	0
6	> 70	30	0	2.488 E–01	0
7	> 70	30	0	2.087 E–01	0
8	> 70	30	0	1.290 E–01	0
9	> 70	30	0	6.245 E–02	0
10	> 70	30	0	2.479 E–02	0
11	> 70	30	0	8.367 E–03	0
12	> 70	30	0	2.473 E–03	0
13	> 70	30	0	6.580 E–04	0
14	> 70	30	0	1.580 E–04	0
15	> 70	30	0	3.400 E–05	0
16	> 70	30	0	7.000 E–06	0
Value of criterion CR_1					$\Sigma C1 = 0$

Table 5 collects the results of calculated criterion $C2$ for values of constant angle of loll caused by negative metacentric height $GM_{\min}$ on the wave crest compared to the criterion for a series of regular waves with parameters given in table 1. The angle of loll φ_{loll} value was obtained by calculations using the Hydromax program for the previously specified ship model and a loading condition assigned to it. The sum value of particular components in the criterion $\Sigma C2 = 0$ [–].

Table 6 contains the results of calculated criterion $C3$ for values of the least of maximum values of the righting lever $GZ_{\min}(\text{m})$ for various positions relative to the wave crest compared to the criterion for a series of regular waves with parameters given in table 1. The $GZ_{\min}(\text{m})$ value was obtained by calculations using the Hydromax program for the previously specified ship model and a loading condition assigned to it. The sum value of particular components in the criterion $\Sigma C3 = 0$ [–].

Table 5. Calculated components of the criterion CR_2

Wave number	Angle of loll φ_{loll} [°]	Parameter R_{PL2} [°]	Logical state	Weighting factor W [–]	Value of the criterion $C2$ [–]
1	0	25	0	1.300 E–05	0
2	0	25	0	1.654 E–03	0
3	0	25	0	2.091 E–02	0
4	0	25	0	9.280 E–02	0
5	0	25	0	1.992 E–01	0
6	0	25	0	2.488 E–01	0
7	0	25	0	2.087 E–01	0
8	0	25	0	1.290 E–01	0
9	0	25	0	6.245 E–02	0
10	0	25	0	2.479 E–02	0
11	0	25	0	8.367 E–03	0
12	0	25	0	2.473 E–03	0
13	0	25	0	6.580 E–04	0
14	0	25	0	1.580 E–04	0
15	0	25	0	3.400 E–05	0
16	0	25	0	7.000 E–06	0
Value of the criterion CR_2					$\Sigma C2 = 0$

Table 6. Calculated components of the criterion CR_3

Wave number	Value $GZ_{\min}$ (m) [m]	Parameter R_{PL3} [m]	Logical state	Weighting factor W [–]	Value of the criterion $C3$ [–]
1	0.232	0.05	0	1.300 E–05	0
2	0.24	0.04	0	1.654 E–03	0
3	0.246	0.03	0	2.091 E–02	0
4	0.254	0.05	0	9.280 E–02	0
5	0.265	0.03	0	1.992 E–01	0
6	0.271	0.05	0	2.488 E–01	0
7	0.276	0.05	0	2.087 E–01	0
8	0.281	0.05	0	1.290 E–01	0
9	0.284	0.05	0	6.245 E–02	0
10	0.287	0.05	0	2.479 E–02	0
11	0.289	0.04	0	8.367 E–03	0
12	0.291	0.04	0	2.473 E–03	0
13	0.292	0.04	0	6.580 E–04	0
14	0.293	0.03	0	1.580 E–04	0
15	0.294	0.03	0	3.400 E–05	0
16	0.295	0.03	0	7.000 E–06	0
Value of the criterion CR_3					$\Sigma C3 = 0$

Summing up the calculations of the vulnerability to *pure loss of stability* we should state that at level 2 the ship is not vulnerable to the considered failure mode – formulas (28) and (29).

$$CR_{\max} = \max\begin{cases} CR_1 = 0 \\ CR_2 = 0 \\ CR_3 = 0 \end{cases} \tag{28}$$

$$CR_{\max} = 0 < R_{PLO} = 0.06 \tag{29}$$

Conclusions

This paper analyzes a fishing vessel model for its vulnerability to the phenomenon of pure loss of stability. The calculations are based on a draft algorithm developed from conclusions and comments of correspondence groups at the SDC/IMO Subcommittee forum [1]. The concluding remarks and comments are as follows:

1) The standard R_{PLA} at level one has shown a large discrepancy. The recommended R_{PLA} value is 0.05 m or the value calculated by formula (4) (lower value is recommended). It seems that the standard value calculated by a simple formula using only ship draft, Froude number and a conventional factor will not be a representative value in assessing the vulnerability to the pure loss of stability at level 1. All the more the differences in calculated values seem to necessitate a broader analysis of formula (4). Another question to be answered is: Can the same standard be used for each type of ship, regardless of the size and operational requirements (e.g. weather conditions)?

2) The results of minimum value of initial metacentric height $GM_{\min}$ of a ship in waves calculated by formula (5) substantially differ from the value computed by Hydromax/Maxsurf (see formula (23)). Formula (5) requires further discussion and analysis as well as its results may be compared to those from tools presently used for ship's hydromechanics computations. Using the same formula for each type of ship hull (size, ratios of main dimensions) seems to be an excessive generalization.

3) The adopted model of waves for level 2 of the assessment under consideration also needs some comment. A series of regular waves that appears in this model with parameters that not necessarily affect the results of analysis for each type of hull (e.g. wave 15 or 16 when the ship length is 25 m). A more accurate solution might be to use various wave models for various ship lengths. Note that the literature sources indicate that waves with length similar to that of the ship impose greatest risks [5].

4) As for the wave angle, the method under consideration takes into account head or following seas. One may agree that an analysis for the following wave is particularly justified, as with similar speeds of the waves and the ship the duration of the hull riding on the wave crest gets longer. It remains unknown, however, how intermediate waves (neither head nor following waves) will affect the shape of waterplane and associated parameters.

5) The present form of the computing algorithm at level 2 is not an accurate physical model of the analyzed phenomenon, as was originally assumed for the assessment criterion.

6) In the original document describing the method, formula (15) has the wrong (reverse) inequality sign. Taking all logical conditions and assumptions of the method this notation is wrong. An affirmative conclusion concerning the vulnerability to pure loss of stability may be considered as justified when the angle at which positive stability (righting) levers vanish is smaller than the standard R_{PL1}.

7) Wave parameters lack indexes i (length, significant height) in formula (20) of the original text, which may create difficulties in formula interpretation. It seems obvious that a standard based on formula (20), i.e. R_{PL3} refers to wave parameters for which the maximum of righting lever curve is being examined.

To sum up, this paper is author's voice in the discussion concerning the method that is still in the phase of development.

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