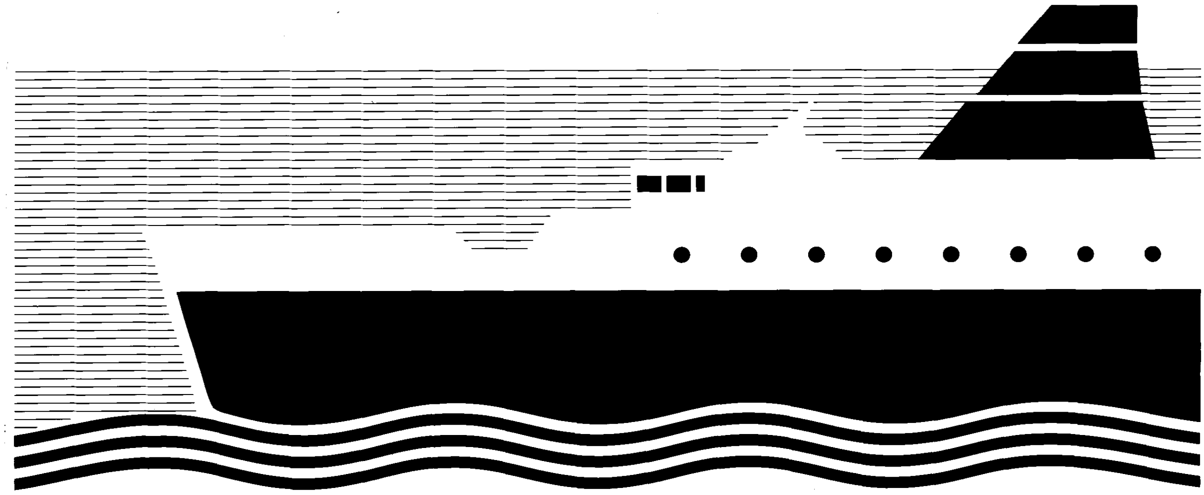
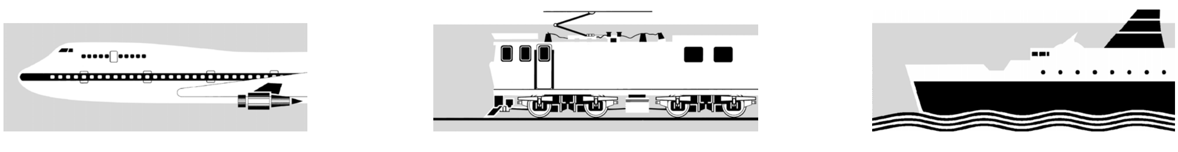


M A R I N E   O C C U R R E N C E   R E P O R T

03-212	**container ship *Spirit of Enterprise*, touching bottom and loss of rudder, Manukau Bar**	**16 August 2003**



TRANSPORT ACCIDENT INVESTIGATION COMMISSION
NEW ZEALAND

Report 03-212

container ship
Spirit of Enterprise

touching bottom and loss of rudder

Manukau Bar

16 August 2003

Abstract

On 16 August 2003, at about 1420, as the container ship *Spirit of Enterprise* crossed the Manukau Bar, it encountered several large swells, causing it to pitch heavily. The ship's rudder struck the seabed with sufficient force to fracture the rudderstock causing the loss of the rudder, thus disabling the ship.

Safety issues identified were:

- insufficient "real time" environmental information
- pre-accident cracking of the rudderstock
- possible pre-damage to the rudderstock from a previous grounding and the jamming of the flap actuating mechanism
- adequacy of the rudderstock size despite the high-strength steel design.

Safety recommendations were made to the Manager Marine Services of Ports of Auckland Limited, the Chief Executive Officer of Bureau Veritas classification society and the Permanent Secretary of the International Association of Classification Societies Ltd

The *Spirit of Enterprise*

Contents

Figures

Abbreviations

GPS	global positioning system
kW	kilowatt(s)
MPa (N/mm^2)	megapascal
NIWA	National Institute of Water & Atmospheric Research
nm	nautical mile
Pacifica Shipping	Pacifica Shipping (1985) Limited
t	tonne(s)
teu	twenty-foot equivalent unit
UKC	under keel clearance
VHF	very high frequency

Glossary

chart datum	zero height referred to on a marine chart
con (conduct)	directing the course and speed of a ship
course	direction steered by a ship
draught	depth in water at which a ship floats
echo sounder	a device for measuring the depth of water below a ship's bottom
electronic chart system	a computer based system which displays navigational charts overlaid by the ship's track derived from GPS data
gross tonnage	a measure of the internal capacity of a ship; enclosed spaces are measured in cubic metres and the tonnage derived by formula
helm	the amount of angle that the rudder is turned to port or starboard to steer the ship
heading	direction in which a ship is pointing at any moment
International Ship Management Code	an International Maritime Organization code adopted in 1993 for the safe operation of ships and for pollution prevention
knot	one nautical mile per hour
made fast	tied up, attached
megapascal	SI unit of pressure
port	left hand side when facing forward
sailing board	notice board placed close to a ship's gangway to inform the crew of the expected time of departure from that port
short shipped	to leave cargo behind to prevent overloading or for operational reasons
significant wave height	average height of the highest one third of the waves
squat	increase in draught, trim or both due to the movement of a ship through the water
starboard	right hand side when facing forward
TEU	an industry standard unit to express the number of containers based on an equivalent length based on 20 foot dry-cargo containers, for example a 40-foot container = 2 TEU
track	the path intended or actually travelled by a ship
under keel clearance	the clearance between the bottom of a ship and the seabed
wave height	the distance from the bottom of a trough to the top of the peak of a wave

Data Summary

Vessel Particulars:

Name:	*Spirit of Enterprise*
Type:	container
Gross Registered Tonnage:	4529
Built:	1999 at Gelibolu Shipyard, Turkey
Length overall:	113.8 m
Breadth:	16.2 m
Depth:	8.5 m
Draught:	Forward 5.60 m Aft 5.85 m
Owner:	Ali Riza Askoy Denizcilik, Turkey
Operator:	Pacifica Shipping (1985) Limited
Classification Society:	Bureau Veritas
Safety Management System Auditor:	Germanischer Lloyd
Port of Registry:	Lyttelton, New Zealand
Propulsion:	a single 4320 kW, MAK M32 diesel engine driving, through a reduction gearbox, a single controllable pitch propeller,
Bow thruster:	560 kW Berk
Crew:	11
Date and time:	16 August 2003 at 1420[1]
Location:	Manukau Bar
Number of Crew:	11
Injuries:	nil
Damage:	loss of rudder and damage to lower stock bearing
Investigator-in-charge:	Captain Doug Monks

[1] All times in this report are New Zealand Standard Time (UTC +12 hours) and are expressed in the 24 hour mode.

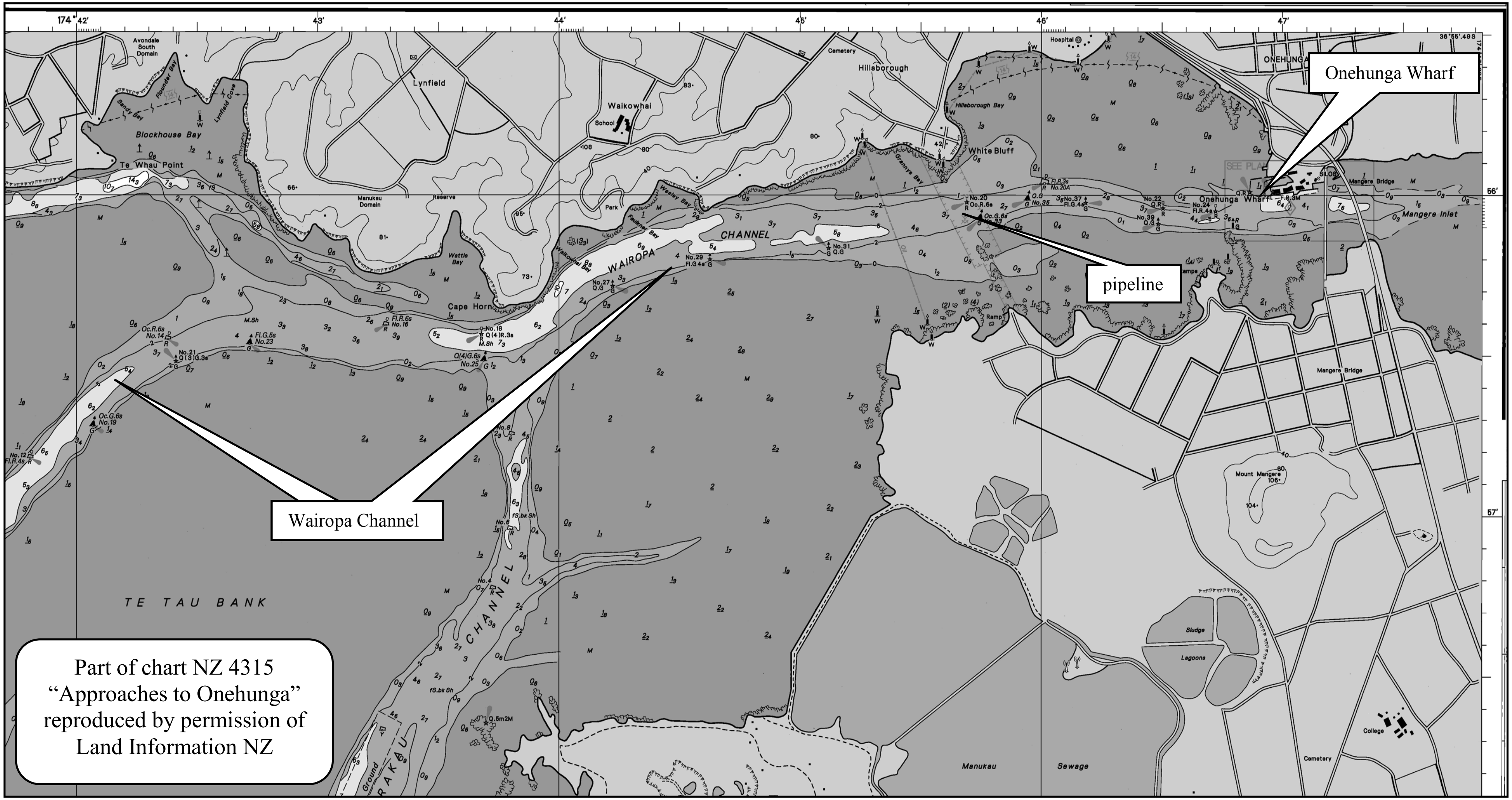


Figure 1
Onehunga to the Wairopa Channel

Factual Information

1.1 Narrative

1.1.1 On Friday 15 August 2003 at 1157, the *Spirit of Enterprise* berthed at Onehunga Wharf, Auckland. The master posted a provisional estimated time of departure of 1200 Saturday 16 August 2004, on the ship's sailing board. Cargo was worked throughout the night and the next morning.

1.1.2 On Saturday morning, the master telephoned the signalman at South Head Signal Station to confirm the ship's departure time of between 1200 and 1230. During the conversation, he was given an update on the prevailing weather, the conditions and minimum depth on the bar, and the shipping movements expected that day.

1.1.3 During the morning, the master completed the "bar crossing – bridge procedures checklist". This gave him a predicted under keel clearance (UKC) over the bar of 1.2 m at 1415.

1.1.4 Shortly after 1130, the master tested the bridge equipment and set the intended route on the global positioning system (GPS) and the electronic chart system. He then called South Head Signal Station to confirm the ship's estimated time of departure of 1230. The signalman confirmed that the wind had remained south westerly at about 25 knots with a 2 to 2½ m swell. The signalman also advised that a gas carrier, the *Hebe*, had crossed the bar inwards that morning and had recorded a depth of 6.0 m over the bar.

1.1.5 At about 1200 the master went ashore to read the ship's draught and to check the tide gauge on the wharf. The maximum draught was 5.85 m and the digital read-out on the gauge showed a height of 3.79 m, against a predicted height of 3.6 m.

1.1.6 At about this time the supervising stevedore asked the master if he would delay sailing to enable the remaining containers to be loaded. The master refused, confirming that he needed to sail before 1245 to have sufficient UKC to cross the shoal area near pipelines in the Wairopa Channel, about one nautical mile west of the berth (see Figure 1) and then to cross the bar (see Figure 2).

1.1.7 At 1230, with 10 containers remaining, cargo work was stopped and the ship prepared to sail. The ship's lines were singled up and were all clear at 1240. The ship then proceeded down the Wairopa Channel.

1.1.8 As the ship passed over the shoal area near the pipelines, the master reduced speed. Once past the shoal area, the master increased speed to between 12 and 14 knots, slowing as necessary to pass over the 2 other shallow areas in the Wairopa Channel.

1.1.9 As the ship approached Puponga Point (see Figure 2), the master called South Head Signal Station on very high frequency (VHF) radio, channel 11, to advise of his intended transit of the bar. Again, he was advised that the weather and the conditions on the bar had not significantly changed. The master and the second mate reviewed the "bar crossing – bridge procedures checklist" and visually checked the bar for breaking waves. They confirmed the master's earlier calculation that they would have a UKC of at least 1.2 m, allowing 1.3 m for a 2.5 m swell. They could see continuous breaking waves to each side of the bar, but the channel between the edges of the bar had the occasional breaking wave only.

1.1.10 The master conned the ship to cross the bar on a track of 241°(T), with Ninepin Rock light bearing 061°(T). The master maintained the track by monitoring the ship's progress using the electronic chart system and by visually observing a transit of Ninepin Rock light and Paratutae. As they neared the bar the master reduced the ship's speed to about 6 knots to minimise any squat that the ship might experience.

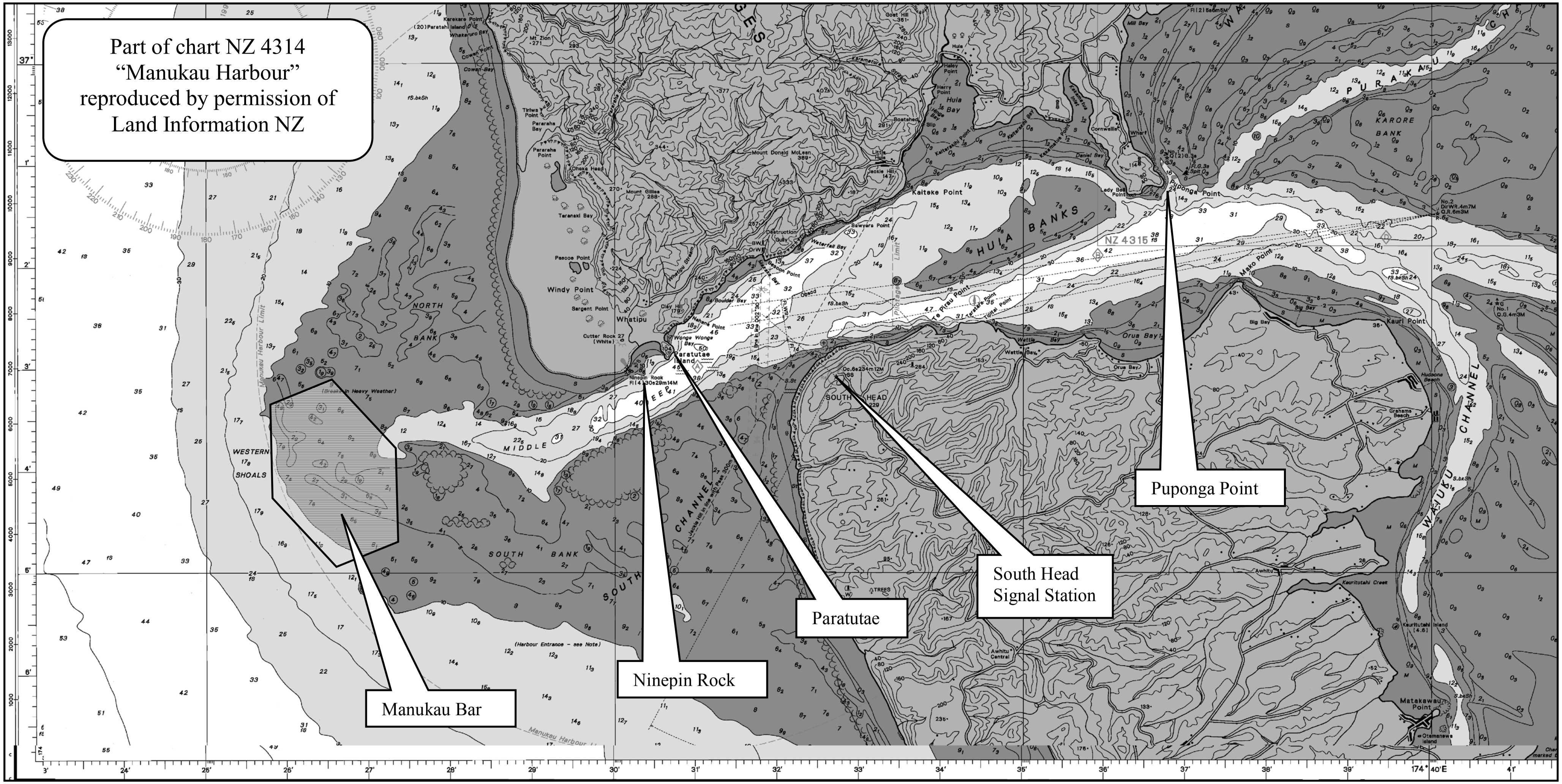


Figure 2
Manukau Harbour and bar

1.1.11 At about 1415, as the ship was moving onto the inner side of the bar, the master noted that the depth on the echo sounder was 0.7 m, which was less than he expected.

1.1.12 The ship pitched as it crossed the bar but was untroubled until it passed over the seaward side of the bar when a larger wave, estimated by the master to be 3.5 m in height, passed under the ship causing it to pitch heavily. As the bow lifted on the second pitch cycle, a thud was heard from the after end of the ship. The chief engineer, who was in the engine control room likened the sound to that of a gong, sufficiently loud for him to go into the engine room to check for problems there. As the ship pitched heavily the master looked at the echo sounder but there was no clear bottom return, possibly due to aerated water under the ship.

1.1.13 The ship continued onwards away from the bar but a few minutes later the helmsman reported that he was having difficulty steering. The ship was falling off to starboard even though the helmsman had hard to port helm on. The master told the helmsman to put the steering into emergency mode. This was done and trial helm movements made, but the ship did not respond, although the rudder indicator followed the helm.

1.1.14 The master then called the engine room and asked the second engineer, who was on duty, to check the steering gear. The chief engineer was still checking in the engine room for the source of the loud noise. Initially the second engineer thought that the steering had jammed as it had done in the past, but when he arrived in the steering gear compartment he could see the steering gear moving in response to the helm movements on the bridge.

1.1.15 While the second engineer was in the steering flat, the ship had turned through about 90° to starboard. It then started to come back to port leading the helmsman and master to believe that the ship was responding to the rudder (see Figure 3). The master advised the second engineer, who returned to the engine room control room.

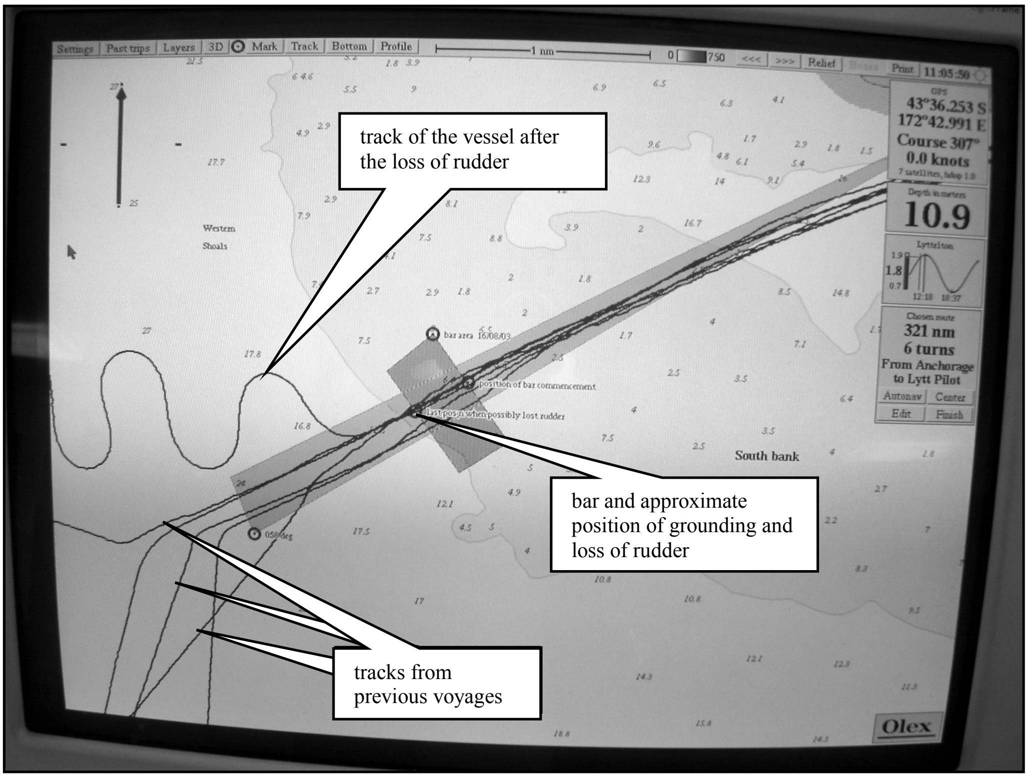


Figure 3
The track of the *Spirit of Enterprise* as recorded on the electronic chart system

1.1.16 Soon afterwards however, the ship fell off to starboard again and the master realised the problem had not been rectified. He called the engine room, this time talking to the chief engineer. Both the chief and second engineer went to the steering gear where they took control of the steering gear at the local position in the steering flat. While moving the steering gear they noted that the hydraulic oil pressure was almost zero, leading them to deduce that there was no load on the system and that they had probably lost the rudder.

1.1.17 The engineers informed the master of the probable loss of the rudder. The master then started to use the bow thruster to control the ship's head; to improve the thruster's effectiveness he reduced the ship's speed to about 3 knots. Using this method he was able to stop the large oscillations of the ship's head and con the ship away from the coast until a tug could be summoned.

1.1.18 The New Plymouth based tug, *Rupe*, rendezvoused with the *Spirit of Enterprise* at 0650 the following morning, whereupon the tug crew confirmed that the rudder was missing. The ship was under tow by 0800. Initially, the ship was towed to New Plymouth where a diver carried out an inspection, which, owing to adverse sea conditions, failed to determine if there was any damage other than the absence of the rudder.

1.1.19 The *Rupe* then towed the ship to Lyttelton, where further inspections were carried out.

1.1.20 An unsuccessful effort was made to locate and recover the rudder from the seabed. As a result, a new rudder had to be constructed.

1.2 Vessel information

1.2.1 The *Spirit of Enterprise* was a container ship built in 1999, in Turkey. It was 113.8 m in length and could carry a maximum of 486 twenty-foot equivalent units (teus). It had a gross tonnage of 4529 and a summer draught of 6.633 m. It was powered by a 4320 kW MAK M32 diesel engine driving, via a reduction gearbox, a variable pitch propeller. It was fitted with a bow thruster of 560 kW.

1.2.2 In September 2000 Pacifica Shipping (1985) Limited (Pacifica Shipping) bareboat chartered the ship from its Turkish owner. The ship was used to trade between South Island and North Island of New Zealand. Each week the *Spirit of Enterprise* and a sister ship alternated between the east and west coasts of the north island and called at the ports of Auckland and Onehunga on the Waitemata and Manukau Harbours.

1.2.3 The ship was in class with Bureau Veritas, and Pacifica Shipping used Germanischer Lloyd to audit the International Ship Management system.

1.2.4 The ship was fitted with a "Becker type" high-lift rudder manufactured by the engineering company Gurdesan Limited of Turkey. The rudder had an active trailing edge, or flap, that increased its turning efficiency. The flap actuating mechanism pivoted about a pin fixed to the hull immediately behind the rudderstock (see Figure 4).

1.2.5 The billet of steel from which the rudderstock had been manufactured had a test certificate which gave a yield strength of 417.2 N/mm2 (MPa) and a tensile strength of 801.4 N/mm2 (MPa). The Bureau Veritas rules extant at the time of construction contained a formula to determine the minimum size of a rudderstock assuming that standard (mild) steel of tensile strength of 400 MPa was used. This formula was complex and took into account many factors including; area of the rudder, length of the rudder, distance of the trailing edge of the rudder from the rudderstock, speed of the ship both ahead and astern, type of rudder and whether it had an active flap. Where steel of different characteristics was used, the Bureau Veritas rules granted a reduction of rudderstock diameter, calculated from an additional formula. The *Spirit of Enterprise* rudderstock had a final maximum diameter of 415 mm and Bureau Veritas confirmed that at the time of manufacture, this was in compliance with its rules.

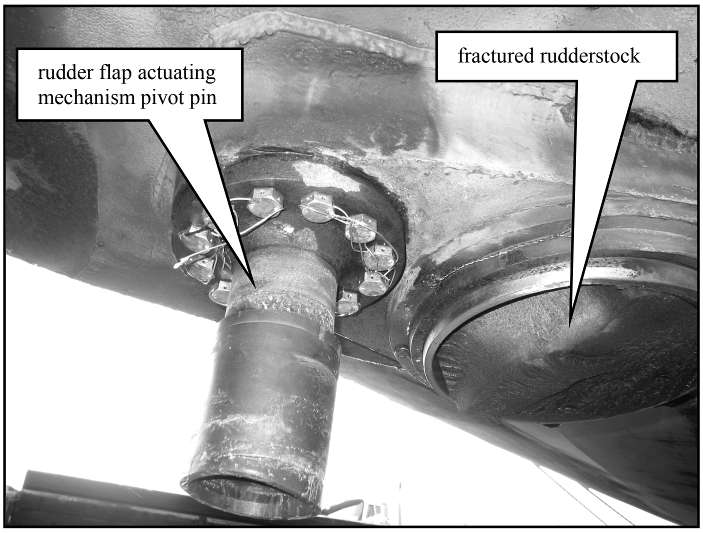
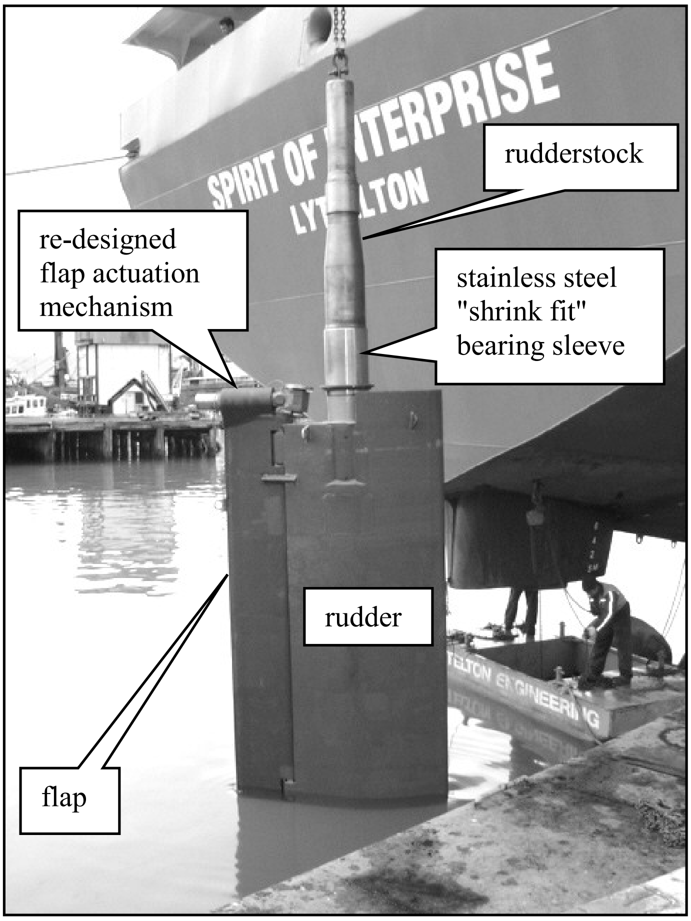


Figure 4
Rudderstock and rudder flap actuator mechanism pivot pin



(photograph courtesy of Steve Taylor)

Figure 5
New rudder and rudderstock being installed October 2003

1.2.6 The strength of steel depended in part on its constituent elements. The most common element was carbon which when added to the steel increased its strength. As the amount of carbon increased, the steel's ductility decreases, thus making the material more brittle. The rudderstock of the *Spirit of Enterprise* was manufactured from steel that had a carbon content of 0.60%, making it medium to high carbon steel. The majority of rudderstocks were constructed from standard steel with a typical carbon content of between 0.15 and 0.25%, and so were more ductile.

1.2.7 In the years between the construction of the vessel and the accident, Bureau Veritas had made 2 revisions to its rudderstock rules. A rudderstock of the same material with the same size rudder constructed under the 2003 Bureau Veritas rules would have required a minimum diameter of 478 mm.

1.2.8 The rudderstock fitted after the accident (see Figure 5) had a diameter of 420 mm (the maximum diameter the rudder trunking could accommodate) and the length of the rudder was reduced from 4600 mm to 4485mm. In addition, the operator redesigned the flap actuating mechanism (see Figure 5).

1.2.9 In accordance with common practice, the sender unit for the rudder indicator was mounted on the steering gear and measured the angle to which the rudderstock was turned. So, even after the rudder was lost, the rudder indicator continued to follow the helm orders.

1.2.10 On 21 December 2003, the *Spirit of Enterprise* was off-hired and left New Zealand for Singapore for re-delivery to its owners.

1.3 Personnel details

1.3.1 The master went to sea in 1968 with the British Royal Fleet Auxiliary, gaining his master's certificate of competency in 1981. He joined Pacifica Shipping in 1987 serving in various ranks, including relieving master, until being appointed as permanent master in 2000. He had joined the *Spirit of Enterprise* as master in September 2002.

1.3.2 During the late 1990's, while serving as chief officer, the master was trained by experienced masters in the pilotage of Manukau Harbour. He completed his first solo transit of the harbour in 1999.

1.3.3 Maritime Rules Part 90 – Pilotage; came into force on 1 April 2003 and designated Manukau as a pilotage area, where previously it had not been. The Part allowed for experienced pilots and masters to be granted pilot or pilotage exemption certificates without the need for additional training. On 1 April 2003, the Director of Maritime Safety exempted the master from the requirement to carry a pilot in the Manukau pilotage area.

1.3.4 The second mate had gone to sea in 1985 and had served in various ranks until he had gained a second mate's certificate of competency in 1998. He had joined Pacifica Shipping in 2001.

1.3.5 The helmsman went to sea in 1962. He joined Pacifica Shipping in 1985 and had sailed as chief integrated rating on the *Spirit of Enterprise* for 3 years. Because of his experience he was the designated helmsman when entering or leaving each port.

1.3.6 The *Spirit of Enterprise* had a minimum safe crewing document requiring 10 crew. At the time of the occurrence there were 11 crew on board.

1.3.7 The signalman at South Head Signal Station had been in the Royal New Zealand Navy for 8 years as a communicator before joining the lighthouse service, where he stayed for 6 years. He became signalman at South Head Signal Station in 1985 and had been incumbent since then. His duties involved observing the weather and bar conditions, monitoring the harbour radio during the period of ship transits and informing users of the port of the conditions of the bar.

1.4 Procedures

1.4.1 Pacifica Shipping had detailed policies and procedures in place to comply with the International Ship Management Code. There were 3 separate procedure manuals; the Fleet Operations Manual, the Ship Safety Management Manual and the Emergency Procedures Manual. The manuals contained checklists for specific tasks, including testing bridge equipment prior to sailing, bridge resource management, bar crossings and emergency situations, such as loss of steering.

1.4.2 Each week the master of the ship using Manukau Harbour was required to complete an Operations Parameters form that identified limiting conditions, possible bar crossing times and the amount of cargo that might be loaded. This document was sent to head office in Lyttelton and the Auckland office in order that the cargo operations and the ship's schedule could be planned.

1.4.3 The master completed the Operations Parameters form for the week of the accident and determined that in calm conditions the bar would have sufficient depth between 0930 and 1545 on Saturday 16 August. However, the shallow area through the Wairopa Channel would only have sufficient water between 1300 and 1330, and so the ship needed to leave Onehunga Wharf before 1245.

1.4.4 On any vessel there is a degree of commercial pressure on its master to maximise loadings on each particular voyage. Often in Onehunga masters were requested to delay the ship's departure to enable all the available cargo to be loaded. On this occasion, the master had been asked to delay sailing so that the remaining containers could be loaded. He refused and so met his calculated latest sailing time of 1245. The 10 short-shipped containers were transferred to another company vessel loading in the port of Auckland.

1.4.5 When the master completed the Bar Crossing checklist he allowed 5.7 m for the depth of water above chart datum on the bar. This was from the latest information from the signalman at South Head. He further made an allowance of 1.3 m, which was 50% of the predicted 2.5 m sea and swell; rounded up to the nearest decimal. The Ports of Auckland Limited (POAL) tide tables predicted the tide at Paratutae for 1415 to be 2.7 m.

Bar chart datum	5.7
Height of tide	+2.7
Depth of water	8.4
Maximum Draught	-5.9
Static UKC	2.5
Allowance for sea and swell	-1.3
UKC	1.2 m

The UKC of 1.2 m calculated by the master did not allow for squat.

1.5 Description of Manukau Harbour

1.5.1 Manukau Harbour provides access to Auckland from the west coast of New Zealand. At the entrance to the harbour is a shifting sand bar with banks and shoals extending 5 miles to seaward. Inside the bar, the harbour is almost filled with mud and sandbanks that dry at low water. On the landward side of the bar there is a natural channel up to Huia Bank which splits at Puponga Point into 4 navigable channels. The 2 main channels are Wairopa Channel, giving access to Onehunga, and Papakura Channel, giving access to a liquefied gas facility.

1.5.2 Wairopa Channel was about 11 nm long. There were 3 areas where the water depth was less than 4 m at chart datum:

- from the berth at Onehunga to an area of 3 submerged pipelines about 1.3 nm away
- from Cape Horn to about light beacon 21, and
- in the vicinity of light beacon 15

Outbound from the submerged pipelines the channel was relatively wide for the size of ship that transited and was marked by a combination of light beacons and buoys.

1.5.3 Manukau Harbour was administered by POAL and managed by a port co-ordinator based at Onehunga. Movements within the harbour were organised and monitored by the port co-ordinator, who was contactable 24-hours by telephone, facsimile and mobile phone. Situated on

South Head at the entrance to the harbour was a signal station manned by a signalman who resided on site. His main function was to advise vessels of the bar conditions and monitor their progress when crossing the bar. He kept a fixed radio schedule and was available 24-hours on request.

1.5.4 When the Auckland Harbour Board was dis-established in 1989 the duties of the Auckland harbourmaster, whose jurisdiction included the Manukau Harbour, were passed to the Auckland Regional Council (ARC). The harbourmaster worked closely with POAL, the commercial arm of the port, to put in place legislation to maintain navigational safety.

1.5.5 The New Zealand Pilot 15th edition 2001 stated the maximum permissible draught for the port of Onehunga was 6 m.

1.5.6 Hydrographic Surveys on Manukau Bar were carried out at varying intervals depending on the movement of the bar. POAL endeavoured to survey the bar every 3 months but had the ability to reduce this period if users indicated that the bar may be shoaling. The last survey before the accident was carried out on 10 July 2003. On 11 July the surveyor in charge sent a memorandum to the manager marine services of POAL summarising the survey results and included copies of the current survey chart together with the chart from the previous survey, which was carried out in January 2003.

1.5.7 The memorandum indicated the limitations of the survey and itemised the minimum depths on reference bearing lines measured from Ninepin Rock light. On the 060° and 062° bearings (the *Spirit of Enterprise* used 061°, between these two bearings, when crossing the bar) the least depth sounding was 6.0 m. The most recent survey did not transit the 061° bearing but it was considered that the least depth there was also 6.0 m.

1.6 Previous damage and accident

1.6.1 On 28 July 2001, the *Spirit of Enterprise* grounded in the Wairopa Channel in Manukau Harbour. The Commission investigated the grounding and Marine Occurrence Report 01-210 was approved for publication 05 February 2002. The ship left the channel and its bow grounded on a mud and sand bottom. An inspection by divers on 30 July indicated that paint had been scraped from the hull forward of the accommodation, but no damage to the propeller, rudder or hull plating about the stern. The ship was dry docked in January 2002 and the out of water inspection confirmed the diver's report.

1.6.2 On 2 occasions, in December 2001 and September 2002, the rudder flap actuating gear jammed, jamming the rudder and causing a temporary loss of steerage. On each occasion the helmsman was able to free the rudder by rapidly turning the helm from port to starboard. On each occasion parts of the flap actuating mechanism were lost and needed to be replaced. While the new parts were being manufactured the rudder flap was locked in the amidships position by plates welded between the flap and the body of the rudder. The flap actuating mechanism was reassembled in October 2002, and because of the continuing problems with the actuating mechanism Pacifica Shipping instigated regular inspections of it. When inspected by the ship's engineers in July 2003, significant wear in the mechanism was found. The flap was again locked amidships until new parts were made of improved materials; these were fitted on 15 July 2003.

1.6.3 On 1 August 2003, the after part of the *Spirit of Enterprise* touched the bottom while swinging the ship prior to berthing at Onehunga. A diver inspection on 6 August revealed that there were signs of grounding on the keel forward of the propeller and on the sole plate (bottom) of the rudder. There had been no loss of steering during the incident.

1.7 Environmental conditions

1.7.1 POAL produced tide tables for the Manukau Harbour. The 2 areas relevant to this investigation were Onehunga, which was used to calculate the UKC in the upper part of the harbour, and Paratutae, which was used for the bar and lower harbour. The POAL tidal predictions were based on a 1989 Royal New Zealand Navy survey. From this survey a suitable datum was derived to which the soundings could be reduced, and also 36 tidal constituents; which were used to compile the annual tidal predictions.

1.7.2 Land Information New Zealand (LINZ) was the national hydrographic authority. It was responsible for providing official hydrographic information for navigational purposes such as navigational charts and nautical information, which included tidal predictions and Notices to Mariners. All information and documents were produced according to International Hydrographic Organisation standards. The New Zealand Nautical Almanac contained the tidal information for standard and secondary ports throughout New Zealand. Onehunga was a standard port and Paratutae was a secondary port.

1.7.3 The height of high water at 1245 on 16 August for Paratutae from the POAL predictions was 3.1m. That calculated using the secondary port information and the pro-forma in the tide table section of the New Zealand nautical almanac was 2.9 m, a difference of 0.2 m. The discrepancy was due to LINZ using older and less reliable information than that used by POAL. The master used the POAL tide predictions for Onehunga and Paratutae to calculate the ship's UKC in the Wairopa Channel and the bar respectively.

1.7.4 The ship was crossing the bar about 2 hours after high water; consequently the tide was ebbing. When a tidal stream encounters a sea and swell from the opposing direction it causes the sea to steepen and the wave period to decrease. This is particularly evident where water crosses a harbour bar.

1.7.5 When the master read the actual tide from the tide gauge on Onehunga wharf, he noted that there was more water than predicted. He assumed from this that there would also be more water than predicted throughout his harbour and bar transit.

1.7.6 The signalman at South Head Signal Station observed and recorded the weather daily at 0600, 0900 and 1800. At 0900 on 16 August he recorded in his meteorological notebook the wind to be 24 knots (force 6) from 240°. In his station logbook he recorded the wind to be 230° at 30 knots gusting to 42 knots and the sea and swell to be 2.5 m occasionally 3.0 m. Although there was no time recorded for these entries, they were written above an entry timed at 1300. The station anemometer had a recording facility and its trace indicated that during 16 August the wind was between 20 and 30 knots with gusts up to 40 knots. It also indicated, erroneously, that the wind direction was from the north by east. The signalman said that the direction indication part of the anemometer had been operating erratically for some months prior to accident and was often about 180° out from actual wind direction. To get an accurate wind direction he observed the wind vane attached to a rotating cup anemometer.

1.7.7 About 66 nm south of Manukau Heads was the Taharoa iron sands terminal. Large iron sand bulk carriers moored to a single point mooring to load slurried iron sand. To improve the safety of the mooring operation, a wave rider buoy was sited at the terminal. On 16 August at 1420 the wave rider buoy recorded the following information:

a significant wave height	4.57 m
a maximum wave height	6.13 m
direction of wind	250° (T)
mean wind speed	20.8 knots
maximum gust strength	29.3 knots

The graphs in Figures 6 and 7 show the trend of the wind speed and swell heights at Taharoa between the 14 and 16 August 2003.

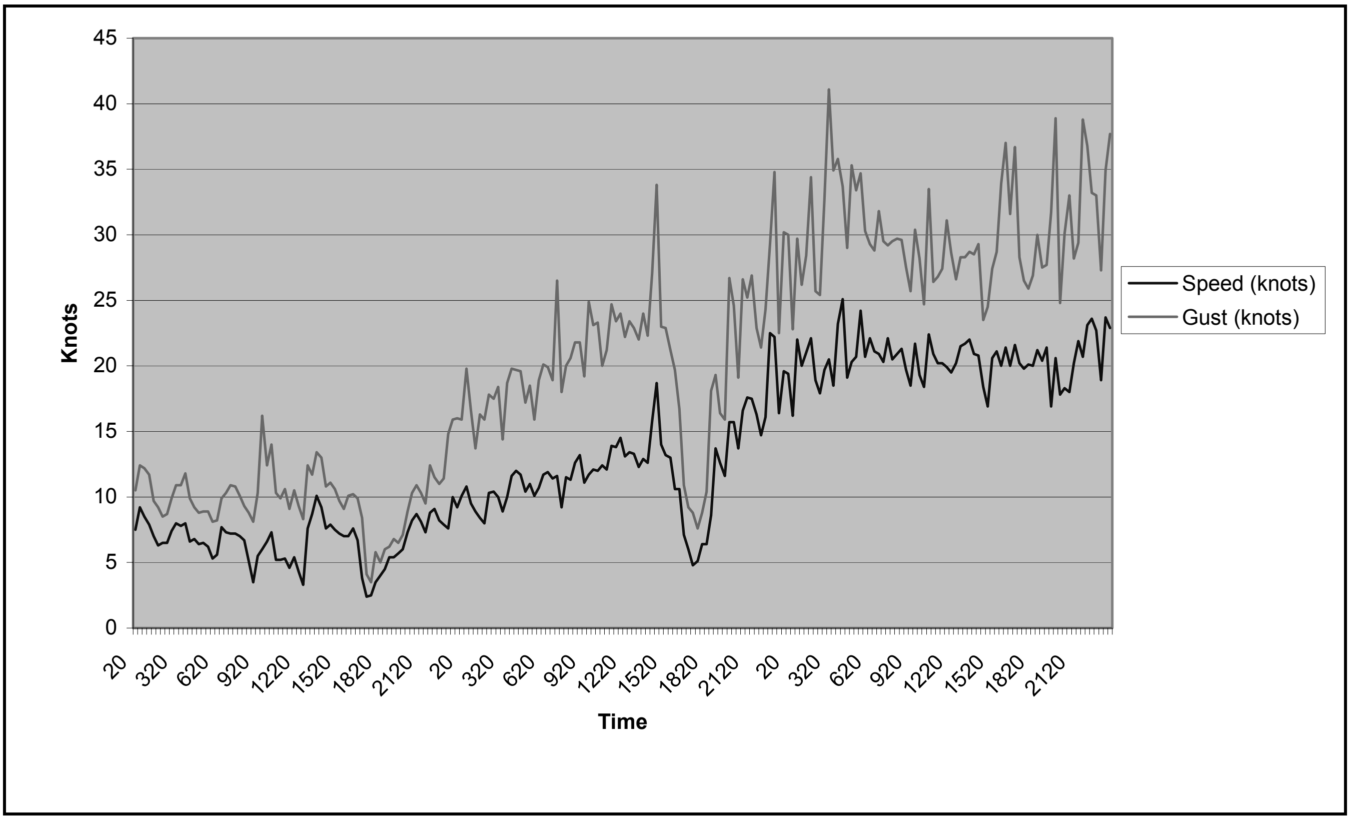


Figure 6
Taharoa wind speed 14-16 August 2003

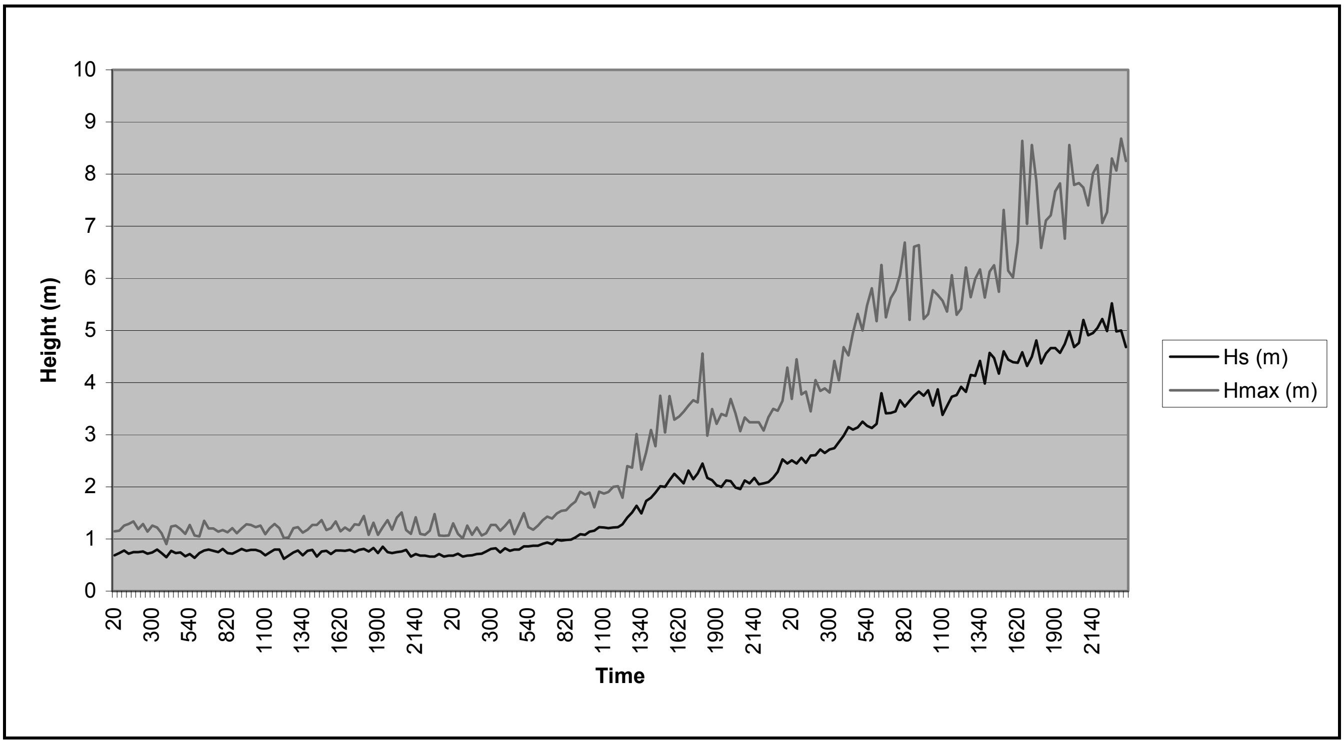


Figure 7
Taharoa Swell Height 14-16 August 2003

The graphs indicate that the swell height increased the longer the wind prevailed from one direction. This information was not available to the signalman at South Head Signal Station or POAL.

1.7.8 The New Zealand Meteorological Service (Metservice) mean sea level analysis chart for 1200 NZDT 16 August showed an intense low pressure to the south of New Zealand with a high pressure over the east coast of Australia (see Figure 8). The wind between these systems was south westerly.

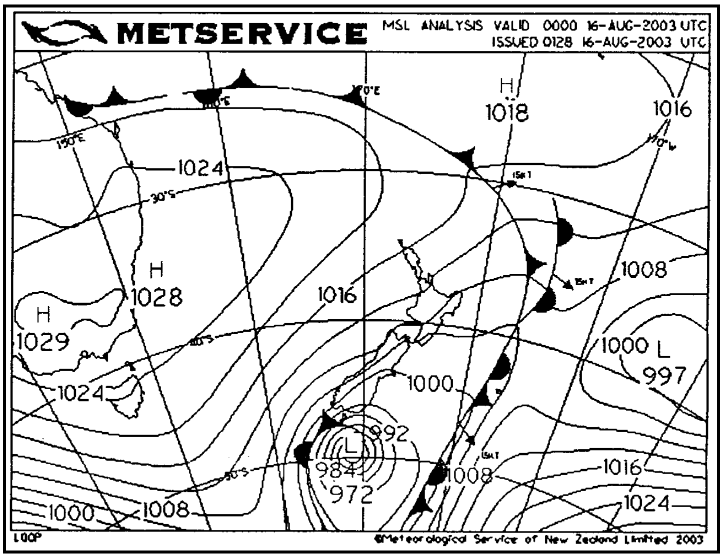


Figure 8
Mean sea level analysis chart for 1200 NZDT 16 August 2003

1.8 Metallurgy report and vessel damage

1.8.1 On 26 August 2003 the remaining upper section of the rudderstock was sent to a metallurgist for analysis of the fracture surface. The analysis noted that the rudderstock had fractured on 2 planes, just outside, and about 1 cm inside the stainless "shrink fit" bearing sleeve. On the planes of the fracture there were areas of load stress cracking on the forward starboard and port sides of the stock and on the after part (see Figure 9). From the pattern of the fracture surface, the metallurgist deduced that the penultimate fracture had occurred at the after part cracking aft to forward and the ultimate fracture propagated from the starboard side load stress crack towards the port side. The final failure would probably have been fast (a cleavage fracture).

1.8.2 He concluded:

A The rudderstock had been made from carbon steel (AISI 1060) having an ultimate tensile strength of the order of 700 MPa.

B Failure occurred as a consequence of corrosion-fatigue cracking at a number of positions around the surface of the shaft.

C Fatigue cracking resulted in the spread of these cracks.

D Final failure by overload had occurred by a cleavage (fast, brittle) failure mechanism.

1.8.3 The metallurgist was of the opinion that the load stress cracks would have continued to grow and the loss of the rudder was inevitable, but he could not estimate how long it would have taken to happen.

1.8.4 The load stress cracks were such that they were probably the result of the cyclical pressures exerted on the rudder during normal operations. That is, the water pressure exerted on the port and starboard side of the rudder set up stress areas on either side of the rudderstock. Those stress areas were concentrated in the area of the rudderstock where it entered the stainless steel bearing sleeve - a known point for stress concentrations.

1.8.5 A second metallurgist assisted the investigation with interpretation of the metallurgy report. His view was that the penultimate fracture was the one that propagated from the load stress crack on the starboard side with the ultimate event being the fracture at the after part of the rudderstock propagating from forward to aft. He agreed that final failures would have been very fast, almost instantaneous, and caused by a significant force. He also suggested that high-strength steel was more susceptible to corrosion in salt water and that it was less ductile, making it more likely to crack rather than bend when an unusual force was exerted on it.

1.8.6 The after section of the stainless steel bearing sleeve was deformed outwards, that is towards the stern (see Figure 9).

1.8.7 There was severe denting, piercing and tearing of a weld on the plate work on the underside of after end of the rudderstock housing, approximately in line with the after extremity of the flap actuator gear attached to the top of the rudder and to the port side of the centreline (see Figure 10). There was no damage to the vessel other than that associated with the loss of its rudder.

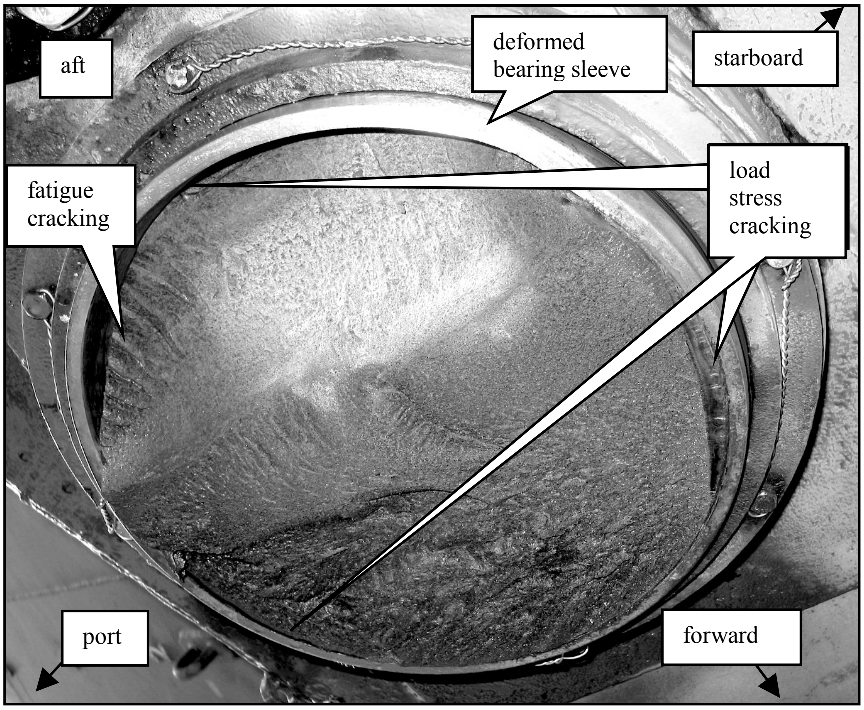


Figure 9
Fractured surface of the rudderstock

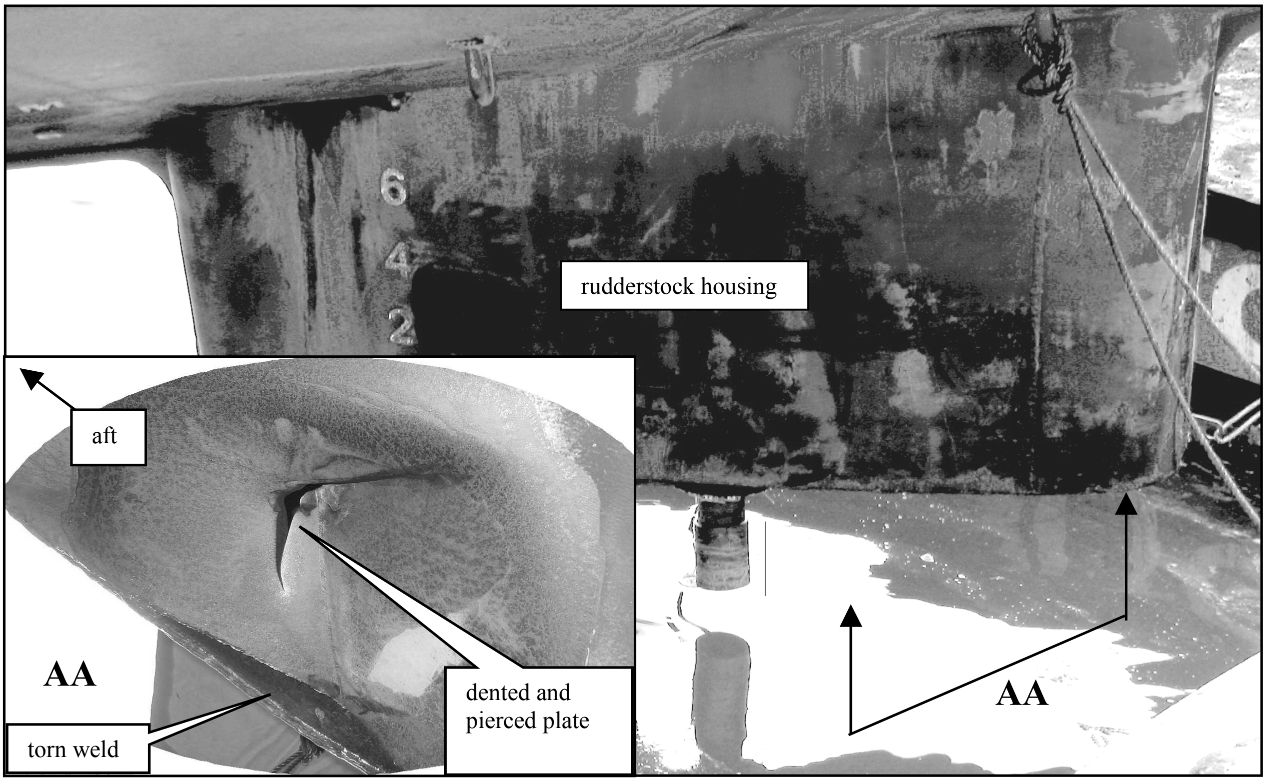


Figure 10
Rudderstock housing with inset AA showing the damage to underside

1.9 National Institute of Water & Atmospheric Research (NIWA) report on Manukau Bar

1.9.1 On 16 October 2003, the Maritime Safety Authority, in conjunction with the Auckland Regional Council, POAL and the Commission engaged NIWA to compile a report into the sea conditions at the Manukau Bar on 16 August 2003.

1.9.2 The first part of the report addressed the weather, wave and tidal conditions prevailing at the time of the accident. The NIWA scientists used reports from Metservice, the wave rider buoy situated at Taharoa, the Manukau Head automatic weather station, Auckland airport and weather surveillance radar and satellite imagery to assist them in compiling the report.

1.9.3 The weather at the time of the accident from the information available was:

- Wind — Southwest with speed ranging between 25 and 35 knots, and gusts over 40 knots.
- Visibility — Mostly good, but occasionally reducing to 10 km in showers.
- State of Sky — Scattered cumulus type, but broken to overcast at times with showers.
- State of sea — Very rough. Significant wind waves in the range of 3 to 4 metres, probable maximum wave height in the range of 4 to 5.5 metres.
- Swell — Southwest about 3 metres.
- Combined waves — Significant wave height in the range 4 to 5 metres, probable maximum wave height in the range of 6 to 7 metres.

1.9.4 The NIWA scientists used a wave model (WAM) to predict the waves around the New Zealand coast for the days either side of the accident (see Figure 11). From that model they concluded that at 1500 on 16 August there were 4.0 m waves from a south west direction. They also considered the data from the wave buoy at Taharoa, and a wave model from the National Ocean and Atmospheric Administration of the United States of America. The trends in each of the models were similar, but the wave buoy gave a higher wave height than the model at the time of the accident.

1.9.5 When considering the level of the tide at the bar on 16 August, the NIWA scientists evaluated the data from an open coast sea-level gauge at Anawhata, a headland about 9 nm to the north of the Manukau Bar. The mean tide range at that station was within about 0.02 m of that of the bar, whereas that at Paratutae was around 0.12 m higher than at the bar. The time of high water at the Anawhata is within one or 2 minutes of that on the bar. The actual sea level at Anawhata at the time of the accident was marginally, about .05 m, higher than that predicted, owing to the prevailing onshore winds and the low atmospheric pressure.

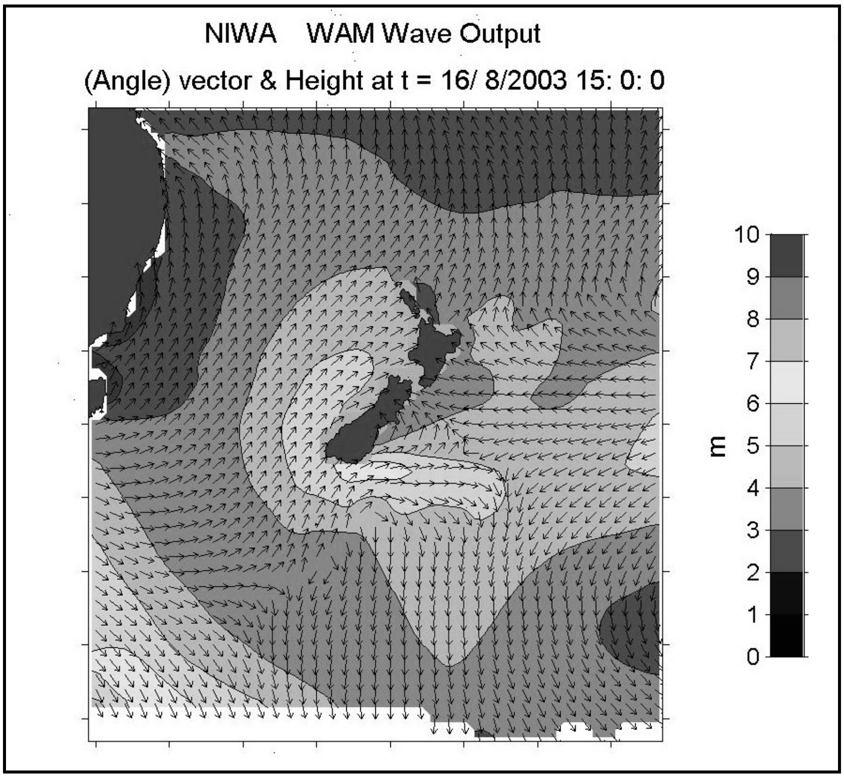


Figure 11
Wave direction and height from wave model

1.9.6 The second part of the NIWA report dealt with options for improving the safety of navigation on the bar. Suggestions made were:

- Possible alternatives to the standard hydrographic sounding surveys, but no financially viable systems were proposed.
- Options of equipment available to measure the height of waves at or near the bar. A wave rider buoy sited close to the bar was the preferred option.
- To use modelling systems to predict wave height and direction.
- Access to the sea level conditions at Anawhata to enable an actual tide reading at the bar rather than relying on predicted data.

2 Analysis

2.1 The extent and severity of the damage to the underside of the rudderstock housing indicated that the flap actuating mechanism on top of the rudder was driven up into the plate work with some considerable force, not consistent with the rudder just falling off.

2.2 The deformed stainless steel bearing sleeve indicated that the rudderstock had been bent towards the stern, either before or during the fracture event. The physical evidence indicated that the bottom of the rudder made contact with the seabed and that, with the combination of the ship's momentum, pushed the rudder upwards and backwards into the rudderstock housing.

2.3 The force imparted was sufficient to fracture the already weakened rudderstock and so allowed the rudder to fall away.

2.4 The metallurgy report indicated that the rudderstock was already in a weakened state from load stress cracking on both its port and starboard side, in way of the stainless steel shrink fit bearing sleeve. This was probably due to the loads imparted on it in its every day use. There was also evidence of fatigue cracking on its after side, which might have been the result of the grounding on 1 August 2003. In addition, the occasions when the flap actuating mechanism jammed may have applied additional torsional stresses on the rudderstock, possibly weakening it. The loss of the rudder was probably inevitable given the pre-accident cracking present.

2.5 When the ship was built, it and its components were built to the classification society's 1996 rules, in force at that time. Those rules appear to have been generous in the allowance applicable when high-strength steel was used in the construction of a rudderstock. The most recent rule, 2003, appears to have acknowledged that using very high-strength steel does not necessarily give a rudderstock the ability to withstand the rigors of the marine environment and changed its formulas to increase the required diameter assuming standard steel, and decreased the allowance for higher-strength steels.

2.6 The steel used to construct the original rudderstock had a high carbon content making it more brittle than standard steel, so making it more liable to stress fractures. Usually, rudderstocks were constructed from standard steel, which was ductile. Had such material been used for this rudderstock it would have been less susceptible to stress fractures and more likely to bend on contact with the sea bottom rather than fracturing.

2.7 With the loss of the rudder, the ship lost directional control. Initially the bow paid off to starboard under the influence of the wind and the waves. When the ship came beam on to the wind, the tall accommodation at the after end of the vessel acted like a sail and caused the ship to turn to port, into and through the wind until it again came beam on. This time the wind was on its starboard side and the sail effect caused the ship to turn to starboard. The ship continued these oscillations until the master used the bow thruster to steady the ship's head. Once it was steady he was able to con the ship away from the coast into safety. It was fortunate that the accommodation block did act as a sail; otherwise the ship may have completed its turn to starboard and grounded to the north of the bar.

2.8 The master and crew of the *Spirit of Enterprise* were suitably qualified and experienced. In its procedures manual the company encouraged the use of bridge resource management and the crew appeared to use those techniques when carrying out the harbour and bar passage.

2.9 The signalman at South Head Signal Station had been incumbent for 18 years and had built up a wealth of experience in estimating wave height, but his observations had never been measured against actual wave heights.

2.10 The Taharoa wave buoy was about 66 nm to the south of Manukau Heads . However, in the prevailing weather conditions, the sea state at each location would have been similar. The sea state models used by NIWA in its analysis support this.

2.11 If the maximum (6.13 m) and significant (4.57 m) wave heights from the Taharoa wave buoy for the time of the accident were used in the calculation of the UKC, the following would result:

Maximum wave height

Bar chart datum	5.7
Height of tide	+2.7
Depth of water	8.4
Maximum Draught	-5.9
Static UKC	2.5
Allowance for maximum sea and swell (6.13/2)	-3.1
UKC	**-0.6 m**

Significant wave height

Bar chart datum	5.7
Height of tide	+2.7
Depth of water	8.4
Maximum Draught	-5.9
Static UKC	2.5
Allowance for significant sea and swell (4.57/2)	-2.3
UKC	**0.2 m**

The master and signalman did not have access to the Taharoa wave buoy information. In each case the UKC did not allow for squat. In each case there was insufficient clearance for the vessel to safely cross the bar.

2.12 Neither the signalman at South Head Signal Station nor the master had accurate wave height information. The signalman was using his experience and visual cues to estimate the wave height and the master was reliant on those observations. The master's calculation of his ship's UKC for the bar crossing was based on a maximum sea state of 2.5 m. Had he known the actual conditions, the master would most probably have realised that there would be less water than he expected, and he would have postponed the bar crossing until the sea had abated.

2.13 Pacifica Shipping had procedures in place for all significant operations of the ship. The checklists that accompanied the procedures were sufficiently comprehensive for each operation. Such procedures and checklists were unable to foresee the use of incorrect information in them. The loss of steering checklist was not referred to until control of the ship had been regained, but the master had followed the information contained therein.

2.14 In every venture there will be a certain aspect of commercial pressure to improve the viability of the operation. In this case there was pressure on the master to delay sailing in order that all available cargo could be loaded. Even with this pressure, the master had sufficient fortitude to maintain the ship's departure at such a time that it could safely negotiate the Wairopa Channel and the bar with the information to hand.

2.15 There was a difference between the tide heights for Paratutae in the POAL tide predictions and those contained in the New Zealand Nautical Almanac. The height from the almanac was about 0.2 m less than that in the POAL tables and so erred on the side of caution. The master used the POAL predictions and so used the most recent data.

2.16 The NIWA report indicated that due to the onshore wind and sea and the low barometric pressure at the time of the accident there was more water on the bar than predicted. Thus, the tide height on the bar was calculated to be at least that of the POAL predictions.

2.17 The hydrographic surveys of the bar carried out for POAL showed that the bar had remained stable for a long period. The hydrographer who carried out the last survey in July 2003, a little over a month before the accident, had concluded that the minimum depth of water on the bar was 6.0 m along the 060°/062° bearing lines from Ninepin Rock light. Even with this information to hand, the master erred on the side of safety and allowed a depth of 5.7 m in his calculation of the ship's UKC.

2.18 The master or pilot of each ship that crossed the bar recorded the least depth it experienced and this was passed to the signalman at South Head Signal Station, who passed it onto masters and pilots of other ships transiting the bar. The pilot of the *Hebe,* that crossed the bar on the morning of 16 August, noted a depth of water of 6.0 m over the bar, corresponding to the depths found during the last survey.

2.19 It is fortunate that the accommodation block did act as a sail; otherwise the ship may have completed its turn to starboard and grounded to the north of the bar.

3 Findings

Findings are listed in order of development and not in order of priority.

3.1 The *Spirit of Enterprise* grounded its rudder on the Manukau Bar causing the rudderstock to fracture, which resulted in the loss of the rudder.

3.2 The rudderstock was already weakened by fatigue cracks before the accident. The loss of the rudder was inevitable due to continued growth of the cracking. Grounding on the bar merely accelerated the process by overloading the remaining material that had not yet cracked.

3.3 The sea conditions at the bar were observed by eye. There was no wave monitoring equipment to assist the signalman and ultimately the master of the ship.

3.4 The sea height 2 hours after high water would have been higher and steeper than that which could be expected at or before high water.

3.5 The bar was about 5 nm from South Head Signal Station making it very difficult for the signalman to estimate the height of the sea on the bar.

3.6 The ship grounded on the bar because the wave height was higher than that estimated by the signalman at South Head Signal Station and the master relied upon that information when he decided to continue with the bar crossing.

3.7 Although the rudderstock was made of high-strength steel, its diameter may not have been sufficient to withstand the high loads the flapped rudder was able to exert.

3.8 Hydrographic surveys on the bar were current at the time of the accident, the last being completed about one month before.

3.9 After the loss of its rudder, the ship was prevented from being pushed by the wind and the sea onto the north side of the bar because the accommodation block acted as a sail and kept bringing the ship's head up into the wind before the master brought the ship under control using the bow thruster and engines.

4 Safety Actions

4.1 After the accident, POAL in conjunction with the Auckland Harbourmaster put in place an Operations Manual for exempt masters on ships using Manukau Harbour. The manual contains similar information and instructions to that in the Practices for Pilotage Operations manual used by pilots of the port.

4.2 When Pacifica Shipping had a new rudderstock and rudder constructed they ensured that it met the current classification society rules. To do this they increased the diameter of the rudderstock and reduced the length of the rudder.

5 Safety Recommendations

Safety recommendations are listed in order of development and not in order of priority.

5.1 On 12 May 2004 the Commission recommended to the Manager Marine Services Ports of Auckland Limited that he:

5.1.1 provide accurate sea condition information to masters and pilots of ships transiting the Manukau bar. In the first instance he should endeavour to gain access to the data from the Taharoa wave rider buoy, either in real time or within one hour of its measurement. (020/04)

and

5.1.2 evaluate the information gained from the Taharoa wave rider buoy. If there is significant difference in the sea conditions between the Taharoa and Manukau or if the Taharoa wave rider buoy data is not available to POAL, he shall urgently take steps to place a wave rider buoy or other suitable measuring equipment close to the bar. (021/04)

5.2 On 9 June 2004 the Manager Marine Services Ports of Auckland Limited replied in part:

> 020/04 Ports of Auckland is in the process of discussing access to the Taharoa wave buoy data with its owners.
>
> 021/04 Upon data access to the Taharoa wave buoy being agreed with the owners. POAL agree to undertake an evaluation to determine the correlation between the Taharoa wave buoy and the conditions experienced at the Manukau Bar. This information would be supplied to users.
>
> POAL have concerns about the practicality of locating a wave buoy at the Manukau Bar. Conditions are at times severe off the bar and the buoys life expectancy coupled with the economics of such a buoy is questioned.

5.3 On 12 May 2004 the Commission recommended to the Chief Executive Officer of Bureau Veritas that he:

put in place an inspection regime to check for load stress cracks in rudderstocks made from high-grade steel that were manufactured to comply with the 1996 rules. (022/04)

5.4 On 28 May 2004 the Chief Executive Officer of Bureau Veritas replied in part:

> With reference to the recommendation 022/04 of the TAIC report 03-212, please be advised that Bureau Veritas are not yet in a position to take a final decision on the appropriate measures to be taken.
>
> This recommendation is also being considered in the light of the explanations that have been given to IACS whereby, according to our understanding, "high-grade steel" should be regarded in the present context as any grade of steel allowing a reduction in diameter of the rudderstock in compliance with the applicable class rules in force. However, we are still not quite sure as to how it should be implemented, as most of the ships are nowadays fitted with rudderstocks with a reduced diameter as per these rule, and therefore the recommendation made by the report should virtually apply to all modern ships.

5.5 On 12 May 2004 the Commission recommended to the Permanent Secretary of the International Association of Classification Societies Ltd that he:

> advise all member Classification Societies of this accident and that where a reduction in diameter was granted for rudderstocks made of high-strength steel, surveyors and ship operators should be aware of the possibility of load stress cracking. Vessels fitted with such rudderstocks should be inspected to check for such cracks. (027/04)

5.6 On 11 June 2004 the Permanent Secretary of the International Association of Classification Societies Ltd replied in part:

> IACS members have carefully considered your recommendation and have concluded that they cannot adopt it as it would likely require the dismounting of the whole rudder system of all the existing ships fitted with rudder stocks of higher strength steel and the root causes of this incident have not yet been fully established.
>
> In order to justify the adoption of the recommendation, a fracture mechanics/crack propagation analysis should be developed; however, this analysis is neither simple nor rapid to carry out and I regret we are not in a position to undertake it.

Approved on 26 May 2004 for publication

Hon W P Jeffries
Chief Commissioner

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Price $ 26.00 ISSN 0112-6962