ANALYSIS OF SECOND GENERATION INTACT STABILTY CRITERIA

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ABSTRACT

A new Intact Stability Code that is called second generation intact stability criteria are likely to be issued by IMO. These criteria include five failure modes of stability vulnerability (pure loss of stability, parametric roll, surf riding/broaching, dead-ship and excessive acceleration). The paper presents sample calculations concerning the assessment of the vulnerability to parametric roll of a bulk carrier. Calculations are carried out for level 1 and level 2 of the criteria under consideration. There are two options for assessment of criteria in Level 2. C1 of Level 2 is used in calculation given in this study.

Keywords: Parametric roll, Pure loss of stability, Second generation intact stability criteria, stability of a bulk carrier.

ÖZET

2. nesil yarasız stabilite kriterleri olarak adlandırılan IMO'nun yeni stabilite kuralları beş adet hata modundan oluşmaktadır: Net stabilite kaybı, Parametrik yalpa, Dalga üstünde seyir ya da boşa çıkma, Sevk sistemi devre dışı kalmış gemi durumu ve aşırı ivmelenme. Bu kriterler güvenlik ve hassasiyet analizlerini içermektedir. Bu makalede, bir yük gemisi için özellikle net stabilite kaybı ve parametrik yalpa hata modları incelenmiştir.

Keywords: Parametrik yalpa, Net stabilite kaybı, 2. Nesil yarasız stabilite kriterleri, Dökme yük gemisi stabilitesi.

1. Introduction

The first international stability rules were revised in IMO A.749 (18), 2008 Intact Stability (IS) Code, which became mandatory in July 2010. The first generation intact stability criteria, which form the basis of the 2008 IS code, were based on Rahola's work in 1939, however, the first studies of the weather criterion were developed in the 1950s.

In the empirical criteria casualty data of ships having their length of 100 metres or less were used for obtaining the relationship between GZ curve parameters and ship stability safety. In the semiempirical criterion casualty data of ships by 1950's were used to determine the critical value of average wind velocity, i.e. 26 m/s. Since they are directly or indirectly based on casualty data of ships existing before their developments, these two criteria could be regarded as the first generation criteria. As a result, applicability of these existing criteria to current ships cannot be straightforwardly guaranteed. The current major ship types, such as containerships, car carriers, RoPax ships, were not so easily found in 1950's and the sizes of these ships, particularly containerships and cruise ships, are drastically increasing year by year. For properly guarantee the stability safety for contemporary ships, new criteria are required, which can be named as the second generation intact stability criteria. [1-10]

The development of the second generation intact stability criteria started in 2002 when the SLF, the IMO subcommittee, established the intact stability working group. However, due to priority of IS code, the actual work started in September 2005 at the 48th Meeting of SLF. The working group decided that the second generation intact stability criteria should be based on the three most important stability vulnerability modes. These:

- Restoring arm variation problems, such as parametric excitation and pure loss of stability
- Stability under dead ship condition, as defined by SOLAS regulation II-1/3-8
- Manoeuvring related problems in waves, such as broaching-to

During this initial development, there was general agreement that the second generation criteria should be based on the physics of the specific phenomena leading to stability failure. The design and modes of operation of new ships take on characteristics that cannot, with confidence, rely solely on the statistics of failures and regression-based methods. Also, there was general agreement on the desirability of relating the new criteria to probability, or some other measures of the likelihood of stability failure, as methods of risk analysis have gained greater acceptance and become standard tools in other industries (e.g. SLF 48/4/12).[11]Relative capsize-risk assessment was including some weaknesses such as not knowing the level of safety and assumption uniform prejudice against all hull forms. Belknap, investigated a methodology for assessing annual and lifetime capsize risk based solely on regular wave capsize model tests. This methodology relies on mapping the model test-based capsize probabilities onto the joint-probability distribution of a given wavelength and period in both a given sea state and in a modal period. This joint-probability distribution is based on the work of Longuet-Higgins (1957). The results of these calculations indicate that the lifetime capsize risk for a typical naval vessel is on the order of a fraction of a percent. Intuitively, this seems to be a reasonable absolute lifetime capsize risk.[12]
The framework for the second generation intact stability criteria, described in SLF 50/4/4 and discussed at the 50th session of SLF (May 2007). The key elements of this framework were the distinction between performance-based and parametric criteria, and between probabilistic and deterministic criteria. Special attention was paid to probabilistic criteria; the existence of the problem of rarity was recognized for the first time and a definition was offered. [11]
Based on the multi-tier approach prepared by Belenky, et al (2008), a draft including all dynamic stability vulnerability considered for the second generation intact stability criteria has been prepared. The study of the subcommittee formed the multi-tier structure of the criteria in SLF 51/4/1 Annex 2. Multi-tier structure bases on a three level arrangement: the Level 1 represents the easiest method of criteria, and also the most conservative one. If the vessel fails to comply with Level 1, a Level 2 check has to be carried out, which is more detailed and complicated evaluation. Finally, if the vessel is also found to be vulnerable under Level 2 criteria, a direct assessment has to be done. Five stability failure modes were presented as the most important criteria which should be discussed in future:

- Pure loss of stability
- Parametric rolling
- Surf-riding/Broaching
- Dead ship condition
- Excessive acceleration

The consideration of excessive accelerations was also added to the list of stability failure modes in SLF 53/19 following the partial stability failure of Chicago Express.
The form of multi-tier assessment bases on the two ways of the risk calculation for five stability criteria. Level 1 of all failure modes is most basic method in calculation the ship parameters, Level 2 of these are the method calculation of similar parameters when the vessel encounters vary of steep wave and length wave.
The criteria in level 2 of failure mode are to estimate the hull risk of each probabilistic ocean component as an index of 1 or 0, multiply the probability value by the risk factor for each component, express the final risk as CR1 and CR2, and determine whether the magnitude of the risk is above a certain value.

2. Pure Loss of Stability

A ship may stay in wave crest while sailing in waves. The submerged geometry of the ship is different from that in calm water. Water plane area changes and gets smaller. The value of initial metacentric height GM decreases. If the ship carries out enough heeling with deteriorated GM, it may end capsize. This critical situation occurs if the vessel's speed is close to the wave's speed. So, there will be enough prolonged period of time for deterioration of transverse stability. The provisions given here under apply to all ships, except for ships with extended low weather decks for which the Froude number, F_n, corresponding to the service speed exceeds 0.24.[13]

For the purpose of this section, F_n, is determined using the following formula:

$$F_n = \frac{V_S}{\sqrt{gL}} \quad \textbf{(1)}$$

Where,
V_S = Service speed, m/s
L = Length of the ship (m);
g = acceleration due to gravity, 9.81 m/s^2

2.1 Level 1 Vulnerability Criteria

$GM_{min} > R_{PLA}$
Where R_{PLA} = 0.05 m
GM_{min} = the minimum value of the metacentric height including free surface correction (m)
GM_{min} should be determined according to:

$$GM_{min} = KB + \frac{I_L}{\nabla} - KG \left[only\ if\ \frac{V_D - V}{A_{;W}(D-d)} \geq 1.0 \right] \quad \textbf{(2)}$$

Where,
KB = height of the vertical centre of buoyancy corresponding to the loading condition under consideration (m);
KG = height of the vertical centre of gravity corresponding to the loading condition under consideration (m);
I_L = moment of inertia of the waterplane at the draft d_L (m4);
∇ = volume of displacement corresponding to the loading condition under consideration (m3);
$d_L = d - \delta d_L$ (m);
d = draft amidships corresponding to the loading condition under consideration (m);
$\delta d_L = Min\left(d - 0.25 d_{full}, \frac{L \cdot S_W}{2}\right)$ (m);
and $d - 0.25 d_{full}$ should not be taken less than zero;
d_{full} = draft corresponding to the fully loaded departure condition (m);
S_W = 0.0334;
L = length as defined in 2.12 of the 2008 IS Code (m);
D = moulded depth at side to the weather deck (m);
∇_D = volume of displacement at waterline equal to D (m3); and
A_W = water plane area at the draft equal to d (m2).

2.2 Level 2 Vulnerability Criteria

A ship is considered not to be vulnerable to the pure loss of stability failure mode if the largest value of the two criteria CR_1 and CR_2 is less than R_{PL0},
Where, R_{PL0} = 0.06

$$CR_1 = \sum_{i=1}^{N} W_i C1_i = Weighted \text{ criterion 1} \quad \textbf{(3)}$$
$$CR_2 = \sum_{i=1}^{N} W_i C2_i = Weighted \text{ criterion 2} \quad \textbf{(4)}$$

W_i = a weighting factor obtained from Table 1 divided by the amount of observations given in the table;
N = number of wave cases for which $C1_i$ and $C2_i$ are evaluated corresponding to wave cases with non-zero W_i from Table 1.1.2 (N=197);
For calculating the restoring moment in waves, the following wavelength and wave height should be used:
Length $\lambda = L$;
Height $h = 0.01iL$, $i = 0, 1 \ldots 10$.
The index for each of the two criteria, ϕv and ϕs should be calculated according to the formulations given in criteria.
In these waves to be studied, the wave crest is to be centred amidships, and at 0.1L, 0.2L, 0.3L, 0.4L and 0.5L forward and 0.1L, 0.2L, 0.3L and 0.4L aft thereof.

Table 1 Wave case occurrences per 100,000 observations for evaluation of pure loss of stability

	Tz (s) = avarage zero up-crossing wave period															
Hs (m)	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5
0.5	1.3	133.7	865.6	1186	634.2	186.3	36.9	5.6	0.7	0.1	0	0	0	0	0	0
1.5	0	29.3	986	4976	7738	5569.7	2375.7	703.5	160.7	30.5	5.1	0.8	0.1	0	0	0
2.5	0	2.2	197.5	2158.8	6230	7449.5	4860.4	2066	644.5	160.2	33.7	6.3	1.1	0.2	0	0
3.5	0	0.2	34.9	695.5	3226.5	5675	5099.1	2838	1114.1	337.7	84.3	18.2	3.5	0.6	0.1	0
4.5	0	0	6	196.1	1354.3	3288.5	3857.5	2685.5	1275.2	455.1	130.9	31.9	6.9	1.3	0.2	0
5.5	0	0	1	51	498.4	1602.9	2372.7	2008.3	1126	463.6	150.9	41	9.7	2.1	0.4	0.1
6.5	0	0	0.2	12.6	167	690.3	1257.9	1268.6	825.9	386.8	140.8	42.2	10.9	2.5	0.5	0.1
7.5	0	0	0	3	52.1	270.1	594.4	703.2	524.9	276.7	111.7	36.7	10.2	2.5	0.6	0.1
8.5	0	0	0	0.7	15.4	97.9	255.9	350.6	296.9	174.6	77.6	27.7	8.4	2.2	0.5	0.1
9.5	0	0	0	0.2	4.3	33.2	101.9	159.9	152.2	99.2	48.3	18.7	6.1	1.7	0.4	0.1
10.5	0	0	0	0	1.2	10.7	37.9	67.5	71.7	51.5	27.3	11.4	4	1.2	0.3	0.1
11.5	0	0	0	0	0.3	3.3	13.3	26.6	31.4	24.7	14.2	6.4	2.4	0.7	0.2	0.1
12.5	0	0	0	0	0.1	1	4.4	9.9	12.8	11	6.8	3.3	1.3	0.4	0.1	0
13.5	0	0	0	0	0	0.3	1.4	3.5	5	4.6	3.1	1.6	0.7	0.2	0.1	0
14.5	0	0	0	0	0	0.1	0.4	1.2	1.8	1.8	1.3	0.7	0.3	0.1	0	0
15.5	0	0	0	0	0	0	0.1	0.4	0.6	0.7	0.5	0.3	0.1	0.1	0	0
16.5	0	0	0	0	0	0	0	0.1	0.2	0.2	0.2	0.1	0.1	0	0	0

The number of non-zero-weighted waves is large in Table 1, so the regulation provides effective wave height method to reduce time of computation. Effective wave height calculated according to Grim method provides the ship with the same energy than the original wave.
In this method, effective wave heights might be computed according to a zero-crossing period (T_Z) equal to 10.5 seconds. Effective wave length is to be taken L. 11 effective wave heights should be considered from 0 to 0.1L. For each wave height, wave crest is to be located at the longitudinal centre of gravity and at each $\lambda/10$ forward and aft thereof in order to find the minimum angle of vanishing stability ($\phi_{V.min}$) and the maximum angle of stable equilibrium ($\phi_{S.max}$).
The successive values of $\phi_{V.min}$ and $\phi_{S.max}$, are to be used in calculation coefficients C1 and C2 in all wave cases of the scatter diagram by linear interpolation.

Criteria 1
The angle of vanishing stability, ϕ_v, should be determined as the minimum value.

$$C1_i = \begin{cases} 1, & \phi_V < R_{PL1} \\ 0, & otherwise \end{cases}$$

Where, R_{PL1} = 30 degrees

Criteria 2
Calculation of the angle of heel, ϕ_s, under action of the heeling lever specified by R_{PL3}

$$C2_i = \begin{cases} 1, & \phi_S < R_{PL2} \\ 0, & otherwise \end{cases}$$

Where, R_{PL2} = 15 degrees for passenger ships; and
= 25 degrees
R_{PL3}= 8 (H_i/λ) d Fn^2

3. Pure Loss of Stability

The phenomenon of parametric roll is generated by the variation of the roll restoring term due to the wave passing along the hull. Its effects are more intense in longitudinal waves, when the wave encounter frequency approximates the double of the ship roll natural frequency. Under these conditions, roll motion can reach very large amplitudes. [14,15]
Where GM_0 is the initial metacentric height in calm water and δGM is the amplitude of the harmonic variation of GM

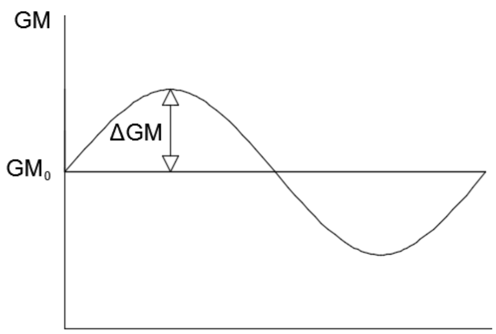

Figure 1: Time-dependent GM variation

Differential equation of roll motion is:

$$I_{XX}\ddot{\varphi} + B\dot{\varphi} + mg[GM_0 + \Delta GM\cos(\omega_e t)] = 0 \quad \textbf{(5)}$$

3.1 Level 1 Vulnerability Criteria

Level 1 vulnerability check is passed if:

$$\frac{\delta GM_1}{GM_C} \leq R_{PR} \quad \textbf{(6)}$$

Where R_{PR} is the criterion standard given by:
R_{PR}= 1.87, if the ship has a sharp bilge;
$R_{PR} = 0.17 + 0.425\left(\frac{100A_K}{LB}\right)$, if $C_M > 0.96$
$R_{PR} = 0.17 + (0.625xC_M - 9.775)\left(\frac{100A_K}{LB}\right)$, if $0.94 < C_M < 0.96$
$R_{PR} = 0.17 + 0.2125\left(\frac{100A_K}{LB}\right)$, if $C_M < 0.96$; and
$\left(\frac{100A_K}{LB}\right)$ not exceed 4;

GM_C = metacentric height of the loading condition in calm water
δGM_1 = the amplitude of the variation of the metacentric height
A_k is bilge keel area (m^2)
C_m is the midship coefficient

$$\delta GM_l = \frac{I_H - I_L}{2\nabla}, \left[only\ if\ \frac{\nabla_D - \nabla}{A_{;W}(D-d)} \geq 1.0\right]$$

$\delta d_H = Min\left(D - d, \frac{L \cdot S_W}{2}\right)$ (m);
$\delta d_L = Min\left(d - 0.25 d_{full}, \frac{L \cdot S_W}{2}\right)$ (m)
$d_H = d + \delta d_H$
$d_L = d - \delta d_L$
$S_W = 0.0167$;
A_W = waterplane area at the draft equal to d (m^2);
I_H, I_L are the second moments of waterplane area at specific drafts d_H and d_L respectively

3.2 Level 2 Vulnerability Criteria

The Level 2 presents two checks. A ship is considered not to be vulnerable if either one is ensured.
First check is R_{PR0} =0.06

$$C1 = \sum_{i=1}^{n} W_i C_i > R_{PR0} \quad \textbf{(7)}$$

W_i is the weighting factor for the respective wave specified in Table 1
C_i = 0, if the requirements for either the GM variation in waves or the ship speed in waves is satisfied
= 1, if not
The requirement for the variation of GM in waves is satisfied if, for each wave

$$GM(H_i, \lambda_i) > 0 \text{ and } \frac{\delta GM(H_i,\lambda_i)}{GM(H_i,\lambda_i)} < R_{PR} \quad \textbf{(8)}$$

Where,
R_{PR} = as defined in Level1
$\delta GM(H_i, \lambda_i)$ = one-half the difference between the maximum and minimum values of the metacentric height calculated for the ship (m)
$GM(H_i, \lambda_i)$ = the average value of the metacentric height calculated for the ship (m),

$V_{PRi} > V_S$
Where,
V_S = the service speed (m/s); and

V_{PRi} = the reference ship speed (m/s) corresponding to parametric resonance conditions, when GM(Hi, λi)>0:

$$V_{PRi} = \left| \frac{2\lambda_i}{T_\phi} \cdot \sqrt{\frac{GM(H_i,\lambda_i)}{GM_C}} - \sqrt{g\frac{\lambda_i}{2\pi}} \right| \tag{9}$$

Table 2: Wave cases for parametric rolling evaluation

Wave Case Number	Weight Wi	Wave Length λi (m)	Wave Height Hi (m)
1	0.000013	22.574	0.350
2	0.001654	37.316	0.495
3	0.020912	55.743	0.857
4	0.092799	77.857	1.295
5	0.199218	103.655	1.732
6	0.248788	133.139	2.205
7	0.208699	166.309	2.697
8	0.128984	203.164	3.176
9	0.062446	243.705	3.625
10	0.024790	287.931	4.040
11	0.008367	335.843	4.421
12	0.002473	387.440	4.769
13	0.000658	442.723	5.097
14	0.000158	501.691	5.370
15	0.000034	564.345	5.621
16	0.000007	630.684	5.950

For the calculation of $\delta GM(H_i, \lambda_i)$ and $GM(H_i, \lambda_i)$, the wave crest should be located at amidship, and at 0.1 λ_i, 0.2 λ_i, 0.3 λ_i, 0.4 λ_i, and 0.5 λ_i forward and 0.1 λ_i, 0.2 λ_i, 0.3 λ_i, and 0.4 λ_i aft thereof.

$$C2 = \left[\sum_{i=1}^{12} C2(Fn_i,\beta_h) + \frac{1}{2}\{C2(0,\beta_h) + C2(0,\beta_f)\} + \sum_{i=1}^{12} C2(Fn_i,\beta_f)\right]/25 \tag{10}$$

Second check is R_{PR1} =0.025
$F_{ni} = V_i/\sqrt{Lg}$ = Froude number corresponding to ship speed,
$V_i = V_s K_i$, means the ship speed (m/s) for each corresponding encounter;
Vs = ship service speed (m/s);
$C2(F_{ni},\beta_h) = C2(Fn,\beta)$ calculated with the ship proceeding in head waves with a speed equal to V_i;
$C2(F_{ni},\beta_f) = C2(Fn,\beta)$ calculated with the ship proceeding in following waves with a speed equal to V_i;

Table 3 Speed factor, K_i

i	K_i	***Corresponds to encounter with***
1	1.0	Head or following waves at Vs
2	0.991	Waves with 7.5^0 relative bearing to ship centerline at Vs
3	0.966	Waves with 15^0 relative bearing to ship centerline at Vs
4	0.924	Waves with 22.5^0 relative bearing to ship centerline at Vs
5	0.866	Waves with 30^0 relative bearing to ship centerline at Vs
6	0.793	Waves with 37.5^0 relative bearing to ship centerline at Vs
7	0.707	Waves with 45^0 relative bearing to ship centerline at Vs
8	0.609	Waves with 52.5^0 relative bearing to ship centerline at Vs
9	0.500	Waves with 60^0 relative bearing to ship centerline at Vs
10	0.383	Waves with 67.5^0 relative bearing to ship centerline at Vs
11	0.259	Waves with 75^0 relative bearing to ship centerline at Vs
12	0.131	Waves with 82.5^0 relative bearing to ship centerline at Vs

$$C2(Fn,\beta) = \sum_{i=1}^{N} W_i\, C_i \qquad \textbf{(11)}$$

W_i the weighting factor for the respective wave cases in Table 1
C_i = 1, if the maximum roll angle evaluated according to next paragraph exceeds 25 degrees
= 0, otherwise

4. Sample vessel

Sample ship complies with the IS code 2008 so, check for second generation criteria can be performed. The sample calculation following includes the detailed check of vulnerability criteria for parametric roll failure of bulk carrier ship.

The ship's characteristics:

LBP (m)	167
Beam (m)	29.4
Depth (m)	13.7
Mean Draft (m)	9.922
Block Coefficient	0.817
GM (m)	4.098
Displacement (t)	40920
Design Speed (knots)	15
Froude Number	0.19

4.1 Pure loss of stability calculation

The criterion is intended for ships having a service speed Froude number larger than 0.24 whereas Froude number of the sample ship is 0.19. Although, Froude number is low for assessment of ship vulnerability, draft calculation of criteria is performed as follow.

4.1.1 Pure loss of stability Level 1 check

I_L is determined according to d_L draft, if

$$\frac{57210 - 39990}{4431(13.7 - 9.922)} = 1.023 \geq 1.0$$

So, d_L draft and I_L moment of inertia are given as below;

$$\delta dL = Min\left(7.442, \frac{167 \cdot 0.0167}{2}\right) = 1.40\ m$$

$d_L = 9.922\text{-}1.4 = 8.522$ m $\rightarrow$ $I_L = 276230\ m^4$

GM_{min} is calculated with KB = 5.11 m and KG = 8.227 m;

$$GM_{min} = 5.11 + \frac{276230}{39990} - 8.227 = 3.79\ m$$

Level 1 of criteria is fulfilled where $GM_{min} = 3.79 > 0.05$

4.1.2. Pure loss of stability Level 2 check

Level 2 vulnerability check is not necessary since Level 1 check is fulfilled. Otherwise, Level 2 check could be performed by effective wave height method as described in 2.1.2.

4.2. Parametric roll calculation

Calculations belong to draft regulation of parametric roll are performed as follow.

4.2.1. Parametric roll Level 1 check

Total overall projected area of the bilge keels, A_k = 17.4 m^2
Midship section coefficient of the fully loaded condition in calm water, C_m = 0.99
R_{PR} constant in the calculation criteria check for Cm > 0.96;

$$R_{PR} = 0.17 + 0.2125\left(\frac{100 \cdot 17.4}{167 \cdot 29.4}\right) = 0.25$$

Calculation of δGM_1 is given below;

$$\frac{57210 - 39990}{4431(13.7 - 9.922)} = 1.023 \geq 1.0$$

$$\delta dH = \mathrm{Min}\left(3.778, \frac{167 \cdot 0.0167}{2}\right) = 1.40 \text{ m}$$

$$\delta dL = \mathrm{Min}\left(7.442, \frac{167 \cdot 0.0167}{2}\right) = 1.40 \text{ m}$$

d_H = 9.922+1.4 = 11.322 m
d_L = 9.922-1.4 = 8.522 m

$$\delta GM_1 = \frac{294576 - 276230}{2 \cdot 39990} = 0.23 \text{ m}$$

$$\frac{\delta GM_1}{GM_C} = \frac{0.23}{4.098} = 0.06 \leq 0.25$$

Although Level 1 of criteria is fulfilled, Level 2 check is performed for vulnerability

4.2.2. Parametric roll Level 2 check

Level 2 vulnerability checks can be performed according to C1 and C2 coefficients. In this study, C1 is used in vulnerability check; also calculated values are given below.
If C1>R_{PR} so that the vessel not to be vulnerable where, R_{PR} = 0.06
The value for C1 is calculated according to GM for each wave, and given in Table 4 with the weighting factors.
Radius of gyration, moments of inertia and natural roll frequency values belonging to sample vessel are calculated as below.
K= 10.4 m I'_{xx} = 450675600 kg.m.sec^2 T_ϕ = 10.3 sec

Table 4 C1 values according to GM for each wave case

Wave Case Number	Weight Wi	Wave Length λi (m)	Wave Height Hi (m)	$GM(H_i.\lambda_i)$	$\delta GM(H_i.\lambda_i)$	C_i	$C1_i$
1	0.000013	22.574	0.350	4.2543	0.0002	0	0
2	0.001654	37.316	0.495	4.2518	0.0076	0	0
3	0.020912	55.743	0.857	4.2638	0.0096	0	0
4	0.092799	77.857	1.295	4.2395	0.0723	0	0
5	0.199218	103.655	1.732	4.2639	0.0263	0	0
6	0.248788	133.139	2.205	4.3178	0.1382	0	0
7	0.208699	166.309	2.697	4.3752	0.2148	0	0
8	0.128984	203.164	3.176	4.3800	0.2796	0	0
9	0.062446	243.705	3.625	4.3143	0.2832	0	0
10	0.024790	287.931	4.040	4.2117	0.2027	0	0
11	0.008367	335.843	4.421	4.2246	0.2077	0	0
12	0.002473	387.440	4.769	4.2358	0.2047	0	0
13	0.000658	442.723	5.097	4.1961	0.0988	0	0
14	0.000158	501.691	5.370	4.2204	0.0906	0	0
15	0.000034	564.345	5.621	4.2430	0.0826	0	0
16	0.000007	630.684	5.950	4.2676	0.0755	0	0

C1 total value is 0, so the criteria check according to GM values is satisfied. Additionally, criteria check according to ship speed might be recalculated. The roll natural period in calm water is to be found for calculation of V_{PRi}.

The value for C1 is calculated according to ship speed for each wave, and given in Table 5 with the weighting factors. If $C1>R_{PR}$ so that the vessel not to be vulnerable where, $R_{PR} = 0.025$

Table 5 C1 values according to ship speed for each wave case

Wave Case Number	Weight Wi	Wave Length λi (m)	Wave Height Hi (m)	$GM(H_i.\lambda_i)$	V_{PRi}	C_i	$C1_i$
1	0.000013	22.574	0.350	4.2543	1.4707	1	0.000013
2	0.001654	37.316	0.495	4.2518	0.2524	1	0.001654
3	0.020912	55.743	0.857	4.2638	1.7116	1	0.020912
4	0.092799	77.857	1.295	4.2395	4.3513	1	0.092799
5	0.199218	103.655	1.732	4.2639	7.8090	0	0
6	0.248788	133.139	2.205	4.3178	12.1189	0	0
7	0.208699	166.309	2.697	4.3752	17.2532	0	0
8	0.128984	203.164	3.176	4.3800	22.9741	0	0
9	0.062446	243.705	3.625	4.3143	29.0475	0	0
10	0.024790	287.931	4.040	4.2117	35.4765	0	0
11	0.008367	335.843	4.421	4.2246	43.3128	0	0
12	0.002473	387.440	4.769	4.2358	51.8901	0	0
13	0.000658	442.723	5.097	4.1961	60.6972	0	0
14	0.000158	501.691	5.370	4.2204	70.8730	0	0
15	0.000034	564.345	5.621	4.2430	81.8192	0	0
16	0.000007	630.684	5.950	4.2676	93.5908	0	0

So, C1 total value is 0.12 and more than 0.025 if the criteria check is performed according to ship speed values.

5. Conclusions

This paper gives an example for parametric roll criteria of second generation intact stability that is the current state of development by the International Maritime Organisation (IMO). The sample vessel is non vulnerable against IS code 2008. Level 1 criteria is fulfilled with ratio of calculated GM amplitude to initial GM which is greater than 0.25.

Level 2 criteria includes C1 and C2 of parametric roll failure mode. In this study, Level 2 calculation is performed with C1 value. So, GM values are calculated according to given 16 wave cases in Level 2. C1 value of each wave case can be satisfied by either the variation of GM in waves or the ship speed in waves in order to fulfil Level 2.

Eventually, level 2 is fulfilled by zero value of total C1. It is observed that C1 calculation according to ship speed is more conservative than that of GM values. Therefore, the vessel which has high speed and GM is more vulnerable against parametric roll failure mode.

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