Departmental investigation
into the
capsize of the crane barge
TITAN
off Smoky Cape, on the 25 December 1992
and
the subsequent sinking of the barge
off Camden Head, on 29 December 1992

Navigation Act 1912

Navigation (Marine Casualty) Regulations

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TITAN

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off Camden Head, NSW, on 29 December 1992.

No 50

Published: 18 October 1993

Additional copies of this report are available from:

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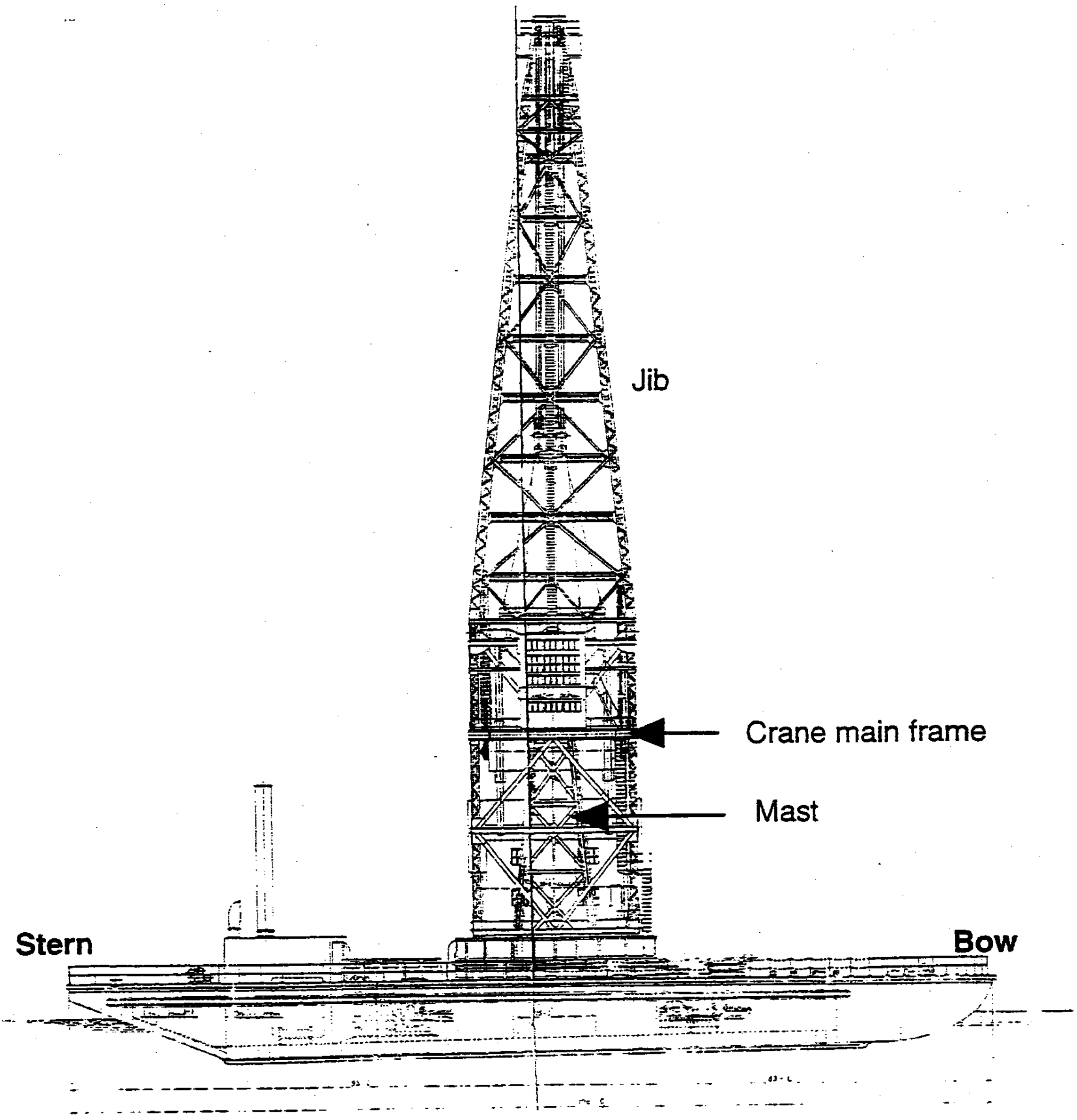


150 tons electrical revolving floating crane
Cowan Sheldon & Co., LD., St Nicholas Works, Carlisle

Part of Original General Arrangement Drawing

Summary

The crane barge Titan, under tow by the former research ship Rapuhia, left Sydney at 1700 on 22 December 1992, bound for Singapore. Titan was unmanned.

The tow progressed slowly northwards off the eastern Australian coast line. Throughout 23, 24 and 25 December, the tow experienced strong head winds and sea from the north or north-east, and a strong counter current.

By 2200 on 25 December, the tow was making good a speed over the ground of about 1 knot, into a head wind of about 26 knots. At about 2250, those on Rapuhia felt a pronounced jerk and a seaman reported the towing line had parted. No trace could be seen of Titan's riding lights, nor could the barge be seen silhouetted against the sky. Rapuhia was immediately slowed and turned to relocate the tow. A target was seen on the radar and a subsequent sweep by Rapuhia's searchlight showed the barge, floating bottom up. A general call was put out to shipping and the capsize reported to the Australian Maritime Rescue Coordination Centre, Canberra. The vessel's principal in Singapore was also told.

On 27 December, divers and people acting on behalf of the owner boarded Rapuhia to assess the damage. The emergency towing bridle was secured to Rapuhia.

It was found that the crane assembly, including the jib and crane tower had fallen off the central lattice work mast. The central mast was bent towards Titan's bow and the slew ring, upon which the crane rotated, was resting at an angle against the central mast.

The upturned barge was towed to a position off Camden Head, out of the strong south-going current to allow work to be undertaken on the upturned hull.

After assessing the situation over a number of days, it was decided that the barge could not be salvaged. The only alternative was to sink it in a controlled manner.

Work to prepare the barge for sinking was carried out off Camden Head. The barge sank at about 2100 on 29 December.

NOTE:

Reference in this report to the Titan's port and starboard side refer to the barge as designed. As the barge was towed stern first, the port hand side light was displayed on the barge's true starboard side and the starboard hand light on the barges true port side.

Information Sources

Mr Trevor MacKenzie, MacKenzie Salvage.

The Master and crew members of Rapuhia.

Mr Paul R Doney, diver.

Australian Maritime Safety Authority.

Mr D. C. Glasson, former painter and docker.

Mr Don Ellsmore, National Maritime Museum.

Captain David M. Pyett, marine surveyor.

Mr G.A. McGoogan, former dock master, Cockatoo Island.

Mr Desmond Kennard, chief executive officer, Sydney Maritime Museum.

Mr John Jeremy, former chief executive, Cockatoo Island.

Mr Rodney Crawford, C and B Engineering.

Gibson Minto and Aiton, marine surveyors.

Mr Walter F Stuart, former foreman rigger, Titan.

Mr Jim Morton, manager, ANI Engineering Services Pty Ltd.

Naval Weather and Oceanography Centre, Royal Australian Navy, Nowra.

Special Services Section, Bureau of Meteorology.

The Ministry of Transport, Wellington, Maritime Transport Division.

The Republic of Panama, Bureau of Maritime Affairs.

Director General of Shipping, Bombay.

Germanischer Lloyd.

Manly Hydraulics Laboratory, Public Works Department, NSW.

Baron and Dunsworth, Naval Architects, were commissioned to analyse stability information.

Dr T O Penman,
BSc(Eng), BE, PhD, DipCivEng, DipChemEng, FICChemE, FIEAust, MRCAI,AIArbA,CEng, CChem(Aust),
reviewed the report in respect of structural issues.

Acknowledgments

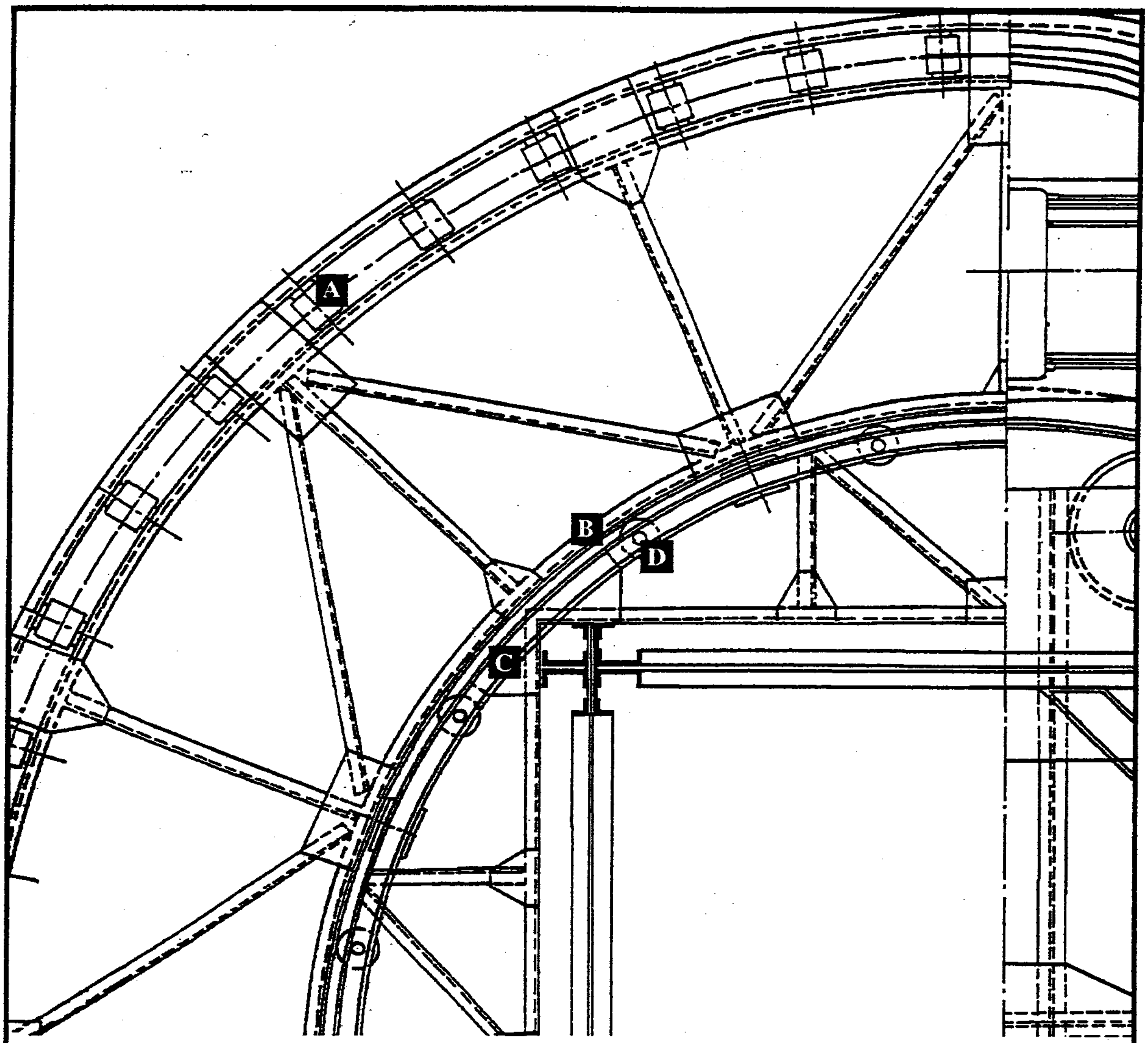
The Inspector is indebted to John Fairfax Group Pty Ltd for permission to reproduce the photograph on page 12.

Photographer: Robert Pearce.

The Inspector is indebted to Mirror Australian Telegraph Publications for permission to reproduce the photograph on page 22.

Photographer: Michael Perini.

The Inspector gratefully acknowledges the co-operation of the Singapore owners in directing Rapuhia to make an unscheduled stop off Townsville to allow the Master, officers and crew to be interviewed.



A. 48- Rollers 203mm dia x 254mm
B. Live Roller Part
C. Curcular grider (part of Mast)
D. 16 Rollers 203mm dia x 102mm

Diagram of live ring
Plan View

Titan

Titan was a floating crane barge, assembled from pre-fabricated parts imported from the United Kingdom during and immediately after World War I. It was 53.899m (176ft 10ins) in length, 24.282m (79ft 8ins) in width, and had a depth of 3.962m (13ft). The crane tower was 19.65m (64ft 5.6ins) high with a crane jib of 39.015m (138ft). At maximum elevation the top of the jib was 57.9m (190ft) above deck level. The crane had a maximum safe-working load of 152.4 tonnes (150 tons) by two 76.2 tonne* (75 ton) blocks in tandem. There was also a 30.5 tonne (30 ton) block and a 10.2 tonne (10 ton) block.

The barge was made up of four basic sections - the jib, the main frame, the central mast and the hull. The jib and the main frame, which included the counter-weights, operators cabin and hoisting winches, made up the crane structure.

The jib was a cantilever type, constructed from steel plates and angles, forming a braced lattice work.

The main frame was a slewing structure, constructed of four heavy steel corner members connected by steel girders forming a lattice construction designed to resist the horizontal and vertical forces. The jib was connected to the front of the main frame by jib foot pins and to the screw driving gear and counter weights at the rear of the main frame, by which the radius of the jib head (the angle of the jib) was controlled. The housing for the lifting wires was also at the rear of the main frame. The operators cabin was on the forward side of the main frame, immediately below the jib foot pins.

The crane rested on a roller path on deck reinforced by double plating. The main section revolved on a system of rollers and girders referred to as the "live ring", that consisted of two concentric rings connected by substantial angle bars and brackets (diagram on page 6). The outer ring was 11.582m in diameter and consisted of 48 horizontal steel rollers 203mm in diameter and 254mm long contained between two steel channel bars. The inner ring was made up of channel bar, about 7.5m in diameter with 16 vertical rollers, 203mm in diameter forming the path around which the inner ring, connected to the main frame, revolved. Towards the top of the main frame, between the mast and crane structure, was also an upper roller path 2.286m in diameter.

Above the live ring was the "slewing ring", made up of two concentric rings of channel bar connected by substantial steel bracing. The outer ring, 11.734m in diameter, was connected to the drive shafts of the two slewing motors. The inner ring, 7.567m in diameter ran against eight vertical rollers which formed an integral part of the mast.

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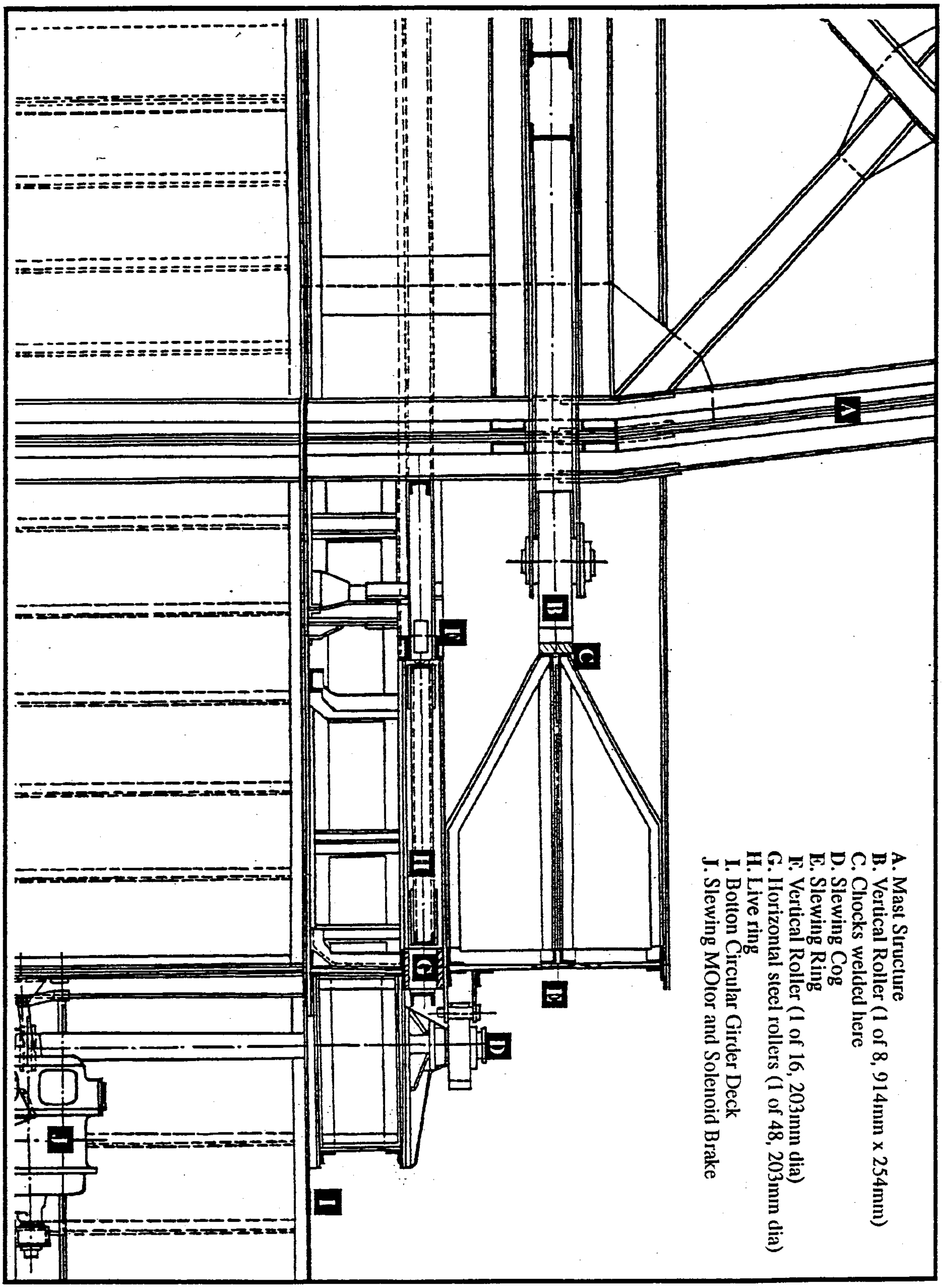
* Refers to the safe working load of the block.



Titian Roller Path
Elevation of live ring and slewing ring

The mast was square, constructed of rolled steel plate and sections with a circular channel bar, about 7.2m in diameter, designed so the mast would resist the horizontal forces imposed on it by the crane, without undue deflection. The main horizontal forces were taken by the eight vertical rollers, and the associated bracing of the mast. Each roller was a little more than 914mm in diameter and 254mm deep.

There was no means of locking the crane to the mast. The only direct connection were the slewing motor shafts, that connected to slewing motors below the main deck by vertical and horizontal shafts. There were automatic solenoid brakes fitted to the horizontal drive shafts from the slewing motors, two to each shaft and a manual break on the vertical shaft.

According to the crane original specifications, the whole of the crane structure was designed to give a five-fold safety factor, taking into account live and dead-load forces, momentum, inclination, and wind pressure.

The barge was of riveted steel construction, having an extensive arrangement of 15 double bottom tanks and further 12 to 14 watertight compartments below the main deck.

Titan was completed on 3 December 1919, and went into service with the Royal Australian Navy's dockyard at Cockatoo Island, Sydney Harbour.

Titan's barge structure was surveyed each year and any defects identified by, or brought to the attention of the surveyor was repaired. As dockyard equipment, it was well maintained throughout its service life.

The crane had been involved in a number of historically significant lifts. Of relevance to this investigation were the delivery of armaments to the Manly Quarantine Station in 1935, and the construction of the Spit Bridge, Middle Harbour, in 1958.

In September 1935, Titan went alongside the vessel Taranaki and landed ten lifts on to the barge's forward deck. Titan was then towed across Sydney Heads to Manly, exposing the crane barge to the swell from the Tasman Sea.

For the passage special eye pads had been welded to each outboard forward side of the barge's deck. The two 75 ton crane hoists were secured to these eye pads by strops, one to each side to act as preventer guys to stop the crane from slewing. The 30 ton hoist wire was secured close to the centre line to a bollard. In the relatively heavy swell the barge rolled constantly. The combination of the hoist wires and the solenoid brake were not able to stop the jib moving, it slewed dangerously and caused a great deal of alarm to all concerned in the operation.

Although the return passage was completed without incident and one further tow took place to the Quarantine Station (after carefully planning the passage to coincide with good weather), it was decided that it was too dangerous to expose the barge to the sea in Sydney Heads. Hence, it became policy not to allow the Titan to operate to the seaward side of Bradley Head.

Between 1939 and 1945, Titan was an integral part of the war effort of the Australian east coast and was fully occupied in Sydney Harbour throughout the hostilities.

In 1958, a request was made for Titan to assist in the construction of the Spit Bridge, which involved its operation to the north of Bradley Head. Against the advice of the foreman rigger responsible for Titan, the barge was towed to Middle Harbour.

On this occasion, the two 75 ton hoists were secured to bollards close to the centre line of the barge, with the jib at the maximum angle of elevation, so the end of the jib was vertically above the barge's forward deck. The initial tow was conducted by two large harbour tugs in the normal harbour manoeuvring configuration, with one alongside and the other towing. Because of the limited depth of water and the restricted width of the channel in Middle Harbour, the tow had to be transferred to smaller tugs.

To the seaward side of Bradley Head, Titan was again exposed to the pronounced swell entering Sydney Heads and began to roll heavily. The tow line to one of the smaller tugs parted and the other could not be made fast. Titan was adrift and out of control, the jib slewing violently, although restrained to a degree by the hoisting wires, the barge rolled alarmingly. A launch from Cockatoo Island eventually passed a line to the tugs and the situation was stabilised.

Anecdotal evidence is that those aboard were seriously concerned for their lives.

The return passage some four days later was completed without incident after additional precautions were initiated.

In the early 1970s a plan to modernise Titan was initiated and an overhaul of the crane structure and wiring was completed.

In 1971, as part of an $800,000 overhaul by the Royal Australian Navy, the crane structure and pontoon were refurbished. Five limited areas of the pontoon's shell plating, including areas of the deck, were renewed or doubled.

With the advent of container shipping, Titan was used to discharge and load containers in addition to its dockyard work. However, with the introduction of specialised container handling equipment, demand for Titan decreased and the use for naval purposes declined significantly.

In 1975, the Navy decided it no longer required Titan, and sought to dispose of it. At this time the dockyard and crane were being managed and operated by the Cockatoo Island Dockyard Pty Ltd, which opposed the disposal of the crane, identifying a continuing need for the crane's lifting capacity and flexibility. The slewing and hoisting power was originally provided by electricity from a steam driven dynamo. The company fitted a diesel alternator and rectifier to power the hoist and slewing motors, as well as air compressors for the deck machinery. The steam plant was decommissioned.

In 1985, Titan was required for 40 lifts, and from 1986 to 1988 inclusive it averaged between 26 and 27 lifts a year. In 1989 it performed only six lifts, none for the Navy.

To operate in Port Jackson, the Titan required a "Port Craft License" issued by the Maritime Services Board of NSW. This was issued on the satisfactory report of a registered ship surveyor and a survey of any boilers or sea cocks by an MSB engineer surveyor. The last MSB survey was in September 1989, when the survey was confined to the sea cock, which was found to be in good condition.

In 1989, the registered ship surveyors engaged by the dockyard (and who had been involved in the survey of the barge for some years) wrote to Cockatoo Island Dockyard and declined to issue a certificate of operation for any more than a three month period. They noted that some frames within the main body of the hull, where the barge landed against wharfs or ships, had been sprung from the hull plating, though the brackets at the foot and head of the frames were intact. This in itself was not considered significant for harbour operations.

The surveyors accepted the basic structure below the water line was sound, but they were particularly concerned at the possible deterioration in the rivets and the condition of some of the shell plates above the water line. They indicated that before any further certificate could be issued, all double bottom spaces would have to be pressure tested, that these spaces should be fitted with sounding pipes, together with an alarm system to indicate any flooding, and an efficient pumping system of double bottoms and void spaces should be fitted. The surveyors also required extensive thickness testing and renewal of any plates found to be excessively wasted.

They stated that, given the age of the vessel, they were unwilling to issue certificates to allow the crane to operate without a full reassessment of the barge.

With the availability of the 250 tonne crane at Garden Island there seemed little justification in the continued operation of Titan and it was laid up. Titan obtained two short-term operating permits to load and unload the steam locomotive "Flying Scotsman" and its tender in 1991.

In April 1992, Titan was auctioned at a Department of Defence Naval surplus sale and bought by MacKenzie Salvage, of New Zealand. Apart from identifying some of the original machinery as being of heritage value, the prospectus indicated no conditions on any potential owner, as to the disposal of the crane.

In May 1992, the hull structure was surveyed on behalf of the owners by a private surveyor, who had not previously had any dealings with the barge or crane. The surveyor assessed the serviceability of the barge to determine what, if any, repairs were necessary and to assess whether the hull was serviceable. He concluded that, apart from some deck plating in areas where water had lain, a number of bent frames and a "tripped" bracket, the general structure was good, with certain areas in the region of the base of the crane in excellent condition. Repairs to brackets and frames were only important if the crane were to undertake heavy lifts, otherwise repairs were considered not to be essential.

He recommended a program of cleaning and de-scaling in some of the spaces. He recommended that a full assessment of the double bottoms should be made, together with thickness testing of the shell plating. Subject to the result of these tests, he assessed the hull structure as suitable for further crane work. In assessing the barge's suitability for open sea tows, the Surveyor noted that this would depend on an assessment of the stability of the barge.

The Titan remained in Sydney Harbour through the winter and spring of 1992, but there was insufficient commercial interest to make the crane operation viable in Sydney. The owner reviewed his options, including selling it.

On 12 November 1992, the owner engaged a naval architect to assess the stability of Titan, with a view to towing the crane in open sea. An inclining experiment, to assess the basic stability of the barge was undertaken. This experiment was completed on 19 November and witnessed by the marine surveyor who had undertaken the May survey for the owner.

A preliminary report of the experiment and the resulting stability data was issued on 24 November. At about this time, the owner was negotiating the sale of Titan to a Singapore interest, Wirana , and the sale was completed by early December.

On 26 November, the stability information was submitted to the Sydney office of the Australian Maritime Safety Authority, with a request that AMSA issue a letter confirming Titan met the stability requirements for a long sea tow. The data from the inclining experiment was submitted to AMSA and was assessed against the International Maritime Organisation's (IMO) "Intact stability requirements for pontoons". The stability was found to meet or exceed (have greater reserves of stability) the IMO requirements. Arrangements were made for AMSA to inspect the barge in accordance with administrative instructions contained in "Instructions to Surveyors (ITS) 20.8.3."

At about this time, AMSA's Sydney office received a telephone call from Wirana seeking approval for the vessel Rapuhia, at that time lying in Wellington, New Zealand, to tow Titan to Singapore.

A meeting was held between AMSA, Wirana and MacKenzie Salvage on 3 December. An initial inspection of the barge was undertaken at No 7 Pyrmont, and the assessment made that the barge was in fair to good structural condition. A "deficiency" notice was issued detailing the measures that the owners would be required to take before the vessel would be allowed to be towed to sea.

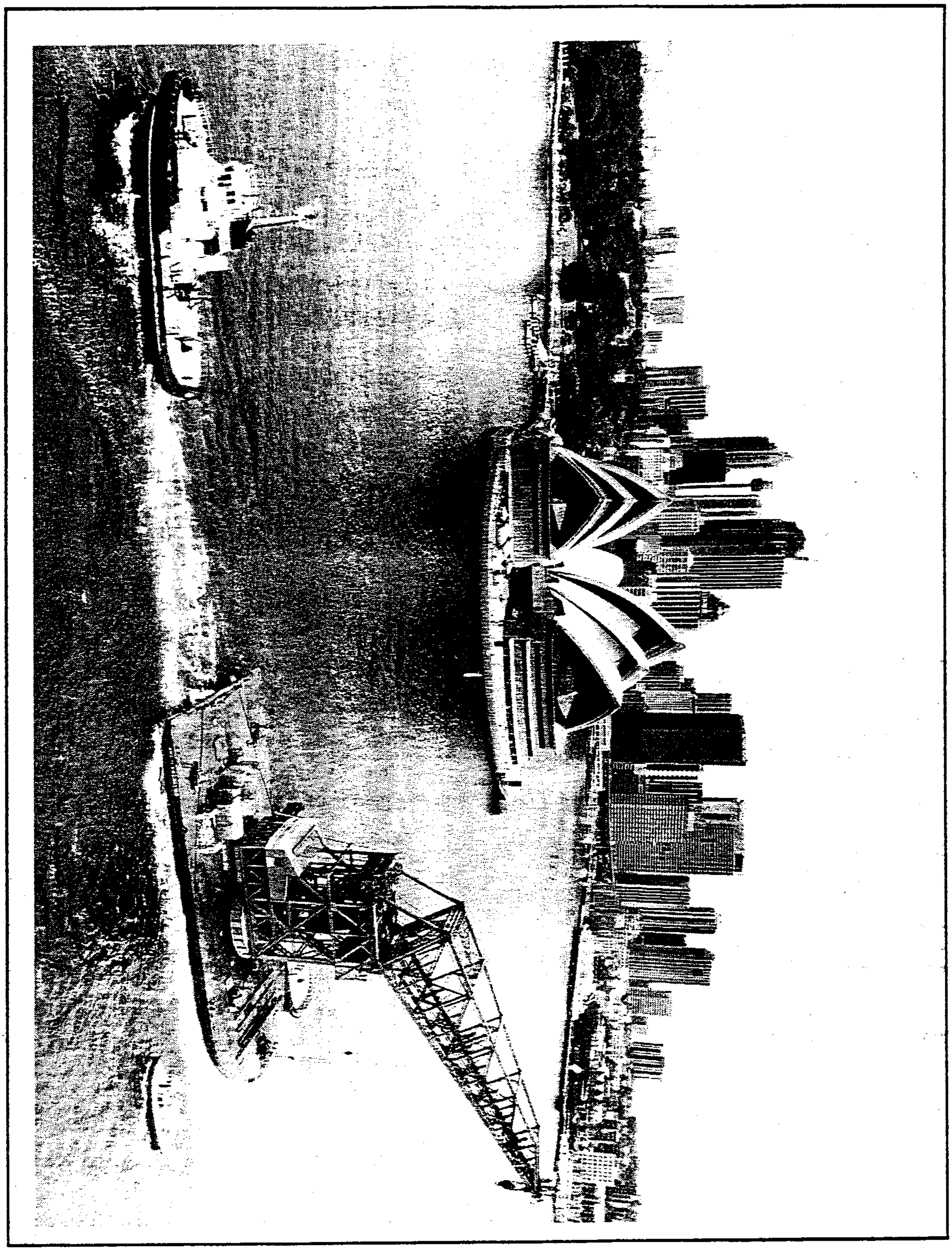
MacKenzie Salvage acted for the new owners in preparing Titan for the tow. Some scrap electrical motors and switch gear equipment were loaded on board, 36 tonnes stowed aft in the old coal bunker space, and about 30 tonnes forward in the bow section. No other solid or liquid ballast was taken on board - and otherwise the weights on the vessel were the same as when the vessel was inclined. When prepared for the tow, the barge had a departure displacement of about 2000 tonnes.

The jib and main frame were prevented from slewing by eight chocks welded to the inner, 7.57m diameter slewing ring, hard against the vertical edge of the eight 914x 254mm rollers. Each chock was about 260mm deep and described as very substantial. The welds were made by a properly qualified welder.

News that Titan was being prepared for a tow reached concerned heritage groups. Titan, being an item or vessel built in Australia before 1930 and in use before 1920, was covered by the provisions of the Protection of Moveable Cultural Heritage Act 1986, and the owner was advised that he would have to apply for an authority to temporarily export the crane from Australia.

An inspection was conducted by three assessing organisations on behalf of the Department of Arts, Sport, the Environment and Territories. Although expressing reservations about the tow and the fact that the owner was an overseas national, and beyond the jurisdiction of Australian Courts, there were no grounds for withholding a favourable recommendation. The assessors reported to the National Cultural Heritage Committee which issued a permit for the temporary export, conditional on the return of Titan to Australia before July 1995.

AMSA conducted a final inspection of the barge and its towing arrangement on 21 December. The surveyor satisfied himself that all safety requirements had been met and noted that all the openings to the interior of the barge had been made weather tight. The crane jib had been lowered to its lowest operating



Crane Barge Titan
Photograph courtesy of John Fairfax Group Pty Ltd.
Photographer: Robert Pearce

angle, to conform to the barge's condition when inclined and on which the stability data had been calculated. He noted also that the crane had been secured to prevent it from slewing. Experience in towing the Titan within Sydney Harbour had shown that it was difficult to maintain directional stability if towed bow first. The practice had evolved of towing it stern first, which overcame the problem. It was, therefore, decided that the Titan would be towed stern first to Singapore.

The towing bridle consisted of a section of the barge's port anchor cable. It was arranged symmetrically around the crane base and led through and around the bitts at the barge's side at frame 33/34, and through and around the bitts at the barge's stern. The two ends of the cable were joined by a 50 tonne shackle to which the towing wire and stretcher would be secured. An emergency towing bridle and towing hawser were rigged along the starboard side of the barge, with the free end buoyed for ease of recovery. The emergency towing arrangement was an insurance against the main tow line parting, to allow the tow to be controlled while a new towing connection was prepared.

Rapuhia

Rapuhia, originally Meteor, was built as an oceanographic research vessel for "Deutsches Hydrographisches Institut of Germany". It was re-engined, re-fitted and purchased by the Department of Scientific and Industrial Research, New Zealand, in 1985. It was operated by the Union Steam Ship Company of New Zealand and classed with Germanischer Lloyd.

The New Zealand registry was closed on 30 November 1992, the vessel having been sold to Singapore interests. The vessel's class with Germanischer Lloyd lapsed on 3 December and was not renewed.

Of the vessel's certificates, the Cargo Ship Safety Equipment Certificate and the International Radio Certificate had expired on 20 September 1992. A separate New Zealand Certificate of Survey was in force valid to 20 September 1995, subject to annual endorsement. The survey for renewing this endorsement, due in September, had not been conducted. An international Safety Construction Certificate, issued by the class society was due to expire in July 1994, and the International Load Line Certificate, also issued by Germanischer Lloyd, expired in June 1996, subject to intermediate surveys. Germanischer Lloyd had also issued an International Oil Pollution Prevention Certificate, which lapsed (with Class) on 3 December.

Rapuhia had a displacement of 3085 tonnes, with a length overall of 82.1m, a beam of 13.5m, a depth of 7.25m and a maximum draught of 5.2m. The vessel's propulsion was by diesel electric from four diesel generators connected to two electric motors each of 736kW, driving a single, five blade propeller. The vessel's designed speed was 10 knots with all motors operating.

The vessel carried modern navigation aids and weather observing equipment, including an anemometer for measuring the wind speed.

On 11 December 1992, Rapuhia arrived in Sydney from Wellington, with a crew of 12.

Under the Port State Control provisions of the Safety of Life At Sea Convention, 1974, Rapuhia was inspected by an AMSA surveyor on 13 December 1992. The general condition of the ship was found to be of a high order. All safety certificates and certificates of competency appeared to be in order and valid, and were accepted at face value, in accordance with the provisions of international Port State Control provisions.

The ship was stated to have been registered under the flag of Honduras, with the port of registry shown as San Lorenzo. It was operated by Hemispheric Maritime Limited, a company controlled by the Singapore Company, Wirana. It carried interim safety equipment, load line, construction, radio and pollution prevention certificates purported to have been issued at Jakarta on behalf of the Honduras Ship Registry S.De.R.L. on 17 and 19 November, and all were notated as valid to 18 March 1993.

The vessel carried a crew of 12 - a master, a mate, a radio officer, a chief engineer and three other engineers (including an electrician), and five other crew.

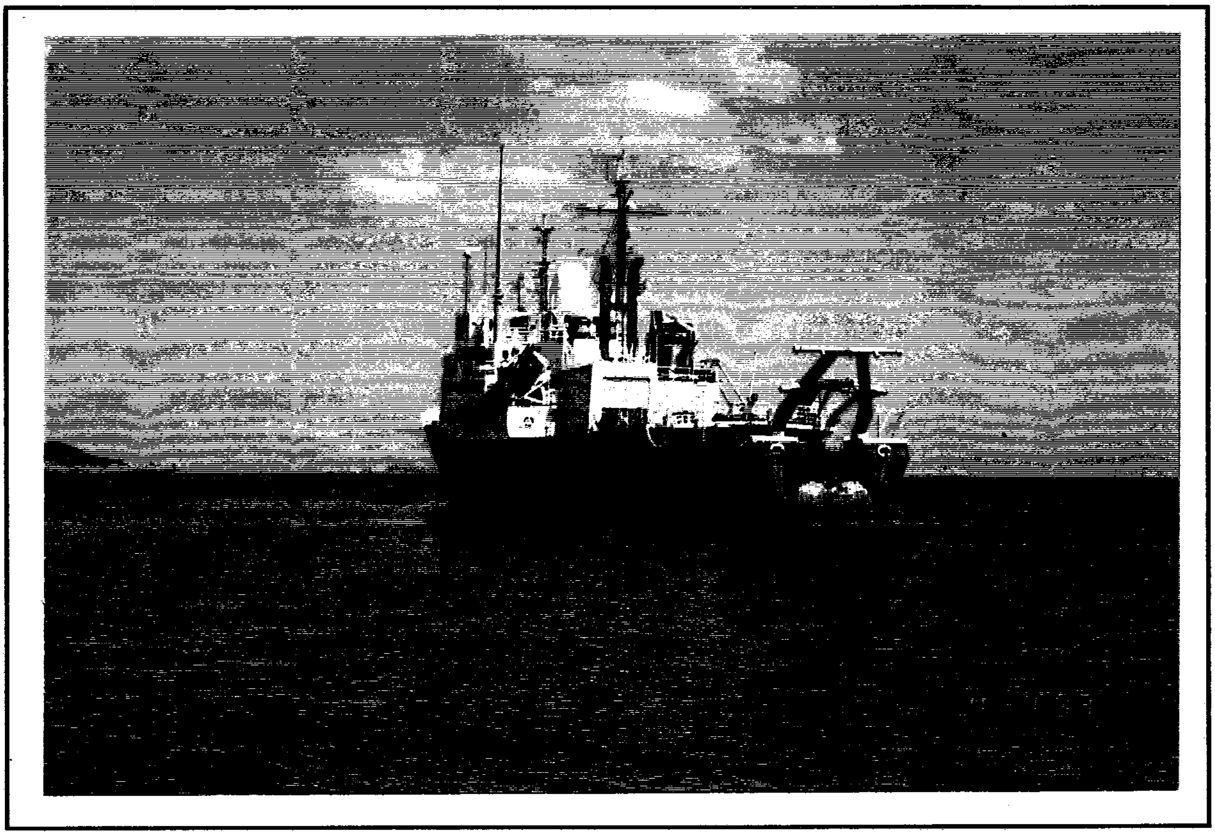
The Master held a certificate of competency as a Foreign Going Master issued by the Indian Government, in August 1974. The Radio Officer held a certificate of Radio Telephony issued in Madras in September 1991. The Mate and Chief Engineer also produced documents supporting their claim that they held the appropriate respective qualifications.

A deficiency list was issued to the vessel listing 12 items that needed to be addressed before the ship could undertake the voyage to Singapore. Four of these referred expressly to the towing operation and associated lights and equipment.

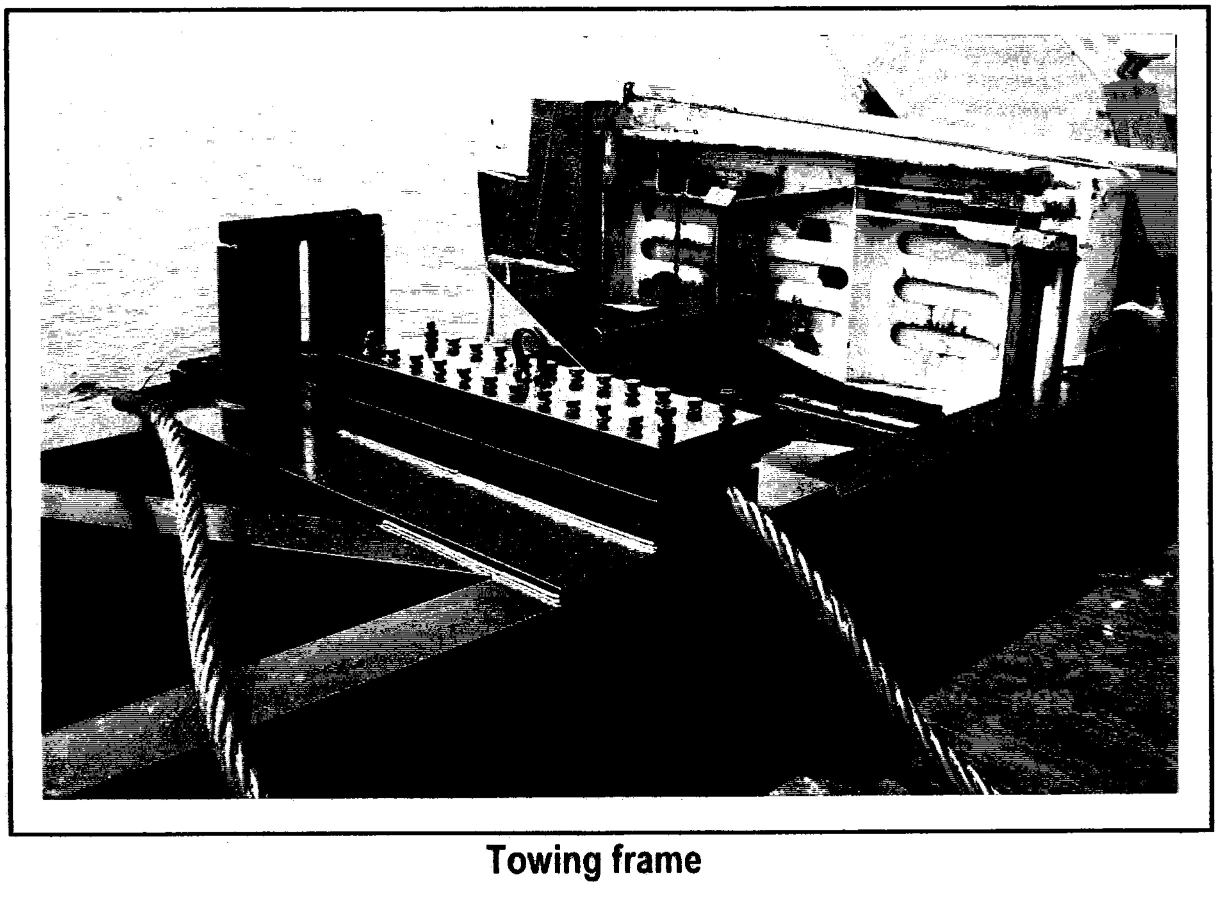
The owners submitted the design of a towing frame which was subsequently approved by AMSA. A towing frame made up of substantial members of grade 250 mild steel, in accordance with the appropriate Australian Standard, was fabricated and satisfactorily fitted. It was constructed to transfer the weight of the tow to Rapuhia's structure and was welded to the framing and strength members adjacent to Rapuhia stern. The towing wire was housed on a winch at the forward end of the after mooring platform. The wire was secured by a towing clamp, the two halves of the clamp holding the wire by 24 substantial bolts.

The towing arrangement was reviewed by AMSA in light of experience of other towing operations involving ships and oil rigs. The proposed arrangements for Rapuhia to tow Titan were well within the parameters of these other tows.

Titan left Pyrmont at about noon, with a draught of approximately 2.31m at the bow and 2.115m at the stern (the end from which the barge was to be towed). Two harbour tugs manoeuvred Titan through the harbour and to the rendezvous with Rapuhia, just inside Sydney Heads. The towing connection was made with Rapuhia at about 1500. A 60mm nylon stretcher, 27m in length, was connected to the shackle joining the two ends of the towing bridle. The Nylon stretcher acted as a "shock absorber" between the chain bridle and the 48mm towing wire - formerly one of the 75 ton crane wires, that passed through a towing clamp on the frame constructed at Rapuhia's stern and on to a winch. The length of the towing wire, stretcher and chain bridle was about 370m.



Photograph Rapuhia



Towing frame

The Voyage

At 1620 on 22 December 1992, the Sydney Harbour Pilot disembarked from Rapuhia and the tow for Singapore began at 1700, on a course of 039 degrees with the propeller turning at 102 rpm. The slight sea and a swell of less than 0.5m was from the north. The wind was logged at 14 knots, also from the north. The proposed route (via the Coral Sea and Torres Strait), together with reporting times and other details was passed to the Marine Rescue Coordination Centre, Canberra.

The crew adopted a seagoing routine, which is stated to have included regular inspections of the towing wire and towing bracket. By night they could see the towing lights aboard Titan, together with the large white inscription on the hoisting gear housing and the silhouette of the crane against the sky.

The next morning, 23 December, the tow was 14 miles from the coast, off Newcastle. In the mid morning it hove-to to lengthen the tow wire by more than 100m to a towing length of about 530m and the wire was marked with red paint at the towing winch. When passage was resumed the propeller shaft revolutions were increased to 110 rpm. From then until midnight on the 24 December the tow progressed without incident at an average speed of about 3.3knots.

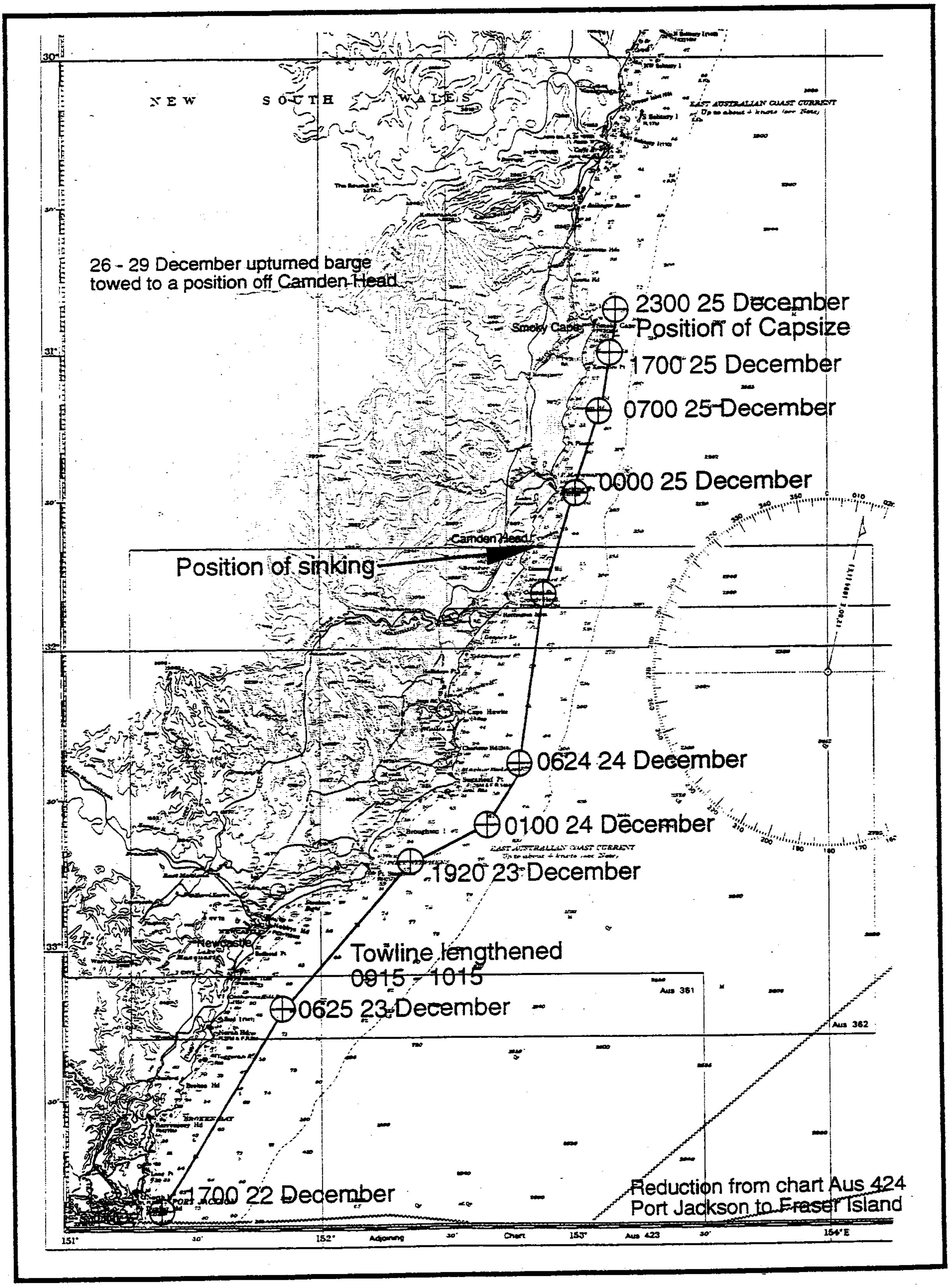
Rapuhia's log book was comprehensively maintained showing frequent position checks and weather observations. The wind and swell varied between just west of north and north-north-east. On 22 and 23 December, the wind tended to be on Rapuhia's port bow. On the afternoon of 23 December, the wind freshened from 14 knots to 20 knots and the sea and swell increased to more than 1m. The log book entries suggest that the tow was behaving well, yawing only marginally no more than 10 degrees on either quarter. From noon 23 December to 0420 on 24 December, the tow had maintained a steady speed of 3.42 knots and a general distance of six miles from the prominent headlands.

At 0420 on 24 December, when about 15 miles out to sea, midway between Sugar Loaf Point and Cape Hawk, the tow altered from a general north-easterly course to 014 degrees, bringing the prevailing wind and sea almost directly ahead. At 1700 a drop of 4 hectapascals in the barometric pressure was noted in the log and at 2000 a note was made of:

> *"moderate head swell, short and sharp".*

During the early hours of Christmas Day the wind increased to about 24 knots and the swell was logged at about 2m. In the mid-morning an entry was made in the log book:

> *"Rise in wind velocity and increase in swell from ahead. Barge pitching and shipping seas, average speed 2 knots."*



Voyage of the Titan

22 December 1992 to 29 December 1992

At noon, Titan was in position 31° 04.7' South, 153° 10' East. Rapuhia was steering 005 degrees to make good a course of 014 degrees allowing for a nine degree easterly set. A drop in barometric pressure from 1009 hectapascals to 1005 hectapascals was noted together with an increase in wind force to 26 knots from the north and a swell approaching 2m. The log book entry for noon stated :

> *". . . v/l moving slowly to rough head sea. Drop in barometric pressure noted".*

Although the wind and sea had increased it did not seem excessive to those on board, and those off watch celebrated Christmas with a traditional lunch. No alcohol was consumed and none was carried on board.

The log book entries for the afternoon noted rough head seas and the fact that the tow was pitching and shipping seas on deck. The speed of the tow had fallen to a little more than 1 knot in winds that were recorded at 28 knots. However, as viewed from Rapuhia, although shipping seas, Titan appeared stable and the jib was seen to remain secure in the fore and aft direction over the bow of the barge.

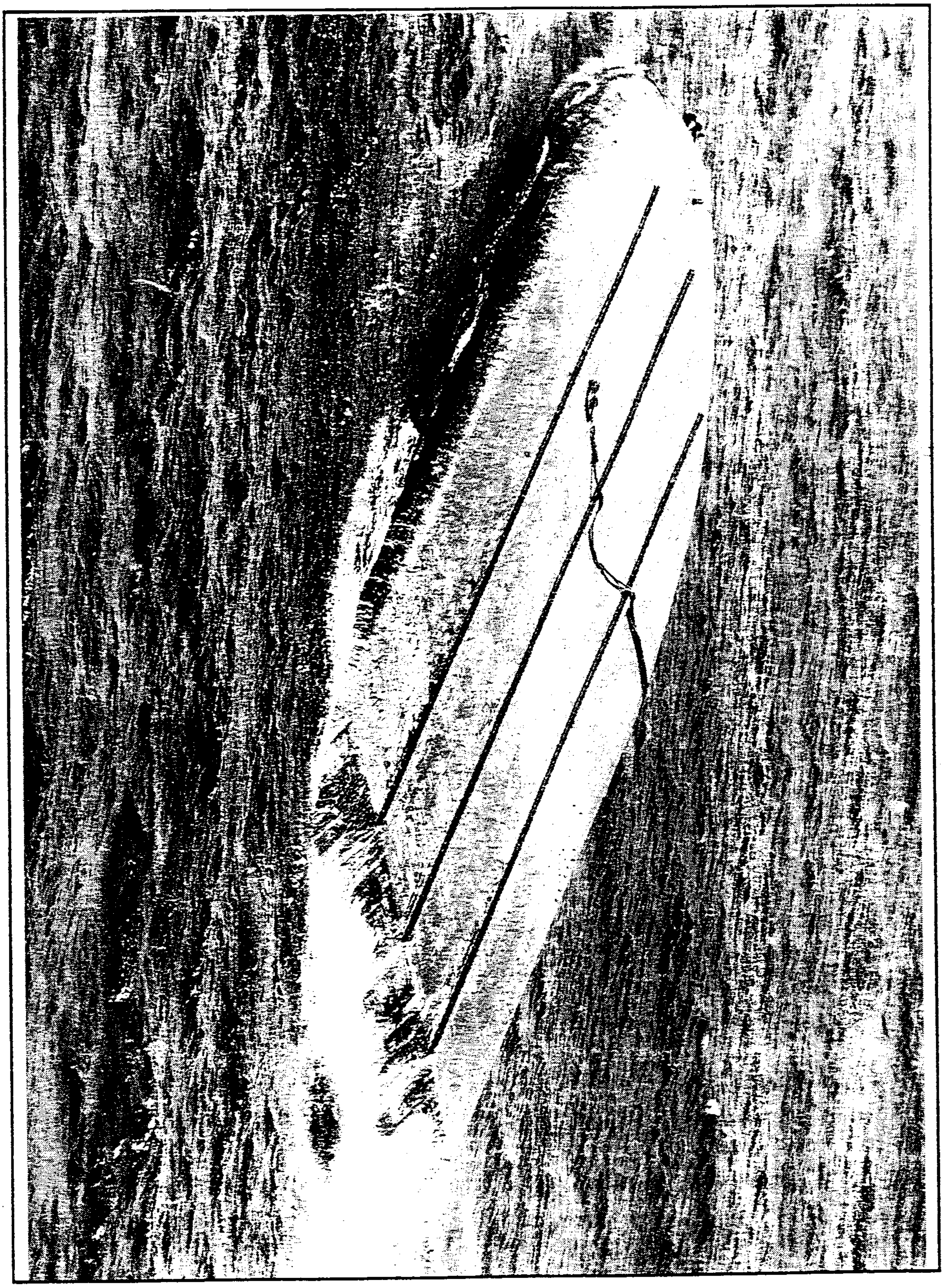
At about 2230, the Master was relieved on the bridge by the Radio Operator. The Master left clear instructions that he was to be called if the Radio Operator was concerned or in the event of an emergency.

Shortly before 2300, those on board felt a jerk or some unusual movement of the vessel. The Radio Operator looked aft and could not see the tow and sounded the general alarm. The Master went straight to the bridge. The Chief Engineer was returning to the accommodation from the engine room when he felt the jerk, which was closely followed by the sound of the alarm bell.

The first reaction was that the tow line had broken, and that the incident was relatively minor. The emergency tow line could be picked up in due time and the situation stabilised. But on looking astern, neither the towing lights of the barge nor the white painted sign could be seen from Rapuhia. An inspection of the towing line confirmed that it had parted. The red paint mark, painted on the wire at the towing winch, had moved about 1m showing that the tow line had been pulled through the towing block by about 1m, obviously under great stress. The force required to pull the wire through the wire clamp must have been considerable.

Rapuhia turned about to find the barge. A visual search could not locate Titan, but a radar echo showed a target close to Rapuhia and a sweep by searchlight showed the capsized hull of the barge.

The position of the capsized vessel was reported as 30° 52.5' South, 153° 15.5' East, 9.5 miles north-east of Smoky Cape in more than 100m of water.



Photograph Capsized Titan

Courtesy of Mirror Australian Telegraph Publications

Photographer Michael Peri

The Master broadcast a safety message ("SECURITE") by channel 16 VHF and 2182 kHz. The Master also reported the capsize to the MRCC and his principals in Singapore. Rapuhia remained close to the capsized barge throughout the night and into the morning of 26 December. The emergency towing hawser could be seen lying over the barge's bottom plating, with the light "messenger" line leading over the bow.

During the morning the wind and sea moderated and the sea and swell were observed to be westerly. The crew recovered the towing wire and found that the wire itself was intact but the nylon stretcher had parted. Rapuhia remained close to the capsized barge monitoring its drift southward.

At 0700 on 27 December, a representative of the owner boarded Rapuhia together with a team of divers and welders.

Underwater examination established that the crane had fallen off the central mast, which was bent at an angle and that the live ring was jammed on the mast at an angle of about 70 degrees to the horizontal. Skylight glass in the engine room skylight had been broken and the engine room plates, normally making up the working surface of the engine room, had fallen against the inverted skylight and interior deckhead.

The strength of the current was such that the divers were unable to work on the barge. It was decided to tow the barge clear of the shipping lanes and fishing grounds, so it could be worked on where the current was manageable for under-water work. A position off Diamond Head was selected as being most suitable.

At 1045, the emergency tow line, which could be seen lying across the upturned bow section, was connected and at 1512 Rapuhia began towing the barge south.

At 0015 on 29 December, the tow arrived off Diamond Head and anchored. A full assessment was made by a diver, experienced in under water survey of ships. By mid-morning it was established that it was not practical to salvage the barge, and the decision was taken to sink the barge. Work began on cutting holes in the upturned bottom plating and the double bottom tank top, to aid in a controlled sinking.

The barge sank at about 2100 on the evening of 29 December, 2 miles south east off Camden Head in approximate position 31° 40' South, 152° 52.3' East in 33 meters of water.

The Master reported the sinking to the MRCC and Rapuhia resumed its voyage to Singapore.

On 30 December, the Inspector asked the owners to make the crew available for interview. On 4 January 1993, Rapuhia anchored off Townsville and the Inspector boarded the ship to interview the Master and others of the crew, and to inspect the ship.

Comment and Analysis

The capsize of Titan occurred in the hours of darkness. Nobody was witness to the capsize, nor was anybody able to closely observe the barge or its behaviour for about two hours before the capsize, from a time between 2019 and 2052 (the times of civil and nautical twilight). Neither direct observation, nor subsequent examination of the barge after capsize or when it had sunk, gives any definitive clue as to the cause of the incident. In all probability the capsize resulted when a number of different elements or forces coincided.

Neither Rapuhia nor Titan carried insurance. The owner-operator therefore, bears the cost of the loss and had nothing to gain by the loss of the crane barge. However, had the barge capsized in an area where it had to be salvaged, or had Rapuhia itself become a casualty or caused pollution, there was no Protection and Indemnity Cover or other insurance, to make good any damage, or cover the cost of operations subsequent to any such accident.

Before leaving Australia, Titan and Rapuhia were subject to inspections by AMSA. These inspections were to ensure the seaworthiness of the tow and the safety of the personnel, as prescribed in the various Marine Orders and ITS.

The cause of the capsize could be due to a number of factors that might or might not be interrelated:

1. The conduct and operation of the towing vessel Rapuhia;
2. The sea and weather conditions;
3. The inherent stability characteristics of Titan;
4. The preparation for the tow, including the securing of the jib, and the watertight integrity of the barge.

Rapuhia

On 30 December 1992, the Honduras authorities were informed of the capsize of the barge and the intention to interview the crew of the Rapuhia. Subsequent inquiries through the Honduras Superintendencia de Marina Mercante Nacional revealed that, in fact, they had no record of the vessel, according to a facsimile sent to the Inspector on 10 May 1993, which stated:

> *"In response to your fax of 21 April 93 regarding the above vessel, (Rapuhia HQSY 1), it was determined that such a vessel does not exist in the Honduran Registry: therefore it was not issued any certificates or surveyed by Honduran Authorities."*

In a further facsimile to AMSA of 1 June 1993 the Honduras authorities repeated that the Rapuhia was not registered on their files and added:

> *"The '"Honduras Shipping Registry S. DE R.L."' Classification company also does not exist in our records. Therefore it is not authorized by the Government of Honduras to issue statutory maritime certification.*
>
> *In view of these circumstances, this vessel has no connection with Honduras, and can be classified as a "flagless vessel" for all purposes."*

Despite having false certificates, there was little doubt that Rapuhia was in very good condition and its hull and machinery well maintained. Both the AMSA inspection and a critical examination by the Inspector, armed with hindsight, showed that the ship was in good order. The engine room was clean and showed every sign of being well maintained. On deck, the ship's condition was fair to good, with no obvious deficiencies. All indications were that Rapuhia had been subject to a thorough maintenance program in New Zealand and the condition of the vessel had not materially altered.

In addition to the false statutory safety certificates, subsequent checks on the certificates of competency produced by the Master and officers revealed that the Mate and Chief engineer were operating under false documentation.

The Liberian authorities issued the Mate with a Master's Certificate in January 1989, on the basis that he held a Certificate as a Master of a Foreign Going Steam Ship, issued by the New Zealand authorities. The New Zealand authorities had no record of having issued any certificate of any grade to the Mate. The Liberian authorities immediately withdrew the Mate's Liberian certification.

The Chief Engineer purported to hold a certificate number 1E6377 as a First Class Engineer, issued in Bombay on 7 April 1976. The Indian authorities confirmed that they had issued a certificate of that number, but to a person with a name other than the name given by the Chief Engineer and that it was a certificate as a Second Class (Motor) Certificate.

Although the Mate and Chief Engineer were operating on false certification, this fact does not seem to have any bearing on the capsize of the barge.

It cannot be established whether or not the Master or other officers were in a position to appreciate the status of the certificates issued to the ship. They joined in Wellington in mid-November and the interim certificates, purported to be issued on behalf of the Honduras authorities, had already been issued to the ship from Jakarta. There seems to have been no reason why the Master should have questioned the validity of the safety certificates. The Mate and Chief Engineer actually held documents that they must have known to be false, but it cannot be established whether or not this knowledge extended to the ship's statutory safety certificates.

As a towing vessel in open sea conditions, Rapuhia was more than adequate.

The ship's configuration of diesel electric motors and associated machinery was well suited to towing, steady and consistent motivating power could be maintained. Three diesel generators were used through the two electric motors. Throughout the tow Rapuhia was using a little over one third of its maximum power.

The towing frame, fabricated in Sydney, was adequate for the tow and the wire clamp seemed adequate for normal towing operations. Despite the great strain that was placed on the wire when the nylon stretcher parted, no distortion or fracturing of the frame, its welds or the associated deck structure could be found.

The maximum speed recommended for the tow by a New Zealand consultant was six knots. Others interviewed stated that five knots should have been the maximum speed. Although the actual progress of the tow was slow, making good three and progressively two and then one knot over the ground, the effective speed through the water was in the region of five knots because of the effects of the adverse south-going Eastern Australian Current, which reaches its maximum velocity on the line of the 100m contour between Smoky Cape and the Queensland border.

Although experienced in off-shore support vessels, the Master had no experience in towing operations. However, the Mate and Chief Engineer claimed significant experience in towing. The catenary (the depth of the towing wire below the horizontal) was not calculated, but all those interviewed were adamant that the towing wire never broke the surface of the water.

The Master chose a route about six miles off the coastal promontories, close to the 100m depth contour. His stated reason for this route was to avoid the larger swells further out to sea. However the course put the tow, particularly from midnight on 24 December to the time of the capsize, in the area of greatest counter current, which is known to run at rates of up to four knots. On 27 December, when the divers attempted to work on the capsized hull, they estimated that the south going current was about four knots. In choosing this route, the tow was placed in the maximum adverse current. However, this factor in itself should not have caused the capsize.

There is no evidence that the loss of the Titan can be attributed to the acts of commission or omission by those on board the Rapuhia or from any deficiency or characteristic of the towing vessel.

The weather conditions

Meteorological reports from the Bureau of Meteorology, the Naval Weather and Oceanography Centre and information from the Manly Hydraulics Laboratory were used in assessing the conditions. These reports were based on areas relatively remote from the area off Smoky Cape. In the case of the sea conditions, these were based on the wave rider buoy off Crowdy Head, about 60 miles north of the position of the sinking . The conditions as recorded by the ship were consistent with these remote readings, but marginally more severe. A buoy further south and close to the position of the capsize was non-operational.

The observations indicate that the significant wave heights at the time of the incident were 1 to 1.5m (recorded as 2m at the ship) and that wave periods ranged from about 4.8 to 7.7sec. The Naval Weather and Oceanography Centre supplied data on the wind speed and direction. At the time of the incident, winds were north to north westerly (consistent with Rapuhia log book recording) at 20 knots moderating to 10 knots.

Rapuhia was equipped with an anemometer, which was used by those on board to record the wind speed at regular intervals between the time the tow departed and the night of 25 December. The actual wind speeds are, therefore, known with reasonable confidence. The maximum wind speed recorded was 28 knots at a time when Rapuhia was making a speed of one knot. Although the description of the sea and swell conditions are more subjective, narrative log book descriptions of the sea and the breaking of the sea over the deck of Titan, the assessment of the wind, sea and swell conditions are accepted as substantially correct.

Taking into account the dimensions and weight distribution of the barge, the estimated natural pitch period is approximately 3 to 3.5sec. This assumes the hull was intact, or at least had suffered no gross damage which would have allowed the free flooding to open compartments.

Any water taken on board at the extremities of the vessel would be likely to increase the natural pitch period.

On this basis, the natural pitch of the vessel was approaching the lower end of the wave spectrum period. In this situation, resonant pitching of the vessel could occur which would result in large pitching moments and accelerations. Given the proximity of the edge of the continental shelf, it is possible that waves outside of the spectrum of those observed were present and that steeper waves at or near the natural pitch period of the vessel could have caused severe pitching and heaving motions.

Any such relatively quick pitching period is likely to generate large stresses in the crane structure and also large longitudinal and transverse dynamic upsetting moments.

Titan

Stability

Titan's owner submitted the inclining experiment report to AMSA on 26 November. This experiment, conducted on 19 November, was not witnessed by any state or AMSA surveyor, but was observed by a private surveyor and the owners representative. The Authority was asked to acknowledge that Titan's stability criteria demonstrated that the barge could be towed in open sea. Based on this report, which was checked by AMSA, the vessel's stability was assessed for the towing operation.

To establish any vessel's basic stability criteria, the vessel is inclined under strictly controlled conditions to establish the height of its centre of gravity above the keel and, by measuring the deflections of a plumb line, a calculation is made of the distance between the centre of gravity and the metacentre.* To maintain positive stability the centre of gravity of a vessel must remain below the metacentre (See Attachment 1). This is calculated for transverse stability. Although there is a longitudinal metacentric height, it is not normally necessary to measure this as ships, as a general rule, have a breadth to length ratio of 1:6.5 resulting in large reserves of longitudinal stability; however Titan had a ratio 1:2.1.

Nevertheless the barge fell within the provisions of the Australian Transport Advisory Council's Uniform Shipping Laws Code, 8.C.7.7 and the inclining experiment met the criteria with ease. The USL Code states:

"When barges are in transit in a seaway under tow, conditions likely to lead to capsize may be more severe than with a derrick or crane operating. Special attention should be paid to the probable effect of strong wind upon lateral areas. The following should be used for guidance:

(a) All practical efforts should be made to ensure that the height of the centre of gravity is such that at an angle of heel of 15 degrees, a vertical line through the KG will not be beyond the line of the deck edge.

(b) ..."

The Inspector engaged an independent firm of naval architects

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* The metacentre is at the intersection of vertical lines drawn through the centres of buoyance in the initial and slightly inclined positions.

to review aspects of Titan's stability and specifically to:

1. Review the inclining experiment report of 24 November 1992 to ensure that:
    - (a) The experiment was conducted to acceptable procedures.
    - (b) The results were correct.
    - (c) The stability data meets the USL Code stability criteria for a tow.
    - (d) The barge met the requirements of IMO MSC/Circ. 503 "Intact Stability Requirements for Pontoons".
2. To examine the possible scenarios to explain the barge's capsize, taking into account transverse and longitudinal stability, and up to three cases of possible damage.

The independent analysis of the stability data noted that the inclining experiment report was clearly marked "preliminary" and had not been witnessed by, or on behalf of, any marine survey authority. The experiment was assessed as having followed general procedures, that closely followed the accepted standards of Australian survey authorities. Because of the inherent stability of the crane when operating (it would list only 5 degrees with a load of 150 tons suspended from the jib at maximum radius), the list created by moving weights of about 24 tonnes was small, but the results of the readings gave a consistency of reading within the normally accepted range of plus or minus 5 per cent. It was also noted that only one pendulum was used. However given the large range of resulting reserves of stability, this was considered acceptable.

The consultant found that the report, based on the experiment's results (Attachment 2), was substantially correct and demonstrated that, according to the relevant rules of the USL Code and the IMO MSC/Circ/ 503, the intact stability was quite sufficient for the proposed tow.

However, it was noted that the report of the 24 November, appeared to contain an incorrect analysis in evaluating the statical stability curve rather than the dynamic stability curve. Notwithstanding this, Titan's resistance to a capsize at small angles of heel was between three and four times greater than the minimum required. The measure of a vessel's ability to overcome an external heeling moment is an imaginary righting lever known as the GZ.

The USL Code stability criterion for barges is based on a 15 degree angle of heel criterion. The consultants noted that the Titan's deck edge immersed at an angle of heel of 9.6 degrees. Once the vessel immersed its deck edge, the dynamics of its stability characteristics would have changed significantly. However, based on the intact stability data, even if the angle of heel had been based on the barge's deck edge immersion, more than adequate stability reserves to meet the criteria remained.

It was also noted that Titan did not seem to qualify as a pontoon as defined in MSC/Circ. 503. The requirements of the circular seem to have been developed for vessels carrying deck cargo and not for a structure such as the crane assembly on Titan. Also, Titan's block coefficient of about 0.81, is less than the 0.91 considered normal for a pontoon.

However, the consultant was of the opinion that Titan was of a generally similar nature to pontoons and the barge easily complied with the criteria.

The consultant concluded that:

> *"The vessel easily met the applied intact stability criteria. If the vessel was intact at the time of the incident, then very significant external forces would be necessary to cause a capsize. Given the short pitching period, the large windage and possibility of resonant wave frequencies, then forces significantly greater than wind heeling criterion may have been generated. However due to the extremely high GM and the large area under the GZ curve, it is unlikely that these forces would have been sufficient to cause capsize."*

During the investigation a number of statements were made to the Inspector querying the stability of Titan, based on the experiences of 1935 and 1958. This led to strong opinions that the barge would not survive in open-sea conditions. All the evidence is that the Titan, in an intact state, was extremely stable. Any perception that the barge would capsize because it was "top heavy" is misplaced and does not appreciate the dynamics of ship stability. It would have been very difficult to capsize. Paradoxically the crane's behaviour in a swell, as observed in 1935 and 1958, was probably a manifestation of its inherent stability.

Indeed, the stability reserves were such as to make the vessel very stiff (having a large righting lever). When heeled in a seaway, the barge would tend to return to the upright position very rapidly, which in turn induces acceleration and other mechanical stresses on the general structure of the vessel, including the hull.

The preparation of the barge and the watertight integrity of the hull

The towing wire and bridle were adequate for the tow. The towing wire consisted of one of Titan's 75 ton safe working load wires. The Block was retained on deck, leaving one block and wire in position.

When carrying out their duties, AMSA surveyors are guided by their professional experience, standards issued by various Standard Authorities, IMO Circulars and documents and other internationally recognised authorities relating to safety and the carriage of goods.

These supplement the AMSA "Instructions to Surveyors", an administrative document, issued to guide surveyors in their duties so as to apply uniform standards.

ITS 20.8.3, covering single voyages of unmanned tows, provides instructions for surveyors for the inspection of the tow and the conditions that have to be met. Although guidance is provided on ensuring the watertight integrity of the tow and a barge's stability, the structural engineering issues of the mechanical stress exerted by such a large crane structure were not addressed.

But, it should be noted that the Titan was relatively unusual in both size and structure. In preparing the Titan for towing, a major area of concern was securing the crane and the crane jib, to prevent it slewing in the seaway. In relation to this ITS 20.8.3.12 refers to

> *"Dredges, crane barges and similar vessels are to be in the designed towing condition. Unless permitted by that condition:*
>
> *(a) top tumblers of dredges shall be removed and bucket ladders shall be removed from their top bearings; and*
>
> *(b) crane jibs, gantries and similar fittings shall be lowered and secured to the surveyor's satisfaction."*

In its recommendations ITS may be considered to be ambiguous because the meaning of the term "lowered", in relation to the crane jib, is not clear. Further the Titan does not seem to have had any designed towing condition, other than that actually practised in the enclosed waters of Sydney Harbour. No condition seems to have existed for deep water tows.

The ITS requirements are consistent with the findings of a Court of Marine Inquiry into the loss of the dredge W.D. Atlas, a self propelled steam bucket dredger, which foundered about 14 miles off Jervis Bay on 20 May 1966, with the loss of 13 lives. The Court found that the W.D. Atlas was not seaworthy.

> *The degree of unseaworthiness was due to:*
>
> *(2) With regard to both stability and freeboard, there was a failure to make the vessel as seaworthy as was practical in that additional dredging equipment, including the top tumbler assembly, was not left ashore*
>
> *(3) The failure to prevent thwartship movement of the top tumbler assembly."*

The Inspector engaged a consultant engineer to assess the report in terms of the crane structure and the stresses that would have been placed on the hull.

For the voyage to Singapore, the crane jib was lowered to its minimum working elevation - the same condition as when the barge was inclined. One 75 ton SWL block, of 2 tonnes or more in weight, had been removed from the jib end, and the associated wire runner had been removed to be used as the towing wire.

The remaining block, was hoisted to about a metre from the head of the jib. The consultant engineer considered that the block would swing with the rolling of the barge. This would transmit large moment through the jib and would add to the overturning effect of the waves.

In addition he added,

> *"Not only that, but the block would continue swinging long after the barge had righted. Each swing would initiate a force through the metal to the tower and through that to the support plates welded to the deck. In time this could cause metal fatigue. There is no way in which the time to failure could be calculated."*

The end of the jib was neither guyed off nor supported in anyway. The crane was secured from movement by restraining the crane housing at the mast by chocks welded to the inner slewing ring and hard against the eight (914mm diameter x 254mm deep) vertical rollers that formed an integral part of the mast. A statement by the engineering firm engaged to weld the chocks in place suggest that the surfaces were cleaned of grease and good penetration was achieved. The welding unit produced 115 amperes on vertical up-welds and 130 amperes on horizontal welds using a 3.25mm electrode, resulting in a 6mm root weld. These chocks were not supplemented by any attempt to secure the crane at the outer 11.582m ring, where the mechanical advantage would have been greater, or of supporting or restraining the end of the jib.

In a seaway, the unsupported jib, together with the counterweights on the crane structure, would have created considerable torque forces, tending to twist the whole structure.

While the crane structure was prevented from slewing, this would not have prevented the jib arm from flexing. Although the movement would have been relatively small, in the order of 20 to 50mm. the consultant engineer stated that the momentum generated by the weight of the jib, a little over 100 tonnes, moving only this small distance would be great. This would add to the upsetting moment of the waves. It would also induce large stresses, transmitted through the crane structure and mast,. These stresses would generate a buckling force in the metal of the deck and the sides of the hull. The consultant stated that the forces can not be calculated.

The two sets of forces would also set up stresses of different amplitudes acting on the slewing ring structure, due to the differing distances of their respective centres of gravity. The slewing ring was designed to support the vertical thrust of the crane together with horizontal thrust on to the mast, and not the type of forces the mast, and not the type of forces induced in the seaway with a jib of 40m in length, acting through the main frame at a point 19.6m above the deck, in turn acting on eight chocks welded to a little more than 7m in diameter. There would also have been considerable forces exerted by the jib and crane tower on the deck and shell plating and the associated the rivets, and plate seams.

There were two possible ways to overcome these forces. The jib could have been either unshipped and carried on deck, or released from the elevating screw and the jib head lowered to or near the deck and restrained on a prefabricated frame. Either option was possible, although the length of the jib did pose problems in the latter option.

Had the jib head been lowered to the deck or to a prefabricated structure on the deck and restrained, these forces would have significantly reduced.

The consultant engineer observed that:

> *"The stresses induced in the hull would have been greatly diminished if the jib had been removed. Either it should have been carried on the deck of the barge, or it should have been shipped separately. The removal would reduce the centre of gravity of the barge, thus making it more stable, and any stresses induced in the riveted joints would be greatly reduced. Guy ropes would have restrained the jib, but ropes are elastic. Some movement of the jib would have occurred."*

The condition of the hull for operation in sheltered waters caused little concern. All the evidence suggests that the steel plating was in fair or good condition and, in general, did not reflect the age of the barge, although the condition of the rivets and some plating on the wind and water line was more questionable. The primary reason that the surveyors declined to issue anything other than a limited certificate in 1989, covering the condition of the barge itself, was the unknown condition of the rivets. A number had been built up by welds and attempts had been made to replace some rivets in the 1980s. However the skill of ship rivetting seems to have been lost and replaced rivets had to be welded up to make them watertight. In general, almost all the rivets were the original rivets being as old as the 73 year old barge itself. The surveyors were confident that the barge would not be subject to any sudden sinking because of the large number of small watertight compartments that made up the hull structure. But they were concerned with slow flooding into inaccessible spaces, hence their requirement for sounding pipes and alarms for such spaces.

In reviewing the integrity of the hull, the AMSA surveyor was satisfied that all openings to the spaces below the deck were adequately sealed and the evidence is that all watertight doors below the deck were closed and secure before Titan left Sydney

Harbour. Vents were removed and the openings closed by plates welded over the openings. Similarly, where glass in the engine room skylights was broken, plates were welded over the openings. All hatches were secured and pitch was used extensively to ensure that all points of possible down flooding were weather tight.
The inspection of the barge by the AMSA surveyor immediately before sailing, together with the observed freeboard, would suggest that there was no water on board when Titan left Sydney. The crew of Rapuhia stated that there appeared to be no change in the condition of the barge during the tow However, this would have been hard to judge with the vessel moving increasingly in the seaway, particularly during 24 and 25 December.

It is also probable that water was taken into the stern section. The water would have gained ingress where rivets failed, due to the hull working in the seaway, through the opening up of the overlapping seams of the shell plating, and possibly through a deck seam. Added to the stresses imposed on the barge's hull by the sea conditions, the rolling and pitching (and the combination of the two) would also act through the crane (jib, main frame and mast) causing additional stresses on the deck and hull plating, the stress being a function of their weight and the height of the centre of gravity.

The capsize

Evidence by the diver who attended the upturned barge on 27 December was that air was being expelled through the side shell plating on the starboard after side at the wind and water line, where rivets had been sprung, and there was water in the after end compartments, although the double bottom spaces cut into were dry. Subsequent dives on the sunken barge strongly suggest that the after (towed end) was also opened up on deck, along the line of a seam and that the bulkhead at frame 15 was buckled.

The consultant engineer advised that in addition to the free surface effect of the water within the compartments, the mass of water washing against the bulkheads as the barge rolled would generate similar forces to that of water hammer, adding to the overturning moment and the induced stress would tend to breach any riveted joint.

The underwater video of the capsized hull showed that the main frame and jib, together with the slewing ring, had detached from the mast and had fallen off, bending the mast. The live ring had slipped down the mast and jammed at an angle against the mast, reportedly at about 80 degrees to the horizontal. The video shows also that the live ring was fractured and badly distorted.

In seeking an explanation for the capsize, the consultant naval architect considered a number of possible scenarios. These were based on careful analysis of the photographs of the inverted barge taken on 27 December and the evidence of the diver. Given the known dimensions of the barge, the inverted draught, freeboard and trim could be estimated with some accuracy, to establish an approximate displacement. The consultant worked on three possible scenarios, with the vessel having taken 300 tonnes, 500 tonnes and 700 tonnes of water on board in the three after compartments, and the starboard space between frames 15 and 37 above the double bottom.

The consultant naval architect estimated that at the time the photograph was taken, there was about 700 tonnes of water on board, primarily in the after compartments. Given the fact that the barge had somehow capsized and, if the vessel conformed to the data calculated as a result of the inclining experiment, such a capsize should have not occurred given the intact stability criterion, it would seem probable that the spaces below the deck at the after end (the towed end) did take on water during the tow, on 25 December and possibly 24 December. This water reduced the reserve stability. The water gained ingress where rivets failed, opening the seams of the hull plating. The rivets failed through the hull working in the seaway.

These scenarios were based on the evidence of the diver and are supported by subsequent dives on the hull. It should be noted that it is not possible to state with certainty that the damage noted on 27 December and since the sinking, occurred on or before 24 and 25 December. However, given that the barge did sink, it is probable that a significant part of the observed damage, including the sprung rivets, did occur before 2300 on 25 December.

Water in the stern (the towed end of the barge) may have caused plunge. This plunging action would normally have been restricted by the tow rope, but in fact may have combined with rolling to cause the vessel to effectively trip over its stern (leading) quarter.

The deck edge immersed at nine and a half degrees. During the day of 25 December, the sea was seen to be breaking over Titan's deck. The seas being shipped on deck and, from time to time the deck being significantly immersed would have introduced stability factors, which together with other dynamic factors, might have been enough to cause a capsize.

However, the longitudinal GM was significantly greater than the transverse stability and, although an element of plunge may well have been present, the greater element would have been a transverse capsize.

There is no evidence available that the eight chocks welded to the slewing ring and against the vertical rollers at the corners of the mast failed. But it is a possibility and, if so, could be explained by the forces placed on the slewing ring by the moments exerted by the jib and the counterweights. Even if it had done so and the jib and main frame had slewed 90 degrees, the heeling lever would have been about 0.7m resulting in a heel of only 2 degrees. However, it must also be born in mind that in the event of such a failure, the jib would have swung backwards and forwards inducing at times a damping effect and at times an acceleration of the heel, increasing the upsetting lever, which would better explain the capsize in theoretical terms.

Even so, the slewing of the crane alone, if it occurred, cannot explain the capsize of Titan. Other factors must have been present.

At least two of these factors acting together would have reduced the barge's stability reserve so that with the wave and swell conditions, possibly combined with wave frequency and a modification of Titan's natural pitch period, led to the capsize of the crane barge followed by the breaking of the tow line.

Conclusions

The reason for the capsize of the crane barge Titan is a matter of conjecture but, in the Inspectors opinion, it is probable that a series of events, each one in themselves insufficient to cause a capsize, combined to change the initial stability characteristic of the barge:

1. Given the evidence available, it is probable that during 24 and 25 December, with the working in the seaway, rivets failed in the after starboard section of the barge, allowing a volume of sea water, probably between 500 and 700 tonnes, to ingress into the starboard after spaces. This reduced the intact stability of the barge;

2. The shipping of seas on deck and the probable immersion of the deck edge had the effect of reducing the barge's reserves of stability;

3. The following factors were present and if they coincided may have contributed to the capsizing moment,

    (a) The plunging of the barge, due to a loss of buoyancy at its towed end,

    (b) The periodic rolling,

    (c) Wind heel effect in wind gusts,

    (d) The effect of the crane block and small movement of the jib contributing to the roll;

4. There is no evidence that the chocks welded to the slewing ring to prevent the crane from moving failed before 2300 on 25 December;

5. There is no evidence that the conduct of those on the Rapuhia or the actions of the towing vessel contributed to the capsize;

6. The stability information computed from the inclining experiment of 19 November was substantially correct;

7. The stability criteria adopted by AMSA were appropriate and allowed reasonable reserves of stability. Notwithstanding the fact that Titan immersed its deck edge at an angle of heel of 9.6 degrees, there was a large reserve of stability at this angle;

8. The AMSA surveyors followed the Authority's Instructions to Surveyors. However, the Titan was not typical of tows normally envisaged in these instructions and it would have been appropriate to consider more fully the engineering aspects of stresses imposed by the crane structure on the securing arrangement and the hull of the barge;

9. The fact that the Rapuhia was unseaworthy by virtue of false certification and the false certificates carried by the Mate and Chief Engineer were not contributory factors to the capsize and loss of the barge.

Submissions

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

The report was sent to the owner of Titan and Rapuhia, the Master, Mate and Chief Engineer of the Rapuhia, MacKenzie Salvage and the Australian Maritime Safety Authority. Where comments and information was received, they have been carefully considered. Where appropriate, the text has been altered to reflect the facts of the incident and where the Inspector cannot accept the argument of any submission the issues are outlined below.

The Australian Maritime Safety Authority made comments relating to Conclusions 1, 3 5 and 7.

1. AMSA continue to have doubts regarding the failure of the rivets and that the trim of the overturned barge could be accounted for by the location of 100 tonnes of test weights and scrap electrical motors.

The Inspector, considering all the evidence (including that of the diver), remains of the opinion that on the balance of probabilities the stern end of the vessel did take water, either through the shell plating, or through a deck seam or both, which contributed to the capsize.

3. AMSA acknowledges the consultant's views as to the dynamics of the capsize but notes that the comments are based on conditions that are themselves assumptions as to what happened prior to the loss of the barge. AMSA is unsure if conclusions can be drawn on the basis of their argument.

The Inspector is satisfied that the barge had taken water and, given the evidence available to the investigation, the conclusion is reasonable based on the probable facts relevant to the incident.

5. AMSA noted that the Radio Operator was regularly keeping a navigational watch and was on watch when the tow line parted. AMSA raised the issue of whether the bridge manning was appropriate.

The Inspector acknowledges that the Radio Officer was not qualified to be in charge of a navigation watch and the bridge manning was contrary to the basic principles to be observed in keeping a navigation watch, required under the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978. However, given the speed of the tow and the availability of the Master, the Inspector does not consider that the bridge manning was in itself an "unsafe act" that contributed to the capsize of the Titan.

7. AMSA acknowledged the difficulties involved with assessing the seaworthiness of tows and is examining its instructions to ensure surveyors identify special features that may impact on towage operation. In response to comments by AMSA on the draft report, the Inspector sought advice from a consulting engineer in respect of stresses placed on the barge by the crane structure.

AMSA agrees with the consulting engineer's comments and considers the additional information enhances the technical content and completeness of the report.

The Inspector accepts that there is no direct evidence that the crane structure caused the failure of any rivets. However, as confirmed by the consultant engineer (pages 32-35), it is undeniable that the crane structure would have transmitted stresses through to the deck and hull plating.

MacKenzie Salvage submitted that when working on the upturned hull, from 27 December to 29 December there was no evidence that the side shell plating was taking water through the seams. There was one very small hole, smaller than a rivet hole, breathing air, but it was so small that it could not have allowed ingress of sufficient water as outlined in the body of the report.

The Inspector accepts that this submission was made in good faith, however as outlined above, regards the totality of the evidence is that the stern section in all probability did take water on 25 and possibly 24 December.

ATTACHMENT 1

Stability Terminology And Principles

The *centre of gravity* of a body or vessel is the point through which the force of gravity is considered to act vertically downwards with a force equal to the weight of the vessel.

The *centre of buoyancy* is the point through which the force of buoyancy is considered to act vertically upwards with a force equal to the weight of water that the vessel displaces. It is the centre of gravity of the underwater volume of the body.

To float at rest in still water, a vessel must displace a volume of water which is equal in weight to the weight of the vessel, and the centre of gravity must be in the same vertical line as the centre of buoyancy.

Figure (A) represents a vessel floating upright in still water. The centres of gravity is shown as point "G" and the centre of buoyancy is at point "B". The letter "K" is the keel.

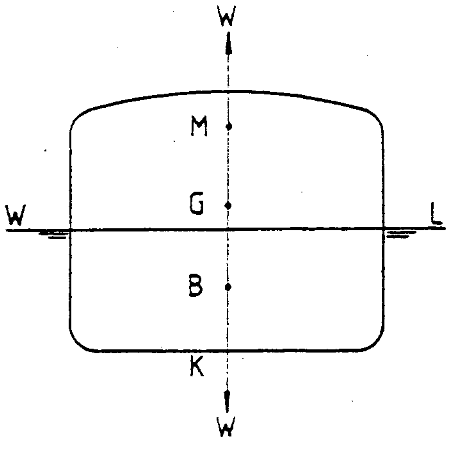


FIG. A

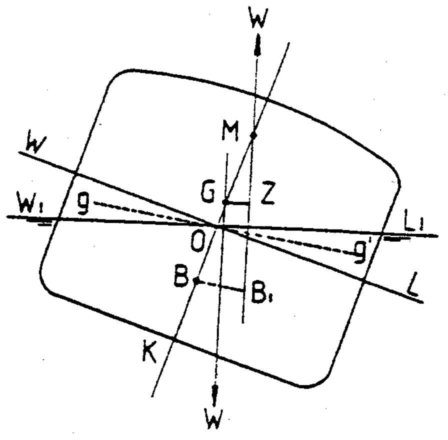


FIG. B

If the vessel is inclined by an external force to a small angle as shown in Figure (B) the centre of gravity will remain static and the weight of the vessel (V) is considered to act vertically downward through this point. Therefore the centre of buoyancy will move into the same vertical line as the centre of gravity and hence move from "B" to "B1".

For angles of heel up to about 15 degrees, the vertical through the centre of buoyancy may be considered to cut the centre line at a fixed point. This point is known as the initial metacentre (M). The height of the initial metacentre above the keel (KM) depends on the vessel's underwater form and the surface water plane area.

The vertical distance between G and M is referred to as the metacentric height. As long as G remains below M the vessel has a positive metacentric height.

A ship is in stable equilibrium if, when inclined, it tends to return to the initial position. For this to occur "G" must remain below "M". Figure (A) shows the vessel upright, having a positive "GM", Figure (B) shows the same vessel inclined at a small angle. The centre of buoyancy moves from B to B1 to take up a new centre of gravity of the underwater volume and the force of buoyancy is considered to act vertically upwards through B1 and the metacentre "M"> If the forces acting around "G are taken then there is a force or moment to return the ship to the upright position. This force or moment is referred to as the *moment of statical stability* and is equal to the product of the force W and the length of the imaginary lever GZ.

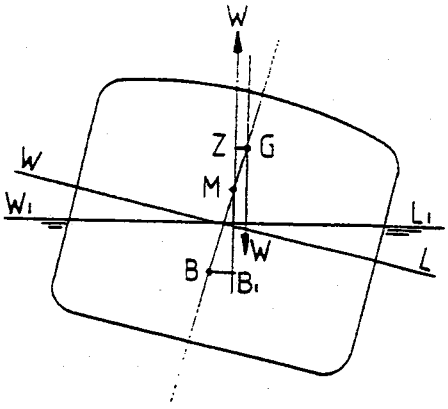


FIG C

When a ship, which when inclined to a small angle of heel tends to heel still further, it is in unstable equilibrium where the centre of gravity is above the metacentre and has a negative "GM". The ship will not stop inclining until G and M coincide.

Figure (C) shows a vessel in unstable equilibrium. While "G stays above "M" the imaginary lever GZ forms a capsizing lever.

ATTACHMENT 2

CRANE BARGE "TITAN"

Investigation into stability matters
relating to capsizing of the vessel while
under tow on 25 December 1992.

Baron & Dunworth
Naval Architects & Marine Consultants

March 26, 1993

CRANE BARGE "TITAN"

Investigation into stability matters relating to capsizing of the vessel while under tow on 25 December 1992.

Contents

Appendices

1. Terms of reference

An investigation of stability and related matters was requested by the Inspector of Marine Accidents, Department of Transport & Communications. The terms of reference of the report were as follows.

1.1 To review the inclining experiment carried out on 24 November 1992 to ensure that:

a. The experiment was conducted to acceptable procedures
b. The results shown are correct
c. The stability data meets the USL Code stability considerations for a tow
d. The barge met the requirements of IMO MSC/Circ 503, (Intact stability requirements for pontoons).

1.2 To examine possible scenarios to explain the vessel's capsize, taking into account transverse and longitudinal stability and up to 3 cases of possible damage.

2. Inclining Experiment and stability booklet

A report entitled "Preliminary Inclining Experiment Report and Stability Booklet" prepared by the Ship Technology Unit (STU) dated November 1992 was examined.

The experiment was not witnessed by any surveying authority and the report is clearly marked preliminary throughout.

This report was found to be substantially correct and demonstrated that, according to the relevant rules of the USL Code and the IMO requirements of MSC/Circ 503, the intact stability was quite sufficient for the proposed tow.

2.1 Inclining Experiment

General

The general procedure of the experiment closely follows the accepted standards of Australian survey authorities.

Draughts

Freeboard readings were taken and from these, presumably with the use of a lines plan the corresponding draughts were calculated. In normal circumstances, for a vessel of this size, the draughts would be directly read from draught marks. Due to the nature of the vessel it is considered that accuracy would have not been lost by measuring freeboards.

Pendulum readings

Due to the very high metacentric height (GM) of approximately 17 metres, the barge was exceedingly stiff and the weights used (totalling 23.89 tonnes) were sufficient to give very small pendulum readings only. However, the percentage difference among the results from these readings was within the normally accepted range of + or -5%.

It was noted that only one pendulum was used, but due to the high GM, the consistency of the results and the large resulting reserves of stability compared with the stability criteria, this is considered to be acceptable.

Hydrostatic tables

The hull lines were used to produce hydrostatic tables to enable comparison with those in the report.

As with any sets of hydrostatic tables derived from different computer programs, there were some differences. However reasonable agreement with the values in the report were obtained. A copy of calculated hydrostatics together with KN values is shown in appendix 1.

Weights to be added or moved after the experiment

Several items were to have been moved in preparation for the tow and the report notes that the list of items was to be revised. In subsequent discussion with the Inspector of Marine Accidents, it is understood that the only other items added were a total of 71 tonnes of ballast weights added inside the barge as listed in the departure condition in appendix 2.

Windage area calculation

The windage area and associated heeling levers as shown in the STU report appear to be correct.

2.2 Stability Criteria

The report assessed stability on the basis of requirements of the USL Code section 8.C.7.7 and IMO MSC/Circ 503 "Intact stability requirements for pontoons".

USL Code

The USL Code requirement specifically relates to crane barges and the vessel meets these criteria with ease.

It was noted that the STU report appears to contain an incorrect analysis in evaluating the statical stability curve rather than the dynamic stability curve. Analysis of the dynamic stability curve is shown as intact departure curve in appendix 5. This criterion is easily met with a capsize resisting lever of 2.4 metres compared with the required 0.7 metres.

The 15 degree angle criterion is also easily met but it is questioned whether this angle is relevant in such an analysis as the deck edge immersed at 9.5 degrees in the departure condition.

IMO Requirements for pontoons

Strictly speaking, the barge does not appear to qualify as a pontoon as defined in MSC/Circ. 503

These requirements appear to have been developed for vessels which do not have high vertical centres of gravity. Para 1.2 of the annex to the document states that a pontoon is considered to be normally carrying only deck cargo. It may be argued that a relatively massive structure such as the crane with its very high centre of gravity presents a different type of vessel. Further Para 2 states that an inclining experiment is not normally required providing a conservative value of lightship KG is assumed. The "Titan" KG is several metres above the deck and the inclining was obviously essential.

Para 1.4 states that the minimum block coefficient is normally considered to be 0.9 whereas the that for "Titan" was about 0.81 based on draught to keel amidships.

In spite of the above comments, the vessel is of a generally similar nature to pontoons and demonstrates easy compliance with the criteria. The relevant cross curve of stability (GZ curve) for the departure condition is shown as the intact departure curve in appendix 4.

3. Prevailing weather conditions

Observations taken at the Crowdy Head waverider buoy were supplied by the Manly Hydraulics Laboratory. This buoy is located approximately 60 miles from where the incident occurred and significantly further inshore.

The observations indicate that significant wave heights at the time of the incident were 1.0 to 1.5 metres and that wave periods ranged from about 4.8 to 7.7 seconds.

The Naval Weather & Oceanography Centre supplied data on wind speed and direction. At the time of the incident, north to north westerly winds of 20 knots, moderating to 10 knots on the following day, were blowing.

This indicates that weather was not particularly adverse. The location of the incident was, however, close to the edge of the continental shelf which can cause wave patterns to be significantly modified.

It is understood that the master of the towing vessel reported that he was heading into the wind and waves at the time of the incident.

4. Condition of barge after the incident

Subsequent to the incident, the barge was floating upside down with an obvious trim by the stern and a list with the starboard quarter immersed more than the port quarter.

It is understood that a diver's survey showed that the jib and the outer tower structure were both missing.

By careful examination of a series of photographs, an estimate of the upside down freeboards was made. From this it was calculated that the amount of water that may have been taken on board at the time that the photos were taken was approximately 700 tonnes. To achieve this volume of water and for the attitude of the barge to have been as it was, water is most likely to have entered the three aft compartments and the starboard compartment from frames 15 to 37. The likely compartments breached are shown in appendix 7.

The amount of water taken on board at the time of the capsize could be any amount from none to the maximum of 700 tonnes. It is quite possible that the vessel had taken some water while under tow, perhaps through opened seams which were observed by the diver in his examination after the capsize.

Bearing this in mind the statical and dynamic stability characteristics of the vessel were examined with various amounts of water on board.

A series of GZ curves with 300, 500 and 700 tonnes of water were constructed. These are shown as separate curves in Appendix 4. With large amounts of water aboard, the vessel has only small margins of stability. The GZ curves assume that the crane structure was still intact. An appropriate amount of water free surface was also included.

The calculated values of GZ curve and associated dynamic stability values are tabulated in appendix 3.

The dynamic stability curve analysis required by the USL Code, was also carried out with progressive flooding included. With the likely maximum amount of water taken on board, the barge fails the minimum capsizing moment criterion. The various dynamic stability curves relating to increasing amounts of water on board are shown in Appendix 5.

5. Behavioural response to prevailing conditions

Taking into account the dimensions and weight distribution of the barge, the estimated natural pitch period is approximately 3 to 3.5 seconds. This assumes the hull is intact or at least has suffered no gross damage which would allow free flooding to opened compartments.

Any water taken on board at the extremities of the vessel would be likely to increase the natural pitch period.

Given the above, it can be seen that the natural pitch of the vessel was approaching the lower end of the wave period spectrum. In this situation, resonant pitching of the vessel could occur which would result in large pitching moments and accelerations. Given the proximity of the edge of the continental shelf, it is possible that waves outside of the spectrum of those observed were present and that steeper waves at or near the natural pitch period of the vessel could have caused severe pitching and also heaving motions.

6. Possible contributing factors to capsize

6.1 Structural failure of the crane

Due to the relatively quick pitching period, it is likely that large stresses would be generated in the crane structure and also large longitudinal and transverse dynamic upsetting moments.

Severe motions could cause the jib to slew which would generate a large heeling moment. In the extreme case of the jib slewing 90 degrees, the heeling lever would be approximately 0.7 metres for the intact condition. While this in itself would cause a static heel of only approximately 2 degrees, this combined with other factors such as water on board and wind heeling may have been sufficient to cause capsize.

Structural failure occurred at some stage and it is unlikely that would have been with the barge upside down. It is considered that the crane structure could have collapsed immediately prior to or during the capsize.

6.2 Significant immersion of the deck edge

The dynamic response to the actual wind and sea conditions particularly if water had been taken on board could easily cause the deck edge or bow of the vessel to be significantly immersed. This, coupled with other factors such as failure of the crane structure and water taken on board may have been sufficient to cause capsize.

6.3 Water on board

Water in the stern of the barge (which was the end being towed) may have caused plunge. This plunging action would normally be restricted to some extent by the force of the tow rope, but in fact may be combined with rolling and cause the vessel to effectively trip over its stern quarter.

To assess the likelihood of this, model tests should prove beneficial. Such tests could be carried out with various amounts of water on board to simulate any flooding that may have occurred.

6.4 Exceptional seas in area of incident

As noted earlier, the incident occurred near the edge of the continental shelf. Such regions could give rise to shorter wave periods and steeper seas which could cause violent motions of the barge.

7. Summary

7.1 The vessel easily met the applied intact stability criteria. If the vessel was intact at the time of the incident, then very significant external forces would be necessary to cause a capsize. Given the short pitching period, the large windage and the possibility of resonant wave frequencies, then forces significantly greater than the wind heeling criterion may have been generated. However due to the extremely high GM and large area under the GZ curve, it is unlikely that these forces would have been sufficient to cause capsize.

7.2 If the amount of water on board at the time of capsize was approaching the amount observed after capsize, then the vessel may not have complied with the applied intact stability criteria. This would have made the vessel susceptible to capsize in adverse conditions. As the assumed amount of water on board decreases, the vessel obviously becomes less susceptible to capsize.

7.3 The mode of capsize could have included a component of plunge by the towed stern if water was on board but it is considered that the vessel would have subsequently capsized laterally due to the restriction of the tow rope pull and the far greater GM in the longitudinal direction than in the transverse direction.

7.4 The crane structure is likely to have been lost immediately prior to or during capsize. The effects of the jib slewing or crane base collapsing, could add considerably to adverse heeling moments particularly in a dynamic situation.

7.5 Model tests could prove beneficial to assess the sequence of events at the time of the incident.

Appendix 1

TITAN - HYDROSTATICS

Trim = -0.196 metres (As Inclined) SG 1.025

Draft	Dispt.	LCB	KB	TPC	LCF	KM	MCTC
2.200	1924.2	-1.48	1.27	11.31	-1.77	27.22	40.57
2.201	1925.4	-1.48	1.27	11.31	-1.77	27.21	40.57
2.202	1926.5	-1.48	1.27	11.31	-1.77	27.19	40.57
2.203	1927.6	-1.48	1.27	11.31	-1.77	27.18	40.57
2.204	1928.8	-1.48	1.28	11.31	-1.77	27.16	40.57
2.205	1929.9	-1.48	1.28	11.31	-1.77	27.15	40.56
2.206	1931.1	-1.48	1.28	11.31	-1.76	27.14	40.56
2.207	1932.2	-1.48	1.28	11.31	-1.76	27.12	40.56
2.208	1933.3	-1.48	1.28	11.31	-1.76	27.11	40.56
2.209	1934.5	-1.48	1.28	11.31	-1.76	27.09	40.56
2.210	1935.6	-1.48	1.28	11.31	-1.76	27.08	40.56
2.211	1936.7	-1.48	1.28	11.31	-1.76	27.06	40.56
2.212	1937.9	-1.49	1.28	11.31	-1.76	27.05	40.56
2.213	1939.0	-1.49	1.28	11.31	-1.76	27.04	40.56
2.214	1940.2	-1.49	1.28	11.31	-1.76	27.02	40.56
2.215	1941.3	-1.49	1.28	11.31	-1.76	27.01	40.56
2.216	1942.4	-1.49	1.28	11.31	-1.76	26.99	40.56
2.217	1943.6	-1.49	1.28	11.31	-1.76	26.98	40.55
2.218	1944.7	-1.49	1.28	11.31	-1.75	26.97	40.55
2.219	1945.8	-1.49	1.28	11.31	-1.75	26.95	40.55
2.220	1947.0	-1.49	1.28	11.31	-1.75	26.94	40.55

TITAN - FREE TRIMMING KNs

Upright Trim = 0.00 KNs in metres

Dispt.	5.0°	10.0°	15.0°	20.0°	25.0°	30.0°
1800	2.467	4.782	6.059	6.530	6.709	6.739
1820	2.446	4.749	6.020	6.488	6.666	6.697
1840	2.426	4.716	5.981	6.445	6.623	6.655
1860	2.406	4.684	5.942	6.403	6.581	6.613
1880	2.387	4.652	5.902	6.361	6.538	6.571
1900	2.368	4.620	5.863	6.318	6.495	6.529
1920	2.349	4.589	5.823	6.276	6.452	6.487
1940	2.331	4.557	5.783	6.233	6.409	6.445
1960	2.313	4.525	5.743	6.190	6.366	6.403
1980	2.295	4.494	5.703	6.147	6.322	6.360
2000	2.278	4.463	5.663	6.104	6.279	6.318
2020	2.261	4.432	5.622	6.061	6.236	6.276
2040	2.245	4.401	5.582	6.017	6.192	6.234
2060	2.229	4.370	5.541	5.974	6.149	6.191
2080	2.213	4.339	5.500	5.931	6.106	6.149
2100	2.197	4.309	5.459	5.887	6.062	6.107
2120	2.182	4.278	5.417	5.844	6.019	6.064
2140	2.166	4.247	5.376	5.800	5.975	6.022
2160	2.151	4.217	5.335	5.756	5.931	5.979
2180	2.137	4.186	5.293	5.713	5.887	5.936
2200	2.122	4.155	5.251	5.669	5.844	5.894

Trim = 0.00

Draft	Dispt.	LCB	KB	TPC	LCF	KM	MCTC	BML
1.50	1172.3	-2.29	0.90	10.61	-1.28	40.55	33.77	147.5
1.55	1225.4	-2.24	0.93	10.64	-1.26	38.97	33.94	141.8
1.60	1278.6	-2.20	0.96	10.66	-1.23	37.53	34.11	136.6
1.65	1332.0	-2.16	0.98	10.67	-1.20	36.18	34.25	131.7
1.70	1385.4	-2.12	1.01	10.69	-1.18	34.93	34.40	127.2
1.75	1438.9	-2.09	1.04	10.71	-1.14	33.78	34.60	123.1
1.80	1492.5	-2.05	1.06	10.74	-1.09	32.70	34.87	119.6
1.85	1546.3	-2.02	1.09	10.75	-1.03	31.67	35.01	116.0
1.90	1600.2	-1.99	1.11	10.76	-0.99	30.71	35.06	112.2
1.95	1652.6	-1.93	1.14	11.04	-1.51	30.50	37.90	117.3
2.00	1706.4	-1.90	1.17	11.26	-1.91	30.17	40.09	120.4
2.05	1762.9	-1.90	1.19	11.25	-1.84	29.29	39.98	116.1
2.10	1819.2	-1.90	1.22	11.27	-1.82	28.52	40.12	112.9
2.15	1875.6	-1.90	1.25	11.28	-1.81	27.79	40.26	109.9
2.20	1932.1	-1.90	1.28	11.30	-1.80	27.10	40.39	107.1
2.25	1988.6	-1.89	1.30	11.31	-1.78	26.44	40.51	104.3
2.30	2045.2	-1.89	1.33	11.32	-1.77	25.82	40.63	101.7
2.35	2101.8	-1.89	1.36	11.33	-1.75	25.23	40.73	99.2
2.40	2158.5	-1.88	1.38	11.34	-1.74	24.66	40.83	96.9
2.45	2215.3	-1.88	1.41	11.35	-1.73	24.13	40.95	94.6
2.50	2272.0	-1.88	1.44	11.36	-1.72	23.62	41.02	92.5
2.55	2326.6	-1.85	1.46	11.29	-1.54	23.00	40.24	88.6
2.60	2383.2	-1.84	1.49	11.43	-1.81	22.76	41.81	89.8
2.65	2442.5	-1.86	1.52	11.78	-2.49	22.89	45.57	95.5
2.70	2501.4	-1.88	1.54	11.81	-2.53	22.49	45.91	94.0
2.75	2560.4	-1.89	1.57	11.80	-2.49	22.04	45.82	91.6
2.80	2619.4	-1.91	1.60	11.81	-2.49	21.64	45.91	89.8
2.85	2678.5	-1.92	1.63	11.82	-2.48	21.25	46.00	87.9
2.90	2737.6	-1.93	1.65	11.82	-2.48	20.87	46.08	86.2
2.95	2796.8	-1.94	1.68	11.83	-2.47	20.52	46.15	84.5
3.00	2855.9	-1.95	1.71	11.84	-2.46	20.17	46.22	82.9
3.05	2915.1	-1.96	1.73	11.84	-2.46	19.84	46.29	81.3
3.10	2974.4	-1.97	1.76	11.85	-2.45	19.52	46.35	79.8
3.15	3033.6	-1.98	1.79	11.84	-2.42	19.20	46.27	78.1
3.20	3093.1	-1.99	1.81	11.92	-2.55	19.00	47.12	78.0
3.25	3152.9	-2.00	1.84	12.02	-2.76	18.85	48.42	78.7
3.30	3213.0	-2.02	1.87	12.03	-2.76	18.58	48.50	77.3
3.35	3273.2	-2.03	1.89	12.03	-2.75	18.31	48.51	75.9
3.40	3333.4	-2.05	1.92	12.04	-2.75	18.06	48.57	74.6
3.45	3393.6	-2.06	1.95	12.04	-2.74	17.81	48.63	73.4
3.50	3453.8	-2.07	1.97	12.05	-2.74	17.58	48.68	72.2

Departure condition

(water sg = 1.021 at inclining)

Item	weight (tonnes)	KG (metres)	LCG (metres)
As Inclined	1931.0	9.90	-1.52
Net weights on (as per STU)	22.0	-2.94	26.48
Ballast weights			
fr 78-80	30.0	1.10	20.11
fr 15-22	23.0	0.50	-16.15
fr 6-10	18.0	2.10	-22.56
Departure	2024.0	9.45	-1.25

Draft	2.292 m.
Trim	-0.354 m. (by the bow)
Draft at FP	2.469 m.
Draft at AP	2.115 m.
GM (fluid)	17.010 m.
LCB	-1.20 m.
LCF	-1.28 m.
KB	1.34 m.
KM	25.67 m.
TPC	11.13 tonnes
MCTC	38.71 t.m.

	5°	10°	15°	20°	25°	30°
KN	2.242	4.401	5.586	6.025	6.201	6.242
KGfSine	0.755	1.504	2.241	2.962	3.660	4.330
GfZ	1.487	2.897	3.345	3.063	2.541	1.912

Appendix 3

Crane barge "Titan" - Tables of GZ and Dynamic Area

GZ values in metres
Dynamic areas in metre-radians

Barge intact - no water on board

Angle	GZ	Dynamic Area
0.0	0.000	0.000
5.0	1.487	0.065
10.0	2.897	0.256
15.0	3.345	0.528
20.0	3.063	0.808
25.0	2.541	1.053
30.0	1.912	1.247

Barge + 300 tonnes water on board

Angle	GZ	Dynamic Area
0.0	-0.323	0.000
5.0	0.944	0.027
10.0	1.978	0.155
15.0	2.155	0.335
20.0	1.795	0.507
25.0	1.236	0.639
30.0	0.593	0.719

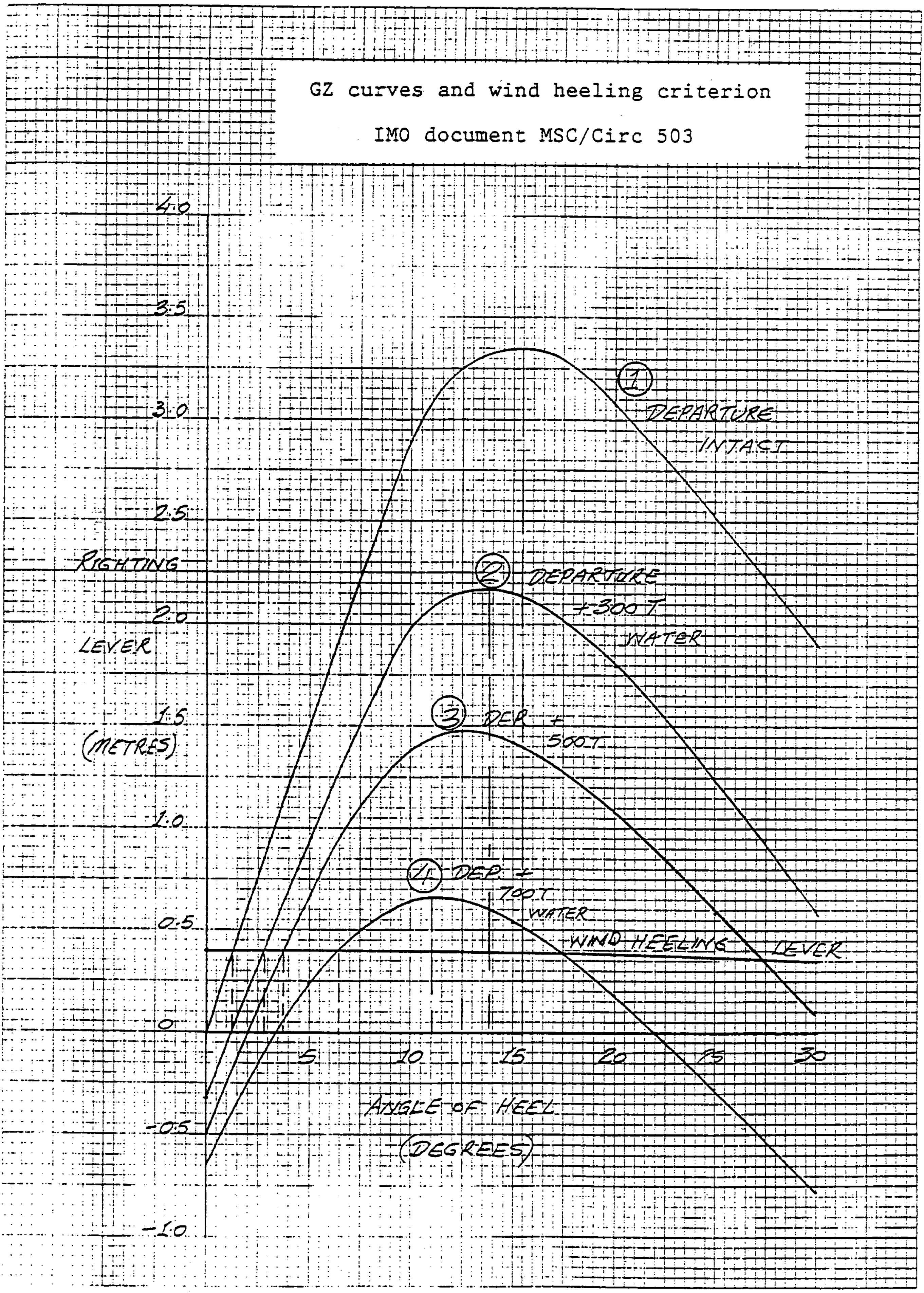
Barge + 500 tonnes water on board

Angle	GZ	Dynamic Area
0.0	-0.495	0.000
5.0	0.666	0.007
10.0	1.382	0.097
15.0	1.417	0.219
20.0	1.076	0.328
25.0	0.579	0.400
30.0	0.011	0.426

Barge + 700 tonnes water on board

Angle	GZ	Dynamic Area
0.0	-0.642	0.000
5.0	0.249	-0.017
10.0	0.641	0.022
15.0	0.536	0.073
20.0	0.181	0.104
25.0	-0.277	0.100
30.0	-0.781	0.054

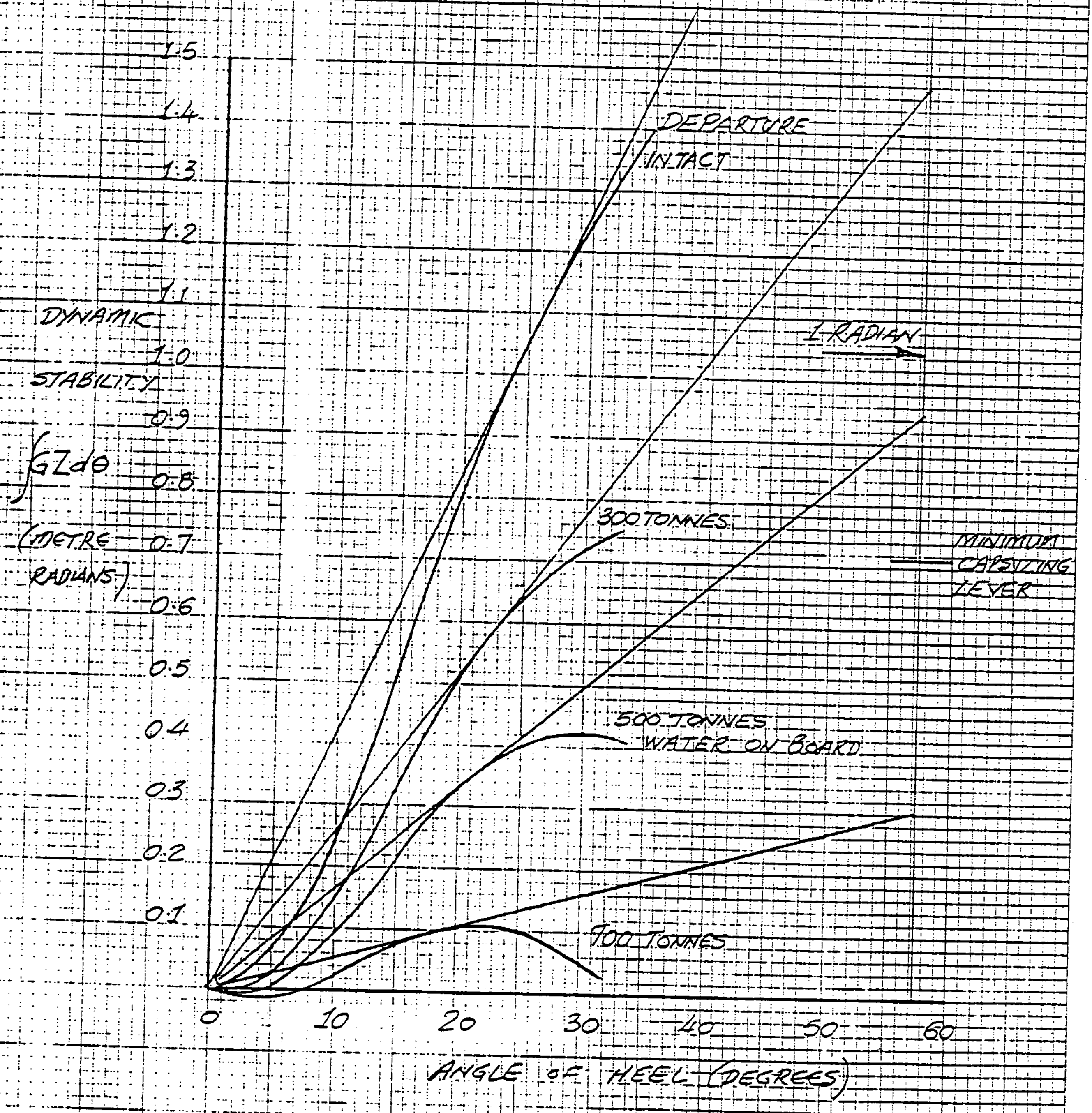
Appendix 4



GZ curves and wind heeling criterion

IMO document MSC/Circ 503

Dynamic stability curves as per USL Code



Appendix 6

Evaluation of stability criteria

IMO MSC/Circ 503

Intact vessel

		required
Area to max GZ	30.06 metre deg	4.58
Range of stability	> 40.0 deg	20.0
Angle of heel in wind	1.3 deg	4.7

Vessel + 300t. water

Area to max GZ	17.41 metre deg	4.58
Range of stability	> 30.0 deg	20.0
Angle of heel in wind	2.8 deg	4.7

Vessel + 500t. water

Area to max GZ	10.38 metre deg	4.58
Range of stability	29.0 deg	20.0
Angle of heel in wind	3.7 deg	4.7

Vessel + 700t. water

Area to max GZ	3.23 metre deg	4.58	FAIL
Range of stability	18.5 deg	20.0	FAIL
Angle of heel in wind	6.5 deg	4.7	FAIL

USL Code

1. For all conditions the centre of gravity at 15 degrees heel is 1.40 metres from vessel centreline at deck level which is well within beam/2 (11.96 metres)

2. Minimum capsizing lever required is 0.70 metres.

Actual Intact value	2.40 metres	
Vessel + 300 t. water	1.47 metres	
Vessel + 500 t. water	0.95 metres	
Vessel + 700 t. water	0.30 metres	FAIL

3. Wind heeling lever not to heel vessel to more than 15 deg

   Angles of heel as per IMO evaluation are all significantly less than 15 degrees.

Appendix 7

Plan of barge showing likely flooding after capsize