SUB-COMMITTEE ON CARRIAGE OF CARGOES AND CONTAINERS
10th session
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DEVELOPMENT OF MEASURES TO PREVENT THE LOSS OF CONTAINERS AT SEA

Summary of incident review and gap analysis

Submitted by Australia and Kingdom of the Netherlands

SUMMARY

Executive summary:	This document presents a summary and gap analysis concerning the review of incidents resulting in loss of containers under the umbrella of the TopTier project.
Strategic direction, if applicable:	7
Output:	7.20
Action to be taken:	Paragraph 2
Related documents:	MSC 104/17/4; MSC 106/INF.16; MSC 107/17/12; CCC 9/INF.25, CCC 9/13/3, CCC 9/13/4 and CCC 10/11/5

Introduction

1 This document presents in its annex a summary and gap analysis concerning the review of incidents resulting in loss of containers in support of the discussions on the development of measures to prevent the loss of containers at sea.

Action requested of the Sub-Committee

2 The Sub-Committee is invited to note the information provided.

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ANNEX

SUMMARY AND GAP ANALYSIS CONCERNING THE REVIEW OF INCIDENTS RESULTING IN LOSS OF CONTAINERS

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1 INTRODUCTION

The sea is a dangerous environment and incidents can never be ruled out. The objective should, however, be to avoid incidents by controlling known root causes, and that exposure to hazards that cannot be controlled is actively avoided.

Incidents unfortunately do occur with vessels compliant to standards, even in conditions that should be considered inside design envelopes. This implies that "gaps" in the sense of unidentified or uncontrollable hazards may exist, or that known hazards are overlooked. What are these gaps, how significant are they, and what could be mitigating actions.

This report provides a summary of the gap analysis by the TopTier project. It is based on a review of current practice and incidents, and feedback from crew questionnaires and project partners in the TopTier Joint Industry project.

Executive Summary

Two quotes from long past highlight the aspects that are still crucial to safe shipping today.

"Anyone can hold the helm when the sea is calm", Publius Syrus, 85 – 43 BC.
"It is skill, not strength, that governs a ship", Thomas Fuller, 1608 – 1661 AD.

The emphasis is obviously on the skill of the crew to handle the ship through severe conditions. The importance of the strength of ship and cargo however is clear as well.

Multiple stakeholders are involved in the preparation, planning and loading of modern containerships. Their joint contributions make up the strength of the cargo stowage arrangement, as well as the internal loads that are induced when exposed to severe conditions at sea. A digital representation of the stowage arrangement in loading and lashing software is used to validate a safe stow. Crews have limited control and insight in both loads and strength of container stowage arrangements as illustrated by recent quote from a first officer in a video clip of a container ship in severe weather.

"I hope the naval architects did their job right"

The review of incidents suggests that incidents occur both when the strength of stowage arrangements is degraded by wear or tear, when the deck stow is loaded differently from the validated stow plan but also when motions at sea exceed the limits that were considered in black box lashing software either because of exceptional motions by parametric roll, or by motion mechanisms not considered explicitly as stack resonance.

The IMO regulatory framework that should endorse minimum safe standards, is lagging behind with respect to the evolution of container shipping over the past 15 years. Operating practices in stow planning, loading and transit stages should be included under the safety validation by the flag State. That calls to include them in the scope of the CSM document for containerships and requires amendment of the guidelines for the preparation of the CSM. At the same time, the standards around lashing gear, containers and lashing software should be updated to have transparent maximum safe working loads and safety margins, and harmonized standards for the lashing software that is used for the voyage-specific validation of stow plans.

2 INCIDENTS

Firm data with respect to root causes, their relevance and potential mitigating actions should come from actual incidents. Detailed information about container loss incidents, however, is not centrally collected. It is typically treated in confidence between carrier and insurances. Only incidents that are investigated by authorities are reported in public domain.

The following sources of information were available to TopTier for review:

- Bi-annual reports into container loss as sea as published by the World Shipping Council since 2008.

- Incident information available in the public domain.

2.1 Incident numbers provided by WSC

The World Shipping Council publishes annual updates on containers lost at sea. The numbers are established from the combined losses reported by the WSC members that together represent approximately 90% of the total global vessel container capacity. WSC assumes for the purpose of its analyses that the container losses for the 10% of the industry's capacity that is operated by carriers that did not participate in the WSC surveys would be roughly proportional to the losses reported by the responding carriers representing 90% of the industry's capacity.

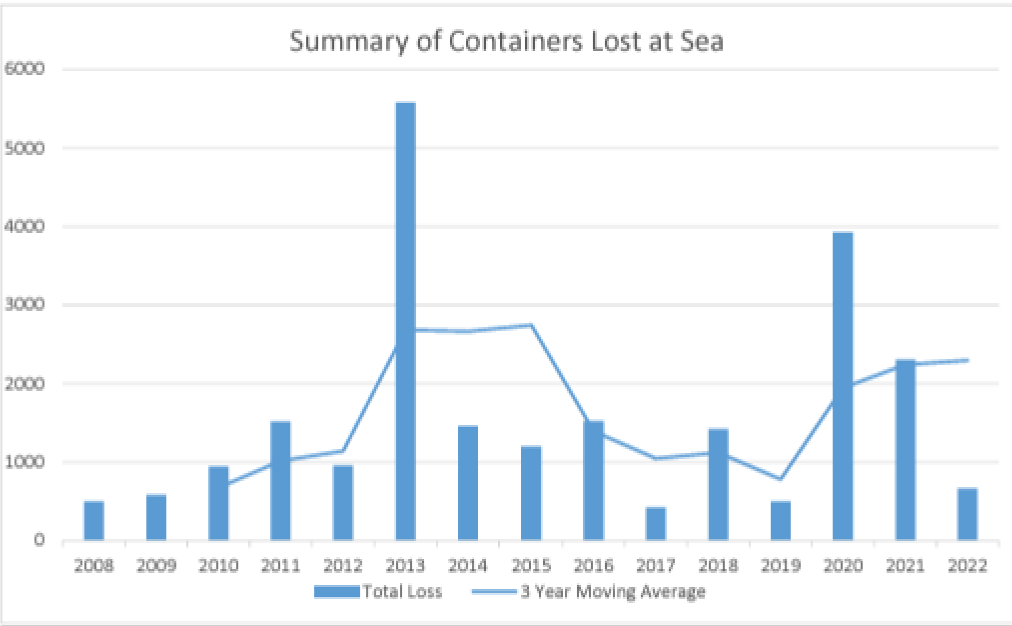

Figure 1 Overview of containers lost per annum (WSC update 2023)

Records over time indicate that annual loss of containers is generally in the order of ~1000 / year with outliers 2013, 2020 and 2021. The outlier in 2013 is related to loss of two vessels (Rena & MOL Comfort). The outliers in 2020 and 2021 are related to failure of securing arrangements in excessive motions. In 2022, 661 containers were lost at sea. This represents less than one thousandth of 1% (0.00048%) of the roughly 250 million packed and empty containers currently shipped each year.

The WSC updates do not provide a breakdown of the reported losses to individual incidents, vessel sizes or principal root causes but due to the survey methodology used by the WSC their findings are generally accepted as valid.

2.2 Incident details from public domain data

A summary of incidents between 1998 and 2021 was assembled by TopTier from information in the public domain. A total of 43 cases representing 9824 containers lost in 23 years were reviewed.

The incidents are classed in several categories according to incident scale as follows:

.1 loose a single container up to the upper part of a single stack;
.2 collapse of an entire stack;
.3 collapse of multiple rows in a single bay; and
.4 gross failure involving multiple bays along the length of the ship.

Some characteristic examples are highlighted as follows:

- Gross failure cases are illustrated by rare but high impact incidents as **ONE APUS**, **Maersk Essen, MSC Zoe**, involving hundreds to nearly two thousand containers per incident. These are explained by occurrence of motions that exceeded the design values considered with the stowage planning. Underlying reasons are parametric roll, but also synchronous roll and roll in high GM conditions.

- Cases with single bay - multi row collapses occur more frequently than the multi bay collapses and are visible enough to make it into the public press. Characteristic incidents show full bay collapse of the aft bays but also further forward. (**Ital Florida, Jepessen Maersk, Merete Maersk, YM Taichung, Ever Smart**). Listed root causes are severe weather, excessive motions, poor condition of lashings and containers, but also large scale but less common phenomena, such as stack resonance and hull girder vibrations.

- Many small incidents with limited container losses may not be in the public domain, although incident investigations by appropriate authorities should be assumed to have been done. E.g. smaller vessels losing boxes by root causes, such as failure of the securing arrangement, shipping green water, poor condition of lashing gear and containers, stowage configuration, overweight cargo, incorrect lashing arrangements, and high crew work load (**OOCL Rauma, Uni Popular, Annabella**).

Smaller damages are better explained by other root causes than excessive motions, since these tend to trigger collapses at multiple locations at same time, thus leading to large losses.

WSC updates suggest an annual number of containers lost is around 1,000. That would add up to a total of around 20,000 over 23 years. The significantly lower number of 9,824 containers lost at sea in the TopTier review of available incident information suggests that publicly available information about root causes etc. may not cover 50% of the total lost containers during the past 23 years based on the WSC's survey. It is possible that the majority of that number is related to smaller scale incidents that went past unnoted. It is also possible that additional incident information resides with the appropriate flag States.
Following is noted:

- Data in the public domain is biased by the high profile incidents that usually make it to headline press coverage.

- Publicly available incident data may typically pertain to bigger losses.

- The TopTier's incident review may not cover up to 50% of the overall estimated number of containers lost although it is possible that incident information may reside with the relevant flag states.

- Smaller scale incidents are expected to dominate the losses for which TopTier has been unable to obtain or access incident information.

The numbers listed are based on extrapolation and are not firm. In the absence of more accurate centralized and accessible data, they are considered sufficiently reliable to conclude that:

In conclusions when it comes to reducing the number of containers lost at sea, it is considered equally important to address and reduce both:

- The rare occurrences of large scale incidents as represented in the TopTier incident overview, and

- The more frequent occurrences of small scale cases that together may make up a significant portion of the overall incidents but for which TopTier was not able to obtain clear incident information.

Identification, ranking and mitigation of root causes for the larger and smaller incidents is essential to understand and address the baseline number of around 1,000 containers that are lost to sea on annual basis.

2.3 High level evaluation

Detailed information on individual incidents typically remains confidential, except for incident reports by authority investigations. Information in the public domain is incomplete and does not provide enough resolution to review basic root causes for individual incidents. That complicates a structured independent summary and ranking of root causes.

A shortlist of principal root causes is established instead, based on information from the few reports that are available in public domain, feedback from crew questionnaires in both TopTier and previous Lashing at Sea project, and feedback from project partners. An overview of potential root causes that could lead to incidents is shown in the fishbone diagram in figure 2.

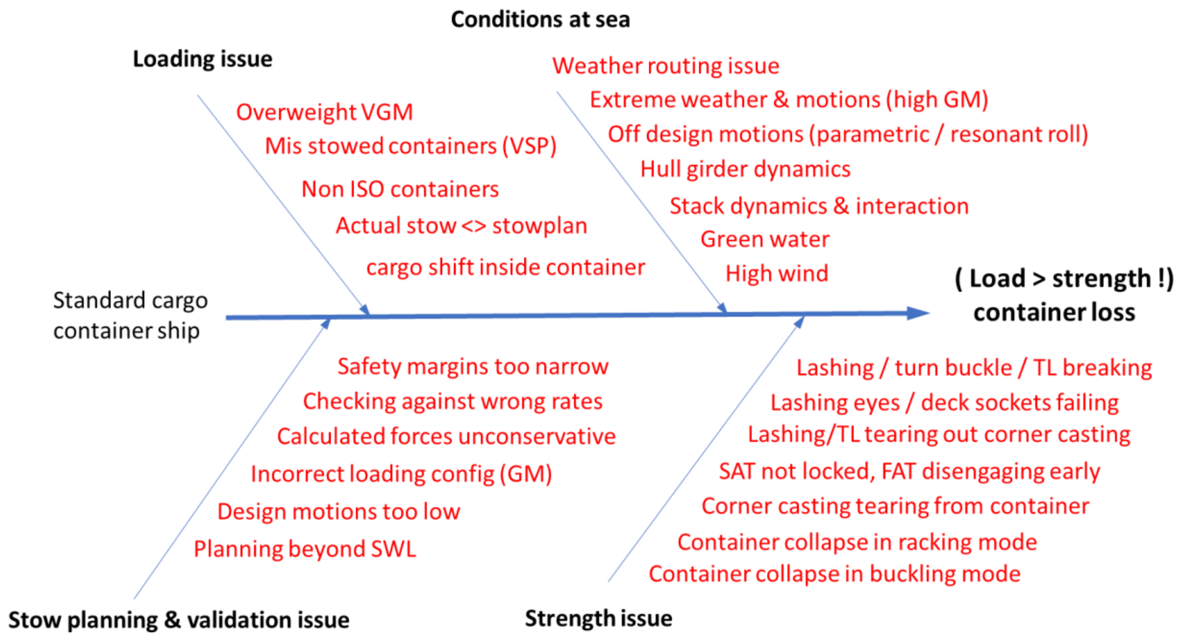

Figure 2: Fishbone diagram overviewing potential drivers to failure

The root cause for an incident at sea could be a stage that preceded the loading and planning of the stow even.

3 SUMMARY REVIEW OF CURRENT PRACTICE

The objective of container shipping is to maximize the intake volume inside the boundary imposed by strength of the cargo securing arrangement. For each port call, cargo stow plans are prepared. These are validated against documented safety margins using dedicated lashing software for OK. Once approved, the vessel is loaded according to the stow plan, and makes the transit to next port where the process repeats. Inspection and maintenance efforts for containers and lashings run on a longer time scale. (figure 3)

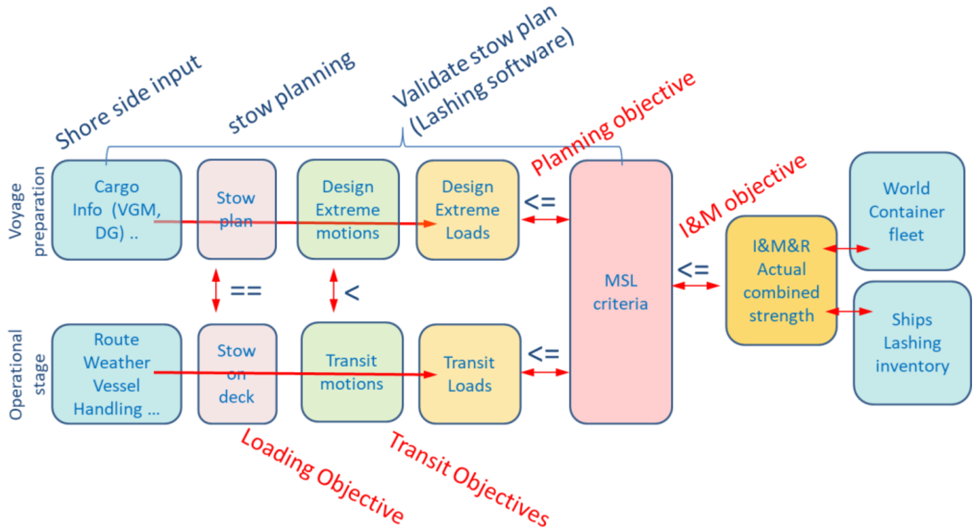

Figure 3: Process overview container operations

The process includes different steps, involves multiple stakeholders, players and responsibilities and relies on:

- The stow planning bein optimized by combining the vessel loading configuration, cargo information, the proposed stow plan, design motions and forces along the route plan and the maximum rates of lashing gear and containers *(planning objective in figure 3)*. Multiple parties are involved, master/first mate, central planning department carrier, and the terminal planners. Central and terminal planners focus on efficient stow plan for utilization of the vessel over time, and for terminal operation. Crew is end responsible for safety of vessel and cargo arrangement. The process relies on complex (lashing) software, accurate (cargo) information, valid safety margins and timely exchange of information and notification of changes.

- Agreement between the planned stow and the actual stow *(loading objective in figure 3)*. The stow plan may be optimized up to maximum safe allowable loads under design conditions. Safety then relies on the loaded cargo actually being loaded in line with the stow plan, or the stow plan being updated and re-evaluated for safety in case of deviations during loading stage. This involves the terminal loading ops, feeding back to the terminal planners, the vessel team, and the deck crew supervising the loading operations.

- Transit motion conditions not exceeding design extreme motions. *(transit objective in figure 3)* This requires the crew to avoid exposure of the vessel to motions not included in the software (parametric roll) and operate the vessel inside motion envelopes as were considered in the lashing software (including presumptions with weather routing).

- Inspection and maintenance regimes that ensure that condition and actual strength of both containers and lashing gear are better than the rated safe working loads *(Inspection and maintenance objective in figure 3).*

Safety is affected both by process, equipment, and operational aspects.

4 OVERVIEW OF CONCERNS AND POSSIBLE GAPS

4.1 Stow planning stage

The preliminary stow plan is optimized for efficiency inside the boundary of maximum safe allowable loads. For this, it is assumed that input data (container VGM) is accurate, that loading/lashing software can accurately determine design motions and lashing forces, and can compare against the right ratings and max allowable safe working loads.

- These assumptions may be unconservative since quality control loops are not mandatory.
    - VGM does not have to be actively verified. Containers may be overweight.
    - There are no harmonized performance standards for loading/lashing software.
        - Envelope and statistics for maximum considered design motions are unclear,
        - Reliability of calculated extreme lashing forces is not clear,
        - Criteria for acceptance of "safe" stow plan are not transparent.
- Existing ISO standards do not cover the full variation of present time container types and ratings. There is no differentiation between 213 kN and 192 kN rated containers, and subsequently lashing software cannot recognize the different rating either.
- There are ratings and design values for container and lashing gear separately. Rut ratings / maximum allowable safe working loads and safety margins for the combination of lashing gear and containers are not transparent.

4.2 Loading stage

- Deviations from the stow are unavoidable during loading. They are not always directly updated to the vessel team, and sometimes not even in the departure stow plan.
- Compliance between final approved stow plan and situation on deck with respect to actual container weights, the actual stowage positions and the applied lashing arrangement, is questionable. The safety validation via the loading/lashing software in that case is not reliable and the stow can be unsafe under "in design" conditions.
- There is no mandatory control feedback loop to ensure compliance between the final stow plan and the actual stow. The master is end responsible but does not have information or control. Terminals have the best information and control but do not have formal responsibility over:
    - Declared mass VGM.
    - Stowed position on board (VSP).
    - Independent review of container and lashing gear condition.
    - Container condition and packing.
- The master is responsible for safe stowage but does not have the information needed for that. Solutions to provide that information exist but require shifting responsibilities to terminal side and investments to collect and streamline information and data flow between shore and ship.

Improvements:

- Ship-shore interface coupling:
  - Container ID, type info, weight, content, structural ratings, condition tracing and history.
  - Updated loading information with actual stow positions and accurate final stowage document.
- Tracing conditions of containers and corner castings
- Tracing conditions of lashing gear
- Maintenance service for lashing equipment

4.3 Performance extreme design motion algorithms

Stow plans for each voyage are validated with lashing/loading software. A key module in that software estimates the worst case conditions to be expected in the voyage. Following aspects are considered typically:

- Estimation of the worst case motions and acceleration under "in design" conditions.
- Consideration of "off design conditions" that are supposed to be actively avoided and left out of the design scope.

Following concerns are listed. Unconservative "in design" motions. This implies that load calculations are done with lower motion levels than might occur in practice. Meaning that systematic overloads could then occur in reality under conditions that were anticipated as "in design":

.1 Biased statistics, or underestimated motion behavior (low/high GM, low speed, engine failure).
.2 Unconservative consideration of weather routing impact (sometimes forecast incorrect).
.3 Leaving out accelerations by hull girder flexibility.

Another hazard is the exceedance of in design motions by not avoiding "off design conditions" that were explicitly left out of consideration, such as:

.1 Parametric roll in following seas.
.2 Resonant roll.
.3 Parametric roll in head seas.
.4 Excessive pounding.

Uncertainties on the "design motions and accelerations" side impact the loads of all stowed cargo at the same time and will directly reduce the safety margin if the estimated values are below what actually occurs at sea. Following challenges and questions are highlighted.

- Adopted algorithms are partly based on empirics but there are limited statistics for design motion extreme conditions of large containerships. Probability of exceeding design extreme motions may be higher than expected.

- Human factors in vessel route planning, and vessel handling affect ship motions in challenging conditions. This is relied upon to prevent entering into "off design" conditions. Incidents suggest that it is difficult to recognize off design hazards on ULCS vessels and take timely action.

- Exposure to weather conditions is limited by relying on weather routing. Resulting motion statistics are thus "coloured" by routing and design limits rely on these statistics. Not all weather conditions, however, may be avoidable, so severe conditions may be encountered despite weather routing.

- Route-dependent reductions for design accelerations are applied in some lashing rule notations.

- What is the impact of changing climatology and increasing number of storm systems on weather avoidance and motions statistics?

- Examples for "off design" conditions are parametric rolling phenomena, excessive wave pounding, and possibly also sea states exceeding certain wave heights. It is not explicit how these conditions are defined, and what motion/acceleration levels and sea states should be actually considered as in or out of design.

- It requires awareness and training already on smaller vessels to recognize and handle threatening hazard of parametric rolling conditions. It will remain a risk for less aware crews to end up in off design conditions.

- How realistic is it to rely on vessel crews to avoid listed off design conditions? Are all off design conditions properly understood? Is it practically possible to recognize and avoid increasing threat of developing off design conditions? In particular on large vessels.

- Accelerations by hull girder dynamics are known to be important for the loads in the cargo stow and securing arrangements. They are, however, not explicitly accounted for in the rule codes for accelerations.

- There are no statistics on occurrence and levels of accelerations due to hull girder dynamics in relation to slamming, whipping, springing and twisting. This makes it impossible to account for these effects in securing calculations during voyage planning stage. What are statistics of hull girder flexibility accelerations as function of ship and environment?

4.4 Performance securing load calculation algorithms

Stow plans for each voyage are validated with lashing/loading software. A key module in that software is calculated forces in the cargo stowage arrangement under the worst case conditions to be expected in the voyage for evaluation against maximum allowable criteria. Uncertainties in the calculation of securing loads for given input motions and accelerations are listed as:

a) Uncertainties in calculated loads due to poor input parameters.

   1) Vertical weight distribution in stacks / mis-stowed containers.
   2) Input weights VGM.
   3) Different stiffness characteristics of real containers, lashing bridge and securing arrangement in relation to the calculation model.

b) Uncertainties due to load mechanisms that occur in reality but are not explicitly or accurately included in calculation models.

- Apart from wind and water forces, the loads imposed on cargo stacks include:
  - Inertia loads imposed from the moving ship structure onto the stack.
  - Interaction forces between the stack and the neighbour stacks.

- Inertia loads from ship structure to cargo stows include:
  - A quasi static part due to the global vessel motions that have oscillation periods well above the natural frequency range of the container rows. Response to quasi static loading can be calculated with some uncertainty. Question is about the level of uncertainty.
  - A dynamic part due to excitations with short periods close to or even below the natural period of cargo stacks. Typically responses to slamming, whipping, and hull girder vibrations with periods of 1 to 3 seconds. Dynamic accelerations are a substantial part of overall accelerations. The impact on loads is not explicitly considered in design calculations and has to be treated as uncertainty. How big is that uncertainty?

Calculation algorithms are used to determine the responses to known excitation and response mechanisms. Following concerns are raised:

- Calculation models rely on individual container stiffness. That stiffness is known to vary across container brands, types and age. The stiffness is non-linear due to the door end configuration. The asymmetric design introduces coupling between racking fore aft and torsion around the vertical and longitudinal axes. It is uncertain what representation produces best computation results in comparison to reality.

- Calculation of reaction loads in single stack securing arrangement is complicated by non-linear effects from slack lashing rods, twistlock gap openings, non-linear stiffness of container door end, and load distribution of parallel lashings. This produces uncertainty in results. The amount of uncertainty is not quantified.

- Deflections of high-tier container stacks are affected by shear deformations in the lower tiers that are under large weight compression, by deformation of the lashing arrangement and lashing bridge, and by heeling of the stack by uplifting at the "windward" corner castings as allowed by the twist lock tolerance or gap opening. This uplifting-related heeling introduces additional deflection and reaction loads, possibly including jerking/snapping loads. This effect is non-linear and depends on condition and tolerance of containers and lashing gear. It is not quantified how this affects securing loads as function of inertial loads.

- Interaction forces between individual stacks and neighbour stacks are not considered in present securing calculations. It is uncertain if they would have a positive effect by constraining individual stacks to the average displacement of the entire block stow, or a negative effect by leaning into stacks that might already be stretched to full loads by their own design.

- The relevance of stack resonance was demonstrated in previous Lashing@Sea campaign, and confirmed by on board observations by several carriers in the project including video footage on board. Discussion is on whether stack resonance should be treated as "off design" topic to be avoided, or an "in design" topic that has to be dealt with inside limits of the securing arrangement.

- Fully developed stack resonance requires phase-locked stack motions in order to have accumulating motion levels without excessive damping due to stack interaction. The character of the transition of individual uncoupled stack response with different mode shapes and periods to phase locked combined response is uncertain. Observations on board suggest light stacks to be more sensitive to resonance. The non-linear effect of uplifting and twist lock gap tolerances is likely to play a role to reach phase locking at lower motion thresholds.

- Can the combined effects that produce uncertainty be combined into a load margin and used to evaluate against the safety margins of lashing gear and container?

4.5 Crew's governing role in transit conditions

- Safe ULCS container vessel navigation relies on human factor decisions. At least two time scales:

  - Strategical – voyage planning. ULCS container ships rely on routing and avoiding weather outside a workable envelope.

  - Tactical – Safe operation will still rely on proper vessel handling in severe conditions.

- In essence, the human decisions boils down to the requirement to operate the vessel inside the envelope of what was referred to in previous paragraphs as "in design" conditions. This requires:

  - Awareness of the "in design" envelope limit.

  - Awareness of the actual load ratio according to present state.

  - Recognize increasing hazard to exceed the limit state.

  - Availability and awareness of mitigation measures/options.

Recent large-scale incidents suggest that vessels were operated outside design conditions for the securing arrangements. Concerns are raised on all of the above items.

  - Are vessel crews aware of the actual limits that were assumed in the securing design calculations?

  - Is it clear at any time what the loading ratio of the securing arrangement is in comparison to the acceptable design limits?

  - Is it possible to anticipate when changing conditions might increase the hazard of exceeding the limits in the short term even if actual conditions now are well inside margins?

  - Can mitigation actions then be performed to reduce the hazard, or can there be conditions such that they are not possible anymore.

- For short term tactical decision, the main concerns identified are:

  - Crew perception of limits may not correspond to actual securing load limits. For crew, it is expressed in motion levels. For cargo securing, it is expressed in kN for breaking strength. The relation is not fixed and depends on load configuration. Awareness of true limits is difficult for a human operator without technical system support.

  - There are no mandatory feedbacks of either motions levels, or loading levels of the securing arrangement in comparison to design limits.

  - Because of the mild motion levels on large vessels, there is limited feel for the behaviour, and it is not trivial to anticipate hazard for parametric roll type of phenomena. Can this actually be anticipated properly?

  - Extreme rolling conditions will always remain one of the aspects to be addressed. There needs to be certainty, though, "that the vessel can be operated safely" under the wave conditions that are deemed acceptable. So, if parametric rolling could occur, is it then possible to operate the vessel safely at different speed or heading?

- For long term strategic decision, it has to be identified what parameters determine the maximum acceptable exposure to weather and waves. And how the routing advice has to be established and conveyed in order to line up short term tactical decisions in advance?

- Weather routing and short term decisions rely on accurate information on the environment. Accurate representation of the sea state and vessel behaviour is crucial in this aspect.
  - There is a need for clear and quantified feedback on wave parameters.
  - There is a need to interpret the actual vessel behaviour in relation to predicted and actually measured or observed wave conditions.
  - There is a need to extrapolate vessel behaviour from the present condition (speed heading) to others. This is traditionally done by experience of the master and other bridge officers. It may be helped by on line / off line technology.

- It is observed that utilization of weather routing and weather routing services is strongly adopted in deep sea shipping. Ship and cargo securing designs actually may already be depending on it. Yet, there is no reference to weather routing procedures and requirements in cargo securing manual procedures. Should there be? And if so, how?

4.6 Strength of containers and lashing gear

- The common perception is that a safety margin of 2.0 is adopted for safe working loads in ratio to minimum break loads. That applies to lashing gear but not to containers.

- The safety margin for the combined strength of lashing gear and containers is not transparent.

- Does present safety factor provide adequate margin for the uncertainties in modern high tier stow configurations.

- The CSC rule on the marking of reduced strength containers has not kept pace with the ISO standard on container strength requirements. It is impossible to differentiate a new standard ISO container (213,316 kg stacking capability) and an older container with a 192,000 kg stacking capability.

- What are the safety margins for the maximum allowable loads in containers? Is there a safety margin at all or are the maximum allowable compression and racking loads directly at MBL?

- Concerns about non-ISO containers, e.g. extended size container: Are the loads' maximum ratings of extended size containers properly handled in the stowage planning. (Certainly an issue; note the 2018 incident: https://www.gov.uk/maib-reports/loss-of-cargo-containers-overboard-from-container-ship-cma-cgm-g-washington).

- Can lashing patterns be applied properly for different sized containers and how does that affect maximum ratings?

- Are testing standards for the combined performance of containers and gear adequate?

- What is the validity/uncertainty of load ratings for:

    - Different types/ages containers.

    - Lashing gear as function of types and age.

    - Combined performance of twist lock – container assembly.

    - Combined performance of lashing hook / penguin hook – container assembly.

    - Dependency of load ratings on container and corner casting conditions.

4.7 Regulatory framework

- SOLAS provides minimum required safety standards for safe carriage of cargoes. It refers to the Cargo Stowage and Securing (CSS) Code that defines a wider framework.

- The mandatory part of the SOLAS implementation is limited. Cargo ships are required to have an approved CSM on board, and operate in compliance with what it describes. Guidelines for the preparation of the CSM do not have mandatory status. The CSM, however, should be drawn out to "at least" the standards that it provides, which makes it the baseline in any case, and covers all relevant aspects.

- The strong reliance of modern container stowage and securing practice to software solutions' input quality, and the different roles and responsibilities involved in planning and loading are not covered in the guidelines for preparation of the CSM.

- The voyage-specific assessment of cargo stowage arrangements, as performed in lashing software, does not align with the SOLAS concept of loading inside prior approved stow patterns approved by a flag State. It does provide more flexibility for handling varying load conditions, stowing configurations, routing options, etc. It allows more efficient stowage planning but relies in quality of input as any computer system.

- The SOLAS Convention puts the responsibility for the approval of the CSM with the flag State authority of the vessel. Over the past decades, national authorities have mandated class societies to approve CSM documents for containerships on their behalf. Without overarching or harmonized standards, the various classification societies apply different rule sets that are not easy to compare.

- Economic pressure to maximize cargo intake may push the limits of non-harmonized standards. There is no transparent framework or standard that allows verification of a "sufficient" safety level.

- Loading/lashing computers handle a deterministic type of calculation but rely on operational procedures to match the digital reality. Is the use of the loading computer and how that is embedded in other procedures included in the approved procedures in the CSM? Typically planning, loading and transit stages.

- How can the regulatory framework address the (essential) involvement and responsibilities of shore-based stakeholders, such as shippers (declared mass), planners, and loading terminals? Both with regard to responsibility for their principal tasks and with regard to role in the control loop to ensure compliance of digital representations and reality.

- Acceptability and conditions to consider reduction factors with regard to weather routing, off design regimes.

5 MAIN GAPS IN CURRENT PRACTICE

5.1 From incident root causes

5.1.1 High profile but rare incidents

The gap between target objective and present condition for safety, when based upon the winter season 2020-2021, is dominated by the 3,000 lost containers in a few incidents on the Pacific that shed 100+ and up to 1,800 containers per incident case. In the same season, multiple similar vessels operated the same area without experiencing similar incidents. Review of incidents suggests that collapse was caused by exceeding "in design" motion regimes. Root cause of these incidents is thus marked to be failure to avoid off design motion regimes.

Important factors shared between the worst case incidents further suggest particular relevance of:

- Following sea conditions at sea states in 4 m to 6 m Hs.
- Loaded conditions with low GM in the range of 1.5 m.

Extreme motions after engine shutdown following alarm state by large motions was mentioned as a key factor in at least one incident.

Parametric roll in following sea conditions triggered off design conditions overloading the limits of the securing arrangement in three cases.

Several high end cases indicate parametric roll phenomena in head seas as root cause.

Resonant roll was found to be an important factor related to incidents with ships operating in coastal areas with limited routing options.

Shallow water and bottom contact was listed in one high end case as an essential factor. Container loss statistics. including total vessel loss, as with MV Rena. illustrate the potential impact.

Anticipating, recognizing and avoiding extreme motion response and parametric rolling, in particular, is identified as the main gap from the perspective of high profile incidents.

5.1.2 Majority of incidents

The gap between target objective and current practice for the years preceding 2020 is dominated by multiple small scale incidents involving few to dozens of containers per incident, and a smaller number of marked outliers shedding 100+ containers in single incidents.

Some incidents involving larger numbers of containers again appear to have been triggered by general motion and acceleration conditions exceeding limit states. Many incident reviews, however, suggest failures that can be related to not following guidelines, incorrect documentation, mis-declared weights, mis-stowed containers, worn or improperly applied equipment, poor packed and poor condition containers.

Obviously, most incidents occur in conditions where vessels are exposed to significant weather. It is uncertain if that weather was worse than could have been expected in the area, if the vessels were not handled properly, or if the securing arrangement was more vulnerable than expected and failed while still inside it was considered as manageable conditions.

Vulnerability of cargo stows is decided in the preparation, planning and loading stage of the vessel. Uncertainties on that front side make securing arrangements unnecessarily vulnerable at sea. Feedback of ship crews suggests that this drives most of the incidents. Reduction of that uncertainty is expected to address the larger number of small scale incidents that together could make up around half of total volume of containers lost to sea.

- Uncertainty in container weights and stowage positions. This has a direct impact on individual stack stability. Firm proof is not shared because of confidentiality but anecdotal references suggest that this dominates container losses on medium to large size vessels.

- Many incidents with container loss scale around 50 to 100 containers at aft bays suggest stack dynamics / row resonance driven by hull girder vibrations. Neither the excitation by hull girder vibrations not the dynamic/resonant response of rows is covered in common stow planning calculations.

- Condition of lashing gear, container frames and corner castings due to wear and tear is a common factor in many incidents. There are concerns about the impact of wear and tear on latest generations of ULCS securing arrangements. In particular, FAT equipment is sensitive to wear and tear, and inspection and maintenance is difficult because of the vast amount of equipment that is carried.

- Existing ISO standards cannot differentiate the full variety of containers that are in circulation and adopt lower design values than the lashing gear on board. The effective safety margin of combined lashing and container may be lower than expected.

- Oversight over loading and lashing operations is listed as a great concern. On larger ships, it is difficult to follow loading operations by the terminal because of size and speed. On (smaller) ships where crew is hands-on involved in loading and lashing operations, the workload is high and fatigue is highlighted as reason for problems going unnoticed.

- Incidents with small (low freeboard) coasters often recall damage due to either green water or extreme motions due to bad weather at low speed. Green water is a root cause issue that should be avoided in vessel design choices (newbuilds) or by weather routing.

5.2 Incident logs

Assessing the performance and potential flaws in current practice of container cargo stowage and securing is complicated due to the unavailability of centralized complete incident information. That information is restricted by confidentiality related to damage and liability cases. It is in effect not possible to establish a total number of incidents over longer time, create statistics of numbers of containers lost per incident, correlate incidents to ship size, and assess the occurrence of categories of root causes.

It would be beneficial if a combined, more detailed, but still anonymized overview could be made available between carriers, insurances and P&I associations.

6 FOLLOW-UP

6.1 Focus points in TopTier

TopTier scope of work aligns along 6 workflows:

1) Working group 1) Determine actual limit values and safety margins for combined container and securing gear though dedicated tests and numerical calculations.

2) Working group 2) Review the ship-shore interface with respect to stowage planning, reliability of declared weights, stowage position of loaded containers, and safeguarding the condition of container and lashing gear. -> reduce uncertainties on the front side prior to departure.

3) Working group 3) Voyage specific worst case design motions.

    a. Investigate and recommend how to avoid "off design motion conditions" that would trigger gross failure of stowage arrangements. (Parametric roll) through model tests and numerical simulations.

    b. Investigate and document realistic envelopes for "in design" motions and hull girder dynamics using onboard measurements on modern large scale vessels.

4) Working group 4) Extreme forces in securing arrangements

    a. Verify the feasibility and requirements to estimate securing loads in planned stows under design extreme conditions using scale experiments, high fidelity numerical calculations, and results from operational solvers for a 15 kTEU reference vessel case.

    b. Document the extent of non-linear contributions in securing forces by uplifting, container flexibility and lashing pattern.

5) Working group 5) Decision support for crew and shore teams.

    a. Highlight essential information for ship crew's situation awareness, and ability to handle vessels within "in design" envelopes.

    b. Identify essential information, as needed, to anticipate and recognize exposure to, and prevent development of "off design" motions.

6) Working group 6) Regulatory framework.

    a. Review existing framework of rules and regulations and identify where improvements should be considered.

6.2 Short term time scale changes

6.2.1 Reliability of departure stow plans

Safe container cargo stowage and securing relies on the concept that a cargo securing arrangement can be prepared in planning stage up until maximum safe working loads are indicated by lashing software. The keystone to that concept is that the loaded configuration on the deck matches the validated configuration in software. That starts with weights and container stowage positions, and extends until the applied lashing patterns, and strength of lashings and containers.

Incident reviews "suggest" that a very large part of annual losses are related to "non-compliances" in this aspect. Ensuring such compliance should ideally be accomplished by systematic solutions or procedures that are part of an operational process that is called for and approved by the flag state. That is not mandatory at the moment but operators are already in the position to consider and implement measures to achieve that.

Carriers should consider options to maximize reliability of departure stow plans, and confidence in condition of lashing gear and containers in dialog with shippers and terminals. For instance, by introduction of control feedbacks on VGM and stowage positions, tracing the condition of lashing gear and containers over time, and introducing incentives for responsible stakeholders to have these within documented parameters.

6.2.2 Prevent excessive motions

The incidents around the 2021 period had a profound impact on the container losses at sea. Preventing such excessive motions is a clear objective that can, and is being, pursued by industry directly.

Strategic decisions - route planning.

As excessive motions are considered to be "off design" for the securing arrangement, than preventing their occurrence must be considered in voyage preparation stage. Route planning in that case must actively consider probability of extreme motions due to parametric roll, resonant roll and loss of propulsion.

- Be aware of vulnerability by determining vessel sensitivity to parametric and synchronous roll type of behaviour as function of loading condition (GM & roll period) and wave conditions.

- Assess exposure along the intended route considering climatology, forecast weather and waves in terms of wave directions, periods and height.

- Consider wave height restrictions for operations in sensitive conditions.

- Improve quality of roll motion calculations -> explicit calculation of Kxx.

Short term decisions – vessel handling

Exposure to parametric roll sensitive conditions might occur even if such was considered in voyage preparation stage. Non-linear motions can develop suddenly without much warning to high amplitudes. Situation awareness in that sense is crucial as well as knowing options to mitigate the hazard.

- Crew should be made aware of the sudden and treacherous motion phenomena by parametric and resonant roll. TopTier circulated a notice to mariners to raise awareness to parametric roll in following seas.

- An active warning/alert based on measured roll and pitching motions possibly in combination with loading computer output on GM and forecast waves is recommended to call for crew attention when sensitive condition develop unexpected.

6.3 Medium and long term actions

Safe container cargo stowage and securing relies on the concept that a cargo securing arrangement can be prepared in planning stage up until maximum safe working loads as indicated by relevant standards implemented in lashing software, that the software representation matches the situation on deck, and that design motions are not exceeding in transit stage.

Ensuring this should ideally be accomplished by systematic solutions or procedures that are called for by authorities. That is not included in the existing IMO framework. Safety, based on best practices and intentions is fair and incidents rates are low. Incidents that occur, however, suggest root causes in mismatched stow plans and deck stow, poor lashing or container conditions, and improper use or non-validated software.

The intention must be to minimize incidents due to known causes. The existing framework calls for a flag State approved CSM documenting all relevant aspects of cargo stowage and securing, at least to the level suggested by the guidelines for the preparation of the CSM. The existing guideline does not cover modern practice and in effect neither do existing CSM's. Safety essentially relies on good practice and trust, but is not explicitly regulated.

To improve the overarching minimum safety baseline, the contents of the CSM should be extended to include software tools, and handling quality ensurance in the crucial stages of stow planning, validation, loading and transit at sea. Such change may be induced by revising the "guidelines for the preparation of the CSM". To be considered:

- Formalize the utilization of modern lashing software on board in place of stowing inside prior to flag State approved stowage arrangements that are part of the classic CSM. A baseline standard is required for lashing software and how it is interfaced to other software at shore side (planning) and on board (loading and seakeeping instruments).

- Highlighting roles and responsibilities of key stakeholders in the operational process and how operational performance is ensured in planning, loading and transit stages, with respect to:

    - Accuracy of input information -> Verified gross mass and stowage positons.

    - Reliability of lashing and container gear conditions and safe working loads.

    - Dependability to information in transit stage as weather updates, rolling period, excessive motion alerts etc.

- Transparency of safety margins for combined lashing and container equipment may involve interacting with the relevant ISO committees that address minimum strength of containers and corner castings.

Obviously, this will require larger debate and discussion involving industry stakeholders as master mariners, carriers, gear makers, terminals, and regulatory organizations, such as IACS and IMO.

6.4 Expected TopTier outputs

The output of TopTier at the end of 2024 will include recommendations for improvements identified from the six working groups, and a suggested roadmap and timeline for their implementation.

Following reports are anticipated to be released from TopTier:

- Summary of incident overview and gap analysis.
- Effective strength and safety margins of combined lashing and container gear.
- Recommended changes in the ship-shore interface with respect to loss of containers at sea.
- Overview of in design conditions to be considered in preparation of the CSA and voyage planning.
- Feasibility and requirements to actively avoid exposure of a vessel to off design motion conditions, e.g. parametric roll.
- Feasibility and accuracy of lashing force calculations for high tier stows.
- Operational considerations and requirements for vessel handling within "in design" envelope.
- Recommended changes to regulatory framework to achieve reduction of container loss at sea.
- Executive summary report steering towards zero loss of containers at sea.

7 CONCLUSIONS

- TopTier reviewed incidents using information available in the public domain and feedback from ship crews via questionnaires.
- Detailed information about incidents is not usually made available except in publicly available incident reports. Consolidated information is scarce.
- Updates published by the World Shipping Council indicate that apart from force majeure outliers, the number of containers lost to sea per year is around one thousand.
- Best effort interpretation combining available information suggests:
    - The number of containers lost at sea is believed to be comprised from a few number of high impact incidents with large losses, and a much larger number of small scale incidents.
    - Exposure to out of design loads in excess of the strength of the securing arrangements dominates the occurrence of high impact incidents with collapses in multiple rows / bays. (E.g. excessive motions by parametric roll, stack resonance, mistaken GM /roll periods.)
    - More frequently occurring small scale incidents are explained by vulnerability to loads inside design conditions that can trigger local failures and collapse of lashings and containers. E.g. weights and positions of individual containers not matching with the validated stow plan, strength of the securing arrangement or containers at individual stacks affected by wear and tear.
    - Best effort interpretation of the available information suggests that high impact and small scale incidents have similar order impact on the total number of containers lost.
- Controlling exposure and minimizing vulnerability in container shipping relies on software solutions, data integrity, and the roles and responsibilities of multiple stakeholders between planners, ship, shipper and terminal. Incidents occur when that fails. To reduce the number of containers lost at sea, that probability must go down. Following aspects are highlighted for improvement:
    - The combined strength of lashings and containers needs to be available and ensured over the service life of the vessel and containers.
    - It is crucial that the outcome of the stow planning and loading stage is a departure stow plan that matches the actual stow on deck in terms of VGMs and stowage positions, is checked by the ship's crew against valid safety margins for lashings and containers, with approved lashing software tools for design extreme motions and forces along the target voyage.
    - Design conditions considered in planning stage must not be exceeded in transit. That requires awareness of design values and actual conditions, and awareness and ability to anticipate avoid or handle off design conditions as parametric roll before they develop.
    - The existing regulatory framework around safe carriage of container cargo does not extend across all these factors and must be updated to provide a minimum baseline.

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