# Polar Chart Approach for Large Container Ships to Avoid Parametric Roll

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**Abstract - An operational guidance in the form of polar chart showing the critical area of parametric roll is an effective means to provide a master with reference information on the risk of heavy roll motion. The authors applied a method based on the extended Grim's effective wave theory which is simplified and practical approach. This method can replace the stochastic assessment in irregular waves with the deterministic assessment in a regular wave, and its computational time is very low. In this study, some seakeeping test data with large container ships were used to validate polar charts. These experimental data include quartering wave data in irregular waves, which were rarely measured before. As another approach, the authors also investigated some reports on container loss accidents in recent years and compared the situation of accidents with the polar chart. As a result, it was found that the polar chart based on the extended Grim's effective wave theory can generally predict the occurrence of parametric roll in terms of seakeeping tank tests and actual accidents.**

**Keywords: Roll motion; Extended Grim's effective wave theory; Operational guidance.**

## INTRODUCTION

Parametric roll resonance was brought to much attention by the accident of C11 post-Panamax container ship in 1998. For recent large container ships, container loss accidents due to heavy roll motion, in which parametric roll is identified or suspected have occurred [1]. The number of container loss accident is very rare, but it could have a significant impact on maritime transportation and industry. Unlike synchronous roll resonance oscillated by wave exciting forces, parametric roll gradually grows by the time-varying change in stability in waves and it might occur unexpectedly. As well known, when the natural roll period is twice the wave encounter period, parametric roll is likely to occur. Some reports on recent accidents of large container ships suggested that the condition of long natural roll period due to low GM and swell with approximately 5 to 6m of wave height from stern quartering are close to that of the occurrence of parametric roll [2-4]. When a ship is in such a condition, parametric roll may occur suddenly. According to the interview with the crews [2], the ship rolled intermittently before they noticed the container loss and damage. Even if its mechanism is known, it would be difficult to apply it to an actual operation and prevent parametric roll.

Thus, a polar chart displaying visually roll angle can provide useful information to avoid the possible condition of parametric roll. IMO released the Interim Guidelines on the Second Generation Intact Stability Criteria, MSC.1/Circ.1627 (SGISC) in which the requirements for operational guidance in the form of a polar chart are described in several ways [5]. When it comes to related studies for a polar chart, several examples based on various simulation code have been shown such as [6-8]. In TopTier JIP project for cargo securing safety on large container ship, a comparative study for polar plot of parametric roll were carried out with various 6-DOF (degrees of freedom) motion simulation [9].

Generally, more than 3-DOF motion simulation in a statistically enough irregular waves can be required to assess parametric roll, but there are several conditions such as ship speed, heading, wave period, significant wave height and GM and the computational cost is enormous.

Therefore, the authors applied a procedure based on the extended Grim's effective wave theory to realize very low simulation time. It is a simplified and practical approach since the stochastic assessment in irregular waves can be replaced by the deterministic assessment in the longitudinal regular wave [10, 11]. For validation of the polar chart, several model test data with container ships were used in this study [9, 11]. These experimental data include quartering wave data in irregular waves, which are very useful for the validation of the polar chart in all directions. As another approach, the authors also investigated the effectiveness of the polar chart by comparing with some reports for accidents in recent years [2, 3]. Accordingly, it was found that the polar chart based on the extended Grim's effective wave theory can generally cover the occurrence of parametric roll.

## POLAR CHART APPROACH

A polar chart for parametric roll usually shows the radial direction as the ship speed and the circumferential direction as the wave encounter angle. For an operation onboard, there is another method for displaying in which the angle is the azimuth (0 degrees is North) so that the operator can visually recognize the ship's course and wave direction easily. The roll angle can be displayed directly, but it can also be linked to probabilistic risk, or some criteria related to safer operation.

This paper focuses on polar chart approach for avoiding parametric roll, but there are various ways to prepare it. Although more than 3-DOF (degrees of freedom) simulation can be performed, it is not easy to obtain the polar chart data for various sea conditions. Especially, a container ship is expected to require the large number of loading conditions. In this paper, a simple method based on the extended Grim's effective wave theory is adopted for preparing polar charts with reference to [10, 11]. If parametric roll simulation is performed in advance, polar chart data can be used onboard. For example, a polar chart can be easily displayed by inputting sea conditions and ship information such as draft and GM on a simple viewer as shown in Fig. 1.

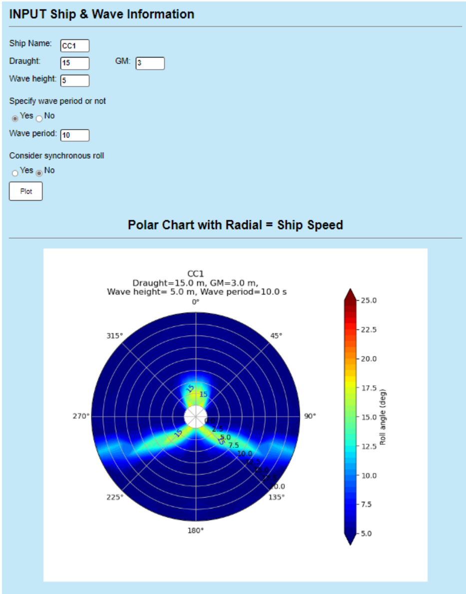


Fig. 1 An example of polar chart viewer

## COMPARISON TO SEAKEEPING TANK TESTS

### *A. 14K TEU class container ship*

Fig. 2 shows the comparative results of a polar chart and representative experimental data introduced in [11]. This seakeeping tank tests used 14K TEU class container ship model with $L_{PP} = 352m$. GM and natural roll period were respectively adjusted 2.0m and 28.8s in full-scale. As for irregular wave conditions, wave spectrum is JONSWAP with long-crested wave and 1.5 of peak enhancement factor $\gamma$. Significant wave height is 6.4m and the peak wave period is 14.3s in this condition. The maximum roll angle in 30 degrees of wave encounter angle and 5knots of ship speed is approximately 12.7 degrees and it is plotted with same contour collar as the polar chart. The duration time in this condition was approximately 0.75 hours and the number of encounter waves was approximately 200. The value of the polar chart based on long-crested wave in the same condition is 19.7 degrees, which is larger than the experiment. According to [11], the polar charts generally tend to show conservative results rather than experimental data. Since parametric roll can be regarded as non-ergodic, measured data can be significantly different with different random phase.

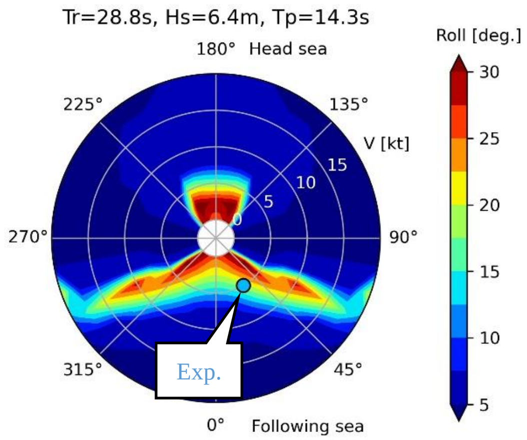


Fig. 2 Polar chart based on long-crested wave plotting maximum roll amplitude by the experiment with 14K TEU container ship [11].

### *B. 15K TEU class container ships*

In TopTier JIP project, seakeeping model test were addressed with 10K TEU and 15K TEU container ship model [9]. In this paper, the comparative results of a polar chart and experimental data for 15K TEU container ship model with $L_{PP} = 352m$ is shown in Fig. 3.

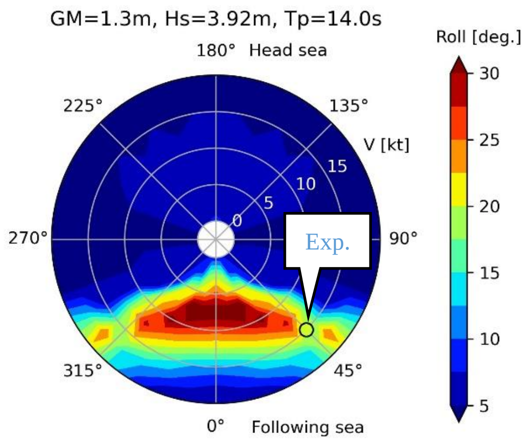


Fig. 3 Polar chart based on long-crested wave plotting maximum roll amplitude by the experiment with 15K TEU container ship [9].

GM and natural roll period were respectively 1.3m and 38.6s in full-scale. Irregular waves with 3-hour duration were generated using JONSWAP ($\gamma = 3.3$) with long-crested wave. Significant wave height is 3.92m and the peak wave period is 14.0s in this condition. The maximum roll angle in 45 degrees of wave encounter angle and 15knots of ship speed is approximately 20 degrees and it is plotted with same contour collar as the polar chart. While the value of the polar chart based on long-crested wave in the same condition is 19.7 degrees. Both results are almost same in this case. Although it may be difficult to estimate accurate roll angles under any conditions, the risk area of parametric roll can be covered by adopting the polar chart based on the extended Grim's effective wave theory.

## COMPARISON TO ACTUAL ACCIDENT CASES

The authors investigated the validity of the polar chart referring the information of some accident reports, case A [2] and B [3]. The conditions in the reports as shown in Table 1 and 2 are used for this comparative study, however there are some assumptions. First, since hull form data is not available, the authors used 14K TEU class container ship [11], whose size is like accident ships.

Regarding sea conditions at the time of the accident, these reports include several estimated wave height and wave period. The wave period and wave height of swell described in the report were regarded as the same as the peak wave period and significant wave height in the polar chart. Basically, it is difficult to specify accurate sea states and it should be noted that there are uncertainties. Finally, the polar charts were prepared using estimated natural roll period in the reports.

Table 1 Conditions of swell [2, 3]

| Case | Wave height [m] | Wave period [s] | Wave direction [deg.] |
|---|---|---|---|
| A | 6.0 | 15 | 300 |
| B | 4.8 | 16.8 | 310 |

Table 2 Conditions of the ship [2, 3]

| Case | Natural roll period [s] | Ship speed [knot] | Ship course [deg.] |
|---|---|---|---|
| A | 42.8 | 10 | 89 |
| B | 39.97 | 22 | 82 |

The polar chart here represents the radial direction as the ship speed and the circumferential direction as the azimuth to identify the state of ship speed and course. The observed maximum roll angles are approximately 26 degrees and 20 degrees respectively and it is plotted on each polar chart in Fig. 4 and 5. As shown in Fig. 4 and 5, the condition of the ship is respectively included in the zone where parametric roll can occur. Table 3 shows the observed maximum roll angle and the value of the polar chart.

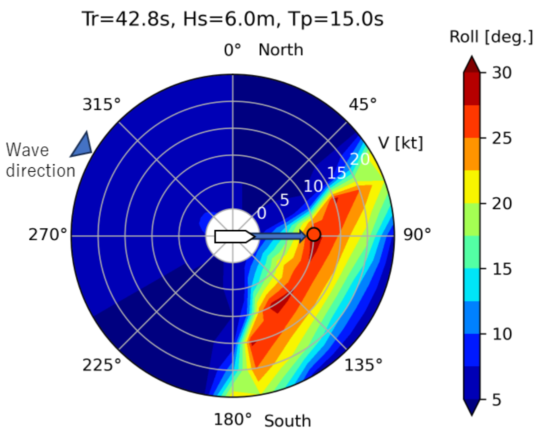


Fig.4 Polar chart based on long-crested wave plotting observed maximum roll amplitude by the report [2].

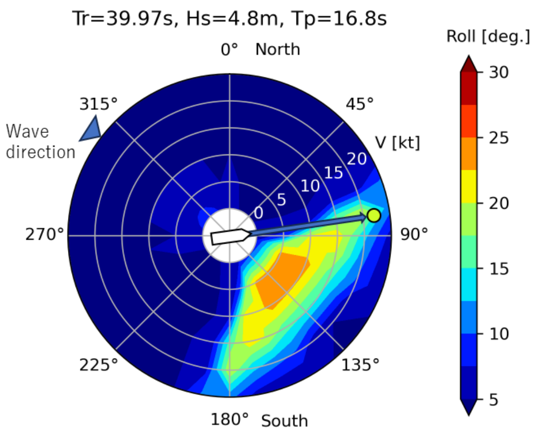


Fig. 5 Polar chart based on long-crested wave plotting observed maximum roll amplitude by the report [3].

Table 3 Comparison of roll angle [2, 3]

| Case | Observed maximum roll angle [deg.] | Roll angle of polar chart [deg.] |
|---|---|---|
| A | 26 | 29 |
| B | 20 | 16 |

Even if the ship is in the risk area in actual operation, heavy roll motion does not immediately occur. A serious accident involving container cargo loss would happen due to not only parametric roll but also multiple factors. However, since an excessive roll can trigger an accident directly, it is important to recognize in advance what conditions can cause parametric roll.

The relationship between the wave encounter period and natural roll period is critical for the occurrence of parametric roll, but wave encounter angle, wavelength, and significant wave height are also important factors. Even if its mechanism is known, it would be difficult to apply it to an actual operation. Thus, the polar showing visually roll angle can provide useful information to avoid the possible condition of parametric roll.

## CONCLUSIONS

The authors proposed the polar chart using a method based on the extended Grim's effective wave theory and found that it could reproduce the occurrence of parametric roll by comparing several experiments and actual accident cases. Many studies have focused on the parametric roll in a longitudinal wave however it occurred in quartering waves for recent large container ships. The polar chart adopted in this study can cover the range of the parametric roll even in quartering waves. Although parametric roll does not occur immediately in the risk area of the polar chart, it is useful to recognize the possibility of its occurrence in advance. Furthermore, from a practical point of view, it is useful to combine the polar chart with the weather routing to avoid the sea state where parametric roll occurs beforehand. Additionally, a polar chart system will contribute to safer operation if the risk of parametric roll can be recognized by linking with navigation equipment or weather forecasts.

## ACKNOWLEDGEMENT

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