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Second Generation IMO Intact Stability Vulnerability Criteria and its Application to Ships Navigating in Persian Gulf and Oman Sea

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ABSTRACT

Second generation intact stability criteria for few past years had been under development by International Maritime Organization (IMO). Since the draft proposed amendments shall be amended to International code on Intact Stability (IS code 2008), new regulations shall enter into force for ships of length more than 24 meter. Generally second generation intact stability criteria (SGISC) refers to vulnerability ship stability modes which occurs when the ship navigating in rough seas. As waves passes the ship, dynamic phenomenon will affects ship stability that may lead to capsizing. Unlike IS code 2008, which study ship stability in calm water with a single level criteria, SGISC check the stability in different levels. In this method, if a ship passes only one level of criteria, means it is safe according to respective dynamic phenomena. In this article in order to understand the functionality of the proposed criteria in last draft amendment provided by IMO, numerical tools have been used to assess the effect of three phenomenon, pure loss of stability, parametric rolling, and surf-riding/broaching. Wide range of ships including fishing, passenger, cargo, Fiber glass and container ships, navigating in Persian gulf and Oman sea are considered to assess a comprehensive effects of proposed criteria. The results shows that all ships pass pure loss of stability and parametric rolling criteria but all passenger ships, 2 tugs, 1 fiberglass and 1 fishing vessel failed the surf riding/broaching criteria. It should be concluded that to pass the vulnerability criteria of surf riding, existing ships (specially passenger ships) should decrease their speed and new building vessels should be designed so that their Froude number do not encounter critical Froude number range as defined by the regulations.

1. Introduction

Sufficient intact stability for a ship is one of the most important and fundamental requirements for any type of vessel. Since 1930s, different stability criteria developed including national regulations as well as classification society rules. However first generation intact stability criteria was originally codified at IMO in Res. A.749 (18) [1] by taking into account former IMO recommendations listed in Res. A.167 (ES.IV) [2]. Finally a thorough code adopted by resolution MSC.267 (85) [3] in 2008 known as International Code on Intact stability, IS code 2008. It was entered into force for ships of length more than 24 meter from July 2010.

The development of the second generation of intact stability criteria started in 2002 with the re-establishment of the intact stability working group by the IMO Subcommittee on Stability, Load Lines and Fishing Vessels Safety (SLF). However, due to other priorities, the actual work on the second generation of intact stability criteria did not start until the 48th session of the SLF, in September 2005. The working group decided that the second generation of intact Stability criteria should be performance-based and address three fundamental modes of stability failures [4]:

- Restoring variation problems
- Stability on dead ship condition
- Maneuvering related problems in waves

According to above assumptions the first proposals for these criteria was that contained in SLF 49 [5] which was submitted by Germany. However this proposal had multiple theoretical shortcomings and was rejected by the working group at 49th session of SLF. In SLF 51 [6] five stability failure modes were presented as the most important criteria which should be discussed in future:

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

Afterward, Blenky et. al [7] proposed a multi-tiered approach based on analysis of experiences and previous efforts of American Bureau of Shipping (ABS) on parametric roll of containerships. It also gave a broad review of the physics background of the dynamic stability failures under consideration. These multi-tiered approaches finally approved on SLF 53 [8] as an appropriate method in study of new generation intact stability criteria (see Figure 1).

In this process (as shown in Fig. 1), the criteria in section 2.2 and then that of Section 2.3 of Part A of the 2008 IS Code apply for all ships covered under IMO instruments. Each ship is also checked for vulnerability to pure loss of stability, parametric roll, and broaching/surf-riding phenomena using level 1 vulnerability criteria (L1). If a possible vulnerability is detected, then the level 2 criteria (L2) is used, followed by direct stability assessment (DA), if necessary. If the direct stability assessment shows an elevated level of risk for the respective mode of stability failure, then ship specific operational guidance (OG) may be developed, which is subject to the requirements of the flag administration. If vulnerability to any mode of stability failure was not detected, or the risk of stability failure is not considered excessive, then no additional requirements must to be satisfied. The process is repeated for all three stability failure modes [9].

Later the discussion transferred to subcommittee of ship design and construction (SDC) and many documents were reviewed for finalization of proposed criteria. In SDC 2 and SDC 3 level 1 and level 2 criteria were finalized and draft amendments were provided for adoption in IS code 2008. In SDC 2 [10] three finalized vulnerability criterion, pure loss of stability, parametric rolling and surf-riding/broaching are presented and other criteria, deadship condition and excessive acceleration, are postponed for more discussion.

In this study, final draft amendments from SDC 2 [10] which discussed by Jahanbakhsh and Masoodi [11] is presented and its application studied to ships navigating in Persian Gulf and Oman sea. For this purpose 23 sample case of different types e.g. fishing, passenger, containership, tug which are Iranian flag existing ships classed by Iranian Classification Society (ICS) are considered and vulnerability criteria are assessed to determine which criteria will fail for any type of ship. It should be noted that if one specific ship do not pass the criteria, it means that ship shall be detained to navigate until the problem of its stability be solved according to international regulations.

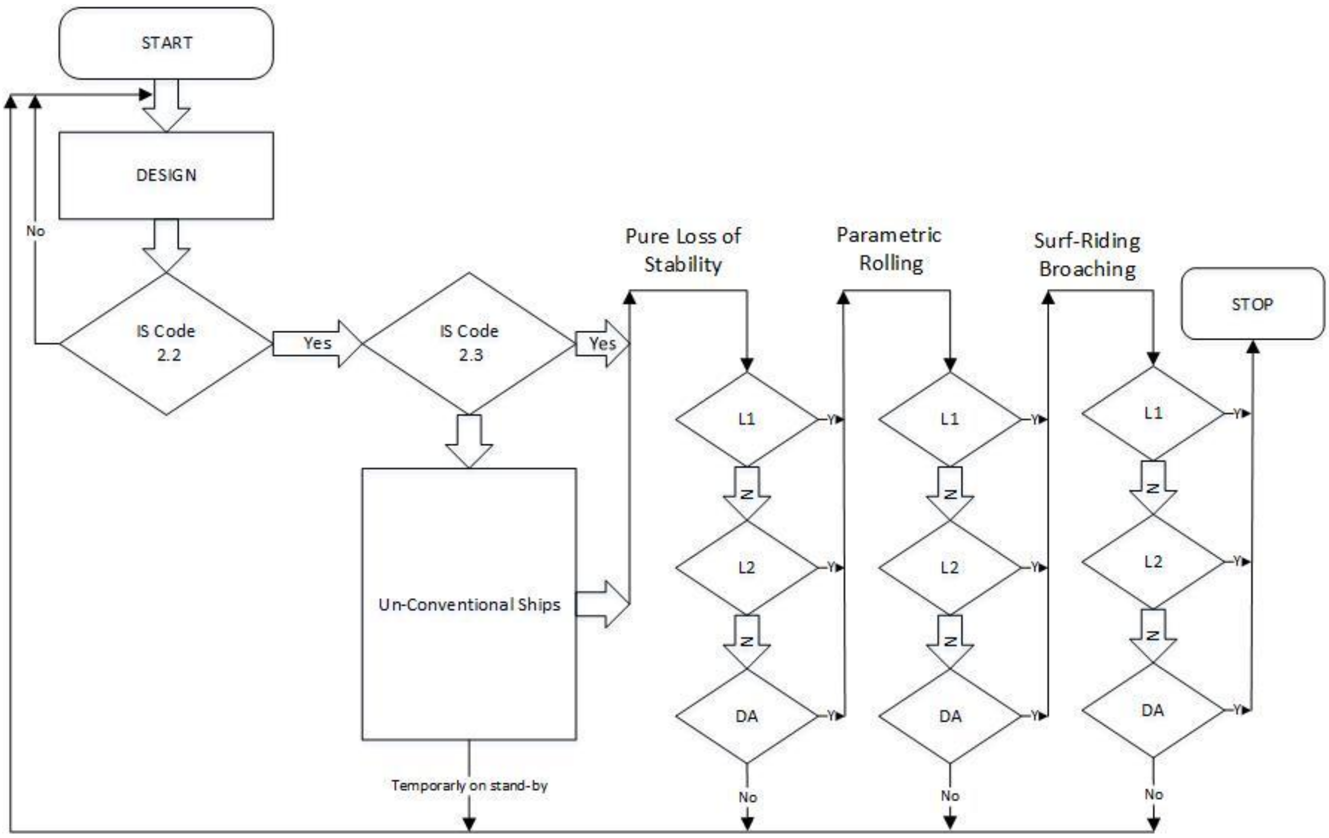

Figure 1. Multi-tiered approach for second generation of intact stability criteria [11]

2. Failure modes and criteria

2.1. Pure loss of stability (PLS)

2.1.1. Level 1 vulnerability criteria for PLS

For each loading condition a ship is considered not to be vulnerable to the pure loss of stability failure mode if [11]:

$$GM_{min} > 0.05 \quad (1)$$

GM_{min} may be determined as minimum value calculated for the ship including free surface correction (m), corresponding to the loading condition under consideration, considering the ship to be balanced in sinkage and trim on series of waves with the following characteristics [10]:

Wave length $\lambda = L$
Wave height $\lambda = 0.0334 \times L$
Where L is ship waterline length.

The wave crest is to be centered amidships and at 0.1L, 0.2L, 0.3L, 0.4L and 0.5L forward and aft thereof. The provision of 3.1.1 shall apply only to ships of froud number of 0.24 and above. Ships of froud number below 0.24 are considered not to be vulnerable to pure loss of stability failure mode.

2.1.2. Level 2 vulnerability criteria for PLS

A ship is considered not to vulnerable to the pure loss of stability failure mode if [10]:

$$Max(CR_1, CR_2) < 0.06 \quad (2)$$

In which:

$$CR_1 = \sum_1^N W_i C1_i \quad (3)$$
$$CR_2 = \sum_1^N W_i C2_i \quad (4)$$

Where W_i is weighting factor obtained from wave data satisfactory to adminstration or the presented table 2.10.3.2 in [10]. Also $C1_i$ and $C2_i$ are calculated as follows:

$$C1_i = \begin{cases} 1 & \varphi_v < 30^0 \\ 0 & Otherwise \end{cases} \quad (5)$$

$$C2_i = \begin{cases} 1 & \varphi_s < R_{PL2} \\ 0 & Otherwise \end{cases} \quad (6)$$

In which φ_v and φ_s are angle of vanishing stability and angle of heel under action of heeling lever specified in [10].Also R_{PL2} is heeling angle which for passenger ships is 15 and other types of ships is 25 degree.

2.2. Parametric rolling (PR)

2.2.1. Level 1 vulnerability criteria for PR

For each loading condition a ship is considered not to be vulnerable to the parametric rolling failure mode if [10]:

$$\frac{\Delta GM_1}{GM_c} \leq \mathrm{R}_{PR} \quad (7)$$

In which $\mathrm{R}_{PR} = 1.87$ if the ship has a sharp bilge and otherwise:

$$\mathrm{R}_{PR} = \begin{cases} 0.17 + 0.425\left(\frac{100A_k}{LB}\right) & C_m \geq 0.96 \\ 0.17 + (10.625 \times C_m - 9.775)\left(\frac{100A_k}{LB}\right) & 0.94 < C_m < 0.96 \\ 0.17 + 0.2125\left(\frac{100A_k}{LB}\right) & C_m \geq 0.96 \end{cases} \quad (8)$$

Where GM_c is metacentric height of loading condition in calm water including free surface correction,ΔGM_1 is the amplitude of the variation of the metacentric height in waves, C_m is midship section coefficient of fully loaded condition in calm water, A_k is total overall projected area of the bilge keels, and L and B are the ship length and breadth respectively. The GM values in waves is as same as calculating GM in 3.1

2.2.1. Level 2 vulnerability criteria for PR

For each condition of loading a ship is considered not to vulnerable to parametric rolling if the value C_1 or C_2below is greater than 0.06.

$$C_1 = \sum_1^N W_i C_i \quad (9)$$
$$C_2 = \left[\sum_{i=1}^3 C2_h(Fn_i) + C2_h(0) + \sum_{i=1}^3 C2_f(Fn_i)\right]/7 \quad (10)$$

In which W_i is weightening factor according to the wave data specified in [10]. Also Fn_i is froud number and $C2_h$ and $C2_f$ are calculated as follows for ship in head sea and following sea respectively:

$$C2_h(Fn_i) = \sum_1^N W_i C_i \quad (11)$$
$$C2_f(Fn_i) = \sum_1^N W_i C_i \quad (12)$$

In which W_i is weightening factor for repective wave cases specified in [10]. Also N is total nuber of wave cases for which the maximum roll angle the maximum roll angle is evaluated for a combination of speed and ship heading, C_i is 1 if the maximum roll angle in head and following waves according to 2.1, exceeds 25 and 0 otherwise.

2.3. Surf-riding/broaching (SR/B)

2.3.1. Level 1 vulnerability criteria for (SR/B)

For each condition of loading a ship is considered not to vulnerable to surf-riding/broaching failure mode if the ship length exceeds 200 m or the ship Froude number is less than 0.3.

2.3.2. Level 2 vulnerability criteria for (SR/B)

For each condition of loading a ship is considered not to vulnerable to surf-riding/broaching failure mode if the value C below is less than 0.005 [10]:

$$C = \sum_{Hs} \sum_{Tz} W2(H_s, T_z) \frac{\sum_{i=1}^N \sum_{j=1}^N W_{ij} C2_{ij}}{\sum_{i=1}^N \sum_{j=1}^N W_{ij}} \quad (13)$$

Where $W2(H_s, T_z)$ is weightening factor of Long-term sea state as a function of significant wave height H_s and zero crossing wave period T_z. Also W_{ij} is statistical weight of a wave with steepness $(H/\lambda)_j$ and wave length to ship length ratio $(\lambda/L)_i$ calculated with the joint distribution of local wave steepness and lengths (see appendix).Finally, $C2_{ij}$ is a coefficient depends on ship propulsion and resistance charactristics as follows:

$$C2_{ij} = \begin{cases} 1 & F_n < F_{ncr}(r_j, s_i) \\ 0 & F_n \geq F_{ncr}(r_j, s_i) \end{cases} \tag{14}$$

Where F_{ncr} is a critical froud number correponding to the threshhold of surf-riding (surf-riding occurring under any initial condition) which should be calculated in accordance with eq. 15 for the regular wave steepness s_j and wavelength to ship length ratio r_i.

$$\mathrm{Fn}_{cr} = \frac{u_{cr}}{\sqrt{L \times g}} \tag{15}$$

Where L is the ship length and g is gravitation acceleration 9.81 m/s^2. Also u_{cr} is the critical ship speed (m/s) determined by solving the equation 16.

$$T_e(u_{cr}; n_{cr}) - R(u_{cr}) \tag{16}$$

In which:

$R(u_{cr})$: The calm water resistance of the ship at the ship speed of u_{cr}

$T_e(u_{cr}; n_{cr})$: The thrust delivered by ship propulsor(s) in calm water determined in accordance with equation 17.

n_{cr} : The commanded number of revolutions of propulsor(s) corresponding to the threshold of surf-riding

$$T_e(u; n) = (1 - t_p)\rho n^2 D_p^4 \{K_0 + K_1 J + K_2 J^2\} \tag{17}$$

Where:

u : Ship speed in calm water (m/s)

n: Number of revolutions of propulsor (1/s)

t_p : Approximate thrust deduction

w_p: Approximated wake fraction

D_p: Propeller diameter (m)

J:$\frac{u(1-w_p)}{nD_p}$ is the advance ratio

ρ : Density of salt water (1025 kg/m^3)

K_0, K_1, K_2: Approximation coefficients for the approximated propeller thrust coefficient in calm water.

3. Ship sample cases and calculation method

To apply formulation and criteria specified in section 3 a wide range of different ship types, all navigating in Persian Gulf and Oman sea, are considered as case studies. Main characteristics of these ships are shown in table 1. There are 2 barges (pontoons), 5 cargo ships, 5 container ships, 2 fishing, 3 passengership, 3 tugs and 3 fiberglass vessel.

Table 1. Sample ship main characteristics

Ship type	Barge		Cargo ships					Container Ships				
Case. No	1	2	3	4	5	6	7	8	9	10	11	12
WL.L	85	90	56	70	28	48	59	55	52	56	80	66
L/B	3.4	3.6	6.1	6.3	4.1	6.2	3.4	6.2	6.1	6.1	6.5	6.6
B/D	4.1	4.1	1.8	1.7	3.9	1.6	4.4	1.7	1.6	1.9	1.9	1.7
CB	0.9	0.9	0.7	0.8	0.8	0.6	0.6	0.7	0.7	0.7	0.8	0.7
VCG_l	4.2	4.1	3.3	3.9	1.2	3.4	2.1	3.5	3.5	3.9	4.2	3.3
VCG_d	7.6	7.9	2.96	4.06	1.82	3.03	4.27	3.33	2.8	3.68	3.88	2.97
VCG_a	-	-	3	4.08	1.89	3.12	4.33	3.45	2.83	3.71	3.93	3.03
F_n	0.09	0.1	0.27	0.21	0.24	0.14	0.3	0.2	0.27	0.27	0.2	0.21

Table 1. Sample ship main characteristics (continue)

Ship type	Fishing vessels		Fiberglasses			Passenger ships			Tug Supply		
Case. No	13	14	15	16	17	18	19	20	21	22	23
WL.L	36	42	19	18	34	17	23	29	14	26	41
L/B	5.1	4.7	4	3.6	3.2	9.8	4.7	6	3.5	4.3	4.2
B/D	1.6	2.3	2.3	2.3	2.2	1.9	2.5	2.4	1.7	1.8	2
CB	0.5	0.7	0.5	0.4	0.5	0.5	0.6	0.6	0.7	0.5	0.6
VCG_L	3.0	2.7	1.6	1.9	3.4	1.9	2.3	1.7	1.6	2.4	3.5
VCG_D	2.92	1.91	1.56	1.69	3.78	1.79	2	1.87	1.53	2.31	3.32
VCG_A	3.12	2.06	1.96	1.94	3.79	1.91	2.14	1.93	1.83	2.73	3.8
F_n	0.27	0.302	0.37	0.27	0.25	0.64	0.56	0.85	0.35	0.23	0.31

In Table. 1:
L,B,D : Length, Breadth, Depth of the vessel
CB: Block coefficient
Fn: Froude number
VCG_L: Light weight vertical center of gravity
VCG_D: Full load departure vertical center of gravity
VCG_A: Full load arrival vertical center of gravity

In order to obtain main hydrostatic information of vessel in different wave conditions and other necessary data MAXSURF software is used. Figure 2 shows GM value for Case No. 11 in wave height 2 meter in draft of 4 meter as an example obtaining ship hydrostatic data in waves.

The GM variation example is given in Figure 3 which shows vessel GM in general loading condition of the vessel. As it is depicted, the minimum GM occures when wave crest reach amidships. On the contrary, when wave trough is amidships, maximum GM is occurred. The bodyline plan of the vessel case No.11 is shown in Figure 4 for more information.

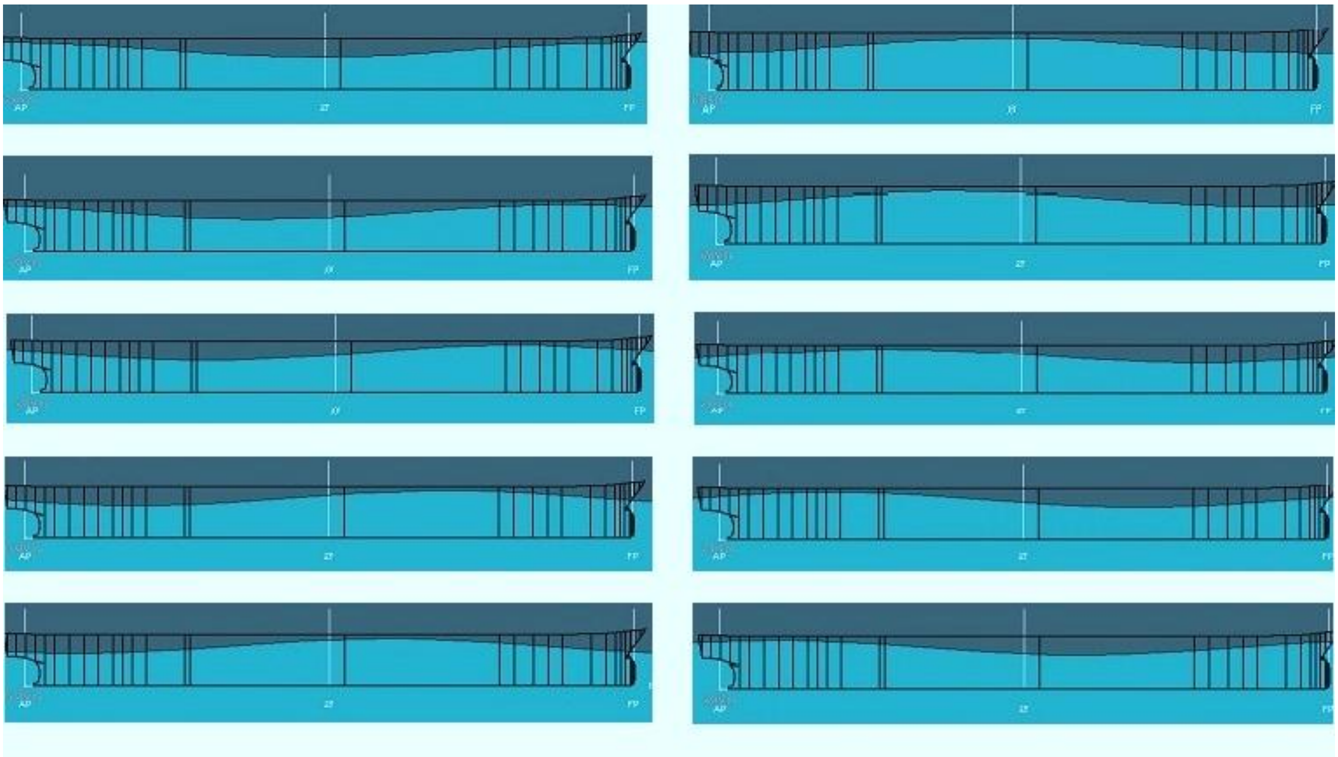

Figure 2. Wave passing the ship case No.11, $T = 4\ m$, $Trim = 0$, $H = 2\ m$, $\lambda = W.L.L$
a (0,L), b(0.1L), c(0.2L), d(0.3L), e(0.4L), f(0.5L), g(0.6L), h(0.7L), i(0.8L), j(0.9L)

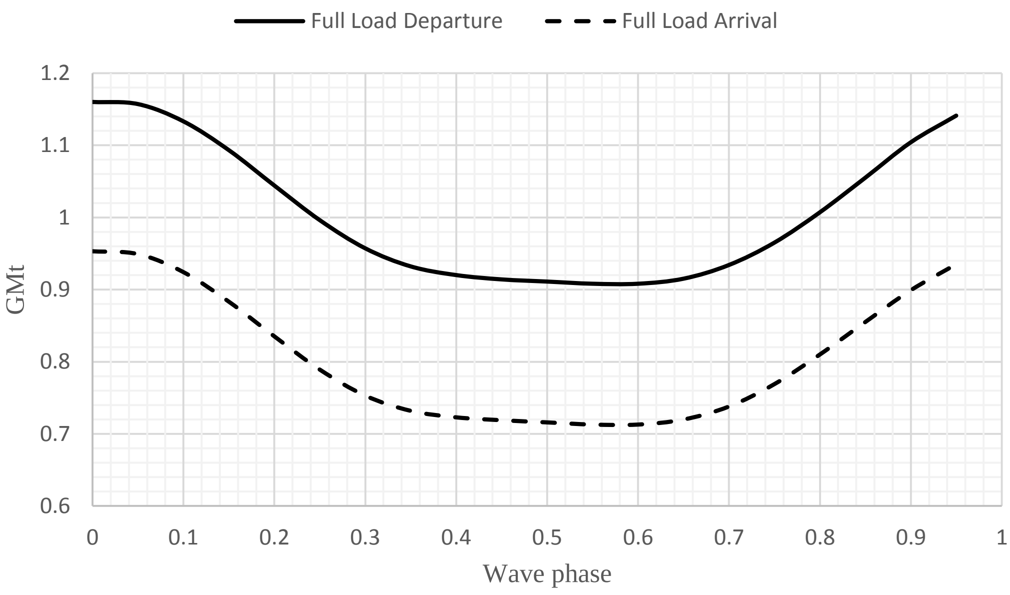

Figure 3. GMt variation when wave passing the ship case No. 11, $wave\ height\ = 2\ meter$

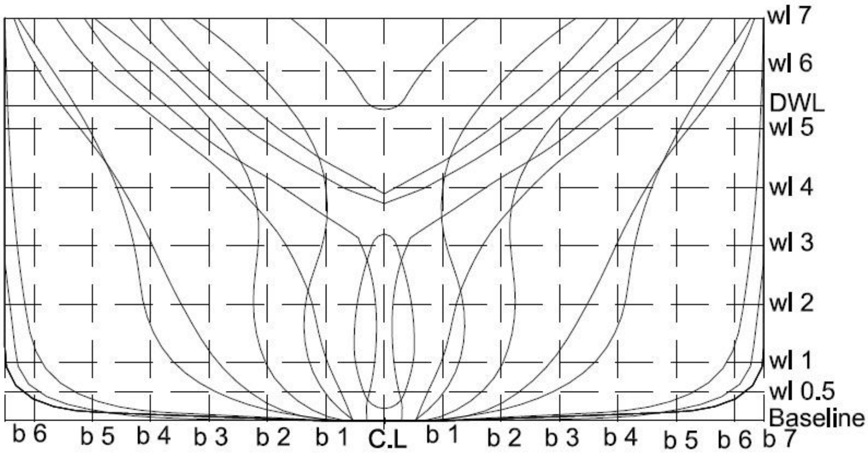

Figure 4. Body lines plan of vessel case No. 11 [13]

4. Results

According to level 1 and level 2 vulnerability criteria for three failure modes described in section 3, an assessment carried out on ships which introduced in section 4. Tables 2 shows the results and ship responses to pure loss of stability failure mode. In order to determine whether one specific ship pass the criteria, vessel metacentric height (GM) evaluated in different wave phases. All ships assumed to be in their most important loading conditions which are “Full Load Departure” and “Full Load Arrival”. Standard definition of these two phrases adopted from IS code 2008 [12].

Letter P in this table refer to “Pass” and as it is shown, all ships passed Level 1 of pure loss of stability. According to section 3 when a ship passes Level 1 criteria, it means that ship will pass the failure mode criteria. Cases No. 1,2 and 22 are not considered in the assessment because their froud number are below 0.24, as according to section 3.1.1 vessels of froud number below 0.24 are considered not to be vulnerable to pure loss of stability failure mode. From table 2 it is concluded that all ships passes the pure loss of stability, so in near future there will be no problem considering adoption of new amendments to the international code.

Table 3 and 4 shows results and ship response to Level 1 parametric rolling failure mode. As it is described in section 3.2.1, prime factor in obtaining level 1 parametric rolling failure criteria is “variation of metacentric height” in waves. Also RPR in the tables is a parameter which calculated according equation 8. Similar to pure loss of stability, two main loading conditions are considered. The results shows that all ships pass level 1 criteria except case no 12, 20 and 21 (1 containership, 1 passengership and 1 tug). According to Figure 1 when L1 failed, L2 criteria should be assessed. Table 5 shows final results of level 2 parametric rolling failure mode in which all remain ships passed the criteria

Table 2. Results of pure loss of stability

Level 1 pure loss of stability																		
Case.No		3	5	7	9	10	11	12	13	14	15	16	17	18	19	20	21	23
GM_{Min}		0.05																
Full Load Departure	GM	1.07	1.62	21.17	0.85	0.42	0.72	1.06	0.95	2.14	1.06	2.28	2	0.39	1.5	2.07	0.19	1.1
	Criteria	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Full Load Arrival	GM	1.25	1.54	20.6	0.99	0.53	0.91	0.46	0.95	2.06	2.23	2.4	1.97	0.45	1.68	2.05	0.53	1.7
	Criteria	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P

Table 3. Results of Parametric Rolling Level 1 (Case No. 1 to 12)

Level 1 Parametric Rolling													
Case.No		1	2	3	4	5	6	7	8	9	10	11	12
R_{PR}		0.17	1.87	0.17	0.17	1.87	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Full Load Departure	$\Delta GM/GM_c$	0.01	0.03	0.06	0.1	0.01	0.09	0.05	0.09	0.01	0.11	0.09	0.16
	Criteria	P	P	P	P	P	P	P	P	P	P	P	P
Full Load Arrival	$\Delta GM/GM_c$	0.04	0.05	0.08	0.12	0.02	0.12	0.05	0.11	0.07	0.13	0.1	0.18
	Criteria	P	P	P	P	P	P	P	P	P	P	P	F

Table 4. Results of Parametric Rolling Level 1 (Case No. 13 to 23)

Level 1 Parametric Rolling												
Case.No		13	14	15	16	17	18	19	20	21	22	23
R_{PR}		0.17	0.17	0.17	0.17	0.17	1.87	0.17	0.17	0.17	0.17	0.17
Full Load Departure	$\Delta GM/GM_c$	0.02	0.03	0.02	0.05	0.01	0.07	0.08	0.16	0.08	0.03	0.04
	Criteria	P	P	P	P	P	P	P	P	P	P	P
Full Load Arrival	$\Delta GM/GM_c$	0.08	0.02	0.05	0.05	0.01	0.168	0.12	0.18	0.28	0.09	0.14
	Criteria	P	P	P	P	P	P	P	F	F	P	P

Table 5. Results of parametric rolling Level 2

Level 2 parametric rolling			
Case. No	R_{PR0}	Full load arrival	
		C1	criteria
12	0.06	0	Pass
20		0.0000013	Pass
21		0.001654	Pass

Table 6. Results of Surf-riding/Broaching Level 1 (Case No. 1 to 12)

Level 1 Surf riding/broaching												
Case.No	1	2	3	4	5	6	7	8	9	10	11	12
L	85	90.7	56.2	70.2	28.8	48.7	59.1	55.3	52.2	67	81	56.1
Froud Number	0.09	0.103	0.27	0.21	0.24	0.14	0.3	0.2	0.27	0.27	0.2	0.21
Criteria	P	P	P	P	P	P	P	P	P	P	P	P

Table 7. Results of Surf-riding/Broaching Level 1 (Case No. 13 to 23)

Level 1 Surf riding/broaching											
Case.No	13	14	15	16	17	18	19	20	21	22	23
L	36.3	42.3	17.4	18.5	34.4	18.1	23.9	28.9	13.9	26.1	41
Froud Number	0.27	0.302	0.37	0.27	0.25	0.64	0.56	0.85	0.35	0.23	0.31
Criteria	P	F	F	P	P	F	F	F	F	P	F

Table 8. Results of Surf-riding/Broaching Level 2 –Considering 100,000 occurance

Level 2 Surf riding/broaching							
Case.No	14	23	15	18	19	20	21
Froud Number	0.3	0.31	0.37	0.64	0.56	0.85	0.35
C	0.0103	0.0034			0.074		
Criteria	F	P	F	F	F	F	F

Table 6 and 7 shows results of surf-riding/broaching criteria and ships response to SGISC. Cases No. 14, 15, 18, 19, 20, 21 and 23 did not pass the Level 1 criteria which explained in section 3.3.1. According to Figure 1, level 2 criteria should be assessed. Based on. theoretical detail of level 2 failure mode which are explained in section 3.3.2, results of level 2 criteria are obtained and are shown in table 8. Albeit no ship fails PLS and PR, 7 ships (including 2 tugs, 3 passenger ships, 1 fiberglass and 1 fishing vessel) fails the Surf-riding/broaching failure mode criteria.
The most essential similarities among these vessels which should be considered are below characteristics:

1 – Ships with high speed (Cases 20, 21, 22)
2 – Ships with small length (Cases 21, 15)

As described in [9] the probability of encounter of a wave capable of causing surf-riding is a function of ship length and nominal froud numbers. The danger of surf-riding is less for longer ships and increases with increasing the speed. Maybe, operational saftey precautions are needed for these ships to prevent possible accidents in Persian Gulf and Oman Sea.

5. Conclusion

In order to understand the functionality and applicability of future International Maritime Organization amendments to Intact Stability code 2008 on dynamic stability of ships, an assessment carried out in this study for ships navigating in Persian Gulf and Oman Sea. Three modes of vulnerability including pure loss of stability, parametric rolling and surf riding/broaching are considered. Then according to latest IMO draft on second generation of intact stability criteria, Level 1 and Level 2 vulnerability criteria are applied to 22 samples of different types of ships using numerical softwares. It is shown that all ships pass pure loss of stability and parametric rolling criteria but all passenger ships, 2 tugs, 1 FRP and 1 fishing vessel failed the surf riding/ broaching criteria. It is concluded that to pass the vulnerability criteria of surf riding/broaching, existing ships (especially passenger ships) should decrease their regulatory speed which defined in international regulations. Also new building vessels should be designed so that their Froude number do not encounter critical Froude number range considering relations between ship length, speed and body line.

6. Acknowledgment

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APPENDIX

1- Definition of $W2(H_s, T_z)$:

Weighting factor of Long-term sea state specified below as a function of the significant wave height, HS, and the zero-crossing wave period, TZ. The value of $W2(H_s, T_z)$ is obtained as the value in Table A1 divided by the amount of observations given in this table. Other sources of wave statistics can be used on the discretion of the Administration.

Table A1: Wave Case Occurrences

Number of Occurrences : 100,000/T_z																
T_Z / H_S	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	5860.4	2066	644.5	160.2	33.7	6.3	1.1	0.2	0	0
3.5	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
4.5	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
5.5	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
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

2- The value of Wij:

It should be calculated using following equation (A1)

$$W_{ij} = \frac{4\sqrt{g}L^{5/2}T_{01}}{\pi v (H_s)^3} S_j^2 r_i^{3/2} \left(\frac{\sqrt{1+v^2}}{1+\sqrt{1+v^2}}\right) \Delta r . \Delta s . \exp\left(-2\left(\frac{L r_i s_j}{H_s}\right)^2 \left\{1 + \frac{1}{v^2}\left(1 - \sqrt{\frac{g T_{01}^2}{2\pi r_i L}}\right)^2\right\}\right) \quad \text{(A1)}$$

Where:

v: 0.4256;
L: Length of the ship in meters;
T_{01}: 1.086× T_z;
S_j: $(H/\lambda)_j$ wave steepness varies from 0.03 to 0.15 with the increment of $\Delta s = 0.0012$
r_i : $(\lambda/L)_i$ wavelrngth to ship length ratio varies from 1 to 3 with the increment of $\Delta r = 0.025$

3- Ships Displacements

Table A2: Vessel Displacement/1000 Tonnes

Ship type	Barge		Cargo ships					Container Ships					Fishing vessels		Fiberglasses			Passenger ships			Tug Supply		
Case. No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
FLD	9.5	8.6	1.5	2.9	0.3	1.3	1.1	1.5	1.1	2.2	4.8	1.3	0.6	0.7	0.036	0.06	0.97	0.07	0.07	0.065	0.05	0.3	0.8
FLA	-	-	1.4	2.8	0.2	1.2	1.0	1.4	1.0	2.1	4.6	1.2	0.5	0.7	0.035	0.06	0.91	0.06	0.065	0.058	0.03	0.21	0.67

FLD : Full Load Departure
FLA : Full Load Arrival

4- Ships Drafts Amidships

Table A3: Vessel Drafts Amidships (in meters)

Ship type	Barge		Cargo ships					Container Ships					Fishing vessels		Fiberglasses			Passenger ships			Tug Supply		
Case. No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
FLD	4.8	4.2	4.2	5.3	1.4	4.2	2.2	4.1	3.5	4.4	4.3	3.6	3.4	2.2	1.0	1.5	4.7	1.4	1.23	0.9	1.5	2.9	3.5
FLA	-	-	3.9	5.2	1.3	3.9	2.1	3.8	3.3	4.2	4.1	3.4	3.3	2.4	1.6	1.8	4.6	1.2	1.18	0.86	1.1	2.4	3.2