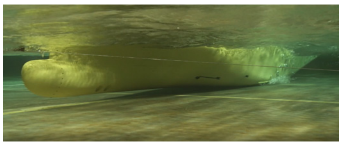
SUMMARY AND RECOMMENDATIONS

'Further Investigations into the Behaviour of Container Ships in Storms above the Wadden Islands', MARIN Summary Report 32558-1-DIR, September 2020.

In the evening and night of January 1 to 2 of 2019, the Ultra Large Container Ship (ULCS) MSC ZOE lost 342 containers north of the Wadden Islands while sailing along the Terschelling-German Bight Traffic Separation Scheme (TSS) to Bremerhaven in north-westerly storm conditions. This resulted in large-scale pollution of the sea and Wadden Islands. As part of its investigations with the Dutch Safety Board (OVV), MARIN concluded that the most probable explanations for the loss of containers are:

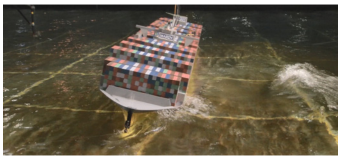
<u>1. Extreme (wave-frequency) ship motions and accelerations</u>
Resonance can occur because the short natural roll periods of wide and stable container ships come close to the wave periods above the Wadden Islands. Large roll angles give large loads on the containers.

<u>2. Ship contact with the sea bottom</u>
The ship does not only roll, but also makes vertical heave motions at the same time. Due to these combined motions, the ship can touch the seabed in shallow water. Bottom contact gives vibrations in the ship and cargo.



<u>3. Impulsive loading on containers due to green water</u>
'Green water' is massive sea water that can hit the containers in high waves. The containers themselves can be damaged as a result, but green water can also push over full stacks of containers like dominos.

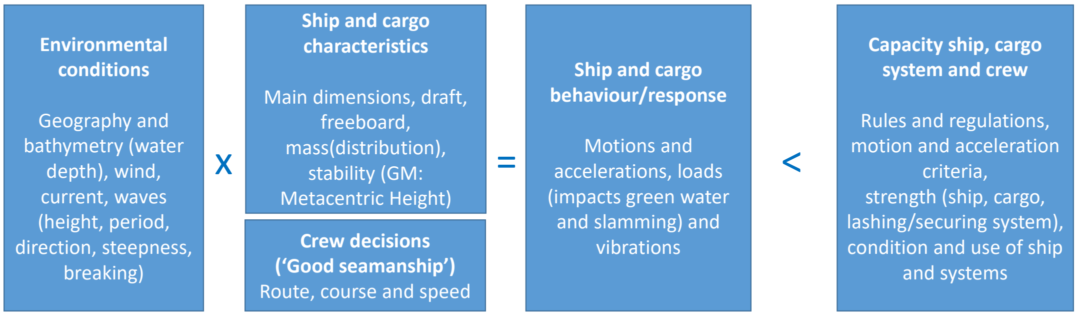
<u>4. Slamming-induced impulsive loading on the hull</u>
Breaking waves again the hull can result in vibrations in the whole ship and cargo. These vibrations can damage the lashing of the containers.



To prevent future loss of containers close to this Particularly Sensitive Sea Area (PSSA), the Ministry of Infrastructure and Water Management asked MARIN to investigate also other container ship types: beside Ultra Large Container Ships as the MSC ZOE (ULCS, typical length 379 m, beam 59 m), a shorter and narrower Panamax (typical length 279 m, beam 32 m) and a smaller container Feeder (typical length 163 m, beam 27 m). The importance of testing smaller ships was underscored when the feeder 'Rauma' lost 7 containers on February 11th 2020 in a significant wave height of approximately 4.5 to 5m.

The three tested containerships at scale 1:63 in the MARIN Offshore Basin

Containership behaviour in storm conditions is a result of the interaction between the environmental conditions and the characteristics of the ship with its cargo. The ship response can be influenced by the decisions of the crew with respect to route, course and speed ('Good seamanship'). A ship and its cargo are safe when their behaviour and loads are below the capacity (safe values) of the design. Damage can occur and containers can be lost when the loads on the ship and cargo exceeds the (structural) capacity of the cargo and/or its securing equipment:



In this step in the follow-up study for the Ministry of Infrastructure and Water Management, MARIN investigated based on model tests, calculations and literature research how three containership types behave in the complex conditions above the Wadden in the shallow southern route directly above the Wadden Islands and the deeper northern route and what this means for the loss of containers.

Based on the results of the present investigations (and the assumptions as summarized in the table and in sections 6.2 and 6.6) MARIN derived **preliminary limiting wave heights** for these ship types and routes. For the accelerations and bottom contact[1], all wave directions and occurring wave periods are considered. The limitations in wave height mainly occur with waves perpendicular to the route, or beam to the sailing direction (+/- 20 to 30 degrees) as the occurring phenomena are typically the strongest at these headings.

With wave heights above these preliminary limiting wave heights, the loading on the ships and their cargoes can exceed their capacity (safe values). The bold criteria are the governing limiting phenomena per ship type and route[2]:

Route	**FEEDER** Assumptions: GM=0.8 to 1.5m 0 to 8 knots 9.20 m draft Freeboard 3.0 m	**PANAMAX** Assumptions: GM=1.0 to 2.5m 0 to 10 knots 12.20 m draft Freeboard 9.2 m	**ULCS** Assumptions: GM=6.0 to 9.25m 0 to 10 knots 12.40 m draft Freeboard 17.9 m
Northern route (37.5m water depth)	Hs > 7.5 m (accelerations) Hs > 7.5 m (bottom contact) **Hs ≈ 3.3 m (green water)**	Hs ≈ 6.5 m (accelerations) Hs > 7.5 m (bottom contact) **Hs ≈ 5.7 m (green water)**	**Hs ≈ 6 m (accelerations)** Hs > 7.5 m (bottom contact) Hs ≈ 7.4 m (green water)
Southern route	Hs > 6.5 m (accelerations)	Hs ≈ 5.5 m (accelerations) **Hs ≈ 4.5 m (bottom contact)** Hs ≈ 4.8 m (green water)	Hs ≈ 6 m (accelerations) **Hs ≈ 4.5 m (bottom contact)** Hs ≈ 5.9 m (green water)

[1] *For the complex problem of green water only beam waves could be investigated at this stage.*
[2] *For the limiting wave height for bottom contact the wave height is used at which the minimum dynamic UKC of 2 metres is reached, for the accelerations the lowest acceleration criteria of the 4 class societies is used and for green water the wave height at which the relative wave motions can reach the lowest container on the deck (threshold = freeboard+2.5m). In all cases the Most Probable Maximum (MPM) in a 3 hours storm is used.*

(21.3m water depth)	Hs ≈ 5.5m (bottom contact)[3] **Hs ≈ 3.4 m (green water)**		

Preliminary limiting wave heights for the three ship types and southern and northern routes.

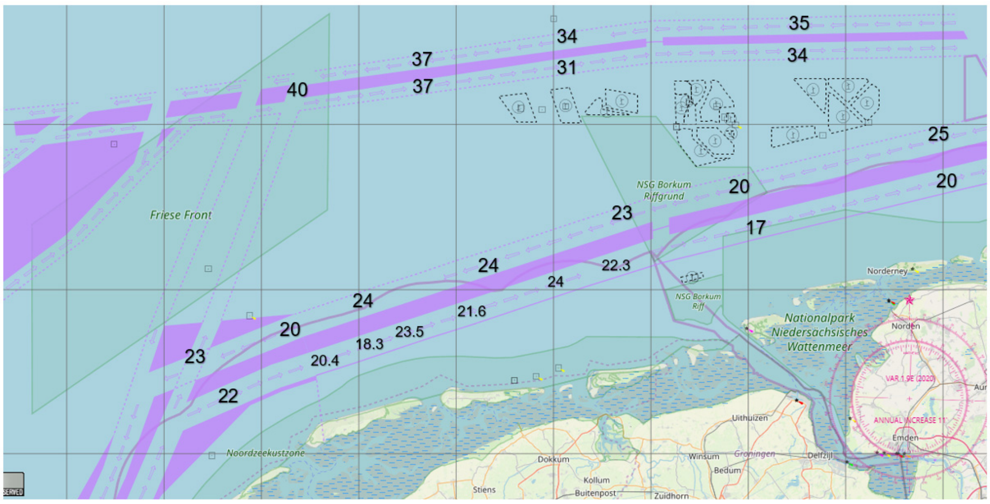
In general the limiting wave heights in the shallow southern route are lower than in the northern deeper route: the risk of losing containers in the shallow southern route is higher than the deeper northern route.

However, also for the northern route limitations MARIN has derived preliminary limiting wave heights to prevent loss of containers. These limitations occur in beam seas relative to the route or ship heading.

Recommendations

These **preliminary limiting wave heights** for these three containership types are important to reduce the risk of container loss significantly. We recommend to use these wave heights and other findings in this report for the decision making about the use of the routes above the Wadden Islands and the advice of the Coast Guard to ships sailing in the area.

Large roll motions and green water are, as mentioned, generally the strongest with waves perpendicular to the route, or beam to the sailing direction. When this type of behaviour occurs, sailing with low speed head into the waves is wise as part of good seamanship.



The Northerly and Southerly routes with water depth (chart datum LAT: Lowest Astronomical Tide).

To determine the **final limiting wave heights** to prevent container loss above the Wadden Islands, a long term (statistical) risk analysis is recommended. As indicated in the Figure at the beginning of this Chapter, it is important to consider in this analysis (the long term distribution of) the environmental conditions, the ship and cargo characteristics and the crew decisions (such as the course relative to the waves). The aspects that are recommend for this risk analysis are given in this report (section 6.6). The determination of the final limiting wave heights requires the definition

[3] *Possible bottom contact (minimum dynamic Under Keel Clearance < 2 m) is predicted for the Feeder for this wave height only in head waves and a speed of 8 knots. At a lower speed of 4 knots (more realistic in these conditions), the limiting wave height increases to 6.5 m.*

of an acceptable risk level for losing containers close to this Particularly Sensitive Sea Area (PSSA) by the government.

It is also recommended to further investigate the complex problem of water loading on the containers, especially for smaller ships such as Feeders with their low freeboard. Green water loading is the limiting factor for this type of ship on both routes. The (statistics of the) the complex non-linear relative wave motions and impacts loads and response of (stacks of) containers need further study to determine the risk level and limiting wave heights more accurately. Also the freeboard height plays an important role in this. We recommend to consider, beside beam waves, also head and bow quartering waves in this investigation. Changing heading with the bow into the waves at slow speed seems a logical decision with large roll motions and green water in beam waves. However, it is important to investigate whether in head or bow quartering waves green water can also hit the containers from the side or over the bow.
As part of this investigation we also recommended to further consider parametric rolling in head waves[4]. Parametric rolling in head waves might occur for unfavorable combinations of wave length, wave period and natural roll period. It should be prevented that the decision to head into the waves, results in large motions due to parametric rolling. Although an extra set of tests on this topic did not show parametric rolling with the present small Feeder model, further tests are recommend to make sure this problem does not occur (or can be prevented by clear instructions to the crews).
Finally it is recommended to investigate crew response to this type of situations: how do they react (from the perspective of good seamanship) when large roll motions and green water on the deck occurs?

The results presented in this report and the preliminary limiting wave heights make concrete the subjects that are mentioned in the IMO Intact Stability code[5]. As shown in Chapter 5 and the supporting report[6], the determination of **final limiting wave heights** requires a more transparent and consistent input on the acceptable acceleration levels from international organizations such as IMO and the class societies[7].

- Container vessel dimensions have increased substantially over past few decades. Limited experience and statistics are available to account for this steep rise in ship dimensions, developments with weather-routed navigation, extreme GM ranges of recent ship designs, and weather dependent reductions on acceleration levels that have become commonly accepted over the past 10 years. Rule values used in lashing calculations may be different from motions that are acceptable in practice. It is important to increase knowledge about extent and probabilistic of loads acting on containers on board modern ultra large container ships.

- The large variations between class rule values for extreme accelerations and motions in lashing design calculation, as shown in Chapter 5, illustrate the differences and uncertainties in various extreme motion prediction load case models. So the fidelity of the probability of exceedance of the design points in the rules is not transparent and cannot be easily verified. It is also unclear how flag state authorities maintain control over the standards that are imposed on the industry in their name.

- Good seamanship is essential to keep actual loads on cargo inside the limitations of the securing arrangements. However, there is at present no mandatory equipment on board to

[4] *Parametric rolling is also considered in the IMO 2nd generation intact stability criteria, but these do not consider explicitly the situation of high (breaking) waves in shallow water.*
[5] *See sections 3.7.5, 5.1.6 and 5.3.6 of Resolution MSC.267(85), adopted on 4 December 2008.*
[6] *MARIN Report 32558-5-PaS: 'Container securing, Overview current practice & regulatory framework'.*
[7] *Zoals SOLAS Chapter VI, de IMO 'Code of Safe Practice for Cargo Stowage and Securing' (CSS Code) en de 'class guidelines' voor 'container securing' van de verschillende classificatiemaatschappijen.*

measure actual ship motions and accelerations. So ship crews do not always have means to relate actual vessel response to design points that are used in the lashing calculations. Also, the crew often doesn't know the rule design values that were used in lashing calculations. It is therefore recommended to support the crews of containership in a better way with the decision processes on board, so that they can recognize developing problems during operations and react.

We therefore recommend the government of The Netherlands to ask international attention for these important aspects based on the findings summarized in Chapter 5 and the supporting report.

Finally it is recommend to extend the investigations in the risk of losing containers along the Dutch cost to other areas of the North Sea, that also can show the combination of shallow water with high waves in some storm conditions.

Ultra Large Container Ship (ULCS) 'MSC ZOE' on 2 January 2019 (left) and the Feeder 'Rauma' on 11 February 2020 (right), source NL Coast Guard.