Research towards Goal-Based Standards for Container Shipping

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ABSTRACT

Commitment to analyse and verify rule-related technical aspects of safe and efficient container shipping initiated broad R&D activities at Germanischer Lloyd. Casualty statistics show that container loss in heavy weather is an important issue for innovative container ship designs. The paper demonstrates two examples of research activities at Germanischer Lloyd aiming at the reduction of cargo losses. One example is ship-specific operational guidance, assisting the ship master to avoid excessive motions and accelerations in heavy weather. The design accelerations underlying the operational guidance are part of classification rules, requiring understanding of the physics of dynamic loads on containers and lashing. The status of the ongoing research in this area is shown, in particular, the study of the effects of container flexibility and dynamic load amplification, not addressed explicitly in the present classification rules.

KEYWORDS

container ships; dynamic stability; cargo loss

INTRODUCTION

As a classification society, Germanischer Lloyd is committed to maintain technical aspects of existing and new regulations related to safe and efficient container shipping. When new regulations are developed, they should be relevant (i.e. address real problems), feasible (not too restrictive to outweigh the expected benefits), consistent with the safety level provided by other measures and efficient (i.e. aiming at the issues where maximum gains can be achieved by ship owners).

In the EU-funded research project SAFEDOR, FSA study for container vessels has been carried out in order to estimate current risk levels for major risk scenarios, develop generic risk-benefit models for future use and identify cost-effective risk-control options.

Historical data *LMI (2004)* were used to determine the frequency of occurrence for different risk categories, based on the casualty data for modern fully cellular container ships for the period 1993-2004.

The world container fleet is relatively young: 71% of ships by number and 81% by the capacity are built less than 16 years ago. Larger container carriers (post-panamax and panamax) comprise 29.1% by number and 60.6% by capacity, while smaller vessels (sub-panamax, handysize and feeder) 70.9 and 39.4%, respectively. The results of the study show that incidents occur for all sizes similarly: while smaller container vessels are known to suffer substantial losses and damages, larger are suspected to be even more vulnerable because of immature technical standards and the associated lack of experience. Because of high rate of innovation in both design and operation of container ships, designers, operators and regulators alike have limited experience regarding cost-effective safety of newly built container ships.

The results show that container carriers are a relatively safe ship type in heavy weather.

The societal risk (F-N diagram) for container ship crew fits into the ALARP range, thus justifying further exploration of cost-efficient risk-control options. However, this risk is dominated by collision and grounding; heavy weather produces the lowest contribution. The individual risk to crew members is also in the ALARP region, dominated by collision (with the contribution 67.9%), fire and explosion (16.7%) and grounding (13.7%); heavy weather contribution (0.3%) is again insignificant.

Environmental risk (the expected quantity of released dangerous cargo from damaged containers) comprises in total about 1.0 t per ship per year, with the largest contributions from collision (53.3%), grounding (26.6%) and fire and explosion (10.3%); heavy weather contribution is 6.4%.

The consequences of heavy weather accidents are dominated by miscellaneous reasons (78% of all accidents in heavy weather, mostly loss of cargo), hull damage (15%) and machinery damage (6%); only 1% of accidents lead to foundering.

This assessment shows that cargo loss and damage due to ship motions in waves is the most significant intact stability problem for container ships, while capsize and hull damage are much less relevant. The situation could change if container ships would sail not on the damage stability boundary, as it is usually now, but on the intact stability boundary due to different subdivision.

Both the SAFEDOR study and data from insurance companies suggest that containers are lost mostly due to excessive ship motions and accelerations in heavy weather (60% of all lost containers according to SAFEDOR results); however, there is large discrepancy regarding the total number of lost containers. According to SAFEDOR results, 100 containers are lost due to heavy weather per year, while according to insurance clubs, this number is at least one order of magnitude higher, comprising 2000 to 10000 containers per year.

This leads to different estimations of long-term safety level provided by container vessels: 0.039 lost containers per ship per year and $1.5 \cdot 10^{-3}$ container loss events per ship per year according to SAFEDOR compared to 0.4 lost containers per ship per year and 0.1 container loss events per ship per year according to insurance companies. As a possible explanation, the authors of SAFEDOR results assume significant underreporting in the used data, because container losses are not safety related. This explanation agrees with the estimation of the number of lost containers per accident: 26.7 according to SAFEDOR data vs. 4 according to insurance companies, which implies that *LMI (2004)* database contains only the largest accidents, while smaller loss events are not always reported, because this leads to delays due to loss claims.

Consistently with the identified risk levels due to heavy weather, the corresponding risk-control options were prioritised in the SAFEDOR FSA study as medium (exact weight distribution, constructive roll-damping devices, shipboard routing assistance and enhanced weather routing) to low (modified hull shape); none of these options were selected for a more detailed assessment with respect to their cost-effectiveness.

COUNTER-MEASURES

Container losses in heavy weather may occur due to accidental combination of several factors, including large accelerations, wave impacts and green water, dynamic deformations of containers and lashing, pre-damaged containers, twistlocks and lashing and improper loading (e.g. container overweight or heavy containers on top of a stack). The risk of such accidents may increase due to innovative ship designs (e.g. higher container stacks), tighter operating and loading schedules, as well as crew with insufficient experience on modern vessels.

Experience from the investigations of container damage accidents highlights the need for prompt pro-active measures in regulatory framework, including stricter control of container strength, weight and stowage, ship loading and operational performance standards. Presently, cargo safety is addressed by the following regulations:

- containers are designed and built according to ISO standards, thus their structural strength is pre-defined
- the *Container stowage and lashing plan* (subject to class approval) specifies allowable weights of container stack and properties of lashing system
- twistlocks and fully automatic locks are subject to class-specific standards
- ship-specific accelerations are maintained by and updated in classification rules

According to GL rules, either rule-based or calculated design accelerations can be specified; the former represent a 'safety envelope' over calculated accelerations for a large number of modern container ships, while the latter follow from hydrodynamic analysis in design wave conditions with an appropriate frequency of occurrence, not covering the most extreme scenarios. The level of safety implied by design accelerations is consistent with the ISO standards for container strength and the class regulations for stowage, lashing and locks. Therefore it would not be efficient to simply increase class-controlled safety level without controlling ISO container standards.

Moreover, the control of the entire system of regulations will not be efficient without the supervision of its implementation. Presently, the implementation of standards regarding container cargo safety is not sufficiently controlled. Although classification societies have competence and infrastructure to do this, authorisation by flag or port authorities is required.

Further, design accelerations as well as other relevant design rules are based on the assumption of prudent seamanship, which may imply increased risks for those modern hull forms where crew experience is insufficient; this issue is also not controlled. Thus, one of important missing parts in the current regulatory framework is the ship-specific operational guidance.

Such operational guidance should be consistent with the other regulations, e.g. with rule-based design accelerations, and is expected to increase the safety level in operation up to the other risks. In other words, the operational guidance supports the achievement of 'prudent seamanship' implied by other regulations, up to standard service performance, which is particularly urgent for innovative designs.

In addition, such an operational guidance provides a very flexible measure for prompt support of future innovative designs and innovative operational solutions, and can also be used to address issues not related to cargo safety, e.g. wave loads and crew safety in heavy weather and people comfort onboard. Broadly speaking, ship master should not be left alone in heavy weather: regulators should take care of operations as strictly as it is done in design. Although increasing number of ships are employing onboard weather routing (*Rathje and Beiersdorf, 2005*) or similar decision-support systems, the quality and safety standards of such systems should be controlled. Development of the requirements to ship-specific operational guidance is presently on the IMO agenda.

OPERATIONAL GUIDANCE

Operational guidance addresses excessive motions and accelerations in waves, which can occur due to rigid-body motions, particularly heave and pitch, due to slamming impacts and whipping responses, as well as due to green water on deck and wave impacts.

The purpose of the operational guidance is to indicate the combinations of operational parameters (ship speed and course) that should be avoided for given loading and seaway conditions. In order to do this, operational guidance requires some short-term performance measure (criterion) and the boundary between acceptable and unacceptable values of this criterion (standard).

Because this standard specifies short-term safety, a way is required of relating it to the long-term performance. Two possibilities were proposed in *Shigunov et al. (2010)*:

- to determine the value of the short-term standard leading to the required long-term (i.e. average over operational life) safety level
- to set standard minimising the difference between additional benefits per time (due to reduced rate of cargo loss) and additional cost per time (due to increased time on route), incurred due to the use of operational guidance.

As an illustration of the first way, the long-term exceedance rate of the maximum (over ship) lateral acceleration *g/2* was computed as a function of short-term standard R_2 using numerical Monte-Carlo simulations for an 8400 TEU container ship. The resulting dependency is shown in Fig. 1.

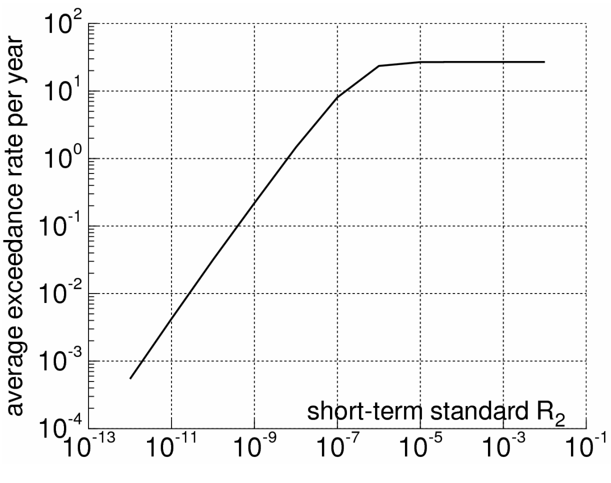

Fig. 1: Average annual exceedance rate vs. short-term standard

Assuming the required long-term safety level as 0.02 container loss events per ship per year the short-term standard R_2 can be set to 10^{-10} $1/(m\cdot s^2)$. Fig. 2 shows examples of unacceptable combinations of operational parameters (grey areas) for the load case with *GM*=2.3 m in two seaways.

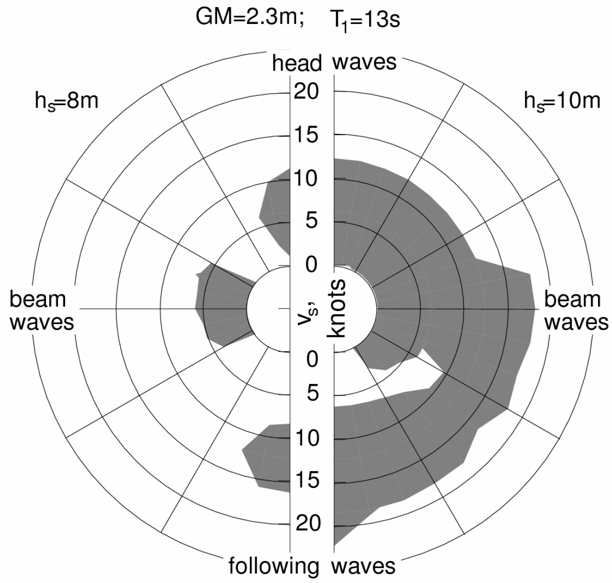

Fig. 2: Areas of unacceptable operational parameters for a 8400 TEU container ship with *GM*=2.3 m in a seaway with the mean period 13 s and significant wave height 8.0 (left) and 10.0 (right) m

SIMPLIFIED DESIGN ASSESSMENT PROCEDURE

In order to distinguish between ships requiring and not requiring operational guidance, a simplified design assessment procedure is proposed in *SLF51/INF.2 (2009)*: numerical Monte-Carlo simulations are performed for 'design' wave height prescribed as a function of the characteristic wave period T_1, and 'design' forward speed, depending on this wave height as well as wave direction μ, in short-crested irregular waves for a wide range of seaway parameters T_1 and μ.

FURTHER FACTORS

Besides rigid-body motions, further factors are becoming increasingly important for container ships: hull girder flexibility and flexibility of container stacks. An example in Fig. 3 shows time history of measured vertical acceleration at the forward perpendicular for a segmented flexible model of an 8400 TEU container ship, indicating significant dynamic amplification of vertical accelerations due to slamming impact

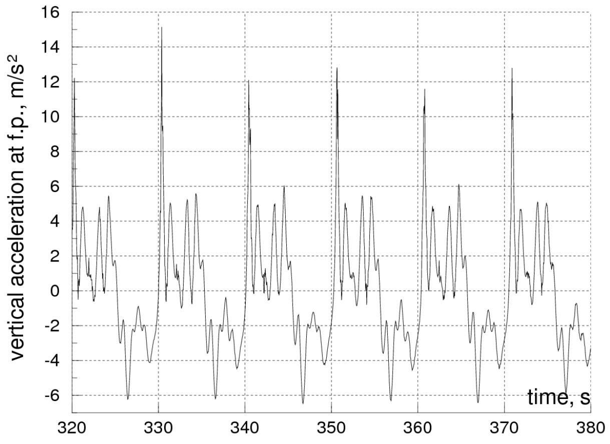

Fig. 3: Measured vertical acceleration at the forward perpendicular of a model of an 8400 TEU container ship (time scaled to full scale)

and the resulting whipping response, *Oberhagemann et al. (2009).*

Wolf and Rathje (2009) studied the influence of container flexibility on container stack dynamics and loads on containers and showed that the consideration of prevailing dynamic effects due to flexible container stacks on the weather deck is essential for the assessment of stack loading.

The dynamic response of a container stack is highly nonlinear due to clearance in lashing, interaction with adjacent stacks, friction effects etc. Therefore, time-domain simulations were performed using a FE model of container stacks. Containers were modelled as super-elements with interfaces to other elements and with contact and friction effects between stacks; stiffness and mass inertia of the super-elements were condensed from a detailed FE-model of a container. Twistlocks were modelled as spring-damper elements with gap and contact capability; their stiffness was derived from a detailed FE-model. Lashing was not considered and is addressed in the ongoing work. Friction and damping parameters for high-frequency responses were derived from full-scale measurements of the dynamics of stowed containers.

An example study is shown for a container stack carried on the weather deck of a 9200 TEU container ship. Roll motion characteristics are derived from hydrodynamic analysis, leading to design conditions with roll period 18 s and amplitude 26°.

Parametric studies were carried out in order to quantify the effects of the cargo distribution over the stack, twistlock stiffness, structural damping and adjacent stack interaction.

The study has revealed that flexibility effects lead to distinctive dynamic amplification of transverse racking forces and, particularly, vertical forces due to successive uplifting and crashing down of the upper containers while rolling to port or starboard, respectively. Due to this effect, the influence of the vertical cargo distribution is especially significant: container and twistlock loads are higher for stacks with higher centre of gravity.

Stack interaction has shown to also have a significant influence: both vertical and transverse loads are amplified due to the interaction of the upper containers in the adjacent stacks, Fig. 4.

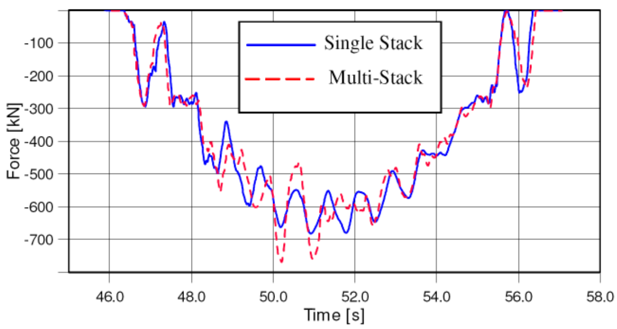

Fig. 4: Effect of stack interaction: vertical forces on container corner for a single stack and multiple stacks

The results of the simulations were compared with loads based on classification rules for a single unlashed eight-tier rigid container stack with proper cargo distribution and standard accelerations.

Simulations (Fig. 5) show asymmetrical front-to rear-end distribution of container loads: the front end carries higher transverse and, particularly, vertical loads because of the higher flexibility of the door end.

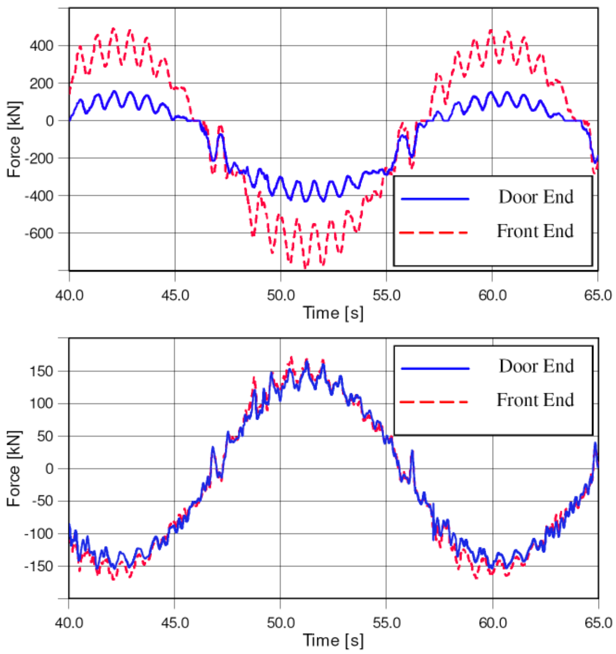

Fig. 5: Front-to-rear asymmetry of container loads: vertical (top) and transverse (bottom) forces on the top of the lower container

This effect is not considered in GL rules for unlashed configurations: for unlashed case, the loads at both ends are assumed identical and, effectively, equal to the average load between the front and rear ends. Therefore, the simulated vertical loads and corner post forces at the door end are lower (respectively, at the front end higher) than those from the rules. On the other hand, the average between the front and rear end lifting force in simulations is about 25% higher than the rule-based value due to dynamic load amplification (container uplifting and bouncing).

CONCLUSIONS

Commitment to analyse and verify rule-related technical aspects of safe and efficient container shipping initiated broad R&D activities at Germanischer Lloyd. The presented results show that cargo loss and damage may be of especial concern for modern container carriers. Mitigation measures are proposed, such as ship-specific operational guidance. Example is shown of a possible approach to operational guidance reducing lateral accelerations to the prescribed long-term rate. Further factors are identified which may be responsible for cargo losses, particularly flexibility of ship hull girder and container stacks.

Ongoing R&D activities concern further factors responsible for cargo loss and their design limits (e.g. vertical accelerations), cost-benefit analysis over operational life for setting economically sound short-term performance standards, incorporation of further factors into operational guidance (slamming and whipping, vertical accelerations, dynamic response of container stacks and lashing, crew safety and comfort) and roll-damping devices.

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