Wave radar application to the simplified parametric roll operational guidance at actual sea

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ABSTRACT

The authors executed measurements of the encounter waves by an X band wave radar and the roll angles by a gyro sensor on board for a Ropax ship. By using the measured wave spectrum, the roll amplitude is estimated by using the simplified method for parametric rolling, which is used for the draft IMO vulnerability criteria. The estimated roll angle shows reasonably good agreement with the measured roll angle. Therefore, the wave-radar-assisted simplified operational guidance could be promising for practical uses on board.

Keywords: *IMO second generation intact stability criteria, RoPax ship, parametric rolling, wave radar, operational guidance.*

1. INTRODUCTION

Current stability safety of ships is realised not only with good ship design but also with appropriate operation. Based on this understanding, the International Maritime Organization (IMO) is going to develop the operational guidance, other than the stability design criteria, as a part of the second generation intact stability criteria those dealing with the five failure modes, i.e., pure loss of stability, parametric rolling, dead ship stability, broaching and excessive acceleration. Both design criteria and operational guidance are based on physics reflecting the state-of-the-art methodology (IMO, 2019).

IMO developed a guidance to the master for avoiding dangerous situations in following and quartering seas as MSC/Circ 707 (IMO, 1995), which was superseded by MSC/Circ. 1228 (IMO, 2007) for covering all wave directions. By using the wave information including the wave height, wave period and wave direction, the master can select appropriate ship course ad speed. This guidance is also based on physics but does not utilise the ship dependent data, such as hull forms and loading conditions. As a result, the dangerous zones specified by this guidance could be often too wide for ships having sufficient intact stability.

For overcoming such drawback, the new operational guidance will be developed to fully utilise the ship conditions, which are used for the new design criteria as well (IMO, 2019). The new design criteria mentioned here is called as direct stability assessment, and evaluate safety level against the specified failure mode by using a numerical tool for simulating ship behaviours in irregular waves in the time domain, which should be validated with model experiments based on the ITTC recommended procedure. While the ship stability failure probabilities under different sea states are summed up in the direct stability assessment, the operational guidance requests the ship master to utilise only the ship stability failure probabilities under the sea state that he or she meets. Even so, for providing the operational guidance, the same computational efforts are required for the ship designers because the guidance should cover all possible encounter sea states during the life of ships.

However, for accurately evaluating such safety level, required computational efforts are not so small that the operational guidance is not always a feasible solution for most of smaller ships. Ironically such smaller ships are more relevant to intact stability failure. Thus, the IMO also agreed to provide a way for the simplified operational guidance, which uses simplified methodologies for the simplified design criteria named as the vulnerability criteria. In the simplified methodologies for parametric rolling, as an example, the safety level is calculated as the probability of encountering dangerous sea states and the dangerous sea states is judged by a comparison of the roll amplitude with the acceptable angle. The roll amplitude is calculated by using an uncoupled but nonlinear roll model in representative regular waves determined from the wave spectrum. Thus, the method still involves nonlinearity of ship dynamics and randomness of wave environment. However, the coupling effect from heave and pitch is ignored so that the final judgement could be conservative to some extent. This nature is suitable for regulatory purpose and the computation could be made even with a spread sheet software.

The use of operational guidance, even in case of its simplified one, is rather new for mariners. In particular, wave information, such as the significant wave height, the mean wave period and the main wave direction, is not easily determined by visual observation on board. In the simplified method, often the shape of wave spectrum is assumed but it could be different from actual one. On the other hand, nowadays the wave radars are available for obtaining the wave information by using reflection of electric waves at the inclined wave surface (e.g. Hirayama et al. , 2010 and Suzaki et al., 2017). In the case of the wave radar, firstly the directional wave spectrum is determined from the spatial distribution of water elevation and then the significant wave height and so on are straightforwardly determined. If this approach is feasible, the use of operational guidance can be a promising beyond the limitation of the capability of mariners on board. Furthermore, the directional wave spectrum data could be directly used for the simplified operational guidance.

Based on this understanding, the authors attempt to apply the simplified method to a Ropax ship at seas. Here the wave information is determined from the directional wave spectrum obtained by the wave radar on the Ropax ship and her ship roll motion simultaneously is recorded by a gyro sensor. By comparing these two data, the feasibility of the simplified operational guidance using the wave radar is investigated. In this paper, we focus on parametric rolling as its first step. Similar research was reported by Suzuki et al. (2014) but focused on synchronous rolling.

2. SUBJECT SHIPS AND USED WAVE RADAR

The subject ship used by the authors is a Ropax ship operated in the coastal area around the Japanese Isle. Its principal particulars and the restoring arm curve are shown in Table 1 and Figure 1, respectively. Because of high freeboard, almost no possibility of capsizing but the danger of cargo shift on the vehicle deck may exist if the roll motion is significant.

Table 1: Principal particulars of the Ropax ship under the designed full load condition.

Items	Ship
Length	208.0 m
Breadth	26.0 m
Depth	20.4 m
Draft	7.4 m
Metacentric height	1.49 m
Natural roll period	15.5 s
Bilge keel area	41.6 m^2

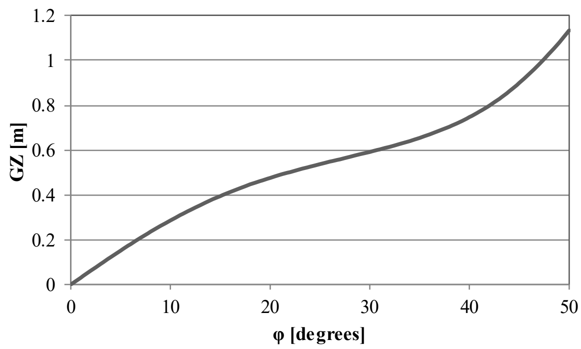

Figure 1: GZ curve of the Ropax ship in still water.

The ship is equipped with a wave radar system, which consists of an X band antenna, a radar display and a computer. Its measuring range is 3.8 km and measuring direction is about 190 degrees. For obtaining the wave measurement, a square 1920 m on a side, which corresponds to 256 meshes, is used so that the wavelength of 40 m or over can be detected. Every one rotation of the radar antenna, i.e. 2 or 3 s, the raw sea clutter image is recorded. An example of the obtained image is shown in Figure 2. Then the 2 dimensional Fourier transformation is applied to the images and their cross spectra are calculated for determining the wave spectrum removing noise spectrum by using a wave dispersion relationship. The average of 50 cross spectra is used for the output having sufficient sound noise ratio. An example of comparison between the visual and radar-measured wave height is shown in Figure 3 (Hirayama et al., 2015). The accuracy of the wave radar is not perfect but could be used for practical purpose.

The second check of the level 2 vulnerability criteria for parametric rolling was applied to this subject ship as shown in Table 3. Here the probability of encountering dangerous sea states in the North Atlantic is required to be calculated as the C2 index. Since this work was done before SDC 6 in 2019, the details used here is based on older version: the number of ship speeds is seven and the averaging method is used so that the standard is 0.06 (IMO, 2015). The results indicate that the limited number of loading conditions, i.e. those having deeper drafts with medium metacentric heights, slightly exceed the standard. The criteria are requested to use the wave scatter table for the operational water area. Since the water area around the Japanese Isles is not so severe as that in the North Atlantic, the identified vulnerability could be removed (Usada et al., 2016). Thus, we can say that no real danger exists for this Ropax ship in the Japanese water area but tendency of parametric rolling may exist.

Table 3: C2 index of the second check of the draft level 2 vulnerability criteria for parametric rolling applied to the RoPax ship. Here d and GM indicate draft (m) and metacentric height (m), respectively.

d＼GM	1.49	1.5	1.6	1.7	1.8	1.9	1.93
6.2	1.29.E-02	1.29.E-02	1.88.E-02	1.93.E-02	1.88.E-02	1.53.E-04	2.07.E-04
6.3	1.88.E-02	1.88.E-02	2.22.E-02	2.30.E-02	2.23.E-02	3.69.E-04	3.69.E-04
6.4	1.93.E-02	1.93.E-02	2.30.E-02	2.47.E-02	2.32.E-02	3.72.E-04	7.02.E-04
6.5	2.29.E-02	2.30.E-02	2.48.E-02	2.49.E-02	2.51.E-02	9.43.E-04	9.51.E-04
6.6	2.46.E-02	2.48.E-02	2.49.E-02	3.59.E-02	2.55.E-02	1.03.E-03	1.79.E-03
6.7	2.48.E-02	2.48.E-02	3.59.E-02	3.99.E-02	3.60.E-02	1.79.E-03	1.84.E-03
6.8	2.48.E-02	2.49.E-02	3.97.E-02	4.22.E-02	4.25.E-02	1.82.E-03	2.35.E-03
6.9	3.57.E-02	3.57.E-02	4.19.E-02	4.42.E-02	4.47.E-02	2.32.E-03	2.37.E-03
7	3.96.E-02	3.97.E-02	4.38.E-02	4.44.E-02	4.54.E-02	2.41.E-03	2.58.E-03
7.1	4.16.E-02	4.16.E-02	4.39.E-02	4.53.E-02	4.54.E-02	2.57.E-03	4.28.E-03
7.2	4.15.E-02	4.18.E-02	4.39.E-02	6.07.E-02	4.61.E-02	4.89.E-03	4.24.E-03
7.3	3.96.E-02	4.15.E-02	4.38.E-02	6.04.E-02	6.15.E-02	4.62.E-02	5.85.E-03
7.4	4.15.E-02	4.15.E-02	4.44.E-02	6.03.E-02	6.58.E-02	2.47.E-02	6.68.E-03

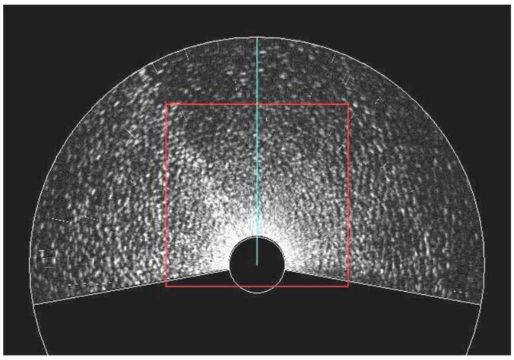

Figure 2: An example of sea clutter. (Hirayama et al., 2015)

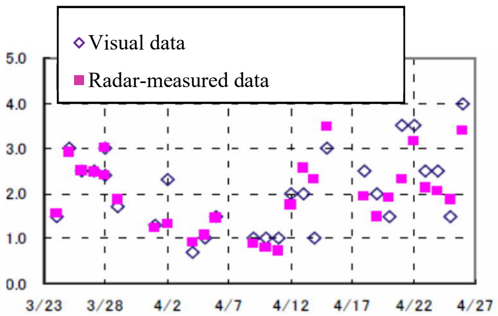

Figure 3: Comparison in wave height (m) between the visual and the radar-measured data on a containership in the North Atlantic and North Pacific for several weeks. (Hirayama et al., 2015)

3. SIMPLIFIED ESTIMATION METHOD FOR PARAMETRIC ROLLING FOR A SHORT-TERM SEA STATE

In this work, a simplified estimation method is used, which is based on an averaging method applied to an uncoupled roll equation with time-dependent roll restoring variation in regular oblique waves (Sakai et al., 2017). The used wave is determined from the directional wave spectrum (Umeda & Yamakoshi, 1994) by using Grim's effective wave concept (Grim, 1961). Further simplified version of this calculation method was adopted for the second check of the vulnerability level 2 criteria for parametric rolling (IMO, 2019). While the IMO criteria deals with the longitudinal waves only, the current method takes account of waves from all possible directions as well. IMO decided to use time-domain simulation by using the Runge-Kutta method but the current method uses the averaging method. It was already confirmed that these two provide the same solution for most of cases if we pay sufficient attentions on the initial value dependence of the time-domain simulation.

4. RESULTS AND DISCUSSION

By using the wave radar and the gyro sensor on board, we automatically recorded the wave spectra and the roll angles for about five years. During the measurement, one of largest roll case is selected for validating the wave-radar-based simplified operational guidance. The selected case is the 9th February 2015 at 10:25 am JST. At this time, the subject ship heading southward off Akita in the Sea of Japan with the Froude number of 0.33. According to weather map, the wind velocity of about 20m per second from the south to the low pressure system situated in Sakhalin. The on-board wave radar outputted the wave spectrum as shown in Figure 4, which results in the significant wave height of 2.15m and the mean wavelength of 177m. Under this situation, the maximum roll angle that she experienced was 12.7 degrees, which is half the critical roll angle that the Japanese administration requested for RoPax ships for avoiding cargo shift. Thus, no actual danger existed for this ship.

The ship was almost fully loaded so that the ship draft is about 7.4m but the metacentric height is not certain. Thus, the simplified method for calculating the representative roll amplitude is applied for different metacentric height, as shown in Figures 5-10. It covers almost all possible metacentric height range, i.e. from 1.49m to 1.9m. The natural roll period is estimated by Morita's formula, which is used in the IMO weather criterion (IMO, 2008) using the relevant metacentric height.

Besides uncertainty in the metacentric height, these comparisons show reasonable agreement between the wave radar-assisted simplified operational guidance and the actually measured roll angle. Therefore, we cannot say that the wave radar-assisted simplified operational guidance does not have practical importance. In addition, this guidance suggests that the roll motion could be significantly reduced if the ship course is changed with just 15 degrees. This information is not relevant to ship capsizing or cargo shift very much but is useful for passengers' comfort.

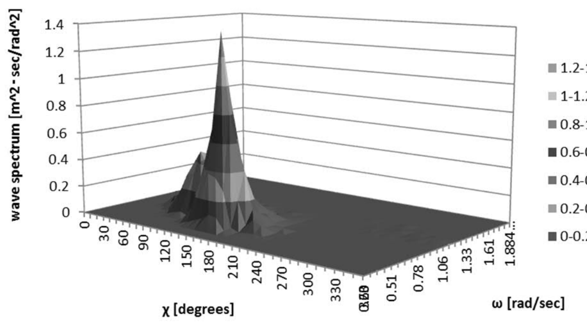

Figure 4: Wave spectrum measured by the wave radar as a function of the wave frequency, ω (rad/s), and directional angle, χ (degreees).

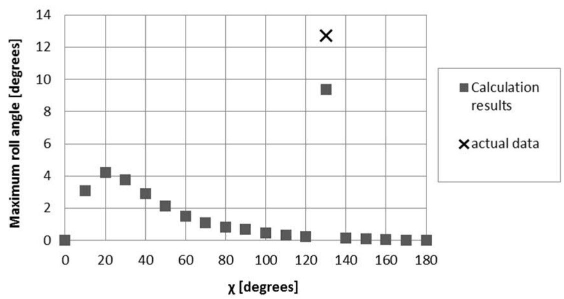

Figure 5: Roll angles estimated by the wave radar-assisted simplified operational guidance and the actually measured roll angle with the metacentric height is 1.49m.

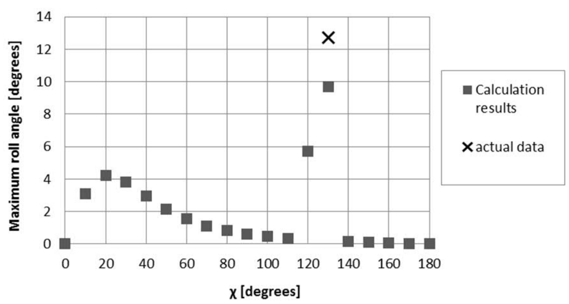

Figure 6: Roll angles estimated by the wave radar-assisted simplified operational guidance and the actually measured roll angle with the metacentric height is 1.50m.

The reason why parametric rolling occurs here is that the mean wavelength is comparable to the ship length and the mean encounter period can be almost half the natural roll period. Whether the fin stabilizer was used under this situation was not recorded so that this is another uncertainty. However, the good agreement with the estimation excluding the fin stabilizer effect suggests that the fin stabilizer was not used during the measurement.

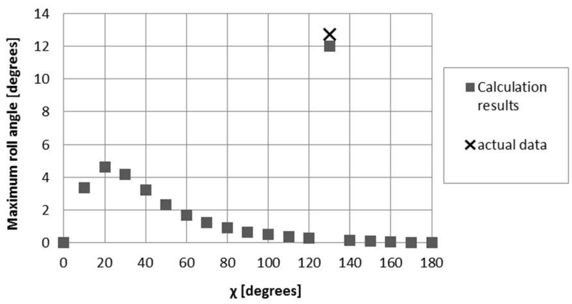

Figure 7: Roll angles estimated by the wave radar-assisted simplified operational guidance and the actually measured roll angle with the metacentric height is 1.60m.

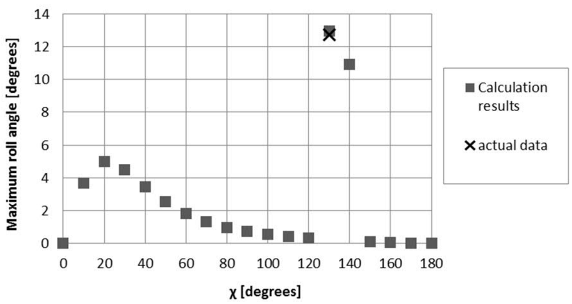

Figure 8: Roll angles estimated by the wave radar-assisted simplified operational guidance and the actually measured roll angle with the metacentric height is 1.70m.

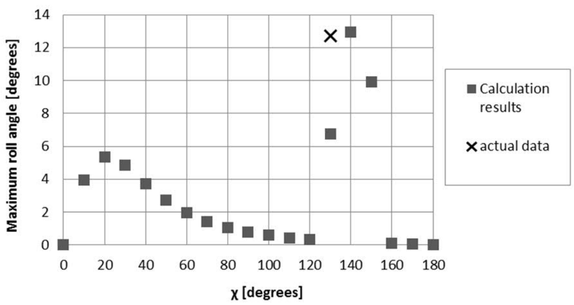

Figure 9: Roll angles estimated by the wave radar-assisted simplified operational guidance and the actually measured roll angle with the metacentric height is 1.80m.

5. CONCLUDING REMARKS

The authors executed measurements of the encounter waves by the wave radar and the roll angles by the gyro sensor on board for a Ropax ship. By using the measured wave spectrum, the roll amplitude is estimated by using the simplified method, which is used for the draft IMO vulnerability criteria. The estimated roll angle shows reasonably good agreement with the measured roll angle. Therefore, we may conclude that the roll angle of 13 degrees that the ship experienced seem to be parametric rolling and the wave-radar-assisted simplified operational guidance could be promising for practical uses on board. In any case this Ropax ship does not have any danger due to parametric rolling if the ship is operated in the water areas around the Japanese Isle. In addition, the guidance suggests that the parametric roll motion can be significantly reduced only if the ship course is changed with only 15 degrees. Further validation study should be encouraged.

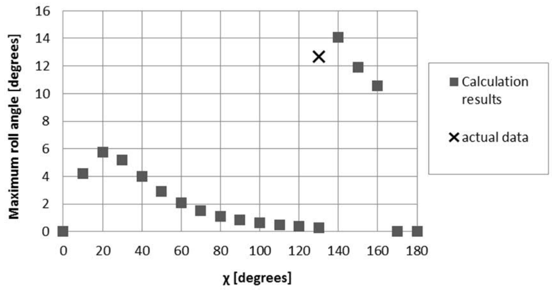

Figure 10: Roll angles estimated by the wave radar-assisted simplified operational guidance and the actually measured roll angle with the metacentric height is 1.90m.

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