On the consistency of the level 1 and 2 vulnerability criteria in the Second Generation Intact Stability

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ABSTRACT

The development of the draft regulations and explanatory notes for the second generation intact stability criteria is ongoing at IMO. For levels 1 and 2, the drafts are already nearly finalized. However, previous sample ship calculations have revealed potential inconsistency in some cases. This paper studies three failure modes: parametric roll, pure loss of stability and excessive accelerations. Additional sample ship results are provided, and the potential sources of inconsistency between level 1 and level 2 are discussed. Also some alternative approaches to resolve the inconsistencies are presented.

Keywords: *Second Generation Intact Stability Criteria, Parametric roll, Pure loss of stability, Excessive accelerations.*

1. BACKGROUND

The development of the so-called second generation intact stability criteria is ongoing at IMO. After several years of hard work (Umeda and Francescutto, 2016), the draft regulations and explanatory notes are nearly ready for level 1 and 2. A vast amount of sample ship results have been submitted, and some inconsistencies between level 1 and level 2 have been observed. An inconsistency here means that the level 1 check is passed while the level 2 check for the same failure mode is not.

In this paper potential sources for inconsistency between level 1 and level 2 for the different failure modes are discussed, supported by sample calculation results. For each failure mode a characteristic sample vessel that is potentially vulnerable is used. Finally, some ways to solve the inconsistencies by adjusting the draft regulations are suggested.

The study is limited to three failure modes: parametric roll, pure loss of stability and excessive accelerations. All calculations have been done with the NAPA software, based on the latest draft regulations IMO (2014 and 2015). Surf-riding/broaching has been excluded since the level 2 calculations would require a lot of data on resistance and propulsion, which is not easily available. Also dead ship condition has been excluded due to the yet unresolved conflict with the mandatory weather criterion. In addition, updates to dead ship calculations procedures have been recently proposed.

2. PARAMETRIC ROLL

Parametric roll has been identified as a possible failure mode, especially for container ships. Therefore, the C11 container ship has been selected as a representative sample vessel for this study. Several different loading conditions are calculated. The natural roll period is approximated based on GM value by using the simplified formula in the weather criterion of IS Code 2008. Level 1 is calculated both with the direct method, using the real GM variation in a longitudinal wave, and with the extremely simplified alternative. Level 2 check 2 is calculated with a time-domain 1-DOF simulation, using GZ curves in waves. The results are presented in Table 1, showing consistency.

Table 1 Sample results for parametric roll with C11 container ship. Red color is indicating that ship fails to meet the standard for the level.

Draft (m)	GM (m)	level 1 simple	level 1	level 2 check 1	level 2 check 2
8.00	2.50	1.290	0.731	0.000	0.000
9.00	2.10	1.331	0.932	0.425	0.001
10.00	1.90	1.307	1.035	0.216	0.006
11.00	1.80	1.216	0.988	0.216	0.011
12.00	1.70	1.106	0.890	0.216	0.012

Level 1

The extremely simplified alternative for level 1 check does not provide any additional value.

Hydrostatic calculations in a wave are trivial, and available in all advanced naval architectural software. The results of the simplified method are much more conservative, and thus a different threshold value could be considered.

Level 2

The standard for level 2 check 2 has remained unchanged since SDC1 (IMO, 2013, Annex 1), and the early sample ship calculation results were done using the averaging method (IMO, 2014). However, recently most of the sample ship calculations have been done using the time-domain method (IMO, 2016). In general, using the more realistic time-domain method, with GZ evaluated in waves, results in smaller index values.

The time-domain method for level 2 check 2 recognizes also lower resonance frequencies of parametric roll, whereas the level 1 and level 2 check 1 are based only on the main resonance. This is a potential source for inconsistency, but such a case has not been identified.

It should also be noted that the current draft regulation is based on a fixed set of forward speeds in both head and following seas. In many cases, the main resonance frequency for parametric roll can occur between these calculation speeds.

3. PURE LOSS OF STABILITY

The pure loss of stability failure mode may be relevant to relative fast and slender ships, such as RoRo or smaller passenger ships. From the sample calculations submitted to IMO (2016), it can be seen that there are multiple cases where large passenger ships are found vulnerable according to the level 2 calculations. There are however no known cases of pure loss of stability accidents for this type of ships. This paper tries to identify possible factors contributing to this. Therefore, the 300 m long FLOODSTAND cruise ship “A” is used for the sample calculations.

Results

Passenger ships have a more stringent limit for the second check of the pure loss of stability where the maximum permitted heel angle is 15 degrees, compared to 25 degrees for other ships.

For pure loss of stability to occur, the ship needs to spend a considerable time with the wave crest close to amidships. Therefore a Froude number limitation was introduced to the criterion to exclude ships with a Froude number below 0.24 outright.

Due to the abovementioned reason the sample ship used for this study was selected to be a large passenger ship with a design Froude number of 0.24.

Table 2 Sample results for pure loss of stability for a large passenger ship. Red color is indicating that ship fails to meet the standard for the level.

Draft (m)	GM (m)	level 1 simple	level 1	level 2 CR1	level 2 CR2
8.1	1.9	-3.543	-0.715	0.088	0.155
8.4	2.1	-2.983	-0.44	0.017	0.087
8.8	2.4	-2.29	-0.06	0.001	0.035

The extremely simplified alternative for level 1 gives results that are in an order of magnitude more conservative compared to the more accurate direct GM calculation in waves. Thus a different threshold value could be considered for the different methods in level 1.

From the level 2 calculation results we can determine that the second check CR2 is the dominating one. In this check the static heeling angle under the heeling lever R_{PL3} is calculated. This heeling lever is intended to replicate the centrifugal force due to large yaw angular velocity, possibly caused by the wave. The heeling lever is defined as:

$$R_{PL3} = 8(H_i/\lambda)dF_n^2 \quad (1)$$

where H_i is wave height, λ is wave length and d is draft amidships. Background information on this equation can be found from (IMO, 2012), where the standard has been based on model tests of three ships. In equation (1), it is assumed that the vertical distance between the center of gravity and the acting point of the hydrodynamic force z_H is equal to the draft of the ship. If this assumption is ignored and z_H is used instead of d, the results become:

Table 3 Sample results studying assumption made on the R_{PL3} heeling lever.

Draft (m)	GM (m)	z_H (m)	level 2 CR2, z_H	level 2 CR2, $z_H = d$
8.1	1.9	15.24	0.174	0.155
8.4	2.1	14.60	0.127	0.087
8.8	2.4	13.76	0.046	0.035

Based on the results shown in Table 2 and Table 3, it seems the heeling lever may be overly conservative and not reflecting the heeling moment experienced by the ship in waves, especially if considering the inertia of the ship.

Another cause for inconsistencies, especially for passenger ships, is the far more stringent maximum heel angle requirement compared other vessels for CR2. These in combination with the level 1 threshold set for the simple method is a likely culprit of the inconsistencies found in the sample calculations at IMO (2016).

The Froude number limitation may also be problematic, as can be seen in the sample calculation above. The selected sample ship currently fails pure loss of stability level 2, but if the design Froude number would be $F_n = 0.239$, the ship would have passed without need for any further analysis, and currently it even fails the level 2 analysis.

4. EXCESSIVE ACCELERATIONS

The excessive accelerations failure mode concerns vulnerability to excessive lateral accelerations caused by the ships response to waves. Some serious accidents have occurred e.g. to large container ships in ballast condition, but also other ship types where persons can be high above the sea level and that may operate with a higher GM are potentially vulnerable.

In the regulation draft (IMO, 2015) there are several standards proposed both for level 1 and level 2 which makes consistency analysis more difficult. The draft regulation also contain a criteria to allow a loading condition to pass the vulnerability checks without investigation. This criterion consists of two parts that both must be met:

- GM is below 8% of the breadth of the ship, and
- the highest location where persons are present is lower than 70% of the breadth of the ship.

In this two-part criterion three main parameters are found and thus selected for further analysis. Exploratory calculations, while varying the GM, breadth and height, were carried out using a general container ship hull form with a length of 195 m. While GM and height easily can be changed in the calculations, the breadth variation was done by transforming the hull shape. Two different x locations, at midship and at the bow, were used for the location where the accelerations were estimated. The vertical position, where the accelerations need to be calculated, is the highest location where crew or passengers may be present. For cargo ships this is usually the bridge, but for passengers ships multiple locations may need to be addressed (Tompuri et al, 2016).

The damping was calculated both with bilge keels and without them, using the semi-empirical Ikeda's method (Kawahara et. al., 2009).

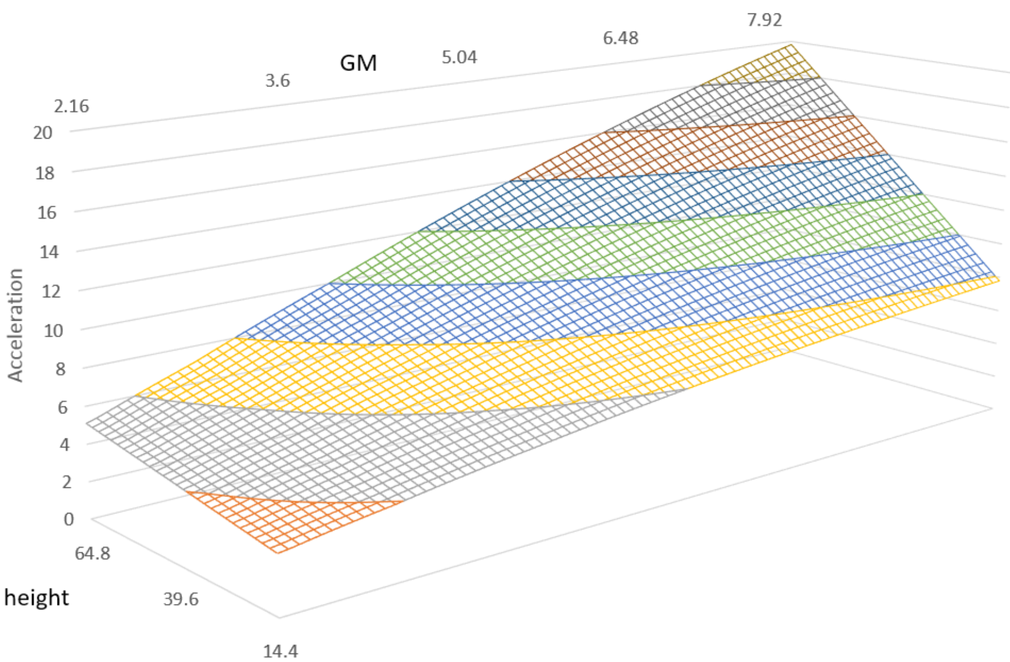

Figure 1: Level 1 as a function of GM and height (midship, B=36).

Level 1

Results shows that an increase in height and GM amplifies the level 1 results. This effect appears to be common for different breadths, and both with or without bilge keels.

Level 2

Level 2 results on the other hand behaves quite different depending on if bilge keels are used or not. No bilge keels seems to induce a GM resonance, as can be seen from figure 2 below, resulting in a differently shaped level 2 results field, while breadth and x location mainly influences the amplitude.

Looking at the standards proposed for both levels, and superimposing the pass/fail boundaries from the level 2 results on the level 1 results reveals more. The level 2 standards 0.043 and 0.0281 results in allowed level 1 accelerations in the bow of up to over 20m/s^2. A level 2 standard of 0.001 results in level 1 accelerations of up to 12m/s^2, and level 2 standard 0.00011 in level 1 accelerations up to 10m/s^2. These values all naturally depend on the ship, x location, breadth, height and GM. It should be noted that for certain values the varied parameters, both the level 1 and level 2 criteria, can fail when the most conservative standard is used. However these cases would automatically be excluded from the calculation based on the height/breadth and GM/breadth ratios.

The standards applied in the reports for sample ships submitted to IMO (2016) have been different. The standards chosen is one possible source for inconsistency and it is therefore important to look at the actual values calculated instead of only the judgement pass or fail.

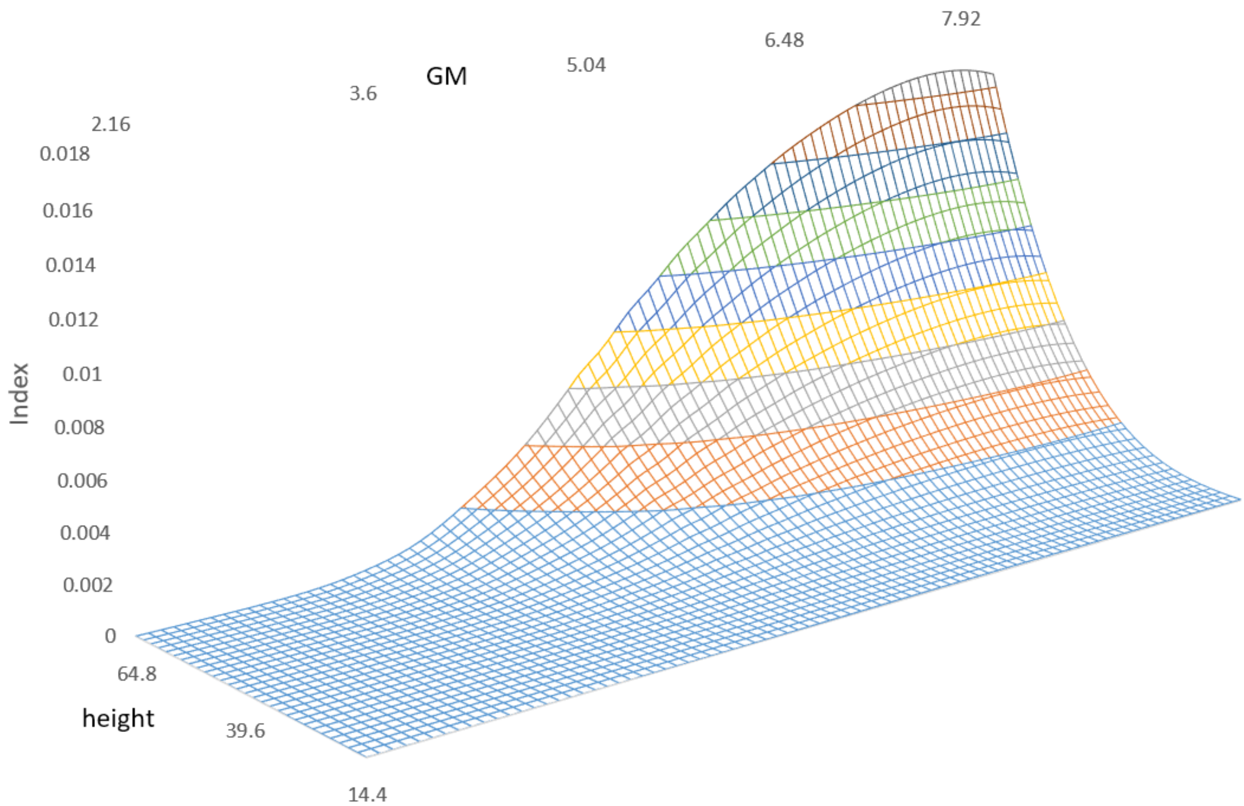

Figure 2: Level 2 with bilge keels (midship, B=36).

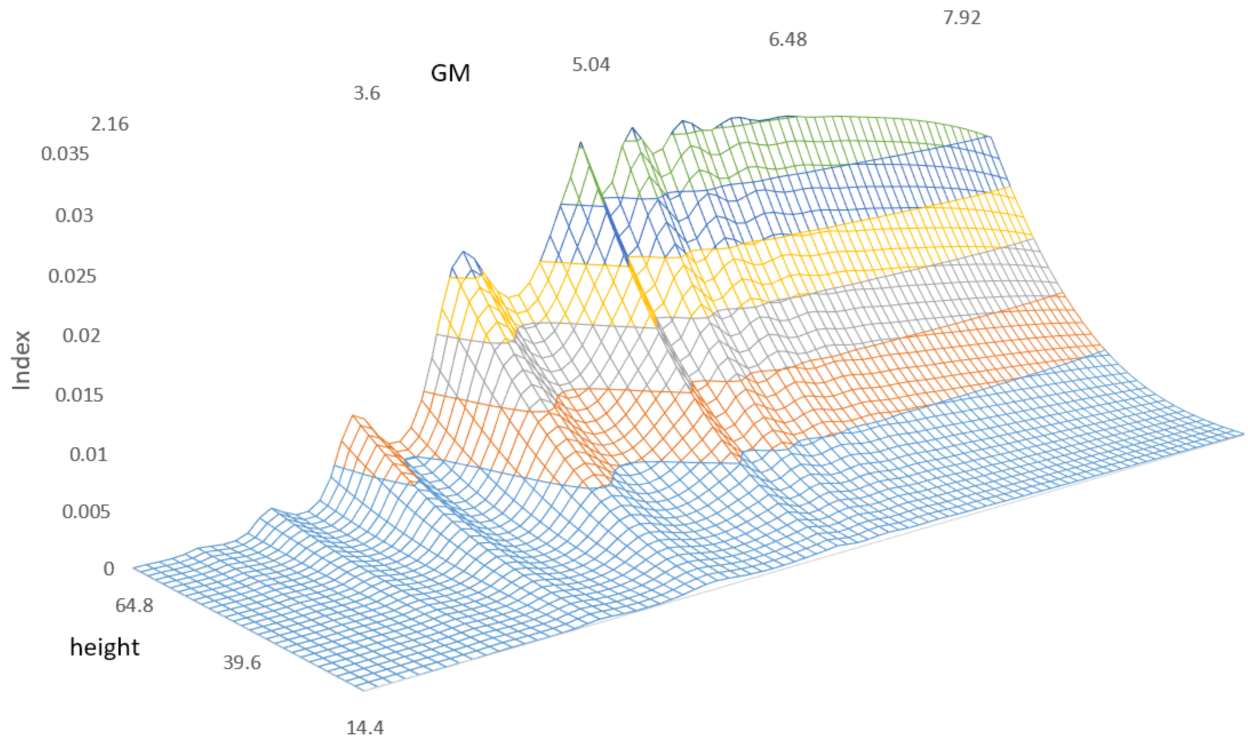

Figure 3: Level 2 without bilge keels (midship, B=36).

5. DISCUSSION

When developing criteria that will be applicable for decades to come, it is important that the regulations are well formulated and works for all the intended ships. The selected methods should be based on physics, well tested and without restrictions or assumptions on ship particulars.

From the results in this paper and from the calculations submitted to IMO (2016) it is clear that the level 1 threshold for parametric roll and pure loss of stability are based on the simplified method. As the direct calculation of GM in waves is an alternative it should also have a different threshold value to avoid inconsistencies. It is also important that level 1 and level 2 thresholds are considered as a whole to avoid inconsistencies.

Currently the bilge keels are the only roll damping devices that can be taken into account when assessing roll damping coefficients. This may be problem for example for ice going vessels that typically do not have bilge keels, but often incorporate other roll damping measures such as antiroll tanks. Inconsistencies for ice-going ships has also been reported to IMO (2016, Annex 3).

Level 1 should work as a conservative check and quickly filter out the ships that should not experience a certain stability failure mode. Level 2 on the other hand introduces sea states and also considerations on the likelihood for the events to occur. Level 3, or direct assessment, is the most accurate analysis, but unfortunately results based on level 3 have not yet been submitted and the calculation is still under development. By widening the calculation spread and applying the results from a higher criteria level to a lower one could help in refining the standards and methods used.

From experience it is known that these stability failures fortunately are rare events. Good seamanship and possible counter measures performed by the crew are likely also contributing factors to keep the number of accidents for these failure modes low.

The Second Generation Stability Criteria are intended for all ships, and thus the methods chosen need to be general in nature and their limitations must be solved. More research into the subject is still needed and inconsistencies should be solved.

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