Sample Applications of the Second Generation Intact Stability Criteria – Robustness and Consistency Analysis

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ABSTRACT

A new Intact Stability Code, the so-called Second Generation of Intact Stability Criteria, is currently under development and validation by the International Maritime Organization (IMO). The criteria are separated into five failure modes, each of which is analyzed by two vulnerability levels and, if needed, a direct numerical simulation. The present paper summarizes results testing the vulnerability levels in these new stability criteria. The calculations are carried out for 17 ships using the full matrix of operational draughts, trims and GM values. Each failure mode criterion is examined individually regarding construction of a GM limit curve for the full range of operational draughts. The consistency of the outcomes has been analyzed, and finally examined whether the new criteria tend to be more or less conservative compared to the present rules by evaluating approved loading conditions.

Keywords: *IMO, Second generation intact stability criteria, Sample calculations, GM limit curves*

1. INTRODUCTION

New intact stability criteria are currently being developed and validated at IMO. The new criteria, which differ very much from the formulations in the current IS Code 2008 (IMO 2008), is based on first principles with the stability examined for the ship sailing in waves. The new intact stability criteria are separated into five failure modes: pure loss of stability, parametric roll, dead ship condition, excessive acceleration and surf-riding/broaching. Each of these failure modes is divided into three levels – two vulnerability levels and a third level, which consists of numerical simulations of the ship's behavior in waves.

Several papers have already presented results for specific vessels. Tompuri et al. (2015) discuss in details computational methods to be used in the Second Generation Intact Stability Criteria, focusing on level 1 and level 2 procedures for parametric roll, pure loss of stability and surf-riding/broaching. They also provide detailed calculations and sensitivity analyses for a specific RoPax Vessel and stress the need for software able to do the extensive calculations. The detailed discussions attached to Tompuri et al. (2015) give a very valuable insight in the current status of development of the new criteria.

The present paper summarizes results performed for testing the Second Generation of Intact Stability Criteria. The paper deals with all five failure modes, with the first four modes evaluated for level 1 and 2 whereas the last criterion, surf-riding/ broaching, is evaluated for the first level only. The calculations are carried out for 17 ships for the full matrix of operational draughts (light service condition to summer draught), trims (even keel and two extreme trims forward and aft) and GM values. The results are presented as GM limit curves from the two levels and compared with the approved GM limit curve from the stability book.

The criteria used in the present calculations are based on Second Generation Intact Stability Criteria as amended in February 2015 and January 2016 by the Sub-Committee on Ship Design and

Construction of IMO. Furthermore, the explanatory notes from SDC 3/ WP.5. Annex 3-7 are consulted.

- Pure loss of stability (SDC 2/WP.4 Annex 1 (2.10.2.1 + 2.10.2.3))
- Parametric roll (SDC 2/WP.4 Annex 2 (2.11.2.1 + 2.11.2.3)
- Surf-riding /Broaching (SDC 2/WP.4 Annex 3)
- Dead ship condition (SDC 3/WP.5 Annex 1)
- Excessive acceleration (SDC 3/WP.5 Annex 2)

Three types of analysis have been performed:

1. Each criterion has been examined individually for the possibility of obtaining usable results for construction of a GM limit curve for the full range of operational draughts.
2. The relationship between level 1 and level 2 – the requirement that level 1 is more restrictive in GM limits than level 2 has been examined.
3. Will the new regulation be more or less conservative? The analysis has been performed for approved loading conditions.

All calculations have been carried out using NAPA stability software XNAPA Release B137 2016.0 sgis, VARDEF*SGIS.MATRIX. This is the same software as used in Tompuri et al. (2015). A more detailed description of the analysis can be seen in a information paper submitted to SDC 4 (IMO, 20016) A more detailed description of the analysis can be seen in a information paper submitted to SDC 4 (IMO, 20016)

2. SAMPLE SHIPS

The sample ships used for the calculation comprise 17 existing vessels. They include eight RoRo ships (six passenger and two cargo vessels); two installation vessels (jack-up vessels); three supply vessels – one standby vessel, one cable layer and one anchor handler; one bulk carrier and three container vessels. Detailed information of the ships and their loading conditions are available. The sample ship particulars can be seen in Table 1.

3. ANALYSIS

The analysis is performed for the full matrix of operational draughts from light ship to summer draught and for three trims – even and two extreme trims forward and aft. The calculations are carried out for the five modes of stability failure:

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

All modes are evaluated for criteria levels 1 and 2, except the last failure mode, where only level 1 is carried out. This last criterion, surf-riding/ broaching is a function of length and speed of the vessel and does not depend on GM of the vessel. The criterion pure loss of stability applies only to ships for which the Froude number exceeds 0.24.

In the mode ‘Pure loss of stability’ in criteria level 2, ships with low weather deck / low buoyant hull can give some unexpected results. The problem is caused when the regulatory wave crest results in water accumulated on the weather deck making the vessel much more vulnerable than it in fact is, see Figure 1. How to deal with this is not yet defined in the explanatory notes.

Figure 1: Illustration of “pure loss of stability” problem.

However, as the whole idea with the criteria is to understand the ships behavior to certain stability failure modes in waves, the hull form is some cases slightly modified, resulting in a more ‘appropriate’ hull form including all parts that provides buoyancy, even though they are not fully watertight due to freeing ports, mooring holes etc..

Table 1: Principal particulars of the sample ships.

Id	Type	L [m]	Fn	Built
1	RoRo Passenger	159.3	0.303	2016
2	RoRo Passenger	135.0	0.262	1997
3	RoRo Passenger	183.6	0.298	2009
4	RoRo Passenger	92.3	0.246	2010
5	RoRo Passenger	88.8	0.298	2013
6	RoRo Passenger	39.6	0.287	2011
7	Ro-Ro Cargo	180.5	0.261	2009
8	Ro-Ro Cargo	185.9	0.241	2014
9	Installation Vessel	155.6	0.170	2009
10	Installation Vessel	79.3	0.169	2011
11	Supply Standby	39.2	0.315	2011
12	Supply Cable Layer	120.4	0.175	2016
13	Supply Anchor Handler	81.6	0.310	2000
14	Bulk Carrier	174.6	0.173	2012
15	Container Ship	382.6	0.208	2006
16	Container Ship	324.6	0.222	1997
17	Feeder Vessel	154.1	0.250	1991

Construction of Limiting GM Curves

Each criterion is examined for the possibility of obtaining usable results for construction of a GM limit curve for the full range of operational draughts. A summary of the results is shown in Table 2.

For some vessels, inconsistency is seen in the results for GM – meaning that there is more than one GM limit for a given draught; these cases are marked in red in Table 2. It is seen that this specially applies to the two criteria parametric roll level 2 (C2) and dead ship condition level 2. For the dead ship condition this inconsistency occurs due to the criterion comprising a variety of resonance conditions. The ship can thereby experience resonance from wind and sea at the same draught for different values of GM. Due to the inconsistency, the two criteria are not suited for presentation using GM limit curves. These criteria might be handled as operational criteria used for specific loading conditions – maybe as an operational polar plot or GM plot marked with restricted and allowable areas, but this would change the criteria to be operational and loading condition dependent.

Matrices and diagrams that show the inconsistency in the GM results and the corresponding GM limit curve are constructed for all vessels, examples can be seen in Figure 2 and 3 for the RoRo vessel no. 3. For vessels having inconsistency in the results for GM, it was decided to use the largest GM value, which may result in a fluctuating GM curve, this can also be seen in Figures 2 and 3.

For one of the vessels, RoRo ship no. 3, the inconsistency in the results is so extreme that it is not possible to construct a GM limit curve.

It must also be noted that the Ikeda (Ikeda, et al., 1978) parameter limits are exceeded for all vessels at certain draughts – especially in the criteria for dead ship condition and excessive acceleration. How this affects the results is not clear and it should be examined to which extent the roll damping results are reliable when extrapolating outside the parameter range for which Ikeda's empirical equations are valid.

Table 2: Evaluation of each failure mode criterion for 17 ships – summary table.

Green	OK - only one GM limit for a given draught
Red	Not OK – several GM limits for a given draught
Blue	Computational problems - no useful results
White	Not calculated – criterion does not apply to ship (Froude number lower than 0.24)
Yellow	Ship does not comply with criterion (surf-riding)
a	No results for smaller draughts
b	Results for smaller draughts only / no results for higher draught

	Pure loss of stability						Parametric roll									Dead ship						Excessive acceleration						Surf-riding Broaching
	Level 1			Level 2			Level 1			Level 2 -C1			Level 2 -C2			Level 1			Level 2			Level 1			Level 2			
ID	Aft	Even	Fwd	Aft	Even	Fwd	Aft	Even	Fwd	Aft	Even	Fwd	Aft	Even	Fwd	Aft	Even	Fwd	Aft	Even	Fwd	Aft	Even	Fwd	Aft	Even	Fwd	
1																												
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16													b	b	b	b	b	b	b	b	b							
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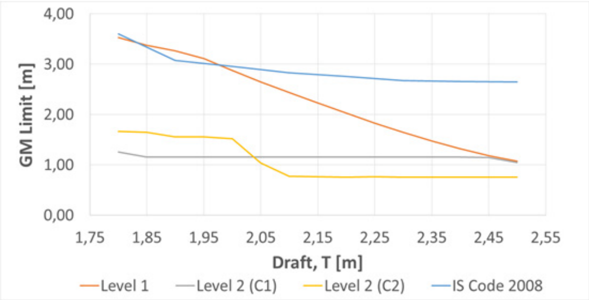

Figure 2: GM limit (T), Ship no. 6. Parametric roll – Trim Aft.

GM [m] \ T [m] ->	1,80	1,85	1,90	1,95	2,00	2,05	2,10	2,15	2,20	2,25	2,30	2,35	2,40	2,45	2,50
0,50	0,999723	0,999829	0,999723	0,999723	0,999784	0,99967	0,99967	0,999776	0,981413	0,944753	0,908074	0,907975	0,886717	0,889628	0,944701
0,60	0,401473	0,364694	0,361204	0,328152	0,300658	0,283079	0,273732	0,275306	0,225042	0,213733	0,195643	0,194949	0,195595	0,196629	0,204251
0,70	0,215928	0,165096	0,175596	0,175266	0,175206	0,140461	0,151135	0,150762	0,138891	0,149063	0,136287	0,145698	0,136399	0,147018	0,136335
0,80	0,067038	0,067038	0,067038	0,030251	0,030251	0,030177	0,030171	0,007609	0,005674	0,005674	0,005674	0,005686	0,001864	0,002227	0,002245
0,90	0,000534	0,012973	8,94E-05	2,39E-05	2,39E-05	0	0	0	0	0,000006	0	0,000006	2,99E-05	0,000006	0,000101
1,00	0,197816	0,194187	0,095044	0,098178	0,093651	0,081699	0,03876	0,013907	0,004161	0,000837	0,000137	2,39E-05	0,000006	0,000006	0,000006
1,10	0,146763	0,096828	0,052496	0,050534	0,050101	0,020118	0,007909	0,003346	0,001991	0,005639	0,005106	0,004137	0,00146	0	0
1,20	0,043295	0,024114	0,012728	0,021842	0,019676	0,019084	0,015468	0,014867	0,030147	0,022974	0,013974	0,012894	0,004137	0,002922	0,000528
1,30	0,019541	0,044308	0,044299	0,035102	0,023469	0,030476	0,043653	0,043646	0,030411	0,014422	0,005021	0,001367	0,001358	0,000249	8,21E-05
1,40	0,068124	0,076644	0,07618	0,05439	0,054279	0,054277	0,051917	0,030382	0,013203	0,004226	0,001367	0,000303	9,34E-05	2,43E-05	2,61E-05
1,50	0,056533	0,079934	0,078108	0,07688	0,06791	0,037428	0,015637	0,005355	0,001438	0,000459	8,91E-05	0,000006	0,000006	0	0
1,60	0,084153	0,080295	0,048096	0,046692	0,031957	0,015002	0,005364	0,001527	9,51E-05	2,39E-05	0	0	0	0	0
1,70	0,048589	0,037025	0,015895	0,015086	0,005983	0,00222	0,000532	8,91E-05	0,000006	0	0	0	0	0	0
1,80	0,015895	0,005993	0,004396	0,002213	0,000797	0,000162	2,39E-05	0	0	0	0	0	0	0	0
1,90	0,001924	0,000791	0,000241	8,91E-05	2,39E-05	0	0	0	0	0	0	0	0	0	0
2,00	0,000156	0,000006	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3: Matrix (T, GM), Ship no. 6. Parametric roll, Level 2 (C2) – Trim Aft.

Inconsistency between Level 1 and Level 2

When analyzing the results from level 1 and level 2, it is expected that level 1 is more restrictive in GM limits than level 2. As the failure mode surf-riding/broaching is not based on a GM evaluation, it is not included in this analysis. For vessels having inconsistent GM results, the highest GM value is chosen.

The results from the analysis are shown in Table 3. The green color indicates that there is a proper relationship between the levels i.e. level 1 is more conservative than level 2 for all operational draughts. The red color indicates the opposite – if the whole or a part of the GM limit curve for level 2 is more restrictive than level 1, the cell is marked red. When it was not possible to obtain results for one of the levels, the consistency between the levels could not be evaluated; this is indicated with white or blue cells in the table.

Table 3 shows that in nearly half of the cases, level 2 results are more conservative than level 1; for the criterion pure loss of stability, it is the case for all vessels!

Loading Condition – Will the new regulation be more or less conservative?

The analysis is performed for approved operational loading conditions taken from the ship stability book. The results are summarized in Table 4.

4. CONCLUSIONS

A series of 17 existing vessels have been evaluated against the current version of Second Generation Intact Stability Criteria (SGISC). These criteria comprise five failure modes: Pure loss of stability, parametric roll, dead ship, excessive acceleration and surfriding/ broaching. Results have been analyzed for different loading and trim conditions in terms of limiting GM curves. This study resulted in the following conclusions.

Construction of limiting GM curves (Table 2): With one or two exceptions for the vessels considered, it is not possible to derive a limiting GM curve. This is so especially for the parametric roll and dead ship failure modes, i.e. at a given draught multiple permissible GM values would be obtained for most of the vessels.

Inconsistency between level 1 and level 2 evaluation (Table 3): None of the vessels shows a consistent result when applying level 2 versus level 1 analysis for all failure modes. For more than half of the cases the limiting GM required by level 2 would be higher (more restrictive) than for level 1 analysis, which is not the intention.

Currently allowable loading conditions (Table 4): When evaluated at realistic operational GM (or KG) conditions allowed according to the current intact and damage stability criteria, none of the vessels satisfies all of the SGISC failure modes. The majority of vessels satisfy some of the failure modes under certain loading conditions. Some of the vessels satisfy the parametric roll criteria for all loading conditions considered. Very few vessels satisfy the excessive acceleration criterion in any loading condition.

In summary, it is concluded that the newly proposed intact stability criteria deliver inconsistent results for all vessels considered.

Table 3: Evaluation of the failure mode criteria – inconsistency between level 1 and level 2.

Green — OK - GM limit for L1 > GM for L2 (except for excessive acceleration, where it is opposite)
Red — Not OK - GM limit for L1 < GM for L2 (except for excessive acceleration, where it is opposite)
Blue (light) — No results - Computational problems for one or both levels
Grey — No results – no GM limit curve available due to inconsistency in results
White — No results – criterion does not apply to ship (Froude number lower than 0.24)

	Pure loss of stability			Parametric roll C1			Parametric roll C2			Dead ship			Excessive acc.		
	Aft	Even	Fwd	Aft	Even	Fwd	Aft	Even	Fwd	Aft	Even	Fwd	Aft	Even	Fwd
1	Red	Red	Red	Green	Green	Green	Green	Green	Green	Green	Green	Green	White	White	White
2	Red	Red	Red	Red	Red	Green	Green	Green	Green	Red	Green	Red	Green	Green	Green
3	Red	Red	Red	Green	Green	Green	Green	Green	Green	Grey	Grey	Grey	Green	Green	Green
4	White	White	White	Red	Red	Red	Green	Green	Green	Red	Red	Red	Green	Green	Green
5	Blue	Red	Red	Green	Green	Red	Blue	Red	Red	Red	Red	Red	Red	Red	Green
6	Red	Red	Red	Green	Green	Green	Green	Red	Red	Red	Red	Red	Green	Green	Green
7	Red	Red	Red	Green	Green	Green	Green	Green	Green	Blue	Blue	Blue	Green	Green	Green
8	Red	Red	Red	Red	Red	Red	Green	Green	Green	Green	Green	Green	Green	Green	Green
9	White	White	White	Red	Red	Red	Green	Green	Green	Green	Green	Green	Green	Green	Green
10	White	White	White	Blue	Blue	Blue	Red	Red	Red	Red	Red	Red	Green	Green	Green
11	Red	Red	Red	Blue	Blue	Blue	Red	Red	Red	Red	Red	Red	Red	Red	Red
12	White	White	White	Red	Red	Red	Red	Red	Red	Red	Red	Red	Green	Green	Green
13	Red	Red	Red	Red	Red	Red	Red	Red	Green	Red	Red	Red	Red	Red	Red
14	White	White	White	Green	Green	Green	Blue	Blue	Blue	Blue	Blue	Blue	Green	Green	Green
15	White	White	White	Green	Green	Green	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
16	White	White	White	Green	Green	Green	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
17	Red	Red	Red	Green	Green	Green	Green	Green	Green	Red	Red	Red	Green	Green	Green

Table 4: Evaluation of loading conditions.

Green — All loading conditions comply with the criteria
Red — One or more loading conditions do not comply with the new criteria. The number in the cell indicates the percentage of loading conditions not complying.
Blue — No useful results for GM limit (whole or part of curve).
White — Not calculated – criterion does not apply to ship (Froude number lower than 0.24)

	Pure loss of stability		Parametric roll			Dead ship		Excessive acc.	
	L1	L2	L1	L2 C1	L2 C2	L1	L2	L1	L2
1	Green	37 (Red)	Green	Green	Green	Green	Green	Green	Blue
2	Green	Green	Green	Green	Green	Green	Green	100 (Red)	Green
3	Green	Green	100 (Red)	100 (Red)	Green	Green	Green	100 (Red)	100 (Red)
4	White	White	Green	Green	Green	Green	100 (Red)	100 (Red)	100 (Red)
5	Green	Green	Green	Green	Green	Green	100 (Red)	33 (Red)	Green
6	Green	Green	Green	Green	Green	Green	100 (Red)	100 (Red)	100 (Red)
7	77 (Red)	77 (Red)	100 (Red)	92 (Red)	77 (Red)	Blue	Blue	23 (Red)	23 (Red)
8	Green	Green	Green	Green	Green	Green	Green	13 (Red)	Green
9	White	White	Green	Green	Green	Green	100 (Red)	100 (Red)	100 (Red)
10	White	White	Green	Blue	Green	100 (Red)	Green	Green	Green
11	100 (Red)	100 (Red)	Green	Blue	Green	33 (Red)	100 (Red)	100 (Red)	100 (Red)
12	White	White	Green	Green	Blue	Green	25 (Red)	55 (Red)	18 (Red)
13	Green	55 (Red)	Green	Green	Green	9 (Red)	72 (Red)	Green	27 (Red)
14	White	White	Green	Blue	Blue	Blue	Green	74 (Red)	52 (Red)
15	White	White	50 (Red)	12 (Red)	Blue	Blue	Blue	25 (Red)	Blue
16	White	White	100 (Red)	100 (Red)	Blue	Blue	Blue	Green	Blue
17	50 (Red)	67 (Red)	Green	Green	Green	Green	Green	82 (Red)	33 (Red)

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