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What is **parametric roll?**

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Ships optimized to carry large volumes of cargo, such as car carriers (PCTC) and container vessels, have achieved dramatic developments in greater efficiency, measured as fuel consumption per cargo volume and distance. While container vessels have increased significantly in overall size, car carriers' length, breadth and draught have so far been restricted by various constraints from routes and ports, with cargo volumes mainly increasing with more decks and greater height. Hereby, a 200m PCTC from 2010 can carry about 40% more cars than a 200m PCTC from 1980, with the same main dimensions.

This increase of cargo space and transport efficiency could not have been achieved without a parallel development of sophisticated hulls with very high form stability, combined with slender lines and low resistance. Similar hull forms can also be found on large passenger cruise vessels with their special requirements for volumes and heights.

These new hull forms show a significantly larger variation in stability during a wave passage compared to more traditional forms. This is not a problem per se because the average stability in waves is generally higher than in calm water. However, in certain conditions this variation might increase the risk of heavy roll or heel amplitudes.

The effect of stability variations in waves has been an expanding research area in recent decades. IMO issued its first circular, MSC/Circ.707, with 'Guidance to the Master for avoiding dangerous situations in following and quartering seas' in 1995, and after some reported incidents in head sea it was replaced in 2007 by MSC.1/Circ.1228 'Revised guidance to the Master for avoiding dangerous situations in adverse weather and sea conditions'.

The IMO circular differentiates three categories of dangerous phenomena

- surf-riding, broaching-to and reduction of initial stability in following and quartering seas
- synchronous roll
- parametric roll

Parametric roll

This is perhaps the most complicated to understand and manage by officers onboard, partly because it is very rare and partly because it may lead to a sudden heavy roll, from nowhere, in otherwise apparently calm and controllable conditions.

What is parametric roll?

Ordinary (synchronous) roll motions in waves can be described as a state of dynamic equilibrium between internal moments from inertia, damping and stability and external moments from the waves. Like all other phenomena induced by irregular seas becomes rolling a random process where the characteristics need to be described by statistical distributions.

The roll response is very sensitive to the period of excitation so that only the part of the encountering irregular wave energy spectrum that coincides with the natural period of roll will be effective. The roll amplitudes are therefore directly dependent on the wave height, length and direction of encounter, while the roll period is almost entirely governed by the initial stability GM and the radius of inertia.

Parametric roll follows the same dynamic equilibrium condition, but instead of having a large variation in the external moments, the excitation is caused by a variation in the internal restoring moment, usually expressed as a variation of GM. A common analogue is a swing in which you can start oscillating by just moving the body without touching the ground with your feet or having any external forces applied.

The stability variation is caused by the waves but there need not be any direct roll moments from waves, so parametric roll can, and will actually most likely, appear in head or following seas when there is very little direct roll excitation from waves. This makes the phenomenon almost impossible to predict using your senses or experience.

What makes parametric roll appear – and disappear?

The following three conditions are required for parametric roll to develop:

1. Large relative variation of stability, which can be caused by a combination of:

   - a hull form with large flare around the water line and large breadth/draught ratio,

   - relatively low initial stability in the loading condition,

   - waves lengths close to the ship length, (most critical at 80% L but at least in the 50-150% L range),

   - sufficiently large wave amplitudes.

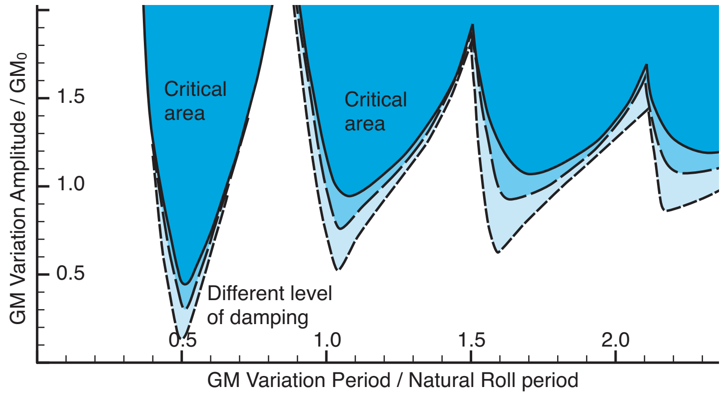

Figure 1. *Illustration of critical areas where parametric roll may appear. The diagram is based on numerical simulations in regular waves. The most critical area is where the stability variation has a period of half the roll period. Long stability variation periods approaches what is generally known as 'loss of stability'*

2. Resonance between stability variation and ship's natural period of roll requiring:
   - a wave encounter period half (or less critical, equal to) the roll period,
   - regularity in waves so that resonant periods are kept for a sufficient number of cycles,
   - a critical phase lag between rolling and stability variation
3. Low hydrodynamic roll damping, which is generally the case for most ships, but typically exaggerated by:
   - a slender hull with large bilge radius, small bilge keels and low speed.

Combined effect

The risk of a severe outcome from parametric roll is the combined effect from these three conditions; if resonance is perfect and damping low there need not be a very large variation in stability and if the variation is large, there need not be perfect resonance.

Figure 1 shows the relationship between the three prerequisites in regular waves where criticality is described as a combination of roll growth ratio and roll amplitudes.

Impossible to predict

It is quite easy to demonstrate the development of parametric roll in regular waves, both in model tests and in numerical simulations. However, for irregular seas, the development of parametric roll becomes almost chaotic in the sense that it is impossible to predict if and when a parametric excitation will actually appear. This is true for both well-controlled numerical simulations and even more in the less well-controlled reality. We can therefore only evaluate the relative risk based on the combined effect of the conditions.

The amplitudes may typically grow very quickly when parametric roll develops but in general the heavy rolling will not last for long because irregularities in wave periods and phase lag will take the ship out of resonance. A crew that is prepared for parametric roll may also enforce rapid changes in speed and course, ultimately altering conditions and stopping further resonance.

Two examples from ships in service

Figure 2 and Figure 3 show two examples of parametric roll as measured onboard ships in service. The first example in Figure 2 shows a case in a following sea with moderate waves where there was hardly any pitch or roll motions before the severe rolling appeared. The second case is from rough head sea. Both cases clearly show the perfect 2:1 resonance between the rapidly increasing roll motions and pitch motions that are directly governed by the encountering waves.

The roll starts to diminish as soon as the regularity is disturbed, either by irregularities in the wave sequence or by action onboard. Both these cases have been published and discussed more thoroughly in ref.[1].

What can be done to reduce the risk?

Following some incidents with parametric roll in early 2000, Wallenius Marine has been very active in managing the risk by developing a better understanding of the phenomenon among all stakeholders in the company, by supporting IMO in developing new functional stability criteria and by installing advanced real-time decision support systems onboard our vessels.

We constantly measure motions on all ships in service with high sampling frequency and may today, within hours, be able to analyze interesting motion sequenc-

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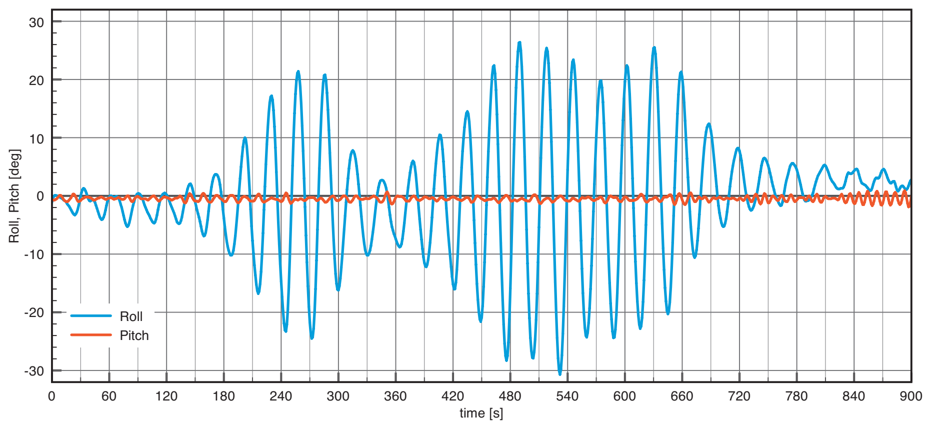

Figure 2. *Parametric roll in following sea. Speed 10 kn, GM 1.2 m, significant wave height 4.1 m, Natural period of roll 28 s, encounter wave spectrum peak period 14.3 s.*

What is **parametric roll?**

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es from our offices and respond to questions from the officers onboard. Over the past four years we have also participated in direct academic research together with KTH Royal Institute of Technology in Stockholm and Seaware with the main focus on mitigating risks from stability variation in irregular seas. This research is financially supported by the Swedish Mercantile Marine Foundation and the Swedish Maritime Administration.

Mitigating risk from parametric roll currently includes a chain of activities

- Design optimization based on extensive numerical simulations to ascertain ships' hull forms that are sufficiently robust for their intended service
- Education of all officers on stability variations in waves in general, on the specific characteristics and service experience of different generations of vessels and on decision support systems onboard
- Decision support systems including:
  - route planning and optimization based on forecasted weather conditions including, among other criteria, assessment of risk for parametric roll along the route
  - real-time assessment of the sea conditions, ref.[2] with warnings and advice on possible actions for avoiding high risk situations, see Figure 4.
- Regular procedures for following up and analyzing all events that may contribute to increased knowledge and awareness

Fewer events in the future

With these actions we aim to have very few events with parametric roll in the future and none with a severe outcome. The statistics and motion analysis from the past three years indicate that parametric roll of any significance is already at a very low rate and detected only about once per five ship years for the latest generations of ships.

It is likely that the IMO working group on intact stability will propose a similar scheme as mandatory for ships that are vulnerable to large stability variations in waves, and that this may be in force worldwide within the next five years.

For the future we also anticipate that there will be active systems developed that could interfere directly with the development of high roll amplitudes through early detection algorithms combined with compensating rudder actions. Wallenius is currently participating in testing and developing such systems, ref. [3], that would form the last link in the chain of actions for managing the risk of parametric roll.

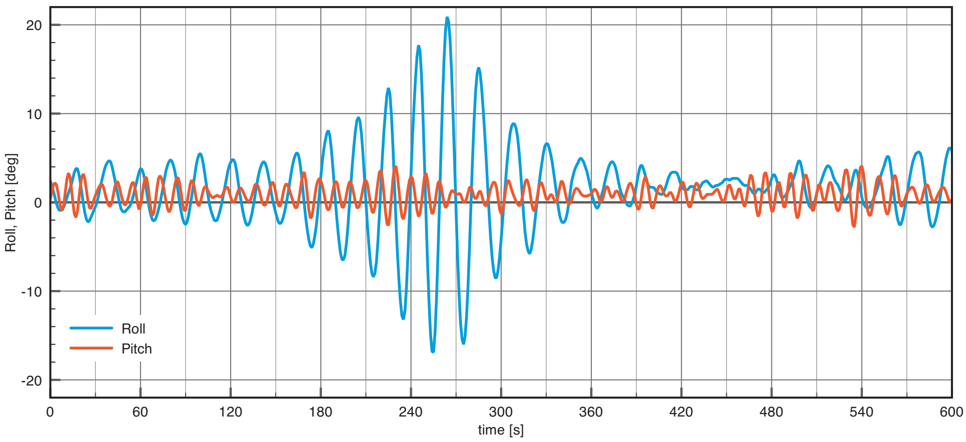

Figure 3. *Parametric roll in head sea. Speed 12 kn, GM 2.3 m, significant wave height 5-6 m, Natural period of roll 21 s, encounter wave spectrum peak period 8-11 s.*

References

[1] Rosén A, Huss M, Palmquist M, 2012. Experience from Parametric Rolling of Ships. Chapter in the book Fossen T. I. and Nijmeijer H. "Parametric Resonance in Dynamical Systems", Springer.

[2] Ovegård E, Rosén A, Palmquist M, Huss M, 2012. Operational Guidance with Respect to Pure Loss of Stability and Parametric Rolling. 11th International Conference on the Stability of Ships and Ocean Vehicles (STAB2012), Athens, Greece.

[3] Söder C-J, Rosén A, Ovegård E., Kuttenkeuler J, Huss M, 2013. Parametric Roll Mitigation Using Rudder Control, Journal of Marine Science and Technology, Vol.18, No.3, pp.395–403.

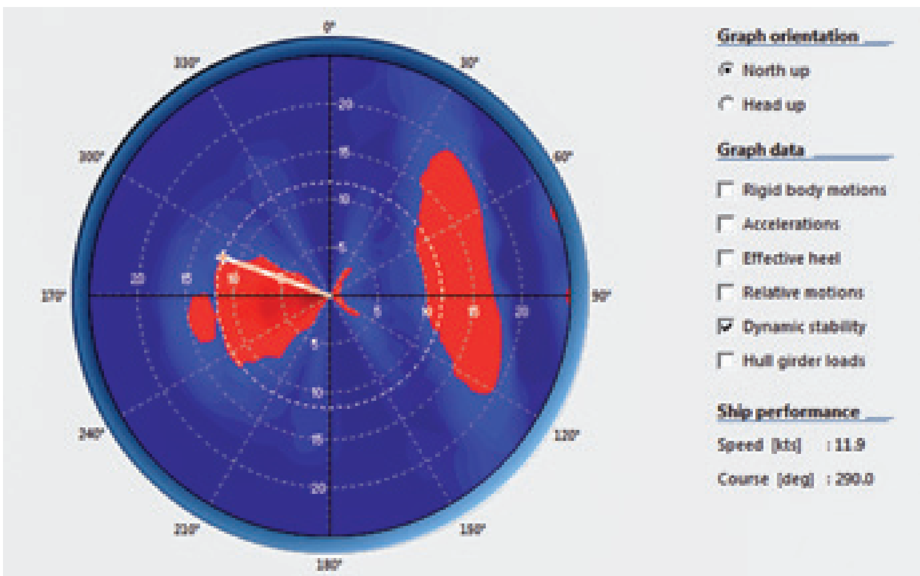

Figure 4. *Real-time operational guidance onboard. Screen dump from Seaware EnRoute Live Advice window where critical conditions relative to set criteria are highlighted in red.*

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