The number of major container losses at sea is on the rise; recent events in particular demonstrate this with frightening clarity. Spectacular pictures of containers floating in the sea and container ships with visible gaps in the container stacks have recently been featured repeatedly in media coverage. The financial losses resulting from such events are enormous. In addition to the damage to the container itself, in most cases, the cargo cannot be recovered. Furthermore, there are the costs of recovery operations, delays, etc. The long-term environmental damage caused by the container or the cargo is generally not taken into account, at least when these incidents take place in international waters.

No mention is made of the circumstances and consequences, not only in media coverage, but also in discussions among the experts. The transportation industry also tries to diminish the extent of the problem by stating that the number of containers actually lost is small compared to the container volume transported. In this respect, there is no consideration of what has been learned from the incidents which have occurred in the past years and how such incidents can be avoided in the future.

This article aims to shed some light on the known causes of container losses at sea and to initiate a discussion with the aim of understanding and improving the situation.

When researching the causes of container losses at sea that do not occur as a result of collisions, it is noticeable that severe weather conditions are often given as the reason. In fact, however, at least some of the losses occurred in weather conditions that do not actually fall into the category of severe weather. A recent case exemplifies the aforementioned proposition: wind speed 6 bft, wave height 5 m-6 m. Such wind speeds and wave heights usually encountered at sea are not to be classified as "severe weather conditions" for a 400 m long and 60 m wide container vessel.

In this respect, other causes seem to contribute to the losses, and the following questions arise:

Are the previous assumptions, calculation models and methods of securing the containers sufficient? Do situations occur in practice that are not covered by theory? Are the small crews too often left alone with the issues in the face of high economic and organisational pressure? How much of the responsibility lies with the shipping companies, who urge their employed captains to maintain the schedules, sometimes contrary to sound nautical judgement?

This article will try to answer these questions in a deliberately basic manner, not in order to simplify the problems, but in the interest of presenting the facts as clearly as possible.

1. Why are there no international regulations for securing containers on board container ships that are based on state-of-the-art technology?

As can be seen, for example, from the investigation report (publicly available) into the *MSC Zoe* case, the cargo-securing measures must comply with the IMO Code of Safe Practice for Cargo Stowage and Securing (CSS Code), edition 2011.

The chapters of the CSS Code describing the fundamentals state that a vessel must be equipped in such a way that the cargo can be safely stowed and secured in order to weather all conditions which may be encountered during the voyage (Chapter 3 - Standardised Stowage and Securing System). (The author refers back to this point in Question 6).

In the further chapters in the CSS Code, it is stated that the Captain is responsible for the proper securing of the cargo. The methods in Annex 13 are provided as tools to perform the necessary calculations.

Annex 13 clearly states that these methods are based on a vessel of 100 m in length. Corrective methods are provided for vessels of other sizes. However, it is also stated that a correction formula can be applied only to vessels of up to 300 m in length.

The fact that there are no adequate regulations presented in the 2011 CSS Code (the most up-to-date edition) is incomprehensible, especially when one considers that, for example, a large Danish shipping line had the first 400 m container vessel constructed as early as 2006, accompanied by considerable media attention.

2. **Are cargo securing manuals or calculation programmes of the classification societies based on data that is not in line with current practice?**

Using the example of the *MSC Zoe*, the published accident investigation report states that the calculations of the cargo securing calculator, based on the vessel's cargo securing manual, assume a GM ≤ 2.08 m.

When requesting the vessel's command during loading operations to advise the vessel's GM at the port of departure or the GM to be expected on long voyages (the long overseas routes), figures of between 6 m and 10 m will often be given. In some cases, the figures will be even higher. In the case of the *MSC Zoe*, the GM was 10.23 m; in the case of loading operations on other large container ships, the author has been provided with GM values of up to 18.5 m.

Such discrepancies are extremely problematic! This is because the acceleration values to be expected are markedly increased by high GM values.

Only in the case of heavy-lift loading operations with qualified personnel, for example a supercargo or a heavy-lift surveyor, is there any possibility at all that such circumstances will be noticed and the cargo-securing measures adapted, if necessary, or the loading operations even aborted.

It could be argued that the vessel's command, or rather the ship planners, could plan the cargo in such a way as to take the GM of the ship into account. This objection may be justified in theory, but it does not correspond to common practice.

Ultimately, in order to increase the weight towards the top with ballast water, the vessel would need "wing tanks". However, in most cases, modern ships are not equipped with these tanks.

It would also be possible to increase the weight of the cargo towards the top. It should be noted here that one increasingly receives the impression that some planners do not understand their ships well enough!

But it is also impractical to assume that the planners are able to position the cargo anywhere on the vessel. In some ports, this would also mean additional containers which would have to be restowed, which the ports generally try to avoid in an effort to be cost-effective.

Issues that exacerbate such problems are slot charter models and, of course, container bays that are stowed according to the port of destination and generally according to the principle of "last in - first out".

Thus, it seems easier to adapt the structure, manner of loading and cargo securing to the changing circumstances than vice versa.

3. Why is there such a large discrepancy between regulatory requirements?

Looking at the CSS Code and the CTU Code, there are a number of differences when considering the same issues. A simple example of this is the different assessment of friction coefficients. Further aspects of this issue will be discussed in Section 4.3 below.

It is important to consider that the classification societies calculate the acceleration parameters on a different basis than the other parties in the international transportation industry.

It is to be noted that classification societies are neither fully commercially-independent nor non-partisan bodies. They are ultimately service-providing market participants. In order to win a contract, they have to offer both their service itself and their requirements for compliance with regulatory requirements within an attractive cost framework.

One cost factor is certainly cargo securing which must always be designed in such a way that it offers more restraining force than the expected accelerations. If lower accelerations are applied, it is possible to compensate these lower values with less cargo securing equipment. Less material on the one hand means reduced costs for purchasing of the necessary material, but above all it saves time for the shipping company. The fitting of additional cargo securing material takes more time and results in higher labour costs and port fees. If the ship acceleration values are calculated according to the methods of a classification society, the acceleration values are generally lower than if they are calculated according to the values used in the CSS Code. As a result, some shipping companies prefer to have their ships certified with a classification society whose conditions of certification match the tight pre-calculated cost framework, or, in some cases, allow other standards of equipment, whereas others use other methods of calculation as a basis.

The definition of the regulatory requirements themselves provides the incentive for such deviations:

The (not perfect, but nevertheless helpful) CSS Code has thus far always assumed a calculated worst case scenario. This does not result in an excessive level of safety, but at least one that covers a wide range of margins.

The analysis method propagated by some parties in this business sector is based on measured ship values or computer models. These, in turn, take into account a vessel’s command that always acts befitting of the circumstances, i.e., avoids sailing into a storm at all if possible, or acts completely freely in the choice of course and speed of the vessel without time constraints or deadlines.

It is obvious, which of the two approaches is advantageous for the individual parties. However, the method which is ultimately the better approach from the point of view of the overall economy, the insurance industry or environmental protection is a different matter.

4. Can calculation models cover the situations that occur in practice with sufficient accuracy?

If we look at the theoretical calculation models, we come up against a number of restrictive marginal conditions:

4.1. Vertical accelerations (common approach so far)

The CSS Code states that vertical accelerations, for example, are only to be taken into account in combination with longitudinal accelerations. (The basic transverse acceleration parameters are already designed in such a way that they take into account the corresponding vertical accelerations).

From practical experience, however, it is known that there are sometimes considerable vertical accelerations with simultaneous strong roll angles. If these are not taken into account separately and included in other considerations, they can have considerable effects.

Additional vertical accelerations reduce the stability of components at risk of tipping. At the same time, frictional forces are reduced, which in turn means that other measures against slipping have to withstand stronger forces.

4.2. Vessel speeds

Vessel speeds undoubtedly have a considerable effect on the transverse acceleration of the vessel. In the formulas of some classification societies for calculating transverse acceleration, it is therefore a marginal condition that a certain ratio of speed to length of the vessel is maintained. Some calculation methods are only comprehensible to the extent that the calculated "minimum speeds" must be regarded as obligatory rather than as a marginal condition for the applicability of the calculation methods.

However, it may be questioned as to whether the vessel will consistently steam at the stated minimum speeds later on. For example, prior to the economic crisis from 2007 to 2010, ships sailed considerably faster. In the course of and after the economic crisis, the actual speed of the vessels was considerably reduced. According to the *MSC Zoe* investigation report, the ship was travelling at a speed of between 8 kn and 10 kn at the time of the most violent movements. According to press reports (www.gcaptain.com), the *APL England* was travelling at a speed of approximately 7 kn at the time of a recent incident in which it lost containers. According to a maritime tracking service during a recent incident in the Pacific, a vessel was steaming at a speed of approximately 12 kn.

It can be seen from these two examples that international shipping no longer occurs at speeds of more than 20 knots, as was the case before 2007. It begs the question as to whether the reduction in speed ought to lead to corrections to the calculation of the transverse acceleration of the vessel.

4.3. Transverse loading and overlapping effects

In many of these cases, experts were repeatedly able to detect unhooked automatic twist locks of various systems during the subsequent investigations of the cases.

These systems are not fundamentally called into question here. Nevertheless, it is striking that it is evidently not possible for such systems which are responsible for the securing of container layers above the lashing bars to offer absolutely reliable protection against unintentional unlocking.

Looking at such systems impartially, one can see that when a container is set down or removed, a certain rotation of the container around the vertical axis is necessary.

Of course, this is not to say that specific rotational movements impact only a single container. However, when a ship is rolling in the swell, other forces are also acting which place the connection between the containers under stress.

However, the assumption that a container must be twisted slightly in order to unlock it completely is too complex. The problem for the vessel's command does not begin when the containers are completely unlocked but rather it starts when only one side, i.e., the front or the rear of the container unlocks, and such cases can occur much more easily, namely when transverse and vertical forces act simultaneously.

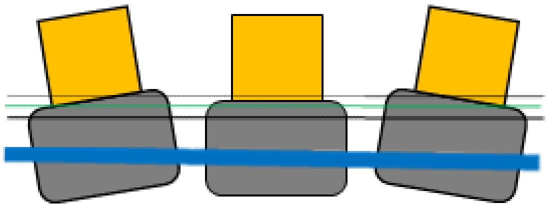
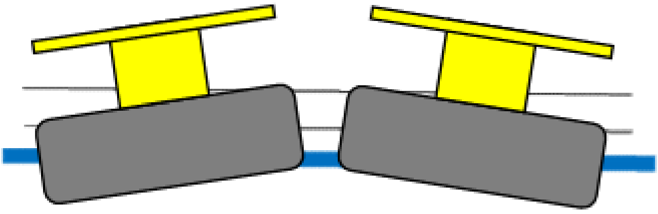
For example, quite simply, static downhill forces act transversely on the inclined side of a tilted container stack. The transversal acceleration forces are also obviously acting. At the same time, however, vertical forces may also be impacting. If we consider these forces in combination on only one end of a container, the releasing of the twist locks is not only conceivable in practice, but also measurable.

Proof for this is provided by the practical cases.

4.4. Additional vertical loads in combination with transverse accelerations

In many publications, vertical accelerations are not considered simultaneously with rolling movements. Historically, this is understandable, as the vessels had a small width and thus a vertical heave effect on the maximum width was negligible compared to the rolling movements.

However, with vessels becoming increasingly bigger, one could argue that this approach is outdated.

	As can be seen from the diagram on the left, the difference in height is not particularly large for a narrow vessel.
	With a wider vessel, however, there is sometimes a considerable difference in height

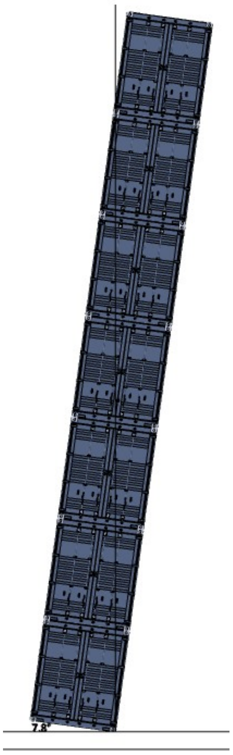
The difference in height illustrated above is now so great that it may no longer be considered insignificant or be ignored.

Actually, the above circumstances are not surprising because today's large container vessels have a width that already exceeds the length of many small vessels.

5. Are the high towers on deck which are basically standard still generally stable at all?

Overall, the development of containers stowed on deck is to be considered. Whereas in 2000 there were often only about 6 layers on deck, today there are stacks consisting of 11 container layers. In the case of the *ONE Aquila*, there were photographs in the press which showed that 7 layers were stowed above the lashing rods alone.

Considering a container stack (with 7 layers) independently of the situation on deck, one easily notices two things.



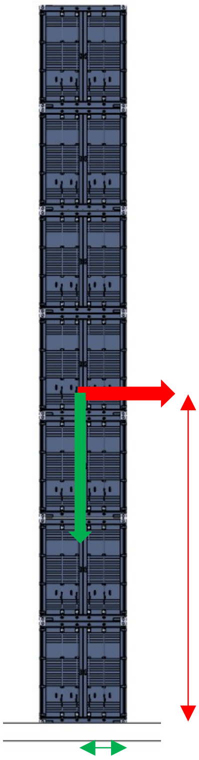
The stack shown here consists of 7 layers:

The individual containers are standard containers, i.e. no high cubes.

The centre of gravity within each container is assumed to be only 25% within each container.

This "stack" of a given height would tip over at a certain angle of inclination. In this case, that is only 7.8°.

The only securing counteracting this is the securing of the base of the stack.



Or in a second example:

An upright tower on which transverse lateral forces act would also tilt if the tilting moment is not counteracted by a sufficient retaining moment.

Tipping moment $M_T = a_x \times m \times \text{height}_{COG}$

Retaining moment $M_R = a_z \times m \times \text{half tower width}$

$M_T < M_R$

If the prevailing tipping moments exceed the effective retaining moments, then again only the securing at the base of the stack prevents the stack from tipping over.

When using a simple numerical example to calculate the forces during tilting in a curve without vertical acceleration by way of example, a very practical problem becomes clear:

The following parameters are assumed as the basis for the calculation:

$m_{Container}$ = 10 mt
Height$_{COG}$ = 7.89 m (2.43 m x 3.25; 3 standard DV containers, 8.0' high, plus a quarter container height)
Half width = 1.22 m
a_x = 0.5 x g (comparable to the accelerations whilst negotiating a curve in a truck or a train)
a_z = 1 x g (no vertical acceleration, i.e. no consideration made for wave motion)

The tipping moment M_T is calculated as follows:

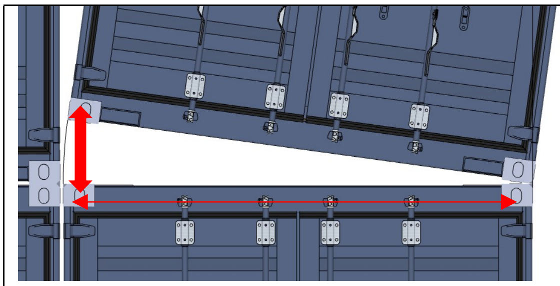
$M_T = 0.5 \times 9.81 \times 7 \times 10 \text{ mt} \times \cdot 7.89 \text{ m} = 2{,}709 \text{ kNm}$

This is compared to a retaining moment of:

$M_R = 1.0 \times 9.81 \times 7 \times 10 \text{ mt} \times 1.22 \text{ m} = 837.7 \text{ kNm}$.

Based on the above calculation there is a difference (tipping moment surplus) of 1,871.3 kNm.

What does this mean for the lowest layer of the twist locks?

	If we look at the situation at the base of a stack of 7 containers compared to other containers below, it becomes clear that the tilting motion results in the acting of a vertical pulling force on the twist locks.

In order to estimate/calculate the magnitude of this pulling force, the excess tilting moment is to be divided by the total lever arm length.

Pulling force = $(M_T - M_R) / \text{width}_{\text{STACK}} = 1{,}871.3 \text{ kNm} / 2.44 \text{ m} = 766.9 \text{ kN}$

Thus, even in such a simple example, it can be seen that there are already approximately 78 mt pulling vertically upwards on the twist locks.

Using the same principle and performing a calculation using different values, namely 12 mt per container and with an average transverse acceleration as stated in the *MSC Zoe* investigation report together with the additional vertical acceleration, this would yield the following result:

M_T = 5.665 x 7 x 12 x 7.89 m = 3,754.5 kNm

M_R = 4.2 x 7 x 12 x 1.22 m = 430.4 kNm

Pulling force = (M_T - M_S) / stack width = 3,324.1 kNm / 2.44 m = 1,362.3 kN

It is at this point, at the very latest, the following issues should be considered:

1. Even if the twist locks do not unhook due to vibration, transverse impacts or other factors, a maximum of two twist locks are counteracting the aforementioned pulling force. However, the twist locks of a well-known and certified manufacturer only have a rated tensile strength of 500 kN. This means that even allowing for two twist locks, they are still both overloaded.

2. Based on the documents of a classification society, the maximum vertical tensile strength of the corner castings is assumed as being 250 kN. Accordingly, on the basis of the above calculation, these would also be overloaded.

6. Is the use of fully-automatic twist locks sensible?

Of course, the use of fully-automatic twist locks saves time as compared to the semi-automatic twist locks which are otherwise used.

Nevertheless, the following questions arise:

Can these savings in favour of a few companies justify the losses to the affected shippers, consignees and the entire insurance sector?

Could these savings be perhaps used to mitigate the environmental damage caused? Is it at all possible to "mitigate" environmental damage?

Possible solutions would be the use of fully automatic twist locks in bays where the above-mentioned tipping problems do not occur. Or one would have to counteract the tipping problem with bridge fitting and thus, so to speak, create a large block from several individual stacks. Ultimately, it begs the question: which effort is ultimately greater?

7. What will be the developments in future international guidelines?

In December 2020, a revised version of Annex 13 in the CSS Code was published by the IMO.

Based on the new Annex 13, acceleration values are reduced by reduction factors for short voyages and/or voyages with easily foreseeable weather phenomena. This is not actually relevant, especially with regard to large container ships.

What is worse is that even the version published in 2020 still includes the restriction that certain factors can only be applied to ships up to 300 metres. One has to ask the question: How many years after the launch of the first 400 m container ship in 2006 do we have to wait until regulations are adapted to these circumstances?

In order to solve a problem, it is important to not treat the symptoms but rather to determine and address the root cause.

Accordingly, calls for "transponders" will not solve the problem. Apart from various technical difficulties and high costs, such transponders do not reduce the number of incidents. In fact, the traceability of containers can be expected to lead to additional costs, which have not yet been recognised and taken into account in the many discussions on this issue.

Any container that does not go overboard equally reduces the environmental problems for the coastal states and ultimately for all of humanity, and at the same time any loss that does not occur reduces the costs for the insurance industry and thus ultimately also for the total number of insured parties.

The unconditional cost-saving principle for shipments could be countered effectively by the port states, especially the few northern European port states as part of an association. Those involved/affected should not hope for international efforts.

A comparison with tanker accidents shows quite clearly: international efforts barely brought about any improvements. However, when the USA, as one of the largest oil importers, made shipbuilding changes a mandatory condition as a port state, the international tanker fleet adapted very quickly.

If one could imagine that only France, the Netherlands, Belgium and Germany imposed regulations regarding certain equipment as a condition for ships to dock, then these four states alone with the main import ports (Le Havre, Rotterdam, Antwerp, Bremerhaven and Hamburg) would generate such high economic pressure via northern European consumers that rapid changes are at least conceivable. If the main southern European ports of Greece, Italy and Spain were to be integrated, almost the entire European market could become unavoidable as a market power for the world's merchant fleets.