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MARIN


# LASHING@SEA

## EXECUTIVE SUMMARY

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| Senter Novem | : | SMIG07002 |
| Report No. | : | 19717-20-TM |
| Date | : | September 2009 |

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# LASHING@SEA

## EXECUTIVE SUMMARY

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| MARIN order No. | : | 19717 |
| Ordered by | : | Maersk Shipmanagement |
| | : | LASHING@SEA project |
| SENTER NOVEM | : | SMIG07002 |

"Aan dit project is in het kader van de Kaderwet Subsidies Verkeer en Waterstaat en het tijdelijke Subsidieprogramma Maritieme Innovaties een subsidie verleend vanuit het programma SMI, dat gefinancierd wordt door het Ministerie van Verkeer en Waterstaat. SenterNovem beheert deze regeling".

| | | |
|---|---|---|
| Reference | : | Cargo securing, SMI |
| Reported by | : | J. Koning |
| Reviewed by | : | Henk van den Boom |

Wageningen, March 2009
MARITIME RESEARCH INSTITUTE NETHERLANDS

# 1 SUMMARY

## 1.1 Verkorte Samenvatting (Dutch)

Het Lashing@Sea project is opgestart om de regelgeving en technologie in het zeetransport te evalueren. Aanleiding was het gesignaleerde ontstaan van een non level playing field en een toenemend aantal incidenten met lading schade en verlies.

Een consortium bestaande uit 23 bedrijven uit de industrie en overheden is samengebracht op het werk te doen en de resultaten te evalueren. De partijen omvatten rederijen, leveranciers van sjormaterialen, overheden, leveranciers van aan boord systemen en kennis instellingen.

De procedures, regelgeving, en voorkomende problemen zijn in kaart gebracht uit documentatie en vooral interviews en questionnaires met betrokkenen uit de praktijk.
De verkregen inzichten zijn getoetst aan de praktijk door middel van metingen aan boord van vijf schepen en gerichte proeven aan de wal.

Er werd geconstateerd dat in de container transport sector een aantal factoren aanwijsbaar zijn die het draagvermogen van lading in gevaar kunnen brengen. Twee significante aspecten zijn geïdentificeerd die niet bij het ontwerp worden meegenomen en dus afbreuk doen aan de bestaande veiligheidsmarges. Dat zijn dynamica uit de flexibiliteit van het schip en interactie tussen naast elkaar staande rijen.
Daarnaast werd geconstateerd dat de betrouwbaarheid wordt beperkt omdat de geladen situatie blijkt te kunnen afwijken van de bedoelde waarmee kritisch geplande beladingen onstabiel kunnen worden.

De bevindingen bij RoRo en Zware lading transport wezen uit dat de ontwerp uitgangspunten overeenkomen met het gedrag van de schepen en lading in de praktijk.
Er zijn ontwikkelingen om minder te sjorren dan volgens internationale richtlijnen wordt voorgeschreven. De ruimte daarvoor wordt binnen die richtlijnen wel geboden echter zonder handvast voor de te volgen procedures. Het Lashing@Sea project heeft daarvoor een voorstel gedaan. Een verzoek om deze vervolgstap verder op te pakken en te formaliseren is uitgegaan naar IACS en IMO. Hiermee is een stap gedaan richting een internationaal level playing field.

## 1.2 Short summary (English)

The Lashing@Sea project was started to evaluate standards and technology in sea transport. Trigger was the noted development of a non level playing field and an increasing number of incidents involving cargo damages and losses.

A consortium comprising of 23 companies from industry and governments was brought together to perform the work and evaluate findings. The group included ship owner/operators, lashing gear and on board software manufacturers, governments, classification societies and technology institutes.

Procedures, rules and typical incidents were summarized from documentation and more specifically from interviews and questionnaires by practical experts. The obtained insights were validated versus the operational conditions on board by measurements onboard of five ships and by means of dedicated tests on shore.

It was found that several factors can be listed in container transport, which affect reliability of the secured cargo stow. Two significant aspects were identified that are not included in present design practice and thus reduce existing safety margins. These are dynamic loads by hull flexibility and interaction between adjacent container rows.
In addition it was found that reliability is reduced by disagreements between the actual cargo stow on board and the planned situation. Critically planned configurations may thus become unstable.

Findings in RoRo and Heavy lift transport showed that design assumptions match the behaviour of the ships and cargo in service. There are developments to reduce cargo securing compared to international recommendations. International legislation allows for such reductions but does not provide guidelines on the procedures to be followed.

The Lashing@Sea project formulated a “Unified Interpretation” of the existing legislation as a first proposal for this. A request to follow up on that was forwarded to IACS and IMO to include the recommendations in practical industry and thus take a step towards a more level playing field.

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## 2 INTRODUCTION

Sea transport is an essential part of global and local (Dutch) economy. It is a highly competitive sector where innovation is crucial. Developments aimed at scale enlargement and cost reductions are the consequence of the large number of transported units and low profit rates per “cargo move”. The challenge in these developments is to maintain a required safety level. This is done by validating the design concepts against standing rules and requirements from authorities and class societies.

Over past years various signals have come forward from the industry with regards to safety. An increasing number of incidents in the container sector suggest that risks have increased. The question is raised whether increase of the transported volume, or reduced safety in general is cause of this.
In RoRo and heavy lift transport the incident numbers are not considered to increase. The industry is tuning the designs of cargo securing systems for particular trade routes. Various flag states are agreeing to different procedures for such cases which introduce a non level playing field. Such is bad for fair competition and thus raises risks for safety as operators will be tempted to deviate from their procedure to match other vessels performance. The industry is now asking for support from the authorities to adopt internationally agreed procedures on this.

In the light of the above considerations, the legislation on cargo securing has become the subject of discussion. A large number of stakeholders with conflicting interests play a part. These parties are not always in direct communication and this complicates dealing with changes in fundamental rules and procedures,

It is crucial for a healthy industry that innovations aimed at improved efficiency remain possible. Safety levels however need to be maintained for the interest of the environment and the common public.

- How can innovations be persuading while maintaining or even increasing safety standards.

The Lashing@Sea project was started to address this question. The following objectives were formulated:

- Bring together a Group of stakeholders to discuss and address the procedures and gear used to secure cargo on board of ships.
- Obtain insight and understanding into the physics of loads and responses in cargo securing on present generations of cargo ships. This building on existing insights such that the industry may validate and develop concepts based on proper assumptions.
- Develop guidelines for securing of cargo under limited environmental conditions and provide bases for a level playing field for all operators.
- By means of the above, raise safety and efficiency on container vessels, RoRo and heavy lift transport vessels.

## 2.1 Project consortium

The project was executed as a joined industry project (JIP) under the subsidy program of MIB/SMI. Maersk Ship management BV was the primary contact towards SenterNovem. The project was coordinated by MARIN with participation and funding from following participants.

**Ship owners/operators**

- Maersk ShipManagement bv, Rotterdam Netherlands;
- CMA CGM head office, Marseille France;
- Danaos ShipManagement, Piraeus Greece;
- Wallenius Wilhelmsen Logistics, Stockholm Sweden;
- Norfolk line, Den Haag, Netherlands;
- NYK / Monohakobi Technology Institute, Tokyo Japan;
- Royal Wagenborg, Groningen Netherlands;
- Spliethoff / BigLift Shipping, Amsterdam Netherlands;
- United European Car Carriers (UECC), Grimstad Norway.

**Classification societies**

- ABS, Houston USA;
- Bureau Veritas, Paris France;
- Det Norske Veritas, Oslo Norway;
- Germanischer Lloyd, Hamburg Germany;
- Lloyds Register, London England.

**Governments**

- Directoraat Generaal Luchtvaart en Maritieme Zaken (DGLM) - Netherlands
- Swedish Transport Agency (SMA) - Sweden
- Maritime and Coast guard Agency (MCA) - United Kingdom

**Lashing Manufacturers**

- German Lashing
- MacGregor
- SEC

**Technology providers**

- Amarcon;
- MARIN;
- MariTerm as;
- SIRI Marine.

Subsidy - funding

- Maritime Innovation Board (MIB) /NML/ Senter Novem – Netherlands.

The project was supported by the foundation Nederland Maritiem Land NML and funded by the Maritime Innovation Board (MIB) under the Senter Novem / SMI arrangement.

# 3 DESCRIPTION OF DURABLE TECHNOLGY

Cargo on ships is secured against the forces of wind, waves and the motions of the ship. The design and use of this securing is based on the expected forces. In order to assure a required level of safety, the design of a cargo securing system has to meet internationally agreed standards and has to be approved by the vessels flag state authority. The rules and standards need to evolve with the innovating industry, changing vessel dimensions and new cargo stowage concepts. In order to evaluate the rules and standards, a thorough understanding of the mechanics and physics in contemporary cargo securing is needed.

A durable transport sector thus requires every now and then that standing procedures and guidelines are evaluated. The industry has taken the initiative for this in the Lashing@Sea project. For the shipping sectors of container transport, RoRo and Heavy lift transport, the focus was on following aspects:

## 3.1 Container transport sector

Economy of scale has changed the design and dimensions of container ships dramatically. New designs are by comparison more flexible than the older Panamax designs of the 80-90-ties. Over a period of only 15 years the transport capacity increased from 4000 to 15000 TEU. Stacking heights increased from 4-5 to 7-8 tiers. Along with this the securing of cargo changed as well. Rules however, effectively stayed the same.

- Design principles did not change principally compared to Panamax designs;
- Changing design ratios have given the hulls different flexible response;
- Vertical lashing concept has made cargo stows much more sensitive to ship motions and transverse loads;
- There is a strong drive towards efficiency improvements. These have brought solutions based on other concepts that those that were known at the time when the rule design principles were developed and formulated;
- There seems to be an increasing number of incidents with damaged and lost containers. Incidents with complete collapsed bays raise the question if loading mechanisms are of interest that are not included in design considerations, and that may exceed design limits well below the intended design envelope.

Lashing@Sea targets the loads in container stacks and their correlation with the behaviour of the ship and the entire cargo stow. The results of the investigation should allow the participants from the industry and authorities to include new insights in the statement of improved rules, and development of innovative solutions for present and new generations of containerships.

Durable safety and efficiency in the transport sector can thus be improved.

For the Netherlands this has following direct consequences:
- Prevent pollution of Dutch waters and beaches by lost cargo from container ships;
- Improve safety and efficiency for ports and stevedores as less cargo will be offered that is close to collapse and thus threaten safety.

Conclusions and recommendations will provide Netherlands with international exposure related to practical rules and standard in transport sector. World port Rotterdam and Netherlands can reinforce the image of knowledge development.

### 3.2 Heavy Lift Transport sector

In Heavy lift transport each journey is engineered one by one to meet stability- and structural requirements and to avoid cargo shifting. It is difficult to adopt standardized design procedures, since specialised ships are used and because transported cargo has often exotic dimensions. This often leads to discussion between operator and warranty surveyors when the lashing documents need to be approved. This in turn results in unfavourable delays and costs when additional calculations or reinforcements are requested.

Netherlands is strong in this sector with companies as Biglift, Jumbo shipping and Dockwise. There is a strong demand for standardized and agreed interpretation of design requirements.

One of the objectives of Lashing@Sea is to evaluate and increase the support for design and operational procedures that are in use for various times in the heavy lift transport sector. By increasing this support, the Dutch heavy lift transport sector may continue and possible extend her international services.

### 3.3 RoRo transport sector

Cargo in RoRo transport is secured according to the procedures in the Cargo Securing Manual (CSM). The CSM has to meet IMO and SOLAS requirements and this is checked by the vessels flag state. The legislation leaves room to take into account local weather conditions and duration of a transit (Weather dependent lashing). No guidance however is provided as to how this should be done. Various flag states have developed and used their own interpretation on this subject. This has lead to a non level playing field that can affect market competition and safety as ships deviate from their CSM procedures under operational pressure.

The Lashing@Sea project has the objective to define guidelines in order to create a level playing field with regards to lashing for limited environmental conditions. Considering the international framework of rules and standards, the results will be brought to the attention of a relevant international platform.

# 4 PROJECT PLAN

## 4.1 Project phasing

Het project was setup in following stages:

- Review of current practice;
- Measurement campaigns;
- Data analysis;
- Ranking of key factors;
- Definitions of conclusions and recommendations.

### 4.1.1 Review of current practice

In this stage, the underlying rules and standards, operational procedures and gear, typical incidents and most relevant hazards were identified from interviews with various stake holders and available documentation. The findings provided the starting points for the evaluation of the results of further stages.

### 4.1.2 Measurements campaigns

The design of both ships and cargo securing systems is based on design rules coming from accepted calculation- or empirical- models. These models, and in particular the criteria that have to be met, are maintained, and when needed adjusted, by authorities and classification societies based on their insight in the physics of loads and responses on board. The measurement campaigns were aimed at the investigation of “in service” loads and responses and the correlation of these with design assumptions.

Five in service measurement campaigns were conducted in the scope of the Lashing@Sea project:

#### 4.1.2.1 Heavy Lift transport

Biglift Happy Buccaneer


**Figure 1 Biglift Happy Buccanneer**

The vessel sailed the Eastern hemisphere mainly between Persian Gulf, Far East and Australia / New Zealand.

Measured quantities included:

- Vessel position, Speed and Heading;
- Wave and wind data;
- Forecasted wave and wind data;
- Ships motion response and accelerations in two locations.

Work was performed by MARIN with assistance and support of:

- Biglift shipping both at main office for logistics, and crew on board during the measurement period of two and a half years;
- Amarcon for logging of forecast data and on board calculation of predicted motion response in the expected waves.

#### 4.1.2.2 RoRo transport

- Norfolk Line - Maersk Voyager Hull response & lashing loads
- Wagenborg Schieborg Hull response & lashing loads
- MTI MCS facility Lashing loads and cargo dynamics


**Figure 2 Maersk Voyager & Wagenborg Schieborg**

Measurements were performed on board the two vessels and included:

- Motions of the vessel at two locations;
- Position, speed and heading;
- Forces in the cargo securing of one transport unit.

Work was done by:

- SIRI Marine for overall measurements in cooperation with
- Norfolk line & Wagenborg for logistics and assistance by crews on board
- Amarcon for logging of wave forecast climate (SPOS) and on line motion predictions using OCTOPUS software suite.

**Figure 3 MCS tests for RoRo sector**

Work was aimed at evaluation of design assumptions for cargo securing system under controlled environment conditions. The MCS facility could be used to generate a clear defined motion response and corresponding acceleration field. Various configurations of cargo units and cargo securing gear were evaluated.

Measure parameters included:

- Platform motions and accelerations;
- Rolling cargo secondary motions and accelerations;
- Lashing loads during the tests;
- Video footage during tests.

Work was performed by:

- NYK / Monohakobi Institute of technology who operate the MCS (multi cargo simulator) where the tests could be conducted.
- MariTerm who coordinated the test preparation, execution and reporting, assisted by
- Wallenius Wilhelmsen who provided materials and engineering support.
- SEC who provide the lashing materials that were used in the tests.

#### 4.1.2.3 Container transport

Measurements were conducted on two ships and in the MCS test facility in Yokohama.

##### 4.1.2.3.1 CMA-CGM Rigoletto


**Figure 4 CMA-CGM Rigoletto**

Work was aimed at identification of load contributions by hull accelerations and deformations, and the response of the cargo stacks to these loads. For that purpose the vessel was fitted with following sensors:

- a grid of 11 acceleration sensors along the length and width of the hull;
- hull deformation and load sensors in two cross sections;
- data link to obtain, position, heading, speed, rpm, rudder and wind data;
- data link with loading computer and weather forecast data;
- Instrumented container that was carried in top tiers of aft bay and first bay forward of the accommodation.

The work was carried out by:

- MARIN who had overall coordination and responsibility for instrumentation in the hull.
- Bureau Veritas who handled the instrumentation and maintenance of the instrumented container and
- CMA CGM who provided logistics assistance to handle the container box, provide the slot to carry it for a period of two years and offer crew assistance with maintaining instrumentation performance and data collection.
- Amarcon who provided the OCTOPUS software that was used to interface with the loading computer and weather forecast module and provide on board calculation of notion response in forecasted weather.

#### 4.1.2.3.2 NYK Argus


**Figure 5 NYK Argus, MARIN instrumented container & lashing rods**

Work was aimed at identification of load contributions by hull accelerations and deformations, and the response of the cargo stacks to these loads. For that purpose the vessel was fitted with following sensors:

- A grid of 11 acceleration sensors along the length and width of the hull;
- Hull deformation and load sensors in two cross sections;
- Data link to obtain, position, heading, speed, rpm, rudder and wind data;
- Data link weather forecast data;
- Instrumented container that was carried in bottom tier of aft bay to record lashing- and container stack- forces.

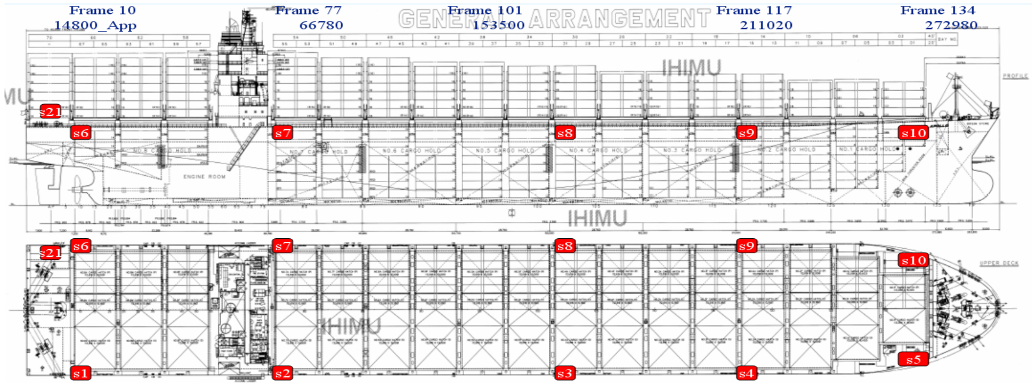



**Figure 6 NYK Argus - Accelerometer sensor grid**

The work was carried out by:

- MARIN who had overall coordination and responsibility for instrumentation in the hull and the instrumented container;
- NYK line that provided logistics assistance to handle the container box, provide the slot to carry it for a period of one year and offer crew assistance with maintaining instrumentation performance and data collection;
- Amarcon who provided the OCTOPUS software that was used to interface with the loading condition and weather forecast module and provide on board calculation of notion response in forecasted weather.

#### 4.1.2.3.3 MCS tests


**Figure 7 MCS - Full scale container tests 2 tiers**

**Figure 8 MCS Model scale tests 2-7 tiers, 1-3 rows**

Target was to address the behaviour of multiple tier and multiple row container stacks and to verify if lashing loads and stack response were in agreement with design assumptions.

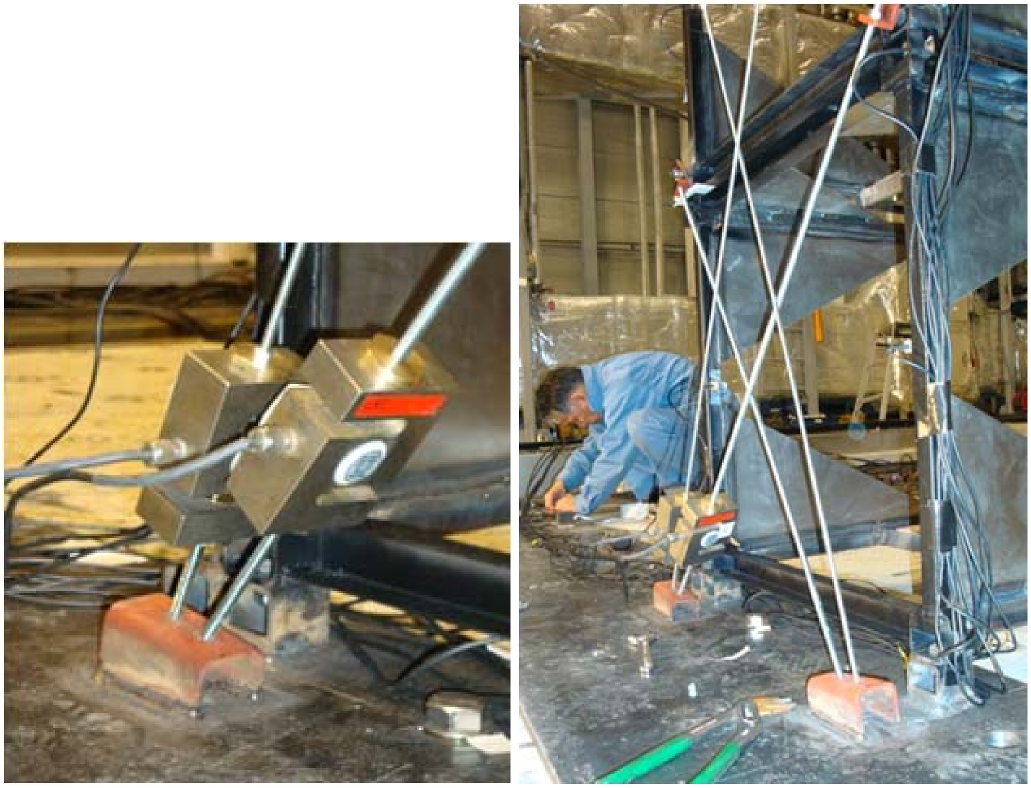


**Figure 9 MCS - lashing instrumentation**

The instrumentation included:

- extensive grid of accelerometers in the stacks;
- motions and accelerations of the test platform;
- lashing forces;
- Video footage.

Work was done by:

- MARIN for coordination of overall test program, scaling procedures, overlooks the execution of tests and data analysis;
- NYK / MTI who assisted in preparation and execution of the tests in Japan and fabrication of the container scale models;
- Germanischer Lloyd who designed a container scale model to meet the scaled requirements for an actual 20 feet container unit;
- University of Tokyo who assisted in the execution of the tests and evaluation of the mechanical properties of the first prototypes of the container scale models.

#### 4.1.3 Data analyses

Data from measurements was analysed according to following procedures:

- remove measurement spikes;
- data reduction to obtain 30 minute statistics of measured signals;
- checking for sensor integrity based on statistics;
- Selection of interesting events;
- Detailed evaluation of selected events for occurring phenomena, rigid body motions, hull deformation, whipping, springing, and torsion deformation in the hull;
- correlation between deck, container and lashing responses;
- Assessment of container stacks dynamics.

A variety of tools and approaches was used and developed in the evaluation of the measurement results.

A spatial filtering algorithm was developed in order to isolate rigid body motions and flexible deformations from the combined measured signals of the 10 accelerometers along the deck.

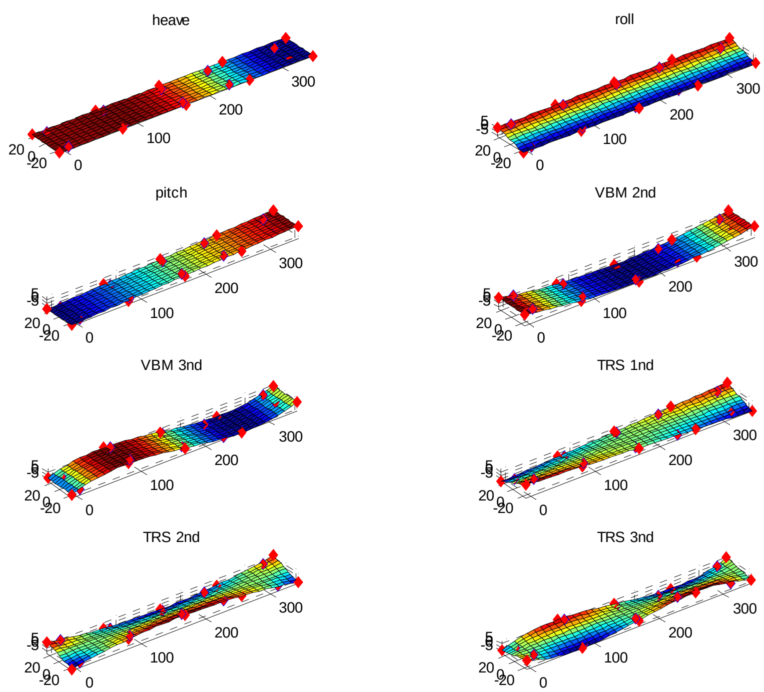



**Figure 10 Hull deformation parameterisations**

Dynamic mode analysis was applied in order to visualise and isolate natural modes and operational mode shape deflections from the measured data.

Selected results were compared with values obtained from design model assumptions in order to assess the relevance of phenomena that were not included in those assumptions.

#### 4.1.4 Ranking of key factors

A series of key factors was identified in the course of the review of current practice and the data analysis of the measurement data from the on board and MCS tests.

These phenomena were ranked in order to produce a clear picture of the most important aspects that determine safety and efficiency of sea transport for the various sectors.

#### 4.1.5 Definition of conclusions and recommendations

Based on the identified ranking of key factors, conclusions were drawn and recommendations were formulated. Part of these was proactive and others were reactive. The proactive part addressed the factors before a vessel goes into operation or puts to sea with a particular cargo and lashing configuration. The reactive part aimed at handling the vessel while in transit in order to minimize the probability for incidents in case of unfavourable conditions.

# 5 RESULTS

## 5.1 Review of current practice

### 5.1.1 Rules

Most important rules & guidelines for cargo securing practice are defined by SOLAS and IMO.

- SOLAS § 5 Regulation 5: Standard cargo on ships should be secured using the procedures and gear as described in the Cargo Securing Manual (CSM).
- IMO – MSC circular 745 on Cargo Securing Manuals
- IMO Code of Safe practice for Cargo Stowage and Securing (CSS code)

Basic purpose of the cargo securing system is to prevent cargo from shifting.

The IMO documents provide a framework for the requirements that the cargo securing system is supposed to meet.
Flagstates are responsible for the practical interpretation of these rules and for the assessment and approval of the operational documents (CSM's) that are offered by ship operators.
After meeting these requirements any design is expected to be fit for purpose. As such gear is designed to meet rule requirement and not specifically to meet operational conditions. Meeting the rule requirements is considered to implicitly mean that operational conditions are met as well.

IMO Circular MSC/Circ.745 on Cargo Securing Manuals § 3.3.1 lists that following factors, among others, should be taken into account when the risk of cargo shifting is considered:
- Duration of the voyage
- Geographical area of the voyage
- Sea conditions which may be expected
- Expected static and dynamic forces during the voyage

Design conditions that are considered explicitly are
- rigid body motions and accelerations by waves;
- wind loads;
- water sloshing loads if applicable;
- internal forces from the cargo securing system.

The CSS code Annex 13 tabulates acceleration values that should be used for the design process. Paragraph 7.1 states that for operation in a restricted area the accelerations may be reduced taking into account the season of the year and the duration of the voyage

The code mentions that higher values could occur under conditions where non linear phenomena as parametric roll, dynamic loss of stability, wave slamming and hull whipping are likely. These conditions should thus be avoided by the crew and as such are **not part** of the design envelope.

- It was noted that no guidelines are given on how to include guidance in the CSM in order to avoid excessive loads by non linear effects.
- Also there is no reference on how the design reductions for restricted environmental conditions should be included in the CSM.

### 5.1.2 Typical incidents

Typical incidents relate to the accidents that may occur. The incidents indicate the type of events that a cargo securing system should be expected to meet and should preferably be designed to deal with.

It was learned that no centralized data base is kept on shipping incidents relating to cargo loss and damages. Damage reports go from vessel to line operator, involved local maritime authorities (coastguard) and P&I club. Line operators are held back to expose incident details as it is bad publicity and since the P&I club are dealing with the matter.
The P&I club investigate the details of the incidents but do not share findings. A reliable evaluation of trends in relation to innovations and scale enlargement can thus not be made.

Interviews with vessel operators, fleet managers, crews and stevedores provide interesting information on incidents and near misses. They are however difficult to quote since generally no details may be shared.
The most interesting source of information then is the Internet where many reports of more or less "public released" incidents are shared on several sites and loose articles in local papers.

It was found that there does not seem to be a single typical type of incident that can be said to explain the majority of cases. Incidents occur along the quay, while leaving port, in head seas, beam seas and in following seas. Incidents occur in severe weather but also in calm weather. This multitude of conditions suggests that a "silver bullet" solution to solve the safety issue is unlikely to exist. A selection of incidents is highlighted in Figure 11 thru Figure 17 to illustrate the variety of conditions where accidents happened.

**Figure 11 Incidents - In port during loading / offloading**

**Figure 12 Incidents - Consequential damage by cargo shift**

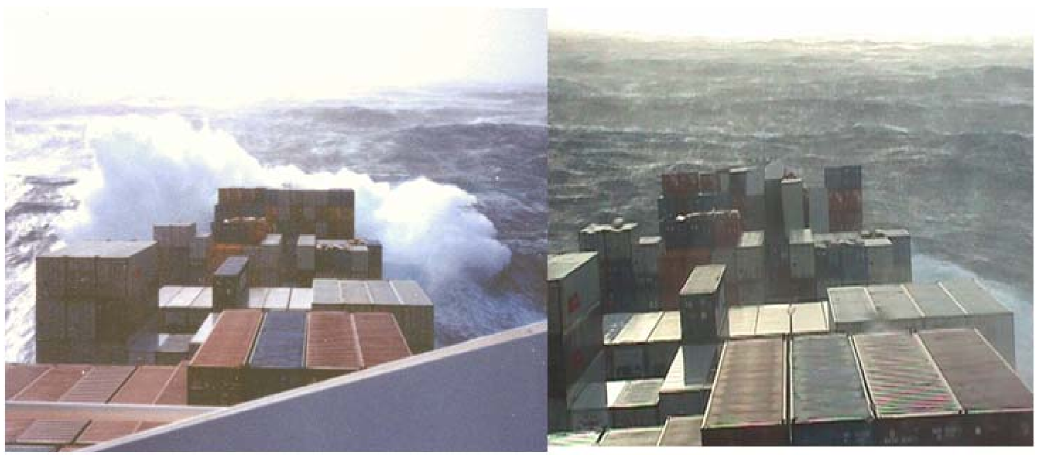


**Figure 13 Incidents - Head seas, high speed -> bow damage**


**Figure 14 Incidents - Head seas, low speed -> parametric roll**

Figure 15 Incidents - low GM / low freeboard

Figure 16 Incidents - Unexplained bay collapse / empty containers


**Figure 17 Incidents - Unexplained bay collapse / loaded containers**

### 5.1.3 Crew questionnaires container vessels

A crew questionnaire was assembled in order to obtain feedback from the operational experts on boards of containers ships. 158 responses were returned from vessels sailing for the ship operators in the project. The objective of the questionnaire was to list the most relevant hazards for cargo securing on board and the concerns that contribute to decision making in the bridge. A selection of results is listed:

The hazards for cargo securing as assembled from the crews responses are shown in Figure 18

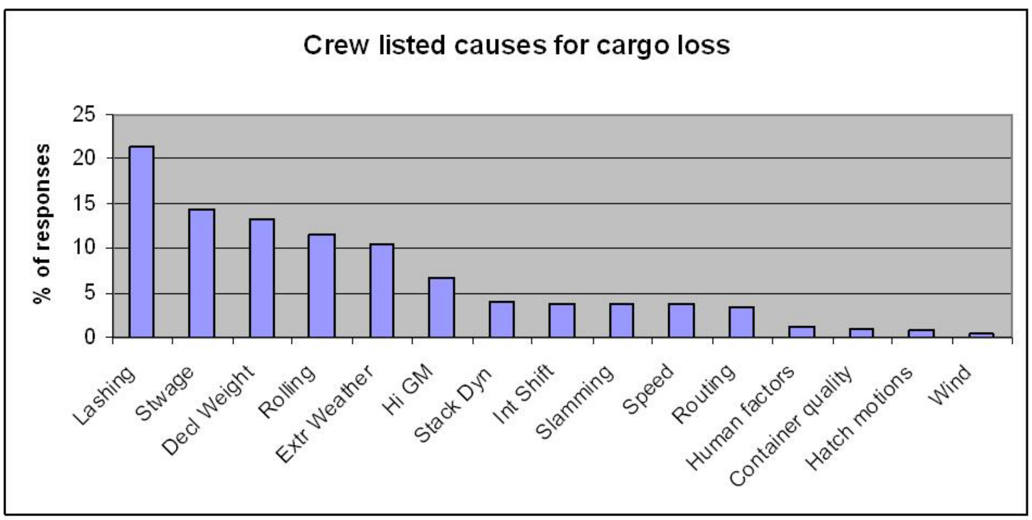



**Figure 18 Crew listed causes for cargo losses**

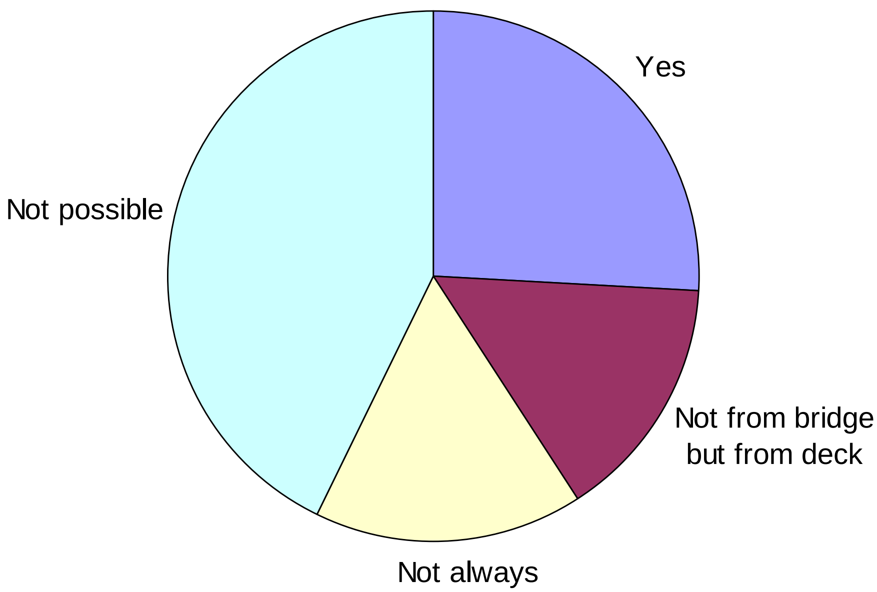
Of the total respondents 30 Percent was found to have experienced damaged or lost container cargo. This seems a high percentage but it is in agreement with the estimated damage probability of 0.05% for a transported container. The small percentage produces a similar probability for incident when combing it with the large number of containers on board in a single trip and the number of transits that average officers sail in their career.

A review of the causes for the actual incidents that were returned produced following short list of factors:

- handing the vessel in severe weather (speed, heading);
- failing twist locks and deck fittings;
- internal cargo shifting and
- poor stowage (weight distribution) and declared weight.

About the feasibility to determine when loads become too high and thus decide when remedial actions are needed (speed, heading)

*Is it possible to get a good impression on the developing loads in the cargo securing's from the bridge and react in time? Or can developing high loads go unnoticed?"*




Obviously it is very difficult for vessel crews to get good feedback from the ship in order to take timely actions to prevent excessive loads.

Crew guidance for cargo securing is supposed to be described in the CSM. It was returned by 25 percent of the respondents that ships are regularly operated in conditions outside those described in the CSM. In this case typically the GM value is above the maximum value evaluated in the CSM. When sailing in part loaded condition, this can not be avoided on many ships.

### 5.1.4 Review of RoRo sector

The RoRo sector was reported to endure most incidents by cargo securing that was not applied according to requirements in combination with roll inducing effects as severe weather or even manoeuvring.

In many occasions RoRo cargo securing is designed to lower standards than those listed in the IMO Code of Safe Practice for Cargo Securing and Stowage. Various flag states have agreed/adopted procedures to evaluate and approve cargo securing procedures for reduced environmental conditions. These are then added with the Cargo Securing Manual.

No internationally agreed procedures exist to provide guidelines for this. This may lead to the development of a non level playing field and possible even to (unintentional) decrease of safety levels since no standards occur.

It was proposed that internationally agreed guidance on dealing with this issue will:

- Create the opportunity to maintain safety by evaluating requirement in wider context.
- Assure a level playing field as all operators can apply to the same set of rules and requirements.
- IMO was listed as the most suitable body to carry such guidance. Classification societies, joined in the IACS community, were however proposed as the best suited platform to develop and maintain such guidance. Their technical and more dynamic nature would allow considering all topics and agreeing on a working document to be offered to the IMO council as an interpretation of standing IMO legislation.

### 5.1.5 Review of Heavy lift sector

The current practice in Heavy lift sector is relatively straight forward.

Choose ship & stowage plan

Design accelerations & loads

Evaluate deck loads

Design reinforcements & sea fastenings

Draw out loading manuals and other documents

The key issue lies in the required approval of the final documents by warranty surveyors. No clear guidance on the requirement for design accelerations and loads is available.

Various values are offered (e.g. by class, design software codes, IMO). Often there is discussion on what design values should be used. This results in delays and extra costs when further reinforcements and sea fastenings must be fitted.

The in service practice learns that incidents in transit are rare. The vessel crews are experienced mariners; most significant loads are induced by rolling and pitching motions. By controlling speed, heading and ballasting condition, these loads are considered to be well under control in the expected sea states. Routing plans are routinely laid out to avoid severe weather if sensitive cargo is mounted. Vessel control is based on crew impression of rolling motions, and probability of wave slamming in head sea conditions.

Main challenge for Heavy Lift sector is to increase acceptance of design procedures that are in use for past years and that seem to perform well as indicated by the good performance of the fleet.

## 5.2 Measurement campaigns & Data analysis

### 5.2.1 Heavy Lift transport

Buccaneer measurement data spans the period from December 2006 until May 2009. In that period she sailed from Europe to the Far East where she stayed and sailed various cargos between the Persian Gulf, Australia and the Far East.

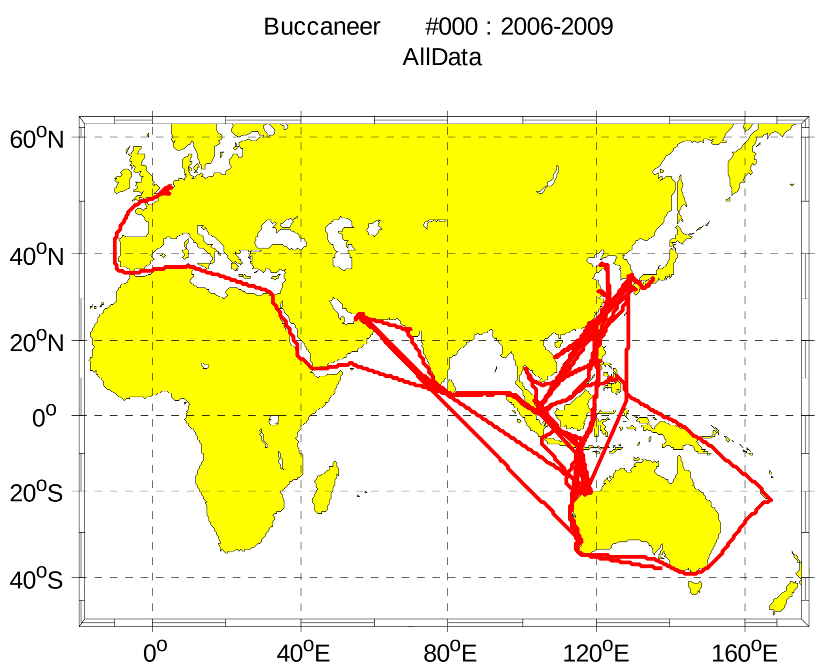



**Figure 19 Sailed track Biglift Buccaneer**

It was learned that motion climate seems to be actively limited to rolling motions of around 15 degrees and pitching motions up to 7 degrees single amplitude. The majority of time operations are in not too severe weather. Maximum sea states up to 9 meters significant wave height however were recorded using the Wave Radar sensor in the bow. Typically Buccaneer successfully evaded the worst parts of forecasted weather.

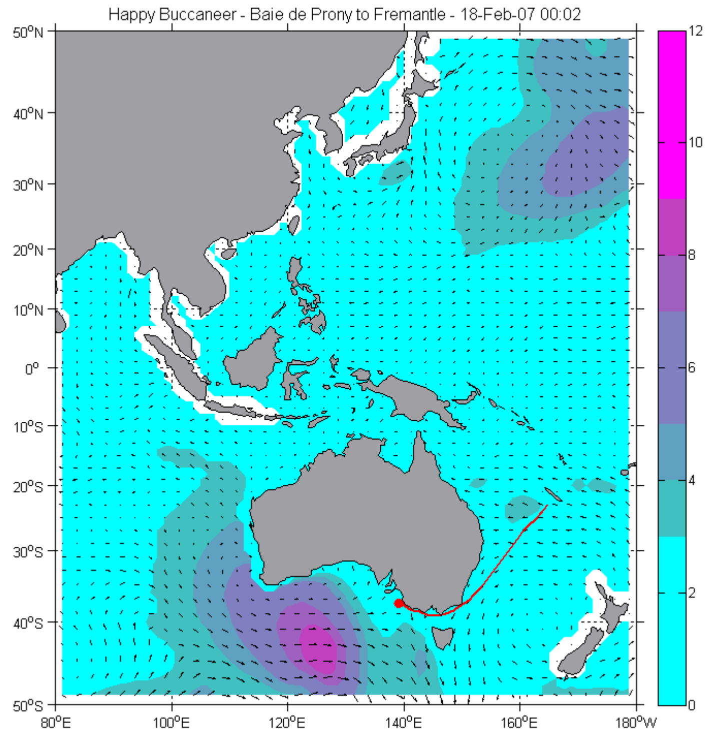



**Figure 20 Buccaneer evading severe Southern Ocean storm**

It was found that acceleration loads in the cargo area, were dominated by transverse and vertical accelerations. Transverse accelerations were highest in combination with rolling motions due to earth gravity contribution. Vertical accelerations were highest by heave and pitching motions. No significant slamming loads were found in the recordings of accelerations.

Highest responses were recorded as follows:

| Departure | Destination | TOD | TOA | extreme | Wind speed | Hs rdr | Hs noaa | Mariners handbook | Hve | Rll | Ptc | AcY | AcZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | knt | [m] | [m] | [m] | [m] | [deg] | [deg] | [m/s^2] | m/s^2 |
| Baie de Prony | Fremantle | 2/13/2007 | 2/22/2007 | 2007-02-19 th | 30 | x | 5 | 5 | 4.5 | 10 | 5 | 3.5 | 3 |
| Dampier | Singapore | 3/4/2007 | 3/12/2007 | 2007-03-7 / 9 th | 50 | x | 4 | 9 | 3.5 | 15 | 7 | 3.5 | 3 |
| Fujairah | Kwinana | 9/24/2007 | 10/11/2007 | 2007-10-7 / 10 th | 30 | 10 | 4 | 5 | 3 | 15 | 4 | 3 | 3 |
| Batam Island | Zhangzhou | 12/31/2007 | 1/7/2008 | 2008/01/1 - 2 nd | 30 | 4 | 3.5 | 5-6 | 3.5 | 15 | 3 | 4 | 3 |
| Dampier | Shanghai | 1/25/2008 | 2/5/2008 | | 35 | 6 | | 6 | 2.5 | 3 | 6 | 1 | 4 |
| Nantong | Fremantle | 4/22/2008 | 5/4/2008 | 2008/05/03 rd | 25 | 5 | 4.5 | 3-4 | 3 | 11 | 3 | 3 | 2 |

### 5.2.2 RoRo vessels

Measurements on board Ms Schieborg and Maersk Voyager lasted from begin 2007 until mid 2008. Vessels were trading the North Sea, German Bight and Skagerrak as shown in route maps of both vessels.

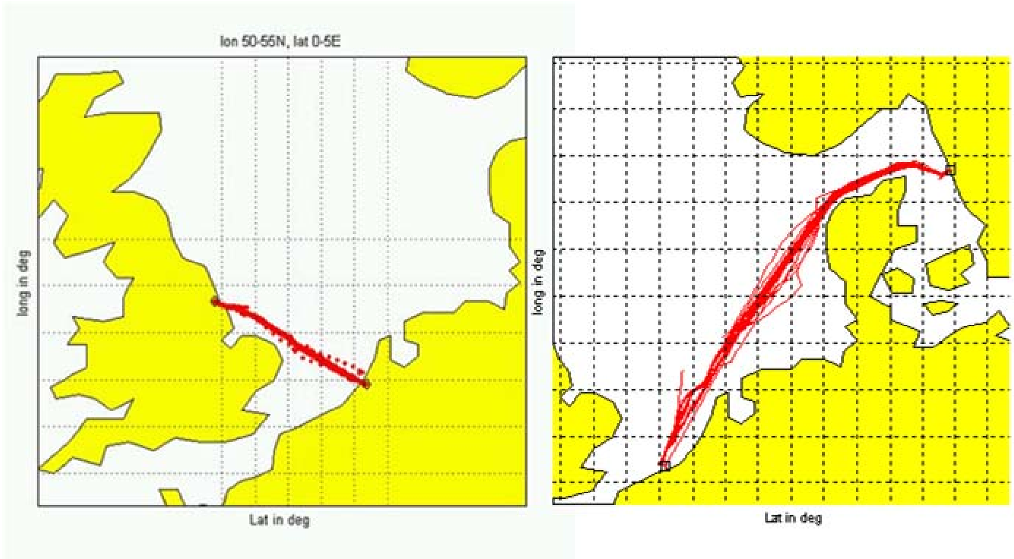



**Figure 21 Sailed tracks mv Maersk Voyager/ mv Schieborg**

The measurements on board the RoRo vessels resulted in similar findings as the results from the Heavy Lift campaign. Highest measured accelerations added to 4 meters/s^2 in transverse direction and 3-4 meters/s^2 in vertical direction. Although some slamming loads were identified in the data it was concluded that rigid body motions dominate the acceleration loads that are imposed on the cargo. Hull deflections and short duration impact phenomena are of smaller importance.

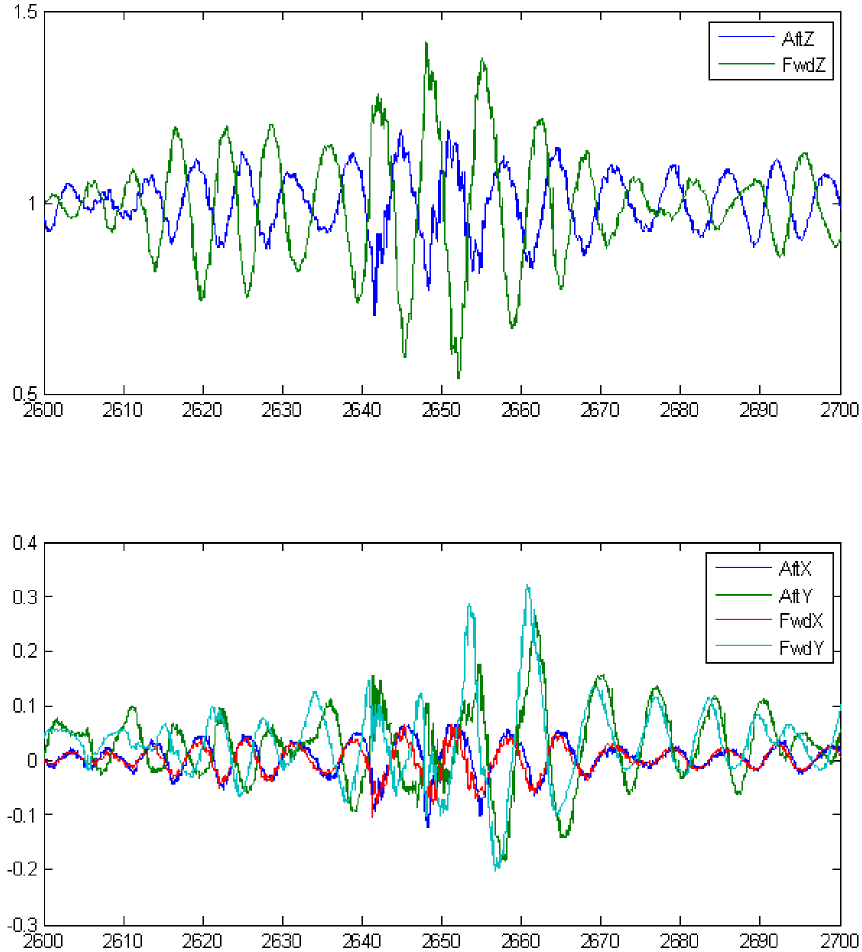



**Figure 22 Measured g-loads in transit Schieborg**

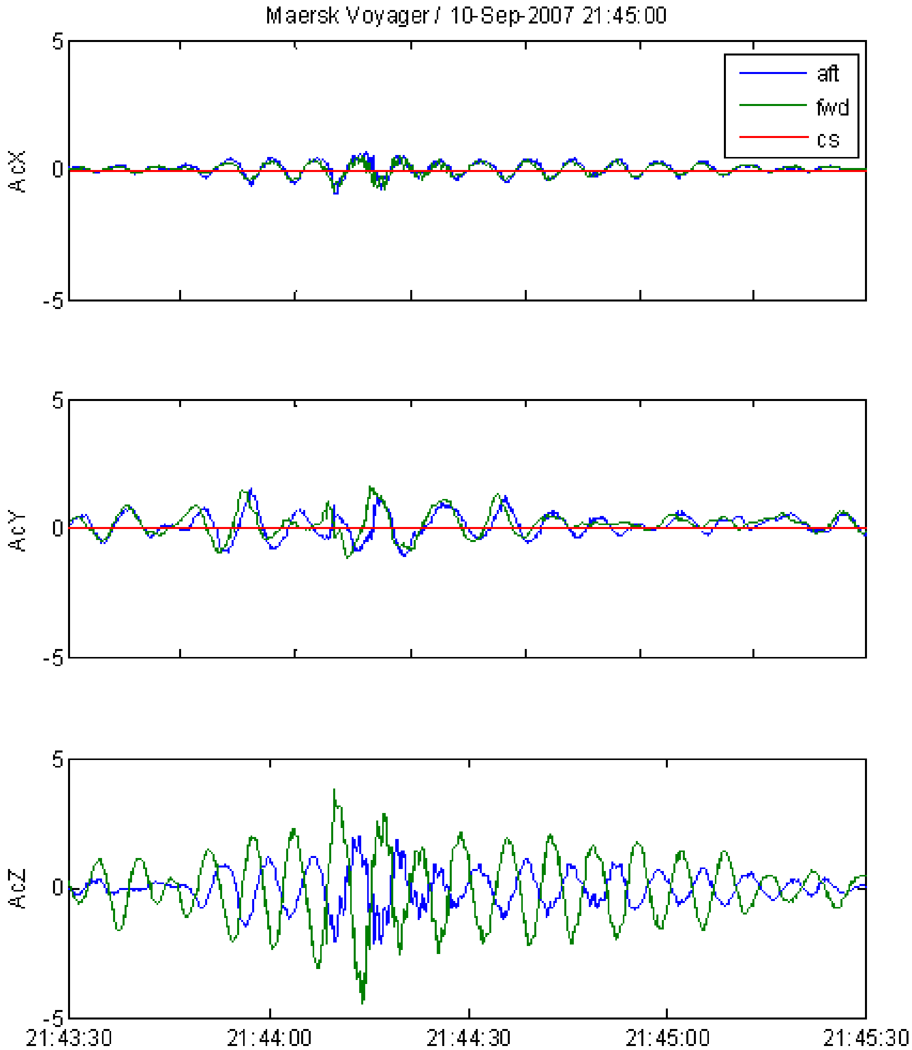



**Figure 23 Measured accelerations Maersk Voyager [m/s^2]**

Lashing Forces were observed both on Schieborg and Voyager and learned that loads are related to the rigid body motions mainly. Pretension levels in the lashings was observed to be around 10-15 KN on average or 1 to 1.5 tons. Upon progress of the transit the pretension levels were observed to reduce. Dynamic loads variations around the mean pretension levels were observed to approach the pretension level potentially causing lashings to fall slack.

It was observed that max lashing force does not solely rely on vessel accelerations. The mass and rigidity of the secured trailer naturally plays an important role as well. These were however not logged.

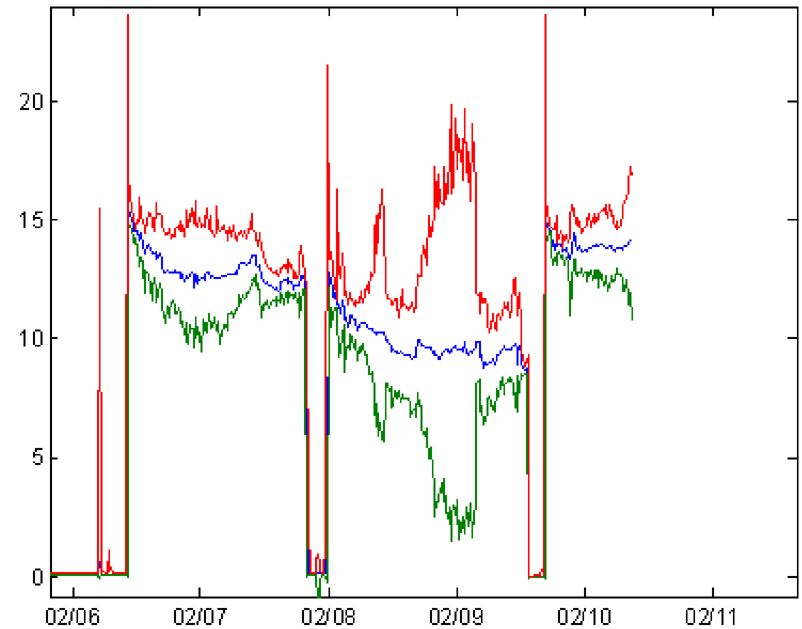



**Figure 24 Typical web lashing force recordings [KN]**

### 5.2.3 Container vessels

The container ship measurements clarified several aspect of in service loads on board.

The loads experienced by the vessel depend greatly on the trading route. The vessels involved in the measurements traded Europe - Far East (Figure 25) and Far East – US west coast (Figure 26).

Rigoletto clearly does not take many actions to avoid severe weather. From one side her route does not give many options to alter course. Sailed distances in vicinity of severe weather areas are short. On the other hand there are not many heavy weather areas along its path. The Gulf of Biscay is renowned and does not provide options to change course and evade weather. In the Far East choices to pass Taiwan to port or starboard in typhoon season provide options to select most favourable route.

NYK Argus on the other hand is crossing the North Pacific twice in her two month round trip. The variation in the sailed tracks reveals the efforts taken by the crew to avoid worst depressions and wave fields.

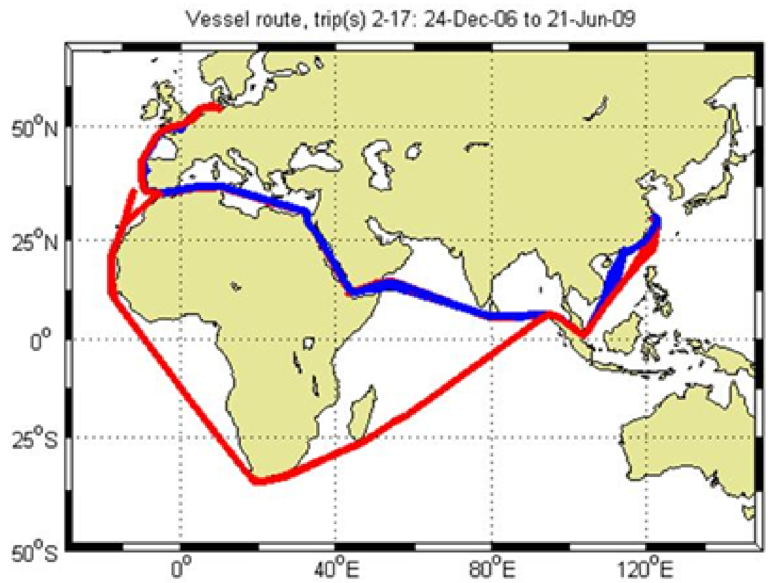



**Figure 25 Trade route Rigoletto (plus trip around cape avoiding Suez and Somalia)**

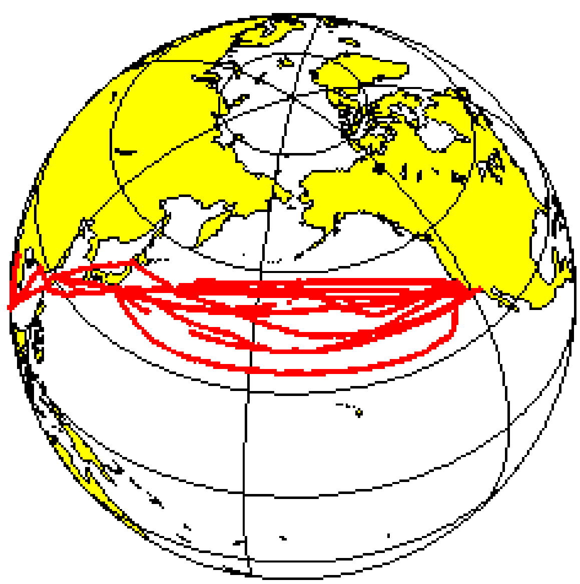


**Figure 26 Trade route NYK Argus and weather avoidance**

Measurements on both vessels learned that accelerations to the cargo are composed of a rigid body motions part and contributions by hull flexibility. The hull structures in combination with cargo weights have lead to hull natural frequency for vertical bending of 0.5Hz or 2 seconds periods. This is close to the excitation loads by waves in head seas.

Following cases are recognised from the measurements:

- Highest transverse loads are occurring in rolling motions by contribution of earth gravity. Rolling motions of 15-20 degrees single amplitude are common in following seas.

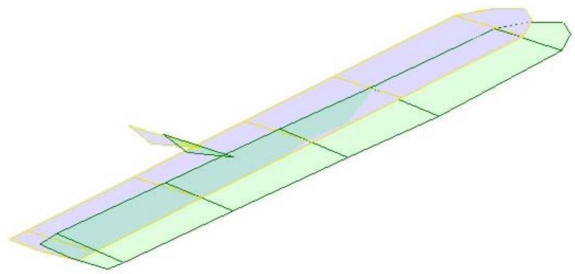


**Figure 27 Acceleration pattern along hull in rolling motions**

- Highest vertical loads are occurring in head sea conditions by combination of heave, pitching and vertical hull bending.

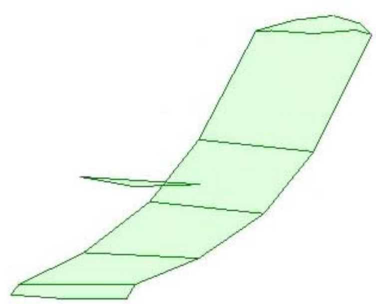


**Figure 28 Acceleration pattern along hull in head seas**

- Flexible hull deformation is adding around 40-50% to the accelerations that could otherwise be expected based on rigid body motions alone.
- The highest loads occur due to wave slamming. This induces an impulsive load that is super imposed over the peak acceleration by heave and pitch.
- The effect of a wave slam is experienced in the aft ship as well. The impact passes through the hull as a travelling wave and when reaching the light and flexible aft structure results in a peak acceleration of similar amplitude as the original slam in the bow.

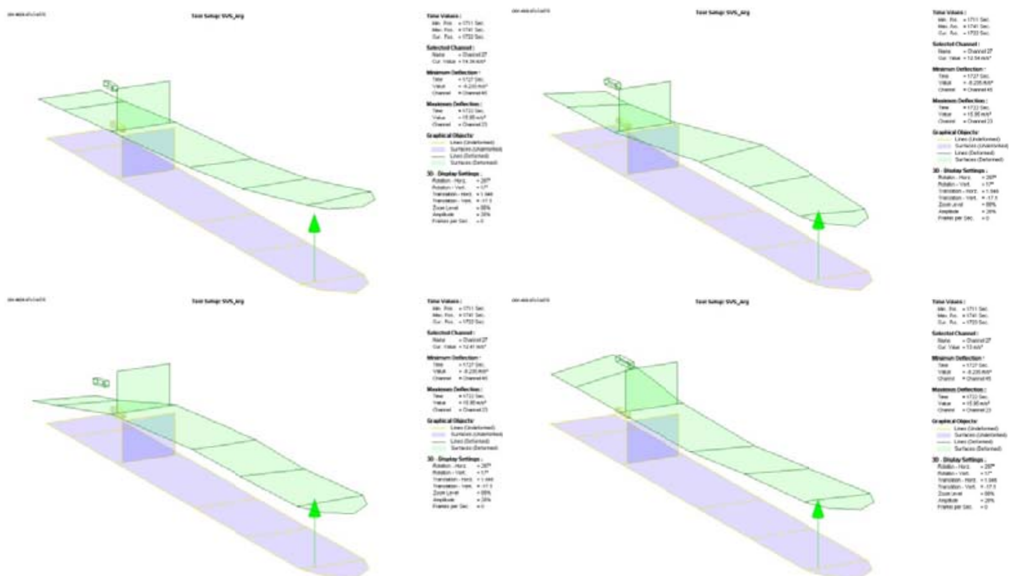


Figure 29 Wave impact (read left to right, top first)

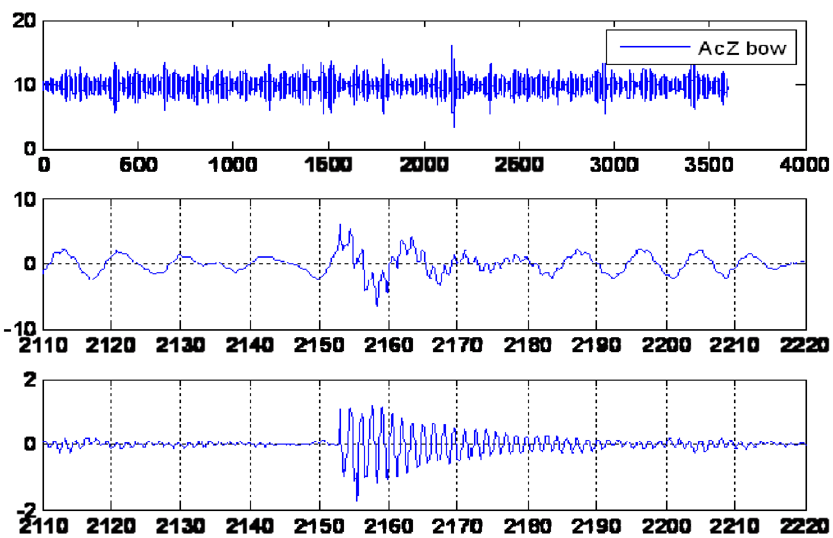



Figure 30 Peak acceleration and decay (1 hr, zoomed, and flex. part only)

- Peak accelerations occur shortly after the impact. Decay of the impulsive response takes around 30 seconds.
- Maximum accelerations to 6 m/s^2 were recorded in bow quartering seas. Bow flare slamming is expected to pose the largest threat for wave impulsive loads. Bow flare slamming is likely to occur in bow quartering head seas.

- Hull deformations occur due to encountered direct wave loads and due to dynamic response in the hull natural frequency.
- The main phenomenon that is contributing to extra accelerations is the vertical bending of the hull in its natural frequency mode. No significant contribution of torsion deformation was observed in the measured accelerations. It is assumed that this is caused by damping from row-row interaction in the container stows and by the small lever arm and torsion deformation angles.
- Torsion as well as bending was observed due to direct wave loads. Torsion showed contributions from rolling motions and wave encounter periods. Vertical bending mainly comprised of wave encounter frequency contributions.
- It was observed that cargo hatches may shift in the order of 2 cm due to vertical bending. No relation with torsion deformation could be obtained from the measurements.
- Measurements in the container stow on board NYK Argus and CMA-CGM Rigoletto learned that dynamic effects in the stacks may be expected when excitation loads have short periods. This occurs typically in head waves and in wave slamming events.
- Highest container stack accelerations however were observed in following seas. These were found to behave very linear and following the expected loads from the vessel closely.
- Highest dynamic loads were observed following a wave slamming event on the Pacific. Measured responses suggested row interaction must have occurred as high forces and g-loads were measured while no heavy boxes were carried in the stack at the time.

### 5.3 MCS tests

MCS tests were aimed at behaviour of RoRo cargo under dynamic loads and the dynamics of container cargo in single- and multiple- row configurations. Following results were obtained.

#### 5.3.1 RoRo tests

- The lashing pretension was observed to slacken off during the tests both for chain and web lashings. With the web lashings it was observed that the straps were creeping out of the ratchets under repeated loads.

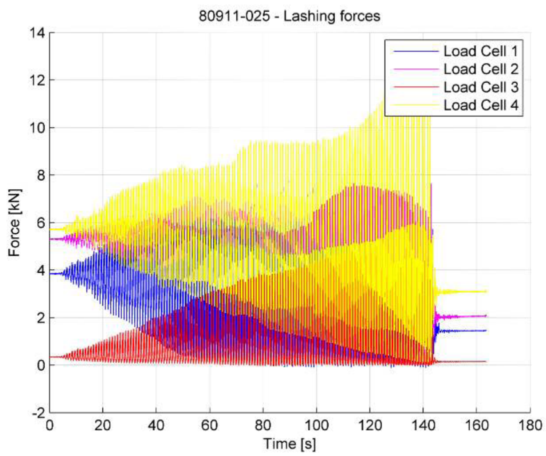
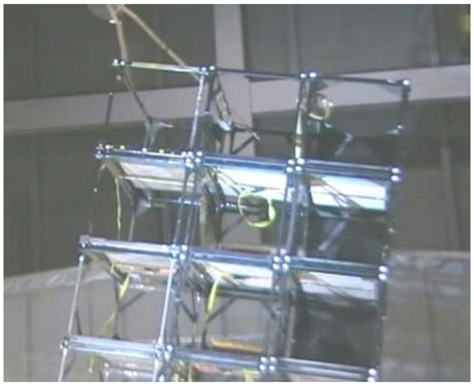



**Figure 31 Lashing forces and ratchet windings**

- It was noted that practical aspects determine the reliability of how the lashings are applied and how pretension is distributed.
- No snapping loads or unhooking was observed in the tests.
- Cross lashings did not add to tipping stability
- The obtained results generally agreed with the calculation methods. On some occasions the distribution of loads over the applied lashings exceeded the safety margin of 1.35 that is used in the CSS model.
- A tendency was found that loads become more evenly distributed at higher loads.
- Cargoes with large own moment of inertia were found to increase the lashing loads under short periods movements (rotations).

### 5.3.2 Container tests

- Racking deformations determine the deformation and reaction forces at lower excitation levels.
- At higher excitation levels uplifting occurs and the deflections are dominated by limited tipping of the stack as allowed by the vertical gap tolerance in the twist locks.
- There is strong coupling between transverse swaying of the stack and twisting around the vertical axis due to the different racking stiffness forward and aft.
- Modal analysis showed only one dominant deformation mode shape. Higher order mode shapes are close to critically dampened by non linear interaction between tiers. (slipping, uplifting)
- Test results indicate that natural periods of the higher stacks can approach 1 second. With extreme weight distributions it may further approach the hull natural period for bending and torsion making stacks sensitive to resonant loads.
- It was calculated and observed that uplifting may be expected to occur at operational heeling angles with stack heights of 7 tiers.
- Configurations with multiple rows exhibit a stabilizing effect to general motion response when all stacks have similar mass and rigidity and move in sync. The interaction and friction between the rows introduces damping.
- Responsive behaviour changes in case of rows with different mass or rigidity (failed lashings). Gaps may open up between the rows in particular direction as more flexible or heavy rows tend to deflect further then the more rigid or light stacks. Rows no longer move in sync and impacts can occur when gaps close up again.

- Peak loads are introduced by impacts when the gaps close due to motions in opposite direction. The more rigid of light stack is found to exhibit peak loads that are factors 2 - 3 higher than the expected values.

## 5.4 Ranking of key factors

Following paragraphs discuss the findings in the previous stages and their relevance.

Obvious considerations for the reliability and thus safety of the cargo securing system are determined by:

- Quality of the underlying design assumptions in relation to true physics;
- Conformity of the on board situation with designed configuration;
- Ability of the crew to keep service loads inside design envelope;

The findings with the various transport sectors are listed as follows:

### 5.4.1 Design model assumptions vs. actual physics

This paragraph reviews if the fundamental assumptions that are the basis of the design rules and standards match the in service behaviour. Findings are grouped for acceleration loads on the stowed cargo, and secondary reaction forces induced in the secured cargo.

- Underlying design assumptions for RoRo and Heavy lift transport acceleration loads match with actual response of vessels to wind and waves as rigid bodies.
- It is considered possible to predict “linear” vessel response and cargo securing loads to known wave climates.
- Determination of the design wave regime / operational profile, and the maximum accelerations in response to that is thus essential.
- For container ships it was found that accelerations due to flexible hull deformation add substantially to the “classic” rigid body design accelerations.
- IMO guidelines do not consider contributions by “non linear” loads such as parametric roll, broaching, dynamic loss of stability and slamming to be a part of the design envelope. These are to be avoided by the crew. Various incidents however suggest that these effects do occur and as such contribute to actual service loads.

- Reaction forces in lashing systems on the (smaller) RoRos and Heavy Lift vessels depend mainly on normal wave induced ship motions.
- Force- and cargo shift- calculation procedures for RoRo trailers should address behaviour of forward and aft end separately
- For large cargo items, the own moment of inertia should be considered since it can increase tipping loads compared to the classic approach.
- Shifting cargo due to reduced cargo securing may affect the survivability of a vessel in the case of an extreme event as a collision. It should be considered to include such an event in the design assessment of the cargo securing system.

- Reaction forces and motions in container cargo are not merely in response to the linear loads imposed by the vessel. Interaction forces between adjacent stacks were found to have a big effect on resulting forces in lashings and container stow.
- These effects may be expected to occur typically when rows are less stable due to failing lashings or poor vertical weight distribution. As a result they will lean into other stacks or open up gaps. The reaction forces across a bay thus are sensitive to deficiencies in separate single container rows.

### 5.4.2 Conformity “design” and “in service” conditions

In service cargo securing is carried out using the procedures and cargo gears as designed using current industry assumptions. Differences between the designed cargo stow and the actual on board “in service” configuration are however likely to occur.

- Most often recurring incident on RoRo vessels relates to shifting cargo inside transport modules. This may trigger further cargo shifting and ultimately affect the safety of the ship. Although this falls under the responsibility of the crew, the master cannot practically be held responsible for this.
- Integrity of the lashing system. The state of maintenance, wear and tear of loose and fixed lashing gear is of primary importance to the reliability of the securing arrangement. Although the majority of gear is in good condition, crew and accident reports indicate that these factors contribute to incidents.
- Properly fitted lashing gear is essential to cargo securing integrity. RoRo findings pointed out that not following CSM prescribed procedures played a factor in many incidents. Findings on container stack dynamics also point out the relevance to have all individual stacks properly secured according to the CSM.
- It was observed that pretension levels decrease over the course of a transit. In RoRo transport slipping of web lashings from ratchets and equalizing of load distribution between chain lashings. Container lashings can lose pretension by loosening of turnbuckles and/or setting of the container stacks. It must be noted that survey and retightening of cargo securing is often not possible in severe weather as decks are too hazardous for access.
- The design of stacked cargo securing on container vessels is based on the weights of the containers and the vertical distribution of these weights in the stack. It is not mandatory to weigh containers. Both actual weight and vertical weight distribution in the stacks are not reliable and introduce uncertainty and potential hazard.
- Design documentation is outlined for a limited number of vessel conditions. Partly loaded conditions with extreme GM are often not included in these cases. The high accelerations in beam seas may overload container stacks.

### 5.4.3 Crew ability to keep loads inside design envelope

Safety issues are stressed by sailing into extreme weather. This is the design case for cargo securing. In practice it occurs only on a limited number of occasions. In these occasions the condition of the securing system as well as the loading configuration should be inside the limits of the design assumptions (see above listed factors). Starting from that point further safety is in the hands of the crew under good seamanship. For that conditions following further considerations were identified.

- Crews are usually able to control vessel motions by changing heading, speed and selecting appropriate ballast condition. Sometimes however uncomfortable vessel motions and accelerations are noted to occur.
- There may be limited options to set appropriate GM in order to avoid large transverse accelerations by resonant rolling in partly loaded conditions.
- Although it is expected from bridge crews to avoid the occurrence of extreme loads, a majority of crews indicates that it is hard to judge if loads are actually becoming unacceptable and when it is time to change speed/heading or other.
- Non linear events as slamming, green water, parametric roll and dynamic loss of stability in following seas need to occur first before action can be taken. (Egg changing speed, heading). The first occurrences could however already be severe. Guidance for these conditions is often missing from the CSM

### 5.5 Conclusions & recommendations

**RoRo**

- IMO / SOLAS legislation allow cargo securing based on design accelerations in restricted environmental conditions.
- SOLAS requires that securing procedure should be in agreement with CSM documentation. This implies that cargo securing for limited environmental conditions should be described in the CSM and should be evaluated and approved by the flag state.
- Guidance as to how this should be done is missing. This guidance should be developed and agreed / accepted at IMO level in order to create a level playing field and maintain a controlled safety level.
- The agreement between design physics and onboard measured responses indicates that existing tools and approaches can be used to evaluate required guidance.
- Such guidelines would typically be a dynamic working document prone to changes in response to new design concepts. It is proposed that a technical body such as IACS (International Association of Classification Societies) would be best suited to maintain such a document and recommend an accepted interpretation to the IMO council.
- The Lashing@Sea project has drawn up a document for such an interpretation and has asked IACS to consider the formation of a working group to take development further with focus on and recommendations for:
    - Requirements for tools used to consider environmental factors
    - How to evaluate the survivability of the vessel in case of reduced lashing
    - Unified requirements for lashing arrangements
    - How to combine various contributions to design accelerations
    - Guidance on the condition of cargo transport units themselves

**Heavy Lift transport**

The challenges in the Heavy Lift transport sector mainly related to the interaction with warranty surveyors for approval of each single transport design. The design procedures are not standardized and give rise to different interpretation.

Evaluations of 3 years measured data on Biglift transports illustrated that design values with class accepted probability levels could be based on local environment with exposure time of typically 10 times the voyage duration. This procedure has to be approved by surveyors for each new transport and will likely keep raising discussion.

It is proposed to follow approach similar to that with the approval of CSM's for RoRo cargo and have the general design procedures and the tools used, documented in the CSM for approval by the flag state. Reference should be made to the same guidelines as these formulated for the RoRo industry. The actual design of the securing arrangement for each trip should then be done in accordance to the described procedures.

The discussion with warranty surveyor about the followed engineering process and assumptions is then illustrated by the vessel specific procedures as approved by flag state -and most likely class society- in the CSM.

**Container transport**

There is a perception that container transport is troubled by unacceptably large losses. This was found to be hard to determine as no centralised databases are kept with regards to losses and details on incidents are typically unavailable. Because of this there is also no means to evaluate for systematic trends in incidents or returning triggers for incidents. It was however clear that the unexplained losses of entire bays in recent years need to be explained.

Several aspects of in service conditions were found to be not explicitly included in the principles of the existing rules and standards. The most important ones are:

- Increased accelerations due to flexible hull deformations (whipping/springing). These are observed to be occurring regularly in severe head seas.
- Multiplication of the expected forces in cargo stacks due to interactions between adjacent rows. This effect occurs if gaps can open up between adjacent stacks allowing impacts when stacks sway sideways. This mechanism concentrates inertia loads on the most rigid row.

Dynamic tests with multiple rows indicated that extreme loads are not expected when securing arrangement is in agreement with the design and no gaps open up. It was however found that the system is sensitive to off design conditions, Dynamic load amplifications up to a factor 2 to 3 were found in these cases. This indicates the need of compliance between designed and actual stow configuration.

Interaction forces are considered to be the most likely reason for progressive collapse of multiple rows when due to a combined occurrence of events one or more stacks become unstable.

Commonly known effects that add to stack instability and increase excitation loads are:
- Poor deck fittings and twist locks have a bad effect on stack stability. Incidents learn that damages and corrosion can go unnoticed;
- Wrong applied lashings;
- Lashings often loosen up and need to be re-tightened. This is done in daily routine surveys (Which is not possible when the weather becomes severe);
- Container weights are the basis of reliable stow design. The weights however are estimated and are not reliable;
- The stow sequence and thus vertical weight distribution is often different from the stow plan. Crews mention this occurs regularly depending on port of call. If heavy boxes are stowed higher in the stack, the forces in lower tiers can exceed design limits and stacks may become unstable;
- High transverse accelerations in off design loading conditions (e.g. extreme GM) may raise excessive loads that loosen up/damage securing of highly loaded stacks, poor lashing gear or bottom tier container integrity;
- Crew questionnaire findings showed that it is hard to recognize when loads become too high and decide when and what measures are needed to keep it inside safe working limits.

Loads that in itself are already hard to recognize for crews, may become higher than anticipated due to stack interactions, triggered by fairly simple phenomena.

In order to reduce probability of incidents following recommendations are listed:
**Increase integrity of actual stows in relation to the CSM and stow plan**
The low incident probability for container transport illustrates that container industry is in principal fairly safe. Lashing@Sea investigations also did not reveal extra ordinary findings in either full scale measurements or in the MCS model tests with setup according to the design assumptions.

The largest effect to substantially increase loads was found to be out off design conditions that are known to occur in service on occasion. (I.e. Overweight/instable rows by weight errors, poor gears, damaged containers). Based on this finding it is recommended to reduce probability for these cases.

- It is essential that gear is in good condition. Fixed lashing gears in particular are hard to check and may wear out unnoticed.
- It is essential to have good agreement between the actual stow and the preliminary stow plan that is assessed and approved by the crew. It is noted though that cargo is stowed different from the plan on occasion.

Procedures for this are already in place. To bring down the last fraction of percentage where incidents still occur, it is essential to make sure that things are also done in agreement to these standing procedures. Since the start of the Lashing@Sea project several things have already happened:

- An international standard for logistics responsibilities has been laid out in the "Rotterdam Rules".
- The international chamber of shipping (ICS) has addressed a recommended practice for container transport. "Safe transport of containers by sea, guidelines and best practices".

To increase safety further it should be endorsed that best practices are actually followed and responsibilities are indeed taken where they should. Following suggestions are listed:

- Weigh container trailers upon entry/exit of the terminal to use the measured mass for stow planning. -> Remove mass uncertainty from process.
- Random surveys to evaluate if stow and lashing procedures are properly followed with feedback to responsible party -> better vertical weight distribution.
- Harmonize maintenance standards of lashing gear and fixed fittings. For instance by including it in the annual hull surveys by class.
- Design and make of lashing gear to be such that it does not loosen up in transit.

**Avoid excessive ship motions and accelerations**

Crews should be assisted to improve the "feel" and "awareness" of loads outside the field of view from the bridge. This includes the effect of sailing in off design stability under high GM and evaluation of stack loads under these conditions. This should for instance be described in CSM, and/or supported by loading computer lashing modules or monitoring systems.

Training, guidance or tools to reduce the chances for extreme loads by "non linear effects" are a second step to be considered. Probability for extreme loads by unexpected resonant roll, wave slamming, parametric roll and dynamic loss of stability may thus be reduced.

The in service measurements demonstrated the possibility to measure loads and responses. It is a big challenge to provide such info to crews in simple format.

**Review design standards and rules**

It has been found that non-linear responses may have an impact on determining the criteria required to ensure the safe stowage of containers during some voyages. However, it is recognized that at this time, due to the vagueness and uncertainty of such factors, it would be an extremely difficult task to immediately prescribe criteria to account for these phenomena. The members of the industry whose task is setting design criteria (Administrations, Standards Institutes and Class Societies) are encouraged to investigate these aspects further, in order to increase the awareness and understanding of these findings

# 6 EXTENDED SUMMARY AND CONCLUSIONS

The Lashing@Sea project ran from the period of mid 2006 through mid 2009. It addressed safety and efficiency for container ships, RoRo ships and Heavy lift transport ships.
The main scope of work addressed the validation of design assumptions by means of full scale measurements, review of current practice and extensive evaluation of findings by a group of stakeholders that was brought together for the project.
The stakeholders that were directly involved in the project included ship owners, lashing gear manufacturers, classifications societies, on board systems suppliers, technology institutes and flag state authorities. Stevedores contributed by interviews. P&I clubs did not participate.
Measurements were conducted on two RoRo ships, two container vessels and one Heavy lift transport ship for a period of more than two years. Ship motions, lashing forces, container forces environmental parameters and loading conditions were recorded.
Secondary response of the cargo was investigated in close detail on a dynamic test facility. Both for RoRo cargo and container cargo the dynamic response of cargo and lashing gear was evaluated.

It was found that there are unclarities in the explicit contents of the international legislation for RoRo and Heavy lift transport sectors. The legislation needs to be elaborated in order to maintain a level playing field and control international safety standards. It should focus on guidelines for the evaluation and approval of procedures for cargo securing for limited environmental conditions and sheltered areas.

It was considered that such a document would need to be dynamic in order to follow technical developments in the shipping industry. IACS is better suited to handle such a document than IMO. Lashing@Sea drew up a proposal document “Unified interpretation on cargo securing for environmental conditions”. This document was forwarded to IACS with the request to consider the formation of a task force that would bring the document further and finally submit it to IMO as a working document.

Developments in the container transport sector were aimed more technically at the evaluation of physics, loads and procedures. A number of unexplained incidents with cargo losses indicated that “new” phenomena may have reduced safety levels.

Measured accelerations did not exceed the design values during the campaigns. It was found however that hull dynamics can amplify vertical accelerations by 50% at fore and aft compared to rigid body response. This effect is not included in design approach.

Unexpected high loads in the securing system and container stacks were found to occur due to stack interactions when there are one or more stacks within the bay which are overloaded or not lashed correctly. This mechanism is identified as the most likely responsible for progressive collapse of entire bays resulting in tens of containers lost to sea in single incidents. Safety improvements with regards to the “unexplained losses” of recent past should be aimed to control this mechanism.

Stack interaction did not amplify loads when cargo is stowed and secured evenly along the rows. Load amplification starts only when gaps open between rows.

Stack interaction can occur due to unstable rows because of loosened, failed, wrong applied lashing gear or because of excessive weights or gross vertical weight distribution errors. In most occasions the neighbour rows will absorb the additional momentum and stabilise the bay. The "normal" loads however will increase and by combination of unfavourable factors they may be amplified to exceed safe working loads / breaking loads at motions that are otherwise considered acceptable.

The options to prevent this are to:

1) Prevent excessive stack interaction from amplifying loads;

Keeping in mind that probability for an incident is already very low; the most practical way to increase safety is to prevent load multiplication by stack interaction. A cargo stowed and secured according to CSM guidelines in unlikely to exhibit excessive interaction. This boils down to reducing uncertainties in the practical cargo stow and follow already agreed procedures:

Uncertainties are in reliability of weights and vertical distribution, lashing gear state of maintenance and application. The involvement of various parties as shipper, stevedores, terminal, crew and maybe port state, calls for a broad ongoing discussion on this topic.

Suggestions:

- Weigh containers upon entry of terminal and use measured weight for planning;
- Improve reliability of stow and vertical weight distribution, in order to meet stability requirements of ship and individual stacks.
- Discuss the interface between shore sections and vessel, responsibilities and endorsing of these in order to maximize reliability of gear, maintenance, lashing application. This could include involvement of terminals/stevedores or including (fixed) lashing gear in annual surveys by class to achieve a fleet wise standard of maintenance.

2) Vessel handling in severe weather avoids extreme loads.

Crews successfully control the motion response of their vessel by choosing appropriate speed, heading and ballast configuration in relation to the weather. Often however it is not possible to evaluate from the bridge deck if extreme loads are developing towards aft or forward. In order to reduce probability for extreme loads, it is recommended to provide crews with feedback on vessel motions, loads forward and aft, probabilities for extreme (rolling and slamming) events and guidelines on dealing with extreme GM conditions.

3) Improve the cargo securing designs and standards

It is recommended that class societies continue the research into topics of hull flexibility and stack dynamics for future designs and understanding of loads and probabilistic.
Both are non linear phenomena and difficult to address. For the reason that nowadays in most cases containers and their corner castings are the weakest link in securing chain the design standards and strength requirements for containers should be reviewed.

# 7 AFTERWORDS

The Lashing@Sea project has been working on cargo securing matters for a period of more than 3 years. A period that seemed to last much shorter when looking back.

It proved to be a very challenging topic. Since the first days of shipping, seafarers have secured cargo. Responsibilities were distributed when more parties became involved. Technology evolved under pressure of operational efficiency. Transport volumes have soared and in the end the reliability can be considered very high. Only few incidents occur in relation to the total transported volume. The tiny percentage however turns into an actual number of incidents because of that same large transported volume. The small percentage of incidents is typically the exception to the rules. Obviously this complicates the discussion about design rules and guidelines.

The project did not actually solve or improve anything directly. We did improve understanding of before mentioned physics and recommended where improvements in lashing technology and operational procedures should be searched for.

It is expected that the participants in the project will use the project findings to evaluate and where needed include the listed effects in the used design procedures, rules and standards. This is expected to actually increase safety and allow ongoing innovative efforts for the benefit of efficiency.

At the end of the project, the Dutch Shipping Inspectorate launched a survey on 50 vessels to review the condition and application of lashing gear and cargo on 50 container vessels. The results of this investigation are expected to provide further numerical facts on the aspects mentioned in the L@S study. Dutch authorities will work on a submission to IMO for improvements of guidelines and procedures as outlined by the Lashing@Sea group.

A correspondence group will continue from the Lashing@Sea consortium to follow up on the findings and bring them to the attentions of IACS and IMO.