Inquiry 09-210: Bulk carrier, Taharoa Express, cargo shift, Port Taharoa, 16 December 2009

Final Report

Marine inquiry 09-210
Bulk carrier, Taharoa Express, cargo shift
Port Taharoa, 16 December 2009

Approved for publication: November 2013

Transport Accident Investigation Commission

About the Transport Accident Investigation Commission

The Transport Accident Investigation Commission (Commission) is an independent Crown entity responsible for inquiring into maritime, aviation and rail accidents and incidents for New Zealand, and co-ordinating and co-operating with other accident investigation organisations overseas. The principal purpose of its inquiries is to determine the circumstances and causes of occurrences with a view to avoiding similar occurrences in the future. Its purpose is not to ascribe blame to any person or agency or to pursue (or to assist an agency to pursue) criminal, civil or regulatory action against a person or agency. The Commission carries out its purpose by informing members of the transport sector, both domestically and internationally, of the lessons that can be learnt from transport accidents and incidents.

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Citations and referencing

Information derived from interviews during the Commission's inquiry into the occurrence is not cited in this final report. Documents that would normally be accessible to industry participants only and not discoverable under the Official Information Act 1980 have been referenced as footnotes only. Other documents referred to during the Commission's inquiry that are publicly available are cited.

Photographs, diagrams, pictures

Unless otherwise specified, photographs, diagrams and pictures included in this final report are provided by, and owned by, the Commission.

The *Taharoa Express* anchored at Tasman Bay

Contents

Figures

Table

Abbreviations

°	degree
Class NK	Nippon Kaiji Kyokai (classification society)
Commission	Transport Accident Investigation Commission
ESP	enhanced survey programme
GM	broad measure of the stability of a ship
IMO	International Maritime Organization
kW	kilowatt(s)
m	metre(s)
MetService	Metrological Service of New Zealand
nm	nautical mile(s)
NS* (Bulk Carrier) (ESP)MNS	ship constructed to Class NK Rules, ship type, ship applies enhanced survey programme for bulk carriers and tankers, main propulsion machinery built to Class NK Rules
NYK	Nippon Yusen Kaisha Line
NZSL	New Zealand Steel Limited
SBM	single buoy mooring
SOLAS	International Convention for the Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

Glossary

aft	near or facing towards the stern of a ship
ballast	any mass placed in a ship to improve stability (usually sea water)
bilge	space for the collection of surplus liquid
corrugated bulkhead	corrugated steel partition between adjacent cargo holds on a bulk carrier
de-ballast	remove ballast from a ship in order to increase its buoyancy
de-cant	remove supernatant water from on top of ironsand within a ship's cargo holds
de-water	physically remove water from ironsand within a ship's cargo holds
free-water or supernatant water	the liquid lying above ironsand after the sand has settled out of the slurry to the bottom of a cargo hold
fwd or forward	near or facing towards the bow of a ship
half roll amplitude	the angle to which a ship heels during roll motion
heel	transverse inclination of a ship owing to external forces such as wind pressure and wave action
ironsand	iron-bearing granular sand material that is mined at the New Zealand Steel Limited Taharoa site
ironsand slurry	ironsand and fresh water mixed in equal proportion by weight
knot	one nautical mile per hour
liquefaction (ironsand)	total loss of inter-particle frictional strength allowing ironsand to flow like a liquid
list	transverse inclination of a ship owing to the disposition of internal weights
metacentre	the point at which a vertical line passing through the heeled centre of buoyancy intersects with the vertical line passing through the original upright centre of buoyancy. The metacentre can be considered as being similar to a pivot point when a ship is inclined at small angles of heel
metacentric height	the distance between the centre of gravity of a vessel (G) and the metacentre (M) is known as the metacentric height (GM). A stable vessel when upright is said to have a positive GM, i.e. when the M is found to be above the G. This is usually referred to as having a positive GM or a positive initial stability
nautical mile	a unit of length equal to 1852 metres
port	the left side of a ship when seen by an observer on-board, facing the ship's bow

roll	the rotation of a ship about its longitudinal axis
roll period	the time period taken to complete a single roll motion
shear	alteration in the shape or dimensions of a substance as a result of the application of stress to it
shear strength	the degree to which a material or bond is able to resist shear
significant wave height	the average height of the maximum third of waves observed during a given period of time
single buoy mooring	a single floating chamber moored offshore where ships can dock and load or unload their cargo
sloshing	movement of liquid actively within a container.
sounding	measure of the depth of a liquid.
starboard	the right side of a ship when seen by an observer on-board, facing the ship's bow
stern	the rear end of a ship
supernatant water	free-water
swell	a long wave on water that moves continuously without breaking.
trimming	levelling of cargo within a cargo hold
ullage	a measure of the height above the contents in a large tank or hold.
weather-deck	the uppermost continuous deck exposed to the weather.

Data summary

Vehicle particulars

Name:	*Taharoa Express*
Type:	bulk carrier
Class:	Class NK (Nippon Kaiji Kyokai)
Limits:	SOLAS ship
Classification:	NK, NS* "Bulk Carrier strengthened for heavy cargoes, Hold Number 2,4,6 and 8 may be empty" MNS*, MO
Length:	269.53 metres
Breadth (moulded):	43 metres
Gross tonnage:	74 364 tonnes
Built:	1990, Hyundai Heavy Industries Company Limited, Ulsan, South Korea
Propulsion:	one direct-drive reversible crosshead diesel engine: Hyundai B&W 5S70MC Maximum Continuous Rating: 15 370 brake horse power at 78 revolutions per minute through a fixed pitch, 4-bladed, 8.2-metre-diameter propeller
Service speed:	14 knots
Owner/operator:	Arafura Shipping Inc. Liberia/NYK Shipmanagement Pte Ltd
Port of registry:	Panama
Minimum crew:	23

Date and time 16 December 2009 at about 2230[1]

Location at the single buoy mooring, Port Taharoa

Injuries nil

Damage nil

[1] Times in this report are New Zealand Daylight Time (Co-ordinated Universal Time+13 hours), and are expressed in the 24-hour format.

1. Executive summary

1.1. At the time of this incident the *Taharoa Express* and the loading operation at Port Taharoa were unique. Iron ore (including ironsand) was normally loaded dry, with particular care needed to ensure that the cargo moisture content was below what was called its transportable moisture limit. The transportable moisture limit was the moisture level at which the cargo was said to be safe from liquefaction.

1.2. The *Taharoa Express* was a bulk carrier that had been modified to load ironsand in the form of a slurry. The ship moored to a single mooring buoy off the port. The ironsand was mixed with fresh water and pumped out to the ship via pipelines on the seabed.

1.3. Once the slurry entered the cargo hold the ironsand sank to the bottom, while fresh water was removed using 2 different on-board processes, eventually leaving just the ironsand in the hold.

1.4. The ship arrived at Port Taharoa on 15 December 2009 to load a cargo of about 116 000 tonnes of ironsand for delivery to China. The ironsand was to be loaded into 5 of the ship's 9 cargo holds in 7 phases.

1.5. The management of the *Taharoa Express* had recently changed and the crew appointed by the new management company were conducting their first cargo-loading operation at Port Taharoa.

1.6. Cargo loading was in its fifth phase when suddenly and without warning the ironsand in more than one cargo hold shifted and the ship listed to an angle of 5 degrees (°). Cargo loading was stopped, but by the time the cargo lines had been cleared of slurry the *Taharoa Express* had listed to an angle of 9°.

1.7. The Transport Accident Investigation Commission (Commission) determined that the most likely reason for the cargo shift in several holds was the ironsand being allowed to mound towards one side of the cargo hold's centreline instead of being evenly distributed across the holds. Once the slope of the cargo reached a critical angle, the cargo slumped across more than one of the cargo holds.

1.8. The most likely reason for the ironsand mounding in the cargo holds was that the crew had not achieved an even sequencing for the direction of the cargo-loading nozzles.

1.9. The Commission identified 3 safety issues:

- New Zealand Steel Limited had not undertaken sufficient research on the properties of the Taharoa ironsand and the way it behaved during the slurry loading process
- the crew on the *Taharoa Express* did not maintain an understanding of the ironsand distribution across each cargo hold, and did not trim the cargo evenly in accordance with the operating procedures and industry best practice
- all of the resources that were available to the new crew to manage the first cargo loading operation were not used to best effect, which resulted in the first mate becoming fatigued.

1.10. New Zealand Steel Limited has since addressed the first safety issue, and the remaining 2 safety issues have been addressed with the *Taharoa Express* being withdrawn from service and replaced by a new, special-purpose bulk carrier that has different loading procedures. The Commission has therefore made no safety recommendations.

1.11. The key lessons learnt from this incident included:

- it is important to ensure that bulk cargo in any form is well trimmed in the cargo hold to prevent it shifting during the loading process and when at sea
- in any ship loading operation, care should be taken to ensure that sufficient operational experience is available and used to ensure a safe and efficient operation.

2. Conduct of the inquiry

2.1. At about 0135 on 17 December 2009, the Commission was notified of an incident that had occurred with the ironsand bulk carrier, the *Taharoa Express,* at about 2230 the previous day while loading at Port Taharoa.

2.2. On 21 June 2007 the *Taharoa Express* had experienced a cargo shift and severe list while sailing to seek refuge in Tasman Bay from forecast severe weather. This incident had been investigated by the Commission and a range of safety recommendations made to the Director of Maritime Safety and the ship's Flag State of Panama. A report on this incident had been published by the Commission on 29 May 2009.

2.3. As the incident appeared to have some similarity with the previous investigation, involving the same ship, the Commission opened an inquiry under section 13(1) of the Transport Accident Investigation Commission Act 1990.

2.4. On 18 December 2009 the ship set sail from Port Taharoa to Tasman Bay.

2.5. Two investigators from the Commission travelled to Tasman Bay on 18 December 2009 and boarded the ship the next day. The master, ship manager and crew of the *Taharoa Express* were interviewed and the ship inspected.

2.6. The ship was again visited by an investigator on 23 December 2009 in Port Taharoa, to gather further evidence for the inquiry and conduct a second interview of the master and the crew.

2.7. Shortly after the incident New Zealand Steel Limited engaged engineering consultancy Tonkin and Taylor Limited to conduct a post-incident geotechnical stability assessment of the ironsand, including a review of the ironsand properties and how the ironsand behaved in the cargo holds of the *Taharoa Express* during the loading process. This study took about 19 months to complete.

2.8. The Commission engaged Rolando P Orense, a geotechnical expert and senior lecturer at the University of Auckland, to review the Tonkin and Taylor post-incident report and provide an independent assessment of the liquefaction resistance of ironsand.

2.9. The *Taharoa Express* loaded her last cargo on 8 May 2012 and was subsequently sold to a ship-scrapping company on 15 June 2012. A new, purpose-built ship, the *Taharoa Destiny,* is currently engaged in the transportation of ironsand from Port Taharoa.

2.10. On 20 November the Commission approved the final report for publication.

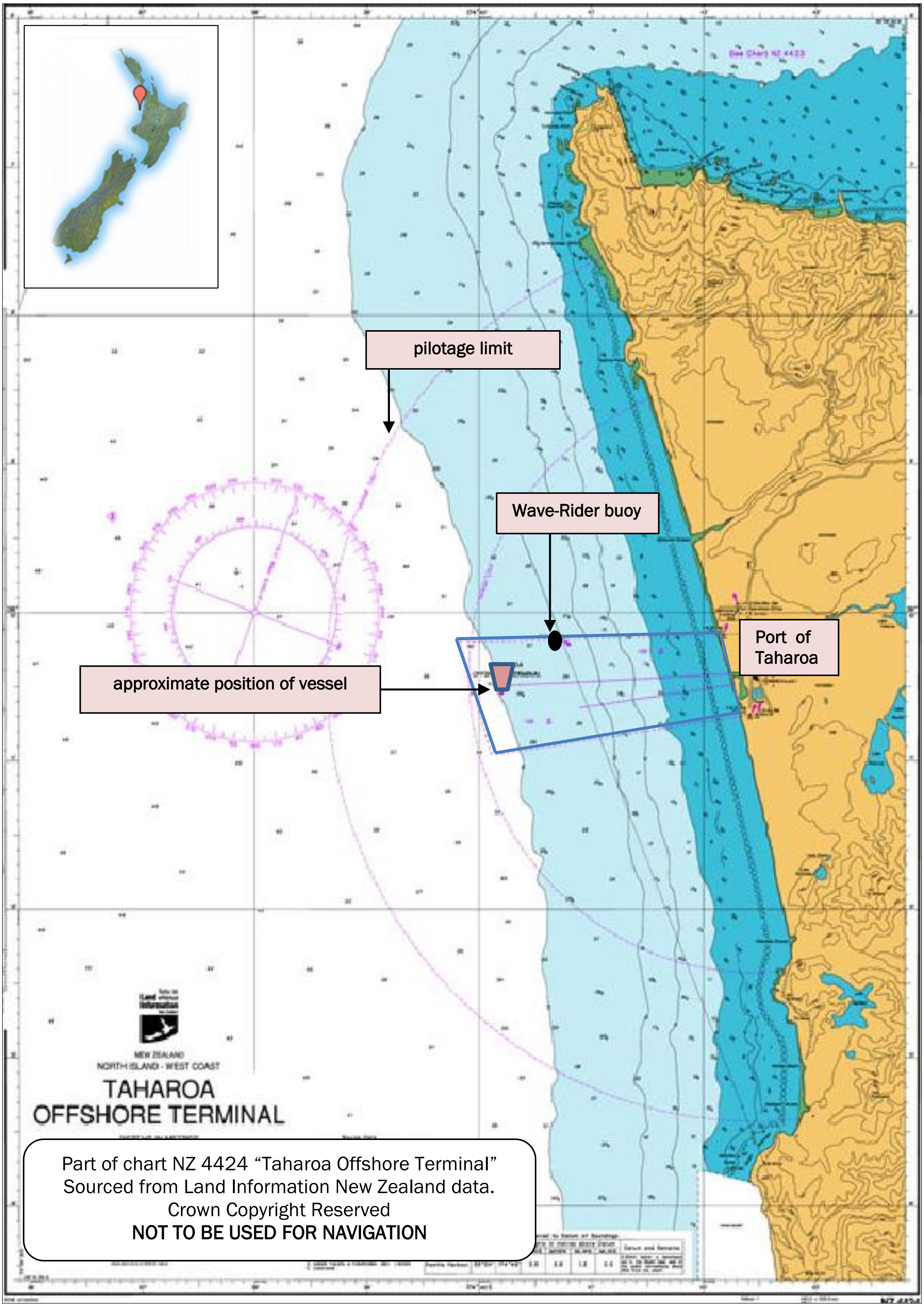

Figure 1
Chart of the general area

3. Factual information

3.1. Background Information

3.1.1. The *Taharoa Express* was launched on 28 August 1990 as the *Stellar Cape*. The ship was designed as a single-hull bulk carrier, specially strengthened for the carriage of heavy cargo in alternate hold numbers 1, 3, 5, 7 and 9[2].

3.1.2. In 1999 the *Stellar Cape* was converted to a specialised carrier capable of loading ironsand as slurry and renamed the *Taharoa Express*.

3.1.3. Port Taharoa was located on the west coast of New Zealand's North Island, about 20 kilometres southwest of Kawhia Harbour. Port Taharoa consisted of a single buoy mooring (the mooring buoy) anchored in approximately 30 metres of water and about 1.6 nautical miles offshore. The prevalent weather at Port Taharoa was westerly onto a lee shore. A Wave-Rider buoy was located about 500 metres northeast of the mooring and provided real-time wind and swell data to the ship and the terminal ashore (see Figure 1).

3.1.4. Ironsand was loaded as slurry by first mixing it with fresh water on a one-to-one ratio by weight. Slurry from the port terminal was pumped through pipelines along the seabed up through the mooring buoy and then through flexible hoses to a manifold on the ship's weather-deck.

3.1.5. From the manifold, 2500 tonnes per hour of slurry were directed to the cargo holds through 2 separate load-lines. Number 1 load-line was connected to numbers 1, 3 and 5 cargo hold nozzles, while Number 2 load-line was connected to numbers 5, 7 and 9 cargo hold nozzles (see Figure 4).

3.1.6. Once the slurry was in the hold, the ironsand quickly separated and settled to the bottom, while the "free-water" collected above the surface of the ironsand. The ship was not designed to carry ironsand as slurry while at sea, so the free-water had to be removed from the holds as the ship was loaded, and before the ship could put to sea.

3.1.7. The removal of free-water was completed in 2 stages: de-canting and de-watering.

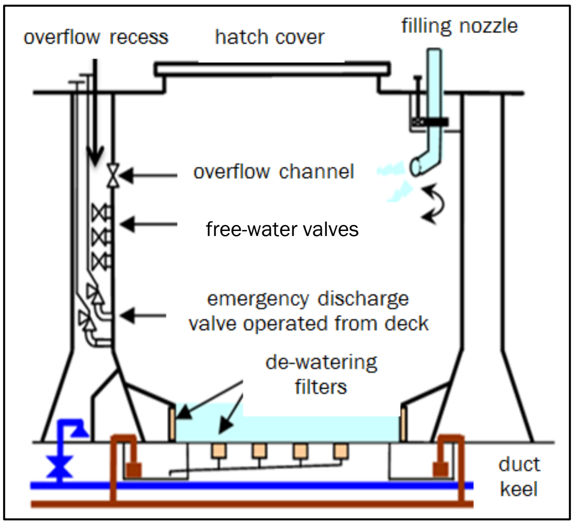

Figure 2
Longitudinal cross-section of a cargo hold

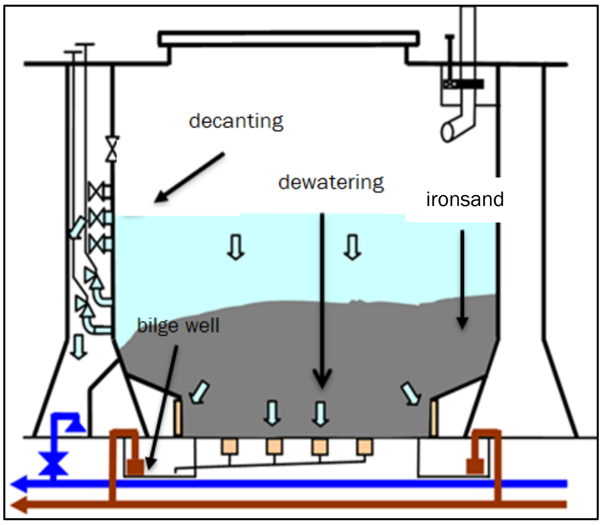

Figure 3
De-watering and de-canting processes

[2] Strengthened against shear force for when the even-numbered holds 2, 4, 6 and 8 remained empty.

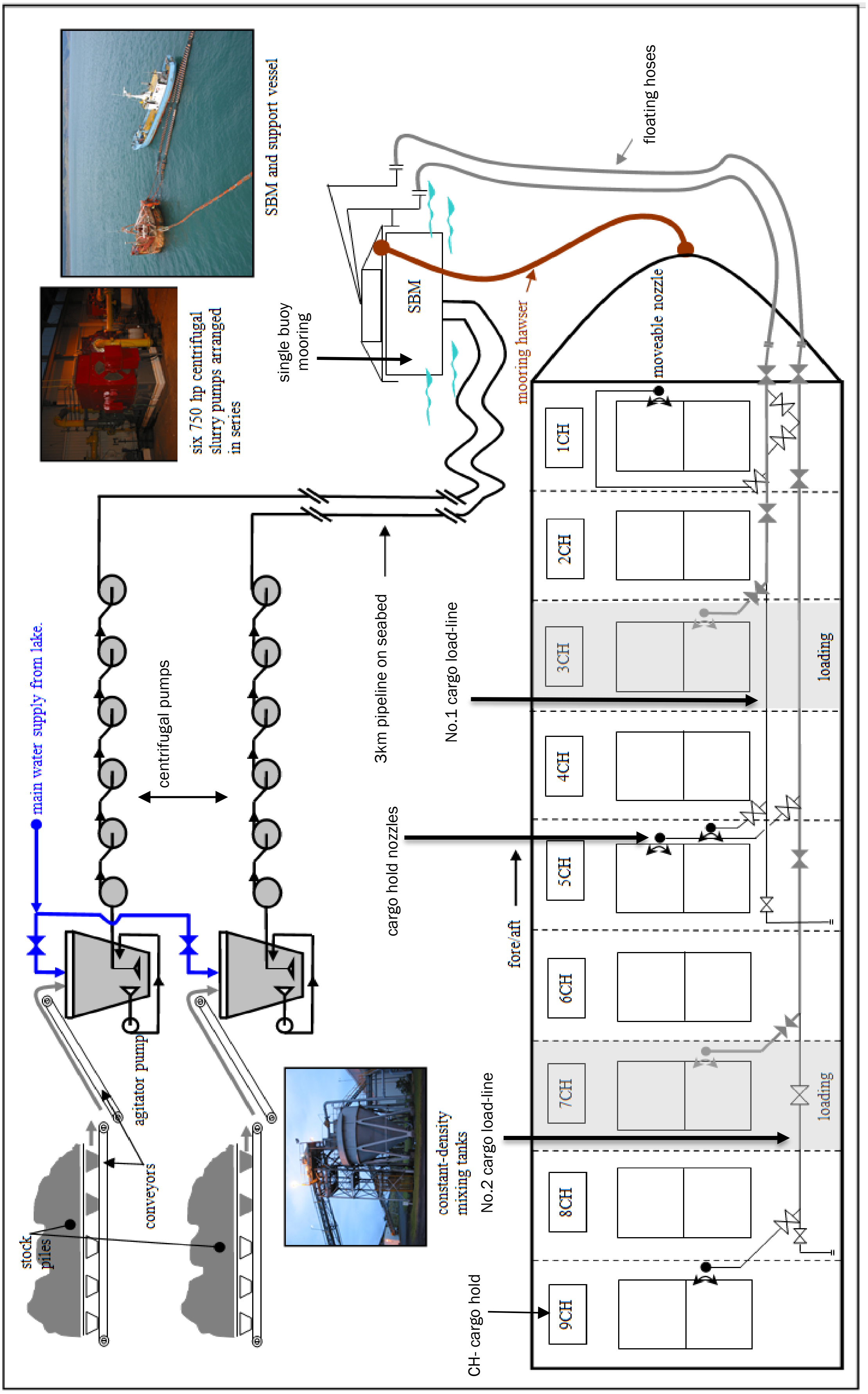

Figure 4
A simplified diagram of slurry loading from shore to ship

3.1.8. De-canting was a process where free-water was drained into an overflow recess located in the aft corrugated bulkhead of each cargo-carrying hold. Free-water could overflow into the recess space via a series of valves and an overflow channel set at various heights in the aft (rear) bulkhead. As the level of ironsand rose in the hold, the lower valves were closed to avoid sand entering the recess space (see Figure 2).

3.1.9. The water in the overflow recess was pumped overboard using 2 overflow pumps located in the ship's pump room. Once free-water was removed through the de-canting process, the water trapped within the sand permeated to the bottom of the hold. Each cargo hold contained a set of stainless steel mesh filters, fitted across the forward and aft ends of the hold. These filters prevented the passage of ironsand but allowed water to flow into bilge wells in each corner of the cargo hold. This process of draining trapped water within the ironsand was called de-watering. The water in the bilge wells was pumped out using the ship's bilge pumping system (see Figure 3).

3.1.10. The cargo loading pipes penetrated the weather deck at the forward end of each cargo hold. Directly under this penetration was a rotatable cargo nozzle. The crew used a wheel on the deck to control the direction of the cargo nozzle (see Figure 5).

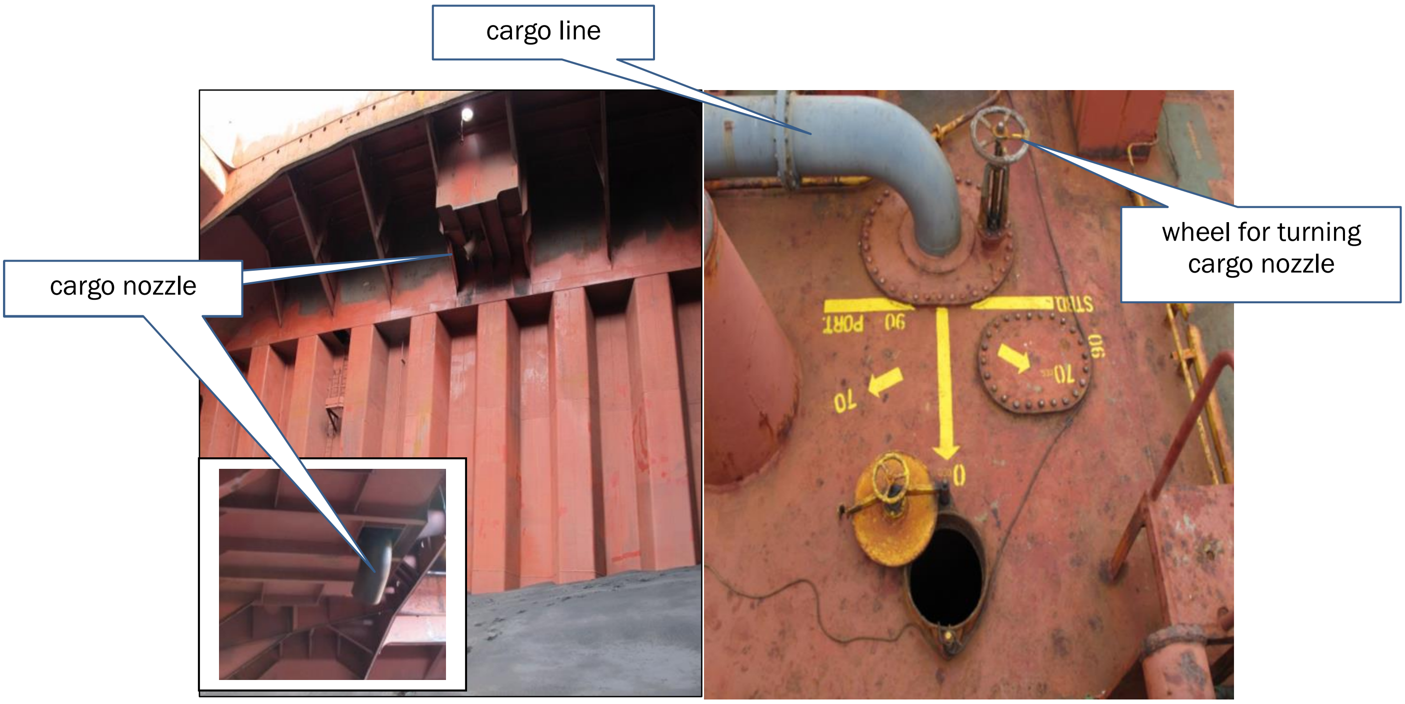

Figure 5
Position of the nozzle in the cargo hold

3.1.11. The nozzle could be rotated to direct the slurry up to 90° starboard or port of the centreline. The nozzle was normally alternated between 70° port and 70° starboard to achieve an even cargo distribution. The angle of the nozzle and the time for which it was left in one position could be adjusted to keep the ship upright. When loading 2 holds at the same time, the nozzles would normally be set in opposing directions in order to keep the ship upright. The nozzles were then simultaneously changed at regular times to achieve an even distribution of cargo across the holds.

3.1.12. A record of the cargo nozzle movements was maintained in the deck logbook. The aim was to maintain an even distribution of ironsand across the cargo holds to prevent it building up or piling on one side or the other, at the same time as keeping the ship upright. The loading took place with the hatch covers closed, so it was not possible to monitor visually the cargo profile in the cargo holds.

3.1.13. "Ullage"[3] ports were built in to the hatch covers to allow the crew to measure the height of the ironsand directly under each port.

3.1.14. There were 8 ullage ports for each cargo hold – 6 on each hatch cover and 2 on the deck, as shown in Figure 6.

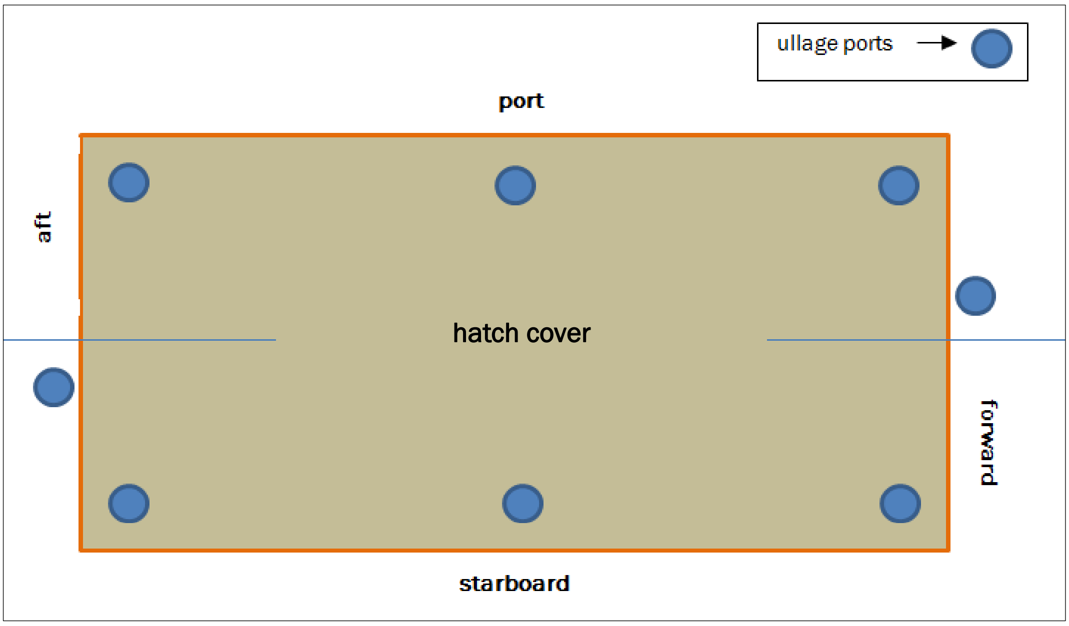

Figure 6
Location of ullage measurement ports

3.2. Narrative

3.2.1. The *Taharoa Express* departed Rizhao in China on 28 November 2009 for Port Taharoa. Operational management for the ship had changed to NYK Shipmanagement Pte Limited (NYK) that same day, and the new NYK crew had taken over the ship. An extra first mate from the previous ship management company stayed on board to assist the new first mate and crew with their first cargo loading.

3.2.2. At about 1350 on 15 December 2009, the *Taharoa Express* arrived at Port Taharoa. The ship was to load 116 000 tonnes of ironsand over 3 days.

3.2.3. At about 1500 on the same day, 2 pilots, who also acted as loadmasters, boarded the *Taharoa Express* and moored the ship to the mooring buoy located about 1.6 nautical miles offshore. The NYK ship manager arrived on board the ship that afternoon.

3.2.4. By about 1545 the 2 floating hoses were connected to the ship and cargo operations began at about 1645.

3.2.5. The new crew had decided to follow the loading plan and sequence used by the previous crew. The loading plan was to load slurry into 5 alternate holds in 9 phases over 79 hours. Table 1 shows the duration, designated cargo hold and quantity of ironsand to be loaded during each phase. The cargo loading progressed as planned until about 2235 the following evening, when the ship was in the fifth phase of loading (see Appendix 1 for a detailed cargo loading plan).

[3] Ullage is the term for the unoccupied volume in a partially filled container. In this case the crew dropped a weighted measuring tape into the hold until it struck the surface of the ironsand. This distance was subtracted from the known distance to the bottom of the cargo hold to obtain the depth of the ironsand.

Table 1: Cargo loading sequence

					incident phase				
Duration of each phase in hours	3	5.5	4.5	11	13	10	8	2	22
phase	1	2	3	4	5	6	7	8	9
hold number	quantity of ironsand discharged								
1		6000				9900		final dewatering	final dewatering
3				12 000	16 000				
5	6000		10 000				11 800		
7				12 000	16 000				
9		6000				11 000			

3.2.6. The third mate was in charge of the cargo watch. The first mate had been supervising the cargo loading since the previous day and had retired for sleep at about 2130.

3.2.7. At about 2235 the duty loadmaster was on the bridge. He noticed the ship take about 2 or 3 slightly larger rolls, then felt a "shudder". The ship then listed about 5º to starboard. The loadmaster alerted the off-duty loadmaster and proceeded to the cargo office, where he was met by the ship manager and the master. After consulting the master, the loadmaster told the shore team to stop cargo loading. The ship had listed to between 5° and about 7° to starboard at that time.

3.2.8. The cargo nozzles in both number 3 and number 7 cargo holds were already pointing 70° to port when the ship listed. The ship manager told the third officer to change the direction of the cargo nozzle in numbers 3 and 7 holds to point 90° to port for the time it took to stop the loading. The first mate awoke and joined the management team in the office.

3.2.9. A further 1200 tonnes of slurry were loaded into each of the holds before the cargo supply from the terminal stopped and the cargo lines had been cleared of slurry. Once the cargo had stopped, the ship had settled at a starboard list of about 9°.

3.2.10. All crew were mustered on deck and assigned to sound[4] the various tanks on-board the ship. All tank soundings were found to be normal, or as expected.

3.2.11. The first mate instructed the crew to take ullage measurements across each hold. The ullage measurements would help to determine the profile of the ironsand lying beneath the free-water. The crew calculated from the ullage measurements that the starboard-side holds had more ironsand than those on the port side.

3.2.12. The management team decided to correct the list by ballasting double-bottom tanks on the port side and pumping overboard any free-water above the ironsand in all the holds.

3.2.13. On the morning of 17 December 2009, a meeting was held between the ship staff, New Zealand Steel limited and Maritime New Zealand personnel. A decision was made to sail to Tasman Bay, which was the nearest port of refuge, where resources were available to level the ironsand in all holds.

3.2.14. At about 0710 on 18 December 2009, the *Taharoa Express* sailed from Port Taharoa to Tasman Bay with a 0.5° list to starboard. The ship arrived at Tasman Bay without further incident.

[4] Measure the contents of a space.

3.3. Weather and environmental conditions

3.3.1. Because Port Taharoa was an open port, the ship-mooring and cargo-loading operations were dependent on the weather, specifically the swell and wave height. Three main sources of weather information were available to the port operation:

- coastal and ocean forecasts issued by the New Zealand Meteorological Service
- sea and swell information from the website www.buoyweather.com
- direct readings from the Taharoa Wave-Rider buoy.

3.3.2. The forecast and actual weather conditions were within the limits set for the port operation. The coastal forecast for the area was for south to southwest winds averaging 15 knots with a 2- to 3-metre southwest swell, easing (see Appendix 2 for a detailed weather report).

3.3.3. Table 2 shows the readings from the Taharoa Wave-Rider buoy for around the time the *Taharoa Express* took on a list (see Appendix 3 for more detail).

Table 2: Wave-Rider and wind data at the time of the incident

time	maximum swell height (metres)	significant swell height (metres)	swell period (seconds)	wind direction (degrees)	average wind speed (knots)
2200	3.23	2.33	10.46	188	17
2220	3.72	2.28	5.88	187	20
2240	3.82	2.48	8.96	182	17

3.4. Personnel information

3.4.1. There were 25 crew members on board the *Taharoa Express* at the time of the incident. Two officers who had previously sailed on the *Taharoa Express* were also on board the ship to assist and advise the new crew on their first cargo-loading operation at Port Taharoa. An additional first mate had “signed on” to the *Taharoa Express* at Port Taharoa.

3.4.2. The master and first mate had been on board the *Taharoa Express* for about 45 days before taking over the ship on 28 November 2009 in China. They were there to learn the operation of the ship.

3.4.3. The master had started his sea-going career in 1979. He held a valid Panamanian master’s certificate of competency, issued on 7 May 2009. The Panamanian certificate was equivalent to his Indian certificate of competency. He had taken command of the ship on 28 November 2009.

3.4.4. The first mate held a valid Panamanian first deck officer II/2 certificate of competency, issued on 7 May 2009. The certificate was equivalent to his Indian certificate of competency, which he had obtained in 2008. He had taken over as first mate of the *Taharoa Express* on 28 November 2009. The first mate was in charge of the deck department and reported directly to the master of the ship. He was responsible for supervising the deck crew and for ensuring that cargo-loading operations were carried out safely and efficiently.

3.4.5. The second mate held a valid Panamanian second deck officer II/1 certificate of competency, issued on 3 August 2006, which was an equivalent certificate to his Philippines certificate of competency. He had joined the *Taharoa Express* on 26 November 2009 at Rizhao, China. While the ship was in port, the second officer kept the 1200 to 1800 and 0000 to 0600 watches.

3.4.6. The third mate held a valid Panamanian third deck officer II/1 certificate of competency, issued on 20 October 2008. The certificate was an equivalent certificate to his Philippines certificate of competency. He had joined the *Taharoa Express* on 28 November 2009 at Rizhao, China. While the ship was in port, the third officer kept the 1800 to 0000 and 0600 to 1200 watches.

4. Analysis

4.1. Introduction

4.1.1. At the time of this incident the *Taharoa Express* and the loading operation at Port Taharoa were unique. Iron ore (including ironsand) was normally loaded dry, with particular care needed to ensure that the cargo moisture content was below what was called its transportable moisture limit. The transportable moisture limit was the moisture level at which the cargo was said to be safe from liquefaction.

4.1.2. Liquefaction is the phenomenon where the cargo can turn into slurry if it is agitated, usually through vibration and movement of the ship at sea. Liquefaction of bulk ore cargo has caused the loss of several bulk carriers often with heavy loss of life. The liquefaction of bulk cargoes is a serious safety issue[5].

4.1.3. The Commission had investigated another occurrence involving the *Taharoa Express* in 2007[6]. The circumstances had been quite different from this incident. In 2007 the *Taharoa Express* had been forced to put to sea into adverse weather, partially loaded and with substantial quantities of free-water still remaining in the holds. The cargo had shifted and the ship had listed heavily on the way to a port of refuge. The mechanism for what caused the cargo to shift had been the main focus of the inquiry. The Commission had been unable to determine whether liquefaction of the ironsand was a factor, but concluded that it was a possibility.

4.1.4. In its report on the 2007 accident the Commission commented on the fact that little research had been conducted on the properties of the Taharoa ironsand and that little was understood about how the ironsand behaved during the unique slurry loading procedure. The 2007 report also commented that a formal assessment had not been conducted to determine whether the Taharoa ironsand was capable of liquefaction.

4.1.5. When this incident occurred in 2009, New Zealand Steel had undertaken some research into the properties of its ironsand. However, a formal assessment of whether it was capable of liquefaction under normal loading conditions had still not been performed. This is a safety issue that is discussed in the following analysis.

4.1.6. A large bulk carrier suddenly taking on an unexplained list is of concern. Such a scenario usually results from a shift of cargo. For the *Taharoa Express*, the fact that the ship normally had large quantities of free-water in its cargo holds during the loading process raises additional concerns. Uncontained water in cargo holds can seriously erode a ship's reserves of stability due to the free surface effect.

4.1.7. Free surface effect is a virtual rise in a ship's centre of gravity, caused by the fact that water in a cargo hold is free to slop from one side of the cargo hold to the other as the ship rolls. The more the centre of gravity rises, the less the reserves of stability the ship will have. This is described in more detail in Appendix 4. The Commission calculated the stability of the *Taharoa Express* for the moment when the ship acquired a list. The ship's stability reserves were seriously eroded due to the free surface effect. However, because the ship was partially loaded with heavy ironsand, low down in the cargo holds, it had large stability reserves to begin with, so in this case it was not in danger of capsize.

4.1.8. The following analysis discusses what caused the *Taharoa Express* to acquire a list. It also discusses the following 3 safety issues:

- New Zealand Steel had not undertaken sufficient research on the properties of Taharoa ironsand and the way it behaved during the slurry-loading process

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[5] Cargo shift due to liquefaction resulted in the loss of at least 3 ships and 44 lives between 2010 and 2011. Report *M/V Jian Fu Star* R-011-11-DIAM 27 February 2011; Report *M/V Hong Wei* R-007-2011 18 December 2010; Report *M/V Nasco Diamond* R-020-2011/DIAM 9 November 2010.

[6] Report 07-207, bulk carrier *Taharoa Express*, cargo shift and severe list, 42 nautical miles southwest of Cape Egmont, 22 June 2007.

- the crew on the *Taharoa Express* did not maintain an accurate "picture" of the distribution and profile of ironsand in each cargo hold, and did not evenly trim the cargo in accordance with the operating procedures and industry best practice
- all of the resources that were available to manage the first loading for the new crew were not used to best effect, which resulted in the first mate becoming fatigued.

4.2. Why the ship acquired a sudden list

4.2.1. A ship will develop a list if its internal weights are not evenly distributed either side of its longitudinal centreline. For a list to develop suddenly there needs to be a sudden movement of weight from one side to the other. A visual inspection of the cargo holds after the incident showed that there was an excess of ironsand on the starboard side in more than one hold.

4.2.2. The *Taharoa Express* had loaded ironsand at Port Taharoa under similar weather conditions many times in the previous 10 years. When considering why this cargo shifted and others had not, the Commission considered the possibility that the properties of the cargo had changed. However, post-incident testing of the ironsand properties (such as testing for the percentage of clay[7]) showed that little had changed in the ironsand properties over the years.

4.2.3. Three possible mechanisms for cargo shifting were considered:

- erosion
- liquefaction
- slumping.

Mechanism of erosion

4.2.4. The erosion of ironsand was researched and considered in the Commission's inquiry into the 2007 occurrence involving the *Taharoa Express*. Erosion is largely reliant on the surface of the sand being exposed to the internal wave action of the free-water. The ironsand can become entrained in the wave action and erode from one side to the other. The effect is exacerbated if the ship already has a small list because the entrained ironsand gravitates from the high side to the low side. A New Zealand Steel Limited (NZSL) report (2007)[8] suggested that the depth of water above ironsand was considered a key factor in cargo shifts due to erosion. The report stated:

> The shallow water depth in the hold over the sand surface would induce the sand to be exposed to water running over and gradually eroding the sand from one side and building up the sand on the opposite side.

Any list developing due to erosion would do so gradually, yet the *Taharoa Express* acquired a sudden list. An analysis of the ironsand/free-water distribution in all holds showed that there was a minimum of about 3 metres of free-water above the ironsand in all partially loaded cargo holds, meaning it would have been unlikely for the ironsand to be exposed to wave action in the manner described. For these 2 reasons, erosion is not considered to have been a significant factor in the cargo shifting.

Mechanism of liquefaction

4.2.5. The liquefaction of cargo is a result of compaction. In a non-liquefied state, the shear strength of the cargo is derived from contact between cargo particles. When the cyclic load and cargo saturation is sufficient, a compaction event can reduce the volume between the cargo particles and increase the water pressure, resulting in a partial or complete loss of shear strength.

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[7] Clay was referred to as 'slimes', which is an impurity embedded in the ironsand that was thought could possibly contribute to liquefaction.
[8] New Zealand Steel Limited report (2007) section 4.3.

4.2.6. Following this incident NZSL undertook a significant project to better understand the properties of Taharoa ironsand and to better understand its stability in cargo holds when loaded as slurry. Probabilistic assessments were made of the *Taharoa Express*'s motion corresponding to sea-state conditions at the mooring buoy and the effects these motions had on the stability of the cargo at different stages of the loading process. A summary of the report and its findings can be read in Appendix 8.

4.2.7. The NZSL report stated that 90% of the modelled conditions should not cause liquefaction of the ironsand cargo. For a further 5% of the modelled weather conditions, localised liquefaction could occur, but the overall mass of the cargo should remain stable. For the worst 1-5% of the modelled weather conditions, ship motions could theoretically induce unstable cargo behaviour, but generally these unstable cargo conditions fell outside the permissible weather window for the ship to remain at the mooring buoy.

4.2.8. The observed weather conditions on the day of the incident were similar to those observed during 3 post-incident cargo-loading phases, when data for the research was collected. The significant wave height typically ranged between 2 and 2.5 metres and the swell time period ranged between 7 and 11 seconds. The ship was observed to be lying side on to the swell.

4.2.9. A half roll amplitude of 4° and a ship roll period between 10 and 14 seconds (the upper limit of the ship motion observed during the monitored cargo loading phases) had the potential to generate considerable localised liquefaction in a half-filled hold, but not enough to cause the ironsand to become unstable (the red rectangle in Figure 7).

4.2.10. In conclusion then, it is possible that localised pockets of liquefaction contributed to triggering the shift of cargo, but this would not have been the main cause.

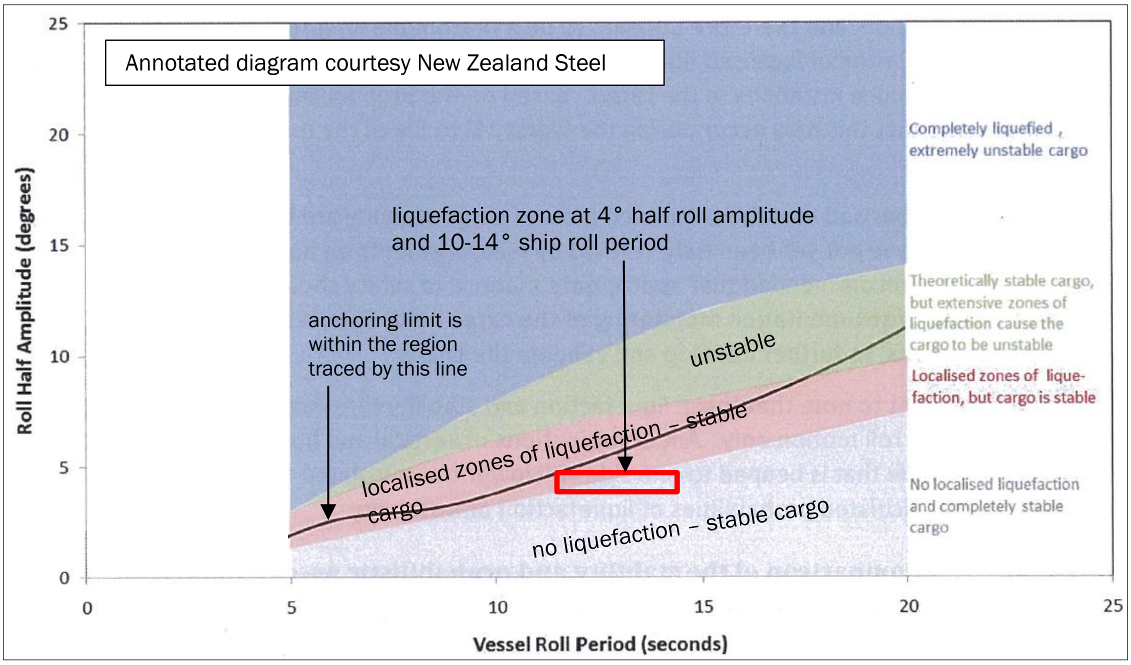

Figure 7
Calculated liquefaction and stability thresholds for a half-full cargo hold

Mechanism of slump

4.2.11. Bulk material such as ironsand will typically slump when its angle of repose is exceeded. The angle of repose is the steepest slope at which the material will stand or, if a bucket of the material is poured onto a flat surface, it is the angle of the slope that is formed. The angle of repose of dry Taharoa ironsand was found to be 30.5°.

4.2.12. Testing for the underwater angle of repose was first done only after this incident. Those tests showed that the underwater angle of repose of ironsand was only 24.7°. This meant that for a slump to occur the pile of ironsand deposited underwater in one or more holds had to develop a slope angle (to the horizontal plane) greater than 24.7°. Under normal loading conditions, such a piling up of the cargo should not have occurred. However, the ullage measurements taken before and after the incident suggested that cargo had been allowed to mount up on one side of one cargo hold, while simultaneously being offset by cargo being allowed to mount up on the other side in another cargo hold. In such a situation the ship would have remained upright and the crew would have been none the wiser unless they were accurately monitoring the distribution and profile of the ironsand in all holds. The evidence suggested that they were not doing this (see the following section 4.4 and Appendices 9 and 10).

4.2.13. Figure 8 shows a photograph taken of the ironsand profile in number 7 cargo hold after the incident. The cargo profile is biased toward the starboard side of the cargo hold. The characteristic slope can be seen forming from forward to aft due to the loading nozzle being located at the forward end of the cargo hold. No ullage records were available for before the ship acquired a list.

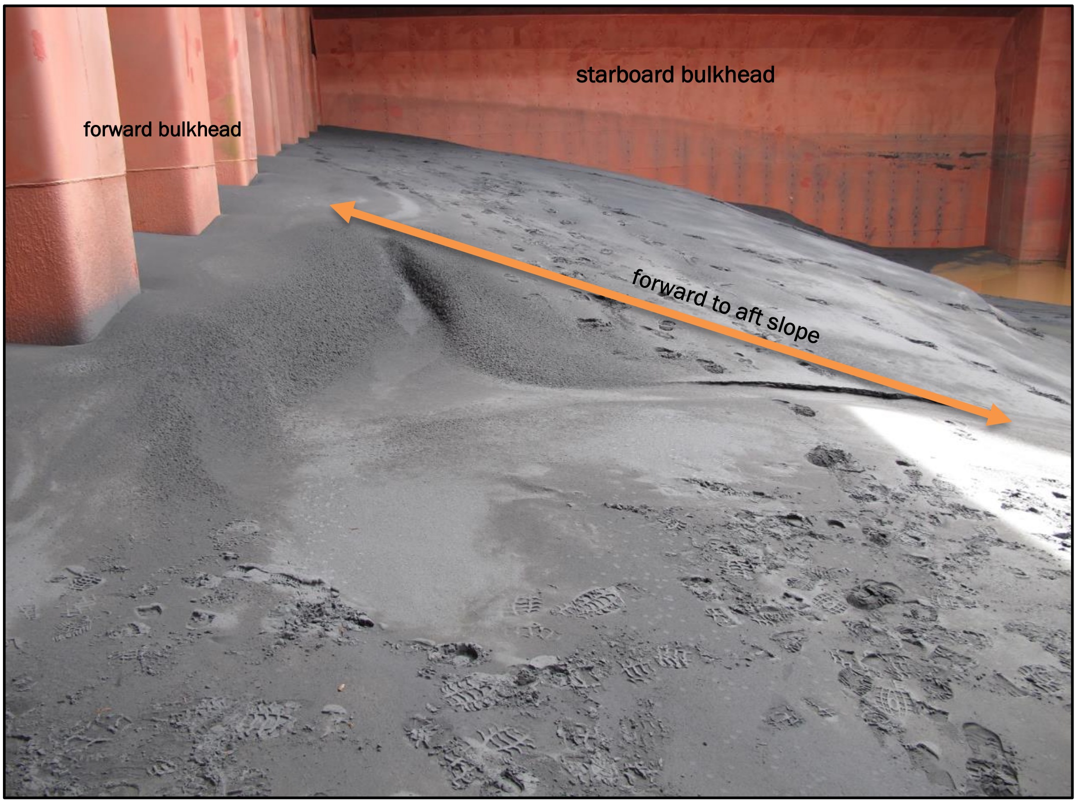

Figure 8
Number 7 cargo hold

4.2.14. Figure 9 shows a photograph taken of the ironsand profile in number 3 hold after the incident. The ironsand in this hold showed the most significant signs of having shifted. There was no appreciable cargo slope from forward to aft, particularly on the starboard side, indicating that the cargo may have shifted from the port forward to the aft starboard corner of the hold.

4.2.15. Numbers 3 and 7 holds were being loaded simultaneously at the time of the incident. The *Taharoa Express* was lying side-on and rolling gently to the swell at the time. The loadmaster recalled feeling a series of slightly larger rolls just before the ship suddenly began to list. It is feasible that the ironsand was piled towards one side of the cargo hold's centreline, close to its underwater angle of repose. The bigger rolls felt just before the ship listed could have tipped the slope angle beyond 24.7°, causing the cargo to flow across number 3 hold and causing the initial sudden list. The sudden 5° list could also have initiated similar slumps in the other cargo holds. This would explain the list progressively increasing to 9°.

Figure 9
Number 3 cargo hold

4.2.16. As explained in the previous section, wave conditions at the time were similar to those that created the ship motion that the NZSL report said could result in localised pockets of liquefaction occurring in the hold being loaded. It is possible, therefore, that localised pockets of liquefaction of the ironsand helped to trigger such a cargo slump.

4.2.17. The initial and final list angles would not have been caused by a shift of ironsand alone. The large quantities of free-water present in all of the cargo holds would have moved across to the starboard side as the ship listed. Therefore, any ironsand slump would not necessarily have been as large as first imagined.

4.2.18. Another factor that would have exacerbated the initial list angle was the further 1200 tonnes of slurry that were pumped into numbers 3 and 7 holds before the cargo lines could be cleared of slurry and the cargo pumps ashore shut down. Although the nozzles in both cargo holds were directed to the port side, the free-water (600 tonnes) would have flowed immediately across to the low side.

Findings

1. The *Taharoa Express*'s sudden list to starboard was likely to have been triggered by the ironsand cargo slumping across the cargo holds under the free-water.

2. It was likely that the ironsand in several cargo holds had mounded away from the ship's centreline until the ship's rolling motion caused it to exceed its underwater angle of repose. Naturally occurring, localised pockets of liquefaction within the ironsand possibly helped to trigger the cargo's slump.

4.3. Responsibility of the shipper

Safety issue – New Zealand Steel had not undertaken sufficient research on the properties of the Taharoa ironsand and the way it behaved during the slurry loading process before this incident.

4.3.1. At the time of the incident the International Convention for the Safety of Life at Sea (SOLAS), Chapter VI specified that the Code of Safe Practice for Solid Bulk Cargoes (2004) and the Code of Practice for the Safe Loading and Unloading of Bulk Carriers should be referred to where bulk cargoes were carried. The Codes reflected the best practices and legislative requirements at that time.

4.3.2. Since the incident the International Maritime Organization has replaced the Code of Safe Practice for Solid Bulk Cargoes (2004) with a new code called the "International Maritime Solid Bulk Cargoes Code", which came into force on 1 January 2011.

4.3.3. The requirements of SOLAS were implemented in New Zealand through Maritime Rules. Maritime Rules Part 24C required that the shipper of a solid bulk cargo provide the ship master or their representative with information that included any relevant special properties of the cargo (Maritime New Zealand, Maritime Rules, 1998).

4.3.4. NZSL had provided the master of the *Taharoa Express* with a document titled "Shipper's Declaration Re Cargo and Further Information"(see Appendix 7). It was a declaration on the characteristics of the cargo, together with extracts from a submission made to the International Maritime Organization to list "Taharoa ironsand" in the 2011 International Maritime Solid Bulk Cargoes Code as non-liquefying cargo. The research on Taharoa ironsand undertaken by NZSL in response to this incident has addressed the safety issue described above. The research should, however, have been conducted following the 2007 accident, especially as the issue of whether the ironsand was a liquefying cargo was unresolved at that time.

4.3.5. Loading ironsand as slurry was a unique operation. The only new information to emerge out of the research was that the underwater angle of repose (24.7°) was less than its dry angle of repose (27°), or for when it was in a saturated state of 13% moisture content (40°).

4.3.6. The 24.7° underwater angle of repose of ironsand was 15.3° less than when it was in its saturated state. The crew should have had that information. It would have reinforced the importance of avoiding the cargo mounding under the free-water in the cargo holds. However, the procedures for loading the ship were already designed to ensure an even distribution of cargo across each cargo hold, so even if the crew had known about the underwater angle of repose, it is doubtful that this new information would have prevented the incident occurring. The more relevant safety issue was the crew not closely following those procedures. This issue is discussed in the following section.

Finding

3. New Zealand Steel had not undertaken sufficient research on the properties of Taharoa ironsand, and its stability in the cargo hold during the slurry loading process, before this incident. New Zealand Steel has subsequently addressed this safety issue.

4.4. Cargo trimming

Safety issue – the crew on the *Taharoa Express* did not maintain an accurate "picture" of the distribution and profile of ironsand in each cargo hold and did not evenly trim the cargo in accordance with the operating procedures and industry best practice.

4.4.1. Cargo operations at Port Taharoa were different from those for loading a conventional bulk carrier. SOLAS Chapter VI and the associated Codes of Safe Practice for Solid Bulk Cargoes and for the Safe Loading and Unloading of Bulk Carriers made no special provision for loading bulk cargoes in slurry form. Nevertheless, they represented international best practice for the carriage of bulk cargoes, and the fundamental risks that the Codes highlighted from a cargo shift perspective were still applicable to the *Taharoa Express*.

4.4.2. The Codes stated that trimming cargo reduced the likelihood of it shifting (IMO, BC Code Section 5, 2004). Trimming cargo refers to spreading the cargo evenly across a hold rather than pouring it only in the middle of the hold, which would result in it sitting at its natural angle of repose. In that situation, if the ship put to sea and the rolling motion of the ship increased the cargo's slope angle beyond its angle of repose, it is possible that the cargo would shift. A cargo shift results in the ship listing and erodes its reserves of stability. Loading ironsand as slurry at Port Taharoa posed the same problem, except in this instance the problem was encountered before the ship put to sea. Loading in an open port meant the ship was exposed to wave motion as it was loading. Ironically the research that NZSL conducted showed that the rolling motion at the mooring buoy could help to spread the ironsand evenly due to the wave action of the free-water above the cargo.

4.4.3. The loading procedures for the *Taharoa Express* were designed to achieve a uniform spread of cargo on either side of the ship's centreline (across the holds). The previous crews had achieved this by rotating the cargo nozzles to opposite sides of the cargo hold at hourly intervals. The new crew appeared to understand this concept, because they decided to decrease the timing of the nozzle change to half-hourly intervals. Their rationale was to achieve a more even distribution of cargo. The rationale was good, but they lost track of how often each nozzle was moved and for how long it was pointing in one direction. This was evident from the records of cargo nozzle movement and interviews with the crew. There were several periods when nozzle movements were not recorded on the log sheet (refer to Appendix 9). The ullage measurements that the crew obtained on completion of the first 3 loading phases showed that the cargo was unevenly trimmed, which is further evidence that the crew lost track of how often each nozzle was moved and for how long it was pointing in one direction (refer to Appendix 10).

4.4.4. Because the ironsand profile could not be seen visually, the ullage measurements were required to monitor and build a "picture" of the ironsand profile. Without that "picture", the cargo could easily become unevenly distributed and mount up on either side of the cargo holds. The objective was **not** to obtain a detailed profile of the cargo. This would be difficult to achieve for 2 reasons:

- the turbulent water movement above the cargo affected the accuracy of ullage measurements
- there were only 8 ullage ports for each cargo hold, meaning the height of the cargo could only be measured at those 8 points.

4.4.5. Instead the objective was to avoid a general bias of cargo to one side of a single cargo hold, which could be reasonably detected by ullaging. A general bias of cargo could go unnoticed if the crew only focused on keeping the ship upright. A cargo bias in one hold could easily be offset by an opposite bias in another cargo hold. That is likely to have happened on this occasion and was likely the main reason for the cargo shift.

4.4.6. On completion of loading phases 1 to 3, the ullage measurements revealed that the ironsand was not well trimmed. Ironsand had mounted up on the port side of number 1 cargo hold and on the starboard side of numbers 9 and 5 cargo holds. This was an indication to the crew that whatever they were doing was not achieving a well-trimmed cargo. The crew did not recognise that fact, or if they did, did nothing to resolve the issue. The ironsand profile in numbers 3 and 7 cargo holds showed evidence of a significant shift in cargo, which meant that the ironsand was not well trimmed in those holds either.

4.4.7. Following the incident the cargo procedures were reverted back to hourly changing of the loading nozzle direction and the crew became more attuned to the need to monitor and log accurately the frequency of nozzle changes to ensure an even cargo distribution in the cargo holds. The procedures were changed to increase the frequency of ullage readings.

Findings

4. The crew on the *Taharoa Express* did not maintain an accurate "picture" of the distribution and profile of ironsand in each cargo hold and did not evenly trim the cargo in accordance with the operating procedures and industry best practice. This allowed the ironsand to mount up in the cargo holds to a point where the rolling motion of the ship probably tipped the slope of the ironsand past its underwater angle of repose, causing it to shift.

4.5. Fatigue and crew resource management

Safety issue – all of the resources that were available to manage the first loading for the new crew were not used to best effect, which resulted in the first mate becoming fatigued.

4.5.1. The first mate had taken over watch at 0400 on 15 December 2009, while the ship was approaching Port Taharoa. When interviewed after the incident, the first mate said that he had continued working for approximately the next 40 hours. He had retired for sleep at about 2130 on 16 December 2009 – about one hour before the incident. He had planned to return to work after about 5 hours of rest, when the ironsand loading would be nearing completion.

4.5.2. The second and third mates shared the cargo watchkeeping responsibility to free the first mate to oversee the whole cargo loading procedure. Under normal circumstances the third and second mates would have been delegated tasks to allow the first mate time to rest at opportune times. In this case, however, both the second and third mates had not observed or participated in this unique way of loading a bulk carrier. Understandably, the first mate would have wanted to oversee their performance more frequently than usual.

4.5.3. The loading was planned to take 3 days. It was not feasible for the chief officer to remain awake and alert for that length of time. He had at his disposal an extra first mate who was very experienced on the *Taharoa Express*. Also on board was the company superintendent, 2 loadmasters and the master. Collectively there were sufficient resources on board to manage the loading and monitor the training of the second and third mates in their first loading at Port Taharoa. The plan for the effective use of the available manpower would have allowed the first mate ample opportunity to rest.

4.5.4. "To be alert and able to function well, each person requires a specific amount of nightly sleep. If individual 'sleep need' is not met, the consequences are increased biological sleepiness, reduced alertness and impaired physical and mental performance. For most people, getting 2 hours less sleep than they need on one night (an acute sleep loss of 2 hours) is enough to cause measurable impairment of performance and alertness the next day. The reduction in performance capacity is particularly marked if less than about 5 hours sleep is obtained. The effects of several nights of reduced sleep accumulate into a 'sleep debt' with sleepiness and performance becoming progressively worse."[9]

4.5.5. It is likely that the first mate's performance was compromised, his having worked 40 hours without sleep. The first mate's ability to maintain an accurate overall mental model of the cargo loading operation was likely to have become increasingly difficult the longer he remained awake. Of note is one of the periods when no records were kept of the cargo nozzle movement. This was during a time when the first mate had taken over the cargo watch from the second mate to release the second mate for other duties.

[9]Philippa Gander, BSc, MA (hons), PhD (Auckland), Sleep/Wake Research Centre, in collaboration with Te Ropu Rangahau Hauora a Eru Pomare and the Wellsleep Clinic at the Wellington School of Medicine and Health Sciences. Expert Testimony: Collision of the passenger ferry *Aratere* and the fishing boat *San Domenico*, 5th of July 2003, New Zealand Transport Accident Investigation Commission, 2003.

4.5.6. The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) recognises the importance of managing fatigue on-board ships, and systems are required to ensure that shipping companies properly manage crews' hours of work. Chapter VIII section A-VIII/1 of the STCW Convention's Code states the mandatory requirements for a watchkeeping officer to be considered fit for duty. Although there are exceptions, generally the watchkeeper is to be provided with a minimum of 10 hours of rest in any 24 hours and the rest hours are not to be divided into more than 2 periods, of which one shall be at least 6 hours in length. These requirements were stated in the *Taharoa Express*'s safety management system. The second and third mates' duty times met these requirements but the first mate's clearly did not.

4.5.7. The master, who had also sailed as an observer with the previous crew and had served as a first mate, should have been aware of the possible hours of work facing the first mate. He should have implemented contingency plans to manage the first mate's anticipated work programme.

4.5.8. It is prudent to have a fatigue management system on board every ship that addresses high workload periods, for example when the ship is loading cargo in port. A system must also be in place to ensure that it is effectively enforced.

Findings

5. There were sufficient resources on board the *Taharoa Express* to manage the first loading by the new crew, but the resources were not used to best effect. The first mate's performance would have been increasingly affected by fatigue as he attempted to oversee the loading alone.

5. Findings

5.1. The *Taharoa Express*'s sudden list to starboard was likely to have been triggered by the ironsand cargo slumping across the cargo holds under the free-water.

5.2. It was likely that the ironsand in several cargo holds had mounded away from the ship's centreline until the ship's rolling motion caused it to exceed its underwater angle of repose. Naturally occurring, localised pockets of liquefaction within the ironsand possibly helped to trigger the cargo's slump.

5.3. New Zealand Steel had not undertaken sufficient research on the properties of Taharoa ironsand, and its stability in the cargo hold during the slurry loading process, before this incident. New Zealand Steel has subsequently addressed this safety issue.

5.4. The crew on the *Taharoa Express* did not maintain an accurate "picture" of the distribution and profile of ironsand in each cargo hold and did not evenly trim the cargo in accordance with the operating procedures and industry best practice. This allowed the ironsand to mount up in the cargo holds to a point where the rolling motion of the ship probably tipped the slope of the ironsand past its underwater angle of repose, causing it to shift.

5.5. There were sufficient resources on board the *Taharoa Express* to manage the first loading by the new crew, but the resources were not used to best effect. The first mate's performance would have been increasingly affected by fatigue as he attempted to oversee the loading alone.

6. Safety actions

6.1. General

6.1.1. The Commission classifies safety actions by 2 types:

(a) safety actions taken by the regulator or an operator to address safety issues identified by the Commission during an inquiry that would otherwise result in the Commission issuing a recommendation

(b) safety actions taken by the regulator or an operator to address other safety issues that would not normally result in the Commission issuing a recommendation.

6.2. Safety actions addressing safety issues identified during the inquiry

6.2.1. Since the incident, New Zealand Steel limited has engaged engineering consultants to carry out engineering studies related to the stability of the cargo and the ship during the loading process. Some of the factors determined in the studies are stated below.

- laboratory testing was undertaken to characterise the geotechnical properties of the ironsand material; the underwater angle of repose of ironsand was investigated and determined
- three-dimensional numerical modelling work was undertaken to understand how the ironsand material could deposit in the cargo holds during the loading process
- instrumentation and monitoring of the loading phases of 3 post-incident voyages were carried out to validate the cargo deposition modelling work.

6.2.2. Since the incident, NYK Line, Dry Bulk Marine Quality Control Group has taken the following action:

- the frequency of ullage measurements has increased, to monitor the profile of the ironsand deposited in the cargo hold.

7. Recommendations

7.1. General

The Commission may issue, or give notice of, recommendations to any person or organisation that it considers the most appropriate to address the identified safety issues, depending on whether these safety issues are applicable to a single operator only or to the wider transport sector.

7.1.1. No recommendations have been identified.

8. Key lessons

8.1. It is important to ensure that bulk cargo in any form is well trimmed in the cargo hold to prevent it shifting during the loading process and when at sea.

8.2. In any ship-loading operation, care should be taken to ensure that sufficient operational experience is available and used to ensure a safe and efficient operation.

9. Citations

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Appendix 1: Load sequence for the *Taharoa Express*

11

1) LOADING SEQUENCE (A) TAHAROA,

incident phase (sequence 5)

			1	2	3	4	5	6	7	8	DEP
Total HRS			3.0	[illegible].5	12.7	23.2	36.5	45.7	53.7	55.7	79.7
HRS			3.0	5.5	4.2	10.5	13.3	9.2	8.0	2.0	24.0
SEQUENCE No.			1	2	3	4	5	6	7	8	DEP
CH #1	IS	NIL		6,000 MT				9,900 MT		15,900 MT	15,900 MT
	W			6,132 MT	4,334 MT	4,334 MT	4,334 MT	4,038 MT	2,240 MT	2,240 MT	1,100 MT
CH #3	IS	NIL				12,000 MT	16,000 MT			28,000 MT	28,000 MT
	W					9,120 MT	5,734 MT	3,948 MT	3,948 MT	3,948 MT	2,987 MT
CH #5	IS	NIL	6,000 MT		10,000 MT				11,800 MT	27,800 MT	27,800 MT
	W		6,611 MT	6,611 MT	8,073 MT	3,531 MT	3,531 MT	3,531 MT	5,577 MT	4,327 MT	4,327 MT
CH #7	IS	NIL				12,000 MT	16,000 MT			28,000 MT	28,000 MT
	W					9,369 MT	5,983 MT	4,184 MT	4,184 MT	4,184 MT	2,150 MT
CH #9	IS	NIL		6,000 MT				11,000 MT		17,000 MT	17,000 MT
	W			6,611 MT	4,412 MT	4,412 MT	4,412 MT	4,500 MT	2,301 MT	2,301 MT	1,900 MT
TTL	IS	NIL	6,000 MT	18,000 MT	28,000 MT	52,000 MT	84,000 MT	104,900 MT	116,700 MT	116,700 MT	116,700 MT
	W		6,611 MT	19,354 MT	16,819 MT	30,766 MT	23,994 MT	20,201 MT	18,250 MT	17,000 MT	12,464 MT
Load cargo qtty			6,000	12,000	10,000	24,000	32,000	20,900	11,800		
Loading hour			2.5	5.0	4.2	10.0	13.3	9.2	8.0	2.0	24.0
F		8.24 m	8.66 m	9.67 m	10.34 m	11.25 m	13.76 m	15.40 m	16.82 m	16.65 m	16.00 m
M		8.84 m	8.70 m	10.53 m	10.54 m	12.43 m	14.11 m	15.61 m	16.57 m	16.44 m	16.00 m
A		9.44 m	8.75 m	11.40 m	10.74 m	13.61 m	14.46 m	15.81 m	16.32 m	16.24 m	16.00 m
T		1.20/S m	0.09/S m	1.73/S m	0.40/S m	2.36/S m	0.70/S m	0.41/S m	-0.50/H m	-0.41/H m	EVEN
S.F.		-86%	-80%	93%	-98%	50%	95%	86%	76%	73%	74%
B.M.		-75%	-98%	96%	83%	-36%	-82%	74%	-74%	-63%	-68%
Hog/Sag		S22	S75	H182	H85	S27	S75	H110	S93	S78	S79
GM		9.85 m	12.24 m	10.74 m	10.52 m	10.17 m	8.43 m	8.18 m	7.96 m	8.03 m	8.24 m
GGo		2.73 m	4.40 m	6.02 m	4.49 m	6.72 m	4.93 m	4.31 m	4.04 m	4.07 m	4.20 m
GoM		7.12 m	7.84 m	4.72 m	6.03 m	3.45 m	3.49 m	3.87 m	3.92 m	3.96 m	4.05 m
F.Water		0	6,611	19,354	16,819	30,766	23,994	20,201	18,250	17,000	12,464
FP		3,668	3,200	1,000	1,000	1,000	1,000	0	0		
1C	DB	1,967 F	1,967 F	500	500	0 E	0 E	0 E	0 E	0 E	0 E
1C	TS	1,264 F	0 E	0 E	0 E	0 E	0 E	0 E	0 E	0 E	0 E
2	DB P&S	5,888 F	5,888 F	5,888 F	5,888 F	0 E	0 E	0 E	0 E	0 E	0 E
2	TS P&S	4,070 F	4,070 F	4,070 F	4,070 F	0 E	0 E	0 E	0 E	0 E	0 E
3	DB P&S	5,804 F	5,804 F	5,804 F	5,804 F	4,000	0 E	0 E	0 E	0 E	0 E
3	TS P&S	4,130 F	4,130 F	4,130 F	4,130 F	0 E	0 E	0 E	0 E	0 E	0 E
4	DB P&S	5,486 F	5,486 F	5,486 F	5,486 F	4,000	0 E	0 E	0 E	0 E	0 E
4	TS P&S	4,130 F	0 E	0 E	0 E	0 E	0 E	0 E	0 E	0 E	0 E
5	DB P&S	1,912 F	1,912 F	1,912 F	1,912 F	0 E	0 E	0 E	0 E	0 E	0 E
5	TS P&S	0 E	0 E	0 E	0 E	0 E	0 E	0 E	0 E	0 E	0 E
AP		906	906	906	906	906	906	0	0	0	0
6 CH		18,665	11,000	7,000	0	0	0	0	0	0	0
TTL		57,890	44,363	36,696	29,696	9,906	1,906	0	0	0	0
DISP		78,616	77,700	94,776	95,241	113,398	130,626	145,827	155,676	154,426	149,890

CES : Confirmation of end of sequence
NSS : Confirmation of next safety sequence with operation criteria.

Appendix 2: Climatic conditions

METSERVICE

TAHAROA - SHIP LOADING FORECAST

Issued by MetService at 05:50am Wednesday 16-Dec-2009

SITUATION AT 0600 WEDNESDAY 16-DEC-2009 NZDT

A ridge spreads across the North Island today then persists through to Friday. A front is expected to move onto the lower North Island late Saturday preceded by a strengthening northwest flow.

FORECAST UNTIL 0900 THURSDAY

Wednesday/Thursday

Wind:
Southerly 10kt, rising to southwest 15kt this morning and to 20kt this afternoon. Easing to 15kt again Thursday morning.

Swell:
Southwest 2m occasional 3m t=11s, easing to 1.5m occasional 2.5m t= 10s.

Combined waves:
2m occasional 3m.

Weather:
Fine and cloudy periods.

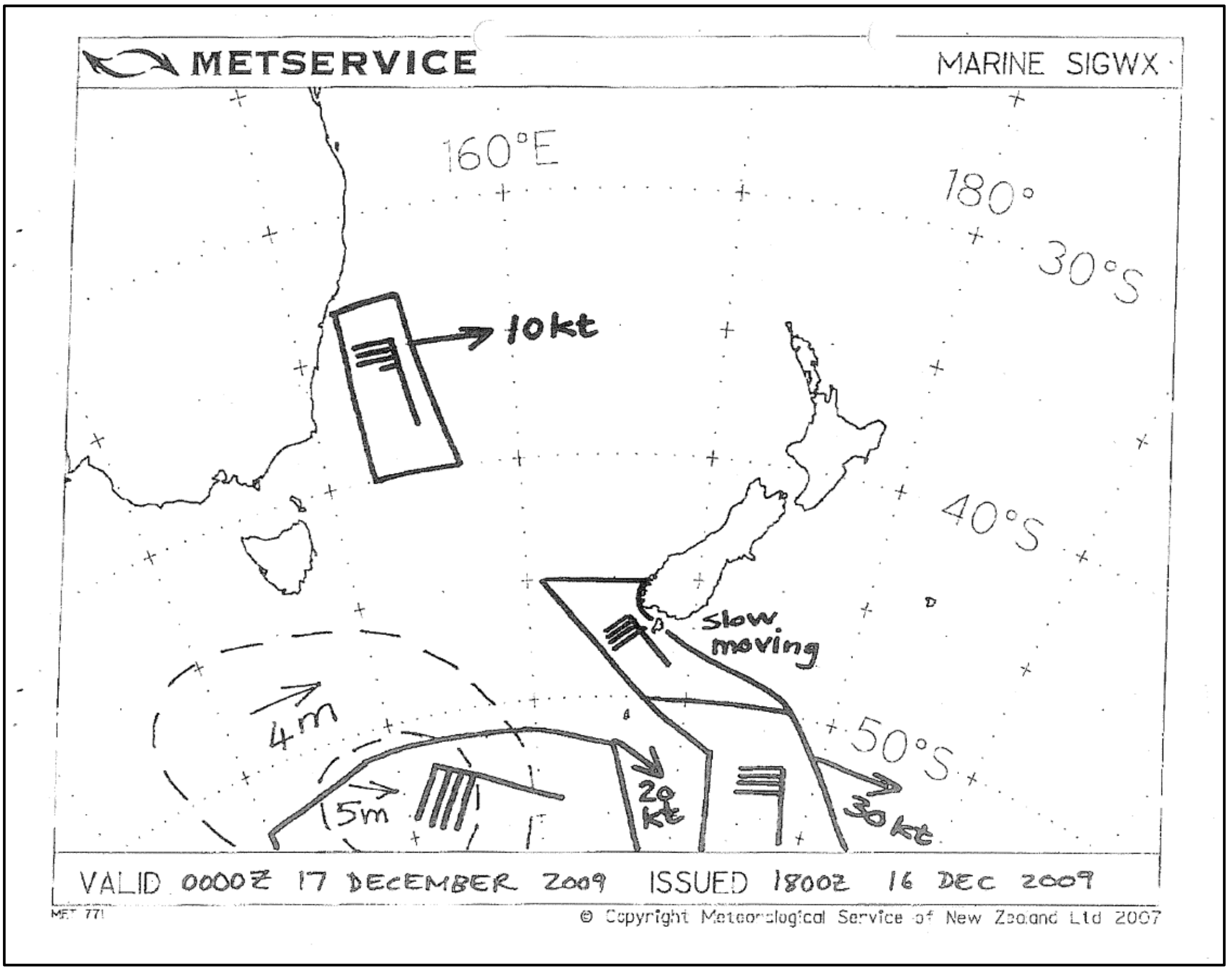
FORECAST FOR FURTHER 24 HOURS:

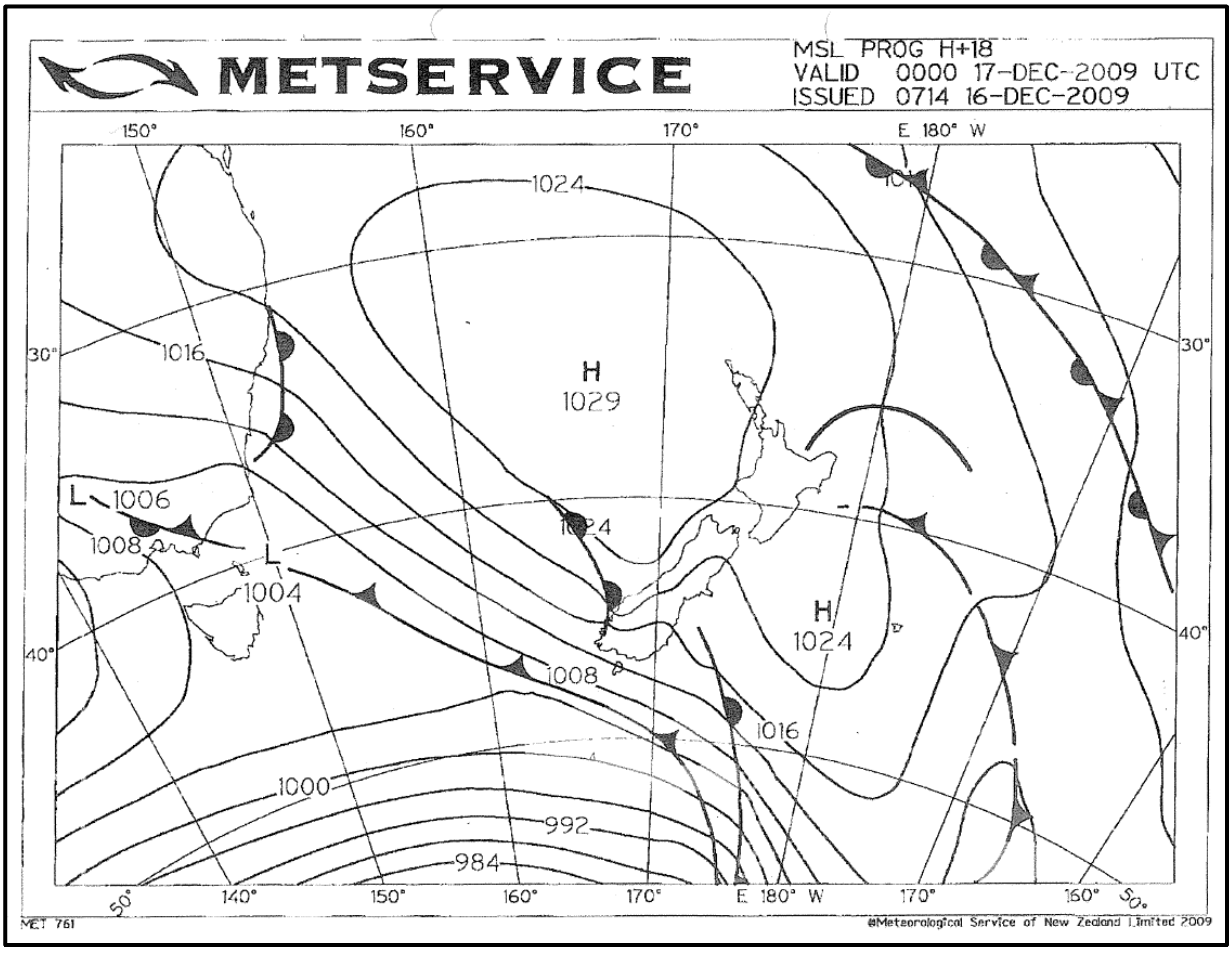
Wind:
Southwest 15kt, easing to 10kt in the evening and to variable 5kt overnight.

Swell:
Southwest 1.5m occasional 2.5m t=10s, easing to 1m occasional 1.5m t= 9s.

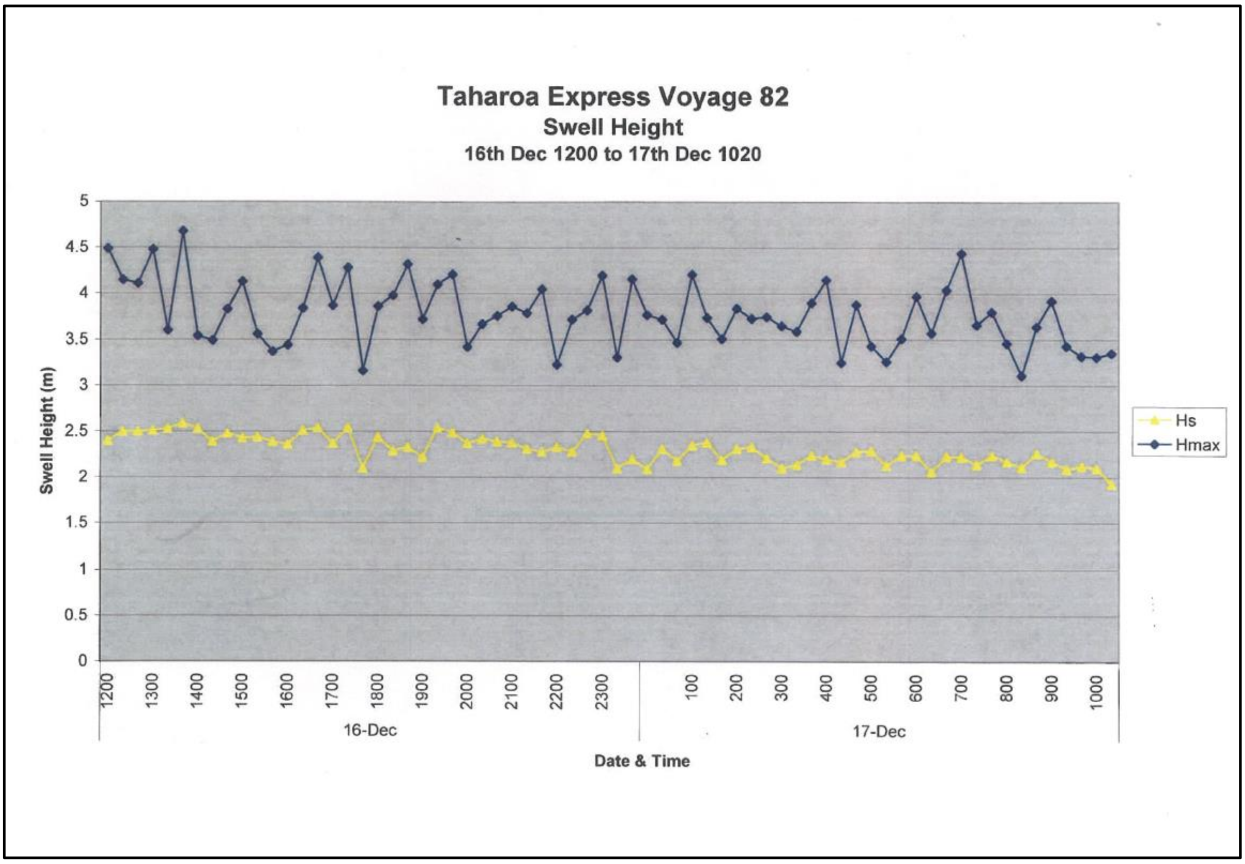
Combined waves:
2m occasional 3m, easing to 1m occasional 1.5m.

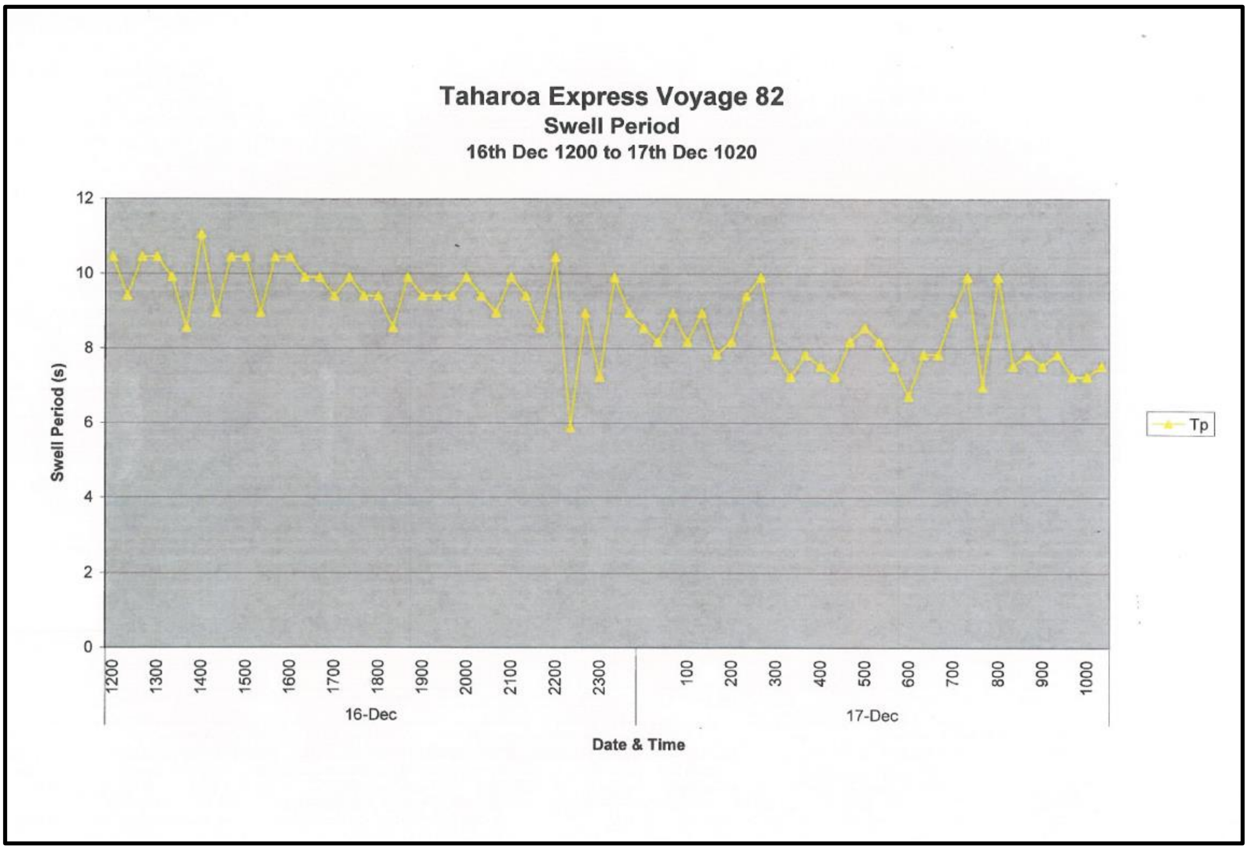
Weather:
Fine and cloudy periods.

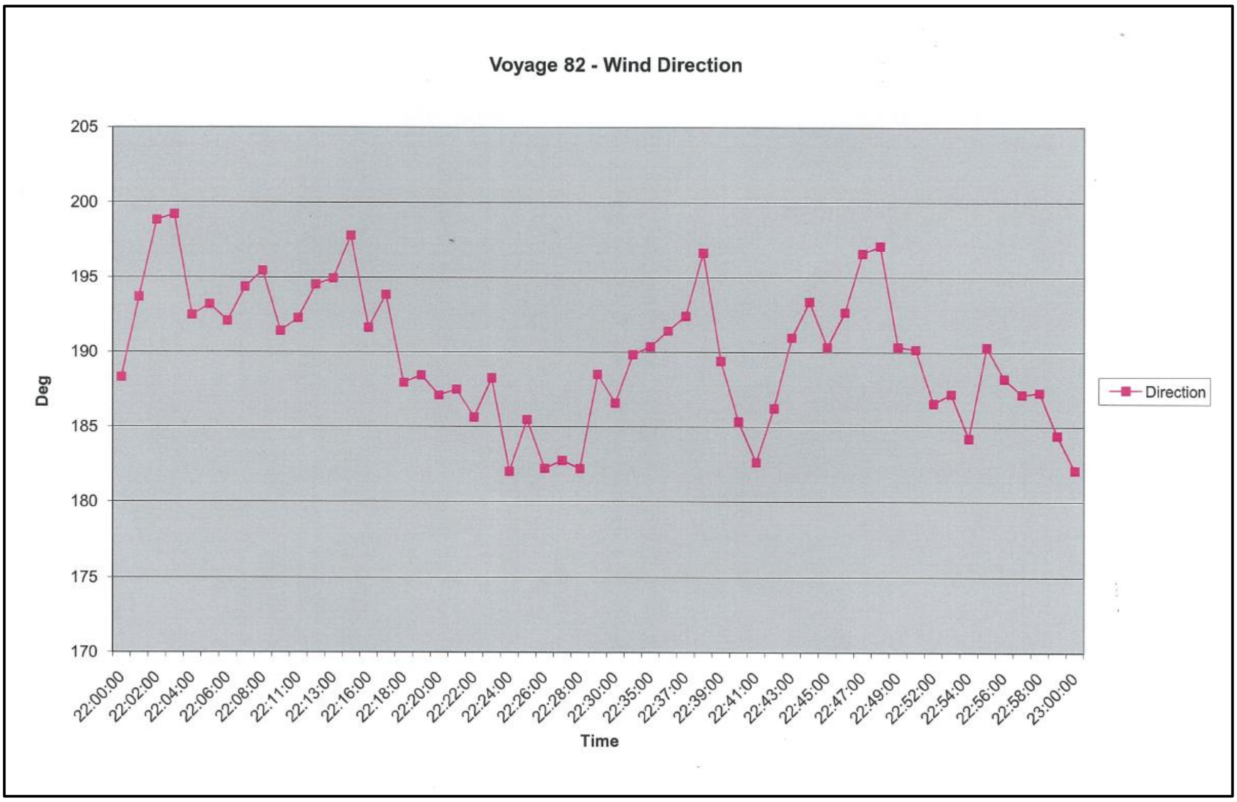

METSERVICE
MARINE SIGWX
160°E
180°
30°S
40°S
50°S
10kt
slow moving
4m
5m
20 kt
30 kt
VALID 0000Z 17 DECEMBER 2009 ISSUED 1800Z 16 DEC 2009
MET 771
© Copyright Meteorological Service of New Zealand Ltd 2007

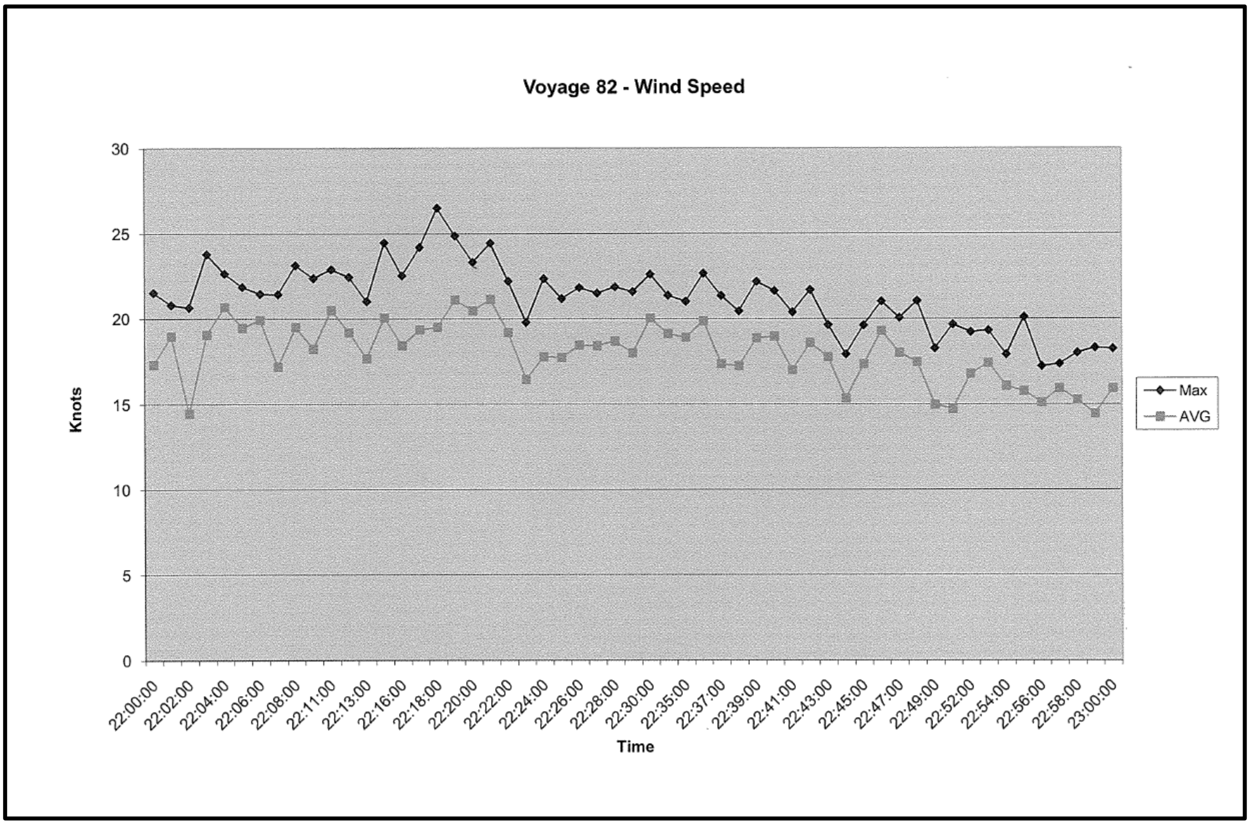

METSERVICE
MSL PROG H+18
VALID 0000 17-DEC-2009 UTC
ISSUED 0714 16-DEC-2009
150° 160° 170° E 180° W
1024
H
1029
1016
L 1006
1008
L
1004
1024
H
1024
1008
1016
1000
992
984
30°
40°
50°
140° 150° 160° 170° E 180° W 170° 160°
MET 761
©Meteorological Service of New Zealand Limited 2009

Appendix 3: Wind and swell data from Port Taharoa Wave-Rider buoy



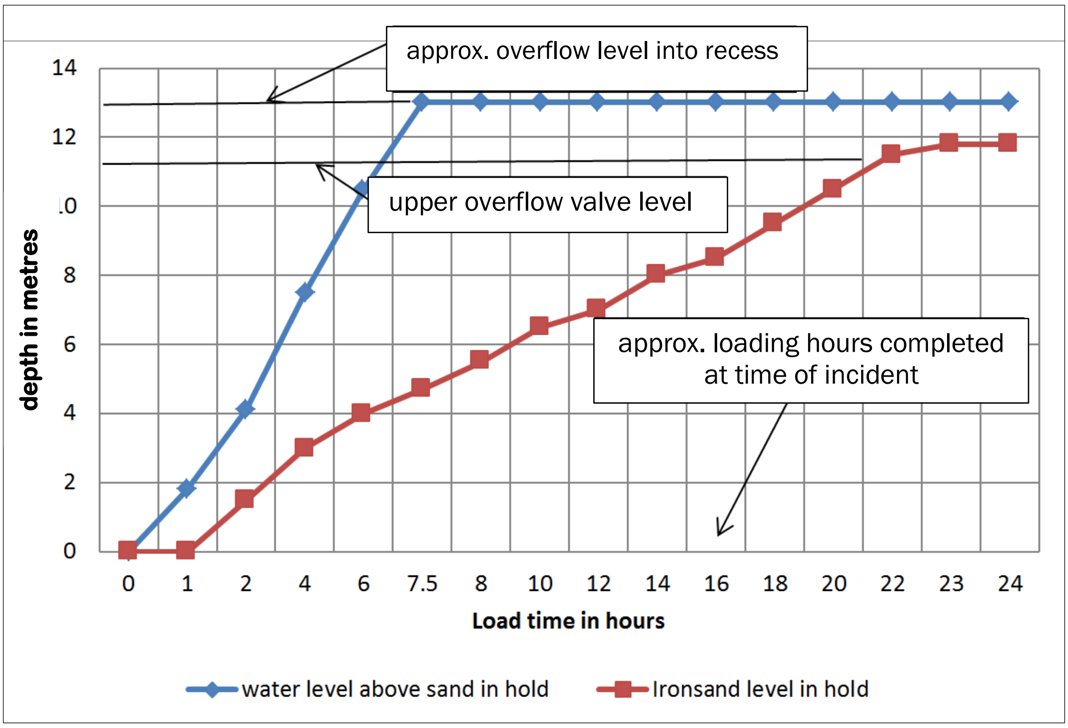



Voyage 82 - Wind Direction
205
200
195
190
185
180
175
170
Deg
Direction
22:00:00
22:02:00
22:04:00
22:06:00
22:08:00
22:11:00
22:13:00
22:16:00
22:18:00
22:20:00
22:22:00
22:24:00
22:26:00
22:28:00
22:30:00
22:35:00
22:37:00
22:39:00
22:41:00
22:43:00
22:45:00
22:47:00
22:49:00
22:52:00
22:54:00
22:56:00
22:58:00
23:00:00
Time


Voyage 82 - Wind Speed
30
25
20
15
10
5
0
Knots
Max
AVG
22:00:00
22:02:00
22:04:00
22:06:00
22:08:00
22:11:00
22:13:00
22:16:00
22:18:00
22:20:00
22:22:00
22:24:00
22:26:00
22:28:00
22:30:00
22:35:00
22:37:00
22:39:00
22:41:00
22:43:00
22:45:00
22:47:00
22:49:00
22:52:00
22:54:00
22:56:00
22:58:00
23:00:00
Time

Appendix 4: Stability commentary and calculation using the ship's stability programme

1. The graph below is drawn from data provided by Class NK (Nippon Kaiji Kyokai) from when the ship was converted to load slurry cargo in 1999. It is an approximation of the relative level of ironsand and water over time when loading number 3 hold. The graph demonstrates the amount of free-water above the ironsand at any given time. When considering that several cargo holds could have free-water above the cargo at any time during the loading process, the effect on the ship's metacentric height can be significant.



Relative levels of ironsand and water when loading, number 3 hold

2. A cargo hold with free-water is similar to a partially filled tank. When the ship is subject to a heeling force, the free-water above the ironsand in the hold will try to remain parallel with the ship's waterline. The centre of gravity of the free-water will move with the liquid, and its effect is to raise the ship's centre of gravity, causing a corresponding decrease in the ship's metacentric height and therefore its stability. This rise in centre of gravity and subsequent reduction in the stability of the ship is called the free surface effect.

3. The metacentric height of the *Taharoa Express* at the time of the incident was calculated using the ship's stability programme and was based on the contents of the ship's tanks, ballast holds and combined weight of ironsand and free-water in the cargo holds. The final metacentric height, without taking into account the free surface effect, was 9.86 metres. When the free surface effect was considered, the metacentric height reduced to 4.06 metres. Although there was a considerable reduction in metacentric height owing to the free surface effect, the final metacentric height showed the ship had a comfortable reserve of stability, which was well within acceptable limits (see calculation below).

Loadcal II/Ver. 2.0.4 (Rev.0)

<TRIM CALCULATION> "TAHAROA EXPRESS (SLURRY-NEW)" Dec.17,2009

CONDITION : V-82 SEQ-4-16DECCOND VESSLEL CARGO SHIFTED

ITEM	DENSITY (T/M3)	%	WEIGHT (MT)	LCG (M)	MOMENT (MT-M)	VCG (M)	MOMENT (MT-M)	RHO X I (MT-M)
LIGHT WEIGHT			18642	6.60	123037	12.11	225755	
D.W. CONSTANT			800	69.00	55200	13.40	10720	
PROV. AND CONSUM.			6	104.33	626	26.00	156	
F.W.T.(P)	1.0000 W	(79.4)	140	120.82	16915	20.60	2884	147
D.W.T.(S)	1.0000 W	(79.4)	140	120.82	16915	20.60	2884	147
COOL.WTK.	1.0000 E	(*)	*	*	*	*	*	*
F.W. SUB TOTAL			280		33830		5767	294
ER.FOT.P	0.9500 W	(27.4)	200	97.56	19512	13.05	2611	329
ER.FOT.S	0.9500 W	(23.6)	200	97.87	19574	12.63	2526	450
DB.FOT(P)	0.9500 W	(33.8)	400	59.29	23716	0.70	281	8210
DB.FOT(S)	0.9500 W	(29.6)	350	59.29	20752	0.62	218	8210
FO.SERV.P	0.9500 W	(78.0)	40	101.40	4056	15.63	625	1
FO.SETT.P	0.9500 W	(77.7)	40	98.20	3928	15.59	624	1
F.O. SUB TOTAL			1230		91538		6885	17201
D.O.T.(P)	0.8500 W	(30.2)	20	101.22	2024	0.70	14	65
D.O.T.(S)	0.8500 W	(46.9)	47	99.39	4691	0.92	43	162
DO.SERV.P	0.8500 W	(46.7)	5	94.20	471	19.13	96	1
DO.SETT.P	0.8500 W	(46.7)	5	94.20	471	19.13	96	1
D.O. SUB TOTAL			77		7658		249	228
SUMP.C	0.9000 E	(*)	*	*	*	*	*	*
THER TK.	0.9000 W	(45.5)	50	94.64	4732	19.10	955	12
L.O. SUB TOTAL			50		4732		955	12
NO.1 HOLD DMT	2.7400 W	(15.5)	6105	-105.64	-644932	4.76	29044	*
NO.2 HOLD	1.0000 W	(*)	*	*	*	*	*	*
NO.3 HOLD	2.7400 W	(33.4)	16898	-59.87	-1011683	6.48	109538	*
NO.4 HOLD	2.7370 E	(*)	*	*	*	*	*	*
NO.5 HOLD	2.7400 W	(31.4)	15785	-13.19	-208204	6.28	99096	*
NO.6 HOLD	1.0000 W	(*)	*	*	*	*	*	*
NO.7 HOLD	2.7400 W	(39.0)	19632	33.68	661206	7.13	139945	*
NO.8 HOLD	1.0000 W	(*)	*	*	*	*	*	*
NO.9 HOLD	2.7400 W	(14.8)	6219	79.98	497396	5.38	33450	*
NO.1 HOLD(DRY)	2.7400 E	(*)	*	*	*	*	*	*
NO.2 HOLD(DRY)	2.7370 E	(*)	*	*	*	*	*	*
NO.3 HOLD(DRY)	2.7400 E	(*)	*	*	*	*	*	*
NO.4 HOLD(DRY)	2.7370 E	(*)	*	*	*	*	*	*
NO.5 HOLD(DRY)	2.7400 E	(*)	*	*	*	*	*	*
NO.6 HOLD(DRY)	2.7370 E	(*)	*	*	*	*	*	*
NO.7 HOLD(DRY)	2.7400 E	(*)	*	*	*	*	*	*
NO.8 HOLD(DRY)	2.7370 E	(*)	*	*	*	*	*	*
NO.9 HOLD(DRY)	2.7400 E	(*)	*	*	*	*	*	*
CARGO SUB TOTAL			64639		-706218		411072	0
F.P.T.	1.0250 W	(40.5)	1500	-122.43	-183645	5.16	7745	6841
NO.1DWBT.C	1.0250 W	(*)	*	*	*	*	*	*
NO.1TWBT(P)	1.0250 W	(*)	*	*	*	*	*	*
NO.1TWBT(S)	1.0250 W	(*)	*	*	*	*	*	*
NO.2DWBT(P)	1.0250 W	(*)	*	*	*	*	*	*
NO.2DWBT(S)	1.0250 W	(*)	*	*	*	*	*	*
NO.2TWBT(P)	1.0250 W	(*)	*	*	*	*	*	*
NO.2TWBT(S)	1.0250 W	(*)	*	*	*	*	*	*
NO.3DWBT(P)	1.0250 W	(*)	*	*	*	*	*	*
NO.3DWBT(S)	1.0250 W	(*)	*	*	*	*	*	*
NO.3TWBT(P)	1.0250 W	(*)	*	*	*	*	*	*
NO.3TWBT(S)	1.0250 W	(*)	*	*	*	*	*	*
NO.4DWBT(P)	1.0250 W	(*)	*	*	*	*	*	*
NO.4DWBT(S)	1.0250 W	(*)	*	*	*	*	*	*
NO.4TWBT(P)	1.0250 W	(*)	*	*	*	*	*	*
NO.4TWBT(S)	1.0250 W	(*)	*	*	*	*	*	*
NO.5DWBT(P)	1.0250 W	(*)	*	*	*	*	*	*
NO.5DWBT(S)	1.0250 W	(*)	*	*	*	*	*	*
NO.5TWBT(P)	1.0250 E	(*)	*	*	*	*	*	*
NO.5TWBT(S)	1.0250 E	(*)	*	*	*	*	*	*
A.P.T.	1.0250 %	(100.0)	975	124.42	121269	15.62	15224	0
NO.2H/PUBWT	1.0250 E	(*)	*	*	*	*	*	*
NO.4H/PUBWT	1.0250 E	(*)	*	*	*	*	*	*
NO.6H/DPTK	1.0250 W	(*)	*	*	*	*	*	*
NO.8H/PUBWT	1.0250 W	(*)	*	*	*	*	*	*
B.W. SUB TOTAL			2475		-62376		22969	6841
NO.1 HOLD(WATER)	1.0000 W	(35.2)	5057	-105.64	-534221	10.37	52421	67132
NO.2 HOLD(WATER)	1.0000 W	(*)	*	*	*	*	*	*
NO.3 HOLD(WATER)	1.0000 W	(29.1)	5368	-59.87	-321382	12.66	67936	143043
NO.4 HOLD(WATER)	1.0000 W	(*)	*	*	*	*	*	*
NO.5 HOLD(WATER)	1.0000 W	(30.8)	5654	-13.19	-74576	12.42	70235	142711
NO.6 HOLD(WATER)	1.0000 W	(*)	*	*	*	*	*	*

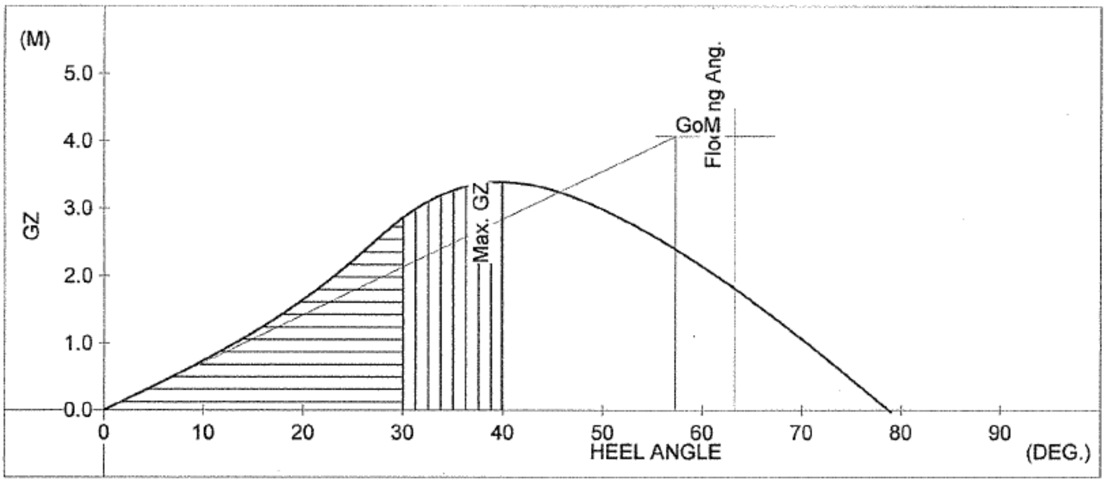
Loadcal II/Ver. 2.0.4 (Rev.0)

NO.7 HOLD(WATER)	1.0000 W (25.3)	4653	33.68	156713	13.41	62401	143374
NO.8 HOLD(WATER)	1.0000 W (*)	*	*	*	*	*	*
NO.9 HOLD(WATER)	1.0000 W (33.2)	5090	79.98	407098	11.21	57051	115705
OTHER SUB TOTAL		25822		-366369		310044	611965
TOTAL		114021		-818343		994572	636540

DISPLACEMENT (MT)	114021	LCG (M)	-7.18	TKM (M)	18.37
DEAD WEIGHT	95379	LCB (M)	-10.35	VCG (M)	8.72
DRAFT AT C.F. (M)	12.44	HBG (M)	3.17	GM (M)	9.65
DRAFT FORE (M)	11.41	LCF (M)	-5.14	GGo (M)	5.58
DRAFT AFT (M)	13.56	MTC (MT-M)	1677.02	GoM (M)	4.06
DRAFT MEAN (M)	12.49	TPC (MT)	99.30	PROP.IMMERSION(%)	113
TRIM(AFT) (M)	2.15			FORE DRAFT/Lpp(%)	4.40
DENSITY OF S.W.(T/M3)	1.0250			TRIM/Lpp (%)	0.83
MIN.DRAFT(SLAMMING)(M)	7.97	MAX.SUMMER DRAFT (M)	17.42	MAX AIR DRAFT (M)	15.14
N.B.Visibility (M)	460.85				

TANK	S.F.	S.G.	F.S.S.G.	Weight (MT)
NO.1 HOLD	13.095	2.7400	*	6105
NO.2 HOLD		1.0000	*	0
NO.3 HOLD	13.095	2.7400	*	16898
NO.4 HOLD		2.7370	*	0
NO.5 HOLD	13.095	2.7400	*	15785
NO.6 HOLD		1.0000	*	0
NO.7 HOLD	13.095	2.7400	*	19632
NO.8 HOLD		1.0000	*	0
NO.9 HOLD	13.095	2.7400	*	6219
NO.1 HOLD(DRY)	13.095	2.7400	*	0
NO.2 HOLD(DRY)		2.7370	*	0
NO.3 HOLD(DRY)	13.095	2.7400	*	0
NO.4 HOLD(DRY)		2.7370	*	0
NO.5 HOLD(DRY)	13.095	2.7400	*	0
NO.6 HOLD(DRY)		2.7370	*	0
NO.7 HOLD(DRY)	13.095	2.7400	*	0
NO.8 HOLD(DRY)		2.7370	*	0
NO.9 HOLD(DRY)	13.095	2.7400	*	0

CONDITION : V-82 SEQ-4-16DECCOND VESSLEL CARGO SHIFTED



IMO A.749(18), Chapter 3.1 Stability

CRITERIA	UNIT	REQUIRED	ATTAINED	JUDGE
Area(0deg.- 30deg.)	M-RAD	0.055	0.657	GOOD
Area(30deg.- 40deg.or Theta f)	M-RAD	0.030	0.561	GOOD
Area(0deg.- 40deg.or Theta f)	M-RAD	0.090	1.217	GOOD
Max.GZ	M	0.20	3.38	GOOD
Theta at Max.GZ	DEG	25.00	39.88	GOOD
GoM	M	0.15	4.06	GOOD
Theta: Flooding Angle	DEG	-	63.23	
Range of Stability	DEG	-	63.23	
VCGo	DEG	-	14.31	
GZ at 30deg.	M	-	2.85	

Appendix 5: Ironsand properties review and comparison with historical data

NEW ZEALAND STEEL

Properties Review of the Bottom sampled Ironsand and a Comparison with Historical Data.

27/01/2010.

Version. 1.1

Following on from the initial report, (Properties Review of loaded Ironsand. 06/01/2010), reviewing the chemical and physical attributes of the ironsand from the top of the cargo shipment V504. Further monitoring was requested to identify any product changes in the bottom of each hold. The intention in both cases was to determine if the product differed in any marked way from prior shipments.

Samples were taken at the unloading port and sent to New Zealand Steel for analysis. 20 samples were received, made up of 10 samples from holds 1,3,5,7 and 9. Two samples from each hold were taken along with back ups. The samples were taken at 200 and 500 mm above the filter housing.

The samples were analysed for the following parameters.

Particle distribution.

Slimes, Mag and Non-mag.

Moisture.

Chemistry using an ironsand calibrated XRF.

Specific Gravity.

The samples, contained in 200 mL plastic bottles were all well sealed and packed in 3 separate plastic bags. Some moisture had erased the identification from a few of the bottles but a sufficient number of containers remained to give a full sample suite.

	p1	p10	p30	p80	Mags	Non mag	Slimes
From Cargo Dec				185			
Averaged Top results	80	119	135	188	93.37	5.30	1.34
Average Bottom results	81	117	132	182	91.7	7.45	0.87
Units	microns	microns	microns	microns	%	%	%

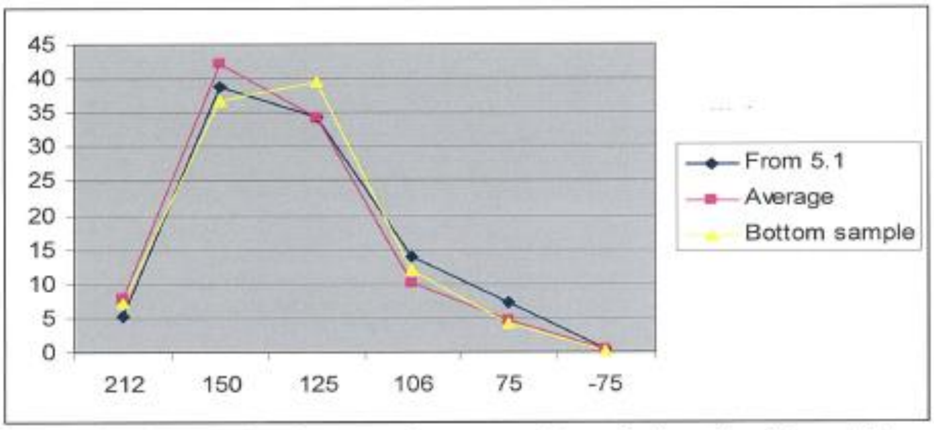
Table Two: Sizing's and Slimes from the Cargo declaration, Top and Bottom samples.

Bottom	% Mags	%Non-Mags	% Slimes
H1 200	88.93	10.53	0.54
H1 500	90.59	8.04	1.37
H3 200	92.49	6.62	0.89
H3 500	90.89	8.18	0.93
H5 200	94.05	5.03	0.92
H5 500	93.59	5.96	0.45
H7 200	92.71	6.9	0.39
H7 500	90.37	7.41	2.22
H9 200	90.54	8.78	0.68
H9 500	92.52	7.13	0.35
Average	**91.67**	**7.458**	**0.87**

Table Three: Comparison of Individual samples for Sizing's and Slimes from the Bottom location.

Top	% Mags	%Non-Mags	% Slimes
H1 T	96.40	2.17	1.43
H3 T	93.60	5.94	0.46
H5 T	94.40	5.10	0.50
H7 T	93.00	6.43	0.57
H9 T	96.40	3.32	0.28
H1 B	91.00	6.99	2.01
H3 B	89.80	7.16	3.04
H7 B	93.30	5.88	0.82
H9 B	92.40	4.68	2.92
Average	**93.37**	**5.30**	**1.34**

Table Four : Comparison of Individual samples for Sizing's and Slimes from the Top location.



Graph Five: Comparison between the current Cargo declaration, (From 5.1), Average of Samples from Top of cargo and from Bottom of cargo.

	Fe	CaO	SiO_2	TiO_2	Al_2O_3	MgO
H1 200	53.16	2.57	7.02	7.17	3.72	3.93
H1 500	54.44	2.21	5.95	7.34	3.75	3.72
H3 200	54.24	2.26	6.14	7.32	3.79	3.79
H3 500	52.82	2.67	7.27	7.14	3.78	4.01
H5 200	56.62	1.57	4.05	7.56	3.72	3.39
H5 500	55.28	1.89	4.9	7.43	3.71	3.57
H7 200	55.29	1.99	5.34	7.43	3.76	3.62
H7 500	53.15	2.65	7.25	7.14	3.79	3.97
H9 200	53.97	2.33	6.41	7.28	3.67	3.74
H9 500	54.47	2.2	5.96	7.34	3.76	3.72
Average @ 200 mm	**54.66**	**2.14**	**5.79**	**7.35**	**3.73**	**3.69**
Average @ 500 mm	**54.03**	**2.32**	**6.27**	**7.28**	**3.76**	**3.80**
Units	%	%	%	%	%	%

Table Five: Chemistry of each hold sample plus overall depth average.

	Fe	CaO	SiO_2	TiO_2	Al_2O_3	MgO
From Cargo dec	56.87	1.46	3.87	7.66	3.74	3.35
Averaged Top results	56.61	1.41	3.87	7.46	3.72	3.26
Average @ 200 mm	54.66	2.14	5.79	7.35	3.73	3.69
Average @ 500 mm	54.03	2.32	6.27	7.28	3.76	3.80
Units	%	%	%	%	%	%

Table Six: Comparison of Chemistry between Cargo declaration, Average of Samples from Top of cargo and from Bottom of cargo.

Section 4

Assessment of acceptability of consignments for safe shipment

4.1 Identification

4.1.1 Cargoes in this Code have been assigned a Bulk Cargo Shipping Name (BCSN). Some have additionally been assigned a United Nations number. When a bulk cargo is carried by sea it should be identified in the transport documentation by the Bulk Cargo Shipping Name. This should be supplemented by the United Nations (UN) number when it is stated in the relevant individual entry.

4.1.2 Correct identification of a bulk cargo facilitates identification of the conditions necessary to safely carry the cargo and determines the emergency procedures necessary to deal with an incident involving some cargoes.

4.2 Provision of information

4.2.1 The shipper should provide the master or his representative with appropriate information on the cargo sufficiently in advance of loading to enable the precautions which may be necessary for proper stowage and safe carriage of the cargo to be put into effect.

4.2.2 Such information should be confirmed in writing and by appropriate shipping documents prior to loading the cargo on the ship. The cargo information should include:

- the Bulk Cargo Shipping Name when the cargo is listed in this Code. Secondary names can be used in addition to the Bulk Cargo Shipping Name;
- the IMO Class for dangerous cargoes in Group B, except MHB;
- the UN number, preceded by letters "UN", for dangerous cargoes in Group B;
- the total quantity of the cargo offered;
- information on the stowage factor;
- the trimming procedures;
- the likelihood of shifting, including angle of repose, if applicable;
- additional information in the form of a certificate on the moisture content of the cargo and its transportable moisture limit in the case of a concentrate or other cargo which may liquefy;
- formation of a liquid base and shipping of cargo;
- any other relevant safety information, such as:
  - chemical properties in the case of a solid bulk cargo not classified in accordance with the provisions of the IMDG Code, but which has chemical properties that may create a potential hazard;
  - toxic or flammable gases which may be generated by cargo;
  - flammability, toxicity, corrosiveness and propensity to oxygen depletion of the cargo;
  - self-heating properties of the cargo, and the need for trimming if appropriate, etc.
- if waste cargoes are being transported for disposal, or for processing for disposal, the name of the cargoes should be preceded by the word "WASTE".

In addition, other elements of information deemed necessary by national authorities may also be shown.

4.2.3 Information provided by the shipper should be accompanied by a declaration.* Further guidance on this cargo declaration is found in the Code of practice for the safe loading and unloading of bulk cargoes (BLU Code) published by the Organization.†

4.3 Certificates of test

4.3.1 To obtain the information, as required in 4.2.2, the shipper should arrange for the cargo to be properly sampled and tested. Furthermore, the shipper should provide the ship's master or his representative, at the loading port, with the appropriate certificates of test, as applicable.

4.3.2 Certificates stating the transportable moisture limits should contain, or be accompanied by, a statement by the shipper that the moisture content specified in the certificate of moisture content is, to the best of his knowledge and belief, the average moisture content of the cargo at the time the certificate is presented to the master. When cargo is to be loaded into more than one cargo space of a ship, the certificate of moisture content should certify the moisture content of each type of finely grained material loaded into each cargo space. However, if sampling according to the procedures recommended in this Code indicates that the moisture content is uniform throughout the consignment, then one certificate of average moisture content for all cargo spaces should be acceptable.

4.3.3 Where certification is required by the entries for individual cargoes possessing chemical hazards, the certificate should contain or be accompanied by a statement from the shipper that the chemical characteristics of the cargo are, to the best of his knowledge, those existing at the time of the ship's loading.

4.4 Sampling procedures

4.4.1 Physical property tests on the consignment will be meaningless unless they are conducted prior to loading on truly representative test samples.

4.4.2 Sampling should be conducted only by persons who have been suitably trained in sampling procedures and who are under the supervision of someone who is fully aware of the properties of the consignment and also the applicable principles and practices of sampling.

4.4.3 Prior to taking samples, and within the limits of practicability, a visual inspection of the consignment which is to form the ship's cargo should be carried out. Any substantial portions of material which appear to be contaminated or significantly different in characteristics or moisture content from the bulk of the consignment should be sampled and analysed separately.

Depending upon the results obtained in these tests, it may be necessary to reject those particular portions as unfit for shipment.

4.4.4 Representative samples should be obtained by employing techniques which take the following factors into account:

.1 the type of material;

.2 the particle size distribution;

.3 composition of the material and its variability;

.4 the manner in which the material is stored, in stockpiles, rail wagons or other containers, and transferred or loaded by material-handling systems such as conveyors, loading chutes, crane grabs, etc.;

.5 the chemical hazards (toxicity, corrosivity, etc.);

.6 the characteristics which have to be determined: moisture content, flow moisture point, bulk density/stowage factor, angle of repose, etc.;

.7 variations in moisture distribution throughout the consignment which may occur due to weather conditions, natural drainage, e.g., to lower levels of stockpiles or containers, or other forms of moisture migration; and

.8 variations which may occur following freezing of the material.

* Refer to the Form for Cargo Information (MSC/Circ.663).

† Refer to the Code of practice for the safe loading and unloading of bulk carriers, adopted by the Organization by resolution A.862(20).

Appendix 7: Shipper's Declaration Re Cargo and Further Information (pre-incident)

NEW ZEALAND STEEL

11 December 2009

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A BlueScope Steel Company

To:
The Shipowners and Master
mv Taharoa Express

Shipper's Declaration Re Cargo and Further Information

Dear Sirs,

Confirming, and updating, our existing documentation of this topic, I offer as follows:

New Zealand Steel have been producing and exporting Titano-magnetite Iron Sands from the Taharoa region of North Island, New Zealand for the past 36 years. During this period, this cargo has always been loaded as slurry onto a suitably modified bulkcarrier for carriage to ports in China and Japan.

As Shippers of this cargo, we make the following declaration:

a) This cargo is Iron Sands mined from the coastal area of Taharoa, West Coast of North Island, New Zealand and is upgraded by various processes to increase its iron content before shipment.

b) The cargo is loaded via an off shore marine terminal facility known as S.B.M. located offshore at Taharoa. The cargo is loaded as slurry with a water content of approximately 50%.

c) While the name Titanomagnetite "concentrate" is used in various documents, we confirm that this cargo is not a concentrate in the context of the meaning that term is given under section 1 IMO Code of Safe Practice for Bulk Cargoes (2004).

d) For this cargo, there is no known danger of a cargo shift taking place due to liquefaction and the moisture content of this cargo.

e) Section 7 and Section 8 of the IMO Code of Safe Practice for Bulk Cargoes (2004), and the related requirements of section 4 and Appendix 2, cannot be applied to the Taharoa Ironsand as a slurry loaded cargo.

f) The load sequence plan will generally aim for an average (for the entire cargo) content moisture on completion of loading\dewatering at Taharao (and before sailing) of 9.3%. Experience has shown that the actual moisture content of the cargo can range from about 9 to 13% - depending on the final de-watering applied by the vessels Master.

To assist you in better understanding this cargo and its characteristics in regard to its loading and transportation, I attach extracts from the "Submission in support of the declaration pertaining to the properties of Taharoa Ironsand as a slurry loaded bulk cargo". Sections 2 to 6 are attached [file "*Submission Supporting Document - Sections 2-6 - 11 Dec 09.pdf*"].

This document summarises the tests and trials New Zealand Steel has carried out, and/or commissioned, into the nature of this cargo, as slurry loaded, together with a summary of the mining and slurry loading operations at Taharoa.

This document has been presented to Maritime New Zealand in order to support the submission to the IMO to have the Taharoa Ironsand cargo - as slurry loaded - listed in the 2011 ISM Bulk Cargo Code as a non-liquefying cargo.

Please feel free to contact us if you need any clarification.

Section 5

Properties of the Taharoa Ironsand as a slurry loaded bulk cargo.

5.1 Basic properties of Taharoa Ironsand.

Passing Screen (um)	% Passing
425	0.01
300	0.31
212	5.01
150	38.93
125	34.37
106	13.79
75	7.16
53	0.27
-53	0.14

Table 5.1: Nominal size distribution of the Taharoa Ironsand.

Element	Nominal wt%
Fe	56.87
CaO	1.456
SiO2	3.87
TiO2	7.66
Al2O3	3.74
MgO	3.35
V2O3	0.446
MnO	0.66
P	0.17
S	0.004
V2O3	0.446
MnO	0.66

Table 5.22: Nominal chemical composition of the Taharoa Ironsand.

5.2 Bulk properties of Taharoa Ironsand.

Testing as per NZSM laboratories. Bulk densities are for light compaction - volumetric container is tapped lightly 5 times.

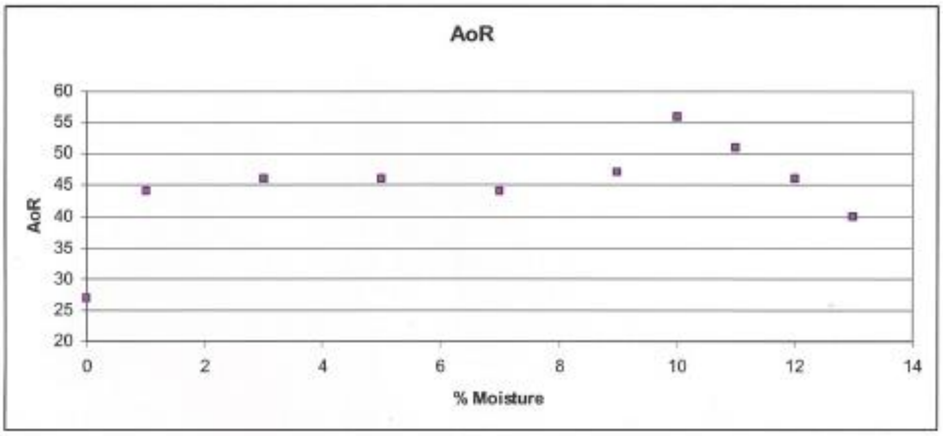
Parameter	Value
Particle Density	4.75 t/m^3
Dry Bulk Density (dry, 0% moisture)	2.74 t/m^3
Dry Bulk Density (saturated, 13% moisture)	2.82 t/m^3
Void Volume (dry, 0% moisture)	42.3%
Void Volume (saturated, 13% moisture)	40.6%
Moisture content at Saturation	13%
Angle of Response (0% moisture)	27°
Angle of Response (saturated, 13% moisture)	40°

Table 5.3: Nominal bulk properties of the Taharoa Ironsand.

20 July 2009 Taharoa Ironsand Submission Data - Section 5

5.3 Angle of Repose versus Moisture content.

When bulk granular materials are poured onto a horizontal surface, a conical pile will form. The angle between the surface of the pile and the horizontal surface is known as the angle of repose. Testing as per NZSM laboratories.



Graph 5.1: Angle of repose vs. Moisture.

Conclusions:

a) The angle of repose is stable from 1% to 13% moisture.

b) As the Taharoa Express dewaters, the angle of repose will remain stable.

5.4 Settling properties of Taharoa Ironsand.

Settling Test: a known volume of sand is shaken vigorously with a known volume of water. The cylinder is then placed onto a flat surface and settling is observed.

Observations:

a) 50% of the ironsand has settled within 2 seconds.

b) 95% of the ironsand has settled within 60 seconds.

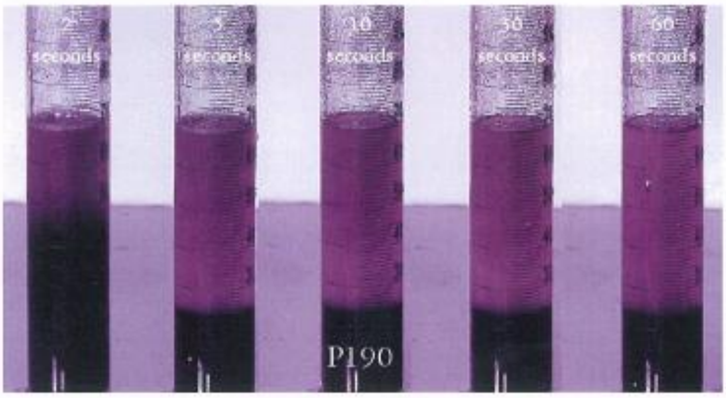


Photo 5.1: Settling properties of Taharoa Ironsand.

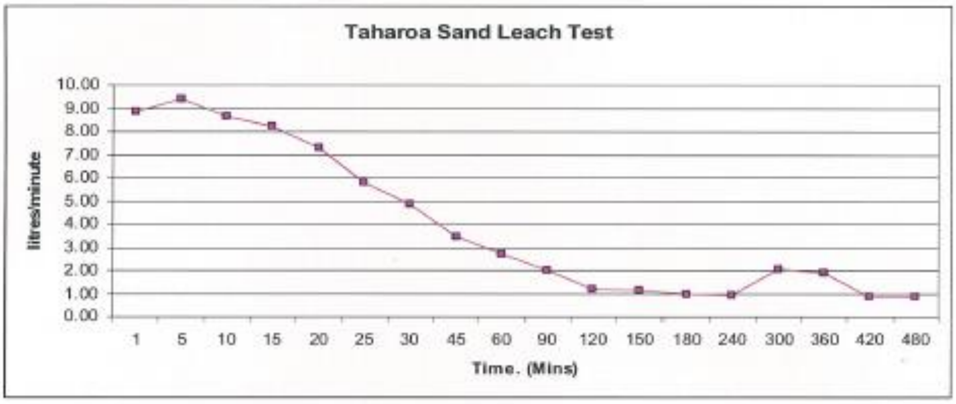
Conclusions:

Taharoa Ironsand settles rapidly to a dense free draining product.

5.5 Free Draining properties of Taharoa Ironsand.

Testing of the free draining character of Taharoa Ironsand was done by pumping product as a 50% wt/wt slurry into a tank 1.2m by 1.2m by 2.4 m. Sand was filled to 10 cm below tank lip.

Volume checks, of the leachate were taken at times as indicated.



Graph 5.2: Draining of water from a test tank filled with Taharoa Ironsand.

Time. (minutes)	Leach rate Litres/min
0	0.00
1	8.85
5	9.38
10	8.63
15	8.24
20	7.28
25	5.78
30	4.85
45	3.48
60	2.70
90	2.01
120	1.18
150	1.15
180	1.00
240	0.94
300	2.03
360	1.87
420	0.86
480	0.84

Table 5.4: Data for above Graph 5.2 re draining of water from the test tank.

Observations:

- The Taharoa Ironsand has very low clay content.
- It will free drain to less than 2% water.
- Water freely flows through Taharoa Ironsand.
- Technically the Taharoa Ironsand is not shipped as a slurry - the water is a transport medium only.

Conclusions:

The Taharoa Ironsand is a rapidly, free draining product.

5.5 Laboratory tested FMP and TML of the Taharoa Ironsand.

Analysis performed by CCI Newcastle in accordance with Australian Standard Methods

Definition	Data
Date Analysed:	22 August 2007
Flow Point (%ar)	10.30
Transportable Moisture Limit (%ar)	9.27

Table 5.5: FMP and TML as determined for Taharoa Ironsand.

5.6 Stability of Taharoa Ironsand in the saturated state.

In the saturated state, at compactions typical of the loaded product, the Taharoa Ironsand cannot be induced to move via mechanism of liquefaction under laboratory conditions. In testing conducted by consulting engineers - Beca Consulting - they report (2007) and conclude:

"*We conducted a series of tests with saturated sand set initially at 18.5 degrees. Liquefaction was induced by hitting the tank at regular intervals; the effects were temporary glistening of the sand surface and some consolidation of the sand each time the tank was hit; some water was observed to seep away from the base of the sand slope. However the relatively steep slope did not shift measurably.* ***This test shows that even under extreme conditions, a saturated sand cargo could not be induced to "flow" or move to any significant degree***"

The non-liquefying statement in NZSM's cargo declaration has been peer reviewed by consulting engineers - Tonkin & Taylor. To paraphrase Tonkin & Taylor report (2008) - Attachment 3 of this submission - and conclude that the Taharoa Ironsand cargo is unlikely to experience liquefaction due to:

- The high particle density of the Taharoa Ironsand.
- The high void volume of the Taharoa Ironsand in the compacted and semi-compacted states.
- The relatively high compaction state of the Taharoa Ironsand as slurry loaded.
- Points 1 to 3 resulting in what little compaction is possible in the cargo will only result in a rise in pore pressure that is easily dissipated without significantly reducing the frictional strength of the cargo.

Tonkin & Taylor conclude:

"***The observation of the experimental work undertaken by others and our conclusion that the Ironsand in the vessel cargoes holds is unlikely to liquefy are both consistent with the observation that in the 35 years of operation, the Taharoa Ironsands as a cargo, has not been known to shift due to liquefaction, both during loading and in the number of times the vessel has put to sea.***"

5.7 NZSM's position on the stability of the cargo.

NZSM maintains that:

"While detrimental cargo migration of the Taharoa Ironsand cargo (as slurry loaded) is possible under some rare circumstances when free water is present over the cargo, ***cargo movement is not possible once the supernatant water has been removed."***

Appendix 8: Post-incident review of ironsand properties and behaviour during slurry loading

Post-incident analysis of the cargo shift

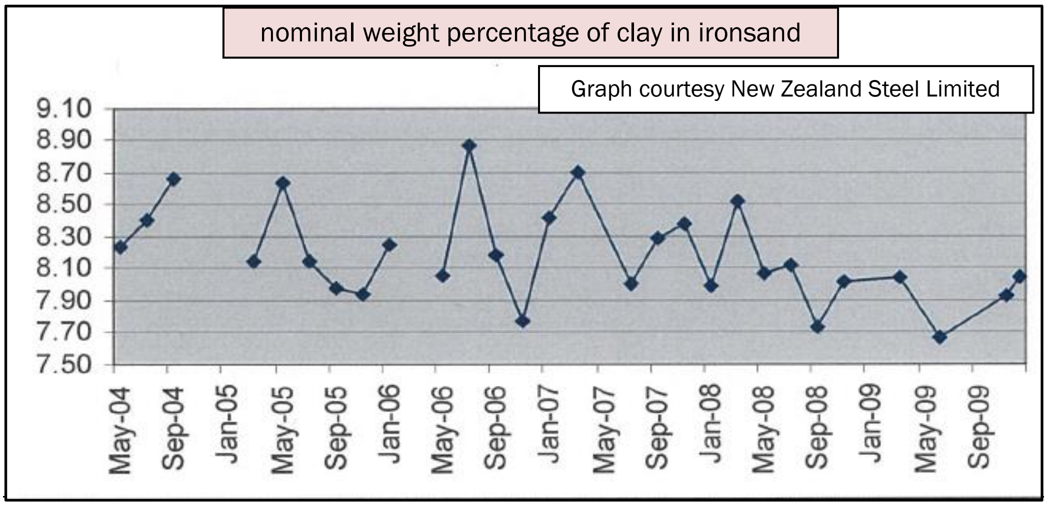
1. NZSL commissioned 2 independent engineering consultants to carry out engineering studies related to the stability of the cargo and the ship during the loading process. A report was subsequently prepared, titled, "Stability Assessment of the Ironsand in the Cargo Holds during Loading" (NZSL report (2011)).

2. An independent expert[10] was appointed by the Commission to comment on the NZSL report (2011) findings and conduct tests to determine the liquefaction resistance of ironsand.

3. The NZSL report (2011) included laboratory tests undertaken to characterise the geotechnical properties of the ironsand material and an assessment of the liquefaction susceptibility of the ironsand material in the cargo holds.

4. The ironsand was tested to determine if clay or slimes (present in the ironsand) were higher than in previous shipments.

5. The results of the review indicated that the physical and chemical parameters of the ironsand were similar at the top and bottom of the hold, and also to the historical and "Cargo Declaration" quoted figures. Also noted was an overall reduction in clay elements in the previous 6 years due to improved processing and cleaning of the ironsand



Historical review of clay elements

6. Dynamic stability modelling was undertaken to assess the stability of the ironsand in the cargo holds for the expected range of ship motions. An attempt was also made to validate the cargo deposition modelling work by monitoring the loading phases of 3 post-incident voyages.

7. The general weather conditions observed on the 3 post-incident voyages, as described in the NZSL report (2011) are stated below[11]:

> The ship heading did not remain constant throughout the loading phases, but fluctuated in orientation by up to 180°. However, the vessel heading was predominantly in the southeast to southwest direction.

[10] Mr Rolando P. Orense, a Senior Lecturer (Civil and Environmental Engineering) at the University of Auckland, with more than 24 years of experience in civil and geotechnical engineering.
[11] NSZL (2011) report, Chapter 10, section 10.4.1.

The significant swell wave height for the loading phase of the three voyages typically ranged between 1 and 2 m and the swell wave period typically ranged between 10 and 15 seconds.

The swell wave direction was predominantly in the north east direction, resulting in a vessel heading relative to the swell waves ranging between 0° (head on) and 90° (side on). However, predominantly the heading of the vessel relative to the swell waves ranged between 30° and 50°.

8. The observations made on the 3 monitored voyages after the incident were that the vessel roll periods typically ranged between 10 and 14 seconds and the ship half-roll amplitudes typically ranged between 0° and 4°. These were similar conditions to those when the incident occurred.

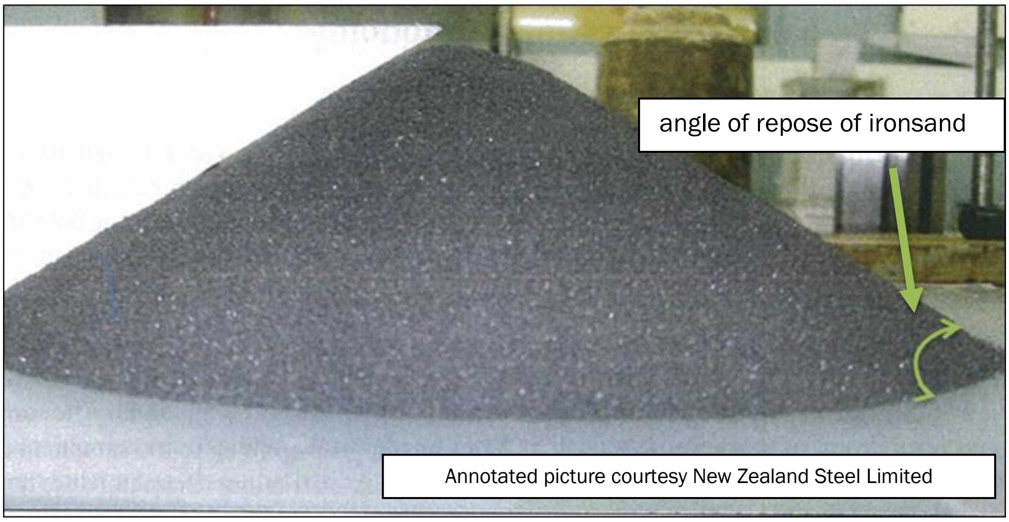
Laboratory testing of the ironsand material

9. Laboratory testing was undertaken on bulk samples of the ironsand material obtained from the stockpile of processed material at Port Taharoa, as well as from numbers 3 and 7 holds on board the *Taharoa Express* at the time of the incident. A number of physical geotechnical engineering characteristics of the ironsand material were determined in the NZSL (2011) report. Some of the physical properties of the ironsand samples, relevant to this investigation as summarised in the NZSL report (2011),[12] are highlighted and shown in table below

Physical properties of ironsand

solid density tonnes/m3	density state	dry density tonnes/m3	bulk density tonnes/m3	friction angle degree	angle of repose degree
	mimimum density	2.22	2.74	27	30.5(dry)
4.6	intermediate density	2.58	3.02	32	24.7(submerged)
	maximum density	2.94	3.3	46	

10. The NZSL report (2011) stated that the angle of repose of the ironsand, measured as the angle above horizontal, was the steepest slope at which the material would stand. The angle of repose of loosely deposited ironsand was determined by 2 methods: deposition as dry ironsand and deposition of ironsand underwater.



Angle of repose of ironsand

[12] NZSL (2011) report, Chapter 5, section 5.2, Table 5-1.

11. The NZSL report (2011)[13] stated that the average angle of repose of dry ironsand was 30.5° and the angle of repose of ironsand deposited under water was 24.7°.

Ironsand deposition

12. Ironsand deposition modelling within a typical hold in the *Taharoa Express* was conducted in the post-incident study commissioned by NZSL. Three filling scenarios were considered: the nozzle rotated hourly between 70° starboard and port; the nozzle held in one direction only (starboard side); and the nozzle held in one direction pointing into the forward starboard corner of the hold.

13. A few of the conclusions drawn in the NZSL report (2011) are stated below.

> The modelling results show that heavy ironsand particles create a falling column of water within the hold, where the jet enters the supernatant water.
>
> The falling column of water drives a continuous circulation of fluid round the cargo hold.
>
> Although much of the heavy ironsand drops out of suspension immediately below the jet entry region, these density driven currents, together with the slope of the bed, carry ironsand throughout the hold.
>
> **The deposited profile is highest under the nozzle region, sloping away with distance from the nozzle. The lowest part of the deposited ironsand profile occurs on the Aft bulkhead and corners, furthest from the nozzle, consistent with onboard observations.** (emphasis added).
>
> By the end of the filling process there is approximately 3 to 4 m difference in elevation from Fwd to Aft and the cargo is loaded preferentially to the starboard side of the cargo hold, matching the modelled offset of the physical nozzle from the vessel's centreline

14. The ironsand deposition modelling described how the ironsand slurry acted within a motionless ship. In reality, the motion of the *Taharoa Express* was affected by the swell and wind conditions. Ship motion would cause the free-water above the surface of the ironsand to slosh within the cargo hold and affect the ironsand surface profile.

15. The NZSL report (2011) addressed this issue, and described the following mechanisms as having the potential to cause the predicted deposition profile to vary from the actual profile of the ironsand on board the *Taharoa Express.*

> A column of high suspended ironsand concentration occurs in the supernatant water directly below where the jet enters the water surface in the cargo hold. The ironsand particles drop out of suspension immediately below this cloud of high suspended sediment concentration within the supernatant water. Sloshing of the supernatant water in the cargo hold moves about the position of the cloud of high suspended sediment concentration of water, spreading out the primary deposition throughout the cargo hold.
>
> Sloshing of the supernatant water also increases the fluid velocities near the bed of packed ironsand. This helps to further spread the soup mixture layer throughout the cargo hold increasing the distribution of the secondary deposition throughout the cargo hold.
>
> The increased velocities of the supernatant water near the bed also increase the erosion process at the crests where the water depth is shallower and re-deposition in the troughs where the water depth is deeper and the velocities are lower.

16. **The deposition modelling indicated that slurry loading during calm weather conditions would result in the steepest deposition profiles, while slurry loaded during rough weather conditions would be more stable as the sloshing free-water flattened the ironsand.** The NZSL report (2011) also stated that if the slurry were loaded during calm conditions and the weather subsequently

[13] NZSL (2011) report, Chapter 5, section 5.3.2.

became rougher, or the ship turned side on to the swell and significant roll motion occurred, the cargo would probably be less stable than if it had been deposited in initially rougher conditions.

Liquefaction

17. A description of the mechanism of liquefaction as stated in the NZSL report (2011), is as follows[14]:

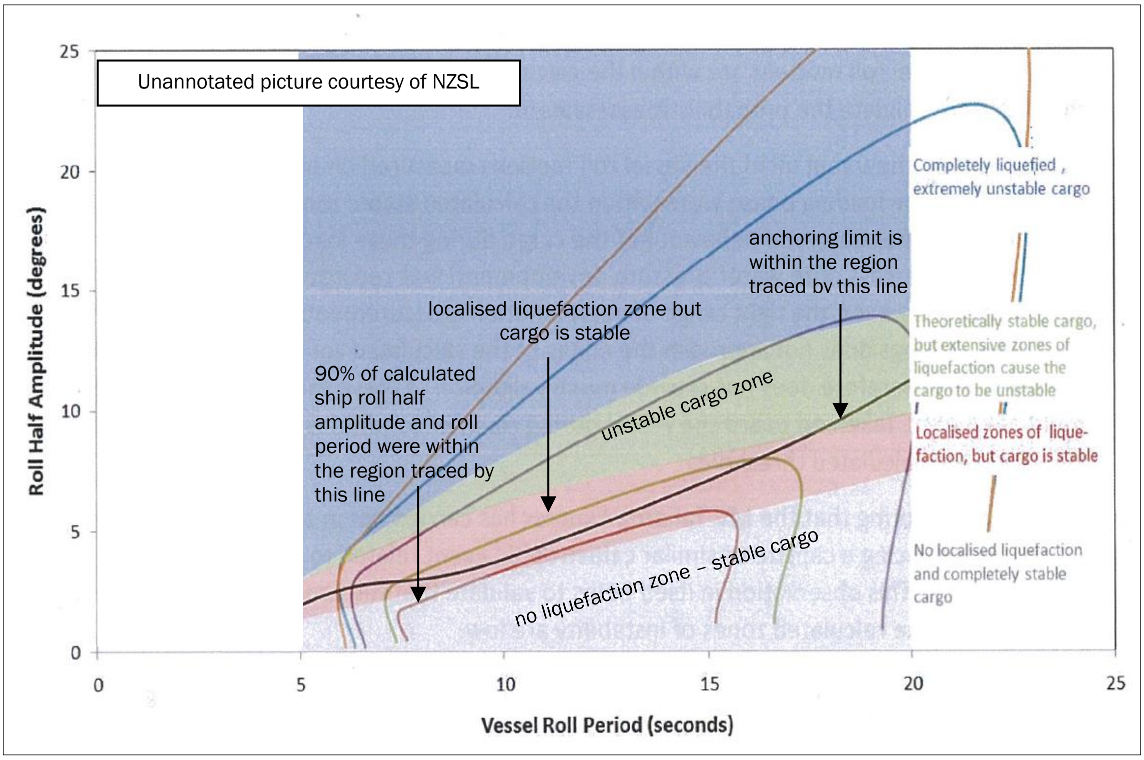
> Loose ironsand, when subjected to cyclic loading or other loading such as single larger perturbation (example vibration), will tend to densify. If the granular material is partially or totally saturated (example: water fills the voids between the particles), then when densification occurs, the decreasing void space between the particles results in a temporal increase in pore pressure because the water in the voids is incompressible. This is known as excess pore water pressure development. The inter-particle frictional strength decreases with increasing pore water pressure. Hence, temporary excess pore water pressure development results in temporary strength loss of the granular material and this is known as the liquefaction process. Liquefaction is defined as the point at which the frictional strength of the granular material is reduced to zero.

18. The dynamic behaviour of ironsand, when subject to a combination of ship motions during loading, was modelled and each combination of ship motion was categorised as being stable or unstable based on the amount of cumulative displacement of the cargo after multiple motion cycles. The report stated that the stability of the ironsand could generally be plotted as a function of ship roll amplitude and roll period for a given level of ironsand and water within the hold.

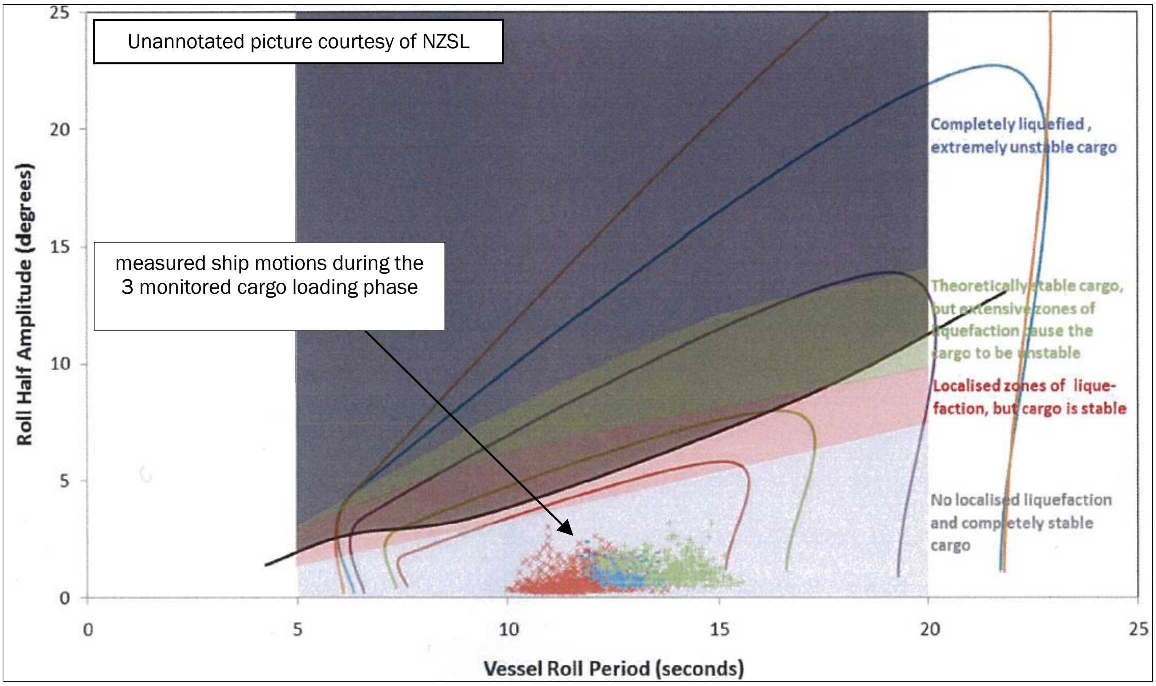
19. The potential of ironsand to liquefy during the loading stage was assessed by comparing the cyclic stresses generated by the ship motion with the cyclic resistance of the ironsand to liquefaction. An assessment of the cyclic stresses imparted on the ironsand cargo due to ship motion was undertaken using the software package FLAC. The cyclic resistance was determined by conducting a series of cyclic tri-axial tests at the University of Auckland.

20. An independent company was commissioned by NZSL to provide a probabilistic analysis of the way the ship would respond to sea and weather conditions[15]. The company modelled weather conditions based on a hindcast of weather information from the past 20 years. In order to determine the likelihood of the ship being subjected to the range of roll behaviours that could cause liquefaction or instability, the results of the probabilistic analysis were superimposed over the liquefaction and stability analysis (see Figure below).

[14] NZSL (2011) report, Chapter 8, section 8.1
[15] NZSL (2011) report, Chapter 9.



Probability of ship roll behaviour superimposed on the calculated zones of cargo liquefaction and stability for a half-full cargo hold (5-metre-deep, saturated ironsand)



Measured ship motions plotted against the calculated liquefaction and stability thresholds for a half-full cargo hold (5-metre-deep, saturated ironsand)

21. The results obtained were interpreted in the report as stated below[16]:

> **For 90% of the modelled weather conditions, the results of stability modelling indicate that the roll behaviour of the MV *Taharoa Express* results in a stable cargo.** (emphasis added)
>
> The figure indicates that for approximately 5% of the modelled weather conditions, localised liquefaction may occur, but the overall mass of the cargo was likely to remain stable.
>
> Beyond the zone of localised liquefaction, the calculations indicate that the roll motions of the vessel may induce instability in the cargo and it may occur during the worst 1% to 5% of the modelled weather conditions

22. Ship movements were monitored during the loading phase of 3 post-incident voyages, and the dominant roll motion characteristics were superimposed over the liquefaction and stability thresholds (see above Figure). The figure shows that all the measurements of ship roll motions were within the stable zone.

[16] NZSL (2011) report, Chapter 10, section 10.6.2.1.

Appendix 9: Nozzle movement logs

Load-line No.1			
Time	Timeline as registered in log book	Nozzle movements as registered in logbook	Cargo Hold
15 December 2009			
1500	vessel on buoy		
1615	start water		No.5 hold
1630	order sand		No.5 hold
1645	start loading		No.5 hold
1837		nozzle direction starboard	No.5 hold
2000	stop loading		No.5 hold
2001	start water		No.1 hold
2009		nozzle direction port	No.1 hold
2110		nozzle direction starboard	No.1 hold
2147		nozzle direction port	No.1 hold
2230		nozzle direction starboard	No.1 hold
no nozzle movement registered in logbook between 2230 and 0150			
16 December 2009			
0150	No.1 Line shifted from cargo hold No.1 to Cargo hold No.5		
0323		nozzle direction starboard	No.5 hold
0600		nozzle direction port	No.3 hold
0730		nozzle direction port	No.3 hold
0800		nozzle direction starboard	No.3 hold
0830		nozzle direction starboard	No.3 hold
0845	No.1 Line stop for repair		
0910	No.1 Line stop ship side		
1000	resume loading		
1119		nozzle direction starboard	No.3 hold
1200		nozzle direction port	No.3 hold
no nozzle movement registered in logbook between 1200 -1750			
1750		nozzle direction port	No.3 hold
1844		nozzle direction starboard	No.3 hold
1910		nozzle direction port	No.3 hold
1935		nozzle direction port	No.3 hold
2000		nozzle direction starboard	No.3 hold
2015		nozzle direction starboard	No.3 hold
2040			No.3 hold
2100		nozzle direction starboard	No.3 hold
2130		nozzle direction starboard	No.3 hold
2200		nozzle direction port	No.3 hold
2230		nozzle direction port	No.3 hold

Nozzle movement log for number 1 line

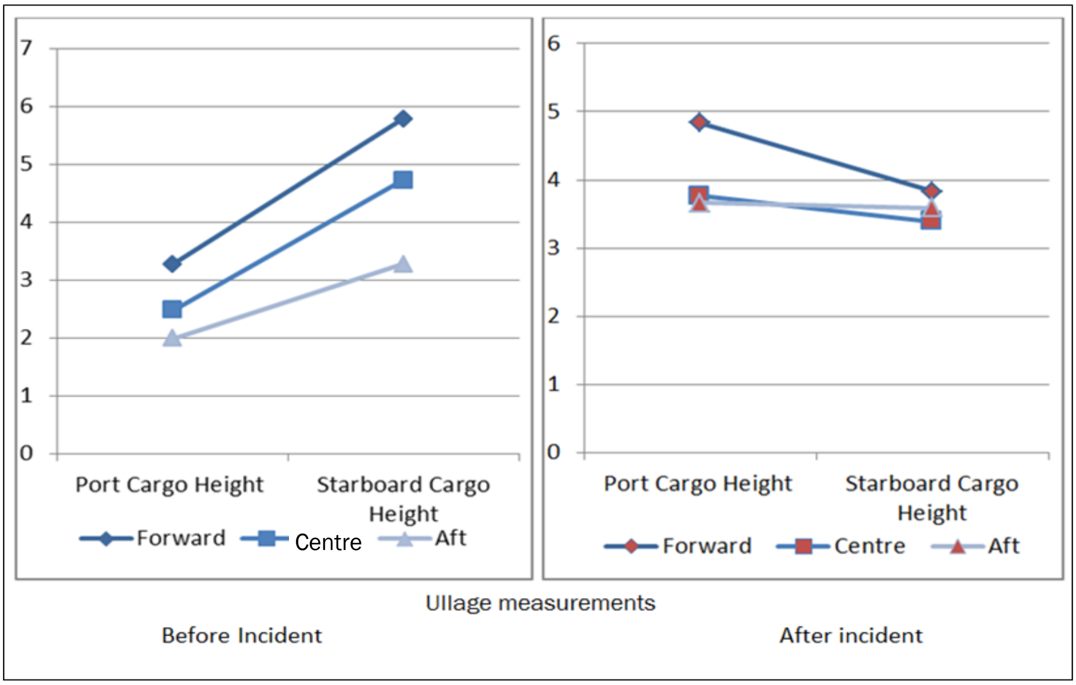
Load-Line No.2			
Time	Timeline as registered in log book	Nozzle movement as registered in logbook	Cargo hold
15 December 2009			
1500	vessel on buoy		
1615	start water		No.5 hold
1645	start loading		No.5 hold
1837		nozzle direction port	No.5 hold
1937	Start free water		No.9 hold
2005	start sand		No.9 hold
no nozzle movement registered in logbook between 2005 and 0028			
16 December 2009			
0028		nozzle direction port	No.9 hold
0100	No 2 line shore stop		
0120	Cargo loading transferred from No.9 hold to No.5 hold		
0125	start sand		No.5 hold
0323		nozzle direction starboard	No.5 hold
0352		nozzle direction port	No.5 hold
0515		nozzle direction starboard	No.5 hold
0600		nozzle direction starboard	No.7 hold
0730		nozzle direction port	No.7 hold
0800		nozzle direction port	No.7 hold
0830		nozzle direction starboard	No.7 hold
1119		nozzle direction starboard	No.7 hold
1200		nozzle direction starboard	No.7 hold
no nozzle movement registered in logbook between 1200 -1750			
1750		nozzle direction port	No.7 hold
1844		nozzle direction starboard	No.7 hold
1910		nozzle direction starboard	No.7 hold
1935		nozzle direction port	No.7 hold
2000		nozzle direction port	No.7 hold
2015		nozzle direction starboard	No.7 hold
2040		nozzle direction starboard	No.7 hold
2100		nozzle direction starboard	No.7 hold
2130		nozzle direction port	No.7 hold
2200		nozzle direction starboard	No.7 hold
2230		nozzle direction port	No.7 hold

Nozzle movement log for number 2 line

Appendix 10: Ullage measurement graphs

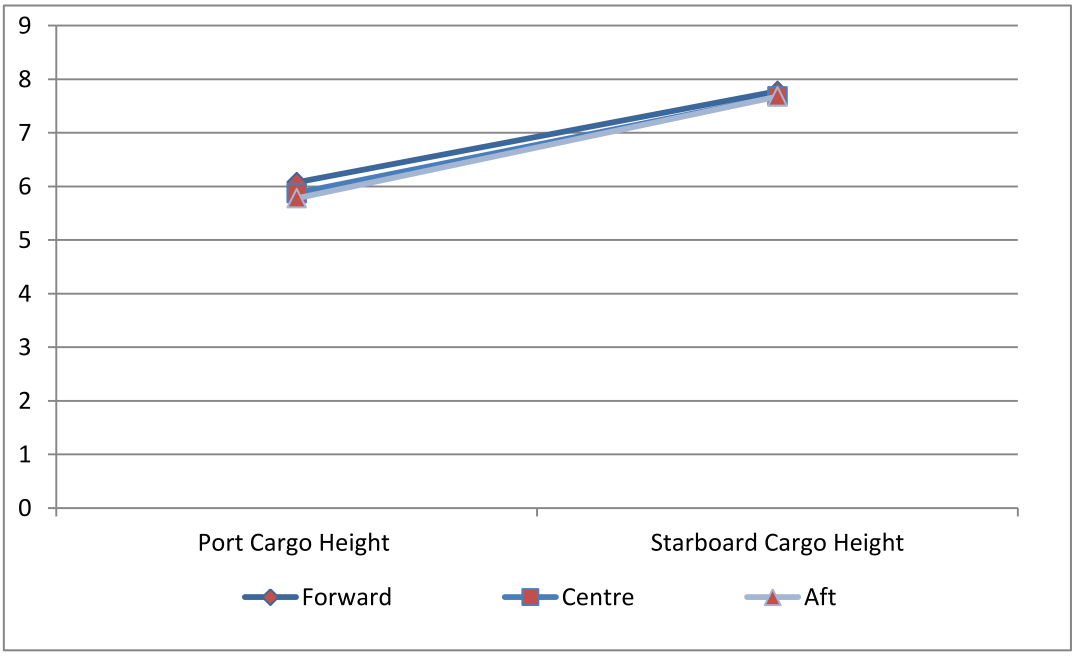
Note: The following graphs are an average of ullages taken directly under each of the 8 ullage ports. Local variations in the cargo profile could affect the average.

Number 1 hold: The measurements taken prior to the incident suggested that the ironsand was trimmed more to starboard than port. Post-incident measurements suggested that the ironsand moved in particular from forward starboard to aft port.



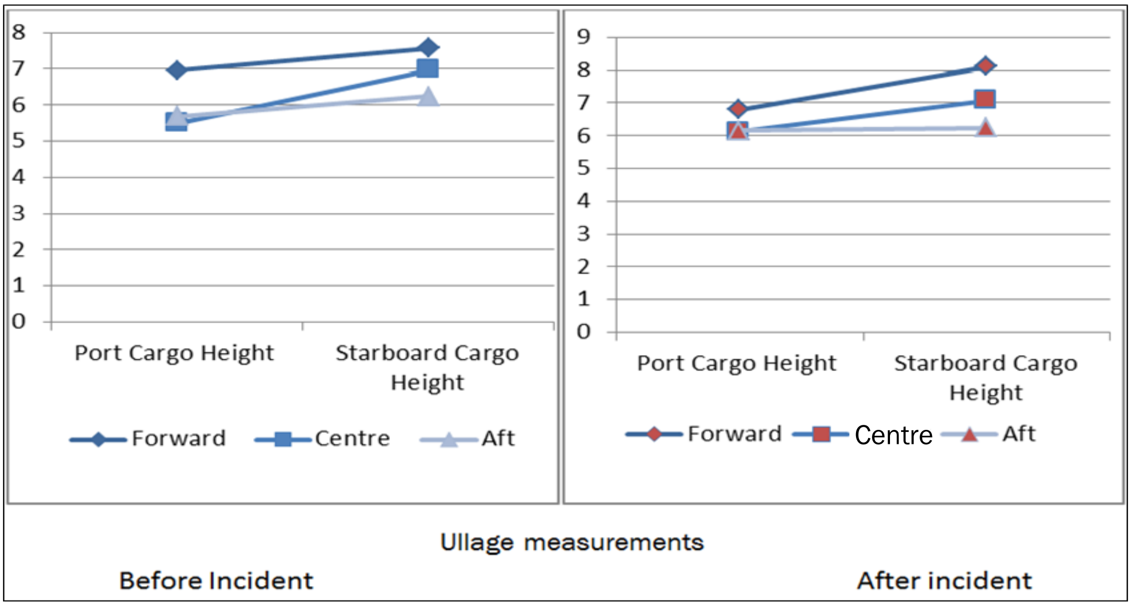
Ullage measurements number 1 hold

Number 3 hold: No ullage measurements were taken before the incident. The measurements taken after the incident indicated that the ironsand in the hold did not have an expected forward to aft slope. Ironsand had shifted towards the starboard side of the hold, particularly towards the aft starboard quarter of the hold.



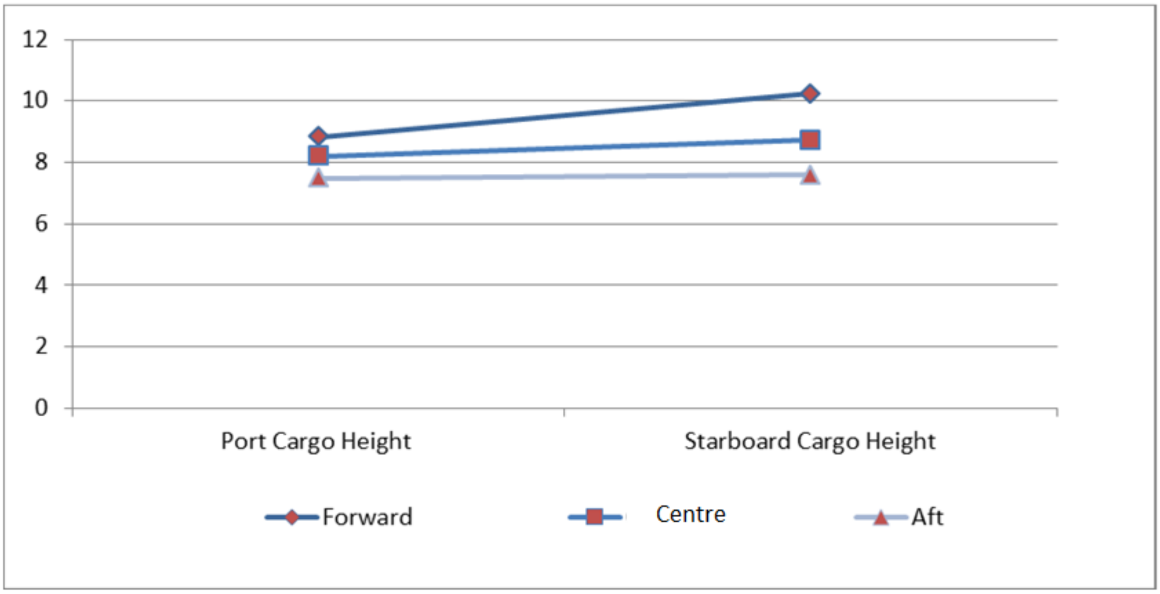
Ullage measurements – number 3 hold (after incident)

Number 5 hold: Ullage measurements taken prior to the incident indicated that ironsand was trimmed more to starboard than port. The ironsand was sloping from forward to aft of the hold. Ullage measurements taken after the incident suggested that ironsand shifted to the forward starboard quarter and aft port quarter.



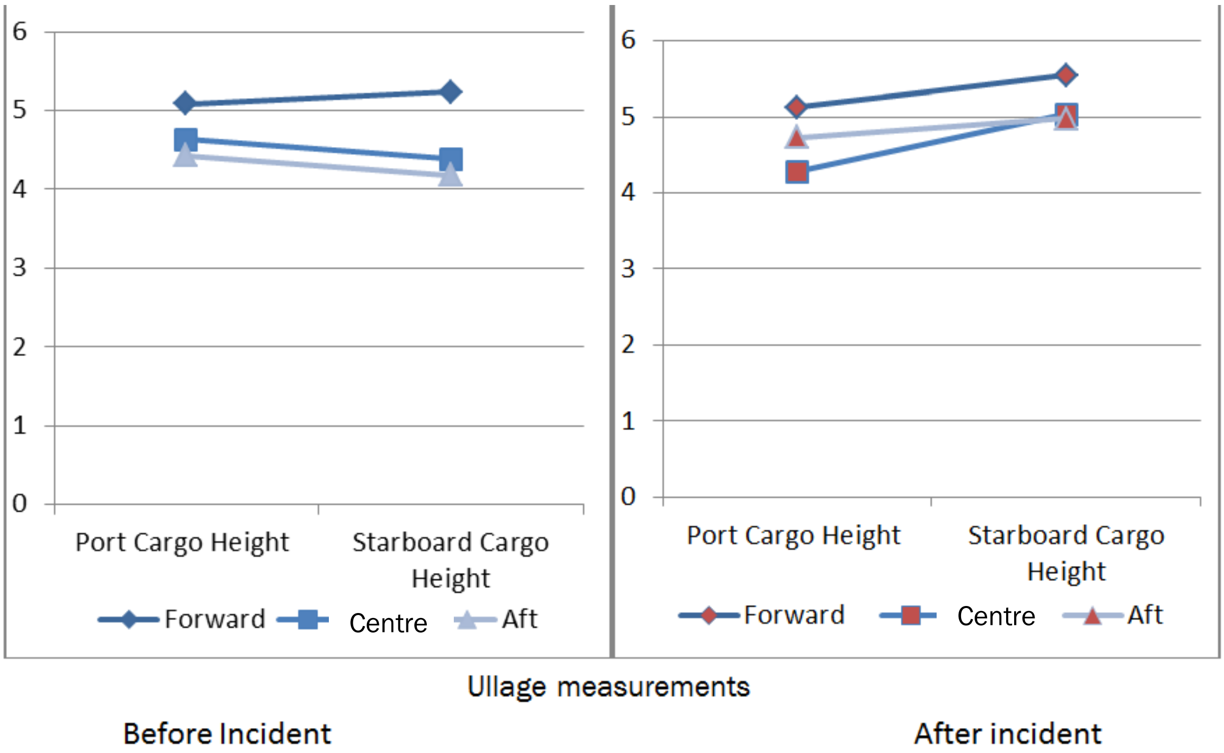
Ullage measurements – number 5 hold

Number 7 hold: No ullage measurements were taken before the incident. The measurements taken after the incident indicated that the ironsand had an expected forward to aft slope. The data also indicated an accumulation of ironsand on the forward starboard side of the hold.



Ullage measurements – number 7 hold

Number 9 hold: Ullage measurements indicated that the ironsand had a forward-to-aft as well as a port-to-starboard slope. Measurements taken after the incident indicated a minor ironsand shift, from aft port to aft starboard.



Ullage measurements – number 9 hold

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