DEVELOPMENT OF NEW GENERATION INTACT STABILITY CRITERIA

Sample calculations on the Level 2 Vulnerability criteria for parametric roll

Submitted by Sweden

SUMMARY

Executive summary: This document presents sample calculations on the proposed Level 2 criteria regarding parametric roll that was submitted by Japan and the United States to the Correspondence Group on Intact Stability.

Strategic direction: 5.2

High-level action: 5.2.1

Planned output: 5.2.1.16

Action to be taken: Paragraph 6

Related documents: SLF 53/3/1, SLF 53/3; SLF 52/19 and SLF 52/INF.2

General

1 The Sub-Committee, at its fifty-second session, re-established the Correspondence Group on Intact Stability, under the coordination of Japan (document SLF 52/19, paragraph 3.19).

2 Several delegations have submitted proposals on draft vulnerability criteria and contributed with relevant sample calculations to the correspondence group. These submissions are available in the report of the Correspondence Group on Intact Stability (SLF 53/3/1).

3 Sweden provided sample calculations and comments on the Level 1 criteria to the correspondence group. However, Sweden could not submit sample calculations on the Level 2 vulnerability criteria for parametric roll within the time frame stipulated by the correspondence group.

4 The study provided in the annex presents sample calculations on the proposals on vulnerability criteria for Level 2 that were submitted by Japan and the United States regarding parametric roll (documents SLF 52/INF.2 and SLF 53/3/1).
5 The sample calculations presented in the annex have been developed by the Centre of Naval Architecture at the Royal Institute of Technology in Sweden. The study is performed on 25 ships of different types with lengths between 90 and 310 metres.

**Action requested by the Sub-Committee**

6 The Sub-Committee is invited to note the information provided in the annex, in its work on the development of new generation intact stability criteria.

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Sample calculations and comments on the

**Level 2 Vulnerability Criteria for Parametric Roll**

that were submitted to ISCG (the intersessional correspondence group on intact stability between SLF 52 and SLF 53) in June-July 2010.

Stockholm 2010-11-02

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**Introduction**

A number of proposals on vulnerability criteria have been submitted to ISCG (the intersessional correspondence group on intact stability between SLF 52 and SLF 53) as part of the process of developing new intact stability criteria. In this report the Level 2 proposals from Japan and USA regarding parametric roll are commented based on implementation of the proposed methodologies and sample calculations for 25 different ships. Also Korea submitted Level 2 proposals regarding parametric roll and Italy submitted a Level 1 proposal which is on the same level as the other Level 2 proposals, these have however not been included in this study simply due to time limitations for performing the study.

**Ship Population**

This study is performed on 25 ships of different types with lengths between 90 and 310 meters and volume displacements between 3700 and 115000 cubic meters. The ships are listed in Table 1 along with characteristic particulars and markers used for identification of the different ships in the result presentation. About half of the studied ship population are real ships, or well documented ships from the literature, with well defined geometry and load cases. Among the rest of the ship population some ships have geometry from real ships but approximated load case, while some are based on approximations both regarding the geometry and the load case. The approximate geometries have been determined by scaling the geometry from one real ship to corresponding values regarding main particulars and form parameters for another real ship of the same type. For the approximated load cases the draughts have been determined in relation to the hull geometry, while the vertical centre of gravity has been determined, either on approximate calculations (for tankers/bulkers) or as the maximum allowable vertical centre of gravity for the ship in question in relation to the IMO intact stability criteria. The later cases also include approximations regarding the lateral area of the ship to evaluate the weather criteria. The studied ship population is the same that was used in an earlier report to the intersessional correspondence group on intact stability between SLF 52 and SLF 53 [Rosén et al, Comments on and evaluation of the Level 1 Vulnerability Criteria for Parametric Roll and Pure Loss of Stability, Sweden, 2010].

![Table 1](image)
USA Parametric Roll

The methodology & implementation
The suggested procedure was implemented in Matlab based on the description in SLF 52/INF.2, Annex 7 and applied to sample calculations on a number of various ships in varying conditions as a verification/validation exercise. The method was fairly clearly described and straightforward in implementation when assumed to be build on top of a hydrostatics module as a part of a ship design analysis package. The method solves the equations of motion in heave, pitch and roll in two steps. In a first step the decoupled equations of motion in heave and pitch are integrated, including the Froude-Krylov moments and forces, in un-heeled condition. The second step is then applied where the roll equation is integrated with time-dependent non-linear stiffness (GM) calculated (time-interpolated) in each time-step within the heave and pitch time series. An initial value of roll perturbation is naturally needed to initiate roll motion. The wave is modeled as a regular wave and a superimposed wave group modulation with the period equal to 7 regular waves. According to the USA-suggestion the most severe condition is found by setting ship speed (within operational limits) to achieve a relative wave frequency of encounter matching exactly the double ship roll resonance. Criterion for the identification of parametric roll is not more explicitly suggested in other terms than to investigate the “maximum angle of ship roll response to a typical wave group”.

Sample calculations

Criterion for parametric roll
Since the USA proposal is not explicit on the criterion of parametric roll the criterion was here selected as maximal absolute roll angle of 3 times the initial condition of 5 degrees. The initial condition may naturally be up for debate and tests show that varying the initial roll amplitude naturally affects the maximal roll response within the wave group. Variations of initial roll amplitudes from 1 to 5 degrees however show fairly consistent roll amplitude growth within the wave group up to the point of very large amplitudes where results may be questioned anyway. It was here argued that the rationale behind the 5 degree amplitude (no angular velocity) condition is reasonable as a non-severe but commonly occurring real-life disturbance. The criterion of 15 degree absolute amplitude was somewhat arbitrary chosen but was assumed to represent a growth in amplitude that is significant.

Sensitivity to decoupled roll equation
Since calculation effort is reduced if the 3 DOF system of equations of motion is solved simultaneously instead of the USA-suggested decoupling of the roll-motion a first set of calculations were done to investigate the difference in solutions of the two approaches. Results from simulations of ≈1000 conditions divided on 5 different hulls, show small and insignificant differences in roll response suggesting that any of the schemes may be used. In the following, the faster coupled scheme is used. The rationale behind the USA-suggested de-coupling is not disclosed in the proposal but maybe has a significance that was not detected here.

Sensitivity to roll damping
Roll damping was set to 4% of critical if not otherwise specified. Some comparative calculations were done on varying roll damping although the damping is actually not a method parameter but a hull
parameter. No significant change in vulnerability was observed for damping coefficients in the interval between 4% and 6% of critical damping for any of the 25 investigated ships.

**Wave group modeling or not**

Based on comparative simulations of about 1000 conditions where wave group modulation was compared to 7 pure regular waves without wave group modulation the question is here raised about the necessity of wave group modulation to establish the hull vulnerability. Without exception, the hull vulnerability to parametric roll was not dependent on wave group modulation, although individual time series for some conditions was affected significantly since excitation is changed. Thus, all hulls would have been categorized in the same way regardless of wave group modulation or not.

**Ship type**

All ships (Table 1) where simulated for the wave conditions in Table 2. The results are assembled in Table 3 and shows that the method targets most container hulls, reefers, RoRo and military hulls as vulnerable whereas the tanker/bulk hulls are insensitive. One might note that this is in accordance with the German observations and remarks on the method from August 31, 2010. These results are more or less expected and thus brings trustworthiness to the method. Some comparative simulations were also done with increased metacentric height with the conclusion that even though sensitivity to parametric roll was decreased, the results in the table below still holds.

<table>
<thead>
<tr>
<th>Hull #</th>
<th>Ship type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-12</td>
<td>Container</td>
<td>Parametric roll for all but #9 (although close...)</td>
</tr>
<tr>
<td>13-16</td>
<td>Tanker/bulk</td>
<td>No Parametric roll</td>
</tr>
<tr>
<td>17</td>
<td>Reefer</td>
<td>Parametric roll</td>
</tr>
<tr>
<td>18-24</td>
<td>RoRo</td>
<td>Parametric roll for all</td>
</tr>
<tr>
<td>25</td>
<td>Military</td>
<td>Parametric roll</td>
</tr>
</tbody>
</table>

**Wave height**

Wave heights between 1 and 10 meters were applied to all investigated hull types. An interesting observation is that the correlation of parametric rolling with wave height is predicted non-linear. Although generally high waves increases risk for parametric rolling, some hulls that are sensitive in moderate conditions show little, no increased or even reduced vulnerability in higher waves. In a few cases (Container #4 and RoRo #2) parametric rolling was observed at significant wave heights of around 4 meters but no parametric rolling at higher wave heights.

**Alteration of ship speed and loading conditions**

Correcting the ship maximum speeds by using a simplified method for prediction of added wave resistance [Alexandersson, M., *A Study of Methods to Predict Added Resistance in Waves*, Stockholm 2009] the hulls RoRo 1 and 2 where observed not experiencing parametric roll, this since the critical ship speed hereby are unachievable in the critical wave condition. Part of the ship population has
estimated loading conditions corresponding to just fulfilling the IMO intact stability criteria. For some of these ships (Container 2, 3, 7 and 8) a number of less stability critical loading conditions are also investigated. Investigation of the low intact stabilities importance in the evaluation is made by altering these loading conditions, using semi empirical design tools. The here studied variations of load cases did however not have any significant effects on the results.

**Conclusions and points for discussion**

Based on the process of implementation of the suggested method and the results from the conducted simulations a few conclusions and points for discussion are raised:

1. The method is fairly straight forward in implementation.
2. The actual vulnerability criterion must likely be discussed further. The initial roll condition of 5 degrees seems rational and the criterion limit for occurrence of parametric roll is here suggested to be 15 degrees, thus somewhat lower and more conservative than the USA suggestion. It is noted that USA uses different initial conditions in the sample simulations. The reason for this is however not disclosed and maybe shall be discussed in relation to the criterion level.
3. Classification of vulnerability will likely require a set of ≈50-200 simulations through the time period corresponding to ≈7 harmonic roll periods which, depending on hull discretization, might be relatively time consuming. As comparison, the average simulation time was in the present implementation about 3-5 times faster compared to full-scale time. A fully developed method shall likely specify a scheme (or test matrix) for selecting conditions and external conditions to follow and may thus need around 30 minutes of CPU-time on a standard PC.
4. It is to the authors not clear what the decoupling of the roll equation of motion from the heave and pitch solutions adds to the suggested method. Simultaneous time integration of the 3 degrees of motion is thus here suggested. A possible alternative could also be to balance the ship in heave and pitch based on strip theory calculations.
5. The proposed method does not address the estimation of heave and pitch damping, nor estimations of mass (and added mass) moments of inertia. Guidelines for these calculations are likely needed in a future method description.
7. The conditions for the sample calculations in the USA proposal are not entirely declared which makes verification difficult.
8. The method suggests ship speed to be set to achieve “principle parametric resonance condition”, i.e. to set frequency of encounter as exactly double the calm water roll harmonic frequency. Sample calculations suggest that this condition maybe shall be “relaxed” to incorporate a range of simulations near this condition.
9. Figure 1 below is from an earlier report to the intersessional correspondence group on intact stability between SLF 52 and SLF 53 [Rosén et al, Comments on and evaluation of the Level 1 Vulnerability Criteria for Parametric Roll and Pure Loss of Stability, Sweden, 2010]. The figure presents USA’s Level 1 measure CVWS in relation to the GM-variation in waves suggested by the ABS method for evaluating parametric roll [ABS, Guide for the Assessment of Parametric Roll Resonance in the Design of Container Carriers, 2004]. The figure also shows how the studied ships (Table 1) relate to the ABS susceptibility and severity criterion, where the marker of a ship is circumfered with a black circle if the ship in question fulfils the ABS susceptibility criterion and with an additional black square if it also fulfils the ABS severity criterion. As seen USA Level 1 criterion clearly distinguishes the tankers and bulkers from the other ship types. The ABS susceptibility criterion distinguishes the tankers and bulkers and yet three more ships (Container 9, Reefer 1 and Ro-Ro 1) and the ABS severity criterion yet another four ships as being insensitive to parametric rolling (Container 1, 4 and 11 and Military 1). In comparison the USA’s Level 2 approach according to the present study only distinguishes the tankers, bulkers and Container 9 (and also RoRo 1 and 2 if considering added resistance in waves). It could here be discussed
whether USA’s Level 2 approach might be too conservative or if the more detailed modelling actually captures sensitive ships which are not identified by the ABS-criteria.
Japan Parametric Roll

The suggested method is based on a single degree of freedom roll model,

\[
\ddot{\phi} + 2\alpha \phi + \gamma \dot{\phi}^2 + \omega_p^2 \phi + \omega_p^2 l_5 \dot{\phi}^3 + \omega_p^2 l_5 \phi^5 + \omega_p^2 \left(GM_{\text{mean}} + GM_{\text{amp}}\cos\omega_t t\right) \left(1 - \left(\frac{\phi}{\pi}\right)^2\right) \frac{\phi}{GM} = 0 \tag{1}
\]

The approach is to prerequisite characteristics of parametric roll, turning the roll model into a model of parametric roll of which conservative steady state solutions can be determined.

The wave length is prerequisite to equal the ship length,

\[
\lambda = L_{pp} \tag{2}
\]

(a demanding case although not necessarily the absolutely worst case) and the roll frequency is set to half the encounter frequency,

\[
\dot{\omega} = \frac{1}{2} \omega_e \tag{3}
\]

The amplitude \( A \) of steady state parametric roll solutions,

\[
\phi(t) = A \cos(\dot{\omega}t - \epsilon)
\]

are determined from the equation,

\[
\frac{\left(\frac{\pi^2 \dot{\omega}(3A^2 \dot{\omega}^2 \gamma + 8\alpha)}{(2\pi^2 - A^2)\omega_e^2}\right)^2}{\left(\frac{6A^2 - 8\pi^2}{4(\pi^2 - A^2)} \frac{GM_{\text{mean}}}{GM} + \frac{-5\pi^2 A^4 l_5 \omega_e^2 - 6\pi^2 A^4 l_5 \omega_e^2 + 8\pi^2 \dot{\omega}^2 - 8\pi^2 \omega_e^2}{4(\pi^2 - A^2)\omega_e^2}\right)^2} = \left(\frac{GM_{\text{amp}}}{GM}\right)^2 \tag{5}
\]

where, besides \( \dot{\omega} \) and \( A \) defined above, \( \omega_e \), is the natural roll frequency, \( \alpha \) and \( \gamma \) is first and third order roll damping coefficients, \( l_5 \) and \( l_5 \) are constant coefficients of third and 5\(^{th}\) order restoring moment in calm water, \( GM_{\text{amp}} \) and \( GM_{\text{mean}} \) are the amplitude of the variation of metacentre height and the mean of the variation respectively, \( GM \) is the metacentre height in calm water.

The Level 2 criterion on parametric roll is suggested to be based on solutions for \( A \) of equation (5) for a variation of ship speeds and for wave steepness (expressed as wave height/wave length) ranging from 0.01 to 0.1 in 0.01 increments.
Figure 2 illustrate equation (5) plotted for various ship speeds. The circles in the figure shows solutions and the dotted lines, representing the equation’s left hand side (LHS), not crossing the constant line of the right hand side (RHS) simply says that parametric roll will not occur at this speed.

The proposal suggests that the level of $A$ should be evaluated with respect to the risk of cargo shift or passenger safety.

![Figure 2](image)

Figure 2. Illustration of the LHS and RHS of equation (5). The LHS curves represents different skip speeds (in this case corresponding to $F_n$: 0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07).

### Sample calculations

With the wave length fixed to the ship length and the roll frequency set to half the encounter frequency any chosen ship speed relates to the roll frequency as (for head seas),

$$\hat{\omega} = \frac{1}{2} \left( \frac{2\pi g}{L_{pp}} + \frac{2\pi U}{L_{pp}} \right)$$

(6)

The amplitude of the variation of metacentre height, $GM_{amp}$, and the mean of the variation, $GM_{mean}$, are determined based on wet section area in relation to the undisturbed wave surface with static equilibrium in heave and pitch. The wave passage is represented by 21 equally spaced steps along the hull. The restoring moment coefficients $I_s$ and $I_5$ are determined by a polynomial fit of the numerically determined GZ-curve.

The roll natural period has been calculated as,

$$T_\phi = 0.85 \frac{B}{\sqrt{GM}}$$

(7)

The constant 0.85 was chosen to fit the known natural period of the container ship $C11$, one of the investigated vessels (also an example in the presentation of the Level 2 criteria Japan (2010)).
The damping coefficients $\alpha$ and $\gamma$ are determined by the method suggested by Japan (Simplified Ikeda method (Kawahara et al. (2009)). The method uses the ship roll moment of inertia, $I_{44}$, the roll added mass $A_{44}$ and the bilge keel dimensions. In the sample calculations the following approximate expressions have been used for those parameters:

\begin{align}
I_{44} &= M (0.4B)^2 \\
A_{44} &= 0.1I_{44} \\
L_{BK} &= L_{pp}/3.5 \\
B_{BK} &= 0.01B
\end{align}

(8) \hspace{1cm} (9) \hspace{1cm} (10) \hspace{1cm} (11)

The bilge keel dimensions are scaled with respect to the dimensions for the C11.

The current implementation of the method shows reasonable agreement with the C11 results displayed in the Japan proposal (Japan 2010) indicated by green curves in Figure 3. Japan states that the ship fails the Level 2 criterion, a conclusion supported by the present calculation.

![Figure 3. Steady state parametric roll amplitude A as a function of Froude number for the container ship C11 heading regular waves of length equal to the ship length and of wave amplitude 1.3, 2.6, 3.9 and 5.2 m (H=2.6, 5.2, 7.6 and 10.4 m).](image)

The calculation is repeated for the 25 sample vessels. It is expected that the vessels passing the Level 1 criterion should also pass the Level 2, besides the Level 2 criterion should be able to identify if others are insensitive to parametric roll. This expected pattern is not always seen. Of the 6 vessels that pass the Japan Level 1 (the four Tankers/Bulkers, the Container 9 and the RoRo 1) not all passes the Level 2 criteria. The only one that definitely do not is the RoRo 1 that shows an A parametric roll amplitude between 50 and 60 degrees for basically all speeds for wave heights 4% of $L_{pp}$ and above, see Figure 4. Results from an earlier study on evaluation of the Level 1 criteria (Rosén et al 2010) are shown in Figure 5.
Figure 4. Steady state parametric roll amplitude A as a function of Froude number for the Reefer 1 & RoRo 1 heading regular waves of length equal to the ship length and of wave height-to-ship length ratio of 0.02, 0.04, 0.06, 0.08 and 0.10. The vertical line indicates the ship calm water cruising speed.

Figure 5. Japan’s Level 1 measure for all ships (Table 1) together with the corresponding GM-variation in waves and relation to the ABS-criteria, where the marker of a ship is circumfered with a black circle if the ship in question fulfills the ABS susceptibility criterion and with an additional black square if it also fulfills the ABS severity criterion. Take from Rosén et al (2010).

The results for the Tankers/Bulkers are shown in Figure 6 and Figure 7. As seen the Tanker/Bulker 4 has no tendency for parametric roll. The conclusion is that the Tanker/Bulker 1 & 3 are not risking parametric roll due to the limited roll amplitudes at speed close to cruising speed in calm water, a speed that in fact must be unlikely to keep in waves. The Tanker/Bulker 2 (Figure 6) seems to be at great risk if the wave height is larger than 8% of the ship length. In this case it turns out that the tendency for parametric roll is eliminated if the bilge keel length is increased from $L_{pp}/3.5$ to $L_{pp}/2$, a change that generally not alters the solution significantly (compare Figure 9 and Figure 10).
Figure 6. Steady state parametric roll amplitude $A$ as a function of Froude number for the Tanker/Bulker 1 & 2 heading regular waves of length equal to the ship length and of wave height-to-ship length ratio of 0.02, 0.04, 0.06, 0.08 and 0.10. The vertical line indicates the ship calm water cruising speed.

Figure 7. Steady state parametric roll amplitude $A$ as a function of Froude number for the Tanker/Bulker 3 & 4 heading regular waves of length equal to the ship length and of wave height-to-ship length ratio of 0.02, 0.04, 0.06, 0.08 and 0.10. The vertical line indicates the ship calm water cruising speed.

The Container 9 was the 6$^{th}$ vessel of the 25 samples to pass Japan’s Level 1 criterion (see Rosén et al 2010). The solution for roll amplitude $A$ is shown in Figure 8. If this vessel is considered to pass the Level 2 is a question of the choice of the $A$-limit. In the proposal, Japan (2010), 30 degrees is mentioned (“tentatively”) as the limit defining the C11 as parametric roll sensitive, -this level might indicate a magnitude? In that case the Container 9 might pass the Level 2 (perhaps after actions to increase damping). Anyway, the conclusion is that 5, at the maximum, of 6 vessels that passed the Level 1 criterion pass the Level 2. The results for all 25 sample vessels are shown in Table 4.
Figure 8. Steady state parametric roll amplitude \( A \) as a function of Froude number for the Container 4 & 9 heading regular waves of length equal to the ship length and of wave height-to-ship length ratio of 0.02, 0.04, 0.06, 0.08 and 0.10. The vertical line indicates the ship calm water cruising speed.

Table 4. Results for the studied ship (Table 1). \( A_{\text{max}} \) indicates the largest \( A \) calculated, for wave height was as large as 10% of \( L_{pp} \) and speeds from 0 to a Froude number larger than the cruising speed in calm water, \( F_n \). Pass L1 and Pass L2 indicates whether or not the ship is considered non-sensitive to parametric roll by the Japan Level 1 and Level 2 criterion.

<table>
<thead>
<tr>
<th>Ship</th>
<th>( A_{\text{max}} )</th>
<th>( F_n )</th>
<th>Pass L1</th>
<th>Pass L2</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container 1</td>
<td>57</td>
<td>0.29</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Container 2</td>
<td>&gt;70</td>
<td>0.27</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Container 3</td>
<td>&gt;70</td>
<td>0.26</td>
<td>No</td>
<td>No</td>
<td></td>
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<tr>
<td>Container 4</td>
<td>45</td>
<td>0.26</td>
<td>No</td>
<td>Yes/No?</td>
<td>Realistic speed in waves?</td>
</tr>
<tr>
<td>Container 5</td>
<td>&gt;70</td>
<td>0.26</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Container 6</td>
<td>60</td>
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<td>No</td>
<td>No</td>
<td></td>
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<tr>
<td>Container 7</td>
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<td>No</td>
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<tr>
<td>Container 8</td>
<td>55</td>
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<td>No</td>
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<td>Container 9</td>
<td>35</td>
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<td>Yes</td>
<td>Yes/No?</td>
<td>Level of ( A )?</td>
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<td>No</td>
<td>Yes/No?</td>
<td>Realistic wave height? Level of ( A )?</td>
</tr>
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<td>No</td>
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<td>Container 12</td>
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<td>No</td>
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<tr>
<td>Tanker/Bulker 1</td>
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<td>Yes</td>
<td>Yes</td>
<td></td>
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<tr>
<td>Tanker/Bulker 2</td>
<td>50</td>
<td>0.16</td>
<td>Yes</td>
<td>Yes/No?</td>
<td>Realistic wave height? Bilge keel dim.?</td>
</tr>
<tr>
<td>Tanker/Bulker 3</td>
<td>10</td>
<td>0.22</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Tanker/Bulker 4</td>
<td>0</td>
<td>0.16</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Reefer 1</td>
<td>42</td>
<td>0.33</td>
<td>No</td>
<td>Yes/No?</td>
<td>Realistic speed in waves</td>
</tr>
<tr>
<td>RoRo 1</td>
<td>63</td>
<td>0.26</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>RoRo 2</td>
<td>66</td>
<td>0.28</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>RoRo 3</td>
<td>60</td>
<td>0.26</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>RoRo 4</td>
<td>&gt;70</td>
<td>0.23</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>RoRo 5</td>
<td>&gt;70</td>
<td>0.22</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>RoRo 6</td>
<td>&gt;70</td>
<td>0.22</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>RoRo 7</td>
<td>61</td>
<td>0.26</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Military 1</td>
<td>47</td>
<td>0.41</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>
The expectation was that the Level 2 method should identify the same vessels as the Level 1 method and a few more. The disagreement on RoRo 1 shall be kept in mind and it is certainly not obvious that the Level 2 method identifies any more ships safe with respect to parametric rolling. Still, three ships, the Reefer 1, Container 4 & 10 seams to be on the limit. The Reefer 1 and the Container 4 have solutions of similar character (see Figure 4 and Figure 8) where the amplitude is relatively low as long as the speed is low. The involuntary speed reduction in waves might largely influence the risk for parametric roll in those cases. For the Container 10 (Figure 9) significant roll amplitudes are indicated for the largest wave heights. The question is if wave heights up to 10 % of ship length is a realistic choice.

The method is straightforward to implement (the difficulties to determine, damping coefficients and metacentre height in waves etc is nothing exclusive for this method but present for all methods). The Japan Level 2 method is also attractive in its way to focus on the conditions of parametric roll and analytical connection to the roll model. In the present form and with the observed ambiguities with respect to Level 1 results and ability to identify “roll safe” ships the impression is that the method is not yet mature as criteria. Guidelines are needed for the interpretation of solutions. The method might also need additional steps, for instance in order to judge how the roll amplitude influence the risk of cargo shift or other safety aspects in order to state a reliable limit for the roll amplitude A. A great help for reliable implementation would be published reference examples where (sub-) methods and input data is well defined and detailed results (and sub-results) explicitly shown.

Figure 9. Steady state parametric roll amplitude A as a function of Froude number for the Container 10 heading regular waves of length equal to the ship length and of wave height-to-ship length ratio of 0.02, 0.04, 0.06, 0.08 and 0.10. The vertical line indicates the ship calm water cruising speed. The result to the right is determined with increased bilge keel length.
Figure 10. Effect of increased bilge keel length for the Tanker/Bulker 2.

References
Japan, Draft vulnerability criteria on parametric rolling and pure loss of stability with their sample calculation results, Submission to the IMO for the Intersessional Correspondence Group on Intact Stability on the 30th of June 2010.
Summary
The Level 2 proposals from Japan and USA regarding parametric rolling have been implemented and applied on 25 different ships.

According to the here performed sample calculations USA’s Level 2 approach distinguish the same ships as being insensitive as USA’s Level 1 criteria. This is of course good. The Level 2 approach however only distinguish very few additional ships among the here studied population as being insensitive. This could indicate that the approach might be too conservative. For the combination of Level 1 and Level 2 to be efficient the Level 2 criteria should have better precision than the Level 1 criteria. Also Japan’s Level 2 approach distinguishes very few additional ships as insensitive compared to Japan’s Level 1 approach. Somewhat remarkably Japan’s Level 2 approach indicates a few ships as prone to parametric rolling which are considered safe according to Japan’s Level 1 criteria.

Both approaches are concluded to be rather straight forward to implement. It is however not described in detail how some of the different steps in the approaches should be treated, e.g. regarding the determination of stability variations in waves and damping, neither are the criteria levels specified. This makes it a bit difficult to evaluate the here performed sample calculations in relation to the examples in the proposals. It also raises questions of how well such details need to be specified in finalized criteria.

Further evaluation and development is concluded to be needed for the two approaches here studied. Things to look deeper into are for example:

- consequences of different ways of balancing the ship in heave and pitch,
- consequences of different ways of calculating stability variations and model the GZ-curve,
- how to determine the roll damping and how roll damping affects the results,
- how to determine roll natural periods and what range of natural period to encounter period to evaluate,
- how to choose ship speed regarding added resistance in waves,
- what relative wave conditions to consider (wave length/ship length, wave height/ship dimensions, wave statistics).

For continued evaluation and development it would further be good to establish a common database with different ship types and load cases together with reference results for the different calculation steps as well as for complete Level 1, 2 and 3 assessments.