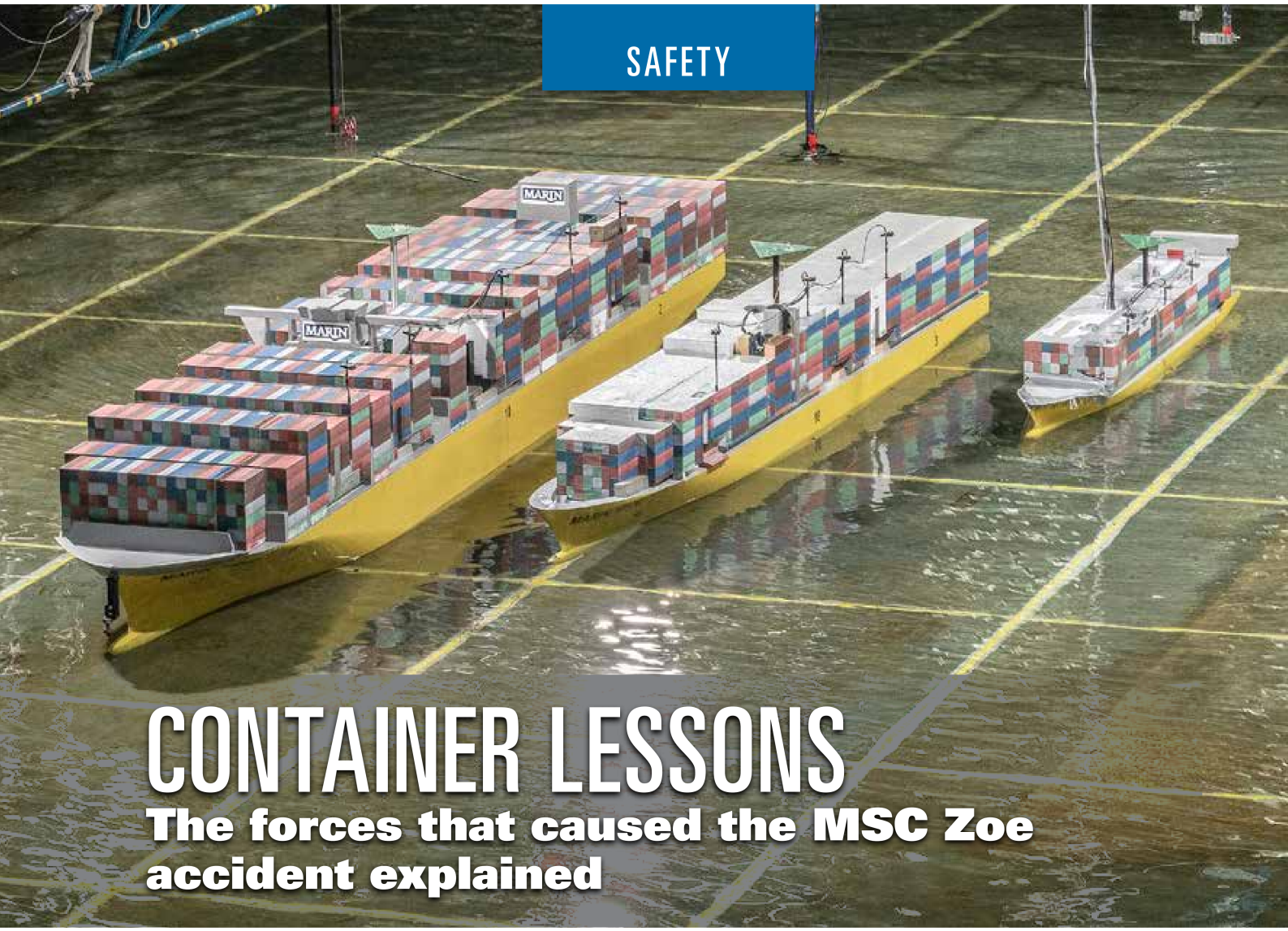


CONTAINER LESSONS

The forces that caused the MSC Zoe accident explained

In the night of January 1 2019, the large container vessel MSC Zoe sailed the southern shipping route above the Wadden Islands into a northwesterly storm. The ship lost 345 containers, which led to big scale pollution of the sea and Wadden Islands. The subsequent safety investigation was to answer two central questions: What could have caused the loss of the containers above the Wadden Islands and how can we prevent this in the future?

The Dutch Safety Board (DSB) took part in this international safety investigation. Deltares Research Institute and the Maritime Research Institute Netherlands (MARIN) were asked to assist. This is an analysis and interpretation by the author of the reports that were subsequently published. The MSC Zoe is a ship of the Mediterranean Shipping Company (MSC) and became the largest container vessel in the world in 2015, together with its sister ships MSC Oscar, MSC Oliver en MSC Maya. The ship's dimensions are L x B x T = 395.5 x 59 x 16 metres, it has a capacity of 19,224 containers and sails under the Panamese flag.

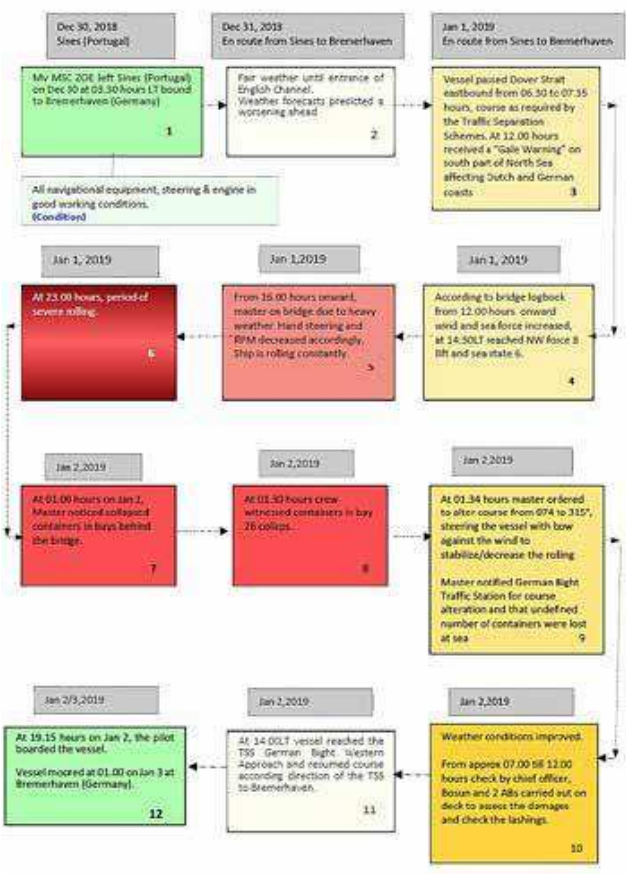
The journey of the MSC Zoe

According to the international joint investigation report, on the way from Sines, Portugal, to Bremerhaven, Germany, the ship entered a northwesterly storm in the German Bight above the Wadden Islands. This caused periods of severe rolling of the ship, which the crew experienced as rolling angles of twenty to thirty degrees. In darkness and bad weather conditions, the crew noticed that some containers were not in the right position and outside inspections showed containers hanging overboard. They estimated a loss of thirty containers, which was directly reported to German Bight Traffic Station.

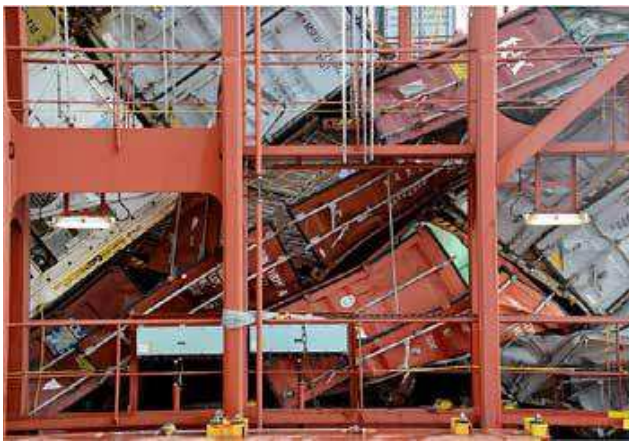
Damage caused by the accident

When the day broke, the crew started to gain a clearer picture of the situation on deck and saw that more containers were missing, including two of the three containers with hazardous substances. The crew also found various loose parts of the lashings, including the tensioners from the lashing rods, hooks and locking pins, and twistlocks that were broken in two. When MSC Zoe was moored at Bremerhaven, a detailed picture of the damage showed that 345 containers were lost. Another 450 were damaged.

Photo: Scale models of a large container ship, panamax and feeder in MARIN's test basin.

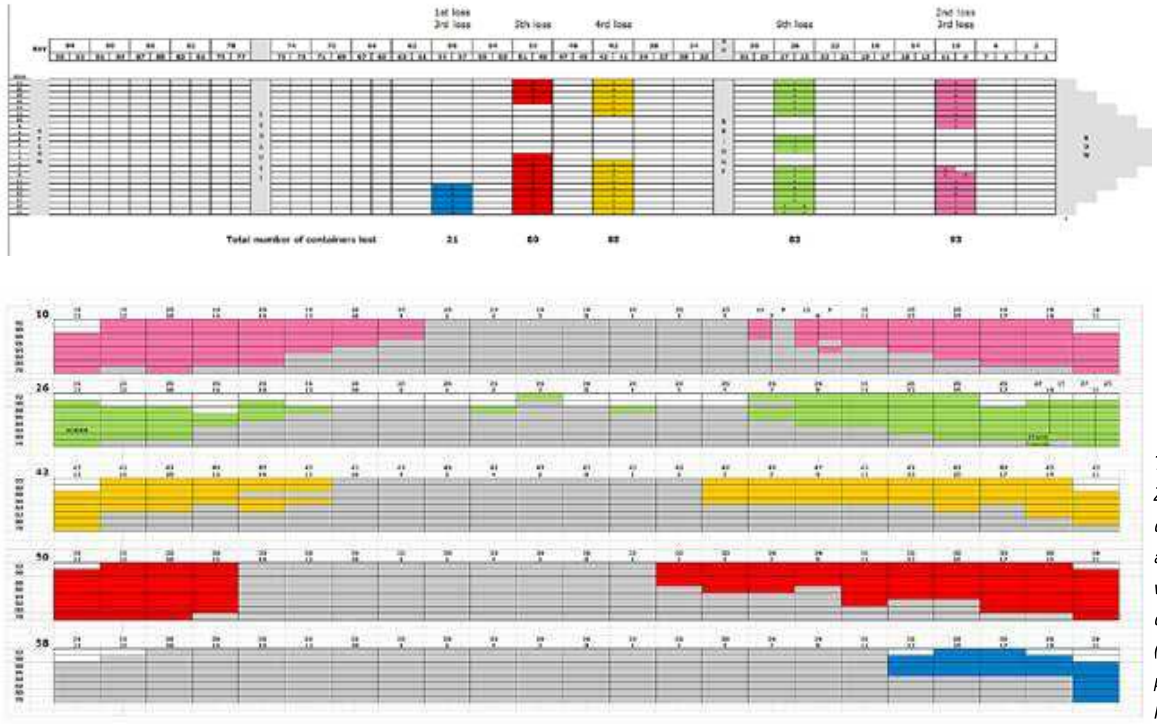


Sequence of events.

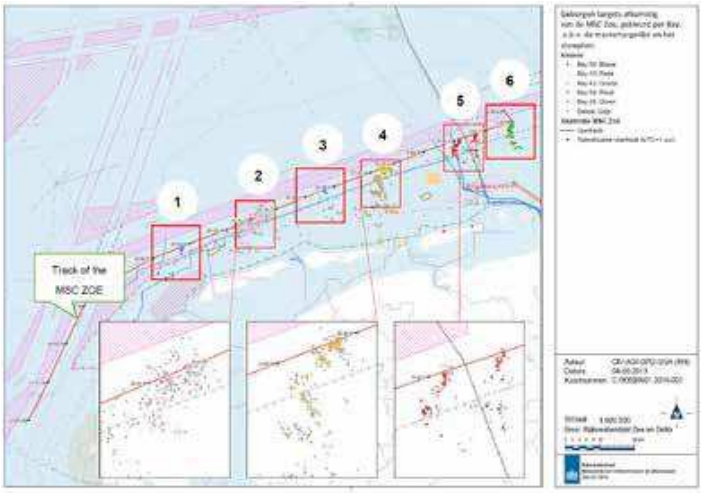


Crushed containers on board MSC Zoe (source DSB).

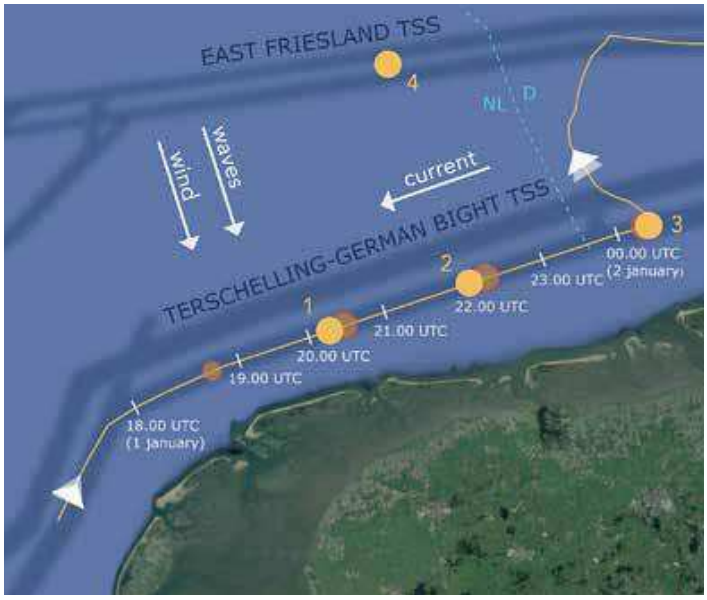
Because the ship lost hundreds of containers, some of them with dangerous goods, plastics and consumables, there was fear of serious damage to the marine environment. Some of the containers washed ashore at the Wadden Islands Vlieland, Terschelling, Ameland and Schiermonnikoog. Others were salvaged from the sea floor or were found floating. Some are still not found and contained dangerous goods. The dangerous goods, plastics and microplastics can end up in the ecosystem, which was of great concern to the Dutch and German government and society. There were at least six moments at which the MSC Zoe lost containers, which can be seen as independent events that may have a different (combination of) cause(s).



Top view of the MSC Zoe with lost containers per bay and cross section view of lost containers per bay (both based on data provided by Rijkswaterstaat).



Locations where containers were lost.



The four reference locations (yellow dots) on the shipping routes above the Wadden Islands for the research by Deltares and MARIN. The red dots indicate a number of suspected locations where containers were lost from the MSC Zoe. The indicated time is the Coordinated Universal Time (UTC; local time = UTC + 1 hour) (source MARIN).

Image of the ship model at the moment of occurrence of a wave impact against the bow and a breaking wave close to the ship (source MARIN).

Investigation of four reference locations

To determine the meteorological and wave conditions along the sailing route of MSC Zoe and the effect of these conditions on such ultra large container ships, the DSB asked Deltares Research Institute and the MARIN to assist. The DSB selected four locations for further investigation, which were discussed in its investigation report. These are three locations on the route of MSC Zoe where the water is shallow, where containers were salvaged and/or where the analysis of the Voyage Data Recorder (VDR) showed violent rolling of the ship. The fourth location for analysis is a reference position on the northern route.

For these four locations, Deltares determined the environmental maritime and meteorological or "Metocean" conditions, like wind, waves, current and water depth. These were identified by calculations, validations with data of weather buoys and historical data of the conditions on the track. The conditions on these locations are characterised by waves with a significant height of 5 to 6.5 metres, a peak period of eleven to thirteen seconds and occasionally creating waves of 11 metres high. The waves propagated from the northwest, perpendicular to the southern shipping route and had time to build up in height and peak until they reached the Wadden coast. This situation is not rare and occurs once or twice every year on the North Sea and above the Wadden Islands. Current and water level were normal.

> This situation is not rare and occurs once or twice a year on the North Sea and above the Wadden Islands

MARIN says in its report it conducted several tests in its Offshore Basin in these conditions for the four reference locations with a model of a reference container vessel at scale 1:63. Next to these conditions, MARIN also examined deep water conditions and conditions with higher waves. The research institute came to the conclusion that four phenomena played a role in the MSC Zoe accident.

Four encountered phenomena

1. *Extreme ship motions and accelerations:* During the tests, roll motions were measured of fifteen to twenty degrees amplitude, combined with sway motions. The large beam of the ship and a high GM result in a high stability and a short roll period of the ship that comes close to the wave periods in the storm. The ship's rolling leads to high transverse and vertical accelerations at several container locations of up to 4.8 m/s^2, the largest magnitudes are close to the design limits for cargo of 5 to 6 m/s^2 for a twenty-year lifetime, as mentioned in the Cargo Securing Manual of the ship. Higher accelerations where observed in the long waves in shallow water depth. Transverse accelerations

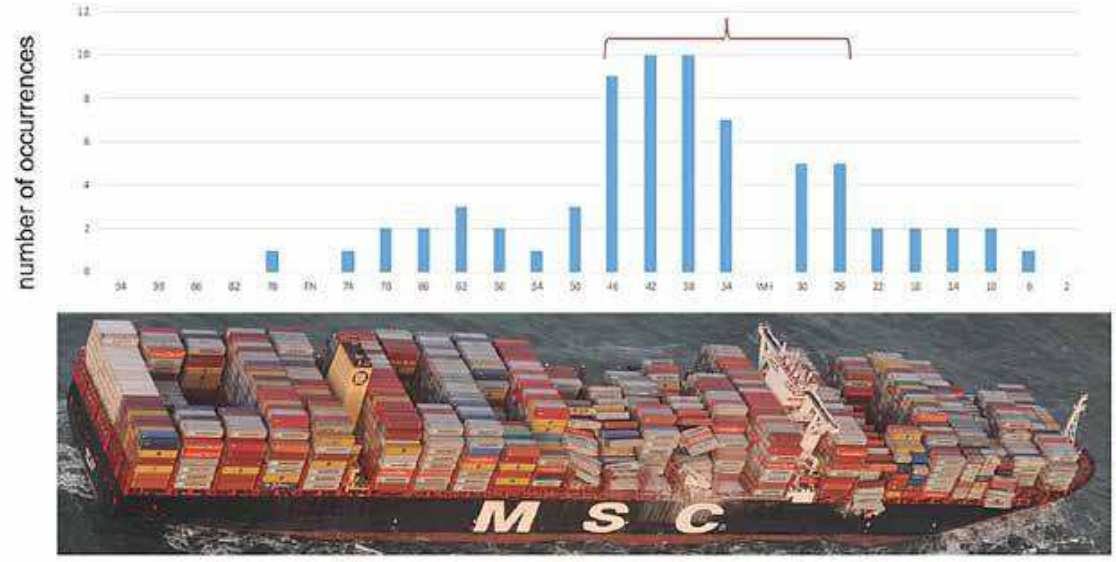
are found to be substantially higher than the vertical accelerations and increase with the height of the containers on deck.

2. *Ship contact with the sea bottom:* A combination of roll and heave motions of the ship in shallow water can lead to contact of the ship's keel in the bilge area on the windward side with the sea floor. During the tests, contact with the basin floor was observed at a water depth of 21.3 metres, with a draught of 12.3 and an under keel clearance in calm water of 9 metres. This contact can lead to high vibrations and accelerations throughout the ship, containers and their lashings.
3. *Green water:* The shallow water beam waves during the storm can have a high horizontal velocity and can be close to breaking. When these waves hit the ship in shallow water, the wave energy cannot flow underneath the ship and finds its way up the side, resulting in a water jet of substantial velocity that may reach the main deck (eighteen metres above the waterline!), where the containers are located. This pulse of green water can hit the underside of the lowest row of containers, as well as the side of the containers at higher levels and can cause damage to both containers and their lashings. When one container is damaged or its lashings fail, a complete stack of containers can collapse and even a domino effect can occur that can push over a complete row. The tests of MARIN showed that the cargo area around the wheelhouse, from approximately four container bays behind to two container bays in front, was most exposed to green water. This is also the area where most of the containers of the MSC Zoe were damaged or lost. Although no green water load measurements have been taken in the tests, this suggests that green water can play an important role in the loss of containers in the tested conditions.
4. Slamming: The short (breaking) waves along the Dutch coast in the tested conditions resulted in wave-induced slamming against the side of the ship, particularly in wave heights of 6.5 metres and above. This slamming can result in vibrations of the ship hull, container movement and extreme loads on their lashings, which can cause them to fail. The large wave impacts on the ship's side ocurred approximately twice as often as the green water events in the three hours of exposure during the tests. In deeper water slamming was also observed, but the frequency of slamming reduces with increased water depth.

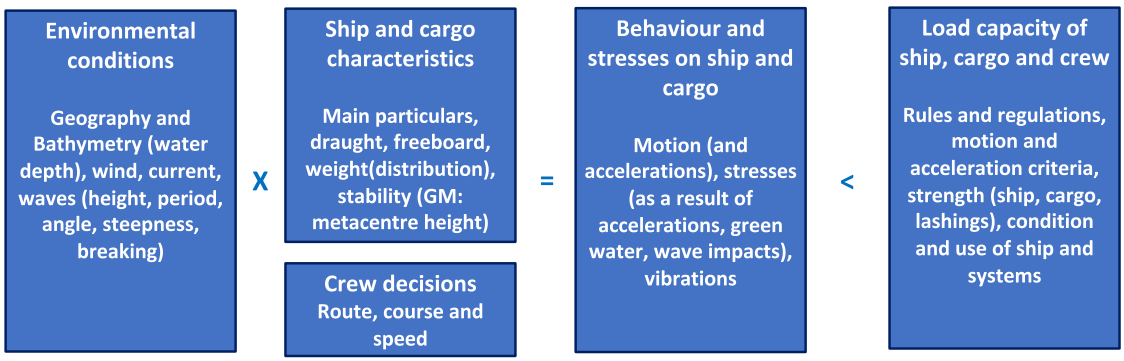
A big container ship that sails under these conditions on this route, encounters a combination of these phenomena. The resulting forces on the ship, containers and lashings are a complex puzzle, also because of the overall bending and torsion reactions of the ship, depending on its stiffness.

Sailing a safer route?

On both the northern and southern shipping route there is a risk of losing containers, which can lead to pollution of the vulnerable environment of the Wadden Islands, concludes the DSB in its report. Even though the northern route is deeper, the wave conditions and resulting forces on the ship and its cargo are the same. Slamming and green water occur on both routes, but more often on the southern route. Because of the extra metres of water depth, contact of the ship hull with the sea bed is unlikely on the northern route. On this route, it is easier to choose a safer direction in a northwesterly storm, because of the availability of manoeuvring space in more open water. From this perspective, the risk of losing containers on this route is somewhat smaller, but it is not a completely safe route. In other conditions, the southern route may even be safer. There are no specific regulations or guidelines for choosing either the northern or the southern route on this part of the North Sea. Because the southern route is shorter, economic factors like saving time and fuel play a big role. The northern route takes two hours extra to get to Bremerhaven. The crews act in good seamanship and make choices to ensure a safe trip. In the case that they encounter extreme conditions, they have to deal with the risks of container loss and take ac-



Green water observations along the ship's length.



Balancing the stresses on and in the ship (source MARIN).

tions like changing their course or sailing route. This situation can be vulnerable because the crew have to base their decisions on little information of the sea conditions they are in. Data of forces on containers and their lashings and characteristics of the present sea state, like wave periods and direction, can be of essential importance in estimating the risks of extreme rolling of the ship. As neither the Dutch Ministry has a warning system in place nor the IMO an adequate ruling on the inherent cargo safe vessel design, containers keep falling overboard. Only now does the Dutch Coast Guard warn ships of the risk of contact with the seabed on the Southern route.

DSB recommendations

When several parties take their responsibilities and cooperate to improve safe passage of the Wadden Islands, protection of the vulnerable environment, ship, crew and cargo can be secured. The DSB report asks for revision of the technical requirements for container ships in regulations and rules: design requirements of containers and lashings, loading and stability requirements, installation of instrumentation that provides insight into rolling and swaying movements of the ship and possibilities of technology that can detect container loss.

The Dutch and German government are advised to ascertain whether the existing TSS of the German Bight Traffic Separation Schemes north of the Wadden Sea have to be adapted, or measures have to be taken particularly for large container ships to guarantee the safety of the voyage on these sailing routes, also because the Wadden Sea is a Particularly Sensitive Sea Area (PSSA). The Dutch Coast Guard should be given the job, mandate and resources to assist container ships in a safe passage on this route.

Ship owner MSC is advised to raise awareness and develop guidelines for the masters and navigational officers on sailing with a vessel with a high stability and on the hydrodynamic phenomena that may be encountered on the sailing routes north of the Wadden Sea. Handling these big ships asks for a different quality of work and the crew have to be trained for that. Shipping companies are also advised to either reduce high acceleration forces in the operation of their ships or properly specify the vessel design requirements.

The World Shipping Council, the International Chamber of Shipping, the Dutch government and organisations like Nederland Maritiem Land and the Royal Association of Netherlands Shipowners (KVNR) are advised to communicate actively the lessons from this investigation. They are to propagate industry standards that will increase the safety of container transport and start an initiative for further innovations in ship design and cargo securing.

Year	Number of occurrences	Number of containers lost	Details
2012	0	0	
2013	1	2	• Container ship (333m); 10-2013 / 2 containers (empty) / off Terschelling / wind force 9 SW
2014	2	13	• Container ship (100m); 11-2014 / 3 containers / off Umuiden / wind force 8 SSW • Container ship (214m); 10-2014 / 10 containers / off Terschelling / wind force 9 NW
2015	1	2	• Container ship (150m); 12-2015 / 2 containers (empty) / off Rotterdam / wind force 8 SW
2016	0	0	
2017	4	43	• Container ship (139m); 12-2017 / 25 containers / off Terschelling / wind force 5 NW • Container ship (203m); 10-2017 / 1 container / off Texel / wind force 8 NW • Container ship 8-2017 / 2 containers (empty) / off Rotterdam / wind force 8 SE • Container ship 1-2017 / 15 containers / off Texel / wind force 7 WNW
2018	2	4	• Container ship (237m); 2-2018 / 3 containers / 15NM W of Texel/wind force 7 W • Container ship (294m); 1-2018 / 1 container (empty) / S North Sea / wind force 10 W

Number of registered shipping accidents (ESO, serious shipping accidents) on the North Sea involving the loss of containers (source Rijkswaterstaat, SOS database).

Have we reached the limit of growth?

The international joint investigation report also points out that due to an increase in world trade, the capacity of container ships doubled over the past fifteen years. Where in 2005 a ship with a capacity of 10,000 containers was called an ultra large container ship (ULCS), recent ships can carry over 20,000 containers. The vessels have grown in size, for example length and beam, but also in stack height. This resulted in container ships carrying more containers on deck.

The growth of container ships leads not only to practical limits, like exceeding harbour limitations, but also leads to limits in structural design as high stresses are caused by the impact of waves on such a big open structure. This can lead to high accelerations in different locations and directions on the hull and the cargo. The ships get so big that they transcend the human size and become too big for the

Container ship growth (source Safety & Shipping Review 2019, Allianz).

crew to have a "feeling" with the ship and its performance at sea. All these described problems lead to an accumulation of risks and insurance costs.

Container loss on smaller ships and in different conditions

Not only big ships lose containers. The described phenomena apply to smaller ships too, but their sensitivity is different. To prevent similar accidents in the future, all ship types and sizes that pass this route have to be evaluated. Analysis of other accidents with containers can lead to important lessons and evaluation of risks.
In the wake of the accident investigation of the MSC Zoe, MARIN is also performing tests with smaller ships: a Panamax vessel of nearly 300 metres long and a feeder of over 160 metres. This appeared to be a relevant step, because on 11 February of this year, the feeder OOCL Rauma lost seven containers above the Wadden Islands.
The evaluation of the four phenomena have led to the conclusion that the behaviour and impact of these conditions on the ship and cargo are a result of the geographic and meteorological conditions multiplied by the characteristics of the ship and crew choices. These combined conditions have to stay within the limits of load capacity of ship, cargo and crew. Rules and regulations have to be a suitable guide for this.

Do we accept airplanes losing cargo?

Bigger transport systems ask shipping companies to innovate in design, regulations and training crew to handle these ships. The Dutch government also has to take its responsibility to aim for zero tolerance for losing cargo in their waters. Do we accept airplanes losing cargo?
As soon as the results of these tests are available, MARIN will publish them in SWZ|Maritime, together with more detailed information on the tests with the reference vessel of MSC Zoe.

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