Departmental investigation into cargo hold bulkhead failure aboard the Malaysian flag bulk carrier GIGA 2 on 5 November 1996

Report No. 101

Contents

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investigation into the cargo hold bulkhead failure
aboard the Malaysian flag bulk carrier
GIGA 2
on 5 November 1996

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Summary

Early on 5 November 1996, the 140,086 tonnes deadweight Malaysian flag bulk carrier *Giga 2* was nearing completion of discharge of a cargo of iron ore at No. 2 discharge berth, Port Kembla. Due to the vessel's light condition, the unloader could not be positioned over No. 1 hold, to remove the 1080 tonnes of cargo remaining in that particular hold. At the suggestion of the shift supervisor, ballast was pumped into No. 4 hold, which was permissible under the vessel's operations manual. Pumping of ballast into No. 4 hold commenced at 0530.

After the lunch break, two terminal workers descended into No. 5 hold, where the unloader was working, to clear iron ore from around the bottom of the forward spiral access ladder. The spiral ladder terminated at the top of the lower stool, six metres above the tank top. They had just completed this task and were about to climb the ladder when the bulkhead to the starboard side of the centre line, between No. 5 hold and the ballasted No. 4 hold, collapsed. Both workers were immediately engulfed by the deluge and, although one was able to haul himself clear, the other remained submerged.

The shift supervisor was working in his office ashore and, alerted by calls over the radio from the Hatchman, dashed on board and immediately descended the ladder into No. 5 hold. Up to his neck in the swirling water and guided by the Hatchman above, he was able to grab hold of the submerged worker. Assisted by another terminal worker, who had followed him into the hold, he was able to haul the unconscious and apparently lifeless worker clear of the water. The shift supervisor then administered cardio-pulmonary resuscitation (CPR), which was successful in restoring breathing in the worker. Very shortly afterwards an ambulance officer arrived on the scene and administered oxygen, before the worker was lifted from the hold and taken to hospital.

To identify the circumstances which led to the collapse of the bulkhead, the ship's procedures and documentation were examined. Also a detailed examination of the bulkhead between holds 4 and 5 was undertaken, which included a metallurgical examination and a finite element analyses of the failed bulkhead.

Sources of Information

The Master, Mate and Second Mate, Giga 2

BHP terminal shift Supervisors and shift workers

The Australian Maritime Safety Authority

Director General of Marine, Marine Department Peninsular Malaysia

Barber Ship Management Snd Bhd (Kuala Lumpur)

Department of Civil Engineering, Monash University

ETRS Pty Ltd

Nippon Kaiji Kyokai (ClassNK)

BHP Transport

Navix Lines

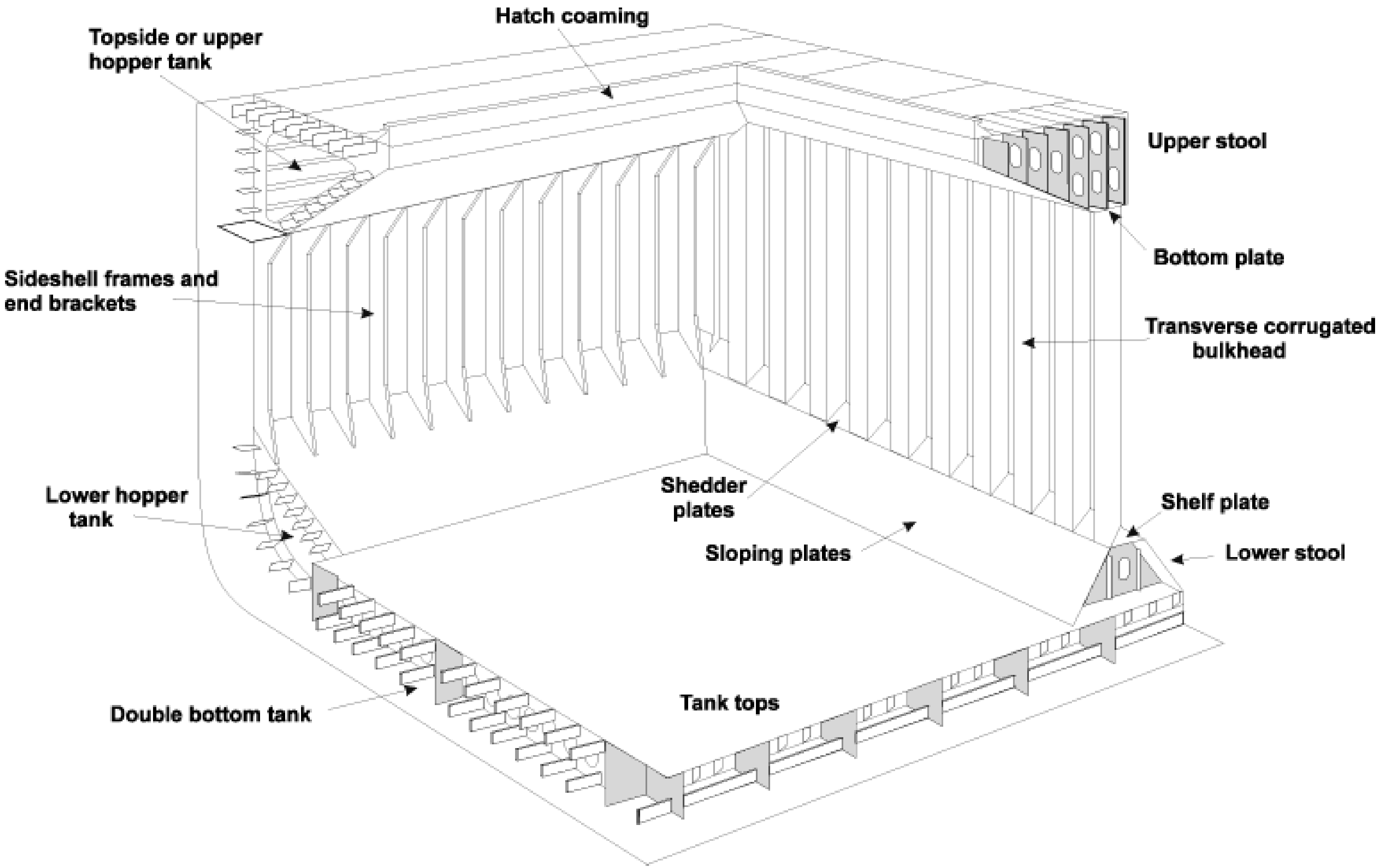
Cido Shipping

Universal Marine

Acknowledgment

The Inspector wishes to acknowledge the cooperation and assistance of the Marine Department Peninsular Malaysia, Barber Shipping Management Snd Bhd, Nippon Kaiji Kyokai and the Australian Maritime Safety Authority, particularly their Senior Surveyor, Port Kembla, in the investigation of this incident and the compiling of this report.

The collapsed bulkhead at frame 193 (the after-end bulkhead of No. 4 hold)



Typical structural configuration of cargo hold for a single skin bulk carrier

Narrative

Background

Giga 2 is a nine hold, “Cape size” bulk carrier of 140,086 tonnes deadweight, having an overall length of 270 m, a beam of 43 m, a depth of 24 m and a loaded summer draught of 16.78 m. The vessel is powered by an 18 cylinder (Vee configuration) MAN diesel engine producing 13, 968 kW, driving a single propeller. Electrical power is provided by one steam turbo-generator of 800 kW and two diesel generators of 440 kW each. The ballast pumps are electrically powered while deck mooring winches and windlass are hydraulic, the hydraulic pumps being electrically driven.

Built in 1981 to Nippon Kaiji Kyokai (ClassNK) classification requirements at the Namura shipyard at Imari, Japan, the vessel was initially owned by the Yamashita-Shinnihon Steamship Company Ltd of Tokyo and named *Yuzuru Maru*. In 1991, the Yamashita-Shinnihon Steamship Company became Navix Lines. In September 1993, the vessel was sold to Cido Shipping Company limited of Panama, under the parent company Midas Maritime S. A. and renamed *Cido Star*. Two months later, in November 1993, ownership was transferred to Dakila Ocean Navigation Corporation, and the vessel traded under the Philippines flag, retaining the same name, before being returned to Midas Maritime ownership and the Panamanian flag on 18 July 1995. On 28 September 1996, the vessel was sold to Tauladan Gigih Sdn Bhd of Kuala Lumpur, for operation by Able Shipping Ltd, and was provisionally registered under the Malaysian flag as *Giga 2*.

The vessel was retained under ClassNK classification throughout, undergoing the third special survey (third four year cycle), at Sasebo, Japan, in June 1994. ClassNK conducted statutory surveys on behalf of the flag State. The vessel underwent an intermediate survey in dry dock at Nantung, China during September 1996, prior to change of ownership.

At the time of the change of ownership, the vessel was under a four-year time charter to Navix Marine Pte Ltd. For the period immediately after the drydocking Navix had fixed the vessel for a voyage charter with BHP Transport Australia Pty Ltd, to load a cargo of iron ore at Port Hedland, WA, for BHP Steel at Port

Kembla, NSW. There was no Australian flag bulk carrier available during this period that could fulfil the voyage requirements.

At the recommendation of Navix, the new owners placed *Giga 2* under the technical management of Barber International Limited. Barber International Limited retained the 27 man Filipino crew, the majority of whom had joined the vessel during the drydocking, but appointed one of their own masters and chief engineers as “staff officers” to assess the vessel and crew.

Giga 2 sailed from Nantung, in ballast, on 30 September 1996 and arrived off Port Hedland, WA, where it anchored in the roads on 14 October 1996. One of the vessel’s two diesel generators suffered extensive damage, caused by hydraulic shock, when an attempt was made to start it with fuel in one of the cylinders. The vessel berthed at 1942 on 16 October.

At sea superheated steam is produced by the main engine’s waste heat unit, this being sufficient to run the turbo-generator at full load. In port, however, the ship’s auxiliary boiler could only produce saturated steam and this was insufficient to run the turbo-generator at enough load to provide electric power for all the ship’s port needs. To overcome this problem it was arranged to hire a portable diesel generator, which was connected to the switchboard by temporary wiring from its position on the open poop deck.

At Port Hedland, before the portable generator was delivered, the vessel was inspected by an AMSA surveyor under the Port State control inspection regime and a detention notice issued covering a deficient engine room vent, a fire damper in the engine room and the reduced capacity for electrical power generation.

The defective vent and fire damper were repaired and the portable diesel generator connected up on deck. With the requirement for electrical power generation met, the detention notice was lifted.

The loading of the cargo of 121,517 tonnes of iron ore, into all nine cargo holds, proceeded according to plan and *Giga 2* sailed from Port Hedland, bound for Port Kembla, NSW, at 1630 on 20 October 1996.

While in Port Hedland, BHP arranged for a firm of private marine surveyors to undertake a “superficial” inspection of *Giga 2*, to protect BHP’s interests in the event of any claims against BHP, by the ship owners, for damage to the ship by discharging equipment in Port Kembla.

The incident

Giga 2 arrived off Port Kembla at 2154 on 30 October and had to anchor off the port to await the next daylight flood tide before berthing. The vessel was all fast alongside No. 2 Discharge Berth, Inner Harbour, at 1220 on 1 November. Discharge of the cargo started at 1230, with No. 3 unloader working No. 2 hold and No. 2 unloader working No. 6 hold.

For the cargo discharge the Mate was in overall charge of operations, while the Second and Third Mates maintained a six-hour watch routine. The Mate retained operational responsibility for ballasting operations, to the extent of sleeping in the ballast control room. As the portable diesel generator could not be run in parallel with the ship's generators, the ship was using just the former to provide its power needs while in port. However, the power provided was only sufficient to run either one of the two ballast pumps, or the mooring winches, in addition to the domestic load. When the moorings had to be tended and the mooring winches were required, ballasting had to be suspended to allow the power to be switched to the mooring machinery.

At the completion of the first stage, at 1820 on 1 November, the Mate changed the order of discharge, but thereafter the discharge followed the programmed sequence until noon on 2 November. At that time, due to the height of the hatch covers with the rising tide, No. 2 unloader had to cease operating at No. 8 hatch until 1640. The same problem arose on the evening high tide, when the terminal operators moved No. 2 unloader to the next berth to discharge another vessel. Thereafter the cargo discharge proceeded with just the one unloader.

No grab clearance problems were experienced over the early afternoon high tide on 3 November, but a 45 minute stoppage resulted on the early morning high tide of 4 November.

By 2300 on 4 November, about 14,000 tonnes of cargo remained on board with about 2500 tonnes remaining in No. 1 hold. At about 2325, with the unloader working No. 1 hold, the grab came in contact with the hatch cover. This was reported to the shift supervisor, who at that time was on board another vessel at No. 2 products berth. He instructed the unloader driver to move to No. 5 hold, where approximately 4000 tonnes of cargo remained. He then drove to *Giga 2* to talk to the Mate.

Discussing the problem with the Mate, who had been asleep and had not been informed of the problem at No. 1 hold, the Supervisor stressed the need for the vessel to be ballasted so that the unloader could work No. 1. The Mate explained that the ballasting of No. 1 ballast tanks was rather slow, because of a seized valve in the starboard tank. The Supervisor informed the Mate that if the vessel was not ballasted down, it would have to vacate the berth, as other vessels were being delayed. Noting on the ballast control panel that No. 4 cargo hold, which was forward of the tipping centre, could be ballasted in port for air-draught purposes, the Supervisor suggested to the Mate that he ballast that hold. He then left to go to another vessel.

Returning to *Giga 2* at 0300 (5 November), the Supervisor found that nothing had been done to improve the situation and he told the Mate he wanted to speak to the Master and the Master was called. After further discussion, among the three of them, it was agreed that No. 4 hold would be ballasted. Also, as the grab clearance at No. 5 hold was nearing safety limits, it was also agreed that the unloader could move to No. 7 hold, where there was approximately 6000 tonnes of cargo remaining.

The Mate called out the crew and set up the ballast system to ballast No. 4 hold; however, the removal of the manhole covers in No. 4 hold took some time as the nuts were seized on the studs. Ballasting of No. 4 hold was eventually started at 0530.

Discharging continued from No. 7 hold but, at 0705, safety clearance for the grab was lost at that hatch also and the unloader moved to No. 9 hold, where approximately 800 tonnes of cargo remained. No. 9 hold was completed at 0915 and the unloader moved to No. 1 hold, working there until 1115, when again loss of grab safety clearance necessitated a shift, the unloader moving to No. 5 hold.

The Hatchman noticed that the bottom platform of the spiral ladder at the forward end of No. 5 hold, situated six metres from the bottom of the hold, appeared to be damaged and possibly in need of repair. After the lunch break and shortly after 1300, two shift workers went down the ladder to clear iron ore away from the platform so that any damage could be assessed and any necessary repairs carried out. Having been warned that some of the ladder supports appeared to be badly corroded and as an extra precaution, the two men lowered a rope through the ladder access hatch as an additional hand hold.

While he was clearing the ore away from beneath the platform and from the top few rungs of the vertical ladder beneath the platform, the man using the shovel tied the end of the rope around his chest. Having completed the task, he handed the shovel up to the other man, who was standing on the platform, and climbed back to the platform himself. As the two men were standing on the bottom platform, there was a loud bang and they were engulfed in swirling water. The man without the rope tied around his chest eventually managed to get a hold on the spiral ladder and haul himself up out of the water, but he could see no sign of his companion.

At some time a little after 1200, the pumping of ballast to No. 4 hold had been suspended and the power switched to the mooring winches to allow the moorings to be tightened. At about 1300, the Second Mate had returned to the main deck and the Mate, who was in the ballast control room, resumed pumping ballast to No. 4 hold.

The Second Mate had moved aft to be in the vicinity of the bunkering hose. He was standing by the hose when there was a loud bang, the vessel vibrated and started to list and his immediate thought was that a mooring line had parted. He then realised there was a commotion near No. 5 hatch, ran up to investigate and saw that the transverse bulkhead between holds 4 and 5 had failed, flooding No. 5 hold. He ran aft and reported to the Mate, who had come out on deck and who returned to the ballast control room to stop the ballast pump.

At 1320, the Mate had been standing at the control panel, with the No. 4 hold depth indicator showing about 10 m, when there was a loud bang and *Giga 2* shook violently. He moved to the window, saw the Second Mate running aft along the deck and went out to meet him and was told of what had happened. The Second Mate then went to the ship’s hospital to organise the stretcher, blankets and the Oxy-Viva equipment.

The Hatchman had been standing at the after end of No. 5 hatch, giving directions to the unloader driver, whose control cabin was directly over the centre of the hatchway. He was also keeping an eye on the two men clearing ore from the bottom of the ladder and noticed some large flakes of paint and rust fall from near the top of the forward bulkhead, on the starboard side. Suddenly there was a loud bang, the bulkhead appeared to peel back from the starboard side at the top towards the centre line, water started pouring in from No. 4 hold and the ship heeled towards the wharf. He immediately put out a call for help over his radio, keeping the transmit button depressed and so broadcasting a running commentary of events. He eventually saw one of the men pull himself clear up the ladder.

The cab of the unloader was caught by a sudden up-draught of air and spume. The driver took the cab clear, at the same time broadcasting an alarm over his radio.

The Shift Supervisor was at his desk in the office at the end of the berth when he heard the Hatchman's call on the radio. He immediately raced out, jumped into his car and drove to the bottom of the ship's gangway. He had some difficulty getting from the quay onto the gangway, *Giga 2* having moved off the berth slightly, but, assisted by others, the delay was short and he made his way to No. 5 hatch. Without hesitation, he climbed down the ladder and tried pulling on the rope fastened to the terminal worker but, although there was weight on it, he was unable to haul it in. He then climbed further down the ladder, until the still swirling water was up over his shoulders. Reaching out under the water and guided by the Hatchman, he managed to get a firm hold on the submerged man and was able to pull him towards the ladder. Backing up the steps of the ladder and assisted by another terminal worker, who had heard the alarm and had rushed to the ship from the adjacent berth, the Supervisor pulled the man up so that his head was clear and tried administering mouth–to–mouth resuscitation. However, the water level was still rising, so the two men pulled the unconscious and apparently lifeless man clear of the water. They then manoeuvred him into a more or less horizontal position and into the recovery position, after which water and mud spilled from his mouth. The supervisor again administered mouth–to–mouth resuscitation to which the unconscious man responded.

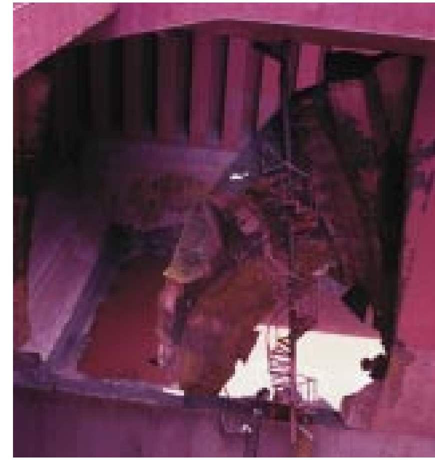
Shortly afterwards, an ambulance officer arrived on the scene, the ambulance having arrived seven minutes after the alarm was raised. The ambulance officer immediately administered oxygen to the unconscious man who was then lifted out of the hold, taken ashore and immediately rushed to the intensive care unit of Wollongong Hospital. The patient remained in hospital until 6 January 1997. The other man in the hold was also taken to hospital but discharged after an examination to ensure he had sustained no serious physical injury.

Post incident

After the bulkhead collapse the vessel quickly developed a port list. To counter the list, the Mate restarted the ballast pump to discharge water from No. 1 port ballast tank. It was found that, with the collapse of the bulkhead, two holes had been torn in No. 3 starboard saddle tank allowing much of the contents of the tank to flood into the now common 4 and 5 holds. Once the vessel was upright, the Mate continued to discharge ballast from both No. 3 port and No. 3 starboard tanks, until the water level in No. 3 starboard had fallen below the holes. *Giga 2* then remained alongside, with cargo operations suspended for a further 24 hours, after which period it was moved to No. 1 coal berth.

Work was undertaken at No. 1 coal berth, during the following days, to make the ship safe for a ballast voyage to Singapore. The collapsed section of the bulkhead was cut away and it was landed ashore. The contractors carrying out the work were instructed that the pieces were not to be sold or otherwise disposed of, but were to be sent immediately to the furnaces of the BHP steelworks.

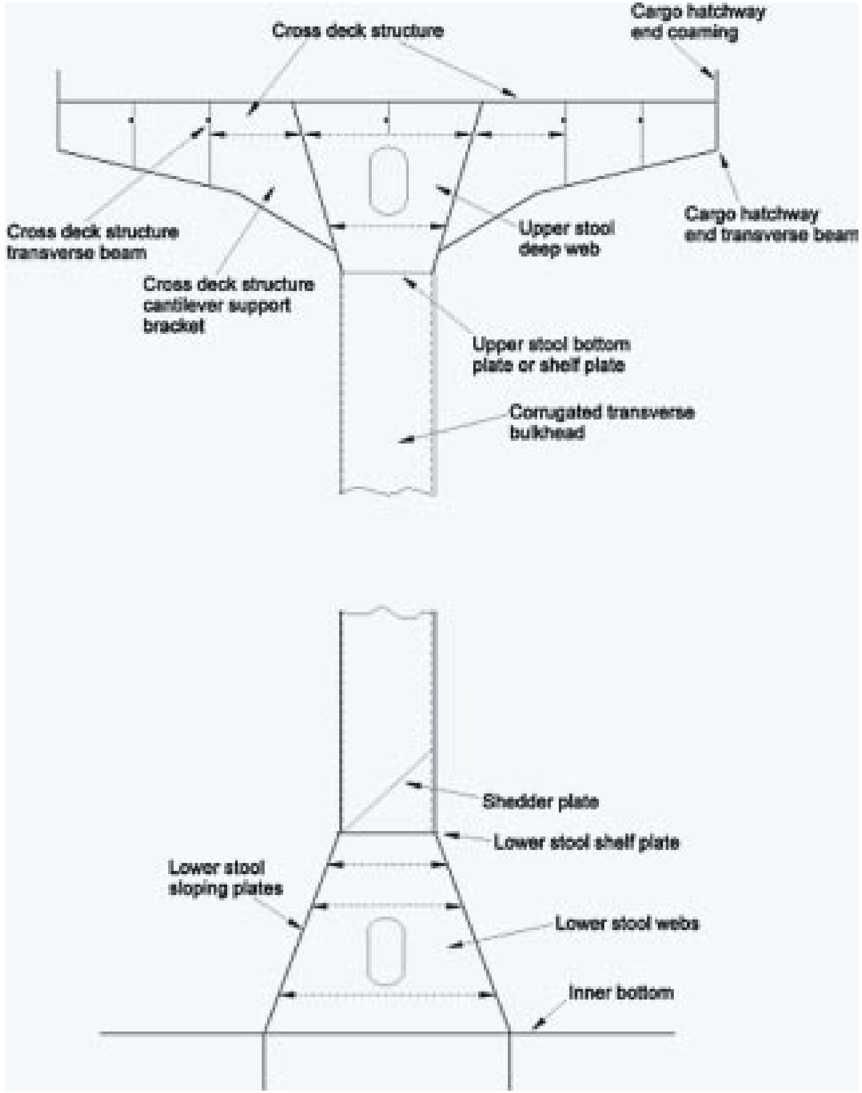
After the incident, *Giga 2* sailed from Port Kembla for Singapore at 1242 on 1 December 1996. It entered dry dock at Jurong Shipyard on 19 December, where the vessel was subject to a special survey which included extensive thickness testing of the cargo hold bulkheads. The thickness measurements showed that the bulkheads were substantially corroded and ClassNK stipulated that all the cargo hold transverse bulkheads, with the exception of those adjacent to No. 6 hold, were to be replaced. They were renewed before the ship entered drydock on 15 June 1997.



Starboard side of bulkhead at frame 193, looking aft from No. 4 hold

Starboard bulkhead at frame 193 viewed from No. 5 hold

Note: Flattening of corrugations at lower half and detachment of shedder plates. Horizontal line along bulkhead indicates level of water in Nos. 4 and 5 holds



Nomenclature for typical transverse watertight bulkhead

Comment and Analysis

Operational procedures

While discharging cargo, bulk carriers simultaneously load ballast into dedicated ballast tanks and spaces to maintain an “air” draught that allows continuous discharge of cargo, to maintain the stresses on the ship’s structure within safe limits and to prepare the ship for sailing when discharge is complete. Although the range of tide between 1 November and 5 November 1996 was less than one metre, such a rise is critical for a cape size bulk carrier such as *Giga 2*, as the ship lightens with the discharge of cargo.

The Mate took personal charge of the ballasting operations, to the extent that he slept in the ballast control room instead of sleeping in his cabin. He monitored the progress of the ballasting by means of the remote depth gauges located on the control panel in the ballast control room.

The Mate had two operational problems:

- the limited electrical generating capacity, allowing the operation of either one ballast pump or the hydraulic pump to run the deck mooring machinery, and
- the filling/suction valve to No. 1 starboard ballast tank, which was partially seized.

Although the generating capacity limited the vessel to using just one ballast pump, each pump is rated at 2300 m^3/hr. This rate of pumping should have been quite adequate for ballasting during cargo discharge operations, even allowing for suspending ballast operations for short periods to allow the moorings to be tended.

The fact that the filling/suction valve in No. 1 starboard ballast tank was partially seized would have prolonged the filling of the tank. This led to the Supervisor trying to persuade the Mate to fill No. 4 hold before No. 1 was complete. The Mate, however, was quite correct in initially resisting those pressures and insisting on continuing with the filling of the forward wing ballast tanks before filling No. 4 hold, so as to avoid possible high stressing of the vessel.

While ballasting No. 4 cargo hold, as with the other ballast tanks, the Mate relied entirely on the remote depth indicator in the ballast control room, although he had not used that hold for ballast before. In evidence, the Mate stated that he purged the depth indicator system to No. 4 hold, as he routinely did when monitoring other ballast tanks.

The Mate and a marine superintendent, who were both in and about the ballast control room immediately before the failure of the bulkhead, maintained that the gauge in the ballast control console indicated a depth well below 14 m. The evidence is that the audible high level alarm, set to go off at a depth of 13 m, did not sound at any time before the bulkhead failure.

Shortly after the bulkhead failure, when the water had settled, a number of witnesses noted the level of water in the now common No. 4 and 5 holds. This led to varying estimates of the depth of water in No. 4 hold immediately before the bulkhead failure. ClassNK, in its investigation, calculated the depth of water in the hold as being more than 18 m.

From the varying accounts, and allowing for the inflow of ballast water from No. 3 starboard ballast tank (ruptured in the structural failure), initial calculations indicated that the level of water in No. 4 hold had been between 16.5 m and 17 m above the hold bottom when the bulkhead failed. The Monash University analysis was based on this depth. Later calculations however, indicated a minimum depth of 17 m (see Appendix 1).

The remote depth monitoring system to the ballast spaces and ballast holds was of a pneumatic type, utilising small bore piping. After the incident, an AMSA surveyor read the No. 4 hold depth gauge and found that, the depth in the hold actually at 9.9 m, the depth gauge showed 6.5 m, an error of 3.4 m. A service engineer tested each gauge on the ballast console using compressed air; all gauges including that for No. 4 hold were found to be satisfactory. Also the high level alarm, set at 13 m, operated correctly when tested.

The AMSA surveyor subsequently examined the piping associated with the depth monitoring system to No. 4 hold for any air leak or damage. Although no leak or crimping of the piping was found, the surveyor emphasised that it is quite possible that he was unable to find such damage as any leak would have been very slight, otherwise the system would not have operated. It is possible that either the system was not purged sufficiently, or there was a small leak in the gauge piping system, which resulted in a false reading.

The Inspector is satisfied that the gauge for No. 4 hold in the ballast control room had a considerable error and, whatever the reading on the gauge, there is no doubt that No. 4 hold was overfilled.

Ballasting No. 4 hold

The crucial questions, however, are how critical was such overfilling and, if critical, were the defences in place adequate to prevent overfilling?

Ballasting No. 4 hold does not seem to have been a frequent operation. Although it is most probable that, at some time in the past, No. 4 hold had been used to ballast the ship in port to reduce the air draught, there were no records on board indicating such an operation. None of the previous owners, all of whom were contacted in the course of the investigation, had any record of the filling of No. 4 hold. The Boatswain, who had been on board the ship for nine months, had not seen the hold used for ballasting during this time. This, coupled with reported difficulties that the crew had experienced while removing manholes to allow the hold to be connected to the ballast system, supports the probability that the hold was seldom used for ballast and had not been used in the preceding 9 months.

Giga 2's loading manual was written in Japanese, the language of the original crew, supplemented by technical terms in English. A single paragraph referred to its use:

The ship had changed to the flag of Panama in 1993, from which time crews of various nationalities operated the ship, and Japanese was certainly not understood by the Filipino crew. However, it was clear from the manual that No. 4 hold could be used as a ballast tank in port, to reduce the vessel's air draught, but the depth of water was limited to a maximum 14 m sounding (ullage of 8.53 m).

A translation obtained by the Inspector read:

> *When in harbour, regulate the air draught by using No. 4 cargo hold as a ballast tank but ensure the SD depth upper limit is 14 m and ullage = 8.53 m.*

The ballast control console depth gauge for No. 4 hold was calibrated to 16 m although the tank calibration tables listed depths only to 14 m. A "dyno tape" note on the console indicated that 14 m was the maximum level and this was backed by the audible high level alarm.

In the hold itself there was no visual indication, such as depth marks or a maximum filling line, to provide an immediate visual check for those on deck. At no time did the Mate get the Duty Mate to take check soundings to confirm the accuracy of the remote gauging system. No independent manual check was made by sounding or ullaging the hold. The Mate relied solely on the remote system in the ballast control room when ballasting No. 4 hold.

The ship's staff were aware of the depth limit, but they did not appear to appreciate the possible consequences of overfilling the hold and placed total reliance on the remote indicator. There was no indication that overfilling the hold would result in unacceptable stresses on the ship's structure leading to the possible collapse of the bulkhead. This was not explained in the operations manual used by the crew, either in the original Japanese or any other language.

The question arises whether a bulkhead, maintained within acceptable limits of wastage, should fail under such circumstances.

The structural failure

After the water had been pumped from Nos. 4 and 5 holds, the collapsed bulkhead at frame 193 (the after-end bulkhead of No. 4 hold) was examined. It was found that the corrugated bulkhead to the starboard side of the centreline stiffener had become completely detached from the upper and lower stools and had torn from bottom to top, about 8 m in from the ship's side. It remained attached only down its inboard side adjacent to the centreline stiffener. The lower half was bowed well out into No. 5 hold and the bulkhead had been stretched to the point where the corrugations in the lower half of the detached section had been smoothed out and virtually disappeared.

The welds connecting the shedder plates to the corrugations and to the shelf top plate of the lower stool had failed. Examination of the shedder plates showed that the edges were left in the condition as when flame cut and had not been ground or prepared for welding. Visual examination of the welds and the plate preparation indicated that the welding was of a nominal rather than structural nature.

Along its top edge, the bulkhead had become detached from the upper stool from a point 1 m outboard of the centreline stiffener (approximately 3.4 m from the vessel's centreline) to the outboard end of the upper stool and to another point part-way down the underside of the upper hopper (approximately 12.3 m out from the centreline). Severe corrosion was found along the lower edge of all the deep webs within the upper stool, extending to a height of some 75 mm to 150 mm up the webs, indicating that water or damp sludge had been lying in the bottom of the stool for a lengthy period. The corrosion was such that most of the webs were virtually detached from the bottom plate of the stool, leaving the load on the top of the bulkhead to be carried almost entirely by the two continuous welds running along the forward and after edges of the bottom plate. These welds had failed and most of the bottom plate of the upper stool had come away with the bulkhead.

On its lower edge, the corrugated bulkhead had become detached from the lower stool from the edge of the centreline stiffener (2.4 m from the vessel's centreline) to a point 13.3 m out from the centreline, a total length of 10.9 metres. Preliminary investigation indicated that the failure was possibly initiated at a point roughly mid-way along this length where the shelf plate of the lower stool had been torn off and was folded back through 180° as the lower edge of the bulkhead separated from it.

Visual evidence indicated that No. 4 hold forward bulkhead at frame 222 (forward bulkhead No. 4 hold) had bulged into No. 3 hold, although it had not failed. Large areas of paint midway up the bulkhead had flaked off, with the majority of the superficial surface rust on the resulting exposed metal extending only up to the level at which the water had settled after the incident showing that the flaking of the paint had occurred very recently and, most probably, at the time of the incident. From within No. 3 hold evidence of buckling could be seen on the forward parts of the corrugations above the lower stool, indicating a compressive loading consistent with the bulkhead having bowed forward into No. 3 hold.

In those areas which were accessible by a cherry-picker, thickness measurements of the failed bulkhead were taken before it was cut up and removed from the ship.

Lower stool shelf plate showing area in which failure was initiated

Bulkhead at frame 222 – forward bulkhead of hold showing paint loss and signs of buckling, viewed from No. 3 hold

Upper stool showing corroded vertical webs and detached shelf plate

Starboard upper hopper tank in No. 4 hold showing failed welding where corrugated bulkhead was connected

Shelf plate detached from upperstool

Note: remaining corroded edges of deep webs and failure of continuous weld along edge of shelf plate

Steel thicknesses — Bulkheads at frames 193 & 222

In addition to the severe corrosion found at the lower edges of the deep webs within the upper stool, the failed bulkhead itself was found to be severely wasted. Measurements of the thickness of the collapsed bulkhead accessible immediately after the incident, (taken by callipers) showed the thickness at the edge of the torn steel to be as little as 10 mm, a measurement which was further reduced by the depth of moderate to severe pitting on both sides.

At the time of building in 1981, the original steel thickness of the corrugated bulkhead in the cargo holds was 17.5 mm. The maximum degree of wastage permissible for a watertight bulkhead is 25 per cent of the original thickness, therefore the minimum steel thickness allowed for the corrugated bulkhead is 13.125 mm.

The International Association of Classification Societies requirements (IACS UR Z10.2 para 1.2.9, Edition 1, 1992) define "substantial corrosion" as "*an extent of corrosion such that assessment of corrosion pattern indicates a wastage in excess of 75 per cent of allowable margins, but within acceptable limits*". Under this definition, the vertical corrugated bulkhead would be considered to be substantially corroded when wastage greater than 18.75 per cent of the original thickness was recorded (14.22 mm or less remaining steel).

Thickness measurements after bulkhead collapse — 16 December

Frame	Frame 222 Port	Frame 222 Starboard	Frame 193 Port	Frame 193 Starboard
No. of samples	32	35	33	16
av. thickness mm	13.03	13.37	14.05	14.7
modal	10.5–11.5	12.9	14.2	–
median	12.65	12.9	17.5	14.9
SE	0.4234	0.4635	0.505	0.5993
%<13mm	36	51	36	23.6

SE = Standard error

In June 1994, at the third special survey in Sasebo, Japan, ClassNK undertook ultrasonic thickness tests of steelwork in the cargo holds. The corrugated bulkheads in No. 4 hold were tested in 12 places, on both the forward (frame 222) and after (frame 193) bulkheads, six on each port side and six on each starboard side. The 12 bulkhead thicknesses measured at frame 193 ranged between 13.9 mm and 15.2 mm (at about $^1/_3$ depth and about $^2/_3$ depth), of which nine readings were between 13.9 mm and 14.22 mm.

ClassNK submitted that, as the thickness gauging showed just under the criteria, the attending surveyor did not require an increase in the number of thickness readings. However, the ClassNK survey report identified the bulkheads at frames 222 and 193 as "suspect areas", to be examined at annual intervals.

ClassNK confirmed that the bulkheads were examined at subsequent surveys:

- the annual survey in May 1995;
- the occasional survey in September 1995; and
- the intermediate survey of 1996.

No action or further recommendation was made by the surveyors acting for ClassNK. At the survey conducted immediately before the BHP charter in September 1996, it was reported that all the cargo holds were sand-blasted and painted. In this context, the attending surveyor dispensed with any thickness measurement of the bulkheads at frames 222 and 193.

After the bulkhead collapse of 5 November and the completion of temporary repairs, *Giga 2* sailed from Port Kembla and arrived in the Singapore dry dock on 16 December 1997. In dry dock, thickness measurements of the bulkhead at frame 222, and the intact areas of that at frame 193, were taken on behalf of ClassNK. This involved selecting 116 points on the vertical corrugated bulkhead as well as a number of points on the upper and lower stool plating. Measurements were taken at the top, $^1/_3$ depth, $^2/_3$ depth and bottom of the corrugated bulkhead.

The common characteristic of the measurements taken showed that the those taken at the top of the bulkhead were close to the original thickness. Measurements at the bottom of the bulkhead showed wastage, but generally the thicknesses were above 13.12 mm.

Maximum wastage in the three sections of bulkhead (frame 222 P&S and frame 193 P) was at the $^{2}/_{3}$ depth of the hold. Twenty seven points were taken at about $^{2}/_{3}$ depth of hold on these three sections of intact bulkhead. Only three of the 27 measurements were more than 13.12 mm with an average thickness of 11.27 mm, (SD 1.49 mm) and a median value of 11.0 mm. At $^{1}/_{3}$ depth, 18 measurements were made with an average thickness of 11.72 mm (SD 1.2 mm) and a median value of 11.5 mm.

It is difficult to compare the six readings of each section, taken in June 1994, with the 30 or more readings taken 27 months later. However, nine of 12 readings taken in June 1994 indicated “substantial corrosion”, which, under IACS requirements and IMO Resolution A.744 (18) “Guidelines on the Enhanced Programme of Inspection During Surveys of Bulk Carriers and Oil Tankers” (4 November 1993), required the extent of measurements to be increased. The IMO Assembly invited governments to apply the guidelines “as soon as possible” after November 1993.

Despite the report of the “suspect areas” made subsequent to the May 1994 survey, the more rigorous regime of determining bulkhead wastage was not followed at either the annual survey, the survey for change of flag in 1995, or during the dry docking in August/September 1996.

The Inspector is satisfied that the condition of the after starboard section of bulkhead which failed was similar to the port section and to the forward bulkhead, and it is probable that more than 36 per cent and possibly over 50 per cent of the bulkhead was below the minimum permitted thickness, significantly reducing its rigidity.

Failure analysis — ETRS report

The full ETRS report is reproduced as Attachment 1
(The Acrobat version of this report does not include the Attachments).

While the vessel was still in Port Kembla, and before the damaged bulkhead was cut away, a company specialising in metallurgy and engineering testing was engaged by the Inspector to investigate the structural aspects of the failure and to carry out metallurgical examination of the welds and on the steel plate.

A visual inspection indicated that along the lower edge of the corrugated bulkhead, the collapse was initiated by failure of the welds securing the shelf plate of the lower stool to the plating beneath it. Once this plate had torn, the failure was propagated by following the continuous weld along the top surface of the shelf plate (lower stool) at the lower edge of the corrugations.

The indications are that then, for a brief instant, the whole hydrostatic load on the starboard half of the bulkhead (and some hydrodynamic loading) was taken on the inboard and outboard edges allowing it to bulge out into No. 5 hold, flattening out the corrugations, before the nominal 17.5 mm plate tore, from the bottom up to the top, leaving the bulkhead hanging by its inboard side close to the ship's centreline. The direction in which the plate tore was shown by the chevron-like striations left on the torn edges.

Following the visual metallurgical examination of the collapsed bulkhead and associated structures, three samples of steel plate were cut from the area on the top of the lower stool where the evidence indicated the failure had been initiated. Of particular interest was the run of weld, on the forward side of the lower stool, joining the underside of the horizontal shelf plate to its sloping side plates. Based on expert metallurgical opinion, it is probable that, as the water pressure caused the build-up of large stresses through the top plate of the lower stool, this weld was the first part of the structure to fail.

Most of the weld metal had remained attached to the shelf plate and had torn away from the sloping side plates, as can be seen in various photographs. In the case of the forward transverse weld, the orientation (at 30° to 45° away from the vertical) indicates that this was a partial penetration butt weld, whereas the after transverse weld appeared to have been a fillet weld. There was little evidence of any significant corrosion of the weld deposits, the welding ripple marks being visible on their surface.

Both welds joining the lower edge of the bulkhead to the shelf plate of the lower stool appeared to be partial penetration butt welds. Several areas of these welds exhibited evidence of significant lack of root fusion and porosity.

Measurements were carried out on the weld metal which was still attached to the underside of the shelf plate on the lower stool. The results showed considerable variation in the weld size and the actual dimensions are recorded in Appendix 2 of the ETRS report (Attachment 1) . When interpreting the results of these measurements, however, the notes listed at 4.2 in the metallurgical report should also be considered.

Metallographic examination

A transverse specimen was excised from each of the three samples and prepared using standard metallographic procedures and examined. The examinations showed that, in all three specimens, the fractures had passed through the weld metal, although there were no features of the microstructure which would have predisposed the welds to premature failure.

Hardness tests carried out on the three specimens revealed no unusual features.

The metallurgical report concludes, however, that although there were a number of sections of weld in areas of the various joints which were clearly not large enough for the application, together with areas which exhibited significant defects, a large percentage of the welds joining the stool shelf plate to the plates beneath it were found to be sound, and it was considered extremely unlikely that the welds were the *principal cause* (Inspector’s italics) of the collapse of the bulkhead.

A number of witnesses gave evidence that the bulkhead appeared to fail at the top, but events were so rapid as to be virtually instantaneous. The ETRS report, however, also concludes that, although the corrosion observed in the upper stool was extremely bad, it was considered unlikely to have been a significant factor in the failure, as evidence indicates that the rupture was initiated at the lower stool.

The ETRS report considered it probable that a major contributing factor in the failure of the bulkhead at frame 193 was the overall loss of rigidity of the bulkhead due to thinning by corrosion. This could result in significant bulging of the bulkhead resulting in extremely high forces on the front edge of the lower stool, it being possible to establish the magnitude of these forces only by a finite element analysis (FEA).

To establish the magnitude of these forces, the Department of Civil Engineering at Monash University, in Melbourne, was contracted to carry out an FEA of the stresses within the bulkhead, stool, and surrounding structure on behalf of the MIIU.

Monash University report

The full Monash University report is reproduced as Attachment 2
(The Acrobat version of this report does not include the Attachments).

As basic references, this analysis considered two alternative water levels in No. 4 hold – one of 14 m (the allowable level) and the other of 16.75 m (an initial estimate by the MIIU immediately after the incident).

As the welds connecting the shedder plates to the lower stool and the bulkhead corrugations were welded into place with nominal, rather than structural, welds, the shedder plates were not taken into consideration in the Monash analysis.

A linear elastic FEA model for the two ballast cases was established, with emphasis on details of the bulkhead. The outputs were studied for areas of significant stress. The feasibility of the results of this FEA was checked by setting up a simple beam model of the bulkhead. This beam model was used to assess the effect of thickness loss on the stresses and also to determine the design stresses in critical welds in the system.

In the case of the elastic FEA, only one thickness of bulkhead plate ("as built") was analysed. It was found that the stiffness of the bulkhead and of the lower stool reduced in direct proportion to the loss of thickness due to corrosion.

The results of the Monash analysis indicated that the stresses were not excessive for the two water depths considered. However, thickness loss through corrosion would elevate the stresses in approximately inverse proportion to the plate thickness. In addition, the stresses are approximately doubled for a rise in water level from 14 m to 16.75 m.

The beam model adopted by Monash revealed that, even at 16.75 m, the stresses were at a level where buckling would not have started. This indicated that other reasons for the collapse would have to be found, such as a higher water level, or the connection at the lower stool should be suspect. (Later calculations by the MIIU indicated that a higher water level was, indeed, a factor).

As a result of this and the fact that, during the FEA, stresses up to three times the average had been found at the connection between the bulkhead and the lower stool, the performance of the weld connections in this area was examined.

Consideration was given to the membrane forces transmitted from the bulkhead to the lower stool and the minimum size of welds required in this area was calculated. The result of these calculations was that the minimum size of weld required to withstand the membrane forces produced when the level of ballast was 16.75 m was 9.3 mm. The size of weld specified in the drawings for the attachment of the lower stool shelf plate to the structure beneath it was 8.5 mm.

It is apparent that this weld size was insufficient to transmit the forces present and failure would occur. This is even without consideration of the high stress concentrations in this area which were revealed by the FEA. The stresses in the welds were exacerbated by non-uniform stress distribution arising from the location of the webs in the lower stool, which varied in alignment with the corrugations of the bulkhead.

The Monash report concludes that:

1. Stresses in critical regions increase disproportionately with increase in ballast water depth.
2. The collapse was initiated by failure of the welds between the lower stool shelf plate, the corrugated bulkhead above and the stool plating below.
3. These welds were sufficiently deficient in size for collapse to occur with only a small increase in water level above the allowable 14 m.
4. With the severe thickness loss evident in the bulkhead, failure of the bulkhead itself (as distinct from the welds) would more than likely have occurred at ballast water levels exceeding 18 metres.

(Note: ClassNK in submission stated that, in its analysis, which included the shedder plates, it could find no deficiency in the size of the welds. It stated that it is very difficult to verify the lack of weld dimensions without an explanation of the mechanical forces transmitted through the welds. ClassNK does not agree that the welding was deficient in size.)

ClassNK report

An FEA of the bulkhead was also carried out by ClassNK and is reproduced as Attachment 3 *(The Acrobat version of this report does not include the Attachments).*

The society provides a figure of 24 Kgf/mm² as the yield strength of the mild steel used for construction of the bulkhead.

“As built” thicknesses were used for the ship’s structural components, with the exception of the bulkhead and lower stool, where the thicknesses measurements taken in December in Singapore were used. The shedder plates, at the bottom of the corrugations, were taken as part of the bulkhead structure and the detachment of the bulkhead from the upper stool was also taken into account.

ClassNK calculated that the water level in No. 4 hold, immediately before the incident, was over 18 m.

The ClassNK analysis is divided into two parts, one based on an elastic analysis using FEA, and the other on an elasto-plastic large deflection analysis.

The elastic analysis can simulate the behaviour of the bulkhead and its surrounding structure, under various load conditions, so long as the stresses produced do not initiate failure of the metal and removal of the load would allow the bulkhead to return to its original position. (That is the stresses do not exceed the yield strength of the steel or the buckling stress for the component.)

The elasto-plastic analysis enables the analysis to be taken further, into the plastic range (where, upon removal of the load, the bulkhead would not return to its former condition), and can simulate the buckling of a component with its subsequent behaviour. Fracture of the bulkhead, however, was not simulated.

The results of ClassNK’s elastic analysis showed that, at a water level of 14 m in No. 4 hold, the stress levels in the bulkhead were so low that neither yielding nor buckling would have occurred. However, the maximum compression stress, calculated by ClassNK, at a water depth of 18 m is 16 Kgf/mm². This is higher than the estimated buckling stress of 12 Kgf/mm². The ClassNK report concludes that some parts of the bulkhead must have buckled.

In the elasto-plastic analysis, a half-pitch of a corrugation of the bulkhead was taken as the model, with five different steel thicknesses simulated. This model was used to simulate the non-linear behaviour of the bulkhead after buckling and to estimate the collapse load of the bulkhead. The elasto-plastic model indicated that a ballast depth of more than 18 m water level produced excessive deformation of the bulkhead in the heavily corroded models.

It is not possible to accurately simulate the boundary conditions in this model and this fact is acknowledged in the report. The report suggests that this may have been the cause of the discrepancy between the results of the two models and the analysis concludes that there must, therefore, have been more than 18 m of water in the hold. It further concludes that the considerable plastic strain at the lowest part of the bulkhead could have caused fracture of the fillet welds at that position.

The report summarises the cause of the incident as consisting of the two following factors:

1. excessive ballasting of No. 4 hold beyond the 14 m allowed; and
2. corrosion of the bulkhead plate and the fillet welds joining the bulkhead to the lower stool.

Overview of stress analyses

Both the ClassNK analysis and that of Monash University were in agreement on the following factors:

1. Both emphasised the fact that the stresses in the bulkhead structure increase dramatically as the water level rises above 14 m.
2. Both the Monash report and the ClassNK elasto-plastic analysis indicated that, taking into consideration the degree of wastage or thinning of the bulkhead plating, plastic collapse (or buckling) of the bulkhead would have occurred when the level of water in No. 4 hold had risen above 18 metres. ClassNK goes further to suggest that this was one reason for the collapse.
3. The ClassNK report mentions that the detachment of the upper stool shelf plate from the webs within the stool, due to severe corrosion, was taken into account during the FEA modelling. In submission ClassNK stated that both the intact and detached conditions were calculated and no significant difference was observed. The Monash analysis, in finding that the bending moments at this point were negligible and the shear forces low, effectively came to the same conclusion.

There were some differences in the approach of the two analyses, these being:

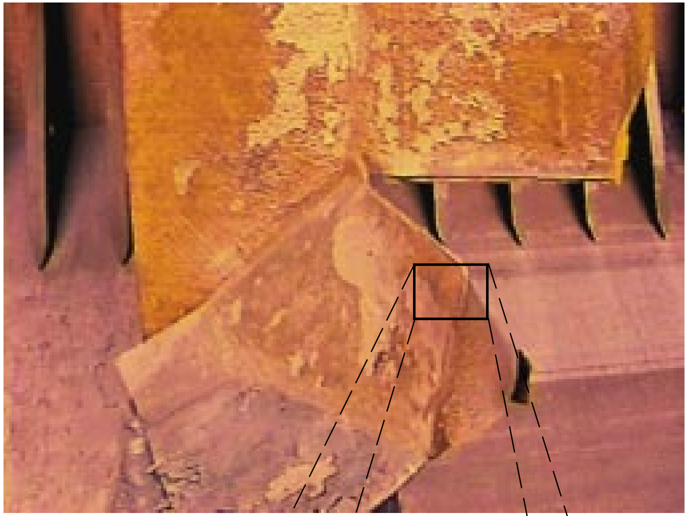
1. The Monash analysis used a “three-quarter hold” model on each side of the bulkhead to make allowance for the complex deformation of the tank top under load and lateral forces on the bulkhead. ClassNK used a “half hold” model.
2. The Monash analysis did not incorporate the shedder plates. ClassNK treated the shedder plates as part of the bulkhead structure in its analysis. Differences in the results of the two analyses indicate that the shedder plates may, in reality, have contributed to the strength of the bulkhead structure to some, albeit an unknown, extent.

The ClassNK report does not go so far as to analyse the likelihood of fracture of the welds and no reference is made to the size of the welds. When the ship arrived in Singapore in December 1996, a ClassNK surveyor tried to identify the starting point of the fracture, but could not find it. He developed a scenario that the fracture of the bulkhead did not “exactly” depend on the size of the weld but would start where the bulkhead was thinner and would result in plastic buckling before the fracture of the fillet weld.

Whether or not the shedder plates are included in the stress analysis is central to the differences in outcome of the two analyses. The inclusion of the shedder plates in the ClassNK analysis indicates that they contributed something to the structural strength of the bulkhead. Based on the evidence of the plate preparation and welding, however, and the manner in which the shedder plates had separated from the lower stool and the corrugations, their contribution to the structural strength of the bulkhead may have been only limited. Whatever the structural requirements may have been when the ship was built, the Inspector considers it reasonable for the shedder plates to have been omitted from the Monash analysis as their effect could not be quantified.

The likelihood of the fillet welds beneath the shelf plate of the lower stool having been the first item to have failed is significantly increased by the high stress concentrations identified in the FEA carried out by Monash University. These areas, once identified in the initial analysis, were further explored by a refinement of the mesh set-up. They were also identified in the ETRS report as the most likely area for initiation of the overall failure.

Detachment of shedder plates at bottom of corrugated bulkhead



Shedder plate (video capture)

Shedder plate showing flame-cut edge unprepared for welding (video capture)

It must be recognised that the bulkhead and weld dimensions relate to a bulkhead designed to withstand a 14 m head of water. However, these welded connections, between the bulkhead and the lower stool, appear to have been the weak link in the system and were identified in the Monash report as being sufficiently deficient in size for collapse to occur with only a small increase in water level above the allowable 14 m.

However, both reports leave little doubt that the overfilling of No. 4 cargo hold with ballast, whether it was to 16.5 m or to over 18 m, was the factor which triggered the bulkhead collapse.

Flag State statutory surveys

Giga 2 is classed under Regulation 27 of the International Load Line Convention 1966, as a “type B” ship and it was assigned an unmodified freeboard. As such, there is no requirement for the vessel to withstand single hold flooding. ClassNK submitted that, accordingly, neither the flooding calculations for reducing to B-60 (B1) nor the damage stability calculations for reducing to B-100 (type A /B2) were carried out in the new building.

Giga 2’s structure and equipment is subject to statutory surveys by the flag State. These involve special surveys every four years while conforming to Japanese statutory requirements, annual surveys and an intermediate survey at, or in between, the second or third annual survey. After 1993, when the vessel left the Japanese flag, ClassNK continued to conduct statutory surveys on behalf of the subsequent flag States.

At special surveys a program of thickness testing is required to cover all areas of the ship’s structure, unless the surveyor is satisfied by close up inspection that there is no structural diminution. Where wastage is suspected the thickness testing may be extended. At annual surveys for vessels over 10 years of age thickness testing may be conducted in conjunction with an overall survey of cargo spaces.
If substantial corrosion is found, the extent of thickness measuring should be increased. Intermediate surveys also require an assessment of the ship’s steel thickness similar to that of the special survey.

In June 1994, the vessel, as *Cido Star*, was subject to its third special survey at Sasebo, Japan. As a vessel over 10 years old, prescribed International Association of Classification Society requirements for the inspection of hold bulkheads were in place. As part of the survey, the cargo bulkheads at frame 193 and frame 222 were examined and thickness measurements taken. In addition, in accordance with an undertaking to AMSA, all hatch coamings were subject to critical inspection.

On 29 May and 30 May 1995, in Brazil, the vessel was subject to its annual survey which was conducted by a non-exclusive surveyor. The surveyor made a recommendation that certain after end hatch coaming brackets in Nos. 5 and 8 holds should be replaced at the owners earliest convenience, but not later than 28 August 1995. Six weeks later, on 14 July, the ClassNK's exclusive surveyor, based in Shanghai, boarded the vessel in Beilun. The surveyor examined No. 5 and No. 8 end hatch coaming brackets and reported:

> *"no obvious defects were found (only slight corrosion)."*

In August 1996, the vessel underwent an intermediate survey, during dry dock in China, when changing both owners and flag. At this time it was provisionally accepted under the Malaysian flag. Such a survey, according to the enhanced survey requirements under the provisions of IMO Resolution A.744 (18), should have also involved thickness testing and close-up survey of the cargo hold bulkheads.

The ClassNK had undertaken thickness testing of the forward and after bulkheads of No. 4 hold (frames 222 and 193) in June 1994 when nine of the 12 readings showed that wastage was more than 75 per cent of allowable margins, indicating that a more extensive examination was required. Additional testing was not carried out, however the two bulkheads were designated "suspect areas" in the survey record. Despite this, no further thickness testing of the bulkheads at frame 222 and 193 was carried out at any subsequent survey. In September 1996, the surveyor appeared satisfied that the bulkhead was sand blasted and painted. The Inspector, however, does not understand what relationship this maintenance had with the thickness of the bulkhead.

This, together with the undetected, severe, corrosion in the upper stools which was evidently of long standing, would suggest that the procedures for surveying this vessel were not adequate to detect wastage rates.

(Note: ClassNK submitted that, although part of the bulkhead, the upper stool is considered as a separate unit of construction. Accordingly, at Intermediate Survey at dry dock in September 1996, internal examination of the upper stool is not one of the items required for survey.)

Port State control inspections

Port State control inspections are not intended as a survey of the ship's structure or equipment. Ship structural surveys are the responsibility of the flag State and the ship owner is responsible for ensuring the ship remains seaworthy in all respects.

Since March 1991, *Giga 2* (as *Yozuru Maru* and *Cido Star*) made 39 loaded voyages, 21 of these to and from Australian ports. The ship had been subject to eight Port State control inspections by AMSA since March 1992. Two of these inspections, in 1994 and 1995, identified cracking in the ship's deck structure in way of the hatch coamings.

On 21 January 1994, a Port State control inspection in Port Kembla found significant cracking at four hatch ways (No. 3, No. 4, No. 5, and No. 7) involving hatch-end beams, hatch coamings and deck plating. The vessel was detained and the cracking repaired under the direction of the classification society. ClassNK noted that:

> *"all hatch coamings must be subject to critical inspection at the next drydocking or by 31 May at the latest."*

In June 1994, the vessel underwent its third special survey.

Within ten weeks of its annual 1995 survey and within four weeks of the examination in Beilun, the vessel was subject to a Port State control inspection at Newcastle. The inspection identified 22 deficiencies which included hatch-end beam and deck cracks in way of No. 2 hatch, No. 4 hatch, No. 5 hatch, No. 7 hatch, No. 8 hatch and No. 9 hatch. The inspection also found wastage at No. 7 hatch coaming. ClassNK withdrew the ship's Cargo Ship Safety Construction Certificate issuing a "short term" Safety Construction

Certificate on 16 August when repairs had been completed to their satisfaction. The “short term” certificate was issued on the condition that permanent repairs were undertaken after discharge of the cargo. The vessel loaded and sailed for Japan on 18 August after a delay of some 136 hours. These defects were outlined in the August 1995 “Ship Detention List” published by AMSA.

After the temporary repairs, ClassNK reported in a memorandum to AMSA, that, after discharging at Tokyo, the ship underwent permanent repairs from 14 September to 29 September 1995. The Society stated:

> *“ . . . all cargo holds were thoroughly examined with close-up survey and cracked and wasted plating on hatch end beam, brackets, frames, deck plates and other members were completely cropped and renewed. . . .”*

A Port State control inspection of 13 March 1996 found 13 deficiencies, none of which related to hatch coamings or the hold structure. The deficiencies were rectified before the ship departed.

Giga 2 was subjected to a further Port State control inspection on 16 October 1996, after the vessel arrived at Port Hedland from dry dock in China, to carry a cargo to Port Kembla. Twenty seven deficiencies, mainly minor in nature were noted. However, three deficiencies relating to an engine room fire damper, worn slipper blocks on the rapson slides of the steering gear and the priming pump of the emergency fire pump, were sufficient for AMSA to issue a detention order. The order was lifted when repairs to these items had been completed, but a further detention order was imposed in relation to the ship’s electrical generating capacity. This detention order was also lifted when a portable generator had been supplied.

Cracking at the hatch corners of bulk carriers is not unusual and the cracking identified on *Giga 2* at Newcastle was fully repaired. (The FEA carried out by Monash University showed high stress levels at the hatch corners at Fig.4 and Fig.6). There is no logical reason to associate past cracking at the hatch corners with the possible failure of the bulkhead.

The inspections of March and October 1996 did not relate to the hold structure of the ship or to No. 4 hold in any way. The repairs to deficiencies identified in Newcastle in August 1995 had been made good and the vessel was apparently fit for the coastal voyage.

No Port State control officer, whether in Australia or overseas, had any reason to inspect the bulkhead structure or examine either the upper or lower bulkhead stools.

Single voyage permits

Applications for single voyage permits (SVP) are made to the Department of Transport and Regional Development. The application includes the basis for the application, a comprehensive form giving the particulars of the ship, details of the ship's international statutory certification and documentation, details of crew management, and a declaration as to the condition of the life saving appliances, fire fighting equipment, mooring arrangements, bridge equipment, engine room machinery and the hull. The application is signed by the Master, the owner, or management representative and attests that the ship is seaworthy and fit for the intended voyage.

Once received, the Australian Shipowners' Association and the Maritime Unions are informed of the application.

Applications for tanker and bulk carrier SVPs are sent to AMSA for examination and checking against their ship inspection records. AMSA informs the Department whether or not there are any known outstanding deficiencies and indicates whether or not the application is considered to be in order. When the vessel arrives in Australia AMSA makes every effort to undertake a Port State control inspection.

Between 1991 and January 1997, approximately 1500 SVPs were issued. Relating to these SVPs, two vessels have subsequently been found to have safety deficiencies warranting detention under Australian Port State control procedures.

BHP Transport has a ship database, as part of a risk management strategy, by which ships identified for possible charter are weighed against a variety of criteria to assess their suitability for charter by BHP. The data includes trade statistics, Lloyd's List entries, the history of ownership and the age of the vessel. Vessels of over fifteen years (sixteen years after launch date) are subject to more rigorous investigation.

In the case of *Cido Star* (*Giga 2*), BHP understood that the disponent owner was Navix Lines, one of the world's largest charterers of Cape size bulk carriers.

On 6 September 1996, BHP applied to the Department for a permit for a voyage by the Panama flag bulk carrier *Cido Star* from Port Hedland to Port Kembla in October with 135,000 tonnes of iron ore, as BHP had no Australian vessels available at this time. The application was on the basis of the eight page questionnaire, required by the Department of Transport and Regional Development, which was completed and signed by a Navix employee. The vessel had not reached its sixteenth year and had just completed a dry dock. Based on these facts and other statistical information, the BHP system assessed the ship as falling within acceptable risk criteria. On 9 September, a BHP representative signed a declaration that the vessel *Cido Star*, on the basis of the information presented to the Department, was believed to be suitable for the intended voyage.

The application, which was sent to the Department, was passed to the Australian Shipowners' Association and the Maritime unions, but no response was received from either of these organisations.

The Department also sent the application to AMSA on 9 September for checking. AMSA replied on the same day, notifying the Department that the application had been examined and found to be in order. The reply noted that *Cido Star* had last been inspected by AMSA, under the Port State Control regime, at Newcastle on 13 March 1996.

An SVP was issued on 10 September 1996.

BHP was aware on 25 September that the name, flag and ownership of the vessel had changed and an amendment to the SVP was sought on 30 September, which was duly granted by the Department on 2 October.

Under the SVP system, the onus is on the charterer to ensure that appropriate documentation is submitted to the Department for assessment. This requirement was met and, in the Inspector’s opinion, there was nothing in the documentation or checking procedure which would indicate that the vessel was unsuitable for the voyage.

Conclusions

These conclusions identify the different factors contributing to the collapse of the starboard side of the bulkhead at frame 193 aboard *Giga 2* on 5 November 1996 and should not be read as apportioning liability or blame to any particular individual or organisation.

1. No. 4 hold was overfilled beyond its maximum allowable depth of water of 14 m.
2. The Mate relied totally on the remote gauging system for filling No. 4 hold, without physically checking on its accuracy.
3. An inaccurate reading was displayed in the ballast control room by the remote gauging system.
4. As the "high level" alarm was not independent of the gauging system, there were no effective defences, other than physical/visual checks, to ensure that the depth of water in No. 4 hold did not exceed the safe level.
5. There was no clear explanation as to the critical nature of the limit placed on the depth of ballast water in No. 4 hold. This was compounded by a lack of clear operating instructions, either in the native language of the ship's personnel or the working language of the ship.
6. The increase in depth of water from 14 m to 18 m resulted in more than doubling the maximum stresses within the bulkhead structure.
7. The specified size of the welds joining the lower stool shelf plate to the structure beneath it was insufficient to withstand the membrane forces developed at the bottom of the bulkhead with the excess water level in the hold.
8. The design and spacing of the webs within the lower stool, in relation to the corrugations of the bulkhead (and depending on the contribution made by the shedder plates), can result in high stress concentrations being formed within the area of failure at the stool shelf plate.

9. Buckling of the bulkhead, due to extensive wastage by corrosion, if not already started at the moment of failure of the welds, was imminent.

10. Extensive corrosion of the webs in the upper stool resulted in the bulkhead and the stool bottom plate being virtually detached from the upper stool. This would have facilitated detachment of the bulkhead along its upper edge during the failure but did not contribute to initiation of the collapse.

11. The quality of structural surveys of this vessel, over a period of time, was not effective in addressing the problem of substantial corrosion as defined and detailed in the International Association of Classification Societies requirements for enhanced surveys, or as recommended in the International Maritime Organisation’s Assembly Resolution A.744(18).

It is further considered that:

1. detection of any deficiencies in the structure of the bulkhead was beyond the scope of Port State control inspections; and

2. based on the system for assessing applications for single voyage permits, there was no reason to refuse the application.

Submissions

Under sub-regulation 16(3) of the Navigation (Marine Casualty) Regulations, if a report, or part of a report, relates to a person's affairs to a material extent, the Inspector must, if it is reasonable to do so, give that person a copy of the report or the relevant part of the report. Sub-regulation 16(4) provides that such a person may provide written comments or information relating to the report.

The final draft of the report was sent to the Owners, the Ship Managers, the Classification Society, the Master and Mate of *Giga 2*, BHP Shipping, the Australian Maritime Safety Authority and the Maritime Division of the Department of Transport and Regional Development.

The Owners

The Ship Managers' comments have been incorporated into amended text within the report.

The Classification Society, Nippon Kaiji Kyokai

Where appropriate, the Society's comments have been incorporated into the text, entered as notes in the main body of the text or are as follows.

Ballasting — Loading manual

Loading manual should be written in a language easily understood by the ship's officer, which would be under owners responsibility. In the normal case of ships being sold to a new owner and changing her registration, the documentation such as manuals and plans is translated into the specific language based on the agreement between the owners, while certain plans such as Fire Control Plan which is clearly required in SOLAS requirements are fully translated into the specific language in such occasion.

Ballasting — Awareness of ship's staff

There are many kinds of limitations on the operations of ships, and deviations from the limitations cause many kinds of unacceptable consequences. Regarding the limitation of ballast water in No. 4 cargo hold, we confirmed the safety within the limitation in the course of plan approval. However, as normal practice, we did not confirm the consequences caused by the deviation, because it depends on the degree and the nature of the deviation. Therefore, we believe that the description in the loading manual without the possible consequences is not perfect but adequate for the qualified ship's crews and officers. We agree that description of unacceptable consequences is desirable as further information, if it is possible to illustrate the simulation of various maloperation.

If the bulkhead had been maintained within acceptable limits of wastage, we consider as follows.

- *For ballast depth of 14m - The bulkhead would not have been sustained with plastic deformation, because the induced water head is considered being within the design limit.*

- *For ballast depth over 14m - The bulkhead would not have collapsed because of the redundancy of the structural strength. However, it might have been sustained with plastic deformation depending on the depth of the ballast. According to our rules, plastic deformation of watertight bulkhead is accepted in an emergency situation such* as flooding of cargo hold.

ETRS report — Weld size

It is difficult for us to understand the contexts without some illustrations. For your information "fillet type of welding", which is extensively adopted for hull structure, was applied to the structural joints between shelf plate and corrugated bulkheads as an approved design. In the case of penetrating type of welding with and edge preparation of groove, perfect welding fusion can be expected, however, in this case, partial root fusion (mentioned as "lack of root fusion" in your report) is acceptable as a normal configuration of such kind of welding. On the completion of subject welding connection, shedder plating (slant plating) were attached to the corrugated bulkhead. Fillet welds between shelf plate and corrugated bulkhead beneath the shedder plating have not corroded too much, because they have been protected from corrosion by the shedder plating.

Metallographic examination — Shedder Plates

We have two comments regarding the following two wordings.

- *"High forces" should be read as high strain. According to our elastic FEM, we could not identify high stress which may cause yielding but could confirm the possibility of buckling. Therefore, we also carried out elasto-plastic large deformation FEA and confirmed that the joint between shelf plate and corrugated bulkheads may have had large strain due to plastic buckling shown in our draft report.*

- *As stated we consider Monash model does not reflect actual structure. Therefore, the analysis may lead to wrong conclusion.*

Survey — ClassNK requirements for bulkhead scantlings

We require the scantling of bulkhead to withstand hold flooding. This has been proven in many casualties. The following is shown as an example:

In June 1994 a capsized bulk carrier classed with our Society had hold flooding in No. 1 cargo hold off South Africa after departing Port Dampier, Australia. Unfortunately she could not take refuge into port because of her increased draft due to hold flooding and, therefore, had to be exposed to heavy weather off Africa for more than one month. However, she did not sink because bulkhead between No. 1 cargo hold and No. 2 cargo hold withstood in the heavy weather.

Annual surveys for vessels over 10 years of age (Para 2 page 28)

NK Rule prescribes that, at Annual Surveys for bulk carriers over 10 years of age, thickness measurements may be conducted subject to the discretion of the Surveyor when extensive corrosion is found, and should not be required at every Annual Survey.

Conclusion 7

We do not see such problem in our model as mentioned above.

Conclusion 8

We do not see such problem in our model as mentioned above. As long as corrugated bulkhead is adopted, webs within lower stool are not in line with corrugations of bulkhead. In many bulk carriers, this kind of design is also adopted in combined cargo/ballast tanks which are fully filled with ballast water during ballast voyage, and we have not experienced serious damages on such kind of construction. As pointed out in above (8), the wording of "very high stress" is too vague to be addressed in the conclusion.

Conclusion 9

We do not agree with your scenario. According to our model, we could not find high stress in the welds. We consider that the detached bulkhead also had similar buckling which was observed in the bulkhead at Fr. 193 and 222. The buckling increases the stress of the connection due to rotation.

Conclusion 11

The hull structure is usually renewed when measured thickness is found to be lower than the allowable limit, therefore, part of some structures remain to be below the allowable limit until the timing of steel renewal. To minimise such cases, extensive thickness gauging and inspection with shorter intervals than regular period are required. Even in the case of the reduced thickness below the allowable limit, the structure with some redundancy withstand the acting loads in normal operation. Considering these situations, the allowable limit of thickness is given being enough lower than the actual critical limit. Further to our comments made in our fax 97TZ09125YU dated 13 June 1997, we are confident the ship had been surveyed in accordance with our rules including the enhanced survey programme and relevant requirements of IACS and IMO in order to keep up the standard as a bulk carrier. Although the bulkhead, unfortunately, collapsed in spite of our surveys being carried out in an adequate manner, we are in the *position that the collapse was caused mainly by filling the water into No. 4 cargo hold over the limitation. We finally conclude that main cause of this incident is that the reduced strength of the structure could not withstand the over load in No. 4 cargo hold due to overfilling of the water ballast. Therefore we would strongly suggest that over load shall be clearly indicated as one of the major causes of this disaster in the conclusion of your report.*

Vessel Details

Name	Giga 2 (*ex Cido Star ex Yuzuru Maru*)
IMO Number	8002004
Flag	Malaysia (Provisional)
Classification Society	Nippon Kaiji Kyokai
Ship type	Bulk carrier
Owner	Tauladan Gigih Sdn Bhd, Malaysia
Charterer	Navix Lines Co.
Year of build	1981
Builder	Namura Shipbuilding Co. Ltd - Japan
Gross tonnage	76,515
Net tonnage	41,889
Summer deadweight	140,086 tonnes
Length overall	270.01 m
Breadth extreme	43.03 m
Draught (summer)	16.782
Engine	Mitsubishi MAN diesel (18v52/55A)
Engine power	13,968 kW
Crew	27

Ballast No. 4 hold

About 90 minutes after the incident occurred, the depth of water at the forward end of No. 4 hold was measured by the local AMSA surveyor as being 9.9 m, whereas the gauge in the ballast control room indicated 6.5 m. At around the same time, the AMSA surveyor noted a wet “high level” mark in No. 4 hold, level with the third ladder rung below the upper stool level, equating to an ullage of 3.4 m, or a sounding of 18.8 m.

At the time of the incident, No. 3 ballast tanks were ballasted to 79 per cent and No. 3 starboard tank contained approximately 4310 m^3. The height of the lower hole in No. 3 starboard saddle tank was 20.8 m, providing a volume of 3830 m^3. Therefore a maximum of 480 m^3 of ballast would have drained into holds 4 and 5 from that tank.

Cargo recovered from No. 5 hold in Singapore was 2976 tonnes, approximately 1100 m^3.

According to the Mate, soundings by the crew showed a water depth of 8.8 m in No. 4 hold and a water depth of 9.9 m in No. 5 hold, providing volumes of 7310 m^3 and 8800 m^3 respectively, or a total of 16,110 m^3. Assuming a “worst case” scenario of 9.9 m sounding in No. 4 hold as well as in No. 5, the total volume is 17,200 m^3. To these totals has to be added the volume of the lower stool, approximately 520 m^3, which was breached. Deducting the cargo volume in No. 5 hold and the total amount of water drained from No. 3 saddle tank, provides a minimum volume of water in No. 4 hold of 15,050 m^3, equating to a depth of approximately 16.99 m. Deducting just the cargo volume provides a “worst case” maximum volume of water in No. 4 hold of 16,620 m^3, equating to a depth of more than 19.75 m.

The time from the start of ballasting No. 4 hold to the incident was 7 hours 50 minutes, which would have been sufficient for the one pump to completely fill No. 4 hold. However, the Mate stated that there were a couple of breaks in the ballasting of No. 4 hold, while the moorings were tended. No records were kept of the stopping and restarting times, but the Mate considered the breaks were each probably of about three quarters of an hour to one hour in duration. A total pumping time of 5.83 hours provides a volume of 13,415 m^3 and a depth of 15.05 m, while a pumping time of 6.33 hours provides a volume of 14,565 m^3 and a depth of 16.5 m.

Visual recollections of the water height in No. 4 hold vary from it being level with the bottom of the saddle tanks (depth 13.8m) to being two or three metres from the hatch coaming (depth 19 m).

From the soundings taken shortly after the incident, it is evident that the depth of water in No. 4 hold was at a minimum, 17m.

CLASSNK calculated that the water level in No. 4 hold, immediately before the incident, was over 18 m. However, allowance does not seem to have been made for the ballast water which leaked out of No. 3 starboard ballast tank immediately after the bulkhead failure. In addition, the cargo remaining in No. 5 hold at the time of the incident is taken in the report as being 4,102 tonnes, and not the 2,976 tonnes, the amount removed from the vessel when it arrived in Singapore.