

Report on the investigation into
the loss of 137 containers from the container ship

CMA CGM G. Washington

in the North Pacific Ocean

on 20 January 2018



Extract from
The United Kingdom Merchant Shipping
(Accident Reporting and Investigation)
Regulations 2012 – Regulation 5:

“The sole objective of the investigation of an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of an investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame.”

NOTE

This report is not written with litigation in mind and, pursuant to Regulation 14(14) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

ABS	- American Bureau of Shipping
ACEP	- Approved Continuous Examination Programme
APC	- Adjustable Platform Container
BIC	- Bureau International des Containers
BV	- Bureau Veritas
CO	- chief officer
CSC	- International Convention for Safe Containers 1972, as amended
CSM	- Cargo Securing Manual
CSP	- Container Securing Plan
DPA	- Designated Person Ashore
ft	- foot
GCD	- Global Container Database
German Lashing	- German Lashing Robert Bock GmbH
GM	- Metacentric height
IACS	- International Association of Classification Societies
IMO	- International Maritime Organization
in	- inch
ISO	- International Organisation for Standardization
ISO 1496	- ISO 1496-1:2013 Series 1 freight containers – specification and testing – Part 1: General cargo containers for general purposes
ISO Containers	- Containers constructed and tested in accordance with ISO 1496
kg	- kilogram
kN	- kilonewton
kt	- knot
m	- metre
MARIN	- Maritime Research Institute Netherlands
MCA	- Maritime and Coastguard Agency
MGN	- Marine Guidance Note
mm	- millimetre
nm	- nautical mile

Octopus system	-	<i>Octopus-Onboard</i> electronic motion monitoring, forecasting and decision support tool
OOW	-	Officer of the Watch
SOLAS	-	The International Convention for the Safety of Life at Sea 1974, as amended
STCW	-	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended
SWL	-	Safe Working Load
t	-	tonne
T _E	-	Period of encounter
T _R	-	Period of roll
TEU	-	Twenty-foot Equivalent Unit
UTC	-	Universal Co-ordinated Time
VGM	-	Verified Gross Mass
WSC	-	World Shipping Council

Container vessel terminology

Bay	-	Transverse deck areas available for container stowage, numbered sequentially from forward to aft.
Hi-cube	-	The standard height of a container is 8ft 6in; a high-cube container has a height of 9ft 6in.
Outer wall	-	The stack of containers within a bay nearest the ship's side.
Row	-	Horizontal co-ordinate used to define the position of a container across a bay. A row is given a numerical designation from the centre line (00), with even rows to port (02, 04, 06 etc) and odd rows to starboard (03, 05, 07 etc).
Stack	-	A number of containers stowed vertically within a given row.
TEU	-	Twenty-foot equivalent unit based on the original container that was 20ft long. The TEU is a unit of cargo capacity used to describe the capacity of container ships and container terminals.
Tier	-	A vertical co-ordinate used to define the height of a container in a given row. A tier is given numerical designation commencing from the deck or hatch level (72). Each tier level increases incrementally by 02.

TIMES: all times used in this report are ship's local time unless otherwise stated.

SYNOPSIS

At 0127 on 20 January 2018, the UK flagged container ship *CMA CGM G. Washington* unexpectedly rolled 20° to starboard, paused for several seconds then rolled 20° to port. The ship was experiencing heavy seas in the North Pacific Ocean while on passage from Xiamen, China to Los Angeles, USA. As the sun rose later that morning, it was discovered that container bays 18, 54 and 58 had collapsed; 137 containers were lost overboard and a further 85 were damaged.

The MAIB investigation concluded that the collapse of all three bays probably occurred during the 20° rolls. The amplitude of the rolls exceeded the ship's estimated roll limits and was almost certainly the consequence of parametric rolling, which had been recorded by the ship's motion monitoring decision support tool. The risk of parametric rolling was not identified by the master or his bridge team because they were unaware of the full capabilities of the decision support tool, and therefore were unaware of its predictions.

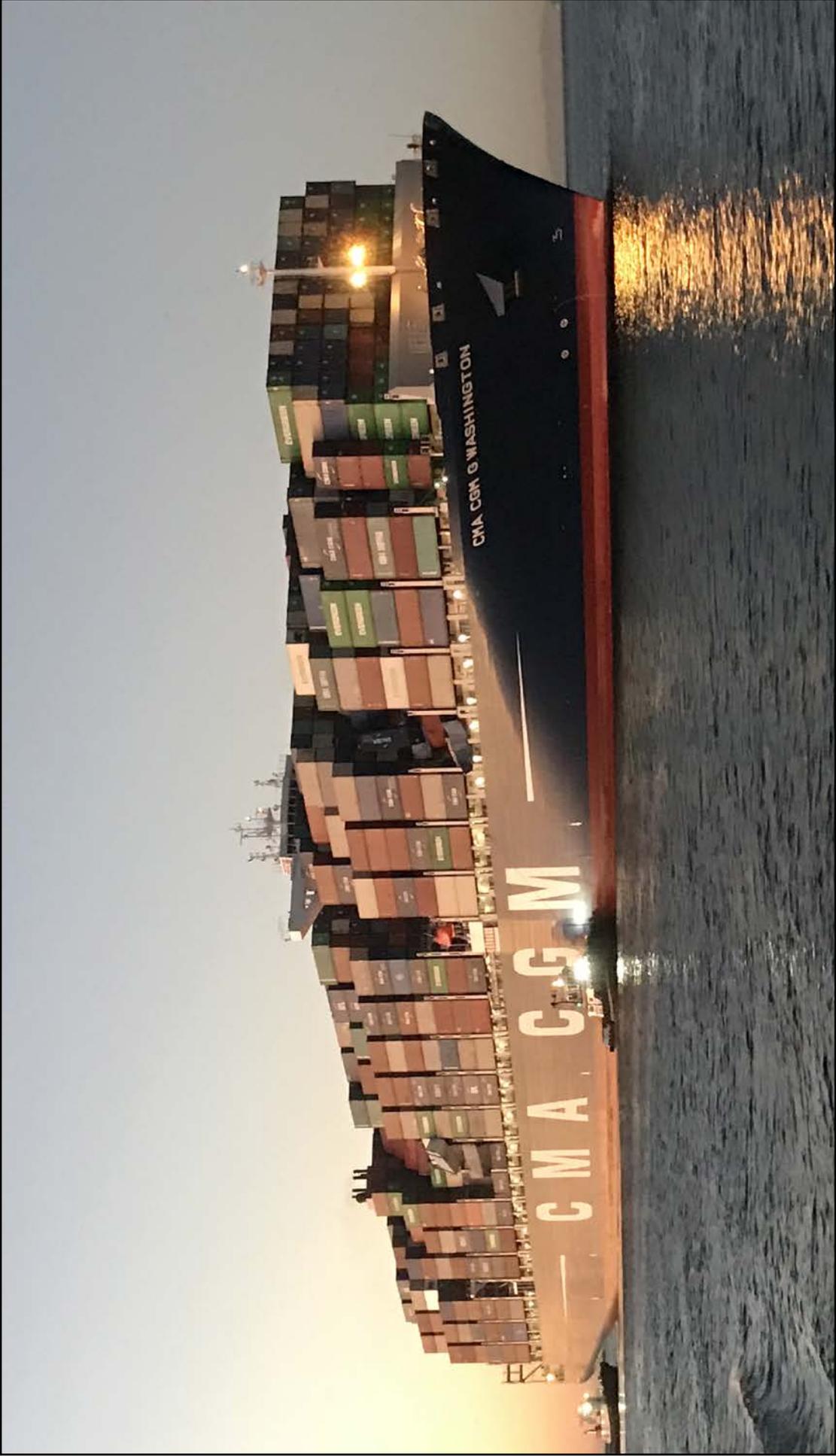
The investigation identified several factors that would have adversely affected the safety of the container stows on deck. These included: reduced structural strength of non-standard 53ft containers, inaccurate container weight declarations, mis-stowed containers and loose lashings. The report concluded that:

- Bay 54 collapsed because the acceleration forces generated during the large rolls exceeded the structural strength of the non-standard 53ft containers stowed in the bay.
- Bay 58 collapsed because some of its containers were struck by the 53ft containers as they toppled overboard.
- Bay 18 collapsed as a result of a combination of factors and was probably initiated by the structural failure of one or more containers.

Action has been taken by CMA Ships, in conjunction with ABB, the manufacturer of the Octopus decision support tool, to improve its presentation of ship-handling advice to masters in bad weather. The training package for operators of this system has also been reviewed. Bureau Veritas, *CMA CGM G. Washington's* classification society, has now amended its rules for the carriage of 53ft containers.

Recommendations have been made to:

- CMA ships, to ensure that, where container terminals routinely weigh containers prior to loading, the cargo plan is updated to reflect these weights.
- The Maritime and Coastguard Agency, to promote UK container owners' involvement in Bureau Internationale des Containers databases.
- Bureau Veritas, to amend its rules to require the approved lashing software installed on the onboard loading and lashing computer to calculate and display maximum roll and pitch angles associated with ship loading condition and intended passage; and, review its rules and approval procedure to ensure Container Safety Certification data is accurately reflected within the ship's loading and lashing computer, whatever the type of container, compliant with ISO standard or not.



CMA CGM G. Washington

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF CMA CGM G. WASHINGTON

SHIP PARTICULARS	
Vessel's name	<i>CMA CGM G. Washington</i>
Flag (at the time of the accident)	UK
Classification society	Bureau Veritas
IMO number/fishing numbers	9780847
Type	Container ship
Registered owner	Haotong International Ship Lease Co., Ltd
Manager(s)	CMA Ships
Construction	Steel
Year of build	2017
Length overall	365.96m
Registered length	365.96m
Gross tonnage	140,872
Minimum safe manning	15
Authorised cargo	13,460TEU

VOYAGE PARTICULARS	
Port of departure	Xiamen, China
Port of arrival	Los Angeles, USA
Type of voyage	International
Cargo information	6466 containers
Manning	27

MARINE CASUALTY INFORMATION	
Date and time	20 January 2018 at 0127 (UTC+11)
Type of marine casualty or incident	Serious Marine Casualty
Location of incident	North Pacific, 32°09.3N 159°17.7E
Place on board	Cargo deck, bays 18, 54 and 58
Injuries/fatalities	None
Damage/environmental impact	137 containers lost overboard; 85 containers damaged
Ship operation	On passage
Voyage segment	Mid-water
External & internal environment	Wind: westerly 20kts; sea: west-north-west 6.0m; visibility: good, darkness
Persons on board	27

1.2 NARRATIVE

The UK registered container ship *CMA CGM G. Washington* arrived in Fuqing, China on 7 January 2018 and began an 8-day, five port loading and discharging programme. The other four ports in the schedule were Nansha, Hong Kong, Yantian and Xiamen (**Figure 1**). On 13 January, the ship arrived in Xiamen, the final port in China before sailing for Los Angeles, USA.



Figure 1: *CMA CGM G. Washington's* Chinese port schedule

Cargo operations were completed at 0518 on 15 January. *CMA CGM G. Washington's* chief officer (CO) checked the ship's loading computer and confirmed the departure metacentric height (GM) as 1.28m. At 0800, the ship sailed from Xiamen with 6,466 containers on board and commenced a 22kt passage through the East China Sea.

At about 1000, the bosun and four deck crew mustered at the forward end of the weather deck and began a post-departure inspection of the deck cargo securing arrangements. They split into two teams and started their checks at the forward most container bay and worked their way aft, checking alternate lashing bays. During the inspection they checked that the manual twistlocks, connecting the first tier of containers to the hatch covers, were locked, and ensured that the container lashing rods were correctly tensioned.

With over 12,000 twistlocks and 3000 lashings to inspect, the checks continued all day, with the CO making periodic deck visits to monitor progress. At 1800, the deck crew completed the inspection of bay 70, which was just forward of the funnel, and stopped work for the day.

At 0800 on 16 January, the deck crew recommenced the post-departure cargo lashings inspection for the remaining container bays. They finished the final bay, bay 86, at midday.

During the afternoon, *CMA CGM G. Washington*'s master received routing advice from the ship's weather forecasting authority, which recommended changing the ship's passage plan to the south to avoid 6.0m waves that were expected on 19-20 January 2018. The master immediately implemented this change (**Figure 2**).

At 0130 the following day, the vessel passed Kagoshima, Japan, and entered the North Pacific Ocean on an easterly heading. Later that morning, between 0800 and 1000, the bosun and his deck team conducted a routine daily inspection of the ship's deck cargo lashings. The crew repeated the inspection routine on 18 January and noted that very few lashings needed adjustment.

During the early hours of 19 January, the weather began to deteriorate. By 0800 the wind had increased to force 6 from the west-north-west and the ship had begun to roll between 7° and 12° in a 3.0m north-westerly swell. The deck crew began the daily lashing checks as usual, but the weather conditions meant that they managed to inspect only the bays forward of the bridge. By 1300 the swell had increased to 4.5m from the north-west.

At about 1800, during a fire drill, the ship experienced a sudden large roll of approximately 16°. On completion of the drill, the CO and bosun went on to the upper deck and conducted a visual inspection of the forward container bays and confirmed that they were still intact.

Later that evening, the ship started to roll routinely to 15° and, at about 2130, the officer of the watch (OOW) requested that the master come to the bridge because the autopilot was struggling to keep the ship on course.

While on the bridge, the master reviewed the data provided by the ship's electronic motion monitoring and forecasting system and, as a result, instructed the OOW to switch to hand-steering and alter course from 088 to 082. Following the alteration of course the ship's rolling reduced to less than 10°. The master stayed on the bridge for the remainder of the watch.

Following the watch handover at midnight, the master instructed the new OOW to return the ship to automatic steering. At 0020 (20 January), confident that the autopilot was able to maintain course, the master told the OOW to call him if he became concerned by the ship's motion. He then left the bridge.

At 0127, the ship unexpectedly rolled 20° to starboard¹, paused for a few seconds, then made a similar roll to port. The master was woken by the roll and went quickly to the bridge where he found various engine alarms sounding, including the main engine's 'lube oil low level' alarm. Conscious that the engine would begin to automatically shut down, he acknowledged and reset the alarms. After a brief

¹ Recorded by ship's inclinometer and electronic motion monitoring and forecasting system.

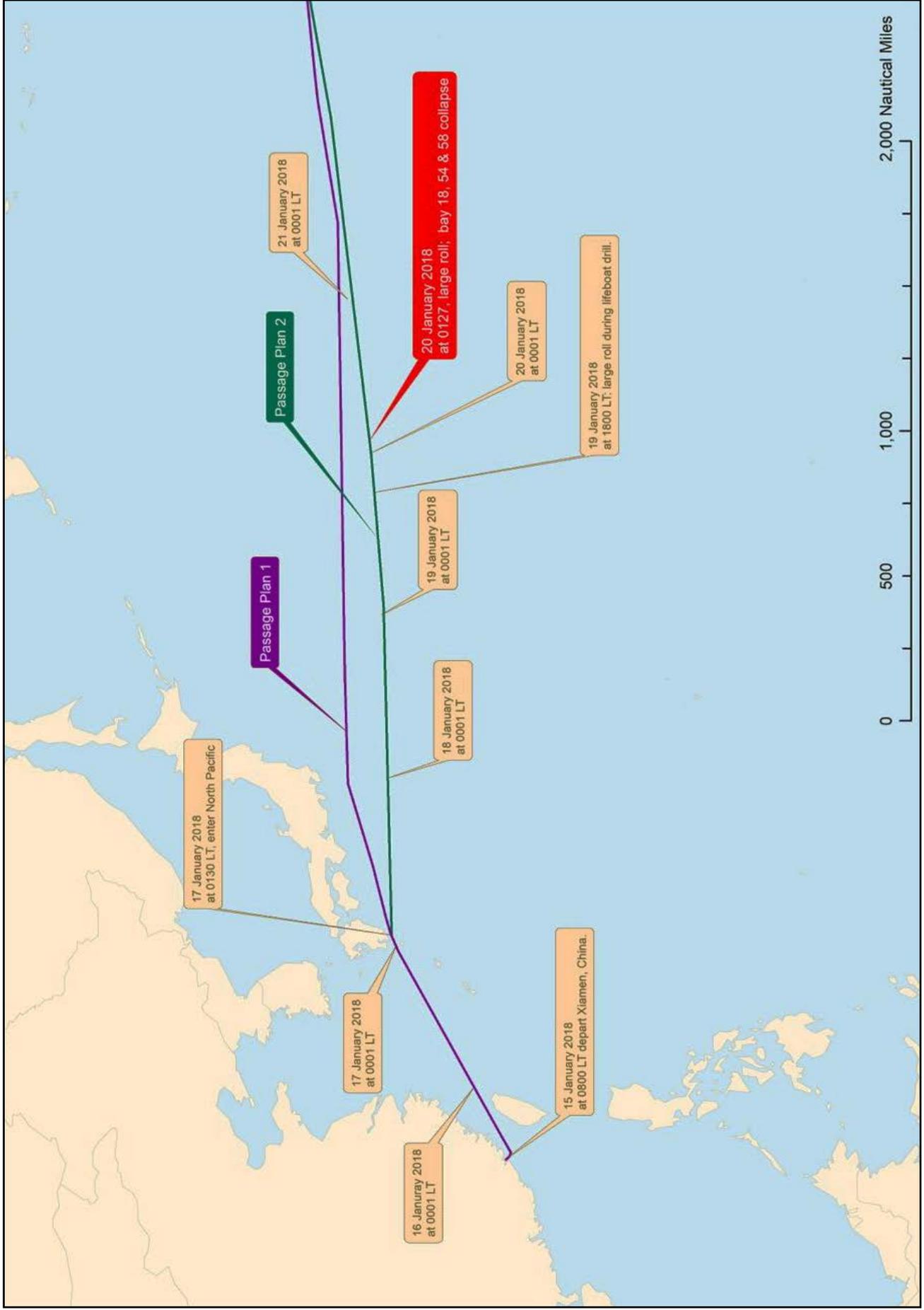


Figure 2: CMA CGM G. Washington's passage plan

discussion with the OOW, the master switched on the deck lights and checked the condition of the deck containers through the bridge windows. No damage was seen, and the container stows appeared to be intact.

The master remained on the bridge until the ship's motion had moderated. At about 0200, when the ship was rolling between 5° and 10°, he left the bridge and returned to his cabin.

At 0815, the OOW noticed that he could no longer see the fore deck through gaps between container stacks and, realising that something was wrong with the forward container bays, alerted the CO. The CO went to the weather deck with the bosun to investigate, and found that bays 18, 54 and 58 had collapsed (**Figure 3**); his initial estimate was that 64 containers had been lost overboard.

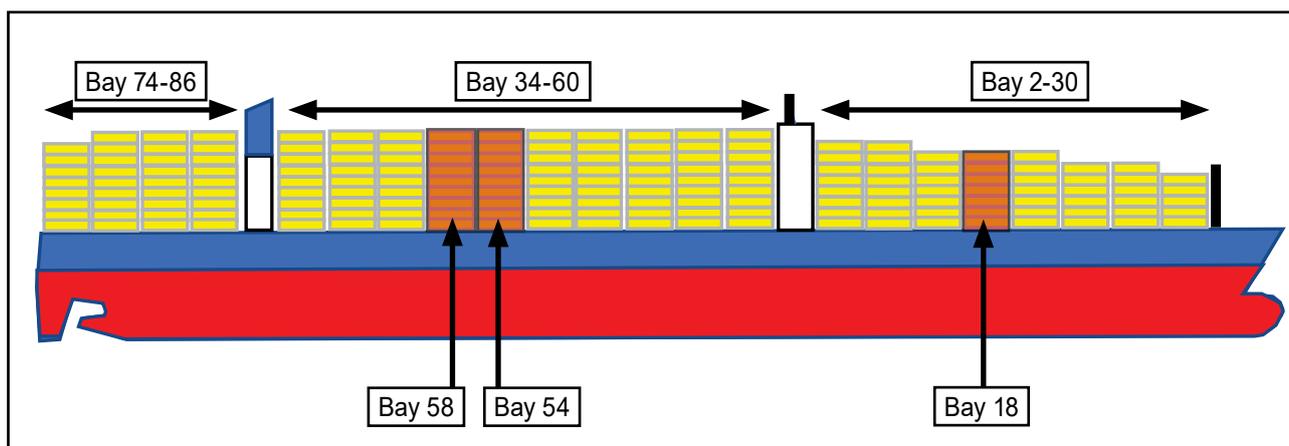


Figure 3: Location of damaged bays

The master reported the accident to the company's fleet operations centre in Marseille, France and the ship's Designated Person Ashore (DPA) in Singapore. He then reported the loss of containers to the Japanese Coastguard, which issued a radio navigation warning advising mariners of the accident and the potential risk to navigation.

Daily container lashing checks continued during the remainder of the voyage. No further containers were lost during the passage and the ship arrived in Los Angeles on 28 January 2018.

1.3 CMA CGM G. WASHINGTON

1.3.1 General vessel information

CMA CGM G. Washington was a 14,400TEU class container ship. It was built in the Republic of Korea by Hyundai Heavy Industries and entered service on 20 April 2017. It was managed by CMA Ships in Marseille and was operated on the CMA CGM group's transpacific trading route between China and the west coast of the USA. The ship's technical managers and DPA were based in Singapore and its classification society was Bureau Veritas (BV).

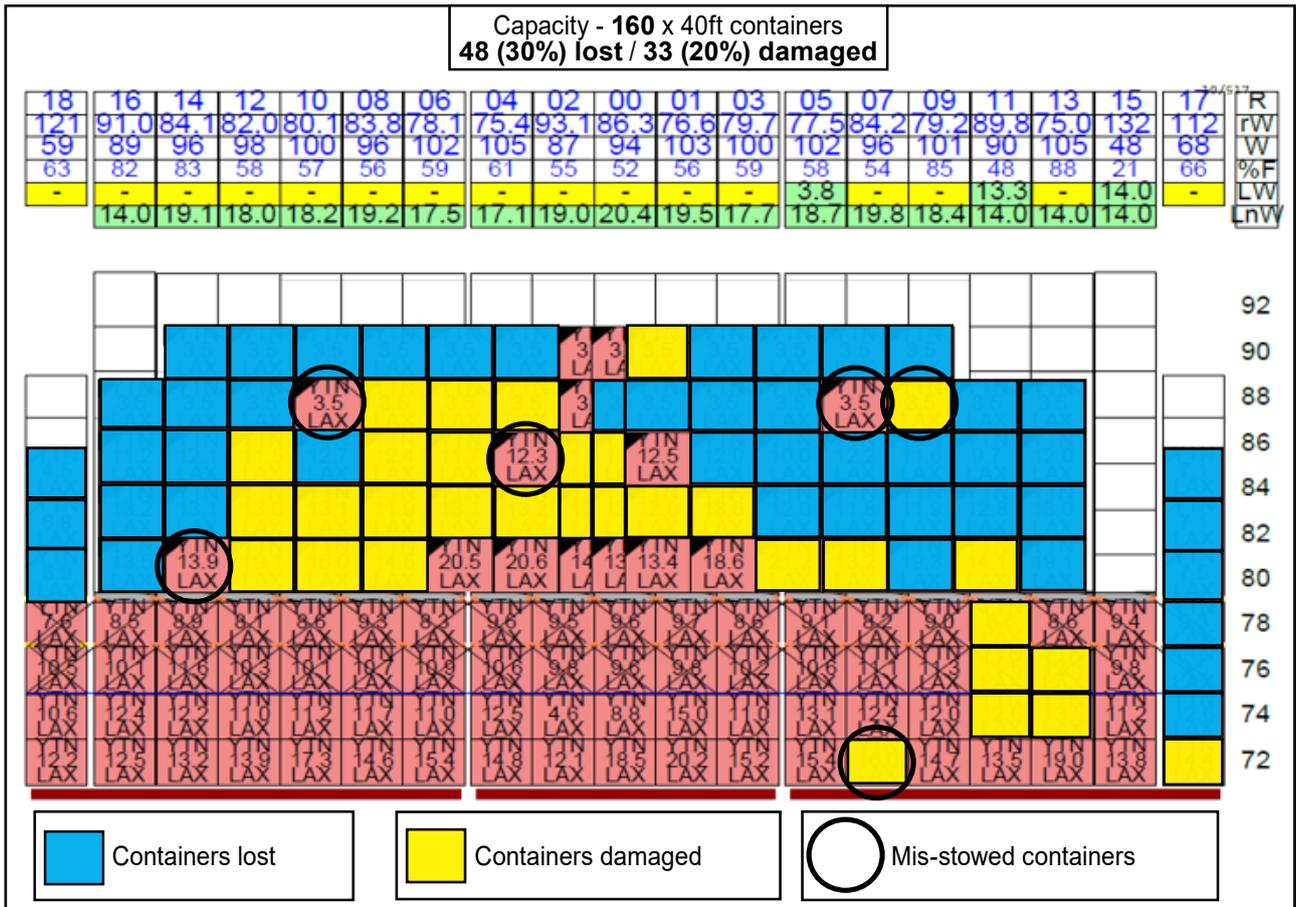


Figure 5: Bay 54 cargo stowage plan showing lost, damaged and mis-stowed containers

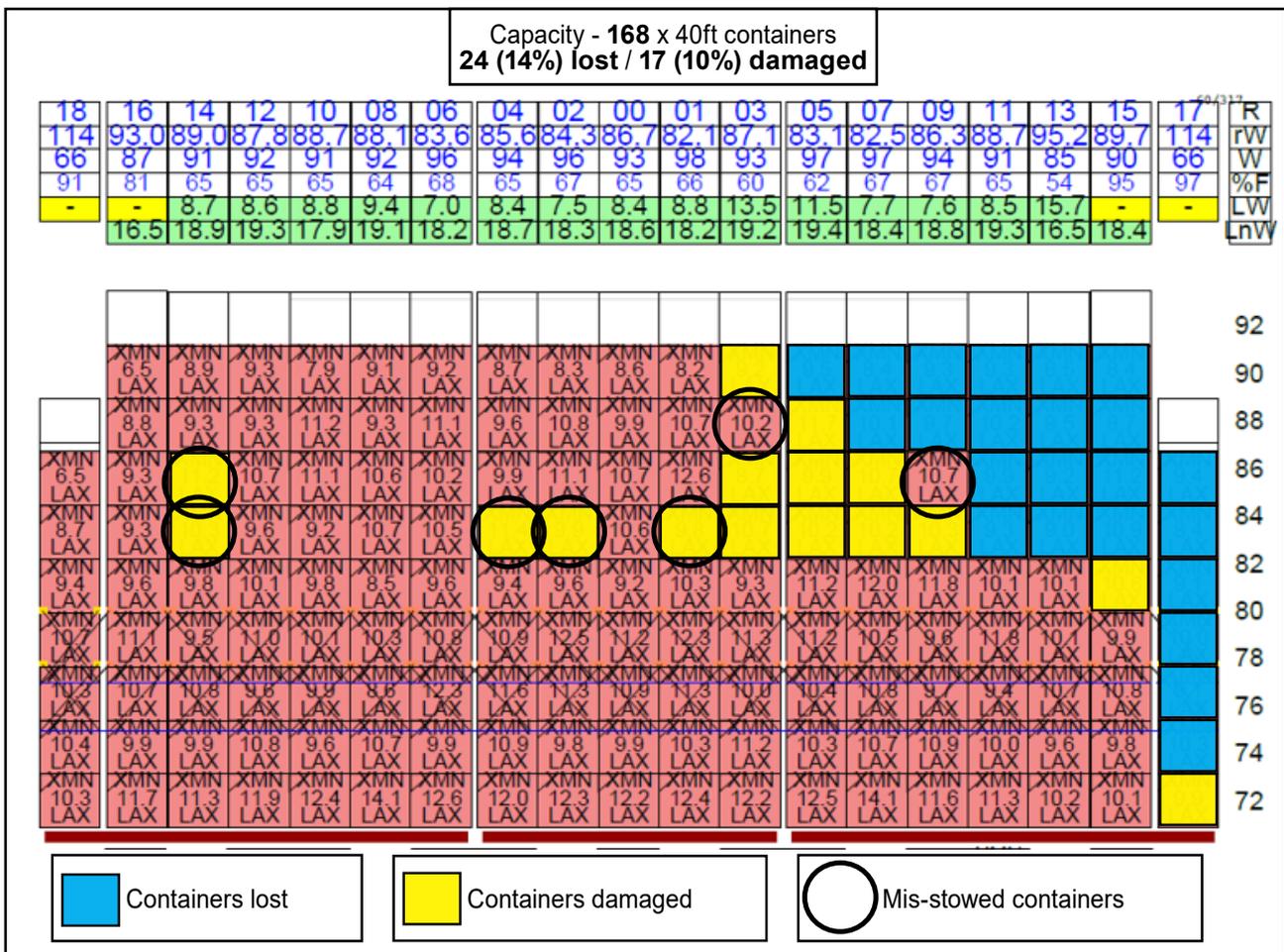


Figure 6: Bay 58 cargo stowage plan showing lost, damaged and mis-stowed containers

1.3.3 Crew

CMA CGM G. Washington had a crew of 27; 12 more than the minimum stipulated in the ship's Safe Manning Document. The ship's officers were Romanian and its ratings Filipino.

The master was 53-years-old; he first went to sea in 1987 and held an STCW class II/2 certificate of competency. He had sailed on a variety of general cargo vessels and joined CMA Ships in 2005 as a CO. He was promoted to master in 2008 and had commanded several container ships up to 11,000TEU. The master had completed one previous contract on *CMA CGM G. Washington*, between May and August 2017, and re-joined the vessel on 26 November 2017 in Hong Kong. He had also completed a period ashore working in the company's fleet operations centre in Marseille.

The CO was 43-years-old; he first went to sea in 1997 and held an STCW class II/2 certificate of competency. He had experience of working on a variety of general cargo vessels but had spent the last 9 years sailing on container ships of up to 13,000TEU. He had been a CO since 2016. He joined CMA Ships and *CMA CGM G. Washington* on 26 November 2017 in Hong Kong and assumed the role of CO following a 3-day handover period.

At sea and in harbour the master and CO were supported by three deck officers, who worked 4-hour watches followed by 8 hours' rest. The CO did not keep watches and was therefore available to oversee cargo operations and deck maintenance as required.

1.3.4 Cargo securing manual

The general principles for the safe stowage of containers on board *CMA CGM G. Washington* were set out in the ship's cargo securing manual (CSM). The CSM was produced by German Lashing Robert Bock GmbH (German Lashing) and approved by the ship's classification society, BV.

The CSM contained the ship's container securing plans (CSPs) for each bay (**Figure 7**). A GM of 3.374m (the ship's most demanding stability condition) was used in the calculations for each CSP and the following principles were to be adhered to:

- The maximum stack mass and height were not to be exceeded.
- The vertical sequence of masses within a container stack should avoid heavy containers being stowed over light containers.
- A container stack should not obstruct the line of visibility from the bridge.
- The stack should be lashed in accordance with the CSM.

In practice, the GM was always different to the one used to compile the CSM. As a result, the crew rarely referred to the CSM and instead relied on the ship's loading computer.

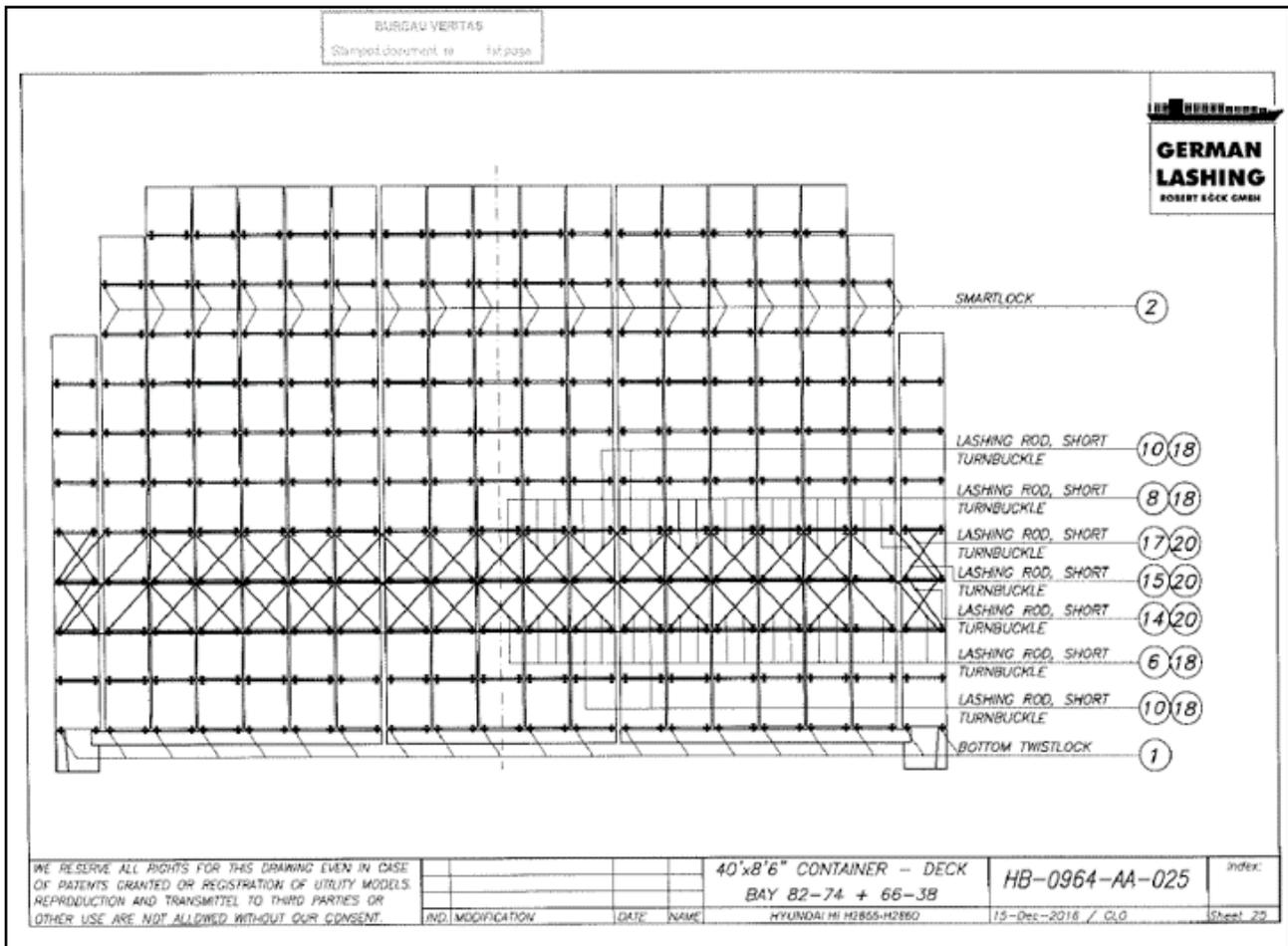


Figure 7: Example of container securing plan

1.3.5 Ship's loading computer

CMA CGM G. Washington was fitted with a MACS 3 ship's loading computer, manufactured by NAVIS and approved by BV. The loading computer was used to:

- Calculate the ship's stability, bending, shear and torsional forces and moments.
- Produce a suitable lashing plan for each bay.
- Calculate the forces acting on individual containers and highlight any areas where lashing or container load limits had been exceeded.

Unlike the CSM, the ship's loading computer provided a bespoke assessment, based on the ship's actual GM, of the forces acting on each container during the voyage. Because of this, the master and CO used the loading computer to identify when container lashing or structural loads had been exceeded, and to confirm that the cargo stowage plan was safe.

Based on the stowage plans used for the voyage to Los Angeles, the loading computer calculated that force limits for the container stacks had not been exceeded in any of the container bays (Figure 8). Of note:

- The bay where the greatest forces were predicted was bay 30, where 16 of its 19 stacks had predicted forces over 90%.

to follow a route from Xiamen pilot station to Kagoshima and, once in the North Pacific Ocean, a rhumb line² track to 34°N 172°E and then a great circle³ track to Los Angeles.

The route advice received from MeteoGroup on the afternoon of 16 January recommended the passage plan be changed to keep the vessel approximately 120nm further south to avoid bad weather and wave heights of more than 6m.

CMA CGM G. Washington was following the amended passage plan at the time of the accident. The *RouteGuard* forecast for 20 January was 4.8m swell, with 2.1m wind waves from the north-west; a combined maximum wave height of 6.9m. The estimated swell and wind wave heights recorded in the ship's logbook by the OOW were 5m and 1.2 to 2.4m respectively.

1.3.7 Ship motion monitoring, forecasting and decision support tool

CMA CGM G. Washington was fitted with an *Octopus-Onboard* electronic motion monitoring, forecasting and decision support tool (Octopus system). The Octopus system was developed by the ABB Group based in the Netherlands. The software combined ship's navigation and stability data with weather forecast information (**Figure 9a**) and ship motion measurements from onboard sensors. The data was used to provide a range of outputs designed to support the master's, and his bridge team's seakeeping and routing decision-making process. The outputs included: a polar diagram, response limits, weather window, measurement display, time traces and an alarm log.

The polar diagram (**Figure 9b**) displayed weather forecast information in a format that allowed the master and bridge team to select the best course and speed to avoid excessive ship motion. In particular, it highlighted zones where the ship could encounter dangerous phenomena, such as high wave groups, surfing/broaching, parametric roll and synchronistic roll (as described in the IMO circular MSC.1/Circ. 1228, *Revised guidance to the master for avoiding dangerous situations in adverse weather and sea conditions*) (**Annex A**).

The Octopus system allowed the user to set response limits (red, amber, green) for a variety of criteria, including pitch and roll, slamming, resonance zones, propeller racing, water on deck, and bending moment (**Figure 9c**). Response limits had not been set in *CMA CGM G. Washington*'s Octopus system.

The system's weather window function provided a long-range view of the risk of exceeding the response limits over a period (**Figure 9d**).

The measurement field provided a real time display of ship sensor information in terms of surge, sway, heave, roll, pitch and yaw (**Figure 9e**).

The time traces provided graphical representation of real time information from onboard sensors, for pitch and roll and, based on this data, calculated the historical probability of parametric roll (**Figure 9f**).

² A rhumb line is an arc that crosses all meridians of longitude at the same angle, that is, a path with constant bearing as measured relative to true or magnetic north.

³ A great circle is a circle on a sphere whose plane passes through the centre of the sphere. The great circle route is the shortest distance between two points.

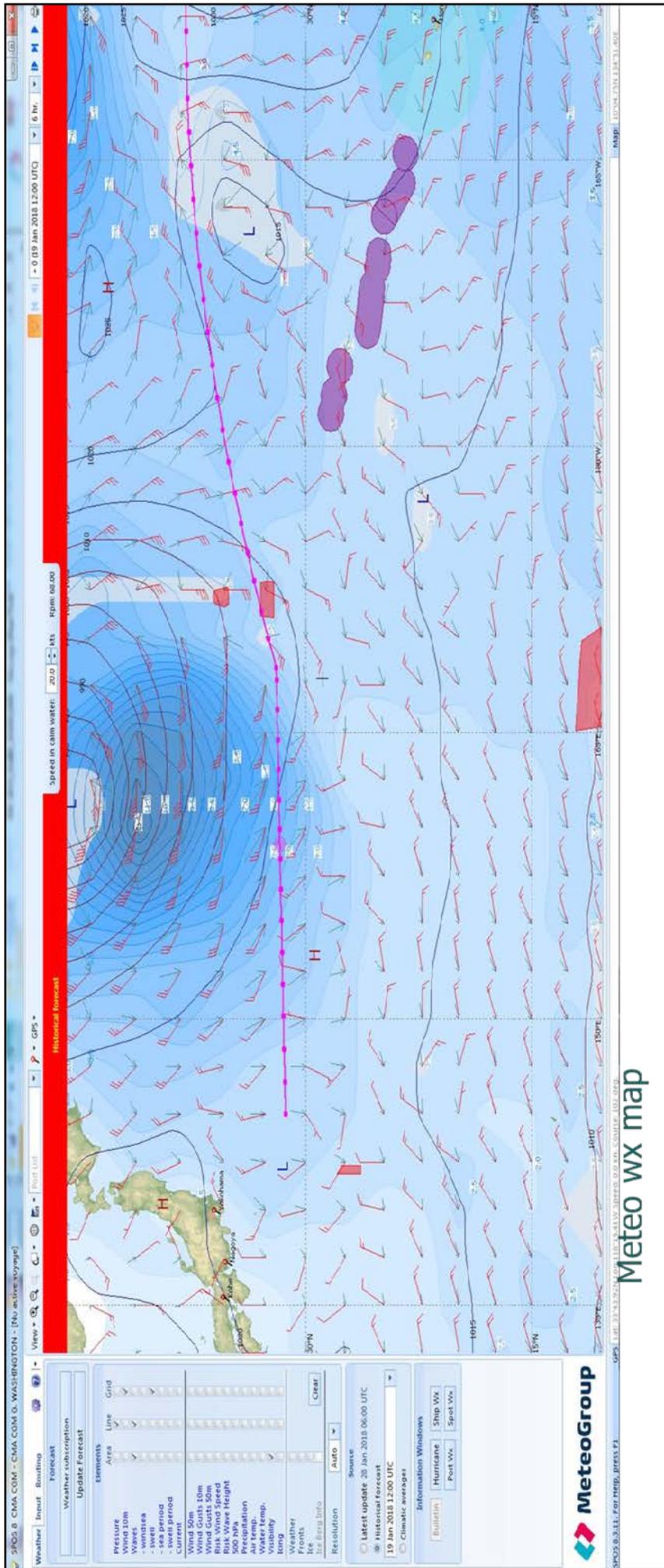


Figure 9a: Weather chart at 2300 on 19 January 2018



Figure 9b: Octopus 'Polar Diagram' at 1654 on 19 January 2018

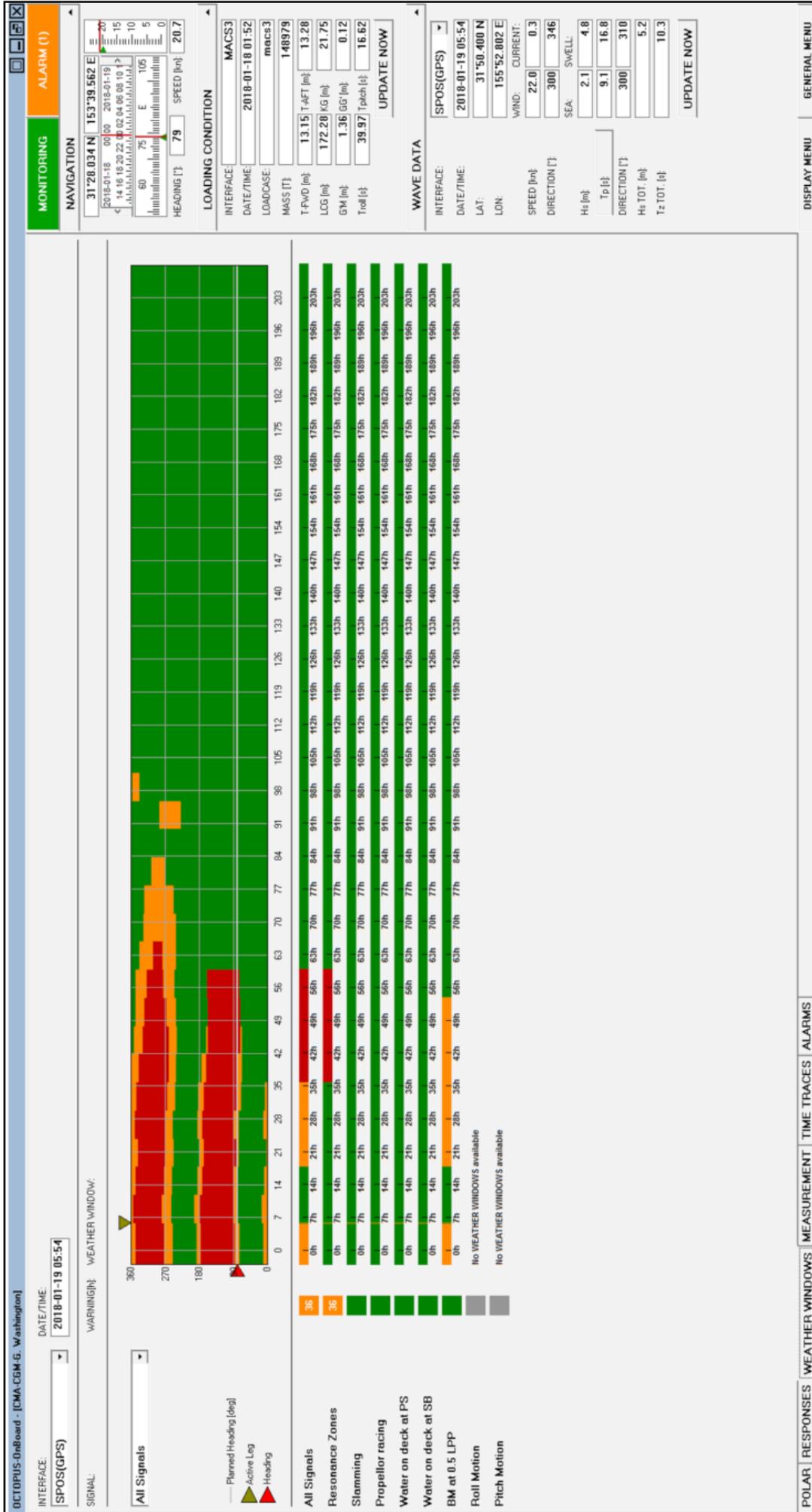


Figure 9d: Octopus 'Weather Window' at 1654 on 19 January 2018

INTERFACE:		DATE/TIME:			
NOWCASTING ▾		2011-02-15 14:00			
SIGNAL	STATUS:	ACTUAL	ALLOWED:	UNIT:	
Surge Motion		0.38	1.00	[m]	(MPE)
Sway Motion		0.34	1.00	[m]	(MPE)
Heave Motion		0.16	2.00	[m]	(MPE)
Roll Motion		1.14	2.00	[deg]	(MPE)
Pitch Motion		0.25	2.00	[deg]	(MPE)
Yaw Motion		0.45	0	[deg]	(MPE)

Figure 9e: Octopus 'Measurement' from the manual

The alarm log provided a list of alarm activations and recorded times. As motion limits had not been set, no Octopus system alarms were activated during the voyage.

The master had used the Octopus system in previous vessels and he and his navigating officer monitored the system regularly during the ocean passage. The master focused his attention on the polar diagram, based on forecast information, and did not refer to the Octopus time trace showing the percentage probability that the ship had experienced parametric roll.

1.3.8 Container lashing system

CMA CGM G. Washington's container lashing system and equipment were designed and manufactured by German Lashing and consisted of the following:

- **Manual twistlocks.** The manual twistlocks secured the bottom tier of containers to the ship's deck or hatch covers.
- **Automatic twistlocks.** The automatic twistlocks (**Figure 10**) were used to secure the subsequent tiers of containers to each other within a stack. They were single cast units with no moving parts and were fitted to the containers' bottom corner castings by stevedores ashore.
- **Rod & turnbuckle lashings.** The rod and turnbuckle lashings (**Figure 11**) were used to secure the mid-tier containers to the lashing bridges. The turnbuckles were fixed to the lashing bridge eye plates and the rods were connected to the container corner castings. The rod and turnbuckle lashings were tensioned using short steel bars; once tightened the turnbuckles were locked in place by locking rings. Stronger lashings were used to secure the containers stacked in the outer walls, which were exposed to wind load.
- **Lashing bridges.** The lashing bridges were transverse steel gantries that allowed rod and turnbuckle lashings to be attached midway up the container stack. The ship had a single or double tier lashing bridge between each bay:
 - Bay 18, which could be stacked up to nine tiers high, had single tier lashing bridges that allowed rod and turnbuckle lashings to be attached to the third and fourth tier of containers within each stack.
 - Bays 54 and 58, which could be stacked up to 11 tiers high, had double tier lashing bridges that allowed rod and turnbuckle lashings to be attached to the fourth and fifth tier of containers within each stack.
- **Adjustable platform container (APC) rack.** The APC rack (**Figure 12**) was built using a set of 40ft steel frames and was used to stack 53ft containers on top of 40ft containers.

At the time of the accident, the lashing equipment used on board *CMA CGM G. Washington* was in date for inspection and in good condition.



Figure 10: German Lashing fully automatic twistlocks

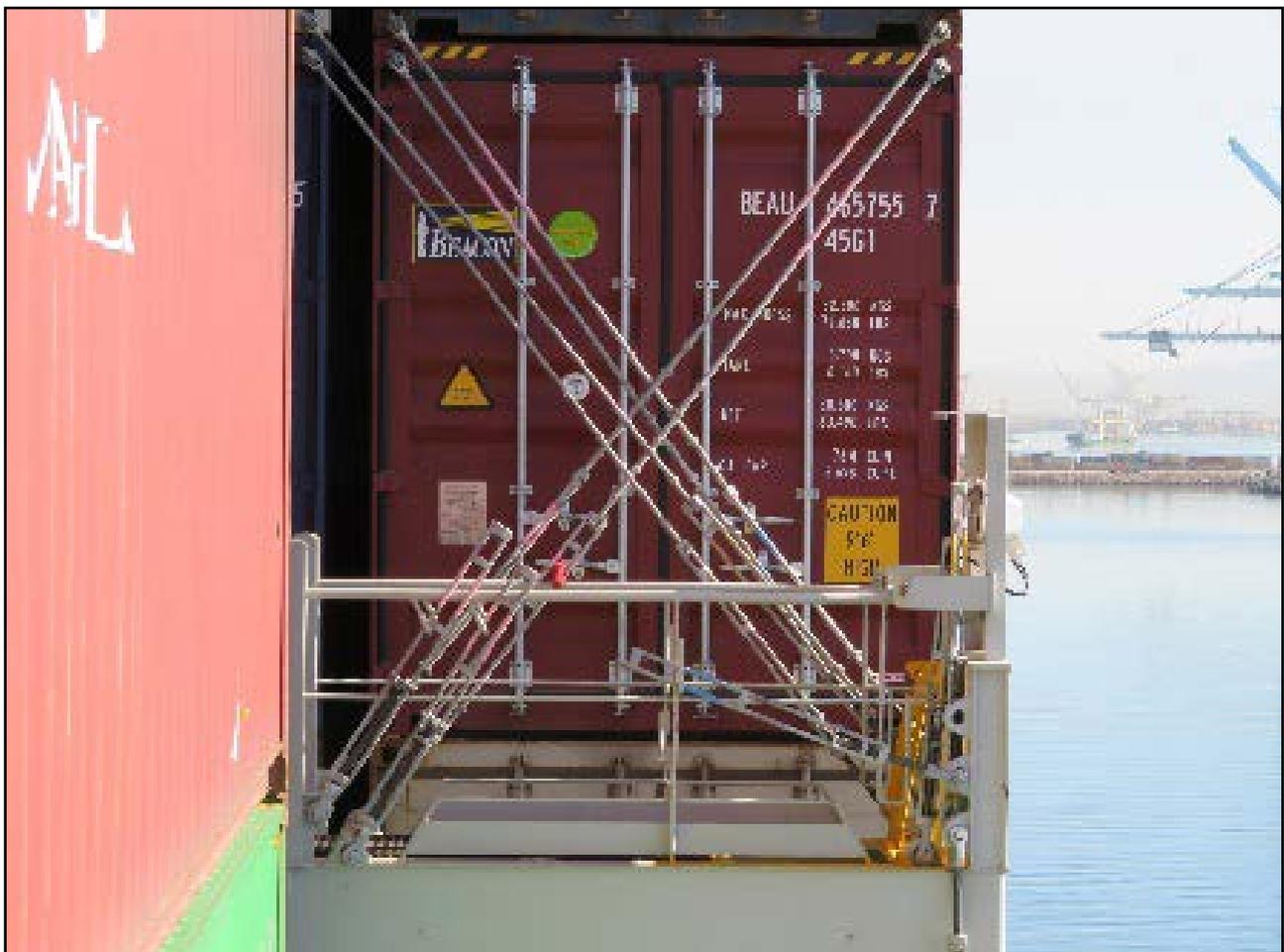


Figure 11: CMA CGM G. Washington's rod and turnbuckle lashings

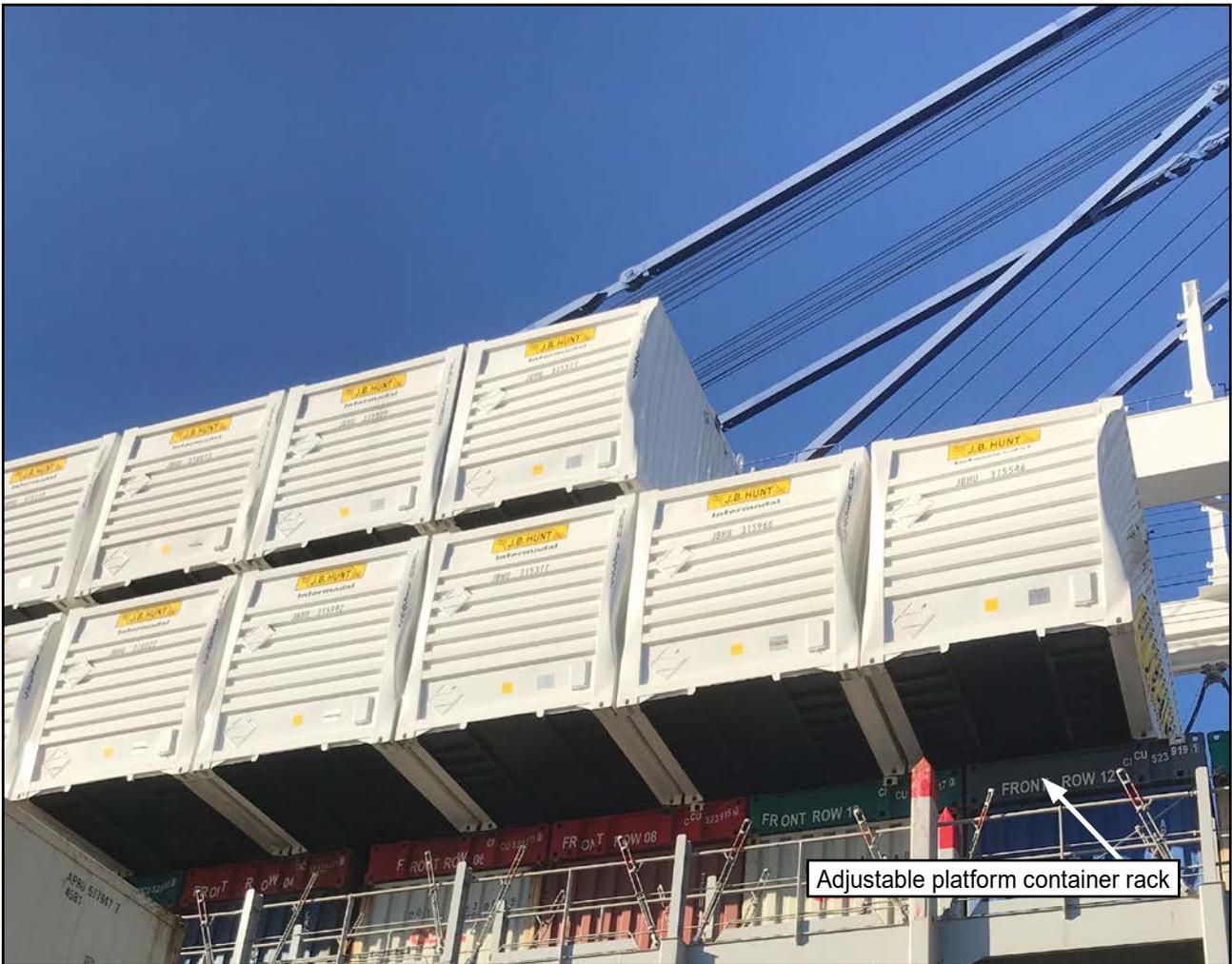


Figure 12: Adjustable platform container rack

1.4 POST-ACCIDENT INSPECTION AND DAMAGE ASSESSMENT

MAIB inspectors boarded *CMA CGM G. Washington* shortly after it berthed alongside in Los Angeles on 28 January 2018. They inspected the accident sites prior to, and after the containers were removed from bays 18, 54 and 58. During the discharge of the collapsed container bays, the following damage was discovered:

- **Bay 18 containers:** 65 of the 142 containers had been lost overboard and 35 were damaged. The containers to starboard of row 04 toppled to starboard; the remainder toppled to port (**Figure 13**).
- **Bay 54 containers:** 48 of the 153 containers had been lost overboard and 33 were damaged. The containers toppled randomly to port and starboard (**Figure 14**). Almost all the 53ft containers suffered significant compression damage and corner post failure (**Figure 15**). The side panels on some of the 53ft containers had been torn from their structural frames.
- **Bay 58 containers:** 24 of the 167 containers stowed in bay 58 had been lost overboard and 17 were damaged. The damage was confined to container stacks on the starboard side of the bay (**Figure 16**).

- **Lashing equipment:** Many of the lashing rods and turnbuckles, and manual and automatic twistlocks used to secure the containers in bays 18, 54 and 58 were damaged or had failed (**Figure 17**). Between five and seven lashing rods were found to be slack (up to 100mm of play) in each of the bays adjacent to bay 18 (bays 14 and 22).
- **Ship's structure:** There was minor structural damage found to the lashing bridge and main deck guardrails, and the hatch covers in bays 18 and 54.

According to the loading computer bayplans (**Figures 4, 5, 6 and 18**), several undamaged containers recovered from all three bays appeared to be stowed in locations that suffered most container losses and damage.

The terminal did not record the weight of the containers removed from bays 18, 54 and 58.

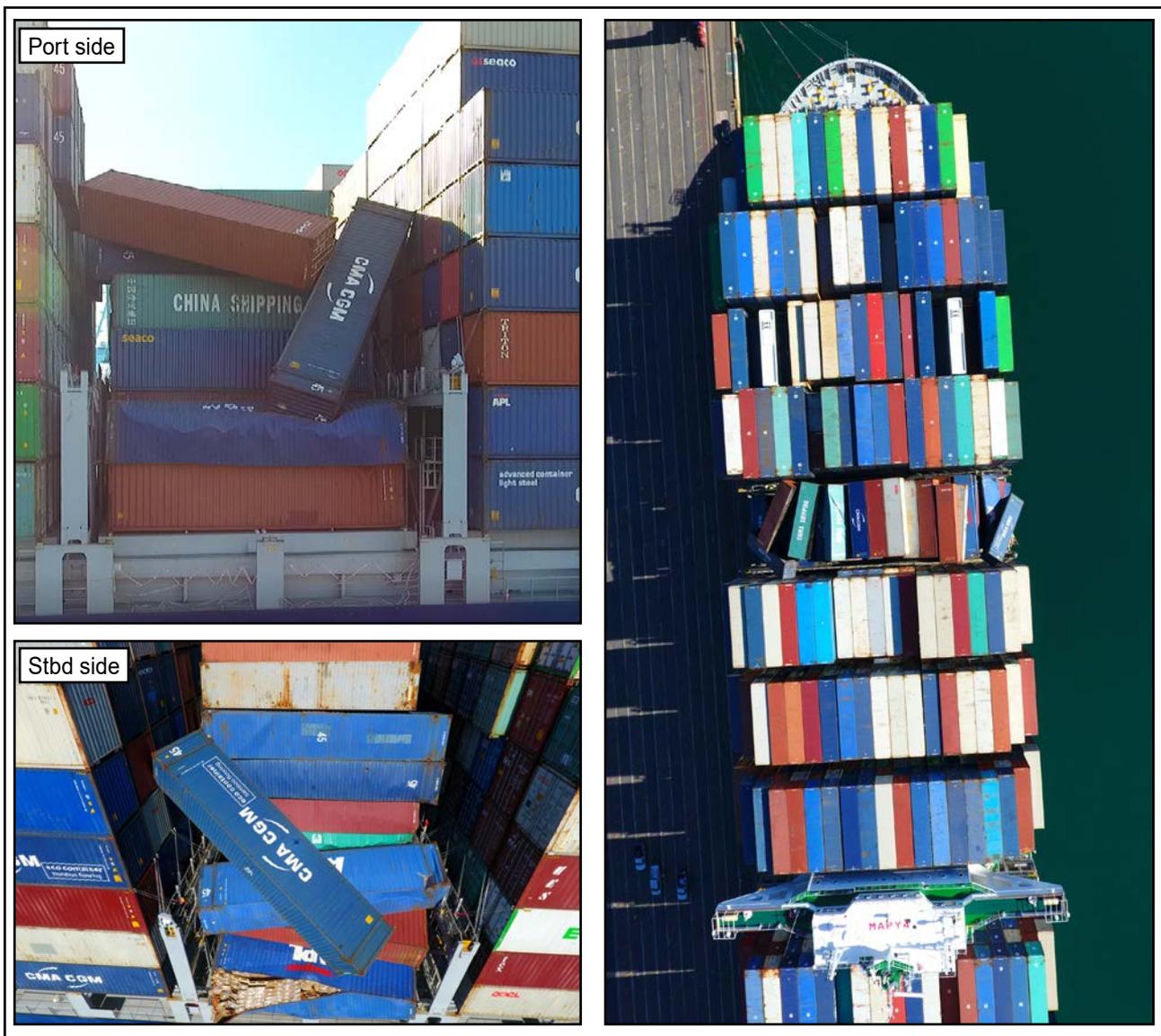


Figure 13: Bay 18 container collapse



Figure 14: Bay 54 container collapse



Figure 15: Damage to the 53ft containers



Figure 16: Bay 58 container collapse

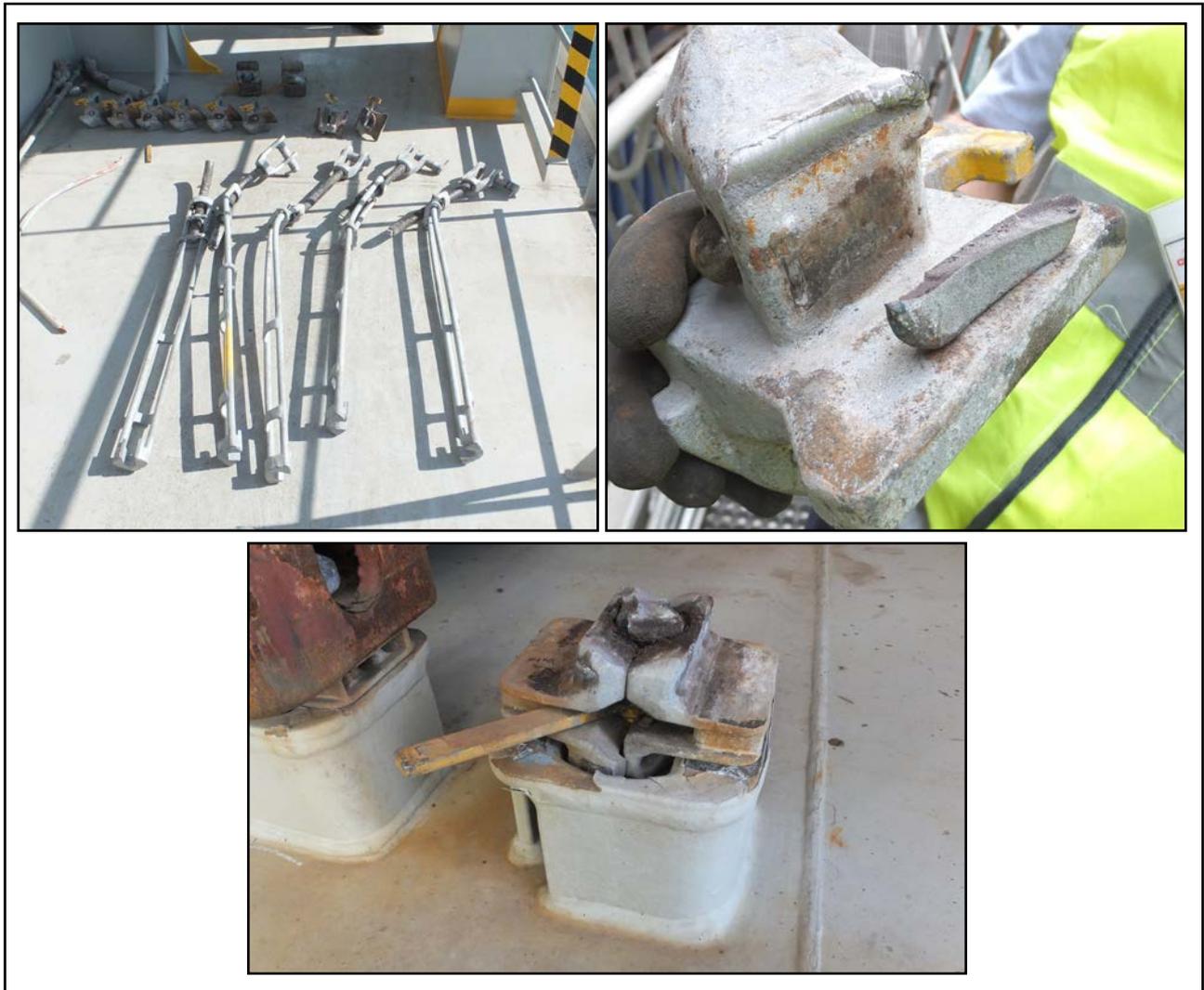


Figure 17: Damaged lashing equipment from bays 18, 54 and 58

Bay 18(aft) TwinView(GM=1.28 m , R=Worldwide, V=22.0kn)

18	16	14	12	10	08	06	04	02	00	01	03	05	07	09	11	13	15	17	R
107	82.0	80.6	69.2	73.2	62.5	72.3	70.4	55.8	63.8	62.5	69.8	89.0	79.0	79.7	94.7	91.7	92.5	105	rW
73	98	99	111	107	117	108	110	124	116	118	110	91	101	100	85	88	88	75	W
100	78	91	98	88	99	87	87	93	88	89	89	77	96	73	76	66	72	99	%F
-	4.8	-	-	-	-	-	5.5	-	-	-	-	7.2	-	6.6	-	5.1	4.3	-	LW
-	18.3	10.2	-	5.1	-	6.0	-	-	-	-	-	8.1	8.6	16.5	8.9	13.3	18.6	-	LnW

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Bay 54(aft) TwinView(GM=1.28 m , R=Worldwide, V=22.0kn)

18	16	14	12	10	08	06	04	02	00	01	03	05	07	09	11	13	15	17	R
121	91.0	84.1	82.0	80.1	83.8	78.1	75.4	93.1	86.3	76.6	79.7	77.5	84.2	79.2	89.8	75.0	132	112	rW
59	89	96	98	100	96	102	105	87	94	103	100	102	96	101	90	105	48	68	W
63	82	83	58	57	56	59	61	55	52	56	59	58	54	85	48	88	21	66	%F
-	-	-	-	-	-	-	-	-	-	-	-	3.8	-	-	13.3	-	14.0	-	LW
-	14.0	19.1	18.0	18.2	19.2	17.5	17.1	19.0	20.4	19.5	17.7	18.7	19.8	18.4	14.0	14.0	14.0	-	LnW

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Bay 58(aft) TwinView(GM=1.28 m , R=Worldwide, V=22.0kn)

18	16	14	12	10	08	06	04	02	00	01	03	05	07	09	11	13	15	17	R
114	93.0	89.0	87.8	88.7	88.1	83.6	85.6	84.3	86.7	82.1	87.1	83.1	82.5	86.3	88.7	95.2	89.7	114	rW
66	87	91	92	91	92	96	94	96	93	98	93	97	97	94	91	85	90	66	W
91	81	85	85	85	84	68	65	67	65	66	60	62	67	67	65	54	95	97	%F
-	-	8.7	8.6	8.8	9.4	7.0	8.4	7.5	8.4	8.8	13.5	11.5	7.7	7.6	8.5	15.7	-	-	LW
-	16.5	18.9	19.3	17.9	19.1	18.2	18.7	18.3	18.6	18.2	19.2	19.4	18.4	18.8	19.3	16.5	18.4	-	LnW

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Key	
R	Row
rW	Remaining stack weight
W	Stack weight
%F	Percentage of allowable force
LW	Loadable weight exposed to wind
LnW	Loadable weight no wind
	40 ft Container
	45ft container
	40ft Reefer container
	Lashing bridge
	Rod and turnbuckle lashing

Figure 18: Loading computer bayplans for bays 18, 54 and 58

1.5 CONTAINERS

1.5.1 Container construction, testing and inspection standards

Containers for carriage on board ships are approved by national governments through classification societies to the standard set out in the *International Convention for Safe Containers 1972, as amended* (CSC). The construction and testing requirements for totally enclosed general purpose shipping containers are specified by the International Organization for Standardization (ISO) in its international standard ISO 1496-1:2013 *Series 1 freight containers - Specifications and testing – Part 1: General cargo containers for general purposes* (ISO 1496).

There were five approved nominal lengths for freight containers (10ft, 20ft, 30ft, 40ft and 45ft), and these were defined in ISO 668:2013 – *Series 1 freight containers – Classification, dimensions and ratings*. All Series 1 ISO containers have a uniform width of 8ft.

Containers constructed and tested in accordance with ISO 1496 (ISO containers) are considered to have met the requirements of the CSC and are fitted with a safety approval plate (CSC plate) that includes load limits⁴ (**Figure 19**). The structural requirements did not include factors of safety for the container load limits.

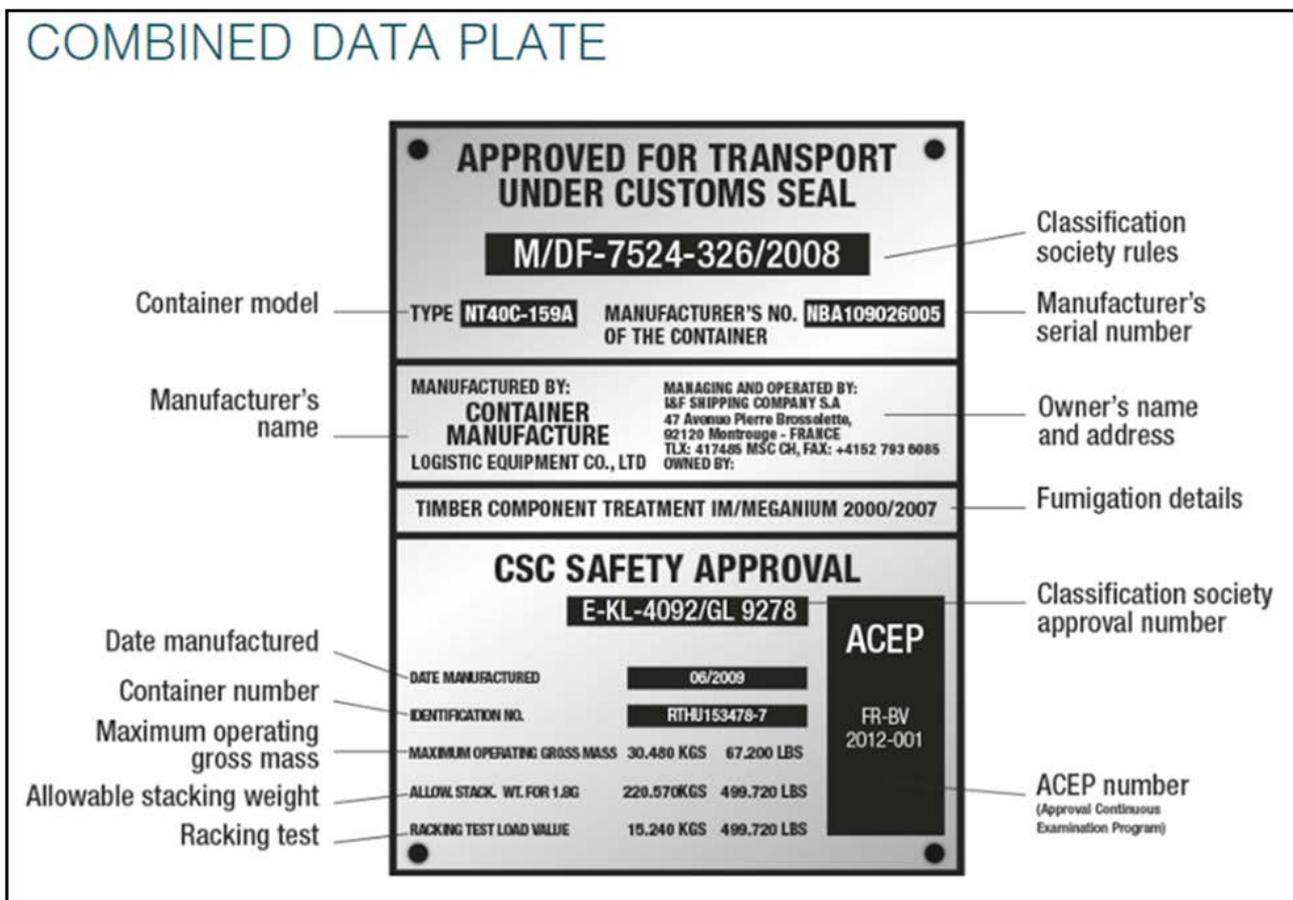


Figure 19: Example of a container CSC plate

⁴ Approximately 1 in 50 newly manufactured containers is subjected to racking force load tests.

Once certified, containers must be periodically inspected at not more than 30-month intervals by a competent person. They are not subjected to further through life structural strength and rigidity testing. Most inspections are conducted in accordance with an Approved Continuous Examination Programme (ACEP). Inspection or ACEP details are also recorded on the container's CSC plate⁵.

1.5.2 Forces acting on a container at sea

A ship in a seaway can experience three forms of rotational motion - roll, pitch, yaw, and three forms of linear motion - sway, surge and heave (**Figure 20**). These motions impose forces (**Figure 21**) on the containers as follows:

- **Corner post load.** The vertical compression forces within a stack (container masses and motion induced acceleration forces) act on the container corner posts. The maximum permissible corner post load assumed in the ship's CSM for an ISO container was 848kN.
- **Racking force.** When a ship rolls, the lower containers in the stack are subjected to horizontal sideways forces. This movement is resisted by the container rod and turnbuckle lashings. The maximum permissible racking load on a standard ISO container is 150kN.
- **Lifting force.** As a container stack is subjected to a transverse force, the outside corner of the container(s) within the stack will be subjected to a tensile loading. If the force is excessive then the twistlock can be pulled out or, the container corner casting damaged. The safe working load (SWL) of *CMA CGM G. Washington's* twistlocks was 250kN.

Containers stowed on deck are also subjected to **lashing load** and **wind load**. Lashing load is the diagonal compressive force imposed on the containers by the lashing rods and turnbuckles. The maximum permissible load from a lashing rod onto a container is between 230kN and 245kN. Wind forces act on the exposed container stacks. In general terms this means that the container weights and stack heights are reduced within the outer walls of deck container bays. The wind load on exposed 40ft containers is assumed to be 60kN for the first and 30kN for the second and subsequent tiers.

The magnitude of the transverse accelerations experienced by containers at sea differs depending on their fore and aft position within the ship. The greatest transverse accelerations are typically experienced by those containers stowed at the bow or stern of the vessel, and the lowest are experienced by those in the bays amidships (**Figure 22**).

Whipping or springing accelerations due to deck deformation in severe head seas, and interaction between container rows, can significantly increase the forces acting on containers and their lashing systems.

⁵ The CSC requires periodic ACEP audits 'at least once every 5 years'. And ACEPs 'should be reviewed once every 10 years to ensure their continued viability'.

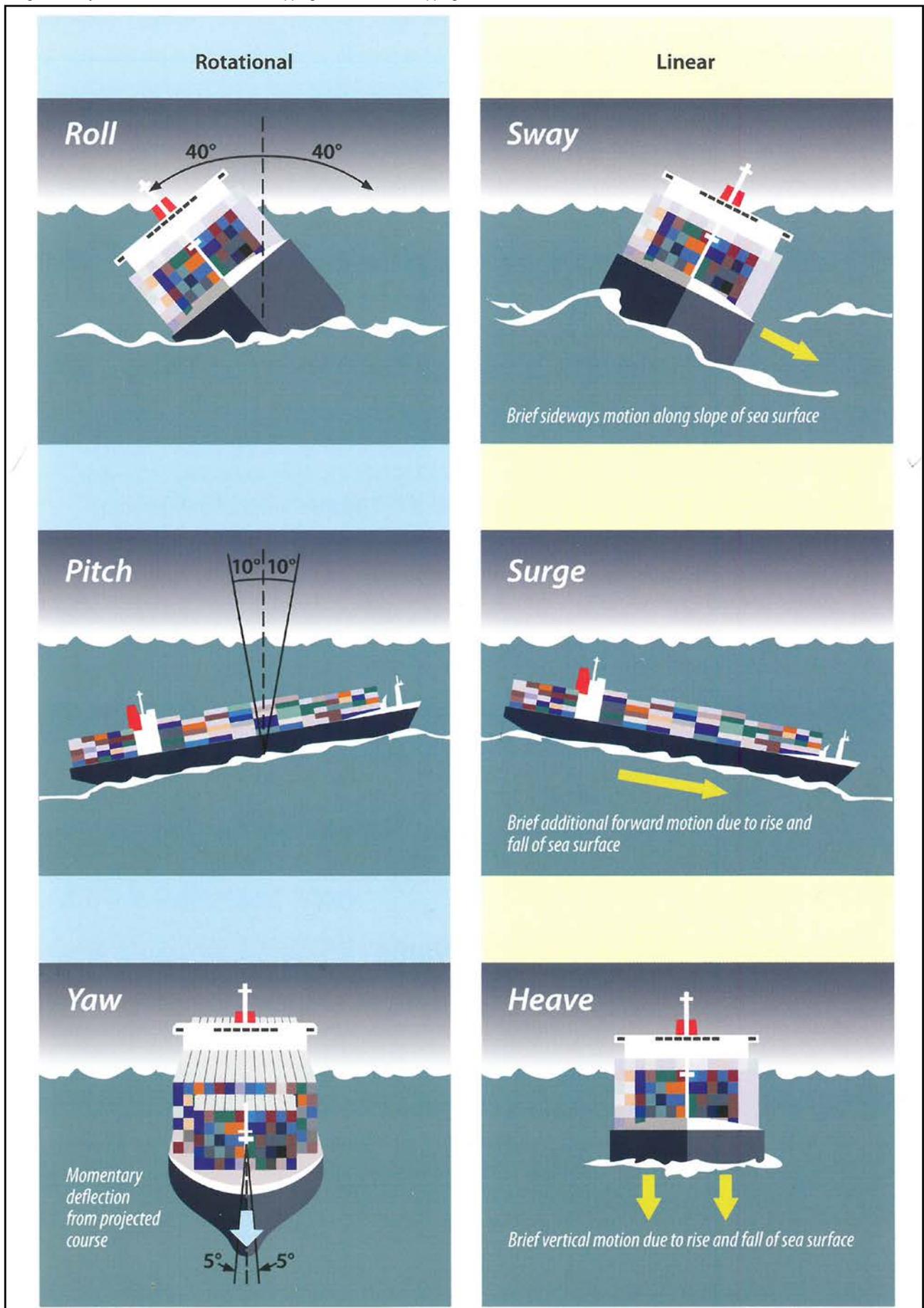


Figure 20: Ship motion in a seaway

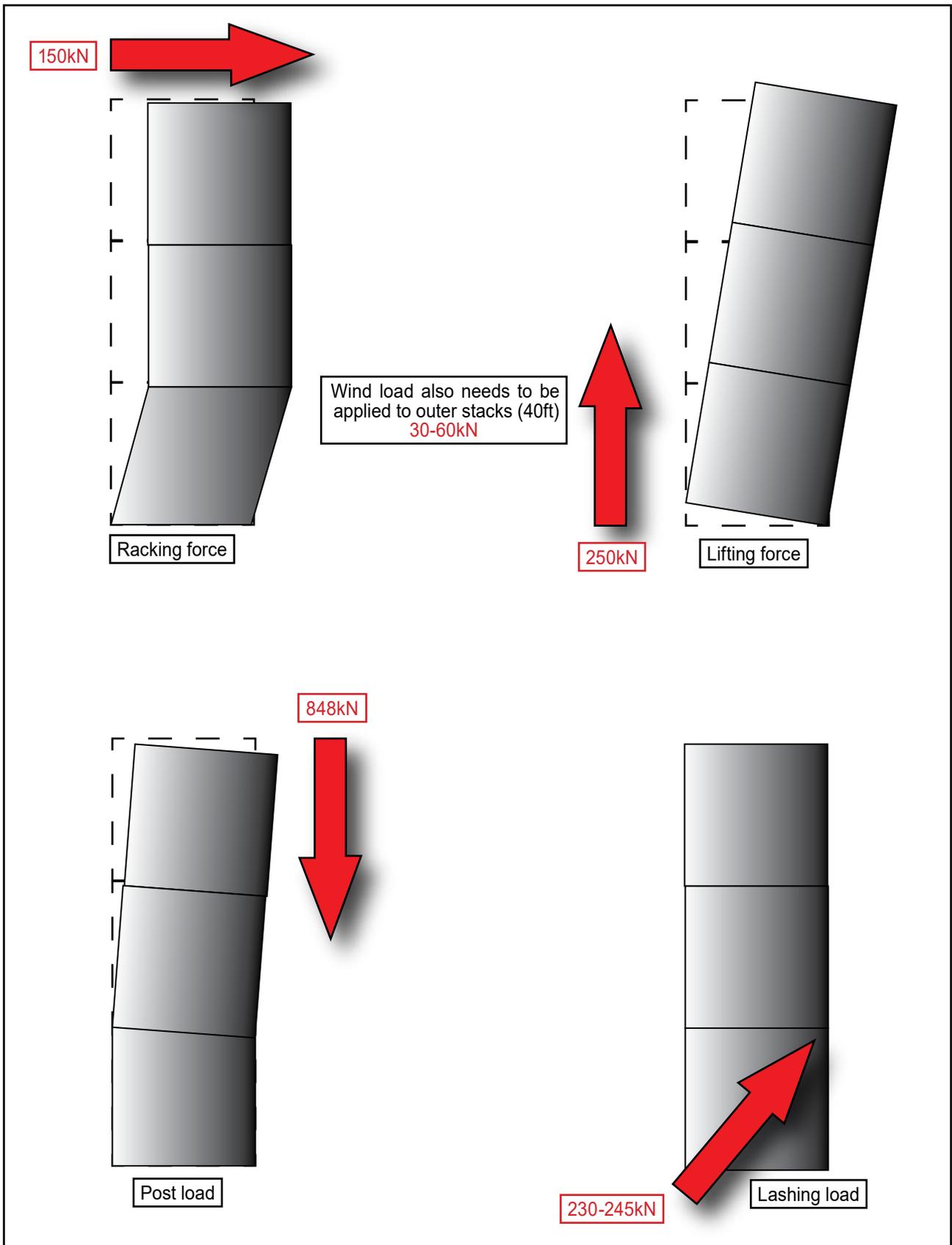


Figure 21: Forces/loads acting on a container

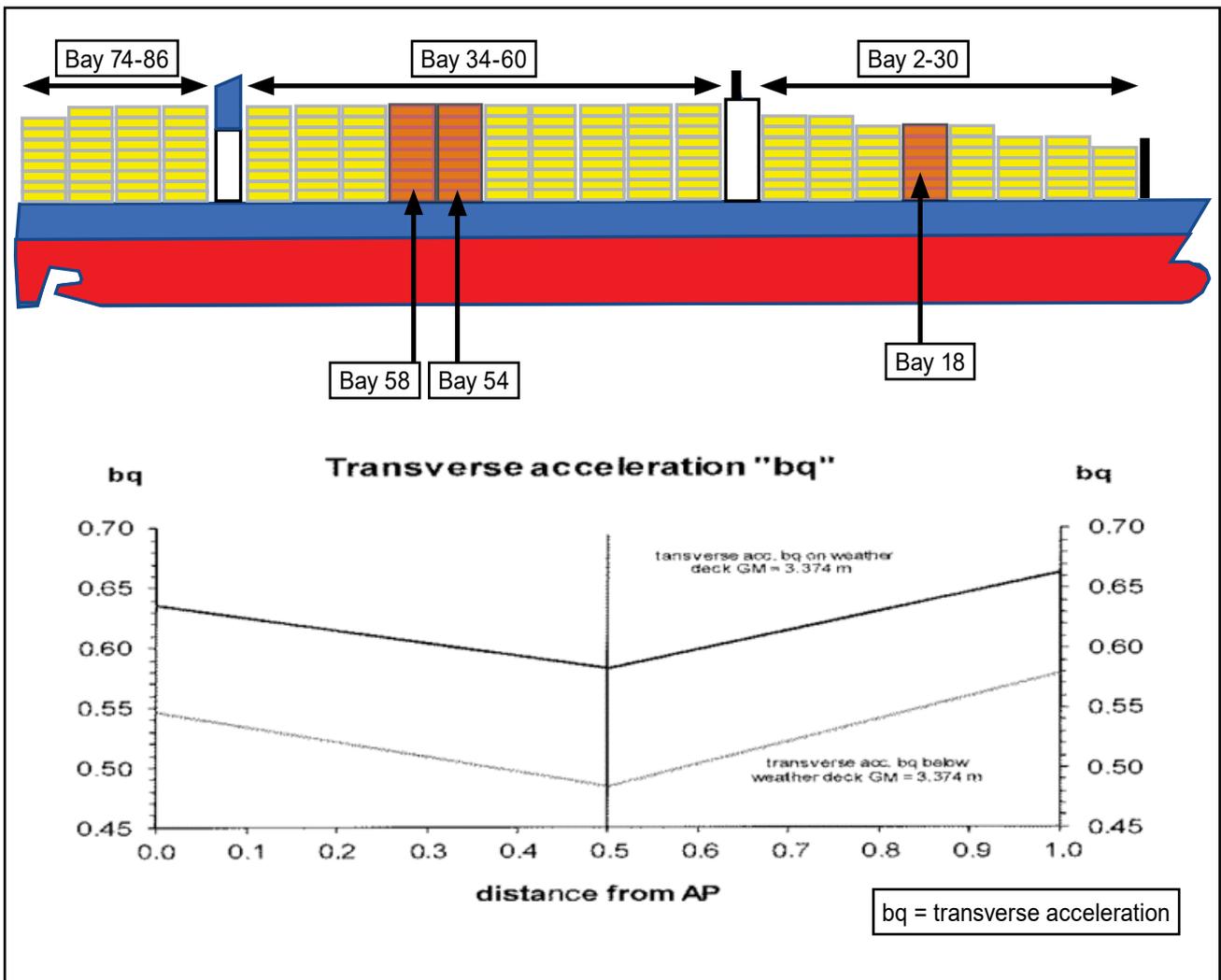


Figure 22: Transverse acceleration

1.5.3 Hull deformation and interactions between container rows in a seaway

In 2006, an international consortium comprising nine shipping owners/operators, three government bodies, five classification societies, three lashing system manufacturers and four technology providers came together to conduct the Lashing@Sea research project. The project was commissioned following a marked increase of incidents involving cargo damages and losses, and industry recognition that the regulatory framework had allowed the development of a non-level playing field. The aim of the joint industry project was to improve the safety and efficiency of cargo securing.

The Lashing@Sea project was co-ordinated by the Maritime Research Institute Netherlands (MARIN). It lasted 3 years and considered three types of marine transport: deep sea container shipping, heavy lift transport and ro-ro shipping.

During the project to evaluate the effectiveness of the cargo securing standards and equipment, the researchers reviewed lashing procedures, rules and gear; conducted interviews, issued questionnaires to ships' crews (158 respondents); recorded 3-years' worth of acceleration, vibration, weather and lashing load data on five ships; and conducted container stow motion experiments using a scale model test rig on shore.

The Lashing@Sea report, published in 2009, noted that:

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.*

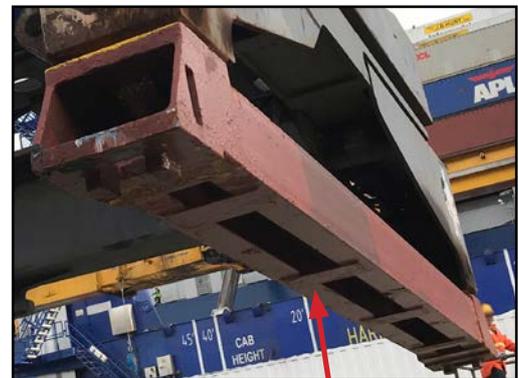
Among the report's conclusions it was stated that:

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.

1.5.4 Non-standard 53ft containers

There are no ISO standards for the 53ft containers (**Figure 23**) stowed in bay 54, which were primarily designed for use ashore within the North American road and rail networks. They were manufactured in China and transported on a one-way sea passage to Los Angeles.

The export of the non-standard containers to the US was well established. Initially, they were transported empty. In 2007, the structural strength of the containers was increased by the manufacturer to allow them to be used to carry cargo at sea. In 2011, the certifying authority, American Bureau of Shipping (ABS), began testing the containers and issuing bespoke CSC plates. ABS estimated that it had issued over 45,000 certificates for the 53ft multimodal containers. The 53ft containers were also fitted with manufacturer's plates (**Figure 24**).



Wide pick beams



Figure 23: Non-standard 53ft multi-modal transport container

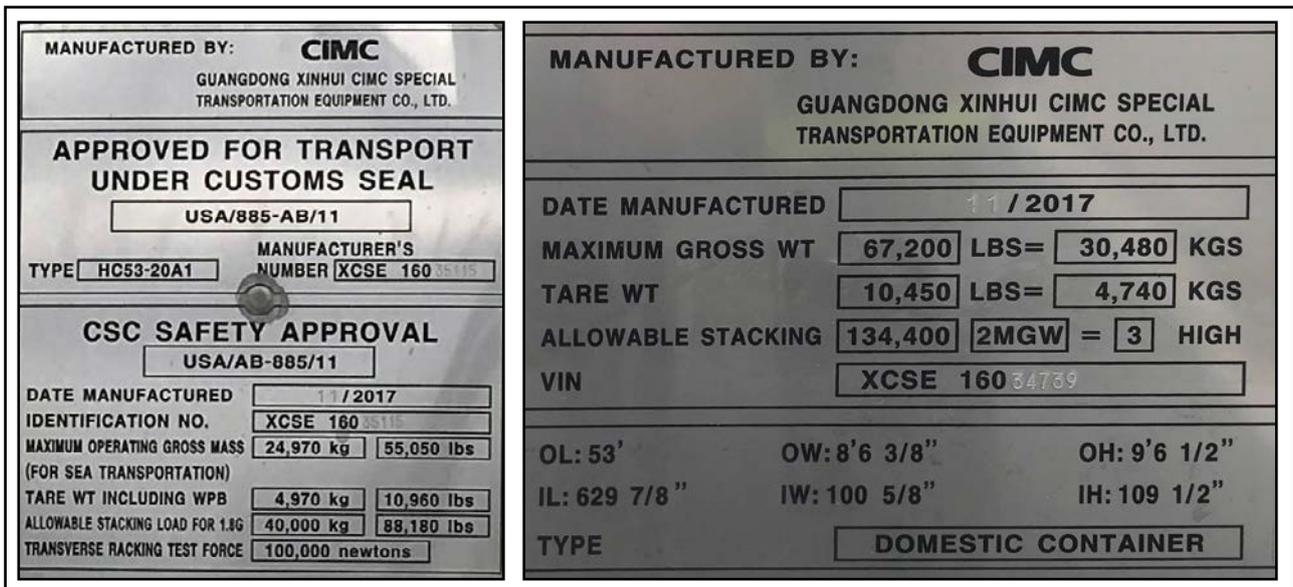


Figure 24: Manufacturer's plates attached to 53ft containers

The 53ft high-cube containers were 6in wider than standard 40ft containers and, by volume, had about a 60% greater cargo-carrying capacity. However, they were still of lighter construction and structurally weaker than ISO containers (**Table 1**). The maximum allowable stack weight for a 53ft container was less than half that of an ISO container; the maximum allowable racking force was two thirds that of an ISO container.

The manufacturer's plate stated that the 53ft containers should not be stacked more than three high. It is understood that this limit was established as a simple means to ensure that the 'allowable stack weight' was not exceeded ashore, by allowing only two fully loaded (30.4t) containers to be stacked on top of another. All reference to this stack limit had been painted or taped over prior to shipping.

Container size	45ft CSC plate	53ft CSC plate (at sea)	53ft Manufacturer's plate (ashore)	Remarks
Dimensions • length • width • height	45ft 8ft 9ft 6inches	53ft 8ft 6inches 9ft 6inches		53ft containers 6in wider than standard ISO containers.
Max gross weight	32.5t	24.97t	30.48t	53ft cargo capacity reduced when carried at sea.
Tare Weight (empty weight)	4.72t	4.97t	4.74t	CSC weight includes the two wide pick beams fitted to the top of the container.
Allowable stack weight/Max corner post load	91.44t/404kN	40t/177kN	60.96t/Not required	
Racking weight	150kN	100kN	Not required	

Table 1: Comparison of the data provided on 45ft and 53ft containers CSC and manufacturer's plates

To allow the wider 53ft containers to be lifted on and off container ships two wide pick beams (**Figure 23**) were bolted to the upper load bearing support beam castings. Similar to 45ft containers, the ends of the 53ft containers extended fore and aft past the 40ft bays (**Figure 12**). The gap between the 53ft containers in bay 54 and the 40ft containers in bay 58 was 377mm.

1.5.5 Post-accident review of container bay loads

Post-accident, BV reviewed the cargo stowage bayplans for bays 18, 54 and 58 and used its lashing software to calculate the likely loading on the individual stacks during the 20° rolls (**Annex B**). BV's calculations indicated that:

- The maximum twistlock loading on the outer walls of bay 18 during the voyage was 285.7kN to port and 283.1kN to starboard. Both these figures exceeded the twistlock SWL of 250kN but were less than the design proof load (325kN) and breaking load (500kN).
- The twistlock loading on the outer walls of the containers in bay 58, at 257.2kN to port and 272.1kN to starboard, also exceeded the SWL but remained within the proof and breaking loads.
- The forces acting on the containers in bays 54 and 58 were within the load limits for ISO containers, but exceeded those set for the 53ft containers. Specifically: the corner post load limit for the 53ft containers (177kN) was exceeded in 16 of the 17 rows, in some cases by up to 250%; and the racking force limit (100kN) was exceeded in 4 of the 17 rows.⁶

1.5.6 Container technical databases

The ISO appointed Bureau International des Containers (BIC) was the container industry's global container prefix registry. BIC was an independent, not for profit organisation based in Paris, France. It promoted the safe, secure and sustainable expansion of intermodal transportation. As part of its role, BIC established several technical databases, including its *BoxTech* Global Container Database (GCD); and its ACEP Database.

The GCD, launched in 2016, allowed the technical details for individual containers to be shared. As the GCD is accessible via automated application programme interface, if fully loaded with the global container fleet, and properly implemented, the database would provide a way of automatically checking for reduced strength containers, thereby helping to ensure they are not stowed incorrectly. At the time of the accident, the details of 11 million containers (approximately 44% of the global fleet) had been uploaded by container operators/owners.

BIC's ACEP database, established in 2013, allowed interested parties to consult the ACEPs issued to container owners/operators. The database also allowed ACEP-issuing agencies to update audit and expiration dates for ACEPs, and provided alert mechanisms to help ensure ACEPs are audited in the 5-year and 10-year timeframes stipulated in the CSC. At the time of the accident, 10 countries had provided details of their container inspection regimes; the UK was not one of them.

⁶ In bay 54 the corner post load was exceeded in rows 00 to 16 and the racking force was exceeded in rows 09,13,14, and 16.

Given the incomplete nature of both databases, it has not been possible to confirm the technical details of all the containers lost overboard.

1.6 CARGO STOWAGE PLANNING PROCESSES

The cargo planning process for *CMA CGM G. Washington* was co-ordinated by a central planner based in Marseille, France, who oversaw the production of 'pre-stow' and 'terminal' cargo bayplans. The central planner's bayplans were checked at each stage by the CO using the ship's loading computer to confirm that they met the ship's stability and cargo stowage criteria. Once the central planner had addressed any issues identified, the 'final terminal bayplan' was issued. This was typically done about 12 hours prior to the ship's arrival in port.

Email exchanges between the central planner and the ship indicated that the CO made several changes to the 'pre-stow plans' for the ports of Fuqing, Yantian and Xiamen. Bays 18, 54 and 58 were not affected by these changes.

The ship's loading computer provided the lashing plan for each bay. Shore stevedores, provided with lashing instructions, secured the cargo using the ship's lashing equipment. Once complete, the stevedores' work was checked by the ship's duty officer, and any shortcomings identified were rectified prior to the work being signed off.

1.7 CONTAINER WEIGHTS

1.7.1 Verified gross mass

The International Convention for the Safety of Life at Sea 1974, as amended (SOLAS) Chapter VI, Part A, Regulation 2 – Cargo information, requires the gross mass of a packed container to be verified by a shipper before it is permitted to be loaded on a ship. The IMO issued detailed guidance on the implementation of the SOLAS requirements for verified gross mass (VGM) in its MSC.1/Circ. 1475 *Guidelines regarding the verified gross mass of a container carrying cargo (Annex C)*. The aim of these guidelines, which became effective from July 2016, was to improve maritime safety and reduce the dangers to ships, cargo and personnel throughout the container supply chain.

The gross mass of a packed container shall be verified using one of the following two methods:

- weighing the packed container using calibrated and certified equipment; or
- weighing all packages and cargo items, including the mass of pallets, dunnage and other securing material to be packed in the container and adding the tare mass of the container to the sum of the single masses, using a certified method approved by the competent authority of the State in which packing of the container was completed.

The VGM must be stated in the container's shipping document, which is required to be submitted to the ship's master or his representative, and to the terminal, sufficiently in advance to allow it to be used in the preparation of the ship's stowage plan.

1.7.2 Verified gross mass discrepancies

It is not the responsibility of a terminal to check or verify the declared gross mass of a container. However, many do, and shippers often request terminals to weigh their packed containers and issue VGM declarations.

MSC.1/Circ.1475 provided guidance on how to resolve any discrepancy between the declared VGM and measured terminal weight. Specifically, it stated that:

Any discrepancy between a verified gross mass of a packed container obtained prior to the container's delivery to the port terminal facility and a verified gross mass of that container obtained by that port facility's weighing of the container should be resolved by use of the latter verified gross mass obtained by the port terminal facility.⁷

Similar advice was provided by the UK's Maritime and Coastguard Agency (MCA) in its Marine Guidance Note (MGN) 534 (M+F) *CARGO SAFETY - Guidance on the implementation of the SOLAS VI Regulation 2 amendment requiring the verification of the gross mass of packed containers*. Specifically, it stated that:

If a packed container is weighed at the port terminal facility, that is the gross mass that should be used for ship stow planning.

The containers loaded on board *CMA CGM G. Washington* in China were weighed, and their weights recorded by the terminals during the loading process. The terminal weight data was not used to check the accuracy of the containers' declared VGM and there was no process in place to do so.

Following the accident, the terminal weight data recorded at Xiamen (2,469 containers) was obtained and compared against the declared container VGM data. The data analysis identified that:

- The total terminal weight for the 2469 containers (30,394t) was 736t (2.4%) lower than the total declared VGM.
- 65% of the containers' VGMs were within +/- 5% of the terminal weights.
- Of the remaining 35%:
 - 2% were over 1t heavier than their declared VGM, with the largest variance being 16t.
 - 10% were over 1t lighter than their declared VGM, with the largest variance being 8t.

Containers loaded in Xiamen were present in bays 18 and 58, but none were stowed in bay 54.

⁷ IMO MSC.1/Circ.1475, Annex, para 9.2.

1.8 METEOROLOGICAL AND SHIP-HANDLING CONSIDERATIONS

1.8.1 IMO guidance to masters

In its *Revised Guidance to the Master for Avoiding Dangerous Situations in Adverse Weather and Sea Conditions* (MSC.1/Circ. 1228), the IMO highlighted the dangers posed by the following four phenomena:

- surf riding/broaching
- reduction of intact stability when riding a wave crest amidships
- synchronous rolling, and
- parametric rolling.

Parametric rolling is where a ship experiences larger than expected roll behaviour due to a cyclic variation in the ship's stability caused by the position of wave crests and troughs. Specifically, when the primary wavelength is similar to the ship's length with either (**Figure 25a**):

- The wave crest amidships and the bow and stern in wave troughs. Or,
- When the ship is supported by a crest at the bow and stern with the trough amidships.

This leads to changes in waterplane area that alter the vessel's centre of buoyancy and cause variation in the GM. This can then result in the ship experiencing a larger than anticipated roll (**Figure 25b**).

The IMO circular suggested that parametric rolling may occur when either the period of roll (T_R) equals the period of encounter (T_E), or the period of encounter is approximately half the roll period.

The risk of parametric roll in a following sea is very sensitive to minor changes in the relative direction of the sea. Large container ships, such as *CMA CGM G. Washington*, are particularly vulnerable to parametric rolling due to their length and fine hull form (**Figure 25c**).

1.8.2 Company guidance to masters

CMA Ships highlighted the guidance contained in MSC.1/Circ. 1228 in a fleet circular issued in 2014⁸. The circular instructed OOWs to monitor and record the wave parameters in the bridge logbook and advise the master if they have concerns about the ship's motion. The circular directed the OOW to inform the master when the T_R is between 1.7 and 2.2 times the T_E .

The ship's loading computer showed the T_R was 32.8 seconds and, applying the guidance provided in the fleet circular, the master should have been informed when the T_E was between 14.9 and 19.4 seconds. No wave parameters were recorded in *CMA CGM G. Washington's* deck log during the voyage.

⁸ CMA Ships FMCL 094-0-14 (Navigation in bad weather).

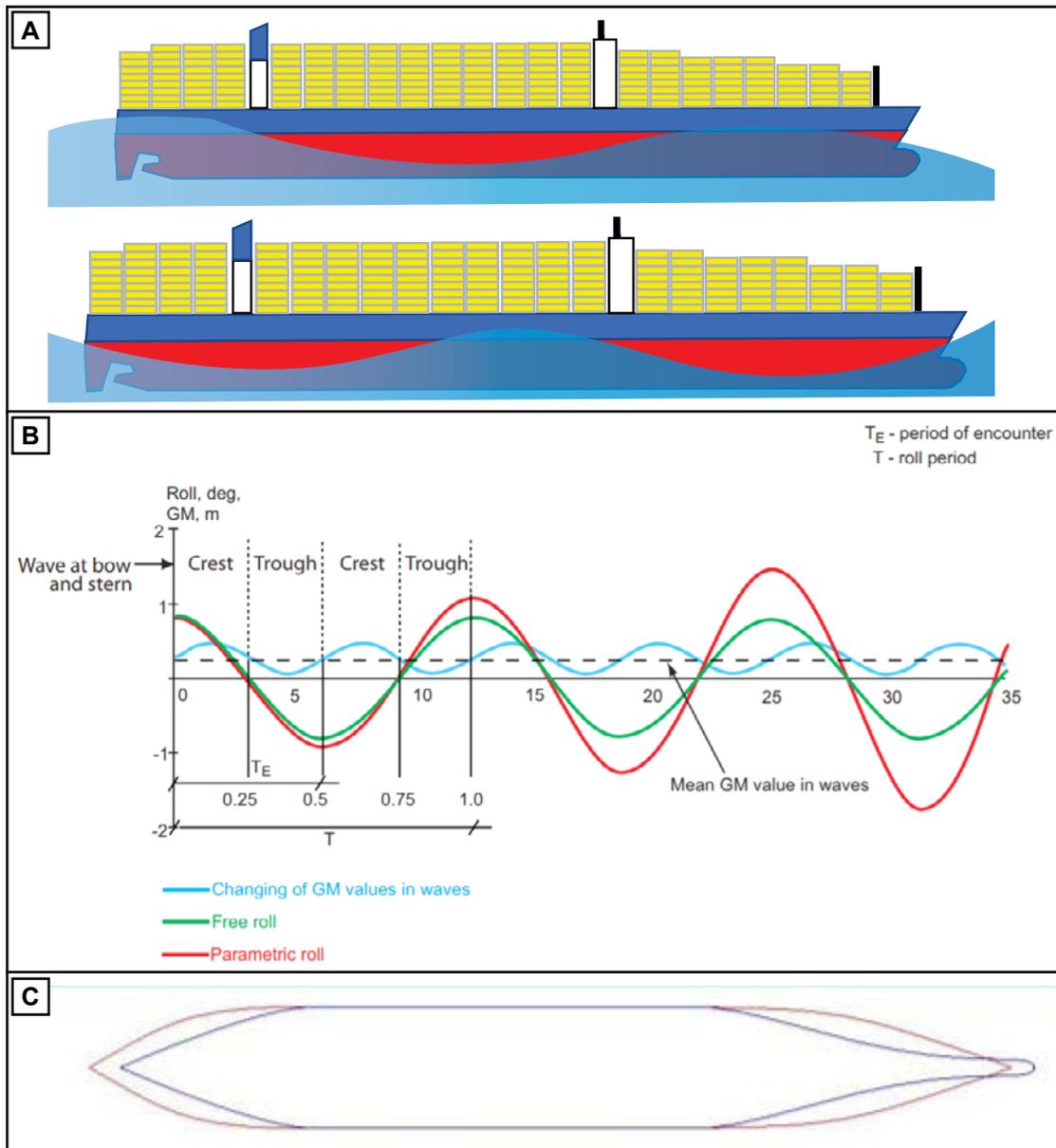


Figure 25: Illustration of a parametric roll

On the evening before the bay collapses, *CMA CGM G. Washington*'s master was concerned about the increased risk of parametric rolling because of the following sea and swell. Unable to effectively judge the sea conditions at night, he closely monitored the Octopus system's polar diagram and ensured that the ship's course kept it clear of the predicted parametric roll zone.

The Octopus system time trace data showed that the historical risk of parametric roll had steadily increased during the day on 19 January. After 1600, the recorded probability was frequently higher than 80%. Immediately prior to the 20° rolls on the morning of 20 January the probability was recorded as 100%. Post-accident calculations, using the IMO method, also showed that there was a significant risk of parametric rolling (**Figure 26**).

1.8.3 Ship motion limits

The magnitude of the forces acting on a container stow is largely dependent on stack weights and the vertical, transverse and longitudinal accelerations created by the ship's motion at sea. The most significant of these are the transverse accelerations.

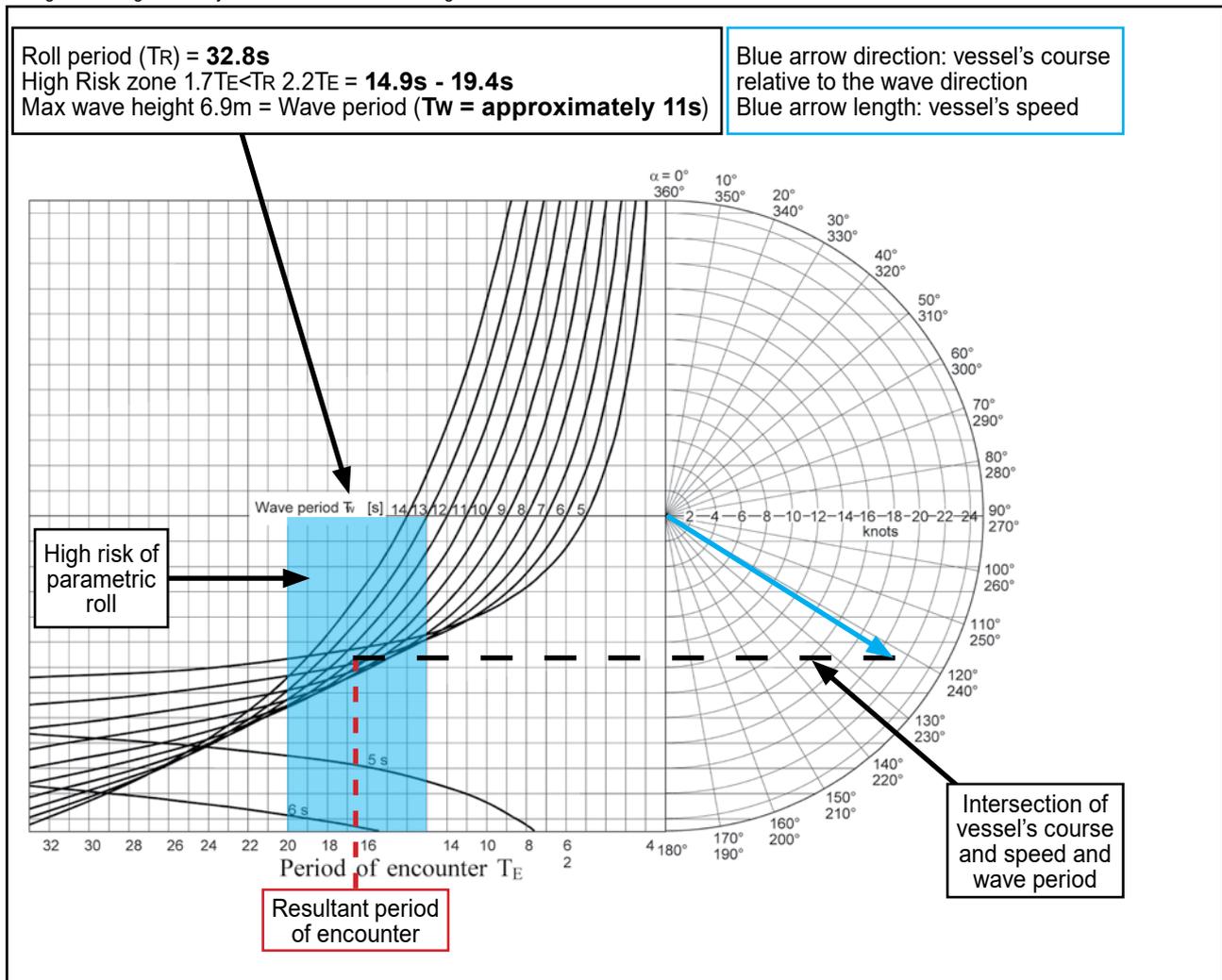


Figure 26: Manual calculation of parametric roll using IMO guidance

In accordance with the International Association of Classification Society (IACS) common structural rules, transverse acceleration comprises the following three components:

- Sway acceleration
- Static roll, gravitational component, and
- Dynamic acceleration.

Both the sway and static roll accelerations are dependent on a combination of the vessel's GM and the roll angle amplitude. To ensure that the structural limits of the cargo containers and ship's lashing equipment are not exceeded, masters need to know the ship's motion limits for given GMs.

CMA Ships had provided advisory response limits of 5° pitch and 15° roll for its 14,400TEU class vessels, but there were no ship-specific limits provided in *CMA CGM G. Washington's* CSM. The ship's loading computer printout indicated that the roll angle calculation parameter during the voyage to Los Angeles was 11.679° (**Annex D**). However, this roll angle was not designed to be used as a maximum roll angle. Unaware of the company's advisory limits, and in the absence of realistic vessel-specific guidance, the master perceived the ship's roll limit to be between 15° and 20°. This was based on the experience he had gained on board previous ships.

Post-accident calculations conducted by BV established the roll limit for the given GM and transverse acceleration limits was 16.5°.

1.9 PREVIOUS ACCIDENTS

1.9.1 Global container losses

The World Shipping Council (WSC) conducts periodic surveys to determine and monitor the extent of container losses at sea. Its 2017 *Containers Lost at Sea Report (Annex E)* analysed the survey information gathered for the period 2014 to 2016. All WSC members participated in the survey and the results of the report represented 80% of the industry's global container capacity.

The WSC 2017 report stated that, excluding catastrophic losses⁹, 612 containers were lost at sea each year, and explained that:

containers lost overboard [in 2016] represent about one thousandth of 1% of the roughly 130 million container loads shipped each year.

A summary of accidents investigated internationally by marine casualty investigation bodies since 2006 is shown in **Table 2**. The average roll angle that initiated the loss of containers overboard in the examples listed was about 30°. In the one accident, other than *CMA CGM G. Washington*, where the roll angle was less than 30° (*CMA CGM Otello*), the cause of container loss was attributed to twistlock failure.

Year	Vessel	Location	Containers lost/damaged	Ship motion (Roll)	Investigating body
2006	<i>CMA CGM Otello</i>	N Atlantic	50/20	20°	BEAmer
2006	<i>P&O Nedlloyd Genoa</i>	N Atlantic	27/32	30°	MAIB
2007	<i>Annabella</i>	Baltic	0/7	30°	MAIB
2009	<i>Pacific Adventurer</i>	Australia	31	40°	ATSB
2014	<i>Svendborg Maersk</i>	N Atlantic	517/250	41°	DMAIB
2018	<i>CMA CGM G. Washington</i>	N Pacific	137/85	20°	MAIB
2018	<i>Yang Ming Efficiency</i>	Australia	81/62	30°	ATSB

Table 2: Summary of investigations into container losses at sea

1.9.2 P&O Nedlloyd Genoa

On 27 January 2006, while on passage from Le Havre, France to Newark, USA, the UK registered container ship *P&O Nedlloyd Genoa* lost 27 containers overboard in heavy weather. A further 28 containers collapsed on deck. The vessel experienced five large rolls shortly after the master had made speed and course alterations to reduce bow slamming and avoid the risk of parametric rolling.

The exact cause of the accident was not determined. However, the MAIB investigation report¹⁰ found that the requirements set out in the cargo loading manual were not followed, such that the weight distribution in Bay 34 was out of

⁹ The report defines catastrophic as: *...a loss overboard of 50 or more containers in a single incident.*

¹⁰ MAIB report 20/2006: Report on the investigation of the loss of cargo containers overboard from *P&O Nedlloyd Genoa*, North Atlantic Ocean on 27 January 2006.

tolerance. The lashings on the affected containers were destroyed, and it was considered probable that the stow was sufficiently out of tolerance for the excessive heavy rolling to cause a refrigerated container in one of the lower rows to buckle and collapse, resulting in a progressive collapse of the stacks to port.

The investigation highlighted that the container inspection requirements did not include the assessment of structural strength and rigidity. The MCA was recommended to:

- *In consultation with MARIN, review the contents of container vessel CSMs and, if appropriate, issue further guidance on their minimum required content.*
- *Use the data from an MCA study into container damage, to review:*
 - *container structural strength and rigidity standards, and*
 - *the need to improve container inspection regimes.*

Following work, which included addressing the issues above, by several organisations, including the MCA, the IMO amended its regulations and guidelines for CSMs and CSC.

1.9.3 Annabella

On 25 February 2007, while on passage in the Baltic Sea, *Annabella* encountered heavy seas, which caused the vessel to roll and pitch heavily. The master reduced speed and adjusted course to reduce the motion, and by the following day the vessel had resumed its normal passage. Later that morning it was discovered that a row of seven 30ft cargo containers in bay 12, number 3 hold, had collapsed against the forward part of the hold.

The collapse of cargo containers occurred because of the magnitude of the downward compression and racking forces acting on the containers at the bottom of the stack. The MAIB investigation report¹¹ identified that the maximum allowable stack weight had been exceeded and no lashing bars had been applied to the containers.

The report concluded that there was a compelling need for the introduction of a Code of Practice for the container shipping industry. In response, the IMO issued its revised Code of Safety Working Practices for Cargo Stowage and Securing 2011 and the International Chamber of Shipping/World Shipping Council published Safe Transport of Containers by Sea; Guidelines on Best Practice in 2008.

¹¹ MAIB report 21/2007: Report on the investigation of the collapse of cargo containers on *Annabella*, Baltic Sea on 26 February 2007.

SECTION 2 - ANALYSIS

2.1 AIM

The purpose of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations to prevent similar accidents occurring in the future.

2.2 FATIGUE

Between 7 and 15 January 2018, *CMA CGM G. Washington* completed a busy programme of five port visits. This included intense periods of cargo operations followed by short sea passages between harbours. However, *CMA CGM G. Washington* had a crew of 27, which was 12 more than the minimum requirement set out in the ship's Safe Manning Document. In addition, the ship's records indicated that all crew members received the required hours of rest during the port operations and the 4-day sea passage immediately prior to the container bay collapses. It is therefore unlikely that fatigue was a contributory factor in this accident.

2.3 OVERVIEW

At 0815 on 20 January 2018, *CMA CGM G. Washington's* crew discovered that three of the ship's deck container bays had collapsed following a prolonged period of heavy weather; the remaining 19 bays were undamaged and remained intact.

These types of container stow collapses are rarely attributed to a single cause and are usually the consequence of several complex factors, such as:

- **Ship's motion:** Ship's motion introduces dynamic loading on container stacks and is affected by the sea and wind conditions, and the ship's course and speed, hull design and GM.
- **Stowage plan:** The safe stowage of containers; specifically, weight distribution and container securing arrangements within each bay are governed by the guidance provided in the ship's CSM and the calculations carried out by the loading computer.
- **Containers:** The structural strength and material condition of containers, and the way they are packed.
- **Container lashings:** The design and condition of the container lashings, their arrangement and application.

CMA CGM G. Washington was a new, purpose-built container ship, employed on a regular route between China and the USA. The 3,220 containers carried on deck were secured in accordance with the CSM, and the stow had been approved by the ship's loading computer.

This section of the report will establish the likely timing and causes of the container bay collapses, the cause of the heavy rolling, and it will examine the factors that contributed to them.

2.4 INITIATION OF THE CONTAINER COLLAPSE

The collapse of the three container bays was not witnessed by the ship's crew. All container bays on deck were intact and secure on the morning of 18 January when the deck crew last conducted a full lashings inspection.

The routine daily lashings inspection was not fully completed on the morning of 19 January because of the worsening sea conditions. However, the container bays forward of the bridge, including bay 18, were intact when they were inspected by the CO and bosun at 1800 following a sudden large roll of 16° to port during a fire drill. Between then and 0127 on 20 January, when the vessel unexpectedly rolled 20° to starboard and then 20° to port, the ship's roll amplitude varied between 10° and 15°.

Even though the bays aft of the bridge had not been inspected on 19 January, there was no evidence to suggest that bays 54 and 58 collapsed during that day. If they had, it would most likely have happened during the 16° roll at 1800. However, the 20° roll experienced by *CMA CGM G. Washington* the following morning exceeded the ship's roll limit of 16.5° (calculated by BV after the accident) and was recognised as a significant event by the master and crew. Therefore, the collapse of container bays 18, 54 and 58 was probably initiated at 0127 on 20 January 2018 by the magnitude of acceleration forces generated when the ship rolled 20° to starboard and port.

2.5 SHIP'S MOTION AND THE USE OF THE DECISION SUPPORT TOOL

CMA CGM G. Washington's master received a forecast of impending bad weather and routing advice shortly after the ship's departure from Xiamen, and he immediately altered his passage plan, in accordance with the advice given, to avoid the worst of the weather. He also closely monitored the weather forecast information and risks of high wave groups, surfing/broaching, parametric roll and synchronistic roll displayed on the Octopus system's polar diagram (**Figure 9b**). As the amplitude of the ship's rolling motion increased to about 15° on the evening of 19 January, the master altered course by 6° to reduce it.

The actions taken to reduce the ship's roll amplitude and mitigate the risk of potentially dangerous levels of ship motion appeared to be effective. However, the ship had a following sea and was therefore particularly vulnerable to parametric roll. The Octopus system's time trace data (**Figure 9f**), which was based on real time measurements from the ship's motion sensors, showed there had been a 100% risk of a parametric roll on the evening of 19 January and at the time of the two 20° rolls. Given the environmental conditions, the Octopus system assessment and the sudden nature and increased size of the roll at 0127 on 20 January, it is almost certain that *CMA CGM G. Washington* experienced parametric rolling at the time of the container collapses. It is also likely that the 16° roll during the fire drill on the previous evening was the result of parametric rolling.

The ship's safety management system, in line with the IMO guidance, contained instructions for navigating in bad weather. The CMA Ships' 2014 fleet circular, *Navigation in Bad Weather*, directed the OOW to measure and record the wave parameters required to estimate the risk of parametric rolling. However, the bridge team thought that, as the Octopus system automatically calculated the probability of this phenomenon, manual calculations were no longer required. This was not an unreasonable assumption, particularly as it is extremely difficult to measure the

period of encounter at night. However, the master and his bridge watchkeepers focused their attention on the Octopus system's polar diagram, and did not refer to the historical time trace based on real time data from the bridge accelerometer.

The master and his bridge team did not use the ship's motion monitoring, forecasting and decision support tool effectively. This was because they did not fully understand all of its functionality. Had the Octopus system's time trace data been monitored, it is highly likely that the master would have taken further action to reduce the risk of parametric roll.

2.6 MOTION LIMITS FOR LARGE CONTAINER VESSELS

Prior to *CMA CGM G. Washington*'s departure from Xiamen its loading computer indicated a roll angle calculation parameter value of 11.679°. The master and CO understood that this figure was too low and was an impractical limit for a vessel crossing the North Pacific Ocean in winter. Instead, unaware that there was a set of company pitch and roll limits for its 14,400TEU ships, the master relied on his own set of subjective ship motion limits (15°-20°), based on experience.

Traditionally, container vessel masters have been provided with ship motion limits (pitch/roll) beyond which lashings or container structures could fail, as part of the ship's CSM. For *CMA CGM G. Washington* and other similar modern vessels this is no longer the case. Instead, acceleration limits are provided, and reliance is placed on the calculations carried out by the ship's loading computer.

Knowledge of the company's roll (15°) and pitch (5°) limits might not have changed the outcome on 20 January. However, such knowledge would have improved the master's ability to assess the probability of lashing/container failure in the prevailing conditions. Indeed, it might have prompted the master to further adjust the vessel's course, speed and track to reduce the ship's rolling.

A set of ship's loading computer-generated roll and pitch limits would have provided a useful prompt for the master and OOW that action was required. In this case, this output was not available. It is suggested that the classification society, which certifies the ship's loading and lashing computer, requests a practical set of roll and pitch limits as an additional software output.

2.7 COLLAPSE OF BAY 18

Most container bay collapses occur following the structural failure of a container within the stow or because of inadequate or failed lashing arrangements. In either case, the containers in the row/stack directly above the unlashd or deformed container will topple sideways into the adjacent row. This leads to a domino effect as one row touches another, causing structural or lashing failure in each adjacent row/stack. This sequence of failure will continue until the outer wall of containers and ship's side are reached, and containers are lost overboard (**Figure 27**).

The investigation did not identify a direct cause for the collapse of the containers at bay 18. Factors that might have made bay 18 more vulnerable to collapse than the 15 undamaged bays included: container stack weights, container weight distribution, lashing arrangements and the material condition of the containers.

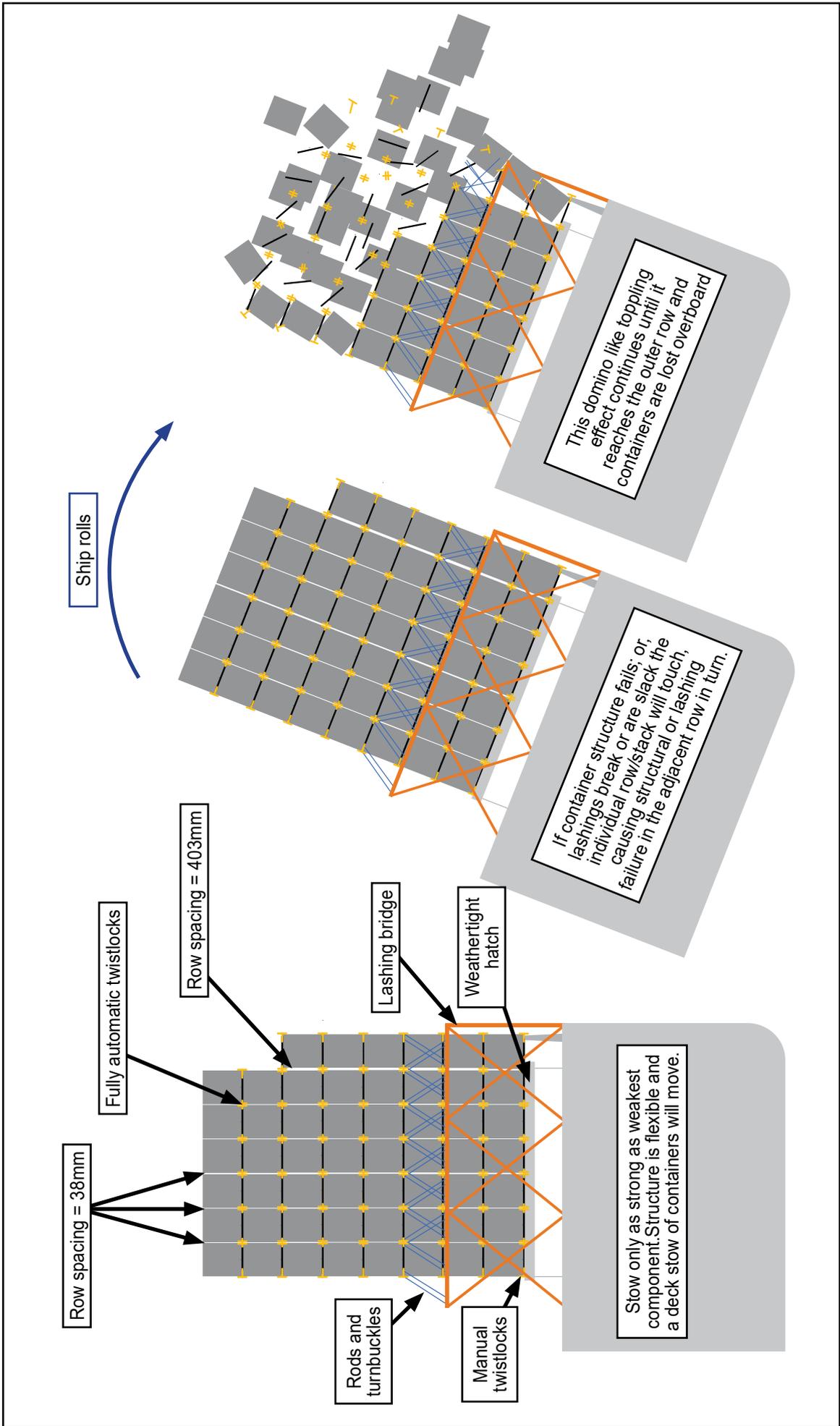


Figure 27: Principles of a container bay collapse

Bay 18 was located towards the bow and therefore would have been exposed to higher transverse acceleration forces than those at the midships section of the vessel. Of the forward stows, bay 18 had the highest outer wall stack loads: 100% in the port outer wall and 99% in the starboard (**Figure 8**). In addition, five other stack loads exceeded 90% load. This is not unusual for container ships, but it did make bay 18 more vulnerable to collapse than many of the other bays.

The location of damaged and undamaged containers within bay 18 (**Figure 4**) indicated that at least four containers were not stowed in accordance with the cargo plan. Given the pace of container loading and the potential for the late arrival of containers at the terminals, it is not surprising that there are discrepancies between the cargo plan and where containers are actually stowed. This, coupled with the likelihood of mis-declared container VGMs made the heavily loaded stacks even more vulnerable to collapse.

The containers in bay 18 had been lashed in accordance with the CSP, and *CMA CGM G. Washington's* bespoke lashing equipment was in good condition. The lashing arrangements had been regularly checked and inspected by the crew during the voyage and there was no evidence to suggest that lashings were missing or had been mis-applied. However, several lashing rods were found to be loose in unaffected bays during the MAIB's post-accident inspections. Loose lashings increase the risk of contact between containers at the top of the stacks, and allow increased racking forces to act on the containers at the bottom of the stacks.

Following the accident, several failed twistlocks were recovered from the ship. The calculations conducted by BV indicated that the lifting forces generated in the outer walls of bay 18 exceeded the SWL of the German Lashing fully automatic twistlocks during the 20° rolls. However, the calculated loads were less than the manufacturer's design proof and breaking loads. It is therefore more likely that the twistlocks failed during the collapse, rather than causing it.

The structural integrity of individual containers is critical to the security of every container stow. Any deformation of a container will almost inevitably be followed by a lashing failure, and the lashing failure will in turn lead to the loss of containers. This risk is increased by the lack of safety margins within the ISO standard and the inability to confirm a container's status prior to loading.

Had there been a defect in one of the containers stowed at bay 18, it could have suffered racking or corner post failure, causing its row/stack to collapse into the row/stack next to it. Many of the damaged containers from bay 18 show evidence of corner post failure, but it was impossible to determine whether these failures initiated the collapse of the bay, or were merely symptoms of the collapse caused by other factors, such as lashing failure.

The way a container is packed can also have a significant impact on the stability of a stow. Most of the containers were lost overboard and therefore could not be examined. Similarly, the way the damaged containers were packed and their contents secured could not be assessed meaningfully given the extent of disturbance that had occurred.

It is most likely that bay 18 collapsed following the structural failure of one of its containers, brought about by a complex combination of factors that could have included: excessive stack loads as a result of mis-stowed or overweight containers; excessive racking loads or contact between containers due to loose lashings; and/or existing damage or poor material condition of a container.

2.8 COLLAPSE OF BAY 54

The review of the bayplans conducted by BV calculated that the acceleration forces acting on the containers in bays 54 and 58 were within the limits for ISO containers, but exceeded those for the non-standard 53ft container. The corner post load limit for 16 of the 17 rows in Bay 54 was exceeded, and the racking force limit was exceeded in four rows. It was therefore unsurprising, during the initiating roll on 20 January 2018, that most of the non-standard 53ft containers suffered structural failure, causing the remainder of the bay to collapse.

The underlying reason why this issue had not been identified previously or during the cargo planning process was that the container stowage plan for these non-standard containers was based on incorrect assumptions about their strength. During the design of the ship, the operator had provided the lashing manufacturer with an example 'Cargo Production Certificate' for a typical 53ft container. However, the lashing manufacturer did not use these production certificate limits to compile the CSPs for 53ft containers. Instead, the load limits were based on the values for a stronger 45ft ISO container. These limits were then used in the ship's loading computer software. As a result, the stow at bay 54 was judged by both the cargo planners and ship's crew to be safe, when in fact it was not.

The lashing manufacturer recorded their assumptions (tare weight and maximum corner post loading) in the opening pages of the CSM addendum, which included the 53ft CSPs. The addendum also warned that *the actual 53' container specification has to be considered*.

However, the crew did not refer to the CSM and were unaware of this caution. Instead, they relied on the ship's loading computer to verify the safety of the stow. Furthermore, not unreasonably, given the difficulty in checking CSC data for these containers prior to loading, the crew assumed that the CSM and ship's loading computer software would be based on accurate data.

To prevent future accidents involving the carriage of similar 53ft containers, the CSM for *CMA CGM G. Washington* and any other affected CMA ships needs to be amended to take account of actual load limits. Similarly, the correct corner post and racking load limits must be programmed into the ship's loading computer.

2.9 COLLAPSE OF BAY 58

Bay 58 was fully loaded with 167, 40ft containers, stacked up to nine high (**Figure 6**). It suffered the loss of 24 containers and damage to 17 others in its outer starboard rows. Of the midship stows, bay 58 had some of the highest outer wall stack loads: 97% and 95% in the two outermost stacks to port and 91% in the starboard outer wall. Like Bay 18, the SWLs for the twistlocks in the outer walls were exceeded according to BV's calculations.

As discussed for bay 18, the highest loaded container stacks would have been the most vulnerable to collapse. However, bay 58 was located amidships and therefore would have experienced lower levels of transverse acceleration force.

Bay 58 was directly aft of bay 54 and the gap between its 40ft containers and bay 54's 53ft containers was only 377mm. Examination of the forward ends of the damaged containers indicated that contact had been made with the aft ends of the 53ft containers. It is therefore highly likely that this contact initiated the collapse of the containers in bay 58.

The diagrams contained in the CSM (**Figure 28**) suggested that the bays fore and aft of bay 54, when loaded with its 53ft containers, should have been empty. In practice, the adjacent bays were almost always loaded with 40ft containers. The risk of carrying 40ft containers in these bays appears tolerable, provided that the load limit for the 53ft containers was not exceeded. Nevertheless, future versions of the 53ft container stowage plans should clearly explain whether, and how the container bays forward and aft of a 53ft stow can be loaded.

2.10 MIS-DECLARED VERIFIED GROSS MASS

For a container to be stowed safely its gross mass must be accurately verified and recorded. At the time of the accident the IMO VGM regulations had been in place for over 2 years. These regulations helped ensure that the Xiamen terminal weight was within 2.4% of the declared VGM for the 2,400 or so containers loaded there. However, within that overall figure the actual weight of some containers differed significantly to their declared weights. If such discrepancies are undetected or unreported, when these containers are loaded they can lead to container structural failure, stacks becoming unstable, and/or lashings being overloaded.

Many container terminals routinely weigh containers prior to loading. Some use the actual weight to confirm the VGM. If the declared VGM is inaccurate, the terminal then charges the shipper and issues a new VGM certificate for the container. This more accurate figure should then be reflected in the final cargo bayplans passed to the ship. However, when the figures provided by the container terminal at Xiamen were reviewed, it showed that *CMA CGM G. Washington*'s final cargo bayplans had not been amended to reflect these more accurate container weights.

The IMO, MCA and WSC¹² guidance is clear that: *'If a packed container is weighed at the port terminal facility, that is the gross mass that should be used for ship stow planning.'*¹³ However, this investigation has revealed that in practice this guidance is not being followed in all ports.

2.11 RELIANCE ON THE SHIP'S LOADING COMPUTER

The ship's loading computer on board *CMA CGM G. Washington* was in almost constant use by the CO during its voyage from Xiamen to Los Angeles. The CO used it to calculate the ship's stability and to check and confirm the various iterations of the cargo and lashing plan. The same version of software was used by the central planners ashore. As the CSM was configured for a single stability condition, it was rarely referred to.

The ship's loading computer offered several advantages over the CSM. It was able to quickly produce results and highlight to the CO any areas where the forces were out of tolerance. Moreover, it also allowed greater flexibility in container planning.

¹² World Shipping Council, The SOLAS Container Weight Verification Requirement, dated February 2015, available at: http://www.worldshipping.org/industry-issues/safety/WSC_Summarizes_the_Basic_Elements_of_the_SOLAS_Container_Weight_Verification_Requirement_February_2015.pdf, accessed on 24 September 2018.

¹³ MGN 534 (M+F) - CARGO SAFETY - Guidance on the implementation of the SOLAS VI Regulation 2 amendment requiring the verification of the gross mass of packed containers, June 2015, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/436986/MGN534_Complete.pdf, accessed 16 October 2018.

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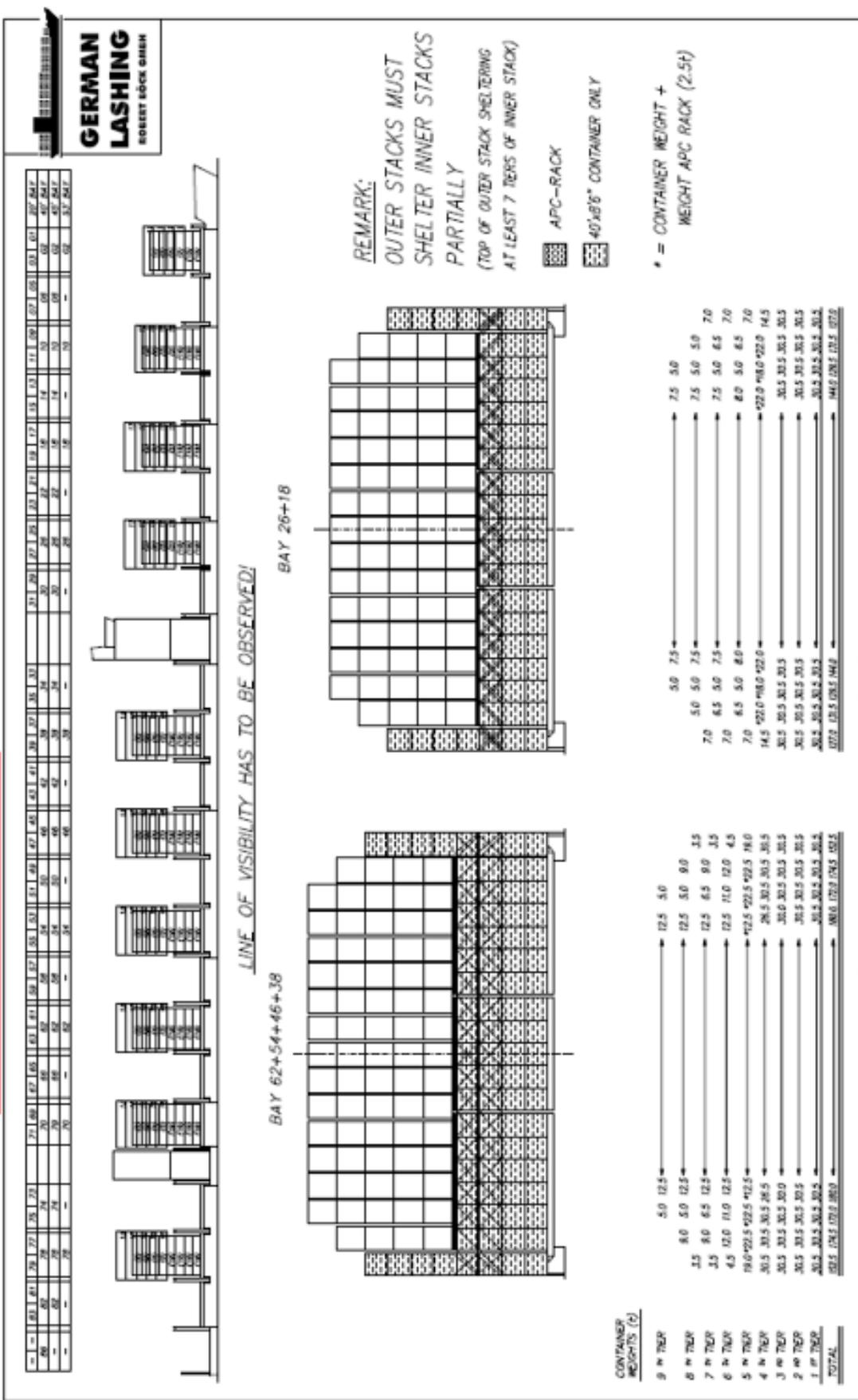


Figure 28: Bay 54 container stowage plan

CMA CGM G. Washington's ship's loading computer had been approved by its classification society, BV. The class approval process required the ship's loading computer manufacturer to demonstrate that the lashing force calculations for two loading conditions were within 5% of the results from BV's software. However, as demonstrated at bay 54, if the software does not reflect the correct limits for the container being loaded, the crew will not be alerted to unsafe cargo stows.

Therefore, given the reliance placed by ship's crew on the ship's loading computer when judging whether a container stow is safe, it is essential that its accuracy reflects the CSC information for non-ISO containers.

2.12 CONTAINER CONDITION MONITORING

Damaged containers are regularly identified and quarantined prior to loading by the ship's crew and dockside stevedores. However, it is not practicable for ships' crews or container terminal workers to assess the material condition or read the CSC plates of all containers prior to or after loading on board a ship.

Access to, and the use of, BIC's GCD and ACEP databases should provide some level of assurance through the remote assessment of the technical specification and inspection history of individual containers. However, the effectiveness of both databases is reduced due to incomplete data. In the case of the GCD, good progress has been made, with approximately 44% of the global fleet uploaded. However, had it been fully populated it could have helped identify the reduced strength of the 53ft containers. In contrast, the ACEP database, launched over 6 years ago to record container inspection regimes, has been populated by only ten countries. The UK is one of the countries that has yet to contribute to this database.

Had the BIC databases been fully populated, this would have allowed the cargo planners and crew to check the maintenance records of each container prior to loading. It is therefore apparent that there is a need to encourage and promote the population of the BIC databases globally.

SECTION 3 - CONCLUSIONS

3.1 SAFETY ISSUES DIRECTLY CONTRIBUTING TO THE ACCIDENT THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. It is likely that the magnitude of the acceleration forces generated at 0127 on 20 January 2018, when *CMA CGM G. Washington* rolled 20° to starboard and then 20° to port, initiated the collapse of the container stows at bays 18, 54 and 58. [2.4]
2. The amplitude of the ship's rolling exceeded the limits set by: CMA Ships for the class of vessel; displayed by the loading computer and calculated by Bureau Veritas after the accident. [2.4]
3. It is almost certain that *CMA CGM G. Washington* experienced parametric rolling prior to and at the time of the container collapses. [2.5]
4. The master and his bridge team were familiar with, but did not fully understand the functionality of the ship's motion monitoring, forecasting and decision support tool and, as a result, did not appreciate the imminent risk of parametric roll. [2.5]
5. Pitch and roll limits were not readily available from the ship's loading computer. [2.6].
6. The exact cause of the container collapse at bay 18 could not be determined. However, it is most likely that its collapse was initiated following the structural failure of one of its containers, brought about by a combination of factors including: excessive stack loads as a result of mis-stowed or overweight containers; excessive racking loads or contact between containers due to loose lashings; and/or existing damage or poor material condition of a container. [2.7]
7. The container collapse at bay 54 was caused by the structural failure of the non-standard 53ft containers during the large roll, caused by the incorrect assumptions of container strength within the vessel's cargo stowage manual and ship's loading computer. [2.8]
8. The container collapse at bay 58 was caused by the damaged containers from bay 54 striking those in bay 58, causing lashing failure and structural damage to the containers stowed on the starboard side of the bay. [2.9]
9. Given the reliance placed by the ship's crew on the ship's loading computer when judging whether a container stow is safe, it is essential that input data for container strength accurately reflects the CSC data for each container loaded, particularly non-ISO containers. [2.11]

3.2 SAFETY ISSUES NOT DIRECTLY CONTRIBUTING TO THE ACCIDENT THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. Ships' teams and central cargo planners are unable to access container CSC information concerning individual containers, dimensions, strength, and inspection status prior to loading. Access to a fully populated Bureau International des Containers, Global Container and Approved Continuous Examination Programme databases would address this. [2.12]

2. The final cargo plan was not updated to reflect the terminal weights in accordance with the International Maritime Organization, the Maritime and Coastguard Agency and World Shipping Council guidance. [2.10]

SECTION 4 - ACTION TAKEN

4.1 ACTIONS TAKEN BY OTHER ORGANISATIONS

Bureau Veritas:

Suspended the carriage of non-standard 53ft containers on board *CMA CGM G. Washington* until its rules were amended with the publication of NR625 (October 2018).

CMA Ships:

Worked with ABB, the manufacturer of the Octopus decision support tool, to optimise the presentation of Octopus data and improve ship-handling advice to masters in bad weather. The training package for operators of this system has also been reviewed.

SECTION 5 - RECOMMENDATIONS

CMA Ships is recommended to:

2020/103 Issue direction to its terminal planners to ensure that, where container terminals routinely weigh containers prior to loading, the cargo plan for those containers is updated to reflect these weights.

The **Maritime and Coastguard Agency** in conjunction with the Health and Safety Executive is recommended to:

2020/104 Promote the involvement of UK container owners and operators in the Bureau International des Containers, Global Container Database and the Approved Continuous Examination Programme database.

Bureau Veritas is recommended to:

2020/105 Amend its rules to require the approved lashing software installed on the onboard loading and lashing computer to calculate and display maximum roll and pitch angles associated with ship loading condition and intended passage.

2020/106 Review its rules and approval procedure to ensure Container Safety Certification data is accurately reflected within the ship's loading computer, whatever the type of container. Compliant with ISO standard or not.

Safety recommendations shall in no case create a presumption of blame or liability

