Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT

Marine Occurrence Investigation No. 263

MO-2009-002

Final

Independent investigation into the loss of containers from the Hong Kong registered container ship

Pacific Adventurer

off Cape Moreton, Queensland

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Abstract

At 0312 on 11 March 2009, the container ship *Pacific Adventurer* lost 31 containers overboard in gale force weather conditions and large swells off Cape Moreton, Queensland. All the containers sank, however, two of the ship's fuel oil tanks were holed as the containers went overboard.

About 270 tonnes of oil leaked from the holed tanks and 38 miles of Queensland's coastline was affected by the oil.

The ATSB investigation found that the ship was probably subjected to synchronous rolling at the time and that the severe and sometimes violent rolling motions caused the lashings on the containers, and possibly some the containers themselves, to fail. In addition, much of the fixed and loose container lashing equipment was in a poor condition and the inspection and replacement regime in the ship's safety management system had not been effectively implemented.

The ATSB identified four safety issues during the investigation: the inspection and maintenance regime of the ship's fixed and loose lashing equipment had been deficient; there was no requirement for a third party to inspect this equipment; the cargo in the containers which were lost overboard was not packaged in accordance with international dangerous goods shipping requirements; and the dangerous goods shipping compliance audit regime did not pick up on this fact.

Safety action to address the safety issues was taken by several of the responsible organisations. The ATSB has issued one safety advisory notice in regard to the outstanding safety issue concerning third party inspections of lashing equipment.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing safety factor: a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Risk level: The ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

Critical safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.

Significant safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.

Minor safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

EXECUTIVE SUMMARY

At 0548[1] on 9 March 2009, *Pacific Adventurer* berthed in Newcastle, New South Wales, to load a cargo of fifty 20-foot[2] containers of ammonium nitrate prills[3] on deck for discharge in Indonesia. Cargo stowed below deck included containers and steel coils loaded at previous Australian ports. At 1738, after the stevedores had lashed the deck containers in accordance with the chief mate's lashing plan, the ship departed its berth, bound for Brisbane, Queensland.

On 10 March, while the ship made its way up the coast towards Brisbane, it became increasingly subjected to the effects of tropical cyclone Hamish, which was moving in a south-easterly direction off the southern Queensland coast. The ship's rolling motions became large and, at times, violent.

The master endeavoured to reduce the rolling motion by sailing at a reduced speed and by altering the ship's heading. However, as the ship settled onto each new heading, it began to experience large rolls again.

At about 0300 on 11 March, when the ship was off Cape Moreton, the master ordered a course alteration to port to take the ship to the Brisbane pilot boarding ground for the pilot to board at 0700. However, shortly afterwards, the ship experienced a number of large rolls, and at 0312, rolled violently to port.

A crew member on the bridge saw a container in Bay[4] 25 collapse during the roll to port. Immediately afterwards, the containers on the port side of Bay 25 fell over the side of the ship. As the ship started to roll back to starboard, the remaining containers on the starboard side of Bay 25 also fell overboard. In less than a minute, all 31 containers in that bay were lost overboard.

All 31 containers sank. However, two of the ship's fuel oil bunker tanks, which were located along the ship's side, were holed as the containers went overboard. The discovery that oil was leaking from one of the holed tanks did not occur until about 2¾ hours after the incident. The discovery of the hole in the second tank did not occur until much later when the ship was alongside a Brisbane wharf.

In total, about 270 tonnes of fuel oil had leaked into the sea. About 38 miles of Queensland's coastline was affected by the oil.

Shortly after receiving the information about the leaking fuel oil, Maritime Safety Queensland (MSQ) activated the National Plan[5].

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1 All times referred to in this report are ship's time, Coordinated Universal Time (UTC) +11 or +10.

2 The international convention to name containers as 20 or 40 foot according to their length is in imperial units.

3 The process of 'prilling' is undertaken to make a solid into granules or pellets that flow freely and do not clump together.

4 Internationally accepted naming convention referring to the stowage position on ships in which containers are carried. They are numbered from the first forward hold/hatch.

5 Australia's National Plan to Combat Pollution of the Sea by Oil and Other Noxious and Hazardous Substances.

Following the loss of the containers, the ship anchored in Moreton Bay where it was assessed by emergency services to ensure that the ship and its remaining cargo were safe before it was permitted to berth in Brisbane. The remaining cargo was discharged before the ship went into dry dock for permanent repairs.

The ATSB investigation found that the most plausible explanation for *Pacific Adventurer*'s severe, and at times violent, rolling motions was synchronous rolling, as a result of the ship's natural roll period matching that of the encounter period of the waves[6] experienced. While the master took action to avoid the rolling, in accordance with the guidance in the ship's safety management system, this action was not sufficient. The option of altering the ship's stability by adjusting the seawater ballast in its tanks, and therefore its natural roll period, as the ship made its way up the Queensland coast, was not considered.

Much of the ship's fixed and loose lashing equipment was in a poor condition. While this had been recognised by senior officers on board, and shore management, the progressive replacement of the equipment had not progressed to the Bay 25 area. In addition, because not all the stacks of containers in Bay 25 were lashed, there was different flexibility in adjacent stacks. It is likely that the unlashed stacks of containers imposed excessive forces on neighbouring lashed container stacks which caused the lashings and the containers to fail when subjected to the significant forces resulting from the ship's excessive roll motions.

The investigation also identified that the ammonium nitrate prills were packed in the containers in such a way that if a wooden bulkhead at the after end of a container gave way, the weight of the cargo could have resulted in a failure of the container's end-wall. This could have contributed to the failure of the containers and/or the lashing system.

The ATSB identified the following safety issues during the investigation:

- The poor condition of much of the ship's container lashing equipment indicates that the inspection and maintenance regime applied to this critical equipment had been inadequate.
- At the time of the incident, there was no requirement for any third party to inspect or survey the fixed and loose lashing equipment on a ship.
- The ammonium nitrate prills were not packaged in the containers in accordance with the requirements of the International Maritime Dangerous Goods Code.
- The Australian Maritime Safety Authority's International Maritime Dangerous Goods Code compliance audit regime had not detected that the method of packaging was not compliant.

Safety action to address the safety issues was taken by several of the responsible agencies. The ATSB has issued one safety advisory notice in regard to the outstanding safety issue concerning third party inspections of lashing equipment.

6 The time interval between the passage of two successive crests relative to a shipborne observer.

1 FACTUAL INFORMATION

1.1 *Pacific Adventurer*

At the time of the incident, *Pacific Adventurer* (Figure 1) was a Hong Kong registered multi-purpose container ship[7]. It was owned by Swire Navigation/Bluewind Shipping, Hong Kong, managed by Swire Navigation (Swire), Hong Kong, operated by the China Navigation Company (CNCO), Hong Kong and classed with Lloyd's Register (LR).

The ship, originally named *Pacific Challenger*, was built in 1991 at the Minami Nippon Shipyard in Usuki, Japan. In 1999, its name was changed to *Changsha* and in March 2005, to *Pacific Adventurer*.

Figure 1: ***Pacific Adventurer***

Pacific Adventurer had an overall length of 184.9 m, a breadth of 27.6 m and a deadweight of 25,561 tonnes at its summer draught of 10.57 m. Its total cargo capacity was 1,123 TEU[8], 150 of which could be refrigerated.

The ship had five cargo holds located forward of the accommodation. Each hold was accessed by four hydraulically operated hatch covers, two on each side of the ship's centreline. When closed, the hatch covers were made weather tight by a set of rubber seals and manual cleats (dogs). Containers could be carried on the hatch covers and over the poop deck aft of the accommodation. Five cargo cranes were located forward of the accommodation, on the ship's centreline. One cargo crane was also mounted aft of the accommodation.

Pacific Adventurer's navigation bridge was equipped with a range of navigational equipment in accordance with SOLAS[9] requirements. This included two Decca BridgeMaster automatic radar plotting aid (ARPA) radars, a Furuno global position system (GPS) unit, a Simrad Shipmate differential GPS unit and a Furuno automatic identification system (AIS) unit. The bridge was also equipped with a

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7 The ship's name was changed in May 2009.

8 Twenty-foot Equivalent Unit, a standard 20 foot shipping container. The nominal size of a ship in TEU refers to the number of standard containers that it can carry.

9 The International Convention for the Safety of Life at Sea, 1974, as amended.

Tokimec course recorder, a JRC echo sounder and a Kelvin Hughes MantaDigital simplified voyage data recorder.

Propulsive power was provided by a single Kobe Diesel Mitsubishi 8UEC60LS two stroke, single acting, in-line engine which produced 14,123 kW at 100 rpm. The engine drove a single fixed-pitch propeller, giving the ship a service speed of 18.5 knots[10].

The ship was equipped with a 'Seamaster' (version 6.8.6) loading/stability program which operated on a Hewlett Packard Compaq desktop computer. The program had been surveyed and certified by LR on 9 March 2005.

Pacific Adventurer was engaged on a regular liner service between ports in Australia, South East Asia, Papua New Guinea, the Solomon Islands and Vanuatu. The ship's crew comprised five Filipino, one British and 21 Chinese nationals, including the master and four mates. The three watch keeping mates maintained a traditional 4 hours on/8 hours off watch keeping schedule. The chief mate did not maintain a navigational watch. All the mates and engineers held the necessary qualifications to sail on a Hong Kong registered ship.

The master held a Philippines master's certificate of competency, which he first obtained in 2000. He had 28 years of seagoing experience and had worked with Swire and CNCO since about 1994. During that time, he had served on a number of container ships, including at least four of *Pacific Adventurer*'s sister ships, known as the 'Challenger' class. He had been a master with Swire since 2003 and joined *Pacific Adventurer* for the first time on 17 January 2009, about 7 weeks before the incident.

The chief engineer had 25 years of seagoing experience. He held a United Kingdom class one (motor) certificate of competency which he first obtained in 1994. He had been with Swire since 1989 and had served as chief engineer since December 1997.

The chief mate began his seagoing career in 1998 as a deck cadet with Swire. He obtained his chief mate's certificate of competency in China in 2006 and was promoted to chief mate in early 2007. He had served as chief mate on three ships and joined *Pacific Adventurer* in November 2008. Although this was his first time on the ship, he had served on another of the 'Challenger' class ships.

The second mate, the officer of the watch when the containers were lost overboard, graduated from maritime college in 2002. He joined CNCO as a deck cadet in July 2003 and obtained his Chinese second mate's certificate of competency 18 months later. He was promoted to second mate when he first joined *Pacific Adventurer* in early 2008. He had completed two contracts on the ship and had rejoined it 2 weeks before the incident.

1.2 Ammonium nitrate prills

The containers lost overboard during the incident contained ammonium nitrate prills[11] in bulk. The cargo was manufactured and loaded into the containers in

10 One knot, or one nautical mile per hour equals 1.852 kilometres per hour.

11 The process of 'prilling' is undertaken to make a solid into granules or pellets that flow freely and do not clump together.

Newcastle, Australia and then loaded on board *Pacific Adventurer* in Newcastle on 9 March. The containers were destined for Benete Bay, Indonesia.

Ammonium nitrate prills are classified as dangerous goods by the criteria set down in the International Maritime Dangerous Goods (IMDG) Code. The proper shipping name for the product is 'Ammonium Nitrate' and the United Nations (UN) number is 1942. It has a classification code of 5.1 (oxidising substances) and is classified within the IMDG Code as packaging group III (substances presenting low danger).

Ammonium nitrate prills are a low density, porous pelletised grade of ammonium nitrate which is specifically formulated for use as an oxidiser in blasting agents in the mining industry, both in Australia and overseas. The granular prills are white to off-white in colour, have negligible odour and are soluble in water.

Ammonium nitrate is a strong oxidizing substance, which will react with materials, reducing agents and metal powders. Whilst not combustible on its own, ammonium nitrate supports combustion by yielding oxygen and therefore increasing the intensity of a fire. Ammonium nitrate prills are not readily detonated in unconfined conditions, but they may explode under confinement and high temperatures.[12]

1.3 Container lashing

Containers loaded on board *Pacific Adventurer*'s hatch covers could be carried to a maximum of 11 abreast and tiered to a maximum of four high. All the containers lost overboard were stowed in Bay[13] 25 and, with the exception of the port and starboard outboard stacks, were loaded three high. The outboard stacks were loaded two high.

On board *Pacific Adventurer*, the containers stowed on deck were 'locked' together, and to the hatch cover, by twistlocks[14]. Twistlocks are made of a hot-dipped galvanised cast steel body which contains a movable central shaft. The shaft has a cone at the top and, depending on the type of twistlock, another on the bottom.

Figure 2: A photograph of a dovetail twistlock in the unlocked position (left) and locked position (right)

12 Prilled ammonium nitrate technical data sheet, Orica Mining Services, 12 March, 2003.

13 Internationally accepted naming convention referring to the stowage position on ships in which containers are carried. They are numbered from the first forward hold/hatch.

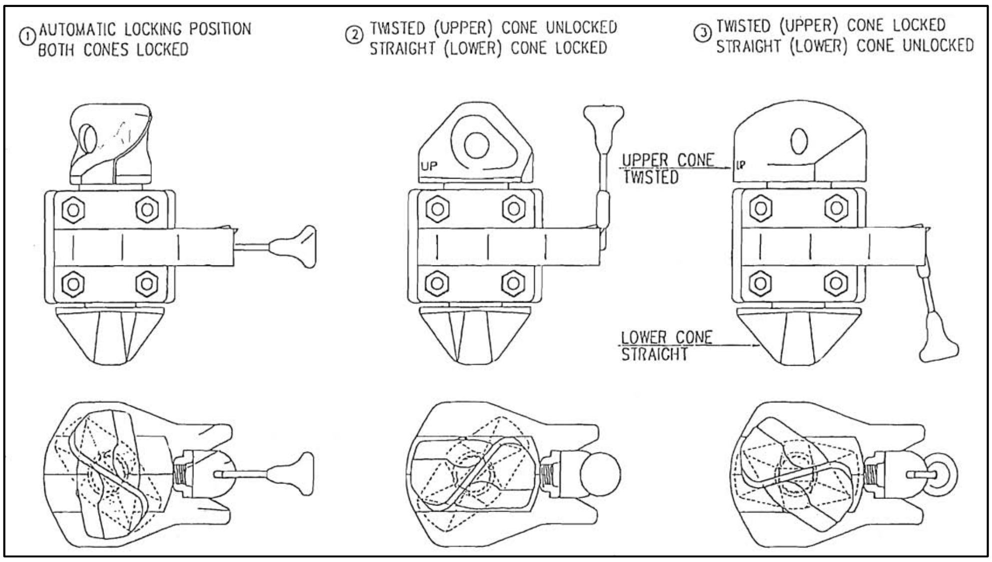
14 A device used to secure the corners of stacked containers together or to secure a container to the ship.

When in the ‘unlocked’ position, the cone/s aligns with the container corner casting hole. For ‘manual’ twistlocks, when in place between containers or the ship, the containers are ‘locked’ together by moving the twistlock shaft (and cone/s) using a handle attached to the shaft, through about 80° so that the cone/s are no longer aligned with the casting hole (Figure 2).

Figure 3: Dovetail twistlocks in place on a hatch cover

The bottom tier of containers on board the ship were secured to the hatch covers using manual, left-hand locking ‘dovetail longitudinal’ twistlocks (Figure 2), which slide into pads welded to the hatch cover or fixed pedestals (Figure 3).

Figure 4: A diagram of a semi-automatic twistlock and how it operates



Semi-automatic twistlocks were used to secure containers in all the remaining tiers (Figure 4). This type of twistlock operates on the same principle as manual twistlocks but they can be fitted to the corner casting of a container on the wharf. When the container is loaded onto the ship, the semi-automatic twistlock ‘self locks’.

Depending on the 'stack weight' of the containers, lashing rods and turnbuckles are attached to the bottom of the containers on the second and third tiers to further secure them (Figure 5).

Figure 5: Remaining ammonium nitrate prills containers in Bay 7 lashed with semi-automatic twistlocks, lashing rods and turnbuckles

When new, the manual dovetail twistlocks had a safe working load (SWL) of 25 tonnes and a designed breaking load, under tension, of 50 tonnes. The pads into which they slid also had a SWL of 25 tonnes and a breaking load of 50 tonnes.

The semi-automatic twistlocks on board the ship were manufactured by several different companies and were type-approved by several different classification societies. When new, these twistlocks had a SWL of 25 tonnes and 21 tonnes (tension/shear) and a breaking load of 50 tonnes and 42 tonnes (tension/shear).

The lashing rods and turnbuckles had a SWL and breaking load of 23 tonnes and 46 tonnes respectively when they were new. The turnbuckles were attached to hinged lashing eyes which had a breaking load of 50 tonnes.

The International Maritime Organization's (IMO's) Safety of Life at Sea Convention (SOLAS) Chapter VI[15] requires a Cargo Securing Manual (CSM) to be carried by all types of ships engaged in the carriage of cargoes other than solid and liquid bulk cargoes. The CSM must also be approved by a classification society.

The contents of the CSM are specified by the IMO and include:

- Specifications for fixed and portable cargo securing devices,
- Inspection and maintenance schemes for the cargo securing devices,

15 Regulation 5.6.

- The stowage and securing of non-standardised and semi-standardised cargo, including handling and safety instructions and for the evaluation of forces acting on these cargo units,
- The stowage and securing of containers and other standardised cargo, including handling and safety instructions, stowage and securing instructions and forces acting on the cargo units.

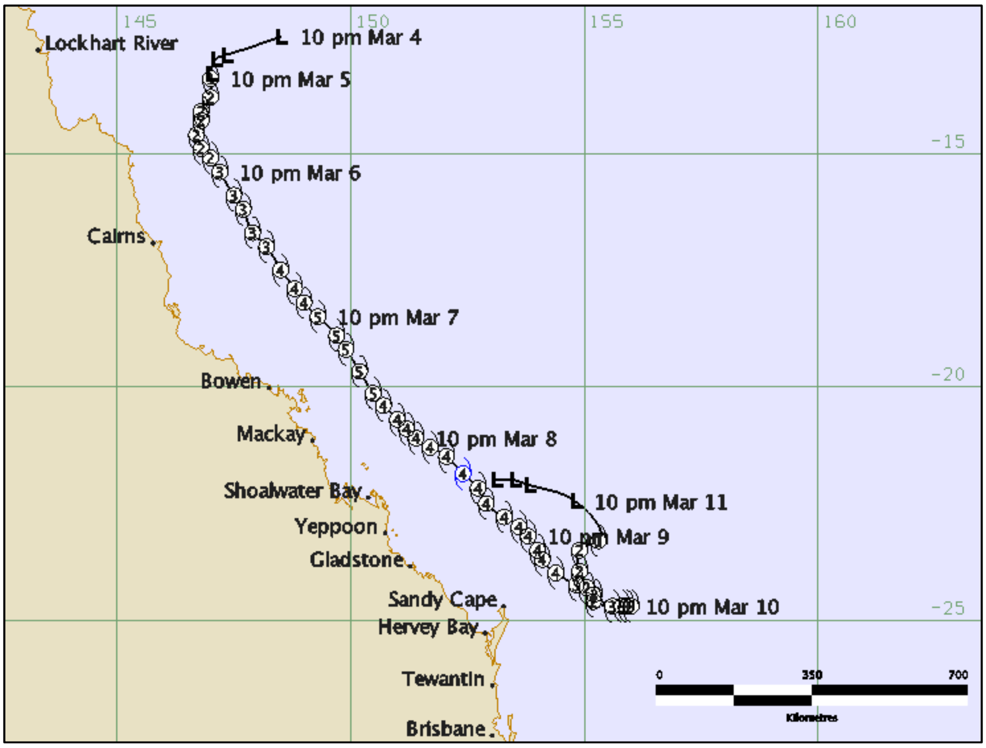
Having a CSM is therefore a statutory requirement and *Pacific Adventurer*'s CSM was approved by LR.

The ship's 'Seamaster' loading/stability program was able to use the weights of each stack of containers to determine the lashings required to be used, given certain parameters such as expected weather en route. The program could then print a lashing plan for the required container bay/s.

1.4 Tropical cyclone Hamish

On 4 March 2009, a tropical low formed in the Coral Sea east of Lockhart River, Queensland (Figure 6). The low drifted to the southwest and intensified. On 5 March, it intensified into a cyclone and was named Tropical Cyclone Hamish (TC Hamish). It continued in a south to southwest direction and intensified over the following 24 hours, before taking a south-southeasterly track parallel to the Queensland coast.

Figure 6: Path of tropical cyclone Hamish



On 6 March, TC Hamish reached category 3[16] intensity and, in conditions favourable for further development, intensified to category 5[17] on 7 March. The now severe tropical cyclone continued its southeast track parallel to the Queensland coast and maintained category 4[18] intensity or higher for the following few days.

By 10 March, it had stopped its south-easterly movement and had begun to meander back to the north and northwest while weakening to below tropical cyclone intensity over the following 24 hours.

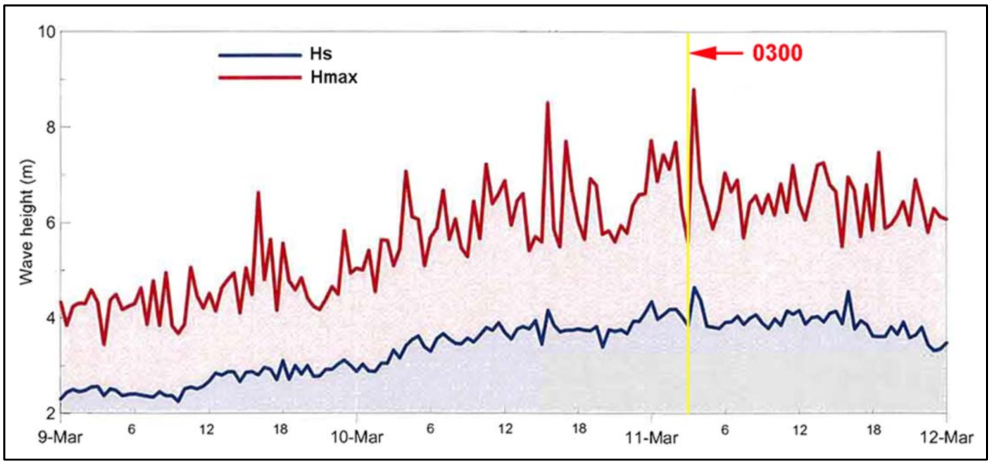
Severe TC Hamish's maximum sustained wind strength was recorded as 215 km/h with maximum wind gusts of 295 km/h. Its lowest central pressure was 925 hPa.

1.4.1 Sea and swell data

Off Brisbane, a wave data recording buoy[19], located to the southeast of Point Lookout on Stradbroke Island, recorded data on the evening of 10 March and the morning of 11 March which is of relevance to this incident (Figures 7, 8 and 9).

From this data, it can be seen that just after 0300 on 11 March, a significant wave height of 4.7 m along with a maximum wave height of 8.8 m was recorded off Point Lookout. At this time, the wave periods were recorded between 9 and 10 seconds, from a 080° to 100° (T) direction.

Figure 7: Heights of significant and maximum waves recorded at the Point Lookout wave data recording buoy



Hs is the significant wave height, defined as average of the highest 1/3 of zero up-crossing wave heights in a record and **Hmax** is the maximum wave height in a record.

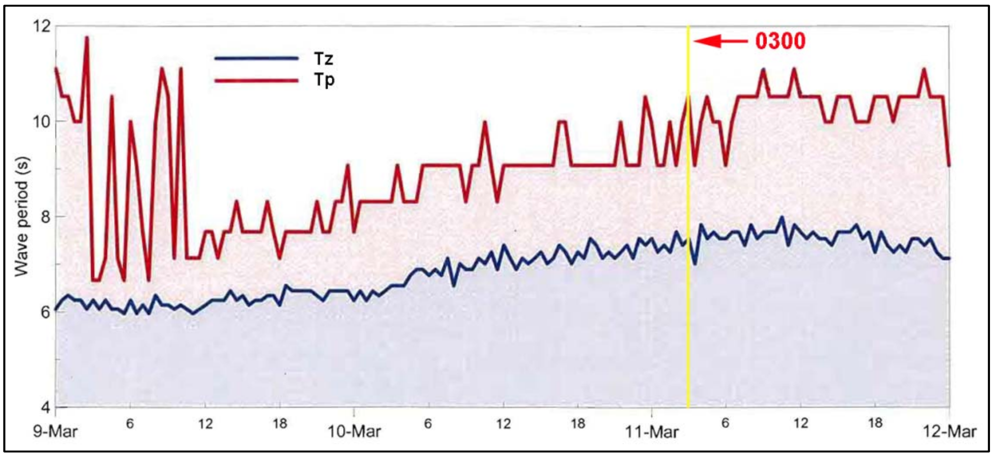
16 Sustained winds of 118 – 159 km/h with strongest gusts between 165 and 224 km/h.

17 Sustained winds of over 200 km/h with strongest gusts over 280 km/h.

18 Sustained winds of 160 – 199 km/h with strongest gusts between 225 km/h and 279 km/h.

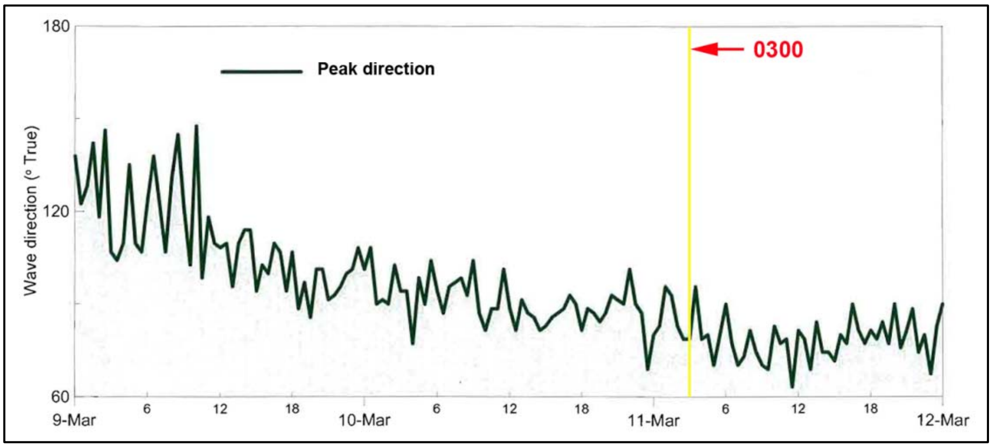
19 A directional buoy in position 27° 29.76' S 153° 37.76' E.

Figure 8: Wave period recorded at the Point Lookout wave data recording buoy



Tz is the average of the zero-crossing wave periods and **Tp** is peak wave period – the wave period at its peak energy.

Figure 9: Direction of peak waves recorded at the Point Lookout wave data recording buoy



Peak direction is the direction that the peak period (Tp) waves are coming from (in degrees true).

1.5 The incident

At 0548[20] on 9 March 2009, *Pacific Adventurer* arrived at Kooragang berth number three in Newcastle, New South Wales (NSW). The ship was to load a cargo of fifty 20-foot[21] shipping containers on deck, each containing about 19.5 tonnes of ammonium nitrate prills, which were to be discharged in Indonesia. Cargo stowed below deck included containers and steel coils loaded at previous Australian ports.

While the ship was on the NSW coast section of the voyage, the master had been monitoring the progress of TC Hamish as it made its way down the Queensland coast. He was aware from the weather reports that the ship had received and from information provided by a private weather routing company, that the passage to

20 All times referred to in this report are ship's time, Coordinated Universal Time (UTC) +11 or +10.

21 The international convention to name containers as 20 or 40 foot according to their length in imperial units.

Brisbane, Queensland, the ship's next port, might be affected by the cyclone. He decided to implement the majority of the recommendations the weather routing company had sent to the ship and the passage was planned accordingly.

The ship would therefore be taking the near coastal route, as originally planned before TC Hamish became a factor in the passage planning. The master considered that sailing further offshore was not an option as he would be putting the ship further into the path of the cyclone as it continued on its south-easterly track, or if the cyclone's course changed further to the east.

While in Newcastle, the master and chief mate discussed the cyclone and the ship's voyage to Brisbane. Knowing that the voyage would be uncomfortable in the expected sea conditions, the master considered delaying the ship's departure for 24 hours. However, he thought he would be put under a certain amount of pressure by the ship's charterers to maintain the ship's schedule, so he decided to sail that afternoon, on the completion of cargo operations.

During the day, the master, in consultation with the chief mate, completed the company's risk assessment for the forthcoming voyage and sent it to the ship managers for their comments. He received the company's risk assessment response before the ship sailed and implemented the required risk controls. Those risk controls included proceeding at a reduced speed to Brisbane to increase the distance the ship would pass from the cyclone, to have the ship's metacentric height (or GM)[22] minimised to reduce the ship's rolling and ensuring that there were correct and adequate lashings on the deck cargo.

At the reduced speed of 12 knots, the ship would arrive at the pilot boarding ground off Brisbane at 0700 on 11 March. The master then advised the ship's managers, charterers and the Brisbane agent of the early morning pilot boarding time.

The agreed water ballast condition for departure included partially filled double bottom and side water ballast tanks.

By 1455, all the ammonium nitrate containers had been loaded, 19 in Bay 7 and 31 in Bay 25. The stevedores had lashed the containers in accordance with the chief mate's lashing plan. However, in preparation for the passage to Brisbane, the chief mate had the second mate, the boatswain and a seaman put additional lashings on the deck containers. Despite these additional lashings, several of the container stacks in Bay 25 remained lashed only with twistlocks. The ship's departure draughts were 7.74 m forward and 8.04 m aft. All of the ship's departure stability criteria were within the required limits, with a final GM[23] of 2.68 m.

At 1718, the harbour pilot boarded the ship and at 1738, the last mooring line was let go and the ship proceeded out of the port. After the harbour pilot departed the ship, the main engine speed was set to its minimum sea speed of 75 rpm.

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22 Metacentric height is one of the critical measurements of a ship's stability. It is usually called GM, the term for it in the equation used to calculate metacentric height.

23 GM(fluid) - a reduction in the calculated GM (GM(solid)) after the free surface correction is applied.

Just after 2000, *Pacific Adventurer* passed Port Stephens, NSW. The wind was from the north-east at force[24] 4 (between 11 and 16 knots) and the sea and swell were about 1m. In these conditions, the ship was making good a speed of 12.7 knots and rolling moderately.

By 0800 on 10 March, the wind had veered as expected and was coming from the east-south-east, still at force 4. The seas and swell had increased to 2 m and the ship continued to roll moderately. It was making good 12.3 knots.

Just after 0800, in preparation for the expected heavy weather and seas from TC Hamish, the chief mate ordered all the deck cargo lashings to be checked to ensure that the twistlocks were locked and the turnbuckles were as tight as possible. The boatswain and several crew carried out this operation.

During the voyage up the northern NSW coast, in an effort to maintain the pilot boarding time and to minimise the rolling, the master varied the main engine's speed between 60 and 70 rpm.

At about 1705, the Australian Bureau of Meteorology's (BoM) Brisbane office issued a hurricane force wind warning:

> At 1600, Severe TC Hamish, with maximum winds of 70 knots, was centred within 10 miles of 24.7° S 155.6° E and moving east-southeast at 8 knots.

This position was about 250 miles to the north-northeast of *Pacific Adventurer*.

The cyclone's forecast position for 0400 the next morning, when the ship would be about 3 hours from the Brisbane pilot boarding ground (in the vicinity of Cape Moreton on Moreton Island), was to be within 40 miles of 24.7° S 156.3° E, about 175 miles to the northeast of the pilot boarding ground, with maximum winds of 60 knots near the centre.

At about 1800, as *Pacific Adventurer* passed Cape Byron to port, the ship began to be more affected by the wind, sea and swells generated by TC Hamish. As the ship continued north, the master steered several different headings in an attempt to minimise the heavy rolling now being experienced. However, as the ship was steadied on each heading, the rolling would resume.

By 2000, *Pacific Adventurer* was off Queensland's Gold Coast (Figure 10). The wind, still coming from the east-southeast, had increased to force 7 (27 to 33 knots) and the waves and swell were now up to 3 m. The ship was rolling heavily and occasionally shipping seas on the starboard main deck. The ship was making good a course of 020° (T) at 10.3 knots.

By 2200, the heavy rolling had made conditions on board the ship extremely uncomfortable for the crew.

At about 2330, the BoM in Brisbane issued another hurricane force wind warning:

> At 2200, Severe TC Hamish, with maximum winds of 70 knots, was centred at 24.7° S 155.9° E and moving east at 3 knots.

This position was about 215 miles to the northeast of *Pacific Adventurer*.

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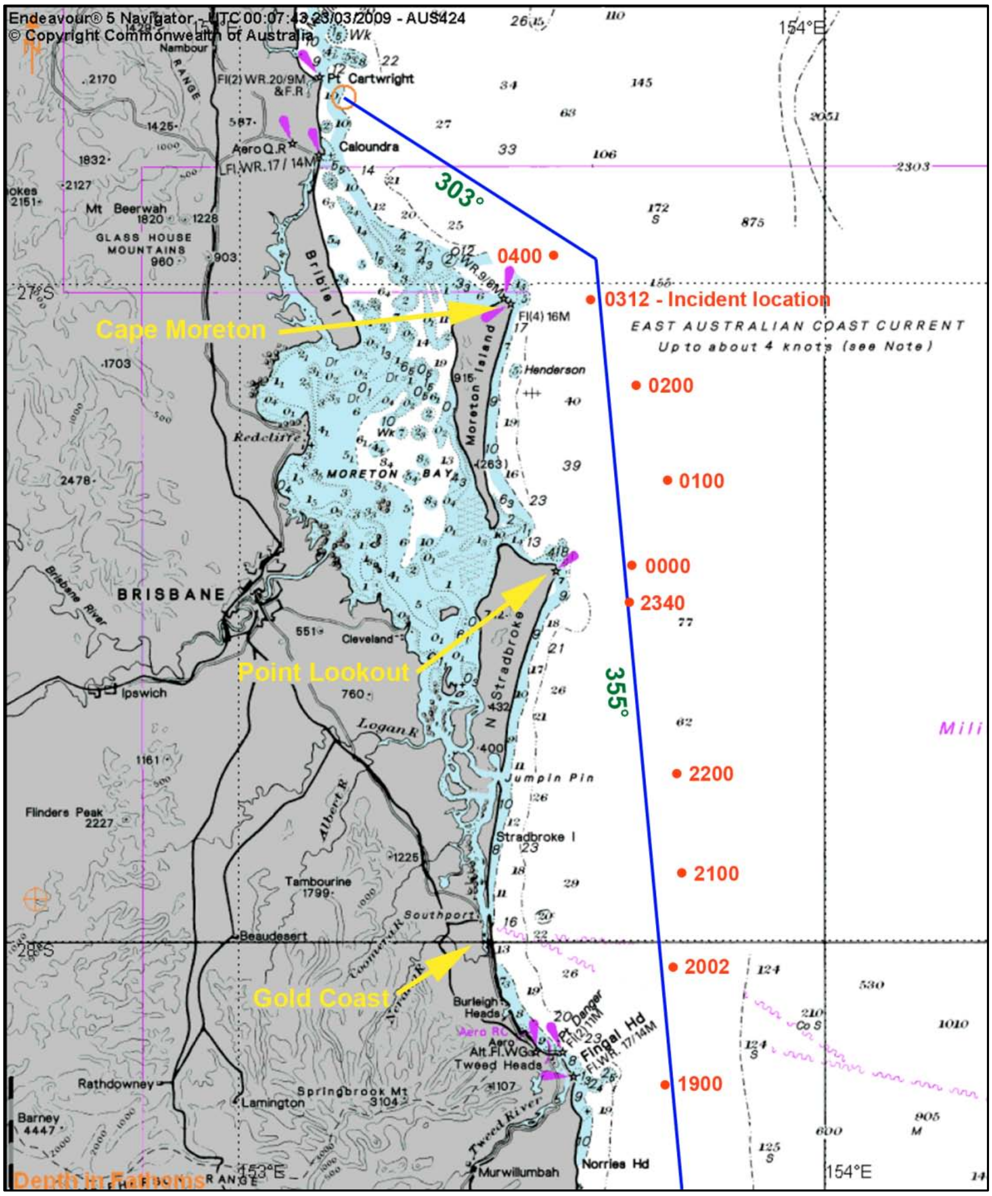
24 The Beaufort scale of wind force, developed in 1805 by Admiral Sir Francis Beaufort, enables sailors to estimate wind speeds through visual observations of sea states.

At about midnight, the second mate went to the bridge to take over the watch from the third mate. When he got there, the master had the conduct of the ship and it was in hand steering mode so that the heading could be adjusted in a continued attempt to reduce the rolling.

At that time, *Pacific Adventurer* was about 5 miles off Point Lookout on North Stradbroke Island (Figure 10). The sea and swell were logged as having increased to about 4 m and the ship's speed had reduced to about 9 knots. The ship was making good a course of 040° (T). Visibility was quite good but the full moon, which was due to set at about 0430, was partially obscured by cloud.

Figure 10: Section of navigational chart Aus 424 showing *Pacific Adventurer*'s track off the Queensland coast (the blue line indicates the planned track)



By this stage, the ship was rolling very heavily, at times as much as 35° to port and starboard[25] in the confused[26] swell. Seas were constantly being shipped on the starboard side. None of the off-duty crew could sleep and those on the bridge were unable to stand without support.

In the engine room, the duty engineer was in the control room answering various alarms due to the rolling. Occasionally, the chief engineer contacted the duty engineer to make sure that he was coping with the situation in the engine room.

At 0020, the master instructed the second mate to steer a course of 000° (T) as the ship needed to head for the pilot boarding ground. The master then handed the conduct of the ship over to the second mate and went to his cabin. After coming onto 000° (T), the second mate made continual small course adjustments to the east, in an unsuccessful attempt to reduce the rolling.

At 0100, *Pacific Adventurer* was making good a course of 350° (T) at about 9 knots. At about 0115, the master returned to the bridge and took over the conduct of the ship.

Between 0130 and 0330, the master tried to reduce the rolling by moving between full ahead and half ahead on the main engine. However, this action was ineffective.

At 0200, the wind was logged as being east-southeasterly and increasing to gale force 8 (34 to 40 knots). The sea and swell were estimated as now being about 6 m and 8 m respectively. The ship was making good a course of 306° (T), at about 9 knots.

At 0300, in order to round Cape Moreton on the northern tip of Moreton Island, the master ordered a new heading of 340° (T) to be steered. This new course would take the ship towards the pilot boarding ground in time for the 0700 boarding time.

At about 0308, the ship was on a heading of 346° (G) with a speed made good of about 8 knots.

At about 0312, in a position about 7 miles to the east of Cape Moreton, the ship rolled violently to port. The second mate estimated the roll to be about 40°.

At this time, the second mate was standing at the bridge front, outboard of the starboard radar. From there, he could see the forward main deck of the ship in the moonlight. As the ship rolled, the second mate saw the containers on the port side of Bay 25 move. He then saw a bottom tier container in a centre stack of the containers in Bay 25 collapse. Seconds later, he saw all the port side containers in Bay 25 fall over the side of the ship. He yelled to the master and as the ship rolled violently back to starboard. He and the master then saw the bottom tier of containers on the starboard side of Bay 25 collapse and the remaining containers on the bay fall over that side of the ship. In less than a minute, the ship had lost all 31 containers overboard from Bay 25.

The second mate entered this position in the deck log book and drew it on the chart in use at the time. The water at this position is about 120 m deep.

25 As measured on the bridge inclinometer.

26 A highly disturbed water surface without a single, well-defined direction of wave travel.

At 0313, the master reported the incident, and the closest estimate of the position of the incident, to Brisbane Vessel Traffic Service (VTS) by VHF radio channel 16.

At about 0317, Brisbane VTS issued a warning to shipping on VHF radio channel 67.

The master tried to telephone the chief mate in his cabin, but the rolling had caused the chief mate's telephone to fall to the deck and break. The master then sent a crew member to tell the mate of the incident. Subsequently, the chief mate went directly to the bridge where he was told what had happened. The master then contacted the ship's agent in Brisbane, telling him of the incident.

At 0335, the Rescue Coordination Centre (RCC Australia) broadcast a sea safety message to shipping in the area warning of the danger of floating containers.

At 0340, the ship's agent informed Brisbane VTS that all the containers lost overboard were carrying ammonium nitrate.

By 0400, the ship was on a course which would take it to the pilot boarding ground. The weather was unchanged from that which was recorded in the ship's deck log book for 0200 and the ship continued to roll heavily.

The weather prevented any of the crew from going onto the main deck to assess the extent of the damage. However, as the ship passed clear of Cape Moreton, the seas and swell started to abate. The chief mate and chief engineer were then able to access the ship's cargo holds through the underdeck passage. From there, they began to inspect each cargo hold to ensure that all the steel coils and aluminium ingots stowed in the holds were secure and not in danger of causing more damage to the ship.

Pacific Adventurer continued towards the Brisbane pilot boarding ground. However, at 0457, to allow authorities to assess the situation, Brisbane VTS told the master that the pilot boarding time had been suspended and that the ship should keep well clear of the pilot boarding ground and at least 5 miles from the coast.

At 0500, the Queensland State Incident Control Centre (ICC) was activated to manage the incident.

At 0503, regular safety broadcasts concerning the lost containers began to be broadcast on VHF radio by local volunteer marine rescue units.

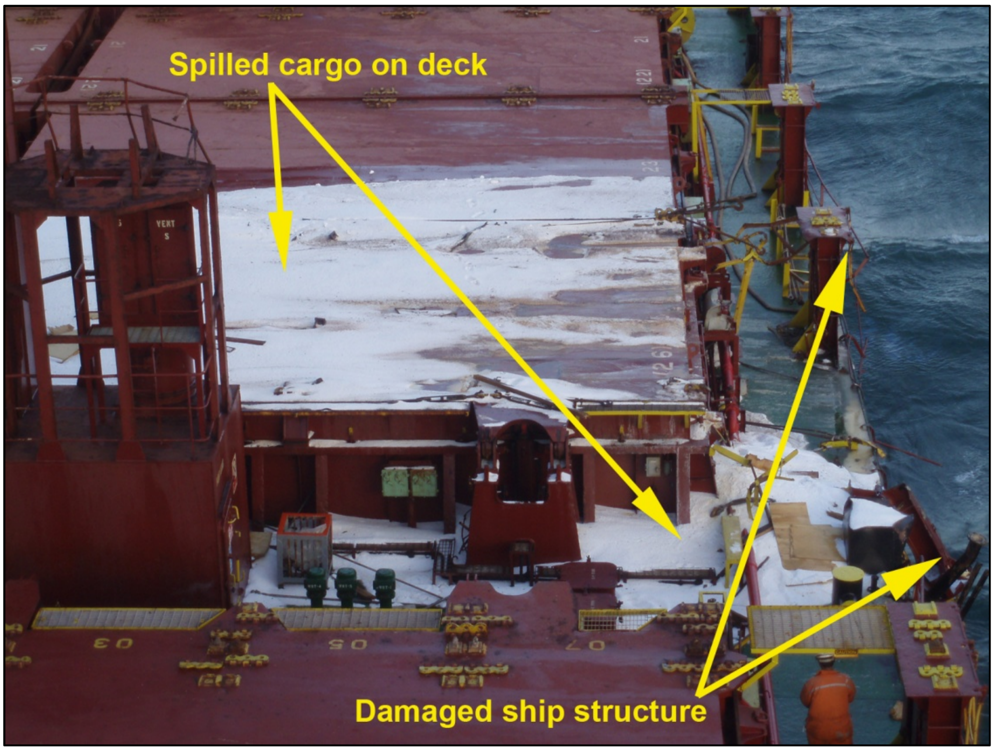
Following the internal inspection of the holds, conditions had moderated sufficiently to allow the chief mate and chief engineer access to the port side of the ship's main deck, just forward of the accommodation. From there, they were able to confirm the loss of the containers from Bay 25 and that the ship's structure in the vicinity of Bay 25 had been damaged as a result of the incident (Figure 11).

Sunrise in the area that day was at about 0546.

At 0552, just after sunrise, during the on-deck inspection, the chief engineer looked over the port side of the ship while it was rolling to port. As the ship rolled back to starboard, the chief engineer saw what looked like fuel oil spouting from the side of the ship. On closer inspection, he was able to see that the ship had been holed and that fuel oil was leaking into the sea from number one port fuel oil tank.

He immediately informed the chief mate who then passed this information to the master and advised that the ship needed to be given a starboard list because of the oil coming from the ship's side. The chief engineer then went to the engine control room and started transferring fuel oil from the holed tank, which he later estimated to have a head[27] of about 25 cm, into number two starboard fuel oil tank which was only about 6 per cent full. This would be a slow process as the capacity of the fuel oil transfer pump was only about 25 m^3/hr.

Figure 11: Bay 25 starboard following the loss of the containers



At 0604, having spoken to the chief mate and chief engineer about what they had seen, the master reported the spillage of fuel oil into the sea to Brisbane VTS. He also advised VTS of the actions that were being taken on board to reduce the pollution. At this time, the ship was 9.6 miles to the southeast of the pilot boarding ground.

Shortly after receiving the information about the fuel oil, Maritime Safety Queensland (MSQ) activated the National Plan[28].

At 0650, the master spoke to the Brisbane harbour master on the ship's mobile telephone and told him that the process of transferring fuel oil out of the holed tank was underway and that the level of oil in the tank had decreased to the point that it only leaked out when the ship rolled to port. The master also expressed concern that he felt it was unsafe for his ship to remain at sea for an indefinite period of time and requested that the Brisbane pilot board as soon as possible.

Between 0700 and 0720, further telephone conversations occurred between the master and the harbour master during which the status of the ship, the leak and the progress of the fuel transfer operations were discussed.

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27 Level of fuel oil in the tank above the level of the hole.

28 Australia's National Plan to Combat Pollution of the Sea by Oil and Other Noxious and Hazardous Substances.

By 0710, the flow of fuel oil from the holed tank had stopped and the ship had a 3° starboard list.

At 0800, MSQ assumed the lead agency role[29] in managing the incident and combating the spill under National Plan arrangements.

At about 0800, during a meeting ashore of interested agencies which included the Queensland Fire and Rescue Service (QFRS), the harbour master expressed the urgency of the situation regarding *Pacific Adventurer* remaining at sea. In response, the QFRS confirmed that there was no safety impediment that would preclude allowing the ship to anchor in Moreton Bay.

At 0833, Brisbane VTS advised *Pacific Adventurer*'s master that the pilot launch was on its way to the ship's position, about 3 miles east of Point Cartwright, and that the pilot would board from the launch.

At 0852, a harbour pilot boarded. He confirmed to Brisbane VTS that there was no oil leaking from the ship (Figure 12). Following this notification, the passage to a suitable anchorage within Moreton Bay began.

Figure 12: The hole in the port side of the ship (enlarged inset showing the hole and its approximate dimensions)

At 1030, the first aerial flight over the oil spill was undertaken to estimate the extent of the oil in the water. The sightings obtained by the persons on board the aircraft were passed to the ICC at 1136.

29 While the incident and initial spill occurred in Commonwealth waters, under Australia's National Plan, ship sourced oil spills which are likely to affect waters inside 3 miles are responded to by the relevant State/NT maritime authority.

Early estimates by the chief engineer on how much fuel had been lost overboard, based on the amount of fuel oil in the port fuel oil tank at departure Newcastle and the amount used during the voyage to Brisbane, gave a figure between 20 and 30 tonnes. This figure was passed to Queensland authorities at 1130.

At 1200, discussions were held in the ICC about using dispersants on the slick. However, because of the weather and sea conditions, the use of dispersants and/or booms[30] was deemed to be 'neither practical, safe, nor realistic'.

At 1230, *Pacific Adventurer* anchored off Shark Spit on the western side of Moreton Island where an assessment of the ship's condition could be made before the harbour master allowed the ship to berth. Immediately after anchoring, a representative of the ship's owners and its agent boarded by launch. As a precaution, the Queensland water police enforced a 500 m exclusion zone around the ship.

At about 1245, personnel from the port of Brisbane and the Queensland Environment Protection Authority (EPA) confirmed reports that oil was coming ashore on Moreton Island.

At 1340, in anticipation that wildlife would be affected by the oil to some extent, the ICC activated the 'Oiled Wildlife Plan'.

At 1434, representatives from several interested agencies, including the Australian Maritime Safety Authority (AMSA), the Queensland police and QFRS, boarded the ship by launch and held a preliminary meeting with the master in connection with the incident. After an assessment of the ship's condition and any potential environmental damage which might occur if the spilt cargo on the hatch covers was washed overboard, permission was given for the ship to berth the following day.

At about 2100, the representatives left the ship and it remained at anchor throughout the night.

At 0624 on 12 March, another harbour pilot boarded *Pacific Adventurer* for the ship's passage to its berth. At 0650, the anchor was weighed and by 0848, *Pacific Adventurer* was all fast port side alongside the Australian Amalgamated Terminal's wharf at Fisherman Islands. Its arrival draughts were 7.8 m forward and 8.2 m aft and its GM was calculated to have increased to 3.0 m as a result of the loss of containers and the estimated loss of oil from the port fuel oil tank.

At 0730 on 12 March, the first of the personnel brought into Brisbane from other states under National Plan arrangements arrived.

Once the ship was alongside, representatives from MSQ, AMSA and the ship's Protection and Indemnity (P&I) Club boarded the ship and began their investigations into the incident. Following a detailed Port State Control inspection, AMSA detained the ship as a result of a number of identified deficiencies.

The remaining 19 undamaged containers of ammonium nitrate prills were discharged and taken to a container depot for inspection. Two other damaged containers, which were carrying orange juice (Figure 13), were also discharged.

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30 Floating containment device for oil on water.

Figure 13: Damaged containers containing orange juice (note: semi-automatic twistlocks still in place between the two containers)

At about 1730, *Pacific Adventurer* moved to a layup berth at Hamilton in Brisbane, where temporary repairs could be carried out.

On the morning of 13 March, during an operation to bring the ship upright, more fuel oil leaked into the Brisbane River. The leaks came from previously undetected holes in the underwater part of number one starboard fuel oil tank. The area around the ship was immediately boomed off and the ship's managers put arrangements in place for a commercial oil recovery company to recover as much fuel oil from the river as possible. Other containment and recovery arrangements were put in place by MSQ.

The discovery of holes in the starboard fuel oil tank required a thorough and accurate set of sounding of the ship's fuel oil tanks be taken so that the chief engineer, accompanied by AMSA surveyors, could recalculate the amount of fuel oil remaining on board and therefore the amount lost.

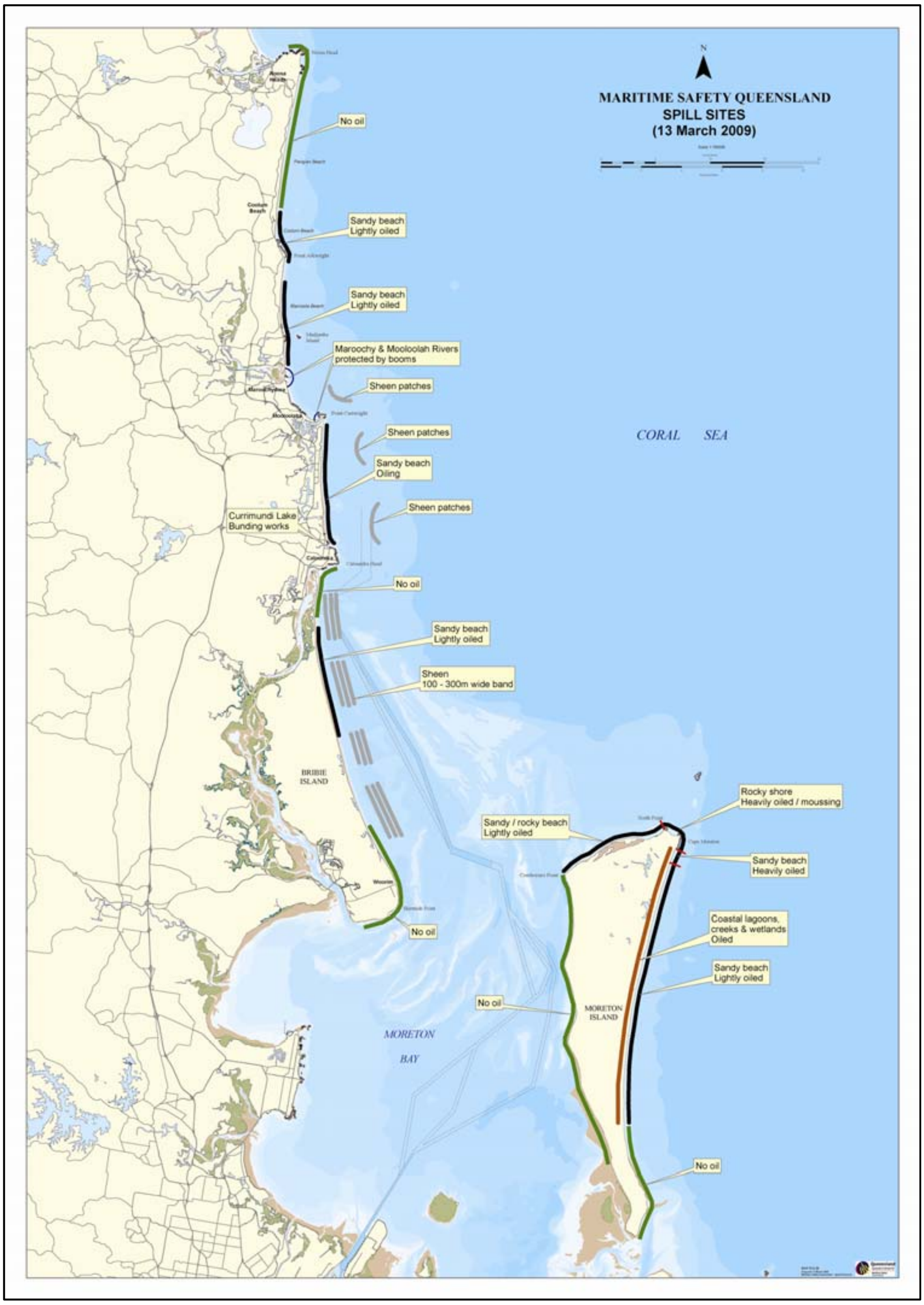
Following the completion of an independent fuel survey, the amount of fuel oil released into the water was calculated to be approximately 270 tonnes.

Pacific Adventurer underwent temporary repairs at the layup berth before it departed Brisbane on 16 April following its release from detention by AMSA. Lloyd's Register issued the ship's owners with short term certification and the requirement that permanent repairs be carried out at an overseas shipyard.

1.5.1 Resultant pollution and the initial response

A significant quantity of oil was deposited by tidal and weather conditions on approximately 38 miles of coastline (Figure 14). This included areas on the northern and eastern sides of Moreton Island, the north-eastern part of Bribie Island, beaches from Caloundra to Point Cartwright and areas between Maroochydore and Coolum Beach.

Figure 14: Coastline affected by the oil



Clean-up operations continued for 2 months. In all, about 2,500 people were deployed for the entire clean-up including workers from many agencies and private contractors including MSQ, the Queensland Department of Environment and Resource Management, local regional councils, Emergency Management Queensland, the Queensland State Emergency Service, Queensland Police Service and the Queensland Fire and Rescue Service. AMSA personnel, as well as 72 members of the National Response Team from all States/NT, the oil industry and contractors also provided assistance during the clean-up.

1.5.2 Locating the lost containers

On 18 March, in an effort to locate the containers on the seabed, the Royal Australian Naval mine hunter *HMAS Yarra* arrived at the approximate position of the loss and commenced searching for the containers. On 20 March, *HMAS Yarra* was joined by a second mine hunter, *HMAS Norman*.

By 31 March, 25 of the 31 lost containers had been positively identified not far from where they were lost (Figure 15). The positions were marked electronically and this information was passed to MSQ and AMSA for future action.

Subsequently, a decision was made that the cost of recovering the containers outweighed any dangers they posed and they remain on the seabed.

Figure 15: Containers on the seabed off Cape Moreton, still partially secured by semi-automatic twistlocks

2 ANALYSIS

2.1 Evidence

On 12 March 2009, two investigators from the Australian Transport Safety Bureau (ATSB) attended *Pacific Adventurer* in Brisbane. The ship's master, the chief engineer, the chief mate and the second mate were interviewed and gave their account of the incident. The investigators also took copies of relevant documents and records. The evidence included the navigational chart in use at the time, log books, the bell book, the course recorder trace, the passage plan, running check lists and various procedures. Numerous photographs of the damage were also taken to assist in the investigation.

While on board *Pacific Adventurer*, the investigators also took possession of the removable hard disk from the ship's simplified voyage data recorder (S-VDR).

On 13 March, the ATSB investigators met with representatives of the manufacturers of the ammonium nitrate prills, Orica Australia, in Brisbane to discuss the packaging and shipping arrangements of the cargo.

Additional information was provided by the managers and operators of *Pacific Adventurer*, Maritime Safety Queensland (MSQ), the Australian Maritime Safety Authority (AMSA), the Queensland Department of Environment and Resource Management and the Maritime Research Institute Netherlands (MARIN).

2.2 The incident

At 0312 on 11 March 2009, 31 containers were lost overboard from *Pacific Adventurer* shortly after the ship's master ordered a heading change to steer the ship towards the Brisbane pilot boarding ground. The ship was subjected to a violent roll as it approached Cape Moreton and the containers were seen to shift in their stacks in Bay 25. Several collapsed and then shifted horizontally before going over the side of the ship. Two of the ship's side fuel oil tanks were holed by the containers and about 270 tonnes of heavy fuel oil entered the water. This oil subsequently washed up on about 38 miles of coastline.

The ship was on a voyage from Newcastle and, as it sailed closer to Brisbane, had been increasingly subjected to the effects of tropical cyclone Hamish (TC Hamish). As a result, the ship encountered large rolling motions, which were described by crew members as violent at times. Before altering the base course towards the pilot boarding ground, the master had endeavoured to minimise the ship's movement in the seaway by altering its heading and speed while trying to sail up the coast towards Brisbane. However, those attempts achieved little in reducing the rolling motion of the ship.

The containers on deck were lashed in accordance with the chief mate's lashing plan, which was derived from a computerised lashing program. However, the chief mate's lashing plan did not have all the containers lashed. In addition, the packaging of the containers was not in accordance with the International Maritime Dangerous Goods (IMDG) Code.

Given the circumstances, and the fact that the containers and much of the lashing equipment was not recovered from the sea, a definitive cause(s) for the loss of the containers could not be determined. However, it is possible to evaluate the evidence obtained during the course of the investigation and list considerations that could have played a role in the loss. These considerations relate to:

- risk assessment undertaken before the ship left Newcastle,
- continued extreme rolling motions of the ship, in excess of the master's expectations,
- actions taken by the crew in the periods before the loss of the containers in an attempt to reduce the rolling motions,
- failure of the container lashing arrangement,
- condition of the container lashing equipment on board, and
- the possibility that the packaging of the containers might have contributed to a failure of the containers themselves which might have had a flow-on to the failure of the lashings in Bay 25.

2.3 Known problems with container loads and lashings

Containers, cars, trucks and other cargo are, by necessity, transported in heavy seas and high winds. The International Maritime Organization's (IMO) *Code of Safe Practice for Cargo Stowage and Securing* provides a means to determine the adequacy of securing arrangements for non-standardized cargo to withstand acceleration loads due to ship motions. However, there is currently little data available on actual acceleration loads imparted by such motions to ships' lashing gear, container stacks and stowed cargo inside the containers.

In order to address this ongoing problem, a joint maritime industry research project, known as Lashing@Sea, was initiated in mid-2006. The objective of the project was to address these topics from an industry-wide consortium, which included vessel operators, flag States, classification societies, lashing gear manufacturers and technology providers. The Lashing@Sea project was coordinated by MARIN and the report of the project was released in early 2010 (www.marin.nl).

In view of this research project and the issues raised in the *Pacific Adventurer* incident, the ATSB commissioned MARIN to examine the evidence with a view to using the information gathered during the Lashing@Sea project to provide information on the possible cause(s) of the excessive rolling motions of the ship and the subsequent loss of the 31 containers on 11 March 2009.

The data contained in the MARIN report provided to the ATSB, in regard to the ship's rolling motion and lashing arrangements, has been incorporated in this safety investigation report.

2.4 Voyage risk assessment

While in Newcastle, *Pacific Adventurer*'s master was aware of the presence of TC Hamish off the southern Queensland coast; its predicted path and its possible effect on the ship's passage to Brisbane. In accordance with company procedures, he used a commercially available, 'marinised' computer based risk assessment tool for the passage and then sent it to the managers of the ship for their comment, which he received before the ship departed Newcastle.

Table 1: Hazards and risk table for the voyage to Brisbane

Hazard	Cat*	Likelihood	Consequence	Risk
Strong wind	UC	Likely	Harmful	SUBSTANTIAL
Violent rolling and pitching	JF	Likely	Harmful	SUBSTANTIAL
Shifting of cargo	UC	Unlikely	Extremely harmful	SUBSTANTIAL
Flooding	UC	Unlikely	Harmful	MODERATE
Structural failure	UC	Unlikely	Harmful	MODERATE
Loose objects	UA	Highly unlikely	Slightly harmful	TRIVIAL

* UC = Unsafe conditions, UA = Unsafe acts, JF = Job factors

Table 2: Risk controls for the voyage to Brisbane

Advise all personnel of expected bad weather along the path. Passage plan to include shelter position for refuge.		
No	**Controls**	**Category**
1	Constant monitoring of weather forecast	Procedural
2	Minimise GM to reduce rolling period[31]	Procedural
3	Correct and adequate lashings of cargo	Procedural
4	Ensure all watertight access are secure	Procedural
5	Check stability conditions, e.g. torque	Design/Engineering
6	Brief staff prior to sailing	Human element
7	Secure all loose objects and monitor	Procedural
Suggested controls: Slow down speed as necessary. Adjust course to minimize strong effect of winds and swell. ER to be manned when under required minimum revs. Hand steering as necessary. Deck department checklist must be complied with. Secure all loose items on deck, ER, galley and accommodation. Consult with weather routing service for recommended route. Check, add and tighten cargo lashings.		

In the overall assessment for the voyage, a list of hazards, their likelihood, consequence and resultant risks were identified (Table 1). The resultant overall operational risk for the voyage, calculated by the software, was substantial. A suggested list of risk controls was then put together by the master and chief mate and these were included on the risk assessment sheet (Table 2).

31 This control statement is discussed later in this report.

At the time the risk assessment was undertaken, the list of identified hazards and the risks they posed to the voyage accurately reflected what was expected, given what the crew knew in Newcastle. Likewise, the risk controls were appropriate for the intended voyage, and the crew probably believed they were effectively implemented as the ship made its way up the New South Wales coast.

Therefore, when *Pacific Adventurer* departed Newcastle, it appeared to those on board that it was prepared for a difficult, but not impossible, passage to Brisbane.

However, with hindsight, the risk controls did not adequately take into account the natural roll period of the ship, the number and condition of the lashings on the containers in Bay 25 or the packaging of the containers of ammonium nitrate that had just been loaded in Newcastle, the latter being something the crew knew nothing about and over which they had no control.

2.4.1 Weather routing advice

One of the considerations the master included in the risk controls, the adjusting of the ship's speed and course on the passage, was derived from weather routing advice he received as the ship made its way to Newcastle from Port Kembla, and then while the ship was alongside in Newcastle. At the time the risk assessment was completed, the weather routing advice was that the ship 'from Newcastle recommend reduced speed as necessary to provide minimum clearance of 180 miles south then west of the centre of TC Hamish'.

On the afternoon of 9 March, just before the ship departed Newcastle, the advice received recommended 'as safe navigation and conditions permit, adjust speed and course as necessary to remain 180 nm away from TC Hamish'. However, on the afternoon of 10 March, the recommended distance to keep away from the cyclone's centre was changed by the weather routing company to 210 miles. This was because the weather routing organisation was getting cyclone track predictions from both the Australian Bureau of Meteorology (BoM) and the United States Navy's Joint Typhoon Warning Centre and there was a slight difference in the 48 hour position forecast for the cyclone, with the BoM predicting a slower movement of the cyclone. Consequently, the 210 mile recommended clearance took into account the slower movement forecast by the BoM at the 48 hour mark.

Pacific Adventurer's master followed the weather routing advice and the ship's closest point of approach to the centre of TC Hamish was 190 miles.

2.5 The cause of the extreme rolling behaviour

The most plausible explanation for *Pacific Adventurer*'s severe rolling as it approached Brisbane is considered to be 'normal' synchronous roll excitation loads. These 'synchronous rolls' were the result of the ship's natural roll period matching, or nearly matching, the encounter period of the waves[32] at the time, approximately 10 seconds (Figure 8).

The ship's actual natural roll period differed from a calculated natural roll period, which was about 12 or 13 seconds (Appendix A, Figure A2), at departure

32 The time interval between the passage of two successive crests relative to a shipborne observer.

Newcastle. This calculated natural roll period came about from a calculated departure $GM_{(fluid)}$ of 2.68 m. The difference in roll periods was most probably brought about because the loading/stability computer used the levels of water ballast in the water ballast tanks (known as the free surface effect (FSE)) on departure to calculate an incorrect reduction to the ship's GM.

One of the tanks, No 5 centre double bottom tank (DBT) was 98 per cent filled and the computer calculated the free surface reduction using the maximum free surface moment for this tank. However, at close to 100 per cent full, the water's surface in that tank could not really be considered to be 'free' anymore as there was a very small amount of space in the tank above the water level for the water to 'move about in'.

If the FSE contribution of No 5 centre DBT is left out of consideration, then the effective GM on departure Newcastle would have been 3.4 m and not 2.68 m. A $GM_{(fluid)}$ of 3.4 m gives a natural roll period for the ship of about 10 seconds (Appendix A, Figure A2). This roll period is about the same as the peak wave encounter period measured by the Point Lookout wave buoy (Figure 8) and could explain the severe and sometimes violent rolling motions experienced by the ship.

In submission, MARIN commented that:

> The essential thing that is at the basis of the event is the interpretation of the roll period by the crew. The loading computer stated that it was supposed to be 12-13 seconds. In fact it may have been 9 or 10 seconds and close to the wave [encounter] periods to explain the excessive roll motions. The crew was thus likely unaware of the fact that ship's roll period was in-line with wave periods. They may have considered the excessive motions to be induced by the extreme effects of TC Hamish. Based on the loading computer, there would furthermore not be much reason for the master to change ballasting. In fact, reducing the filling of the No. 5 double bottom tank in the loading computer would very likely not have altered the reading of the display. Changing the actual filling level of the tank with the ballast pumps (which would have made the correction for FSE viable) would have taken a lot of time.

A more in depth discussion on this section can be found in Appendix A to this safety report.

2.5.1 How to reduce the rolling

In order to reduce the synchronous rolling of the ship, the GM needed to be reduced. The only way *Pacific Adventurer*'s crew could do this en route to Brisbane was to reduce the amount of water ballast in the ship's tanks. This would have effectively increased the FSE of the ship's water ballast. However, to undertake this consideration and any associated calculations in the prevailing circumstances and conditions would have been practically impossible. Consequently, this was not done and the ship continued to roll excessively.

In submission, the master's legal representative stated:

> Prior to departing Newcastle, calculations were made using Seamaster to see if the GM could be reduced further by reducing the water ballast. Seamaster indicated that the vessel's GM actually increased if more ballast was removed.

While this is acknowledged, the final departure stability calculations were carried out by the Seamaster program with the FSE of No 5 centre DBT being included. As discussed earlier in this report, this tank could have been considered to be 100 percent full and if the amount of water in the tank was reduced by a relatively small amount, the tank would then have been subjected to the FSE used by the Seamaster program and the actual condition of the ship would have matched the calculated $GM_{(fluid)}$ more exactly. The loading/stability computers calculations did not have to be carried out again.

Other strategies which could have been employed were to stay further south from the cyclone's predicted path and alter the ship's course so that the ship sailed directly into the seas, known as head seas, which were predominantly coming from the east. While *Pacific Adventurer*'s master did order the ship's heading to be changed, it was mostly around the northerly course needed to get to Brisbane and not towards the east.

His decision not to do this was almost certainly because he was endeavouring to get the ship to the Brisbane pilot boarding ground on time. Changing course to head into the easterly swells would have taken the ship away from its destination. Furthermore, he was not entirely sure as to the actual direction of the swells (he believed the sea conditions were confused) and he was not aware of how the vessel would respond if he altered course into the swells.

A more in depth discussion on this section can be found in Appendix A to this safety report.

2.6 Actions taken to minimise ship movement

Pacific Adventurer's large rolling motions started after the wind veered to the east-southeast and the swell, and later confused seas, started to build from an easterly direction. More severe rolling motions were reported after passing Point Lookout at about midnight on 10 March. At that time and place, the master did not have many options available to him in terms of what he could do with the ship or where he could take it.

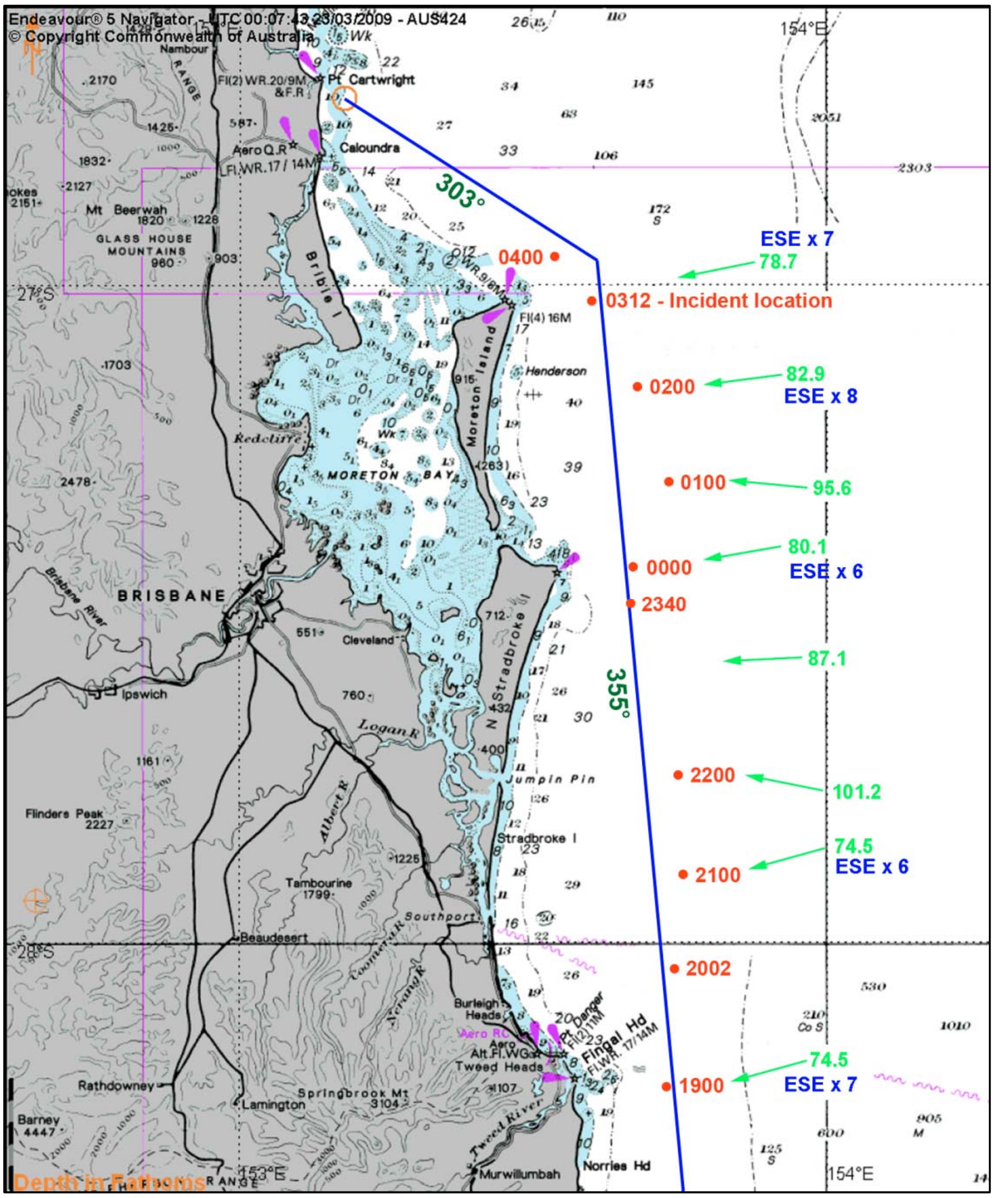
There was no shelter available to shore and no port of refuge was in range. Had there been one, taking on board a pilot with the severe vessel motions would have been hazardous.

Heaving to and putting the ship's head into the swell to wait out the storm might have meant that the ship continued to experience uncomfortable motions, this time in the form of pitching. With the predicted south-easterly path of TC Hamish, the master did not know when conditions would have improved enough for the ship to resume its passage. This option would mean delaying the pilot boarding time. Consequently, the ship would have been faced with a change in berthing times and subsequent departure time from Brisbane. This could have had an impact of the ship's schedule after Brisbane.

The other option was to proceed back towards Newcastle. This would have initially resulted in the ship experiencing similar rolling motions to those it had when it was sailing north. This option would have resulted in a greater delay in the pilot boarding time than that experienced if the ship was hove to because of the increasing distance between it and the pilot boarding ground. This would have had a greater impact on the ship's schedule.

Consequently, the master decided to maintain a reduced speed and continue towards Brisbane. The ship's track (Figure 16) indicates that those heading changes were limited to variations around the northern target heading required to get to the course alteration point off Cape Moreton.

Figure 16: The ship's track up the Queensland coast, with swell direction shown in green (from the wave data buoys) and the ship's logged wind direction and force shown in blue



In submission, the master's legal representative stated that:

> The vessel was in relatively close proximity to the Brisbane pilot station when the conditions worsened. The master had not been advised that the pilot station was closed which to him indicated the weather in the area of the pilot station was acceptable. He therefore considered the most prudent course was for the vessel to try to reach the pilot station where the conditions seemed to be better. Also, with a pilot onboard, he considered the vessel would be able to reach fully sheltered waters.

2.6.1 Safety management system guidence

Pacific Adventurer's safety management system (SMS) contained extensive guidance through procedures and fleet circulars to the master and crew of the ship in regard to actions to be taken in the event of heavy weather.

Those documents dealt with: risk assessment guidance; heavy weather action to prevent damage to ship; operating with excessive stability; and synchronous and parametric rolling.

The procedures not only provided guidance to the crew but also referred when necessary to company manuals and to commercially available references, such as codes of safe working practice and the international requirements of the IMO, including the IMDG Code and the Load Line regulations.

With regard to synchronous rolling, the procedure in the ship's SMS explained what the phenomenon is and when it will occur and stated that:

> To overcome synchronous rolling, the two roll periods must be *unmatched*. It is obviously impractical to alter the ship's roll period, hence the **apparent** wave or swell period must be changed either by altering the ship's course and/or speed. Altering course would normally be the quickest solution.

As discussed earlier in this report, it would have been possible for the ship's natural roll period to be changed by using the FSE of the water ballast on board, but this was not done. While it is probable that, at the time, the master did not recognise that the ship was being subjected to the effects of synchronous rolling, he attempted to alter course and speed as the ship made its way up the Queensland coast. By doing so he was following the guidance he was provided with on board.

However, no 'head sea' headings or change in ballast configuration were attempted to reduce the ship's rolling.

With regard to 'head sea' headings, it may be that the master considered the ship's overall response would not have improved significantly with more easterly headings (more head on waves). It is also possible that he decided the risk of continued rolling motions, taking into account that he believed the cargo was properly secured, was less than the risk of moving towards the predicted path of TC Hamish.

The events occurred at night time, in gale force winds, with high and confused seas, roll motions in excess of 30°, seas being constantly shipped on deck, and the awareness of a cyclone approaching. Consequently, at the time the ship was approaching Cape Moreton, the situation on board did not allow for a quiet, well considered assessment of the situation by those on the ship's bridge.

When decisions were being made regarding which speed and heading would be the most appropriate to reduce the ship's rolling motion, in accordance with SMS procedures and guidance, while still attempting to get the ship to the pilot boarding ground on time, the wave data from the buoy off Point Lookout was not known to anyone on board. Any calculated approach to speed, heading and stability (ballast) changes were not a viable option and any changes either were or would have been carried out on a 'trial and error' basis.

2.6.2 Commercial pressure

The evidence obtained by the ATSB indicates that *Pacific Adventurer*'s master was concerned about getting the ship to the pilot boarding ground on time. While in Newcastle, it is highly probable that, like many masters faced with similar circumstances, he thought that he would be put under pressure from the ship's charterers to sail to Brisbane directly so that the ship could maintain its schedule.

The evidence indicates that his opinion probably did not change as the ship made its way up the Queensland coast. The port of Brisbane was not closed and pilots were still boarding ships at the boarding ground. He and his crew would have experienced large rolling motions before but the ship, its containers and their lashings had withstood the rolling. However, as the ship neared Cape Moreton, the rolling the ship experienced was more extreme than expected.

In submission, the master's legal representative stated that:

> The master did consider delaying the ship's departure for 24 hours as one of a number of options open to him to be taken if conditions so required. However, the master did not reject this option because he would, despite the expected sea conditions, be under any significant commercial pressure to maintain the ship's schedule. Rather, the master decided after appropriate consideration that proceeding without a 24 hour delay did not involve undue risk.
>
> The times stated for arrival at the pilot boarding ground were estimates only and were always subject to change. Expected times for pilot boarding and other activities are (for planning purposes) necessarily discussed, propagated in emails etc but are nonetheless fluid and can be changed without any significant consequence or real effort. There are no fixed times for the vessel to meet and the expression "on time" is not meaningful. The evidence shows that the master was not seeking to maintain a fixed schedule or fixed arrival times and was prepared to adjust the vessel's progress in accordance with the weather conditions without concern for the vessel's schedule.

While the master might consider that he was not under any significant commercial pressure to get *Pacific Adventurer* to Brisbane by the nominated pilot boarding time, the evidence shows that at no time during the ship's passage to Brisbane, and especially when it began to experience the severe rolling motions, was any attempt made to change the pilot boarding time. The master continued to have the ship proceed in a northerly direction, despite the conditions being experienced, taking it closer to Brisbane.

The master's actions on the night of 10/11 March indicate that he continued to give significant weight to making the pilot boarding time, while doing what he thought might reduce the rolling motions of the ship. As master, he was in the difficult position of having to maintain the ship's schedule while ensuring the safety of the ship, its crew, cargo and the marine environment.

A master's first responsibility is the safety of the vessel and its crew. The master must therefore make the best decisions in this regard without undue reference to any competing commercial considerations. In *Pacific Adventurer*'s case, the master's decision to press on with the voyage in severe and deteriorating weather conditions to meet the pilot boarding schedule significantly limited his options regarding the actions he could implement to ensure the safety of the ship, its crew and cargo, and in the event, the protection of the marine environment.

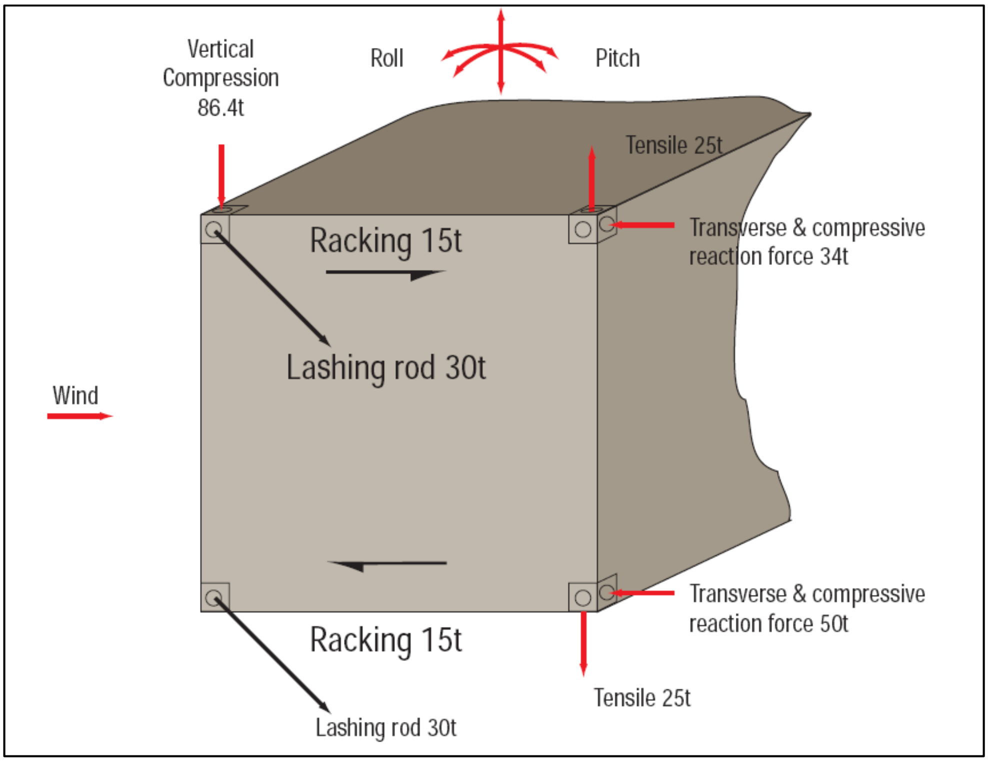
2.7 Container securing arrangements

2.7.1 Forces on a container at sea

A ship in a seaway has six degrees of freedom – roll, pitch, heave, yaw, sway and surge. The ship itself can bend and twist as waves pass and hatch covers can move relative to the hatch openings and a stack of containers can move as tolerances in lashing equipment are taken up.[33]

This movement imposes forces on the containers and their lashings, with rolling being the motion which results in the largest forces (Figure 17).

Figure 17: Allowable forces on an ISO container (Lloyd's Register Rules)



Failures in containers and/or lashing equipment may be brought about as a result of the following forces[34]:

Racking - When a ship is rolling, the lower containers in a stack are subjected to a horizontal sideways movement. This tends to change the rectangular cross section of the container to a parallelogram. This movement is resisted by the crossed end lashings. Racking forces act differently at each end of a container because the end with the door is not as 'stiff' as the other end.

Compression - The vertical force which acts on corner posts as a result of a stack tilting and also vertical acceleration. A failure in a corner post will almost certainly cause a stack of containers to collapse.

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33 Lloyd's Register/The Standard P&I Club. *A master's guide to container securing*. London (p2).

34 Australasian Institute of Marine Surveyors newsletter, April 2004. Accessed on line January 2010: www.aimsurveyors.com.au.

Corner shear - A horizontal force, related to racking, which tends to shear off twistlocks.

Separation - The tipping which tends to separate container corner fittings or twistlocks in a stack, as a ship rolls from side to side. If the rolling is excessive, twistlocks can be pulled out of the corner castings, break or separate a corner casting from the body of a container.

A structural failure in a container will almost inevitably be followed by a lashing failure and a lashing failure will probably lead to the loss of containers.

2.7.2 Failure of the lashing equipment

The officers on the ship's bridge first saw signs of container/lashing failure when a bottom tier container, in a centre row of containers in Bay 25, collapsed immediately before the containers on the port side of the bay fell over the side as the ship continued to roll to port. Upon the next roll to starboard, the bottom tier of the starboard row of containers collapsed and the remaining containers in Bay 25 then fell over the side to starboard.

Figure 18: Damage to the ship's starboard side

Extensive damage was caused to the ship's side and hand railings, outboard container pedestals and general structure as the containers fell over the side (Figure 18). Damage to the hatch cover and loose lashing equipment, as a result of the forces on the containers and lashings, included bent lashing rods (both older and newer), turnbuckles with sections sheared off, lashing eyes on the hatch cover torn out, dovetail twistlocks (both older and newer) with sheared centre shafts and sections of the deck twistlock sliding plates sheared off (Figure 19).

This damage indicates that the forces generated by the ship's movement in the prevailing conditions were greater than the breaking loads of the fixed and loose lashing equipment that was in poor condition (discussed later in this report). Additionally, several container corner fittings were found on the deck, indicating that the containers were subjected to separation forces in addition to the other forces.

Design loads of a cargo securing system typically consider roll motions of around 30°, and this was reflected in the ship's cargo securing manual (CSM). However, given *Pacific Adventurer*'s reported roll motions[35] of up to 40° on 10/11 March, combined with the condition of much of the lashing equipment; it is not surprising that the cargo securing system failed once it had been compromised.

Figure 19: Damage to the ship's lashing gear

The rolling motions of a ship, as previously discussed in this report, introduce reaction forces as follows:

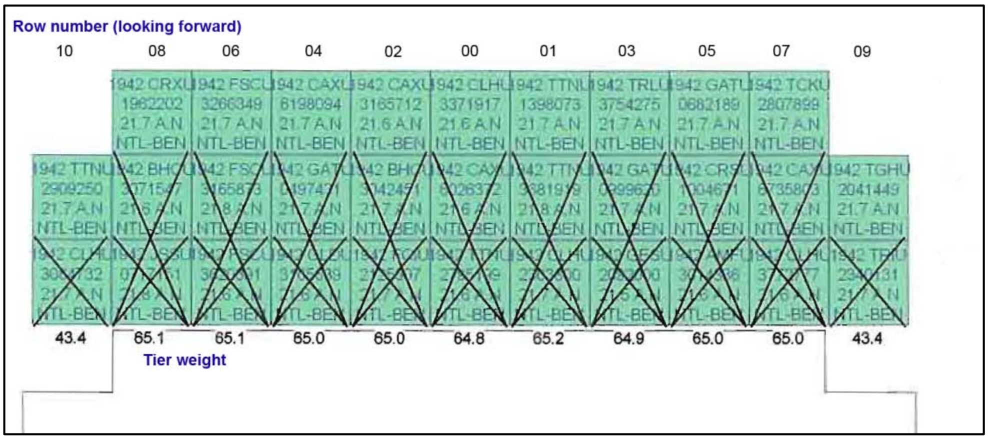
- racking forces in the bottom tiers of containers,
- compression loads in container corner posts,
- alternating tensile and compressive loads on lashing rods,
- snapping loads in twistlocks, due to the lifting of the containers when lashings become slack,
- turnbuckles becoming loose by repeated loading and unloading of the lashings, and
- higher bottom tier racking loads as the lashings become loose.

Lashing arrangements for container ships are designed to take the loads expected for each separate row according to the 'vertical lashing' concept. During the Lashing@Sea project, it was learned that reaction forces are amplified by dynamic row interactions. As such, lashing forces, racking and compression loads are

35 As measured on the bridge inclinometer.

significantly higher when neighbouring container rows have differing flexibility i.e. when the lashings applied to adjacent stacks of containers are not the same.

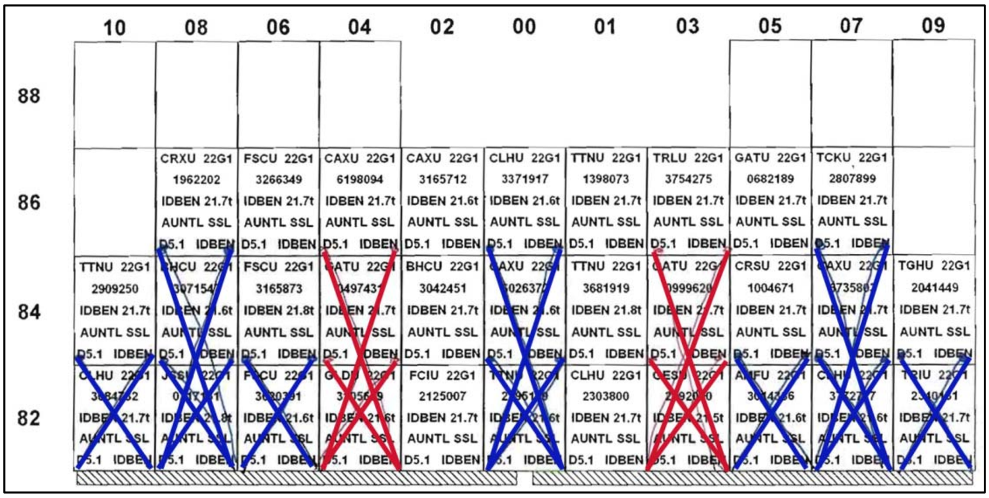
Figure 20: Computer generated lashing plan for Bay 25



On completion of loading in Newcastle, a computer generated loading lashing plan for the deck cargo was produced by *Pacific Adventurer*'s chief mate (Figure 20). The plan had lashings applied to the bottom of all the second tier containers in Bay 25 (partially lashed) and additional lashings applied to the bottom of all the third tier of containers (fully lashed).

The ship's procedures stated that containers must be secured in accordance with the approved CSM or stability/loading program carried on board. However, when the chief mate drew up the lashing plan to give to the stevedores, and for the additional lashings which were added, he modified it such that rows 00, 03, 04, 07, 08, 09 and 10 were fully lashed; rows 05 and 06 were partly lashed; and rows 01 and 02 were not lashed at all (Figure 21), except with twistlocks.

Figure 21: Chief mate's lashing plan where blue indicates lashings applied in Newcastle and red indicates the additional lashings applied by the ship's crew before it sailed (ATSB emphasis of chief mate's annotations)



The chief mate probably amended the ship's loading program's lashing plan because he believed, like others in his position on container ships, that applying lashings, as he indicated in Figure 21, would be sufficient as the outboard and inner most containers were lashed to the maximum extent possible and that other lashings would be sufficient as the rows of containers were not directly ‘exposed’ to the prevailing or expected sea and weather conditions.

By not having the containers in Bay 25 lashed in accordance with the lashing plan produced by the ship’s loading computer, which took into account the weight and disposition of the containers on deck, the chief mate did not follow the guidance provided in the ship’s SMS for container securing.

Despite the pre-departure risk assessment listing ‘correct and adequate lashings of cargo’ as a risk control, the ship went to sea with the deck cargo inadequately lashed for the conditions the ship was expected to encounter on its passage to Brisbane.

The Lashing@Sea research has identified that this type of lashing arrangement, and the differing flexibility it produced within the stacks of containers, imposes previously unknown additional loads on the lashing gear and containers.

The lashing pattern in the chief mate’s plan clearly included rows with different flexibility. Not having lashing rods on rows 01 and 02 meant the stiffness of the lower tier of containers was reduced. Consequently, this allowed some ‘uplifting’ which resulted in dynamic row interaction.

These two unlashed rows would have imposed large additional loads on the centre row (00) as the ship rolled excessively in the seas experienced in the time leading up to the loss of the containers. The already weakened lashing arrangement (due to the worn condition of the lashing gear) is likely to have become progressively less secure in the hours of rolling during the evening and night of 10 March. With the lashing bars and turnbuckles losing tension and thus carrying progressively less load, the transverse loads were probably carried more and more by the twistlocks with the loads being affected by the racking resistance of the bottom tier of containers.

Based on the condition of the lashing gear, and the witness account of a collapsing container in the centre stack, it seems that the most likely scenario is that, at some point, a dovetail twistlock pulled free of the deck fitting in one of the centre rows (01 or 02). The momentum of this full row of moving containers was then imparted to the centre stack which, in turn, collapsed. The crew reported that this event coincided with an extreme roll motion to port of about 40°. The centre row, which was fully lashed, is then likely to have collapsed due to the racking failure or corner post buckling of the containers.

The additional momentum of the combined free rows was then sufficient to break the worn, remaining container lashings on the rows of containers to port which then fell away to port. In addition, the debris around the centre row is likely to have damaged the first of the rows to starboard, possibly 03, during the collapse. The damaged row then pushed the remaining rows over the side in the following roll to starboard.

Had the containers in Bay 25 been lashed in accordance with the loading computer generated lashing plan, the reliability of the securing arrangements would have been improved with rows 01 and 02 secured to the same degree as the centre row 00.

2.7.3 Hatch cover securing arrangements

Following the loss of the containers, an inspection of the hatch covers on which the containers in Bay 25 were stowed, revealed that a number of the securing cleats (dogs) were not in place.

The ship's SMS procedure on hatch cover securing arrangements required that all of the cargo hatches were to be properly secured before it departed for sea.

As a result of the hatch covers not being properly secured, or 'dogged down', the port and starboard covers, in addition to not being properly weather tight, could move more than if they had been properly secured as the ship moved in the seaway.

This movement might have contributed to the loosening of the lashings on a number of containers; the centre stack of containers (00) straddled both hatch covers and the outboard stacks (09 and 10) were lashed to a hatch cover and a fixed container pedestal.

The *Masters Guide to Container Securing* states that:

> A hatch cover is designed to move as the ship bends and flexes. A container stowed on a pedestal, a fixed point, will attempt to resist hatch cover movement if also secured to a hatch cover.

Consequently, by not being properly secured, the amount of movement in the hatch covers could have introduced additional, different and larger degrees of movement in some of the containers and increased the loads on their lashings than would have been present if the hatch covers had been properly secured.

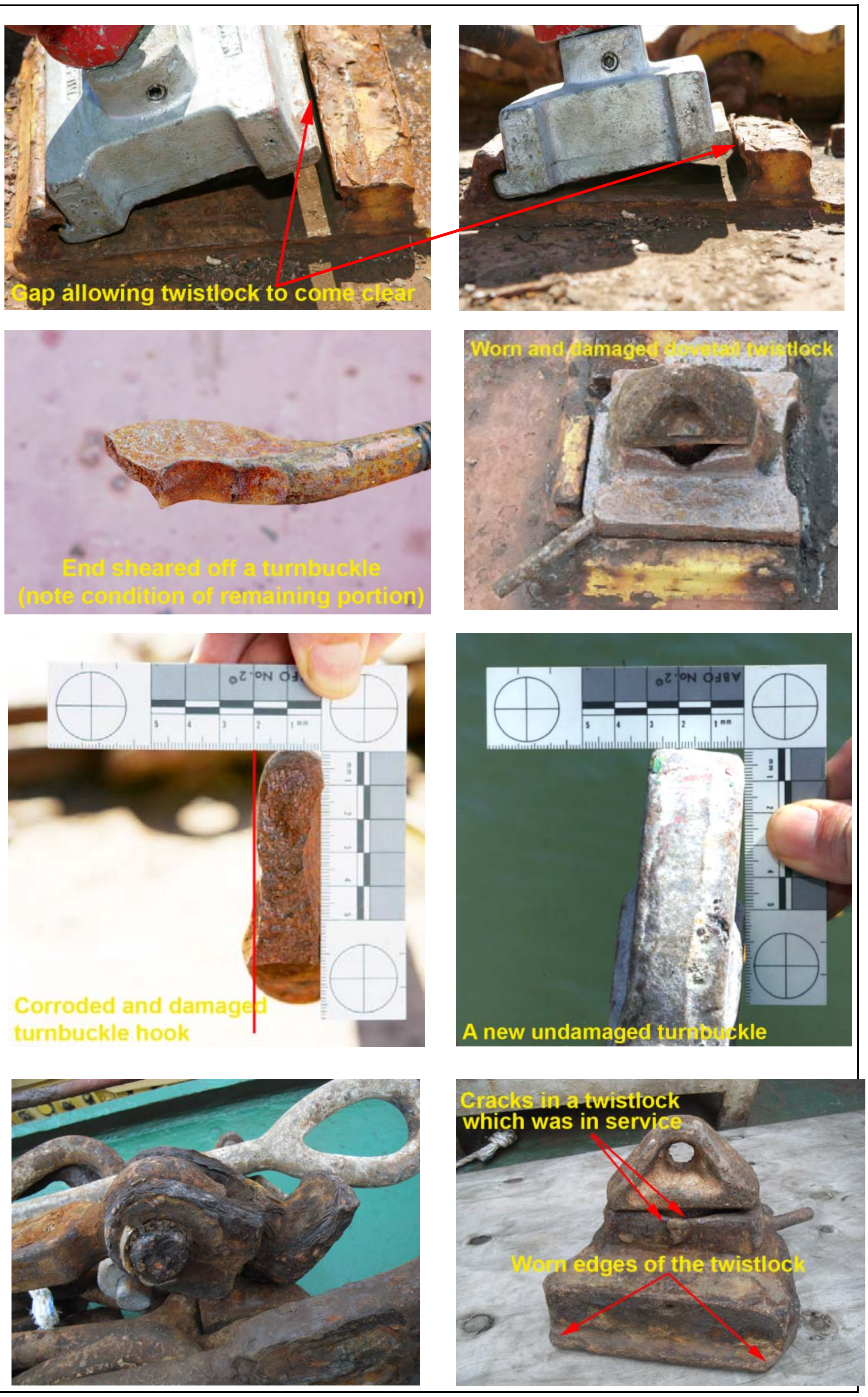
2.8 Condition of *Pacific Adventurer*'s lashing equipment

The evidence indicates that those responsible for the risk assessment for the voyage did not consider cargo shift as a likely scenario. This is probably because they considered that the lashings on the container were sufficient and secure.

Inspection of *Pacific Adventurer*'s fixed and loose lashing equipment after the incident revealed that much of it was in poor condition (Figure 22). Many of the deck plates, into which the dovetail twistlocks slid on the hatch lid, were worn to the extent that the twistlock could lift and twist while in position. Many dovetail twistlocks were corroded, could not be locked, and had cracks in their bases. Turnbuckles and lashing rods also suffered from corrosion with extensive material loss (by up to two-thirds in some cases), thus degrading their ability to perform as designed.

Following the loss of the containers, Maritime Safety Queensland (MSQ) commissioned two United Kingdom marine consultancy companies, Brookes Bell and Safety at Sea, to undertake tests/examinations on samples of *Pacific Adventurer*'s lashing equipment to determine the degree of corrosion and when the equipment, both in good and poor condition, would fail. The results of those tests/examinations can be found in Appendix B of this report.

Figure 22: A sample of the condition of lashing equipment



This issue was further highlighted by Safety at Sea, on behalf of MSQ, in their submission on the draft ATSB safety report:

> Based on our analysis of the lashing loads, [I] believe the loads in the lashings were very much lower than their SWL's while the container stacks were in place.

> Given that the breaking loads are double the SWL's [I] have concluded that the failure of the lashing gear when in a sound condition is highly unlikely. [I] believe that the loss of the containers is due to the corroded lashing rods (which had a breaking load in their corroded state around 43% of the equivalent value in sound condition) or failure of the deck twistlocks (these could be lifted from the deck by hand and could not withstand vertical loads of any significant magnitude).

The poor condition of much of *Pacific Adventurer*'s lashing equipment had been recognised by the ship's senior officers and its shore management. In October 2008, the then master was sufficiently concerned about the condition of the twistlock deck plates and the lashing eyes that he sent an email to the ship's managers. The email highlighted his concern and suggested that it would take a fitter 2 or 3 months to complete their replacement.

In reply to the master's email, the ship manager acknowledged the condition of the deck fittings and reminded the master that spare fittings were on the ship but to order more if they were required. He also agreed that the replacement of the fittings was a high priority and that the deck and engine departments should work together to ensure that the fitters on the ship worked on deck, replacing the fittings when the deck cargo and weather allowed. He also told the master that attempts were being made to provide the ship with another fitter while the ship was on the Australian coast that voyage.

As a result, the ship's crew had been directed to order new equipment each voyage. Therefore, a process was in place to progressively replace/repair the deck fittings, as container operations (in port), loading on deck and weather conditions allowed. However, at the time of the incident, this work had not progressed as far as Bay 25.

In addition to the replacement of the deck fittings, new lashing rods, turnbuckles and twistlocks were being supplied on a regular basis for introduction into service. However, while there was evidence that some of the new lashing equipment was being used on deck, many of the new, unused lashing rods and turnbuckles were stored in the ship's forecastle store.

2.8.1 Lashing equipment maintenance

Senior ship's officers probably considered that, while much of the lashing equipment was worn and in need of replacement, there was sufficient strength remaining in the lashings and that the equipment was still capable of functioning properly; ensuring that the containers remained secure during the voyage.

Pacific Adventurer's SMS and CSM contained guidance on the type of maintenance that should be carried out on the fixed and loose lashing equipment, including when consideration should be given to replacing items. The procedures also referenced additional documents which could assist the crew in the task of maintaining this equipment in a proper operational condition.

The container securing procedure stated that:

> The lashing equipment used must be in a well-maintained condition and suitable for its intended job. Items of lashing equipment which are not in a good condition must not be used.

To emphasise the ongoing need to ensure that lashing equipment was in an operational condition, a Swire fleet 'alert' was sent to all ships in August 2006. This ‘alert’ reminded masters and chief engineers of the need to ensure that 6 monthly checks of the cargo securing system were carried out and that:

> Where wasted, fractured or distorted fittings are found, they are to be repaired or taken out of service so that they cannot be used as part of the lashing system. This is very important as the consequence of failure of any part of the securing system can, in extreme cases, lead to major loss of containers and endanger the ship.
>
> Please ensure that the container and cargo securing fittings are maintained in good condition and recognise that substandard fittings will usually fail under excessive loading due to the effects of heavy weather and or freak conditions combined with poor stowage.

To reinforce the requirement to carry out thorough checks of the cargo securing fitting on the ships, Swire provided each ship with a copy of the Lloyd’s Register/Standard P&I Club publication *‘A master’s guide to container securing’*. This publication was also referenced in the SMS and contains a great deal of information regarding the maintenance of lashing equipment.

Despite this reminder, the condition of much of the fixed and loose lashing equipment on board *Pacific Adventurer* deteriorated further and it was allowed to remain in service on board the ship. This indicates that the inspection and replacement regime on board the vessel was inadequate.

2.8.2 Third party inspections

At the time of the incident, a ship’s cargo securing arrangement and CSM were the subject of flag State approval, by virtue of SOLAS chapters VI and VII. However, there was no statutory requirement for a ship’s flag State/recognised organisation or classification society to inspect all loose and fixed cargo securing equipment during annual surveys.

There was also no requirement under the Port State Control (PSC) inspection regime for this type of equipment to be inspected during a PSC inspection. However, the CSM itself and verification of its use on board a ship was covered by PSC procedures.

The maintenance and replacement of this equipment was entirely the responsibility of ship and shore personnel, following the guidance provided in an approved CSM.

At the time of the incident, there was no requirement for any third party to inspect or survey the fixed and loose lashing equipment on a ship. Had this been done, the maintenance and replacement regime of such equipment on board *Pacific Adventurer* may have been more effectively implemented.

2.9 Container packaging

The carriage of ammonium nitrate at sea is governed by the International Maritime Dangerous Goods (IMDG) Code. Chapter 3.2 of the IMDG Code allows ammonium nitrate to be carried in a ‘closed bulk container’ (coded as a BK2 package). A closed bulk container is defined in chapter 6.9.1 of the IMDG Code as being a totally enclosed bulk container, having a rigid roof, sidewalls, end walls and floor. Special Provision 952 of the IMDG Code states that the competent authority[36] must give approval for ammonium nitrate to be carried in BK2 packages.

If a closed bulk container complies with the requirements of International Standard ISO 1496-4:1991, and is siftproof[37], then it is deemed to meet the general design and construction provisions for BK2 packages of section 6.9.3 of the IMDG Code (provisions for the design, construction, inspection and testing of freight containers used as bulk containers).

Standard freight containers are designed and tested in accordance with International Standard ISO 1469-1:1990 and the end wall strength requirements of that standard are different to those contained in ISO 1496-4:1991. According to section 6.9.3.1.2 of the IMDG Code:

> Freight containers designed and tested in accordance with ISO 1469-1:1990 "Series 1 freight containers – Specification and testing – Part 1: General cargo containers for general purposes" shall be equipped with operational equipment which is, including its connection to the freight container, designed to strengthen the end walls and to improve the longitudinal restraint as necessary to comply with the test requirements of ISO 1496-4:1991, as relevant.

Consequently, if ammonium nitrate is to be carried in standard freight containers, arrangements have to be put in place to ensure that the end wall strength of the containers is increased. If a standard freight container is to be used, then a competent authority must approve the packaging arrangements to ensure that the provisions of section 6.9.3 of the IMDG Code are met.

The current 'model' regulation format of the IMDG Code became mandatory in Australia in 2000 with the adoption of AMSA's Marine Order Part 41 (Carriage of Dangerous Goods). Every time a new version of the IMDG code is to be adopted, notification of this is promulgated by a Marine Notice. The application provision of Marine Order Part 41 means those subject to the order are required to comply with the 'current' edition of the IMDG code.

Orica Australia (Orica), the manufacturer and shipper of the cargo, had obtained permission from AMSA, the relevant authority in Australia, to ship the cargo in bulk prior to the IMDG Code becoming mandatory in Australia.

In addition to issuing a Marine Notice to the shipping industry regarding the implementation of the IMDG Code, AMSA specifically wrote to ORICA in September 2002 in relation to modifications to the IMDG code previously issued by AMSA relating to the segregation and stowage of ammonium nitrate prills containers and other classes of dangerous goods on board a container ship. In this correspondence, AMSA informed Orica that previous modifications, concerning the stowage of containers of ammonium nitrate prills in relation to any other dangerous goods on board, could no longer be relied upon as new requirements under the IMDG code were becoming mandatory under SOLAS.

This advice to ORICA did not address the issue of the packaging of ammonium nitrate in containers. However, AMSA was, in effect, informing ORICA that the

36 Defined in the IMDG Code as meaning any national regulatory body or authority designated or otherwise recognised such for any purpose in connection with the code.

37 Packagings impermeable to dry contents, including fine solid material produced during transport.

shipping rules for that cargo had changed and the company should comply with all the provisions of the IMDG Code when exporting the cargo. This included the packing provision for shipping containers.

However, following the mandatory application of the IMDG Code in Australia, Orica continued to ship the ammonium nitrate prills in containers in a manner which was non-compliant with the packaging provisions of the IMDG Code.

Furthermore, at the time of the incident, AMSA's IMDG Code compliance audit regime had not identified the fact that the shipping of the prills was not in compliance with the requirements.

In submission, AMSA stated that:

> AMSA's audit regime is a combination of desktop audit and site inspections. Site inspections are conducted either randomly or on the basis that the desktop audit reveals possible issues. In this case, the documentation provided for this shipment reflected that the packaging was in compliance with the IMDG Code.

The prills on board *Pacific Adventurer* were packed in standard 20 foot freight containers. Inside the containers, a single woven polypropylene bag was secured to the container and a wooden bulkhead was erected to keep the prills clear of the container door (Figure 23). The bag was then filled with approximately 19.5 tonnes of the prills and the bag sealed with tape to prevent moisture from entering the bag and spillage of the cargo. The container door was then closed and secured normally.

Figure 23: The packaging of the ammonium nitrate prills in a container similar to those lost from *Pacific Adventurer*

By packaging the prills in this manner, the container could be quickly emptied. After the door was opened, the wooden bulkhead could be removed and then the container tilted to allow the prills to flow freely from the polypropylene bag.

While ammonium nitrate prills could be shipped in bulk, in this way, there was a potential problem with the strength of the wooden bulkhead. The wooden bulkhead did not comply with the end wall strength provisions of section 6.9.3.1.2 of the IMDG Code. In addition, the use of wood did not comply with section 4.3.2.3 of the

IMDG Code (additional provisions applicable to bulk goods of class 5.1), which stated that bulk containers shall be so constructed or adapted that the goods cannot come into contact with wood or any other incompatible material.

In submission, Orica stated:

> Orica had previously worked with AMSA to develop approved procedures for the method of packaging of ammonium nitrate which was used for the cargo on *Pacific Adventurer*, and packing had been undertaken in accordance with these procedures from at least as early as 1991. It is accepted that, due to administrative oversight by Orica, those approvals had not effectively been renewed and were not current as at 11 March 2009.

In the sea conditions experienced in the time prior to the loss of the containers from *Pacific Adventurer*, the movement of the prills in the container could have resulted in the wooden bulkhead giving way. If this did occur, then the weight of the prills may have imposed larger forces on the container doors than they were designed to withstand. This, in turn, may have resulted in the end wall failing, which would have resulted in the container itself collapsing. Hence, it is possible this could have contributed to the failure of the lashing system.

It cannot be definitively concluded that the packaging of the ammonium nitrate in the containers contributed in their loss. However, *Pacific Adventurer*'s second mate stated that before the first containers fell overboard, he saw a container in the centre stack in Bay 25 collapse. Furthermore, the master and the second mate saw the bottom row of the remaining containers on the starboard side in Bay 25 collapse before the containers were lost over the side.

3 FINDINGS

3.1 Context

At 0312 on 11 March 2009, the container ship *Pacific Adventurer* lost 31 containers overboard in gale force weather conditions and large swells off Cape Moreton, Queensland. All the containers sank, however, two of the ship's fuel oil bunker tanks were holed as the containers went overboard.

About 38 miles of Queensland's coastline was affected by the oil.

From the evidence available, the following findings are made with respect to the loss of containers and should not be read as apportioning blame or liability to any particular organisation or individual.

3.2 Contributing safety factors

- *Pacific Adventurer* probably experienced synchronous or resonant rolling in the time leading up to the loss of containers, brought about by the ship's natural roll period matching the encounter period of the waves.
- The risk controls put in place by the ship's crew before *Pacific Adventurer* left Newcastle and sailed into the anticipated poor weather did not adequately take into account the natural roll period of the ship or the number and condition of the lashings put on the containers in Bay 25.
- The master attempted to alleviate the rolling by altering the ship's heading and speed, in accordance with the usual practice of seamanship and the ship's procedures, but the rolling continued. However, he did not order a course alteration to take the ship into a 'head sea'.
- No changes to the ship's water ballast configuration, either before the ship departed from Newcastle or during the passage, were attempted in an effort to reduce the ship's actual or expected rolling motion.
- The containers in Bay 25 were lashed in a way which allowed different flexibility in adjacent stacks. Consequently, it is likely that the unlashed stacks of containers imposed excessive forces on the neighbouring lashed container stacks; which probably contributed to the failure of the lashings and the containers in the prevailing conditions and excessive roll motions.
- The hatch covers on which the containers in Bay 25 were stowed were not properly secured. As a result, they could have moved in the sea conditions experienced on the passage to Brisbane. This movement may have contributed to the failure of the lashings on a number of containers by introducing different degrees of movement in the containers and their lashings.
- While the poor condition of much of the fixed and loose lashing equipment on board had been recognised by senior officers on board and shore management, the replacement of the equipment had not progressed as far as Bay 25 when the ship departed Newcastle.

- The poor condition of much of the ship’s container lashing equipment indicates that the inspection and maintenance regime applied to this critical equipment had been inadequate. *[Significant safety issue]*
- At the time of the incident, there was no requirement for any third party to inspect or survey the fixed and loose lashing equipment on a ship. Had this been done, the maintenance and replacement regime of such equipment on board *Pacific Adventurer* may have been more effective. *[Significant safety issue]*

3.3 Other safety factors

- The ammonium nitrate prills were not packaged in the containers in accordance with the requirements of the IMDG Code. The containers were packed in a way which allowed the prills to move within the container which may have contributed to the failure of the containers and/or the lashing system. *[Minor safety issue]*
- Before the incident, Orica Australia had advised the Australian Maritime Safety Authority (AMSA) that their packaging method for the prills was fully compliant with the IMDG Code’s provisions. However, AMSA’s IMDG Code compliance audit regime had not detected that the method was not compliant. *[Minor safety issue]*

4 SAFETY ACTIONS

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the organisations responsible for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

4.1 Swire Navigation

4.1.1 Condition of the lashing equipment

Significant safety issue

The poor condition of much of the ship's container lashing equipment indicates that the inspection and maintenance regime applied to this critical equipment had been inadequate.

Action taken by Swire Navigation MO-2009-002-NSA-028

Swire Navigation has advised the ATSB that, at the time of the incident, the company (and ship) had in place a comprehensive inspection and maintenance regime which included regular inspection and maintenance and/or replacement of the vessel's container lashing equipment. The upkeep and replacement of relevant cargo securing equipment by the crew was progressing at the time of the incident.

Following the incident, Swire Navigation has reviewed the inspection and maintenance process for the container fitting system in use on the ship at the time of the incident and, although Class approved, has decided to replace the entire system with an alternative Class approved system for all eight ships of this class that the company believes will be even more robust.

ATSB assessment of action

The ATSB is satisfied that the action taken by Swire Navigation adequately addresses this safety issue.

4.2 Coastal and Flag States and Classification Societies

4.2.1 Third party inspection of lashing equipment

Significant safety issue

At the time of the incident, there was no requirement for any third party to inspect or survey the fixed and loose lashing equipment on a ship. Had this been done, the maintenance and replacement regime of such equipment on board *Pacific Adventurer* may have been more effective.

Action taken by the Australian Maritime Safety Authority MO-2009-002-NSA-032

The Australian Maritime Safety Authority (AMSA) has advised the ATSB that, while Port State Control procedures cover the Cargo Securing Manual and the verification of its use on board, AMSA also implemented its own specific cargo securing inspection regime. Since March 2009, AMSA has conducted in excess of 300 cargo securing inspections.

In addition to the above, AMSA conducted a focused inspection campaign on cargo securing arrangements from February to May 2010.

Finally, AMSA continues to provide their marine surveyors with specialised dangerous goods and IMDG Code training and has extended surveyor training to cover the issue of cargo securing.

ATSB assessment of action

The ATSB is satisfied that the action taken by the Australian Maritime Safety Authority adequately addresses this safety issue.

ATSB safety advisory notice MO-2009-002-SAN-029

The Australian Transport Safety Bureau advises that coastal States, flag States and classification societies should consider the safety implications of this safety issue and take action where considered appropriate.

4.3 Orica Australia

4.3.1 Container packaging

Minor safety issue

The ammonium nitrate prills were not packaged in the containers in accordance with the requirements of the IMDG Code. The containers were packed in a way which allowed the prills to move within the container which may have contributed to the failure of the containers and/or the lashing system.

Action taken by Orica MO-2009-002-NSA-030

Orica has advised the ATSB that the company has taken two main actions relating to packing of ammonium nitrate for sea transport following the incident.

Orica has worked with AMSA to agree on a revised packing procedure for ammonium nitrate prills. The new approved procedure differs from the previous method in three respects: the plastic liner inside the shipping container is now closed with a zip, rather than tape; the wooden bulkhead has been replaced with a steel bulkhead, in order to reduce the presence of combustible material inside the container, but not, as Orica understands, due to concerns about structural integrity in using a wooden bulkhead; and the containers are now packed with 18.5 tonnes of ammonium nitrate, rather than 19.5 tonnes.

Orica has also developed a training program with respect to IMDG compliance which has been rolled out to all Orica personnel and contractors involved in packing and loading of shipments of ammonium nitrate. This program was developed in consultation with AMSA, and has been approved by AMSA.

ATSB assessment of action

The ATSB is satisfied that the action taken by Orica Australia adequately addresses this safety issue.

4.4 The Australian Maritime Safety Authority

4.4.1 Container packaging

Minor safety issue

Before the incident, Orica Australia had advised the Australian Maritime Safety Authority (AMSA) that their packaging method for the prills was fully compliant with the IMDG Code's provisions. However, AMSA's IMDG Code compliance audit regime had not detected that the method was not compliant.

Action taken by the Australian Maritime Safety Authority MO-2009-002-NSA-031

The Australian Maritime Safety Authority (AMSA) has advised the ATSB that work has been undertaken with Orica and other ammonium nitrate shippers to ensure that the IMDG Code packaging requirements are understood. To further assist with this education campaign, AMSA published an information sheet in June 2009 covering all the relevant issues of shipping ammonium nitrate.

In the case of Orica, AMSA have specific approvals covering their loading of ammonium nitrate prills into containers to ensure that the end-wall strength requirements of the IMDG Code are complied with. AMSA have also conducted inspections of Orica’s loading arrangements to ensure that the approvals are complied with.

In accordance with chapter 3.1 of the IMDG Code (2008 edition), AMSA has, through Marine Orders Part 41, implemented the requirements for training of shore-based personnel involved in all aspects of IMDG Code compliance. This has involved AMSA formally accepting training providers and courses for certain levels of training, and it includes an additional audit function.

AMSA has also published a dangerous, hazardous and harmful cargo handbook for use by industry.

More information on these safety actions can be found on AMSA’s web site (www.amsa.gov.au).

ATSB assessment of action

The ATSB is satisfied that the action taken by the Australian Maritime Safety Authority adequately addresses this safety issue.

APPENDIX A: THE SHIP'S ROLL RESPONSE

Generalised considerations on rolling responses

The roll response of a given ship in beam seas, the type of conditions *Pacific Adventurer* was experiencing as it approached Cape Moreton, is determined mainly by the wave induced rolling moments, the natural roll period of the ship and the wave period.

Typically, the ship's natural roll period should be as far away as possible from the dominant wave encounter period (the peak period), so as to avoid resonance[38].

Waves can impose the following type of roll excitation loads on a ship:

- 'non-linear' which can result in parametric rolling, and
- 'normal' synchronous which can result in resonant rolling.

Non-linear roll excitation loads (e.g. parametric rolling)

Parametric roll excitations, and so called 'dynamic loss of stability induced rolling motions', occur in head or following sea conditions. The excitation loads are generated by variations of the ship's stability as a result of the changing immersed shape of the ship's hull when wave crests pass it.

The predominantly beam sea conditions that were experienced by *Pacific Adventurer* on the morning of 11 March indicate that it is unlikely this type of phenomenon played a part in the ship's rolling motions.

Normal (synchronous rolling)

This is the rolling response of a ship to waves coming from its beam.

There are two parameters which determine the roll excitation force on a ship which results in normal synchronous rolling. These are the 'roll moment amplitude' and the 'period of the wave induced overturning moment'.

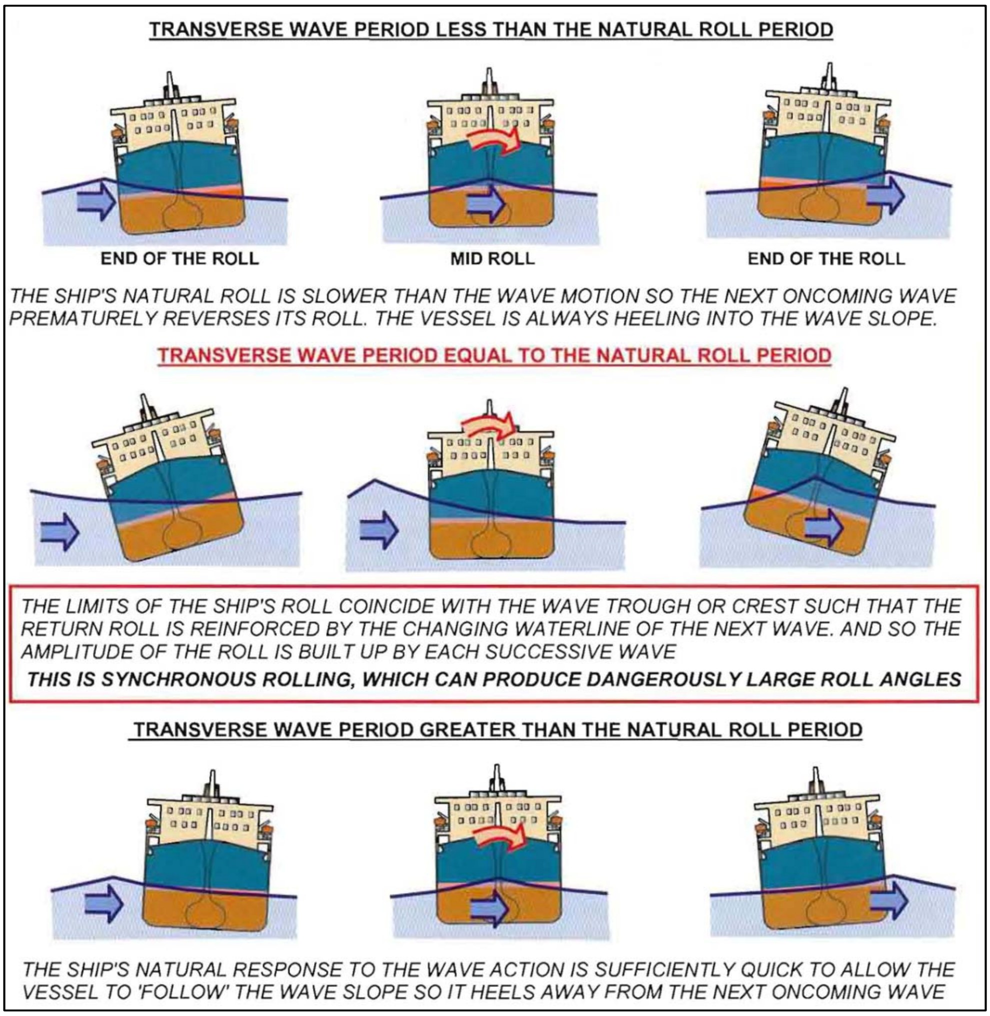
The 'roll moment amplitude' is caused by the wave height, the slope angle of the wave and the ship's heading in relation to the wave direction. Waves coming from the beam usually induce the highest roll or heeling moments.

The 'period of the wave induced roll moment' is determined by the wave period and the speed of the ship, which can shift the period of encounter.

Typically, resulting roll motions remain low if wave forces have shorter or longer periods than the natural roll period of a ship (Figure A1).

38 The phenomenon of building up extreme rolling amplitudes by the addition of exciting forces.

Figure A1: A ship's natural roll period and its rolling in a beam sea



Conversely, a ship's roll motions are highest when the roll excitation forces are large and wave encounter periods coincide with the natural roll period of the ship (Figure A1). When this happens, efforts should be taken on board the ship to reduce the roll motions so that forces on the ship, its crew and its cargo are reduced as much as possible.

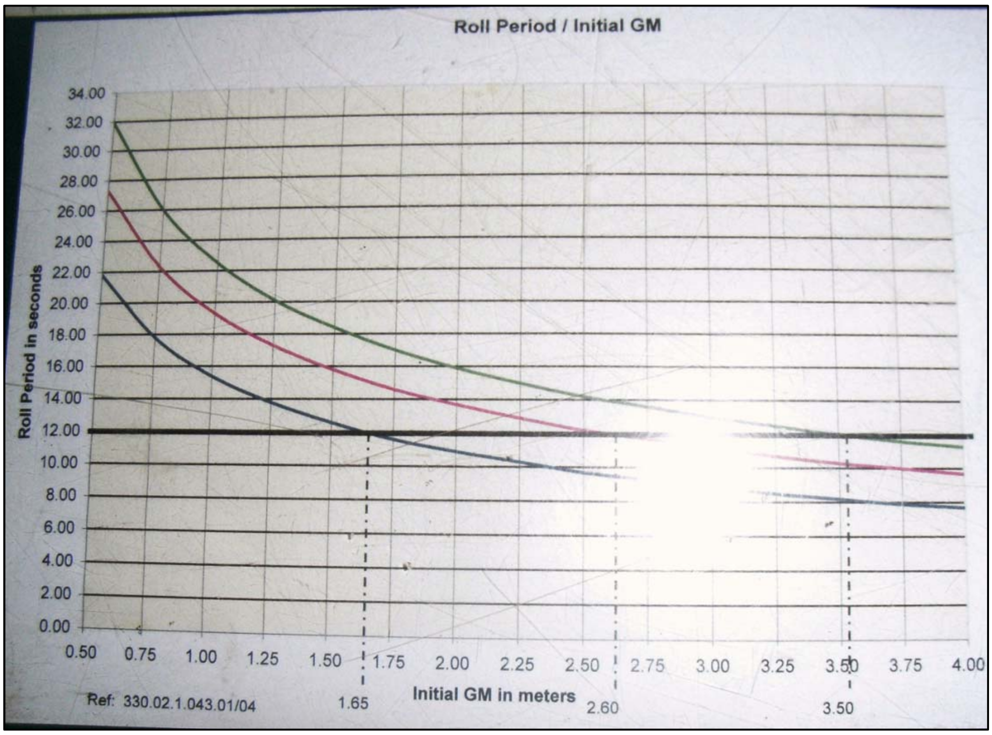
Pacific Adventurer's extreme rolling behaviour

The fact that the ship might have been subjected to large rolling motions during the passage to Brisbane was foreseeable, given the presence of TC Hamish and the ship's loaded condition which resulted in a final GM of more than 2.5 m. While it was an identified event in the risk analysis, those conducting the risk analysis probably did not consider that the ship would be subjected to severe rolls, sometimes violent and estimated to be about 40°.

As *Pacific Adventurer* became subjected to the sea conditions resulting from TC Hamish, the master tried to alleviate the rolling by altering the ship's heading and speed, in accordance with the usual practice of seamanship and company procedures. However, none of those actions had the desired effect and the excessive rolling continued.

The calculated departure GM(fluid) of 2.68 m gave *Pacific Adventurer* a natural roll period of 12 or 13 seconds (Figure A2). While this was close to the recorded wave periods of 9 or 10 seconds at Point Lookout (Figure 8) (obtained after the incident), it would not lead to the expectation of excessive roll responses in the predominately beam seas which were expected/predicted for the passage to Brisbane, and appears to provide a reasonable margin against extreme roll motions.

Figure A2: ***Pacific Adventurer*'s roll period (in red) graphed against its GM**



Therefore, the fact that roll motions, and the resultant roll angles during the passage were so severe, and encountered for prolonged periods of time, suggests that the ship's natural roll period must have been close or equal to the wave encounter period that was in the vicinity of 9 or 10 seconds.

With this in mind, the most plausible explanation for *Pacific Adventurer*'s severe rolling motions is considered to be 'normal' synchronous or resonant roll excitation loads. However, the question remains as to why there was a difference between the 'calculated' natural roll period and the 'actual' natural roll period.

Free surface effect (FSE)

A factor which could have contributed to the complicated and severe roll motion response of the ship was the effect on the ship's GM(fluid) of the free surface of the water ballast in the ship's ballast tanks.

The effect of free fluid surfaces is a quasi-static approach to consider the effect of fluids that flow from port to starboard in a tank under changing roll angles. Free surface effects of liquids begin to exert a significant influence on a ship's stability as soon as its tanks (ballast or fuel) are not filled to 100 per cent. This effect provides a reduction of overall stability that is accounted for as a theoretical reduction in, or a correction to, the ship's GM(solid).

On departure from Newcastle, the contribution of various water ballast tanks to the free surface moment was calculated by the ship's stability/loading computer and the results shown in Table A1 below.

Table A1: Ballast tank condition and resultant free surface moments

Tank	Tonnes	Percentage full	Free surface moment (tm)
Forepeak	0	0	0
No 1 centre double bottom	255	50	1628
No 2 centre double bottom	613.3	70	13350
No 2 port side	0	0	0
No 2 starboard side	0	0	0
No 3 port heeling	360	53	55
No 3 starboard heeling	300	44	56
No 3 port side ballast	49.9	10	2886
No 3 starboard side ballast	49.9	10	2886
No 4 port side ballast	52.6	10	3524
No 4 starboard side ballast	52.6	10	3524
No 5 port side ballast	0	0	0
No 5 starboard side ballast	0	0	0
No 5 centre double bottom	690	98	16194
After peak	30	10	250

The calculated 2.68 m departure GM(fluid), and resultant natural roll period of 12 seconds, of *Pacific Adventurer* was the result of a GM(solid) of 4.44 m with a reduction of 1.76 m applied for FSE. It can be seen from Table A1 that the water ballast tanks accounted for most of the 1.76 m reduction in GM calculated by the loading computer.

The largest free surface contributions were from No 2 Double Bottom Tank (DBT) (13,350 tm) and No 5 centre DBT (16,194 tm). It can also be seen that No 5 centre DBT tank was 98 per cent filled and the maximum free surface moment for this tank was used to calculate the departure GM(fluid).

However, at close to 100 per cent full, the fluid's surface cannot really be considered to be 'free' as there is a very small amount of space in the tank above the water level. It is therefore questionable whether the contribution of No 5 centre DBT should have been taken into account when calculating the free surface correction of the ship's GM.

If the FSE contribution of No 5 centre DBT is left out of consideration, then the free surface reduction of GM is closer to 1.0 m and not 1.76 m. Therefore, the ship's effective GM on departure Newcastle would then have been 3.4 m instead of 2.68 m.

A GM(fluid) of 3.4 m means the natural roll period of the ship on departure Newcastle was probably closer to 10 seconds than the 12 seconds as calculated by the loading/stability computer (Figure A2). This roll period is much closer to the 9 or 10 second peak wave encounter period measured by the Point Lookout wave buoy (Figure 8) and could explain the severe and sometimes violent rolling motions experienced by the ship.

Altering the ship's roll behaviour

Moving a ship's natural roll period away from the wave encounter period

Moving *Pacific Adventurer*'s natural roll period away from the wave encounter period would have required one of the following two actions:

- Sail into the waves at an increased speed, without risking damage to the ship from slamming, and thus reduce the wave encounter period, or
- Physically change the ship's natural roll period.

With regard to sailing into the waves and swell, this option would probably not have been seriously considered by the master as it would have taken the ship into the predicted path of the cyclone. In addition, it is likely that the speed required to alter the wave encounter period significantly would have resulted in a high engine load and wave loading over the bow (pounding/slamming).

In addition, the crew did not know with any degree of accuracy what the peak wave periods were in various locations as they encountered the progressively deteriorating conditions. As the ship moved up the Queensland coast, it was dark and progressively more windy, making observation of specific wave characteristics difficult. Consequently, estimating the ship's natural roll period with respect to the wave encounter period, even if the crew had considered this course of action, would have been practically impossible.

Altering the natural roll period of the ship was therefore the most suitable means to minimise the rolling motions.

This option was listed in the voyage risk assessment. However, the risk assessment statement 'minimise GM to reduce rolling period' was confusing as the objective of minimising a ship's GM is to 'increase its roll period'. Had the statement read 'minimise GM to reduce rolling', it might have been better understood and the ship's GM reduced to increase the ship's natural roll period.

The natural roll period of a ship is determined mainly by its metacentric height (the distance between centre of gravity and meta-centre, i.e. its GM and its 'roll moment of inertia'; often estimated using 40 per cent of a ship's beam as its dynamic roll radius of gyration (k)[39].

39 Defined as the square root of the ratio of the moment of inertia of a body about a given axis to its mass.

The natural roll period of the ship (T_{roll}) can be calculated using the following formula:

$$T_{roll} \cong 2\pi 0.4B/\sqrt{gGM}$$

(where B is the ship's beam and g is the acceleration due to the earth's gravity)

This formula shows that only a reduction in the GM could change the ship's natural roll period, as all the other values are constant.

For ships like *Pacific Adventurer*, moving cargo either towards the end of, or after, cargo operations, to minimise its GM while the ship is alongside or when the ship is moving in heavy seas is not a viable option. Therefore, the management of water ballast remained the only feasible way to reduce the ship's GM.

The effect of ballast and free surface on GM and natural roll period

With usual swell wave periods being around 5 to 10 seconds, the typical approach to reduce roll motions, either actual or expected, is to reduce a ship's GM as much as possible, while staying within defined safety limits, to achieve a natural roll period well above 10 seconds. This can be achieved by adding, discharging or shifting water ballast and/or, when possible, changing cargo weight and/or position.

However, the options available to a ship's crew to reduce stability are limited by the need to ensure its safety against capsizing and for the stability to remain inside specific requirements before the ship proceeds to sea.

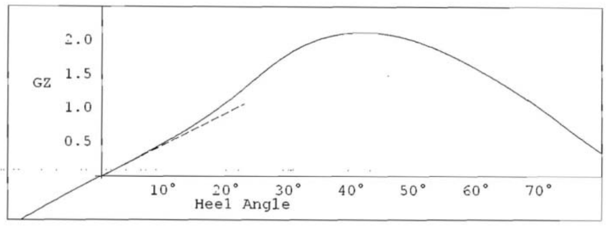
Pacific Adventurer's ballast condition on departure from Newcastle (Table 3) was selected to minimise GM, while staying inside the overall stability safety requirements. This included No 5 centre DBT being 98 per cent full. The loading computer output (Figure A3) indicates that seagoing stability requirements were met with ease. Therefore, the $GM_{(fluid)}$ could have been reduced further and the ship still would have been within stability requirements. The same would have applied if the actual departure $GM_{(fluid)}$ was greater than the calculated 2.69 m, as discussed earlier in this appendix.

The easiest way to reduce *Pacific Adventurer*'s GM was to raise the ship's centre of gravity. This could not be achieved by adding ballast water as adding ballast water would have lowered the centre of gravity. With cargo already loaded and in place, this could only have been achieved by reducing the amount of water ballast in the lowest water ballast tanks.

Whether this was actually practical is more difficult to say. *Pacific Adventurer*'s largest water ballast tanks were located in its double bottom. Removing a large quantity of water ballast would have reduced the draught of the already relatively lightly loaded ship and probably resulted in problems due to propeller immersion and slamming forward.

Figure A3: ***Pacific Adventurer*’s departure stability printout**

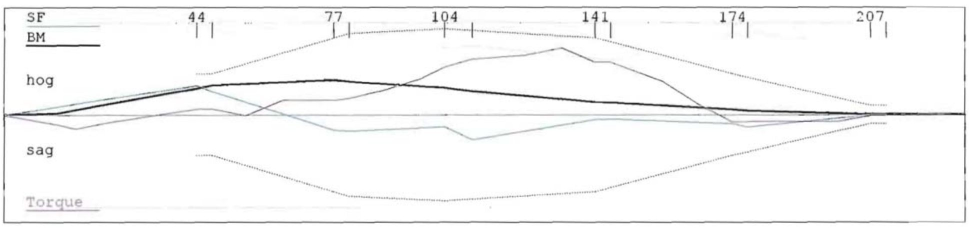
```
  2453.3t WATER BALLAST                        019 N
  1163.0t HEAVY FUEL OIL                       NTL
    80.5t DIESEL OIL                           09/03/09
   203.0t FRESH WATER                          NEWCASTLE
    62.5t LUBRICATING OIL                      File c:\program files\seamaster for changsha(20 ju
     0.0t MISCELLANEOUS                        Serial No SB298.686 © 20 July 2006
     0.0t VOID SPACES
   450.0t USER-DEFINED DWT
  9651.7t DECK/BREAK CARGO
  2231.9t CONTAINER CARGO:   1128.9 ON DECK & 1103.0t BELOW DECK
 25690.9t CALCULATED DISPLACEMENT       Water Density = 1.025 t/cu.m

TRIM & STABILITY (m)                    AREAS UNDER GZ-CURVE (m.rad)
Draft at FP     7.779                    0.0 - 30.0°  0.432 (min 0.055)
Draft at AP     8.615 (min 6.92)         0.0 - 40.0°  0.782 (min  0.09 )
Midship Draft   8.197 (Summer=10.588)   30.0 - 40.0°  0.350 (min 0.03)
Equiv Draft     8.208                   Peak GZ       2.12m (min 0.2 m)
Trim            0.836                   Occurs at 42° (over 25° required)
Propeller         75% immersion         Deck edge immersion at 25.2°
KM             11.826                   Down Flooding at 46°
VCG             7.385                   51.4 kg/m² WIND & 17.9° ROLL (IMO A.749)
GM (solid)      4.441                   Steady Wind Heel  1.5°(max 16.0°)
FS correction   1.756 (calibrated)      Area Ratio "b/a" 5.99 (min 1.0) to 45.9°
GM (fluid)      2.685 (min 0.15)
Static Heel       0.0° (port)

Air Draft       35.44
LCG             86.236
MCTM            350 tm/cm
Visibility     187m Ahead of Bow

Deck Stowage:  SHIP cranes
```



Strength for SEAGOING — **Permissible Condition**

Frame	Dist from AP	Shear Force (tonnes) Actual	Permissible	%	Bending Moment (1000 t.m) Actual	Permissible	%	Torque %
44	32.7	1314	3947	33	29.0	45.0	64	7
48	35.7	1055	3803	28	32.5	45.0	**72**	7
77	59.2	-640	2664	-24	38.4	85.0	45	16
81	62.1	-696	2708	-26	36.5	90.0	41	19
104	80.6	-499	2980	-17	29.9	95.0	31	53
111	85.9	-1079	3058	**-35**	25.7	93.2	28	61
141	109.6	-187	2489	-8	13.6	85.0	16	57
145	112.5	-182	2418	-8	13.2	80.5	16	57
174	136.0	-378	3505	-11	5.5	45.0	12	-8
178	139.0	-519	3642	-14	4.1	41.1	10	-7
207	162.5	4	3022	0	0.2	10.0	2	0
211	165.4	30	2944	1	0.2	10.0	2	0

Worst Torque: 3285t.m = 73% of 4500 Permissible at Frame 133



However, the free surface of the water ballast could have been used by the crew to their advantage. Using this factor, they may have been able to effectively lower the GM(fluid), and hence reduce the rolling of the ship, by increasing the FSE.

If the observation[40] made earlier about the contribution of No 5 centre DBT in the FSE calculation is correct, then *Pacific Adventurer*’s severe rolling motions could probably have been reduced significantly. This could have been brought about by reducing the amount of water ballast in No 5 centre DBT, from 98 percent full (690 tonnes) to, for example, 80 per cent full (563 tonnes). This would have resulted in a negligible reduction of about 3 cm in the ship’s after draught and would have meant

40 This observation is based on overview of information provided by the ship’s loading computer printout.

that the ship's actual condition would have been a more accurate match to that calculated by the Seamaster loading/stability program.

This appendix has highlighted the issue of shipboard loading/stability programs applying a free surface correction to a ship's $GM_{(solid)}$ using the FSE of tanks, some of which might be almost 100 per cent full. The fluid in these tanks cannot be considered to be 'free' and the inclusion of the FSE of these tanks in the stability calculations for a ship will probably result in the calculated $GM_{(fluid)}$ being different from the actual $GM_{(fluid)}$.

Consequently, ship crews need to be aware that the resultant calculated roll period of a ship will probably be different to the actual roll period. Furthermore, a small reduction in the level of fluid in those almost full tanks might have a beneficial result on a ship's movement on a seaway and the actual condition of a ship might more accurately match that given by the loading/stability program.

Roll excitation force/load amplitude reduction

Without calculations or model tests, the actual roll behaviour of *Pacific Adventurer* at the time the containers were lost cannot be reproduced. While the ship's natural roll period could have been changed by a small reduction in the water ballast, the option was not attempted.

However, the effects of the synchronous roll motions on 10/11 March could have been altered en route by reducing the amplitude of the roll excitation force/load.

Roll excitation force/load acting on a ship is typically reduced by changing its heading such that waves are taken on the bow or stern. As a result of this change, pitching motions are excited instead of roll motions.

While *Pacific Adventurer*'s master did order the ship's heading changed, it was mostly around the northerly course needed to get to Brisbane. At no time did he change the ship's heading to head into the swells, which were predominately coming from the east.

His decision not to do this was probably because he was endeavouring to get the ship to the Brisbane pilot boarding ground on time. Changing course to head into the easterly swells would have taken the ship away from its destination. Furthermore, he was not entirely sure about the actual direction of the swells (he believed the sea conditions were confused) and he was not aware of how the vessel would respond if he altered course into the swells.

Estimating roll angles

Estimates of *Pacific Adventurer*'s roll angles provided by the master, the second mate and as recorded in the ship's deck log book, varied from 30° to 45° in the lead up to the loss of the containers and in the hour afterwards. These roll angles were either estimated by the crew members themselves or were the result of readings provided by the bridge mounted inclinometer.

Part of a report on the *Pacific Adventurer* incident, commissioned by Maritime Safety Queensland (MSQ) from the Scottish marine consultancy company Safety at Sea Limited, discussed the issue of crew members and inclinometers on bridges overestimating the angles to which a ship rolls in a seaway.

This was further highlighted by Safety at Sea, on behalf of MSQ, in their submission on the draft ATSB safety report:

> When a vessel moves in a seaway, the bridge will be inclined as the vessel rolls but [it] will also experience transverse accelerations. As the bridge is situated at an elevated position on the vessel and she was experiencing a significant degree of roll the primary cause of the transverse acceleration will be due to this mode of motion. A secondary cause of horizontal acceleration will be due to the transverse and vertical movement of the vessel as she moves in the seaway.
>
> Transverse accelerations will cause any free-hanging objects (such as the needle on an inclinometer) to swing considerably further than the actual angle of roll. Any other loose objects on the bridge will slide at angles considerably lower than if the vessel was held still at constant angle of heel. Crew members will experience a horizontal force (causing them to either lean towards the inclined deck or hold on to a support) of magnitude much larger than would be expected from the inclination of the deck alone. Without a measure of vessel roll which is unaffected by transverse accelerations (such as a view of the horizon or special instrumentation), it would be impossible for an observer on the bridge to be able to distinguish a correct angle of heel and would be likely to overestimate this value considerably. This is particularly true in the case of the *Pacific Adventurer* which was experiencing significant roll with a relatively short period.
>
> Taking into account the horizontal acceleration caused by the roll motion, the reading that an inclinometer will read on the bridge can be calculated.... Using the ATSB's figures for natural roll period, and assuming the inclinometer is 1 meter above the bridge deck, the actual roll based on an inclinometer reading of 40 degrees [can be calculated to be] 27.9 degrees.
>
> Based on our sea keeping analysis, in the worse case, [I] would expect the transverse accelerations on the bridge to cause the inclinometer to read a maximum of 30 degrees at the time of the incident. If the 2nd mate was relying on other visual information, such how far he (or others) needed to lean into the slope to stay balanced, this could have been overestimated as 40 degrees as reported.

Regardless of the actual degree that *Pacific Adventurer* rolled when the containers were lost, the forces induced by the ship's rolling motions were significant enough to result in the failure of the containers and their lashings, particularly those lashings which were in poor condition.

APPENDIX B: LASHING EQUIPMENT EXAMINATIONS

Brookes Bell were commissioned by MSQ to undertake visual and metallurgical examinations on sample pieces of *Pacific Adventurer*'s lashing equipment (twistlocks, turnbuckles and lashing rods) to determine their condition. Their final report was extensive and contained a great deal of data from the tests undertaken on the sample pieces of equipment.

A summary of the visual inspections was:

Twistlocks:

Most of the twistlocks inspected exhibited significant corrosion and wastage and the majority of the cones were loose fitting because of wastage. In some instances, the locking lever was heavily deformed and wasted and the cones could not be rotated into the closed position; as such, these items could not have functioned correctly.

Turnbuckles:

In most instances, the jaw and box frame body areas of the turnbuckles exhibited significant corrosion. Most of the turnbuckle hooks had heavily corroded, resulting in a substantial reduction in thickness in way of the hook. Of the samples that were tested, only the corroded and wasted turnbuckle hooks had failed.

Lashing Rods:

The eye and bar of the lashing rods exhibited corrosion but did not appear to exhibit significant wastage. However, in most instances, the securing hook and hinge pin were heavily corroded and wasted.

As a result of the testing, Brookes Bell concluded that:

1. The results of the chemical analysis, micro-structural examination and mechanical testing indicated that the cargo securing equipment (CSE) provided for investigation were likely to have been suitable for their intended purpose at the time of manufacture.

2. Visual inspection and dimensional verification of the samples revealed that most items of CSE provided for inspection exhibited substantial wastage. One of the turnbuckle hooks was measured and compared to a new hook, which revealed that the cross-sectional area in this region had reduced by 64%. The corrosion and wear observed on the twistlocks had resulted in the locking mechanism not working properly in some instances.

3. In consideration of the extent of wastage, and the typical rates of corrosion of low alloy steel in seawater, I believe that some of the turnbuckles may have been in use for at least 10 years or even longer and should have been replaced much sooner.

4. The extent of corrosion and consequential wastage observed in some of the CSE samples significantly reduced their strength. Indeed, one of the wasted turnbuckle samples failed significantly below its safe working load when tested. The normal in-service loads experienced by the wasted CSE could have resulted in the onset of final failure mechanisms such as stress corrosion cracking (SCC) or corrosion fatigue.

5. In any event, the main contributory factor to failure of CSE was the extent of wastage, regardless of whether some of the CSE items failed by mechanisms such as SCC or corrosion fatigue; these final failure mechanisms would have been more likely to have occurred because of increased stress on the reduced cross-sectional area of material. That said, there was no clear evidence of corrosion fatigue or SCC found during testing at Sheffield Testing Laboratories.

6. In CSE items such as the twistlocks, if the extent of corrosion found during the investigation at Sheffield Testing Laboratories was representative of the condition of many of the other twistlocks, then this would have been likely to have resulted in the locking mechanism not working properly in those items.

Similarly, Safety at Sea also conducted tests and their conclusions were:

1. Based on the finite element analysis[41], we would conclude that the breaking load of the corroded turnbuckle hook is between 19 and 20 tonnes. This is significantly below the intended breaking load of 46 tonnes. This is under the assumption that the corroded turnbuckle hook has the same surface quality (in terms of surface defects) as the un-corroded turnbuckle hook. Any cracks or pitting caused by corrosion can potentially significantly reduce this figure.

2. Loads calculated in the turnbuckle hooks were estimated to be between 6 and 15 tonnes which is below the 19-20 tonnes calculated for the breaking load for the corroded turnbuckle hook. The presence of surface defects in the corroded turnbuckle hook (not accounted for in the FE analysis) could have lowered the breaking strain of the turnbuckle hook sufficient for it to break. The lashing loads calculated in this analysis are significantly lower than the breaking load of a sound turnbuckle hook (46 tonnes). This would indicate that it was almost impossible for a sound turnbuckle hook to have failed under the conditions the vessel was experiencing at the time of the incident.

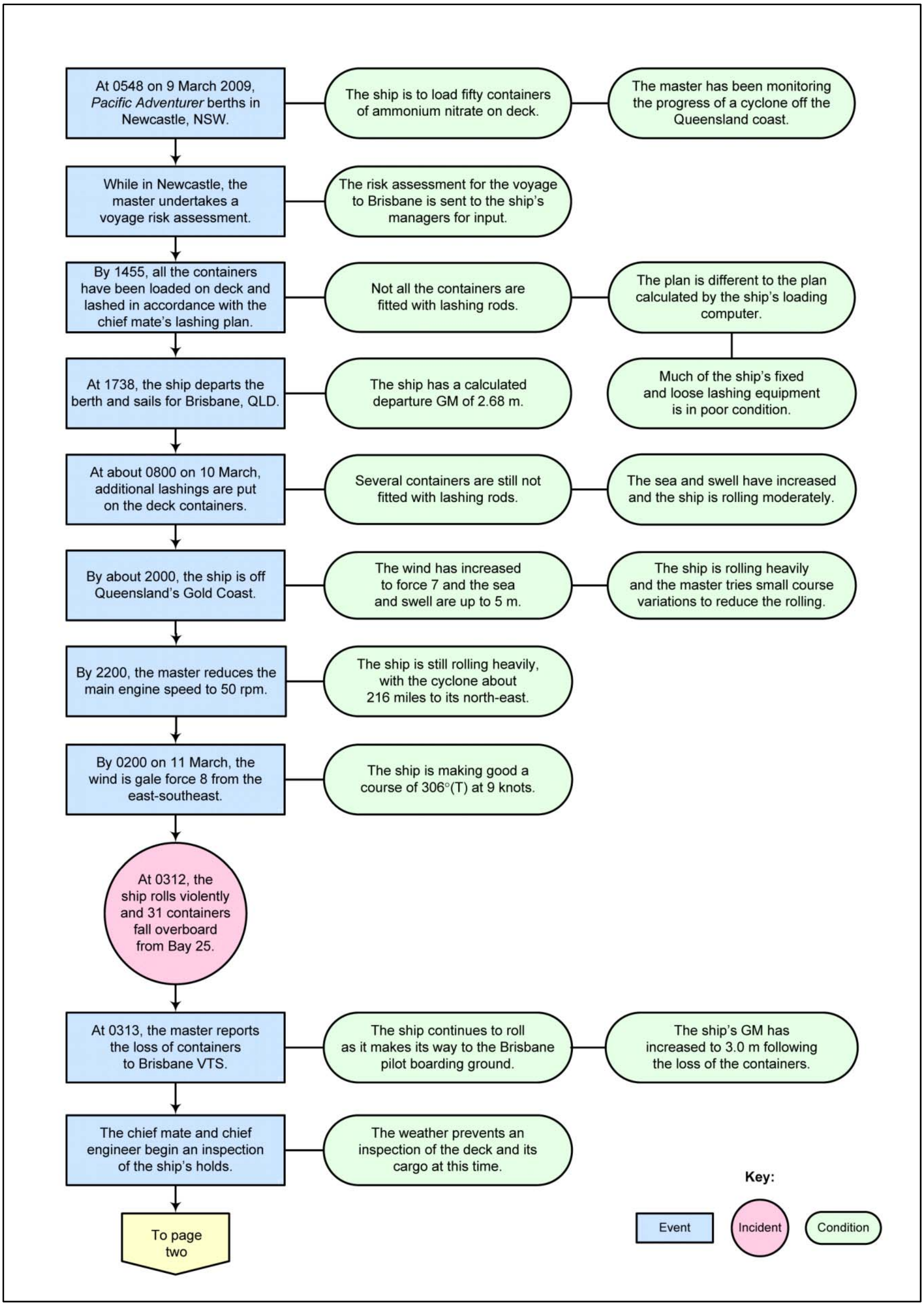
3. The maximum expected pull out loads on the twist locks were expected to be approximately 27 tonnes which is around the SWL of the twist lock and is less than the 50 tonnes they were certified for. Note that we would expect the seating arrangement to be designed for a similar pull out load (50 tonnes). This would indicate that a sound twist lock and seating should not have failed under the conditions the vessel was experiencing at the time of the incident.

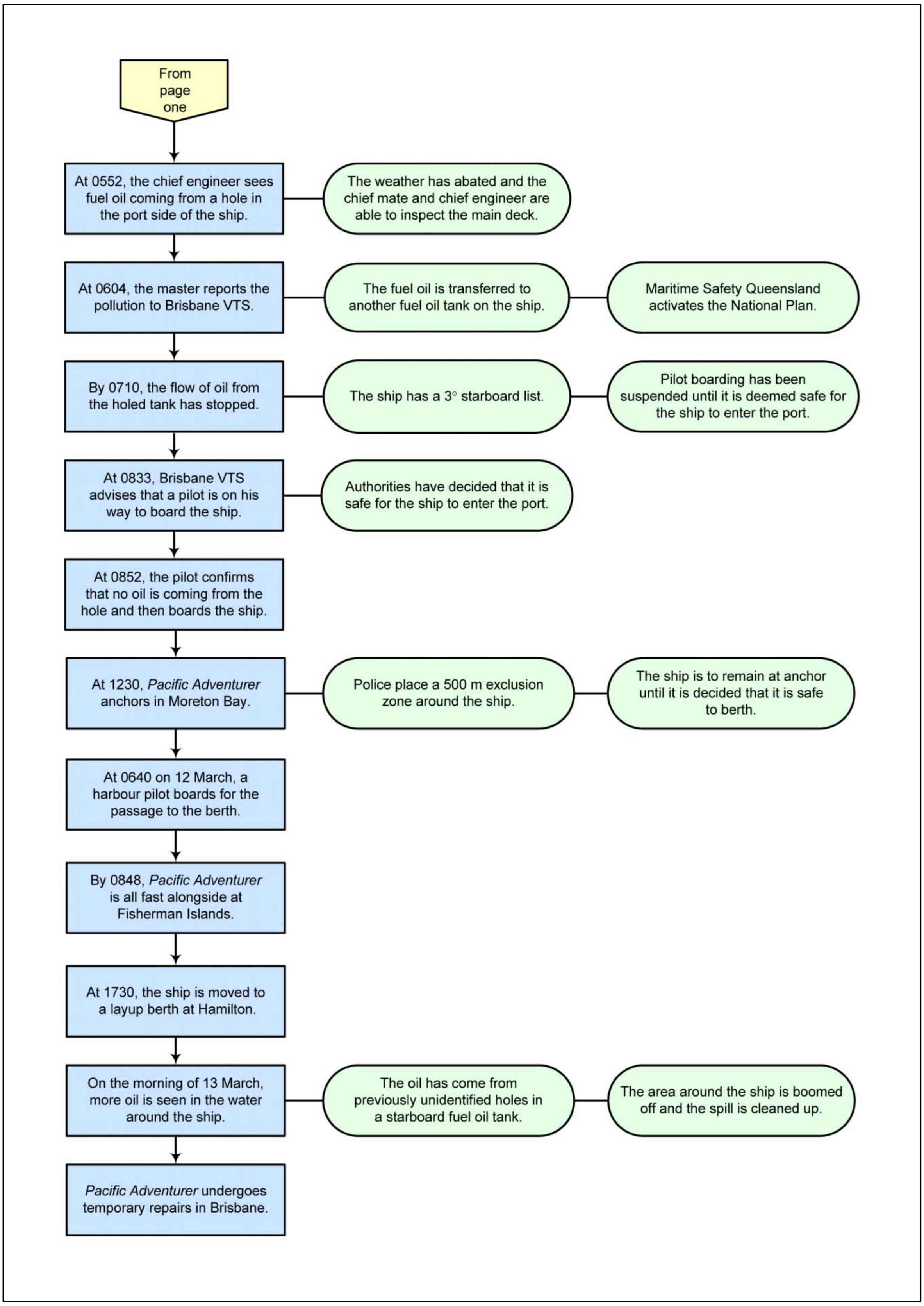
4. The analysis on the twist locks indicates that both before and after the failure of the turnbuckle hook, the loads were sufficiently high to lift the twist locks from corroded seating. Obviously we would expect a container with no lashing rods in place or twist locks would experience significant movement and potentially be lost overboard.

5. Given the above discussion regarding the twist locks and turnbuckle hooks we would conclude that had the lashing gear been in a sound condition, the containers would not have been lost over the side of the vessel. The failure of the lashing gear can be directly attributed to the high levels of corrosion seen during inspection.

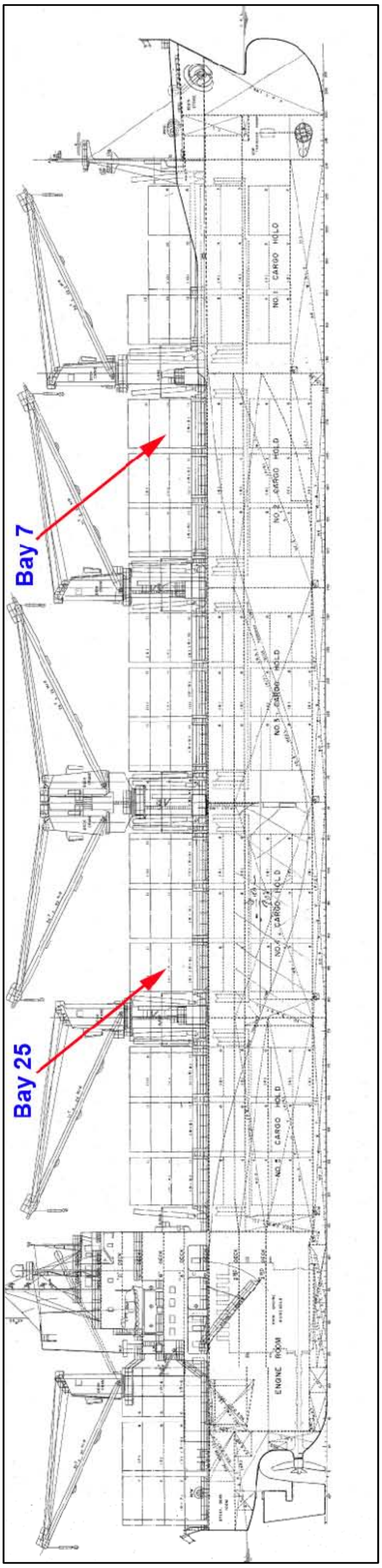
41 A mathematical technique for analysing stress, which breaks down a physical structure into substructures called 'finite elements'. The finite elements and their interrelationships are converted into equation form and solved mathematically.

APPENDIX C: EVENTS AND CONDITIONS CHART




From page one
At 0552, the chief engineer sees fuel oil coming from a hole in the port side of the ship.
The weather has abated and the chief mate and chief engineer are able to inspect the main deck.
At 0604, the master reports the pollution to Brisbane VTS.
The fuel oil is transferred to another fuel oil tank on the ship.
Maritime Safety Queensland activates the National Plan.
By 0710, the flow of oil from the holed tank has stopped.
The ship has a 3° starboard list.
Pilot boarding has been suspended until it is deemed safe for the ship to enter the port.
At 0833, Brisbane VTS advises that a pilot is on his way to board the ship.
Authorities have decided that it is safe for the ship to enter the port.
At 0852, the pilot confirms that no oil is coming from the hole and then boards the ship.
At 1230, *Pacific Adventurer* anchors in Moreton Bay.
Police place a 500 m exclusion zone around the ship.
The ship is to remain at anchor until it is decided that it is safe to berth.
At 0640 on 12 March, a harbour pilot boards for the passage to the berth.
By 0848, *Pacific Adventurer* is all fast alongside at Fisherman Islands.
At 1730, the ship is moved to a layup berth at Hamilton.
On the morning of 13 March, more oil is seen in the water around the ship.
The oil has come from previously unidentified holes in a starboard fuel oil tank.
The area around the ship is boomed off and the spill is cleaned up.
Pacific Adventurer undergoes temporary repairs in Brisbane.

APPENDIX D: PACIFIC ADVENTURER PLAN



APPENDIX E: SHIP INFORMATION

Pacific Adventurer

IMO Number	9003847
Call sign	VRWS3
Flag	Hong Kong SAR
Port of Registry	Hong Kong
Classification society	Lloyd’s register (LR)
Ship Type	Geared, multi-purpose container ship
Builder	Minami Nippon Shipbuilding, Japan
Year built	1991
Owners	Swire Navigation/Bluewind Shipping, Hong Kong
Ship managers	Swire Navigation, Hong Kong
Gross tonnage	18,391
Net tonnage	9,229
Deadweight (summer)	25,561 tonnes
Summer draught	10.57 m
Length overall	184.9 m
Length between perpendiculars	176.0 m
Moulded breadth	27.6 m
Moulded depth	14.7 m
Engine	Kobe Diesel 8UEC60LS
Total power	14 123 kW
Speed	18.5
Crew	27

APPENDIX F: SOURCES AND SUBMISSIONS

Sources of information

Master, crew and managers of *Pacific Adventurer*

Maritime Safety Queensland

Orica Australia

Queensland Department of Environment and Resource Management

The Australian Maritime Safety Authority

The Maritime Research Institute, Netherlands (MARIN)

References

Australasian Institute of Marine Surveyors newsletter, April 2004

Australian Maritime Safety Authority. *Port/Flag State Control – Focused Inspection Campaign.* Marine Notice 2/2010

Barrass, Dr C. B. (2001). *Ship stability – notes and examples*. Kemp & Young, 3rd edition.

Biran, A. (2007). *Ship Hydrostatics and Stability*. Butterworth Heinemann, Oxford

Clark, I. (2005). *Ship dynamics for mariners*. The Nautical Institute, London

Dodworth, K. (2010). *Report for Maritime Safety Queensland on Pacific Adventurer – Vessel motion and container strength analysis*. Safety at Sea, Glasgow. 7 May, 2010

Hong Kong Marine Department. *Hong Kong Merchant Shipping Information Note No. 13/2007*. Hong Kong, 12 February 2007

International Maritime Organization. *Revised guidance to the master for avoiding dangerous situations in adverse weather and sea conditions*. London, 11 January 2007

Keenor, M. and Luukas, R. (2010). *Report for Maritime Safety Queensland on Pacific Adventurer – Loss of containers and fuel oil spillage, 11 March 2009*. Brookes Bell, Liverpool. 7 May, 2010

Lloyd's Register/The Standard P&I Club. (2006). *A master's guide to container securing*. London

Maritime Research Institute Netherlands (MARIN). (2009). *23977-1-TM Report for the ATSB on the Pacific Adventurer Incident, 11 March 2009 – MARIN assessment of relevant factors*

Maritime Research Institute Netherlands (MARIN). (2010). *Lashing@Sea project report*

Pepper, Captain G.M. (2008). *Thomas' Stowage – The properties and stowage of cargoes*. Brown, Son & Ferguson Ltd, Glasgow. 5th edition

The Mariner's Handbook (NP 100). The United Kingdom Hydrographic Office. Eighth edition, 2004.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003*, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report

A draft of this report was provided to the master, the chief mate, the second mate and the chief engineer of *Pacific Adventurer*, Swire Navigation, the Australian Maritime Safety Authority (AMSA), Maritime Safety Queensland (MSQ), Orica Australia, the Marine Department of the Hong Kong SAR (MARDEP), Lloyds Register (LR) and the Maritime Research Institute Netherlands (MARIN).

Submissions were received from the master, the second mate and the chief engineer of *Pacific Adventurer*, Swire Navigation, AMSA, MSQ, Orica Australia, MARDEP and MARIN. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

Independent investigation into the loss of containers from the Hong Kong registered container ship *Pacific Adventurer* off Cape Moreton, Queensland on 11 March 2009.