TopTier, seakeeping and container cargo securing safety

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THE GAP BETWEEN PLANNING FOR, AND ACTUALLY DEALING WITH SEAKEEPING

ABSTRACT

Thomas Fuller (1608 – 1661 AD) wrote "It is skill, not strength, that governs a ship". Good ships are designed to be safely operated instead of being intrinsically safe. That still holds firmly today. The TopTier JIP project addresses cargo securing safety on large container ships. Securing arrangements are based on design motion levels that do not include the truly worst case conditions that could occur. It is relied on good seamanship and conscious vessel handling to operate inside a safe envelope and avoid "off design" conditions. Incidents where vessel motions exceeded design values suggest that high motion levels may be reached before crews are alerted. Is there a gap between what is considered as extreme conditions in design world, and how good seamanship, can realistically operate the vessel inside that envelope.

Keywords: *Container loss, Parametric roll, Design motions, Design loads.*

1. INTRODUCTION

There is common agreement that shipping should be safe. There is less common understanding of what that safety is and should be. Mariners facing bad conditions out at sea, coastal communities concerned with environment after incidents, financial stakeholders in shipping onshore and ship designers, each have a different perspective. The introduction and operation of modern large containerships with high tier cargo emphasised the contrast between these various views. Commercial pressure and economy of scale are driving bigger ships and higher stows. Crews on board are challenged to operate these vessels in safe boundaries. Coastal communities, find that the introduction of bigger ships increased the probability of higher numbers of lost containers and debris into their environment.

Good seakeeping performance is beneficial from each of these viewpoints. Operability of the vessel increases, the vessels would handle better, be safer, and in consequence should loose less cargo. Good seakeeping characteristics however require efforts, and design modifications that may have a cost aspect. The benefits of good seakeeping are often overlooked alongside increased cost until incidents occur. Incidents unfortunately do occur and have raised concerns about the safety of container shipping with the general public, politics and in industry.

2. RECENT CONTAINER LOSS INCIDENTS

Trends on annual container losses are published regularly by the World Shipping Association. The trends are determined from information provided by the world's leading container carriers.

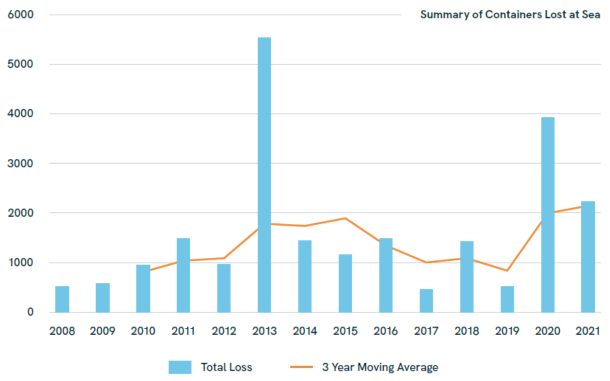

Figure 1: Annual trends containers lost to sea - (World Shipping Council 2022)

The trend shown in Figure 1 is taken from the 2022 update. It indicates that the annual number of containers lost to sea, apart from the loss of MOL Comfort in 2013, have varied around one thousand five hundred over recent years. A review of 44 individual incidents (not including vessel total loss cases) over a period of more than 20 years was performed in TopTier using public available information. In these incidents a total of 9824 containers were lost. Adding up to a staggering average of 223 containers per incident. The average is biased by a few number of severe incidents with large vessels. On new year's day 2019, 342 containers were lost in a single incident just off the Dutch coastline (MSC Zoe). In the winter of 2020-2021 nearly 3000 containers were lost together on the Pacific in 4 separate incidents (ONE Aquila, ONE APUS, Maersk Essen, Maersk Eindhoven). News coverage and detailed incident reports (e.g. BSU, 2020 and DMAIB, 2022) indicate that, extreme motions triggered the collapse of securing arrangements. The question is raised why so many extreme motion related incidents occurred in a relative short time. The incidents show that the vessels moved more than the deck cargo could take. Were weather conditions extraordinary severe, or were the ratings of the securing arrangements too low? Fact is that cargo securing arrangements are not typically prepared for the worst 'possible', but for the worst conditions that are 'expected' to occur. The crew handling the vessel under good seamanship is supposed to avoid more severe "off design" conditions. For that purpose the crew must be aware of the in-design limits, has to have mitigating options in order not to exceed, and be able to recognize and avoid explicit off design conditions. This has become more challenging on large containerships. With high tier stows, cargo can be planned to the maximum utilisation of the securing capacity taking into account favourable motion response of larger ships. Safety margins for larger ships can already be stretched at motion conditions that used to be normal for smaller ships. The uncertainties in securing loads caused by the behaviour of new ships designs, high tier stacks, and different operational practice need to be considered.

3. CONTAINER STOW PLANNING

Container standardized cargo ships have specific securing arrangements with ship specific load ratings. During load planning, the container intake for each voyage is matched to the capacity rating of the securing arrangement. The load plan is verified by checking that the maximum expected securing loads are less or equal than the approved limit criteria for the securing arrangement. The loads are calculated using the planned container mass distribution on the deck in combination with expected motion extremes. SOLAS demands this is done according to procedures described in the flag state approved Cargo Securing Manual (CSM). A CSM is a ship specific paper document that lists all equipment, the stowing arrangement, and in particular the allowable container mass distributions for all cargo stacks and stow configurations, in combination with their required securing arrangements. Before loading starts, stow plans must be compared against approved configurations in the CSM. The effect of varying loading conditions, and resulting change in seakeeping behaviour was accounted in the CSM by listing different stow configurations for low, medium and high GM values. Calculations required for the preparation of the CSM are done in the design stage of the vessel. First step by estimating design motions at the various GM cases and the operating area for the vessel, and second step by evaluation securing loads for the reference load configurations. Approval is done by shipping inspectorates, or by authorized classification societies.

CSM's however have become unpractical over the past 15 years due to increasing TEU capacity of ships. There are too many rows, bays, possible stowing configurations, and range of possible GM/loading conditions to document in a single a priori prepared paper document. Container lashing computers are now used to validate cargo stow plans.

The lashing calculations that used to be flag state approved during build stage, are now done by computer prior to each individual loading/discharge port call. The computer provides the exact view of the planned stowage arrangement and weight distribution. Algorithms under the hood can evaluate any loading condition with related extreme motion levels and securing forces. Many vessels carry class approved loading and lashing modules, but there are no mandatory requirements or performance criteria. Different lashing modules can have different algorithms providing different results.

The basic principle however is similar. A high level representation for the validation procedure of a proposed stow planning (i.e. cargo weight distribution) as evaluated in a loading computer is given by the requirement that all calculated securing loads F_{s_i} in lashings, twistlocks and containers as function of the planned mass distribution m_j when exposed to an expected worst case accelerations a_k should be smaller than the allowable securing loads or criteria F_{c_i} for each load carrying component:

$$F_{s_i} = \Phi_\mathrm{i}(m_j, a_k) < F_{c_i} \tag{1}$$

With:

- F_{s_i} Securing force component i, i=1..n for all lashings, twistlocks and container forces
- F_{c_i} Max limit force criterion to failure for the particular securing force component F_{s_i} (listed in CSM including a Safety Factor)
- Φ_i Calculation algorithm to determine the securing force F_{s_i}. FEA, or non-linear mechanics
- m_j Planned mass distribution for all container masses j=1..m and their position in the stow
- a_k Motion (acceleration) component k=1..o for all relevant motion components

The ships loading condition and GM are determined by the proposed mass distribution. This is used to determine design motions. The design motions in combination with the weight distribution per stack is used to determine securing loads using a load calculation algorithm. The estimated extreme motions, the weight inputs, the load calculation algorithm, and failure criteria all have uncertainties that can be listed more or less as:

$$\Phi_\mathrm{i}(m_j + \Delta m_j, a_k + \Delta a_k) + \Delta\Phi_\mathrm{i}(m_j + \Delta m_j, a_k + \Delta a_k) < F_{c_i} - \Delta F_{c_i} \tag{2}$$

The sensitivity of calculated forces to the various uncertainties is shown by linearizing the expression around the “design” point and noting that the effect of input uncertainty on the uncertainty of the algorithm is neglected:

$$\Phi_\mathrm{i}(m_j, a_k) - F_{c_i} + \frac{\delta\Phi_\mathrm{i}(m_j, a_k)}{\delta m_j}.\Delta m_j + \frac{\delta\Phi_\mathrm{i}(m_j, a_k)}{\delta a_k}.\Delta a_k + \Delta\Phi_\mathrm{i}(m_j, a_k) + \Delta F_{c_i} < 0 \tag{3}$$

The first two terms represent the ideal load planning target. Cargo can be planned such that each securing reaction load is less or equal to its limit state criterion. The remaining terms represent the sensitivity of the calculated loads to uncertainties in planned weights, extreme accelerations, calculation algorithm flaws, and the securing load criteria being lower than expected. Safety is then defined by the conditional probability that:

$$P\left(\frac{\delta\Phi_\mathrm{i}(m_j, a_k)}{\delta m_j}.\Delta m_j + \frac{\delta\Phi_\mathrm{i}(m_j, a_k)}{\delta a_k}.\Delta a_k + \Delta\Phi_\mathrm{i}(m_j, a_k) + \Delta F_{c_i} < 0 \mid \Phi_\mathrm{i}(m_j, a_k) = F_{c_i}\right) \tag{4}$$

Important note is that there is no clear information for the actual uncertainties in the input parameters Δm_j and Δa_k, the algorithm uncertainty $\Delta\Phi_\mathrm{i}$, or the criteria safety margins ΔF_{c_i}. The TopTier project is aiming to quantify these uncertainties and sensitivities. Because of the interest of the ISSW conference, motions are highlighted in particular.

When neglecting uncertainties on mass inputs, the safety of a cargo securing arrangement due to motions is given by the probability that:

$$P\left(\frac{\delta\Phi_i(m_j, a_k)}{\delta a_k}.\Delta a_k + \Delta\Phi_i(m_j, a_k) + \Delta F_{c_i} < 0 \mid \Phi_i(m_j, a_k) = F_{c_i}\right) \quad (5)$$

The probability that the combined uncertainties due to accelerations and systematic errors in the force calculation algorithm are larger than the safety margin ΔF_{c_i}, under the condition that the stow plan is aimed to utilize the full allowable capacity with modelled accelerations and weights. The questions to address are:

- What are the inertia loads and motions a_k to use as design extreme values?
- What are the uncertainties in these motions?
- What is their effect on the load calculation algorithm?
- How big does the safety margin have to be to have and acceptable safety?
- What is an acceptable safety?

IMO maintains minimal requirements for ship stability and survivability. Explicit requirements or guidelines for cargo securing however are limited. Compliance to an approved cargo securing manual is mandatory for containerships. But there are no requirements to use specific design motion extreme values. Guidelines in the CSS code mention design extreme motions and accelerations as function of ship dimensions, loading condition, and operating area. It is mentioned that worse accelerations may occur due to extreme motions that must be avoided by proper ship handling. The motions to be avoided are resonant roll, parametric roll, loss of stability, excessive pounding and broaching. IMO MSC circular 1228 provides guidance on how to avoid these. Cargo securing and load planning is thus aimed at expected “in design” extreme motions under the condition that the worst “off design” phenomena are avoided. In and off design components have different driving and response mechanisms and thus also different uncertainties

$$a_k = a_{k_{in}} + \Delta a_{k_{in}} + a_{k_{off}} + \Delta a_{k_{off}} \quad (6)$$

Off design motions are not considered in day to day load planning calculations. The contributions $a_{k_{off}}$ and $\Delta a_{k_{off}}$ are basically neglected under the assumption that the crew successfully avoids their occurrence. The validity of the probability concept then is not determined by the most likely amplitude or an acceptable level for off design motions, but more by the probability that off design motions can successfully be avoided. “Off design” conditions can systematically overload all cargo at the same time and trigger gross failures. The consequential damage of such failures is too high to leave to mere chance. Clear and transparent control options have to be available to anticipate and avoid or recognize and handle off design conditions. If not, then these off design conditions may have to be considered as in design components with low probability of occurrence in order to include their hazard in the discussion about acceptable safety. Following questions are thus added to the previous listed set.

- What is the probability that off design conditions can be avoided?
- What are the available options to anticipate, recognize, avoid or handle off design conditions?

4. ESTIMATION OF EXTREMES AND UNCERTAINTY OF “IN DESIGN” MOTIONS

Cargo securing design motion climates for deep sea ships used to be determined based on experience and worst case weather worldwide. Over past decade increasing vessel dimensions outpaced experience. Computer models are used in addition to extrapolate experience into design extremes for new vessels. Effects of ship dimensions, loading condition, local climatology along the route, and weather routing can be taken into account to produce sea state scatter diagram and most likely extreme motion climate and accelerations imposed on the cargo.

There is no harmonized approach to the specification of design extreme values for motions and accelerations in IMO, lashing codes, or class rules. Different implementations are known to suggest different values for extreme motions. Different ships and operators on the other hand can also follow different voyage preparation strategies, resulting in different sea state exposure, or aim for different loading characteristics (e.g. GM) such that induced motion levels in the same operating area can be different. If safety margins for different operational procedures and rules have to compare, then the impact of these aspects on safety need to be investigated and understood. Following are listed in particular:

- Extreme motion statistics for large vessels in reference scatter diagram conditions.
- Sensitivity of acceleration climate to load planning strategy (GM)
- Effect of human factors i.e. weather routing and short term vessel handling on extreme motions en route.
- Effect of weather routing and short term vessel handling in near shore areas with restricted manoeuvrability.
- Statistics of accelerations by hull girder flexibility under in design conditions.

5. AVOIDING OFF DESIGN MOTIONS

The “off design” loads concept implies that these phenomena can be actively avoided. The emphasis in this should be on active. Active avoidance requires awareness. In TopTier this is linked to the OODA loop which is an acronym for Observe, Orient, Decide, Act. It must be possible to Observe threat levels for off design phenomena, compare that with past time and extrapolate into the future (Orient), in order to Decide it is time to take mitigating actions. At that time viable control options have to be available in order to Act properly to reduce the threat.

Unfortunately it has become difficult for ship crews on ultra large ships to be aware of the surrounding environment, its effect on the vessel, and how much that susceptibility may be changed by variations of speed and heading around. Questionnaires were circulated amongst vessel crews during the Lashing@Sea project in 2009 and again in present TopTier project in 2022. Both learned that it was and still is, difficult to have a good understanding and situational awareness of the surrounding sea state, vessel response and developing loading ratio in the securing arrangement. The bandwidth between mild and design motions on large vessels is narrow. Normal occurring motion levels may be in order of 5 to 10 degrees where design extreme values can already be just over 15 degrees. There are no intuitive indicators that trigger for off design response mechanisms with ill-behaved characters as parametric roll, slamming and loss of stability. Waiting for the first occurring extreme values is hazardous. The focus instead should be on recognizing unfavourable, enabling conditions instead. At the same time visual observation of wave conditions is difficult because of height above the water, and obstructed view by cargo.

Particular concern in TopTier was raised to parametric roll in following seas conditions. The incident reviews suggested this likely played a role in the 2019-2020 incidents. Model tests performed within the project (see Figure 2) confirmed that ULCS vessels are more sensitive than expected to this response mode because of low GM conditions in full load conditions combined with low speeds due to port congestion and Easterly swells in winter time. An Excel support tool and explanatory video were circulated to explain the phenomenon and recognise enabling conditions prior to occurrence of extreme motions. This requires conscious observations that remain difficult to perform for instance at night time. Objective sensor based indicators alerting to enabling conditions for parametric rolling and screening wave conditions are to be evaluated and validated over coming months.

Figure 2: Example of parametric roll in following seas for a 10,000 TEU container vessel (wave height 4 m, wave period 11.9 s, vessel speed 10.6 kn, max. roll angle 19.7 deg)

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