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تشریح مطالعات موسسه رده بندی ایرانیان در خصوص معیارهای نسل دوم پایداری شناورها به کمیته SDC4 سازمان بنادر و دریانوردی و سازمان بین المللی دریانوردی شماره: ۳۲/۹۵/۰۱۳۳ تاریخ: ۱۳۹۵/۱۱/۲۷



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

Ship Design and Construction (SDC) Working Group - Ports and Maritime Organization (PMO) - Iran

1. Abstract

Second generation intact stability criteria for few past years were under development by International Maritime Organization (IMO). As the draft proposed amendments shall be included in International code on Intact Stability (IS code 2008), it will 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 happens when navigating in rough seas. As the waves passes the ship, dynamic phenomenon will affects ship stability that may lead to capsizing. Unlike the IS code 2008 which study ship stability in calm water with a single level criteria, SGISC check the stability in different levels. In this way, a ship passes only one level of criteria, it means it is safe accroding to respective dynamic phenomena. In this article 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. 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,1fiberglass and 1 fishing vessel failed the surf riding 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 Froud number do not encounter critical Froud number range as defined by the regulations.

Key Words: IMO,Pure Loss of Stability, Parametric Rolling, Broaching,Surf-Riding

2. Introduction

Sufficient intact stability for a ship is one of the most important and fundamental requirements for any type of vessels. 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]:

- 1- Restoring variation problems
- 2- Stability on dead ship condition
- 3- 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 theoritical 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 :

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

Afterward, Blenky et. al [7] proposed a multi-tired approach based on analysis of experiences and previous efforts of American Bureau of Shipping (ABS) on parametric roll of containerships. It also gave abroad review of the physics background of the dynamic stability failures under consideration. These multi-tired 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, the criteria contain in section 2.2 and then that of Section 2.3 of Part A of the 2008 IS Code is applied for all ships covered under IMO instruments. Each ship is also checked for vulnerability to pure loss of stability, parametric roll, and broaching and surf-riding phenomena using level 1 vulnerability criteria (L1). If a possible vulnerability is detected, then the level 2 criteria (L2) are 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 (ADM). If vulnerability to each 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].



Figure 1. Multi-tired approach for second generation of intact stability criteria

Later the discussion transferred to sub committee 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 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.

3. Failure modes and criteria3.1. Pure loss of stability (PLS)3.1.1. 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]:

$$GM_{min} > 0.05 \tag{1}$$

 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 amiships 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.

3.1.2. Level 2 vulnerability criteria for PLS

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

$$Max(CR_1, CR_2) < 0.06$$
 (2)
In which:

$$CR_1 = \sum_{i=1}^{N} W_i C1_i$$
(3)

$$CR_2 = \sum_{i=1}^{N} W_i C2_i$$
(4)

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

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

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

3.2. Parametric rolling (PR) 3.2.1. 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]:

$$\frac{\Delta GM_1}{GM_c} \le \mathbf{R}_{PR} \tag{7}$$

In which $R_{PR} = 1.87$ if the ship has a sharp bilge and otherwise :

$$R_{PR} = \begin{cases} 0.17 + 0.425 \left(\frac{100A_k}{LB}\right) & C_m \ge 0.96\\ 0.17 + (10.625 \times C_m - 9.775) \left(\frac{100A_k}{LB}\right) & 0.94 < C_m < 0.96\\ 0.17 + 0.2125 \left(\frac{100A_k}{LB}\right) & C_m \ge 0.96 \end{cases}$$
(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

3.2.2. Level 2 vulnerability criteria for PR

For each condition of loading a ship is considered not to vulnerable to paramteric rolling if the value C_1 or C_2 below is greater than 0.06.

$$C_{1} = \sum_{i=1}^{N} W_{i}C_{i}$$
(9)
$$C_{2} = \left[\sum_{i=1}^{3} C2_{h}(Fn_{i}) + C2_{h}(0) + \sum_{i=1}^{3} C2_{f}(Fn_{i})\right]/7$$
(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:

$$C2_h(Fn_i) = \sum_{i=1}^{N} W_i C_i \tag{11}$$

$$C2_f(Fn_i) = \sum_1^N W_i C_i \tag{12}$$

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 accordign to 2.1, exceeds 25 and 0 otherwise.

3.3. Surf-riding/broaching (SR/B) 3.3.1. 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 froud number is less than 0.3.

3.3.2. 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 :

$$C = \sum_{H_S} \sum_{T_Z} W2(H_s, T_Z) \frac{\sum_{i=1}^N \sum_{j=1}^N W_{ij} C_{2ij}}{\sum_{i=1}^N \sum_{j=1}^N W_{ij}}$$
(13)

Where $W2(H_s, T_z)$ is weightening factor of short-term sea state specified in [10], W_{ij} is statistical weight of a wave specified in [10] and $C2_{ij}$ is a coefficient depends on ship propulsion and resistance charactristics as follows :

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

Where F_{ncr} is a critical froud number correponding to the threshold 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 .

$$Fn_{cr} = \frac{u_{cr}}{\sqrt{L \times g}}$$
(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 surfriding

$$T_e(u;n) = (1 - t_p)\rho n^2 D_p^4 \{K_0 + K_1 J + K_2 J^2\}$$
(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/m³)

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

4. Ship sample cases and calculation method

To apply formulation and criteria specified in 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. 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.

Table 1. Sample ship main charatristics

Ship	Bar	ge	Car	go sl	nips			Container Ships			Fishing Fiberglasses			Pass	Passenger			Tugs					
type													vess	sels				ship	s				
Case.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
No																							
WL.L	85	90	56	70	28	48	59	55	52	56	80	66	36	42	19	18	34	17	23	29	14	26	41
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	5.1	4.7	4	3.6	3.2	9.8	4.7	6	3.5	4.3	4.2
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	1.6	2.3	2.3	2.3	2.2	1.9	2.5	2.4	1.7	1.8	2
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	0.5	0.7	0.5	0.4	0.5	0.5	0.6	0.6	0.7	0.5	0.6



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

The GM variation sample 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 the wave crest is in amidships. On the contrary when wave trough is amidships, maximum GM is occurred.

5. Results

According to level 1 and level 2 vulnerability criteria for three failure modes described in 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 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, means that ship will pass the failure mode criteria. Case No. 1-2 and 22 are not considered in the assessment because their froud number are below 0.24 and according to 3.1.1 vessels of froud number below 0.24 are considered not t be vulnerable to pure loss of stability. 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 amendments to the international code.

					1 401	<i>u </i>	conno	ojpu	10 105	5055	aonn	y						
					L	evel 1	l pure	e loss	of sta	bility								
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	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
Departure	Criteria	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р
Full Load	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
Arrival	Criteria	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р

Table 2. Results of pure loss of stability

Table 3 and 4 shows results and ship response to Level 1 parametric rolling failure mode. As it is described in 3.2.1 important factor in level 1 parametric rolling failure criteria is variation of metacentric height in waves. Also R_{PR} is 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 which all remain ships passed the criteria.

			Leve	l 1 Par	ametr	ic Rol	ling						
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	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р
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	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	F

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

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

		L	evel 1	Paran	netric [Rollin	g					
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	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р
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	Р	Р	Р	Р	Р	Р	Р	F	F	Р	Р

 Table 5. Results of parametric rolling Level 2

	Level 2 parametric rolling											
Case.	R _{PR0}	Fu	ll load arrival									
No		C1	criteria									
12	0.06	0	Pass									
20		0.0000013	Pass									
21		0.001654	Pass									

Table 6 and 7 shows results of broaching/surf-riding 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 3.3.1. According to Figure 1, level 2 criteria should be assessed. The theoritical detail of level 2 failure mode are explained in 3.3.2. Results of level 2 criteria is shown in table 8. While 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. Maybe local saftey precautions are needed for these ships to prevent possible accidents in Persian gulf and Oman sea.

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

			Level 1	L Surf r	riding/l	oroach	ing					
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	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р	Р

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

		Leve	el 1 Sur	f ridin	g/broac	ching					
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	Р	F	F	Р	Р	F	F	F	F	Р	F

	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										
С	0.0103	0.0034	0.074										
Criteria	F	Р	F	F	F	F	F						

Table 8. Results of Surf-riding/Broaching Level 2 – Considering 10,000 occurance

6. Conclusion

In order to understand the functionality and applicability of future International Maritime Organisation 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 levels of vulnerability including pure loss of stability, parametric rolling and broaching/surf riding 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 broaching/surf riding criteria. It is concluded that to pass the vulnerability criteria of surf riding/broaching, existing ships (specially passenger ships) should decrease their speed and new building vessels should be designed so that their Froud number do not encounter critical Froud number range as defined by the international regulations.

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