Report of the Chief Inspector of Marine Accidents
into the loss of the Suction Dredger

BOWSPRITE

with four lives
in the North Sea
on 5 December 1988

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Marine Accident Investigation Branch
5/7 Brunswick Place
SOUTHAMPTON
Hants SO1 2AN

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Marine Accident Investigation Branch
Department of Transport
5/7 Brunswick Place
Southampton
Hants SO1 2AN

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The Right Honourable Malcolm Rifkind QC MP
Secretary of State for Transport

Sir

I submit my Report following the investigation into the loss of the suction dredger BOWSPRITE with four lives in the North Sea on the 5 December 1988.

This accident occurred before the Marine Accident Investigation Branch (MAIB) became operational and the Merchant Shipping (Accident Investigation) Regulations 1989 came into force. The investigation was commenced by the Marine Directorate and MAIB assumed responsibility for it at a later date. The provisions of those Regulations concerning the publication of reports therefore do not apply.

However, as the accident was serious and would have been the subject of an Inspector's Inquiry if it had occurred when those Regulations were in force, it is recommended that the Report should be treated as if those Regulations applied.

I wish to place on record appreciation for the co-operation extended to the Inspectors, who carried out the Investigation, by the parties concerned and particularly those who survived the ordeal of that night.

Grateful acknowledgement is made to Sheffield University Metals Advisory Centre and Bureau Veritas for the research work associated with this accident. Also to the help received from Brugse Scheepssloperij NV Belgium, to whose facilities the salved stern half of the vessel was towed.

As will be clear, the actions both of the ship's own crew and of those in other ships responding to her distress and from ashore were in the highest traditions of the sea.

I am, Sir,
Your obedient servant

Captain P B Marriott
Chief Inspector of Marine Accidents

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1. SUMMARY

During the night of 4/5 December 1988 the suction dredger BOWSPRITE was bound from a position off Nieuwpoort, Belgium, towards the River Thames with a cargo of marine aggregate. Just before midnight, when about 15 miles NNW of Nieuwpoort, the bottom shell fractured. The weather was severe, with strong gale (force 9) westerly winds and very rough seas. The fracture occurred at about midships (half length) and quickly developed to the extent that the ship broke into two, the forward part sinking and the aft part remaining afloat.

Four of the crew of ten died as a result, while others suffered injuries.

An investigation was initiated immediately and, for expediency, was undertaken in two parts. The first part of the investigation reported in May 1989 and its principal conclusion was that the loss of the BOWSPRITE resulted from the structural failure of the steel hull of the ship. The second part of the investigation, to establish the reasons for the failure of the hull structure, included extensive research by Sheffield University Metals Advisory Centre (SUMAC) based chiefly upon examination of the salved after portion of the wreck, with testing and analysis of samples taken from it. Research was also carried out by the ship's Classification Society (Bureau Veritas).

Despite this research, the reasons for failure have not been fully established. It is, however, found that:

1. High stresses were generated in the region of frames 66 to 68 in the ship's bottom shell as a result of the motions of the ship when heading fully loaded into very severe weather conditions. It has not been possible to quantify these stresses due to the complexity of the local concentration and interactive stresses caused by the geometry of the structure, the intersection of welds and the shell plate wastage and pitting in the areas concerned.

2. The high stresses resulted in hull plate fractures being initiated and propagated in the bottom shell.

3. The primary source of initial fracture occurred in the bottom shell starboard in way of frames nos 66 and 67, and spread rapidly to the port side. Weakened by this fracturing, the ship broke completely in two.

Findings and Recommendations are summarised at Sections 10 and 11. The two principal recommendations are that:

1. The Department of Transport, Marine Directorate, should consider issuing UK dredgers of similar age and configuration with a "condition of operation" pending assessment of the findings of relevant individual surveys.

2. The Department of Transport, Marine Directorate, should sponsor a research project to establish the order of stresses likely to result in structural fractures and the conditions under which such stresses might occur.

PART I FACTUAL ACCOUNT

2. PARTICULARS OF SHIP AND CREW

2.1 BOWSPRITE

Port of Registry	:	Cardiff
Official Number	:	309332
Call Sign	:	GVLE
Keel Laid	:	8 July 1965
Completed	:	March 1967
Built by	:	Ailsa Shipbuilding Co Ltd Troon (Yard No 523)
Owners	:	East Coast Aggregates Ltd
Managers	:	South Coast Shipping Co Ltd
Classification	:	Bureau Veritas (classed with Lloyds Register until 4/3/87)
Gross Tonnage	:	1502.62
Net Tonnage	:	814.30
Deadweight	:	2156.79 Tons
Loaded Displacement	:	3292.00 Tons
Summer Loaded Draft	:	14ft 01½ins (4.306m)
Winter Loaded Draft	:	13ft 10ins (4.217m)
Freeboards	:	Summer 927 mm Winter 1016 mm W N A 1067 mm F W A 83 mm
Registered Dimensions	:	255.45ft x 44.35ft x 17.5ft
Length Overall	:	263.75ft (80.470m)
Type	:	Aggregate Suction Dredger with bridge and engines aft and raised quarterdeck
Sand Hold Capacity	:	33,000 cu ft (934.43 cu m)
Safety Class	:	VIII

Engine	:	1 Mirrlees 8 cylinder type KLSSDM 4-stroke Cycle Single acting. 1864 shp at 350 rpm (1390 kW) Speed 12.5 knots
Generators	:	2 x 165 kW 1 x 35 kW

(Annex 3 Figures 1 and 2 show the vessel whilst dredging and a plan of the vessel)

2.2 Certificates

(a) International Load Line Certificate (BV)
Issued 6.6.88 Valid until 5.3.92
Last Annual Survey : London 27.10.88
Valid only while vessel is engaged within the Near Continental Trading Area

(b) Cargo Ship Safety Construction Certificate (BV)
Issued 6.6.88 Valid until 5.3.92
Last Annual Survey : London 27.10.88

(c) Cargo Ship Safety Equipment Certificate (DTp)
Issued 14.10.88 Valid until 11.10.90

(d) Cargo Ship Safety Radiotelephony Certificate (DTp)
Issued 18.2.88 Valid until 16.2.89

(e) International Oil Pollution Prevention Certificate (DTp)
Issued 27.11.86 Valid until 24.11.91
Mandatory Annual Survey : 27.10.88

(f) Safe Manning Certificate
Not carried

(g) Inflatable Liferaft (10 man Dunlop No 3/28627)
Last service 12/87

2.3 Crew Onboard 4-5 December 1988

Master	:	Certificate of Competency Class 3 with Limited European Command Endorsement General Radio Telephony Certificate Aged 27
Chief Engineer	:	Certificate of Service Class 3 with Endorsement as Chief Engineer Aged 53
Chief Officer	:	Certificate of Competency : Master (FG) Aged 57
Second Mate	:	Certificate of Competency : Fishing Vessel Second Hand with Endorsement as Class 3 Aged 45

Second Engineer	:	Certificate of Competency Class 4 Aged 58
Third Engineer	:	Certificate of Competency Class 4 with Endorsement as Chief Engineer Aged 36
Able Seaman	:	Certificate of Competency AB Aged 63
Able Seaman	:	Certificate of Competency AB Aged 50
Extra Mate (Trainee Master)	:	Certificate of Competency Class 2 with Command Endorsement Aged 31
Cook	:	Aged 51

2.4 Navigational Equipment

(a) Magnetic Compass : Henry Browne "Sestral"

(b) Echo Sounder : Marconi "Seamark"

(c) Decca Navigator : Mk 21

(d) Radar : KH D.40

(e) VHF : Sailor RT144B

(f) Radio Telephone : KH Skanti TRP 2000

(g) Watchkeeper : KH Minch II

2.5 Life Saving Appliances

(a) Appliances sufficient for 10 crew

(b) Two (2) Class "C" GRP Lifeboats. Each 17 ft (4.91m) long with capacity of 17 persons each. Fitted with Columbus "Lum"/Crescent type davits.

(c) One 10 man Dunlop Inflatable Liferaft (No 3/28627) serviced 12/87.

(d) Eight Lifebuoys
2 fitted with combined light/smoke signals (man overboard)
2 fitted with lights
2 fitted with buoyant lines
2 plain

(e) Lifejackets - total 14 DOT standard

(f) 12 Parachute red distress rockets (Pains Wessex)

3. NARRATIVE
(NOTE : ALL TIMES IN THIS REPORT ARE GMT)

3.1 The BOWSPRITE had recently been employed dredging material from an area just south of the Shipwash in the approaches to the Thames Estuary. She had discharged a cargo of aggregate on 1 December 1988 at Nine Elms (River Thames) and loaded again at the Shipwash, this time for Nieuwpoort (Belgium) where she berthed at 0550 hrs on 3 December. She returned to the Shipwash area for a further cargo for Nieuwpoort and completed loading at about 2230 hrs on 3 December. It is estimated that she had taken on board about 945 cubic metres of aggregate, having a gross weight (including water content) of some 1930 tons; effectively a full cargo. The estimated draught was 13' 9", one inch less than her maximum winter draught.

3.2 BOWSPRITE's normal crew was 9: Master, two Mates, three Engineers, two Able Seamen and a Cook. On this voyage she also carried an extra Mate/Trainee Master, giving a total complement of 10. The Master had only been promoted about 2 months previously but he had served in dredgers for some 2½ years. All personnel were properly qualified.

3.3 Weather conditions during loading on 3 December were quite rough, with wind south-westerly, force 6, but not rough enough to cause concern. However the forecast was for more severe conditions with the wind veering westerly and increasing, occasionally to reach force 9. At 2300 hrs orders were received to divert to the River Thames because of the adverse weather, and at 0440 hrs on 4 December BOWSPRITE arrived at West Leigh Anchorage.

3.4 During the morning the weather improved and at 1040 hrs BOWSPRITE weighed anchor and began to return towards Nieuwpoort; but whilst she was on passage the wind strengthened again. At about 1945 hrs in the vicinity of the Nieuwpoort Bank West Buoy contact was made with the Pilots and it was established that the port was closed because of gale force winds. The Master reported the situation to owners, and at 2030 hrs received instructions to divert, again, to River Thames.

3.5 Before making the necessary alteration of course to carry this out, the ship was inspected and it was ensured that all access openings were secured. At this time the cargo was quite stable although a few stones were being lost via the spillways. The drain pumps were running continuously. The Master discussed the return voyage to the Thames Estuary with the Chief Officer, and decided to return the same way as they had come, via the Negenvaam Channel and the West Hinder Traffic Separation Scheme (TSS). They agreed that the vessel could cross the Kwintebank, providing that there was a charted depth of at least 6 metres, to assist the motion of the ship.

3.6 The Master left the bridge at about 2045 hrs, turning in at about 2115/2130 hrs. The Chief Officer was still officer of watch at this time with an Able Seaman at the wheel. The weather was now westerly with wind speed of 40 knots (force 8/9) and progress was slow as the BOWSPRITE was steering 260°M (variation 3½°W) and heading right into the weather. Some seas were coming on board at the break of the forecastle. These seas were not heavy, according to the Chief Officer, but enough to cause superficial damage. A ladder, which had been stowed on the bridge front, broke loose and the vessel was hove to so that it could be re-secured. Once this was done, speed was increased again to 280 rpm (full speed was 320 rpm).

3.7 BOWSPRITE reached the Nieuwpoort Bank Buoy at 2138 hrs and altered course towards the North. With the strong gale now on the port beam, and the tide setting NE'ly (High Water Nieuwpoort 2130 hrs : Neap tides) at rather less than 1 knot, she made good a course of about 010°T at nearly 7½ knots until 2200 hrs, when with the ship some 3 miles North of the Buoy the Second Mate took over the watch on the bridge. At the same time the Third Engineer took over in the engine room.

3.8 Soon after taking over the watch the Second Mate decided to cross over to the deep water of the Kwinte Channel. He therefore altered course to the North-West and crossed in the deep water south of the Kwinte Bank and then again altered course to the NNE up the middle of the Kwinte Channel towards the West Hinder Traffic Separation Lanes. The vessel reached the TSS and passed "A-Zuid" Buoy at 2310 hrs; she crossed the east bound lane on a 360°M course, and at 2320 hrs when about 1 mile south of "A-Noord" Buoy and in the West Bound lane, she altered course to 275°M.

3.9 BOWSPRITE was now heading right into the sea and the wind which was westerly at about 45/46 knots (force 9 strong gale). She was only making about 3 knots, and pitching and occasionally pounding into the head sea. Visibility was good and the lights of a number of ships could be seen clearly.

3.10 At about 2356 hrs a "bang" was heard by the Engineer on watch, followed by structural vibrations and soon after a second "bang". The engines then raced before cutting out. On the bridge, the Officer of the Watch heard a loud noise "like a tearing sound". The Chief Engineer, who was in his bunk reading, heard the first noise, which to him sounded like a "crack", after which he got up, then heard a second "crack".

The Officer on the bridge could now see a dark shape forward and switched on the floodlights to see that the forward section of the ship was sticking up steeply. The ship had broken her back.

3.11 Annex 3 Figures 3 and 4 are chartlets of the general area and the approaches to and from Nieuwpoort.

4. EMERGENCY ACTION : SEARCH AND RESCUE

4.1 The Second Mate rang "Stop Engines", sounded the General Emergency Signal and sent a short MAYDAY message by VHF. He checked the ship's position and the Master (who had come quickly to the bridge) sent a further MAYDAY saying that the ship had broken her back and was sinking in position 51°22'N, 02°35'E 3 miles west of "A-Noord" Buoy.

This distress call was immediately acknowledged by Ostend Radio, and logged by them at 0007 hrs on 5 December 1988.

4.2 Ostend Radio Broadcast a MAYDAY relay message at 0013 hrs and advised that they had despatched a helicopter, the tug ZEETIJGER and the lifeboat. This message was received by North Foreland Radio at 0017 hrs and relayed to Dover at 0018 hrs.

4.3 Having sent the MAYDAY call, the Master told the Extra Mate to launch the inflatable liferaft and then went to the starboard wheelhouse door and fired off one or two red parachute distress rockets. The Extra Mate, assisted by other members of the crew, successfully launched the liferaft, albeit with some difficulty in the existing conditions, and all hands then mustered wearing lifejackets. The Master sent a further VHF message confirming the position and reporting the action taken.

4.4 Further distress rockets were fired. The liferaft was in danger of being blown under the stern and several crew members attempted to pull it forward. All the crew at this stage were accounted for, but at approximately 0020 hrs or a few minutes later, the BOWSPRITE completely folded in two with both sections going nearly vertical. The sand grader at the break of the forecastle smashed into the wheelhouse top, the casings on the starboard side of the wheelhouse and the forward starboard lifeboat davit. Several survivors reported hearing the noise of the cargo rushing out of the hold. All lights now went out and the ten crew members were scattered.

4.5 The forward section of the BOWSPRITE then fell off to starboard, eventually broke clear of the stern, capsized and sank vertically some minutes later. The after section of the ship now returned to an almost even keel and floated. It seems that the engine room did not take water during this upheaval. (See Annex 3 Figure 5)

4.6 When the ship folded, the Master managed to grab and hang on to a lifebuoy rack until the ship returned to the upright.

The Chief Officer slid down the deck until he hit the starboard lifeboat winch where he jammed and managed to hold on.

The Cook was thrown against the rails just aft of the lifeboat and got tangled up with the rails and somehow managed to hang on although he was frightened that the stern was going to go straight down. It is probable that he sustained serious internal injuries at this time.

The Chief Engineer was swept into the water and could see both halves of the ship sticking up above him but managed to swim clear and bumped into the liferaft and managed to hang on.

The Second Officer slid on his back down into the water, going completely under and then bobbing up to the surface. He saw the bow section sink and then he drifted away. He was subsequently picked up by HMS UPTON at 0055 hrs. He suffered a broken right leg and damage to his right knee, plus extensive bruising to the body.

The Third Engineer fell forward and hit the starboard lifeboat davits hurting his thighs and left arm and then fell into the water off the starboard forward end of the boat deck. On entering the water, his lifejacket came over his head, but he managed to put it back on. He also found a lifebuoy and hung on to it. He drifted away from the wreck but was sighted by a Belgian helicopter and literally blown to HMS UPTON where he was picked up at 0126 hrs having been in the sea for about an hour.

4.7 The remaining four crew members unfortunately did not survive.

The bodies of the Second Engineer and one Able Seaman were picked up by HMS UPTON. Both had slipped out of their lifejackets and were hanging about a foot underwater.

The body of the Extra Mate/Trainee Master was washed ashore near Ostend on 8 December 1988. The body of the remaining Able Seaman has not been recovered.

4.8 When the after section of the BOWSPRITE returned to the almost even keel position, the three crew remaining on board picked themselves up and the Cook climbed inboard again, apparently having only just done so when the main mast crashed down over the starboard side in the position where he had been. The Master could hear voices shouting from close alongside on the starboard side and ran to the rail and threw over two lifebuoys including one with a light which burned brightly. He could see the Chief Engineer close alongside the liferaft. He was convinced that the after section would not remain afloat for long and ordered the Cook to climb down a mooring rope into the raft. He fell the last few feet but fortunately landed in the raft, and helped pull the Chief Engineer into the raft which was full of water. The raft was dangerously close to the upturned bow section of the ship and they tried to pull on the painter to keep clear.

4.9 The wind was now on the starboard side of the stern section and the raft was banging against the ship's side. In fact soon after getting into the raft the Cook had suffered further injury to his back when the stern came down on his back in the swell. He was very weak due to his injuries and exhaustion and the Chief Engineer kept talking to him to keep him going.

When the ship folded, the remaining distress rockets were lost and the Master and Chief Officer tried to find the pyrotechnics in the starboard lifeboat. As the ship was in darkness and the boat's gear was, naturally, completely disarranged they could not be found.

The Master could see ferries with searchlights on nearby and he made his way back to the badly damaged wheelhouse and tried the VHF set but with no success.

Returning to the starboard lifeboat the Master and Chief Officer found the liferaft painter caught round the keel chocks. They managed to pull the painter clear and then towed the liferaft round the stern and made it fast to the bitts on the port quarter so that the liferaft was clear of the wreck.

4.10 There were by now a number of vessels standing by including the ferries PRIDE OF BRUGES and OLAU HOLLANDIA who were illuminating the area with their searchlights. The British Minesweeper HMS UPTON was acting as "On-Scene Commander".

The first Belgian helicopter arrived on the scene at about 0045 hrs and quickly lifted off from the stern first the Chief Officer and then the Master, who directed the helicopter to the liferaft astern of the wreck. Both men in the raft were winched to safety, although the Cook was now in a very bad way. The helicopter searched further for a while and then flew directly to the hospital in Bruges and landed the four survivors.

4.11 At about 0130 hrs a Belgian helicopter winched down a doctor to the deck of HMS UPTON who assisted the warship's medical team in treating the Second Officer and the Third Engineer who had by now been picked up. At 0210 hrs the starboard shaft of HMS UPTON was fouled by a mooring rope from the wreck forcing her to shut down the starboard engine. She continued to operate on one engine.

At 0250 hrs the Second Mate and Third Engineer and the Belgian doctor were lifted off HMS UPTON by helicopter and flown to hospital at Bruges.

Meanwhile HMS UPTON had picked up two bodies at 0109 hrs and 0140 hrs. Both had slipped out of their lifejackets and were hanging about a foot underwater. The bodies were subsequently identified as those of the Second Engineer and an Able Seaman.

4.12 Back at hospital in Bruges, the Cook was operated on at about 0800 hrs for a ruptured spleen and severed urethra whilst the Second Mate's broken leg and smashed knee was operated on two days later when the swelling had decreased.

The other survivors were flown home to Southampton later in the day (5 December 1988).

HMS UPTON arrived at Dover at 1450 hrs on the same day and landed the two bodies to the care of the Coroner's Officer where they were identified by a relief Master of the BOWSPRITE.

4.13 The Second Mate returned by ferry to Hull where he underwent further hospital treatment. The Cook was returned by ambulance and ferry on 16 December 1988 and taken to hospital for further treatment.

4.14 The body of the Trainee Master was washed ashore near Ostend on 8 December 1988. The body of the second Able Seamen has not been recovered.

PART II CONSIDERATION OF POSSIBLE FACTORS

5. WEATHER

5.1 The weather in early December was dominated by a series of depressions and their associated frontal systems. Each of the four Meteorological Office shipping forecasts broadcast by the BBC on 4 December began with gale warnings for all areas except Trafalgar and South East Iceland. A vigorous low off Western Scotland early on that day moved east and a Wave Depression developed on its accompanying Cold Front and affected the Southern North Sea. An Atlantic low, deepening and moving rapidly east, was approaching the English Channel.

5.2 The morning shipping forecast issued by the Met Office at 0505 hrs on 4 December 1988 (broadcast by the BBC at 0555 hrs), while the ship was at the West Leigh Anchorage, gave for sea area Thames:-

"South West veering West 7 to severe gale 9. Showers.
Good [visibility]"

The forecast at 1305 hrs (broadcast at 1355 hrs), by which time BOWSPRITE was on passage, was similar.

For sea area Dover the forecasts were, at 0505 hrs:-

"South West veering West 6 to gale 8, occasionally severe gale 9, decreasing 5 or 6 later. Rain or showers. Moderate or good [visibility]"

and at 1305 hrs:-

"West or South West 7 to severe gale 9, but storm 10 for a time, veering North West later. Rain or showers. Moderate or poor [visibility]"

Nieuwpoort is near the border between areas Dover and Thames, but just within the former.

5.3 At 1700 hrs (broadcast at 1750 hrs) the forecasts were, for Thames:-

"West or South West veering North West 7 to severe gale 9.
Showers. Moderate or good [visibility]"

and for Dover:-

"West veering North West 7 to severe gale 9 occasionally storm 10. Rain at times. Moderate or poor becoming good [visibility]"

5.4 The late evening forecast, issued at 2343 hrs and broadcast at 0033 hrs on 5 December was, for Thames:-

"West veering North West 7 to severe gale 9. Showers.
Moderate or good [visibility]"

and for Dover:-

"Westerly veering North Westerly 7 to severe gale 9, decreasing 5 for a time. Rain or showers. Good becoming moderate or poor for a time [visibility]"

5.5 The entries in the ship's deck log for weather on 4 December 1988 after leaving West Leigh were:-

1200 hrs Wind West, 10 knots [force 3 to 4], rippled sea, visibility 3 miles, barometer 993 millibars.

1600 hrs Wind South West, 35 knots [force 8], rough sea, visibility 10 miles, barometer 995 millibars.

The last entry in the ship's deck log recording weather, for 2000 hrs on 4 December, shows the wind as Westerly, 40 knots [force 8/9], sea very rough, visibility 10 miles plus, barometer 999 millibars. Evidence from ships engaged in the rescue suggests if anything some increase in wind speed by the time they reached the scene, to a full force 9 - some 45 knots. This is broadly in accord with the conditions to be expected from the synoptic situation, the Meteorological Office hindcast prepared after the event suggesting for midnight 4/5 December:-

Wind Westerly force 8, resultant wave height 3-4 metres, and good visibility.

The slight discrepancy is well within the range commonly found between observed and deduced conditions.

5.6 The actual height of individual waves will, as is normal, have varied greatly, and some will have been well in excess of the "resultant" figures quoted. The resultant wave approximates to the significant wave, whose height is the mean height of the largest 1/3 of all the waves. Over an appreciable period it is likely that a small number of waves will be as much as twice the significant height, and even greater waves will occasionally occur. Moreover, it is common experience that in the relatively shallow and constricted waters of the Dover Strait and Southern North Sea, with a Westerly wind blowing up the English Channel, closely spaced steep waves build up quickly in even moderately severe conditions causing a very nasty sea to develop.

6. THE SHIP'S ACTIONS

6.1 The entrance to Nieuwpoort is open to the North and West and the Port is not infrequently closed with strong winds from those quarters. However, it will be seen that, at the time of the decision to leave West Leigh Anchorage, there had been a considerable improvement in the weather; and although the forecast, and the weather pattern - with a depression to the North and another approaching from the West - indicated that the improvement would not last long, it was reasonable to hope that it would suffice to allow the vessel to enter Nieuwpoort when she arrived there, (the passage distance is approximately 90 miles). The morning forecasts quoted at Section 5 above for sea areas Thames and Dover are by no means out of the ordinary and would certainly not require a well found vessel of BOWSPRITE's size not to attempt the passage, especially as that for Dover promised winds decreasing to force 5 to 6.

6.2 The forecast at 1305 hrs on 4 December 1988, though similar for Thames, was significantly different for Dover: there was now no mention of a decrease in wind strength and indeed on the contrary it gave "storm force 10 for a time". By this time the ship was on passage; no doubt the Master will have considered returning to shelter, but the actual weather was still moderate and his decision to continue the passage in the reasonable hope that Nieuwpoort would be reached before the storm developed was justifiable.

6.3 By the time the Master learnt that Nieuwpoort was closed, the ship was approaching the port and was on a lee shore. The decision to return to the Thames was in accordance with good seamanship in gaining sea room and taking the ship clear of the coast: the weather was now bad but neither the actual nor the forecast conditions were such that serious hazard to the ship would be anticipated in the open sea. No fault can be found with the decision to head away from the shore and back towards the Thames.

7. RESEARCH INTO CAUSE OF FRACTURE

7.1 The aft part of the BOWSPRITE which remained afloat after the accident was eventually slipped at the yard of Brugse Scheepssloperij NV in Bruges, Belgium, (see Annex 3 Figures 6 and 7). This part of the ship was inspected on the 22-23 March 1989 in company with the representative from Sheffield University Metals Advisory Centre (SUMAC).

7.2 A number of structural samples were selected and cut from the bottom shell of the aft part of the ship in way of the fracture. These were delivered to SUMAC for laboratory investigation.

7.3 The aft part of the ship was subsequently broken up for scrap; the forward part of the ship has not been salvaged.

7.4 The results of SUMAC's laboratory examinations and tests indicate that:

7.4.1 The initial fracture of the BOWSPRITE's hull occurred in the bottom shell on the starboard side in the region of frames 66 to 68, that is just forward of the mid length.

7.4.2 Two sources of initiation of fracture are identified as the possible primary source of fracture. In both areas it is not possible to quantify the order of stress which resulted in the structure fracturing. This is due to:

1. The unknown residual stresses built into those areas as a result of the intersection of the longitudinal and transverse structural welds.

2. The difficulty in assessing the loading stresses in way of the changes in geometry of the structure and the effect of the wastage and pitting which was present in the shell plates.

3. The source of fracture in both instances took place in weld metal, the fracture properties of which are unknown.

7.4.3 The surfaces of the fractures in the bottom shell were undamaged. This suggests that the fractures occurred instantaneously as a result of single applications of load and that their surfaces remained separated after fracture.

7.4.4 The sources of brittle fracture identified in the bottom shell had propagated both port and starboard of the probable primary initial source of fracture. However, the overriding direction of propagation was from starboard to port through the keel structure.

7.4.5 After the bottom shell structure had fractured, the top plates of the double bottom structure (tank top) were bent upwards about a transverse axis in the region of frames 66 to 68. This resulted in a brittle fracture of the tank top in the region of frame 66 on the starboard side and frame 68 on the port side.

7.4.6 With both the bottom shell and the tank top structure now fractured, the resistance of the ship's hull to further longitudinal bending moments was destroyed, with the result that the structure failed completely and the ship folded in two.

7.5 Extracts from the SUMAC Report are at Annex 1.
It will be seen that the researchers:-

7.5.1 report on their analysis of the material and welds in the bottom shell, the general overall conclusion being that they were of an acceptable quality and standard;

7.5.2 refer to wide steel plate tests reported on in relevant technical literature, suggesting that stresses of the order of 90N/mm^2 are necessary for the propagation of brittle fracture;

7.5.3 express the opinion that given that some parts of the early stages of fracture were ductile shear fractures, nominal stresses in excess of 90N/mm^2 might have been required to develop the large scale fracture that occurred in this case;

7.5.4 state that it is not possible to make a satisfactory estimate of the stresses necessary to initiate fracture. The reasoning behind this statement is dealt with in para 7.4.2 above;

7.5.5 state that brittle fractures of the structure would have been accompanied by "loud" reports, of an intensity dependent on the level of stress and the size of the fracture developed and various lesser reports would have occurred as new sources of fracture were initiated and the overall fracture of the hull propagated. However, the loudest reports would have occurred when the keel and the tank top plates fractured.

7.6 Bureau Veritas, as the classification society under which the BOWSPRITE was classed, undertook two studies subsequent to the accident into the longitudinal strength properties of the BOWSPRITE and her near sister ship of similar age, BOWBELLE. Extracts from their reports are at Annex 2.

7.7 The Bureau Veritas studies used:-

the BV Rules to estimate the still water bending moment for the loaded ship, together with:

the midships section modulus, calculated for the structural thicknesses as measured during the January 1987 survey of the BOWBELLE. Ultrasonic readings had been taken on board the BOWSPRITE in March 1987 giving comparable readings to those of the BOWBELLE. The thicknesses were modified as necessary to reflect actual bottom structure measurements of the samples taken from the BOWSPRITE aft section after the accident; and

the BV Rules to estimate a wave bending moment for a wave height having a probability of occurrence of 10^{-5}.

7.8 The studies concluded that:

7.8.1 "breaking of the ship cannot be due to insufficient design scantlings."

7.8.2 "calculations according to reduced thicknesses cannot explain the breakage of the vessel, if we consider that BOWSPRITE's remaining scantlings were equivalent to those measured on the BOWBELLE"; and

7.8.3 the stress levels and all the longitudinal strength criteria calculated using the estimated structural thicknesses for the time of the accident comply with the Bureau Veritas Rule requirements for "Deep Sea" notation, at deck and bottom.

7.8.4 the BV calculations indicated that the stress in the hull bottom of the ship would be of the order of 75N/mm^2 while stress in the weather deck could be 112N/mm^2.

7.9 Using the figures calculated by Bureau Veritas for still water bending moment and modulus, but including a 'maximum' value for the wave bending moment (as allowed in the Bureau Veritas rules para 3.34.31 of Part II-A Hull Structure), ie for a wave probability level of 10^{-8} rather than 10^{-5}, a hull bottom stress estimate of the order of 90N/mm^2 results.

It will be seen that this broadly equates to the figure quoted by SUMAC as that which might be required to develop the fracture.

7.10 The likelihood of BOWSPRITE having encountered very large waves is discussed in Section 8.5 below. The 10 metre wave suggested there as a possibility is of the same order in size as the 10^{-8} wave referred to by Bureau Veritas, or at any rate only very little less, even though the theoretical probability quoted in Section 8.5 is 1:300,000. The discrepancy is not as significant as might appear: firstly because it is not only the height of waves which is important, but also their length (between crests) and steepness; and secondly because, whichever figure is taken, such a wave is unlikely but not impossible.

PART III FURTHER DISCUSSION

8. CAUSE

8.1 Major structural failure of a ship is most probably caused by one of the following, either singly or in combination:

1. Collision, grounding or explosion
2. Improper distribution of cargo
3. Gross overloading
4. Structural weakness, either inherent or developing with age
5. Exceptional weather and sea conditions

8.2 In the present case, there was no collision or explosion, and there is no evidence to suggest contact with the bottom. Further, because of the depth of water when the accident happened, any such contact would have had to take place appreciably before the fractures occurred and the evidence is against any significant delay between cause and effect; see Section 7.4.3.

8.3 The cargo was distributed normally, which with vessels such as BOWSPRITE means that there was a concentration of weight amidships. Such ships are designed to allow for this. With the vessel at about her winter marks, deadweight was within the maximum designed load.

8.4 Inherent weakness can be ruled out, both because of the research findings and because the vessel had operated successfully for many years. Weakness developing with age is discussed further below.

8.5 The weather was severe but not exceptional; the ship must often have experienced as bad or worse conditions. However, this fact does not exclude the possibility of exceptional seas. As mentioned briefly in Section 5.6, much greater waves than the general run can occur in any seaway: to be more specific, by theory one wave in 1175 is over three times the average height and one in about 300,000 exceeds four times the average*. The validity of this theory, at any rate in broad terms, is borne out by experience. This could mean a greatest wave in the conditions at the time of the accident of some 10 metres height. Clearly, a ship could steam for several hundred hours in severe weather before encountering such a wave but equally clearly, one could be met at any time.

Moreover, an exceptionally large wave does not usually occur in complete isolation but rather as the greatest of a group. At the time of the accident BOWSPRITE was heading almost directly into the weather, and so will have been subject to the greatest possible stress when between the crests of successive waves.

* Statistics of a Stationary Random Process: see L Draper, Oceanus, Vol 10 No 4, Page 13 et seq.

8.6 Nonetheless, waves very much higher than 10 metres are recorded in bad weather and are successfully withstood, so it is necessary to look further at the ship's fitness. BOWSPRITE had been built under survey to recognised classification standards, her shell being constructed with riveted seams and welded butts. Renewal surveys had been regularly carried out under proper supervision by her owners and the Classification Society, and repairs to, and renewals of, shell plates and associated structures had been made as necessary; the shell plate steel and the welding were shown by analysis of the samples taken from the salved portion to be of suitable quality and standard. Nevertheless, she was 23 years old and her life had been passed in a hard-working trade and in the frequently hostile environment of the waters around the British Isles and near continent. Examination of the salved portion showed wastage and pitting in varying degrees. This is to be expected in an old ship, and it should be said that the point of initiation of fracture most favoured by the researchers was not the most seriously wasted region. Vessels are designed and constructed in such a way that there is sufficient structural integrity to allow for natural wastage of steel due to corrosion over their life. However, overall the vessel cannot have had the same strength as she had when new. The wastage and pitting, together with the geometry of the structure and the probable residual internal stresses caused by the intersection of longitudinal and transverse structural welds, may have resulted - if the vessel, in loaded condition, was sagged between two very large waves - in local concentrations of stress beyond those which could be withstood.

8.7 Records show that the main deck starboard, in way of the midships dredge davit was buckled sometime in early 1988. It is understood that this buckling occurred as a result of the suction pipe being heavily reseated and that it was examined with a view to repair being made during the ship's refit and survey period in April 1988. In the event such repairs were not undertaken.

While some local transfer of stresses might be anticipated, it is not considered that this buckling could have led directly to the hull failure; the SUMAC Report positively finds that failure originated in the bottom hull plating.

8.8 To summarise, despite the extensive research which has been undertaken, the reasons for the fracture which led directly to vessel's loss and thus the loss of life, are still not fully explained. In considering the most likely cause, the following factors are considered significant:-

8.8.1 The sequence of events preceding the accident; the recollections of survivors; and the results of the metallurgical and mechanical examination and testing of samples of the salvaged stern section have an identifiable correlation, and point to sudden, virtually instantaneous, failure.

8.8.2 The weather, though not exceptional, was severe enough to have caused random very high waves possibly of a height of some 10 metres; BOWSPRITE may have encountered two or three such waves in rapid succession.

8.8.3 The ship was fully loaded so that there was a concentration of weight amidships.

8.8.4 The geometry and method of construction (including repairs carried out over the years) will inevitably have led to local stress concentration.

8.8.5 Wastage and pitting of the structure must have led to some loss of strength as compared with that of the ship when new.

8.9 None of the factors mentioned in 8.8.2 - 8.8.5 above would singly have led to the fracture. It is considered however that they acted in concert, and that the most probable explanation is that the ship, heading almost directly into the weather, encountered two successive very large waves so that she was momentarily sagged between them; and the concentration of weight amidships acting with in-built stress upon an ageing hull, led directly and immediately to catastrophic failure.

9. RESPONSE TO THE EMERGENCY

9.1 The Search and Rescue operation was well handled and had it not been for the sudden violent folding together of the two halves of the BOWSPRITE all ten crew would have probably been rescued, despite the very severe weather. Special mention must be made of the Belgian helicopter crews who showed skill and courage in lifting the survivors to safety and also of the Belgian doctor who was lowered on to the deck of HMS UPTON to give treatment to the injured survivors.

9.2 The British Minesweeper HMS UPTON assumed the roll of on-scene commander and was handled with great skill by her Commanding Officer throughout. Four of her crew entered the water in extremely hazardous conditions to recover the exhausted survivors.

9.3 The Belgian lifeboats R2 from Nieuwpoort and R4 from Ostend stood by the wreck in very severe conditions as did the Dutch tug ZEETIJGER.

9.4 Various merchant vessels assisted at the scene but particular mention must be made of the West German Ferry OLAU HOLLANDIA and the British ferry PRIDE OF BRUGES who illuminated the wreck and area with their searchlights and assisted in ship to shore communications.

9.5 The crew of BOWSPRITE clearly conducted themselves with calmness and courage during their ordeal, and the Master acted throughout in exemplary fashion. His immediate actions when the accident first occurred were right, and even after his rescue he continued to help the helicopter crew search for further survivors. The actions of the Cook, in helping the Chief Engineer into the liferaft despite his own very serious injuries; and that of the Chief Engineer in succouring the Cook thereafter, were especially praiseworthy.

9.6 It is disturbing that two of the bodies recovered had partially slipped out of their lifejackets, and one man who survived reports that his lifejacket "came over his head" though he managed to pull it back on. It would seem that in all those cases the neck tapes of the lifejackets (which were of the standard pattern) had not been properly secured. Both the deceased had suffered severe injuries and might not have survived even had they remained fully supported by their lifejackets; nonetheless, the importance of tying both waist and neck tapes tightly is clearly emphasized.

9.7 There were weaknesses in communications during the SAR operation, especially in that the helicopters could not communicate directly with the ships. The equipment of the helicopters is clearly a matter for the Belgian Authorities who will no doubt consider whether any additional fitting is required; in any case it is not considered that the shortcoming reduced the effectiveness of the helicopter crews' contribution to the operation, nor does it detract from the skill with which they carried it out.

PART IV CONCLUSION

10. FINDINGS

The investigation was undertaken in two parts. The first part was initiated immediately after the accident occurred and the Inspectors reported in May 1989, and their principal conclusion was that the loss of BOWSPRITE resulted from the structural failure of the steel hull of the ship.

The second part of the investigation, to establish reasons for the failure of the hull structure, included extensive research by Sheffield University Metals Advisory Centre (SUMAC) based chiefly upon examination of the salved after-portion of the wreck, with testing and analysis of samples taken from it. Research was also carried out by Bureau Veritas, the ship's Classification Society. Despite this research, the reasons for failure have not been fully established.

I consider the findings of the Inspectors who carried out the investigation which are given in this section of the Report are a true reflection of the actual events which occurred on that night.

10.1 BOWSPRITE suffered a major structural fracture at about 2356 hrs GMT on 4 December 1988, in approximate position 51°23'N, 2°32'E, that is some 15 miles NNW of the port of Nieuwpoort, Belgium.

10.2 At about 0020 hrs on 5 December, or shortly thereafter, the vessel broke completely in two. The fore-part sank; the after part was salvaged.

10.3 When the vessel broke in two, seven of her crew of ten were thrown into the water. Of these seven, four were lost: the Extra Mate/Trainee Master, the Second Engineer and two Able Seamen.

10.4 Despite the partial salvage, the ship became a total loss.

10.5 The loss of four lives; and the loss of the ship, resulted from the structural failures.

10.6 The weather at the time of the accident was severe, with winds of force 9 (severe gale). The weather had been correctly forecast by the Meteorological Office. When fracture occurred, the ship was in the westbound lane of the West Hinder Traffic Separation Scheme and was heading almost directly into the weather.

10.7 The vessel had been bound for Nieuwpoort but was unable to enter the harbour as it was closed because of the bad weather. At the time of the accident she was making for the Thames; the decision to clear the coast (which was a lee shore) and attempt to reach the open sea and then the shelter of the Thames estuary was proper and seamanlike. Although the weather was bad, it was not exceptional and there was no reason to expect that it would seriously endanger the ship once she was clear of the coast.

10.8 BOWSPRITE was properly certificated and was manned with a sufficient number of correctly qualified personnel. The ship had been properly maintained with regular surveys and, so far as can be ascertained, repairs as they became necessary had been correctly carried out. But she was 23 years old and some deterioration, leading to reduction in structural strength relative to her condition when new, was inevitable.

10.9 The ship was loaded, almost to her winter marks. She was not overloaded.

10.10 It has not been possible, despite extensive research, to establish positively the reasons for the fracture. The most probable explanation is that the ship, heading almost directly into the weather, encountered two successive very large waves so that she was momentarily severely sagged; the concentration of the weight of the cargo amidships acting with in-built stress upon an ageing hull, led directly and immediately to catastrophic failure.

10.11 The Master and crew of the ship conducted themselves in exemplary fashion, and the Search and Rescue operation was carried out with skill and courage in very adverse conditions.

11. RECOMMENDATIONS

The first part of the investigation, which is referred to in Sections 1 and 10 of this Report, resulted in the near sister ship to BOWSPRITE being examined at her next dry-docking, which further resulted in that vessel being restricted in her area of operations. This restriction, though modified, is still in force.

Completion of the full investigation does not in my opinion merit the lifting of this restriction, but results in a further examination of other UK registered dredgers. This is provided for in Recommendations 1 and 2 which follow in this Section.

The research carried out by SUMAC as a component of the second part of the investigation, indicated that two sources of initiation of fracture were identified as the possible primary source of fracture. (See Section 7.4 and Annex 1). They further stated that it is not possible to make a satisfactory estimate of the stresses necessary to initiate fracture, (see Section 7.5.4 and Annex 1). It has not been possible to establish positively the reasons for the fracture which resulted in the loss of the vessel, therefore if the correct measures are to be taken to prevent this type of accident happening again it would be prudent to undertake research to identify what order of stresses cause fracturing to occur and develop in some ship structures. With this in mind Recommendation 3, which follows, is made.

1. Pending the receipt of the reports of survey referred to in Recommendation 2, case by case consideration should be given by the Department of Transport, Marine Directorate, to the issue of a "Condition of Operation" to each UK registered dredger of similar configuration and age to the BOWSPRITE.

1.1 The condition should detail the allowable weather during which each ship may be operated and should include advice on the actions to be taken if severe weather conditions are encountered, particularly when the ship is fully loaded.

1.2 The condition should be attached to the ship's loadline certificate.

1.3 In forming the condition, account should be taken of the content of this Report to the extent that is appropriate to the particular ship and her area of operation.

2. A suitably detailed structural survey should be undertaken on each of the UK ships referred to in paragraph 1 above as soon as is practicable.

2.1 The surveys should be suitably specified and be undertaken by recognised surveyors from either Marine Directorate or a recognised classification society.

2.2 After due consideration by the Department of Transport, Marine Directorate, of the report of each of these surveys, in parallel with the ships longitudinal strength details, a decision will need to be made as to whether the "condition of operation" recommended in paragraph 1 should be continued or cancelled.

It is appreciated that proposals to "improve/make good" some existing part-rivetted part-welded ship structures could worsen rather than improve matters, in that in-built stresses might increase. In such cases 'conditions of operation' might be kept in force for the remaining life of the ships concerned.

3. A research project which should include ship forms and structural configurations other than those representative of dredgers should be sponsored by the Department of Transport, Marine Directorate, to establish:

3.1 The order of local stresses which would be likely to initiate and propagate fractures in structures representative of typical construction methods and the materials used, and;

3.2 The operational procedures, conditions of loading, weather, and structural deterioration which might result in such stresses occurring.

The project should be undertaken in close liaison with the recognised class societies so that their expertise and experience in respect of ship structures and their analysis is fully utilised.

REPORT BY SHEFFIELD UNIVERSITY METALS ADVISORY CENTRE (SUMAC) - EXTRACTS : INTRODUCTION, DISCUSSION AND SUMMARY

Investigation of the Failure of the Dredger "BOWSPRITE"

1. INTRODUCTION

The vessel BOWSPRITE fractured transversely, approximately at midships in heavy weather on 5 December 1988. The stern part of the vessel remained afloat and was eventually slipped at a breakers yard in Bruges, Belgium. This part of the vessel was inspected on 22-23 March 1989 in company with a Principal Ship Surveyor from the Department of Transport.

A number of samples were cut from the vessel and these were delivered to SUMAC for laboratory investigation.

6. DISCUSSION

6.1 The field examination and laboratory investigations lead to the general conclusion that the failure of the vessel was caused by a fracture of the bottom on the starboard side, at the weld line between frames 66 and 67.

Subsequently the bottom fracture progressed on the port side along the line of frame 67. The critical event would have been the sudden fracture of the keel plate, which would have been accompanied by a loud report. After the failure of the bottom, the tank top appears to have been intact, but bending of the plates of the tank top (about a transverse axis in the region of frames 66, 67) caused a large scale brittle fracture of the tank top. With the complete fracture of the bottom and the tank top, the vessel was effectively lost.

6.2 We turn now to enquire as to what was the initiating event and consider firstly the sources of brittle fracture discovered during the laboratory investigations.

6.2.1 The source of brittle fracture in the keel plate (Annex 3 Figures 8 and 9) is associated with a ductile shear fracture of the first 200mm on the starboard side of the plate. The detailed configuration of the chevron markings on the fracture surface at the source of brittle fracture leads firmly to the conclusion that this brittle fracture initiated at mid-thickness of the plate and extended to port. It is therefore a continuation of the ductile fracture at the starboard side of the plate. Thus this brittle fracture of the keel plate cannot be the event that initiated the fracture of the bottom.

6.2.2 The source of brittle fracture at the overlap of the plates B7 and A7 (Annex 3 Figures 10 and 11) is on the bottom of the A7 plate at the junction of the transverse butt weld (joining plates A7 and A8) and the longitudinal fillet weld at the edge of B7. The fracture markings show growth both to port and starboard.

In the port direction the brittle fracture runs out of the weld after 160mm and becomes a ductile shear fracture in the A7 plate itself. In the starboard direction the brittle fracture runs to the edge of the A7 plate. (See Annex 3 Figure 11).

The fracture in B7 is complex. In the wasted region on the port side fracture is brittle for 300mm, and then shear fracture through the remaining 350mm. The central region of the plate where the wastage is small has a brittle fracture, with a clear indication that fracture has passed from port to starboard. The remainder of the fracture, to the starboard side of the plate in the wasted region, is a shear fracture. There is no definite indication of a source of fracture within this plate, although it is possible that brittle fracture initiated at the welded longitudinal angle near the centre of the plate.

Fracture of C7 follows the weld for 950mm and is generally brittle. There are two small regions where chevron markings can just be discerned which suggest that there is a source of fracture within the plate. For the remaining 750mm fracture follows the line of rivet holes at frame 67 and is generally ductile. There is a short length of brittle fracture between two rivet holes, where the chevron markings show that fracture has passed from port to starboard.

6.2.3 It is not possible to deduce the exact sequence of events in the fractures of the bottom plates from the evidence obtained from a study of the fractures.

The fracture of A7 (starboard) at the rivet holes and the initial part of the fracture of the keel plate both show considerable ductility and therefore are likely to be the last regions to fail before the brittle fracture of the keel plate. We cannot envisage such a ductile failure <u>before</u> the failure of C7, B7 and the initial part of A7, where ductility is more limited.

There is no evidence to indicate whether or not the brittle fracture in A7 in the region of the overlap has resulted from the fracture of B7, or has caused the fracture of B7.

The outstanding feature of B7 is the heavy wastage in the region of the weld, on the port and starboard sides of the plate. The wastage will have resulted in some increase in the general level of stress, but more importantly the altered configuration at the weld will have acted as a stress concentration, and therefore have significantly increased the local stress levels in the wasted regions along the line of the weld. Here then is a possible reason for the initiation of fracture. The fracture in the wasted region at the port edge of the plate is brittle for 300mm (nearest the A plate) and then a ductile shear for 300mm. Further to starboard, in the region of the welded longitudinal angle, where severe wastage is absent the fracture is brittle. It is unlikely that the brittle fracture in the wasted region has led to brittle fracture at the longitudinal angle because of the intervening ductile shear. There are however, no indications on the fracture in the wasted region that give any indication as to the direction of movement of fracture.

There is another possible source of fracture in plate B7. Near the centre of the plate, is welded longitudinally a piece of 70 x 70mm angle. In this region wastage is small, and the fracture of the plate is brittle. Where the longitudinal weld crosses the transverse plate weld is also a region of stress concentration and internal stress, and the situation is typical of the type of detail that have in the past led to the fracture of ships plates. The fracture indications in this region are, as above, insufficient to indicate the direction in which fracture travelled, or the source of fracture. The only certain indication of the direction of travel is where the brittle fracture runs into the parent plate for a short distance, where the fracture has grown from port to starboard.

Plate C7 shows much less wastage than B7, although there is some severe pitting. Fracture follows the weld for 800mm from the port side of the plate and is generally brittle. Fracture markings suggest a source of fracture between 300 and 500mm from the port edge. It should be noted that the maximum wastage is some 20mm from the weld and therefore there is no severe stress concentration at the weld, except at the overlap with plate B, where there is a longitudinal weld. It is possible that fracture of this plate initiated at this point. We also note a clear indication near the starboard edge of the plate that fracture has proceeded to starboard.

6.3 Our interpretation of the sequence of events is based on the following significant features:-

(i) Fracture in the B and C plates, and in part of A follows the line of the transverse weld. This fracture is partly brittle and partly ductile.

(ii) The places where longitudinal fillet welds intersect the transverse butt welds are associated with regions of brittle fracture. Thus the overlaps at A/B and B/C, and the longitudinally welded angle near the centre of plate B are all connected with regions of brittle fracture. These fractures are essentially undamaged (that is to say the mating fractures have not worked against each other).

(iii) Where fracture "runs" out of the weld (and the associated heat affected zone) near the starboard extremity of plate C8, and in plate A7, fracture is a ductile shear, and this is compatible with the relatively high toughness of these plates.

(iv) The brittle fracture of the keel plate is consequent on the ductile fracture at its starboard extremity.

Fracture, in our opinion is most likely to have initiated in plate A at the overlap with plate B (at the identified source of brittle fracture) or at the longitudinally welded angle near the centre of plate B. In both cases longitudinal and transverse welds intersect, giving a complex pattern of internal stress, and in both cases there exist stress concentrations due to the geometrical situation. In as much as these appear to be more severe in plate A at the overlap, initiation at this point is the more likely.

However, in both regions, the fracture surface appears to be undamaged, that is to say the mating fracture surfaces have not been in contact after fracture occurred. This suggests that the fractures have occurred during a single application of load, which led to the extension of these fractures across the B plate to the C plate, and across the A plate. At this stage the vessel would have had a crack nearly 3m long. Further extension of the crack along the line of rivet holes at frame 66 (of plate A7) was accompanied by significant local deformation, as was the initial part of the fracture in the keel plate. Brittle fracture of the keel plate then took place, followed by the failure of the port side bottom. The resistance of the vessel to bending movements was now severely reduced and deformation and fracture of the tank top was inevitable. The complete failure of the vessel then ensued.

Other interpretations of the earliest events may be possible. Thus it may be supposed that the initial fracture was in the severely wasted region at the port side of plate B. We consider this unlikely to be the first significant event since extension from this region to starboard involved 300mm of ductile shear fracture before reaching the longitudinally welded angle where brittle fracture took place. It is also difficult to envisage how fracture in this wasted region led directly to the brittle fracture in the A plate.

It is not possible to make a satisfactory estimate of the stresses necessary to initiate fracture, or to propagate it. The geometrical situation is complex, and the state of residual stress is unknown (in the regions of the intersecting welds). Furthermore, the fracture in the regions of initiation have taken place in weld metal of unknown fracture properties.

Wide plate tests reported in the literature suggest that stresses of order $90N/mm^2$ are necessary for the propagation of brittle fracture. Bearing in mind that some parts of the early stages of fracture are ductile shear it seems likely that nominal stresses in excess of $90N/mm^2$ might be required to develop a large scale fracture in the bottom of the vessel.

6.4 The chemical analyses and mechanical properties of all samples investigated conform to BS 4360, Grade 40A and we have found no inferior material that could have in any way contributed to the initiation of failure of the vessel. Indeed, the early stages of failure all took place at welds (or immediately adjacent thereto) where the mechanical properties would undoubtedly have been different from those measured.

The weldability of the plates was satisfactory (as judged from the calculated values of the carbon equivalents), and we have found no indication of weld cracking, nor any evidence of unduly high hardness in the heat affected zones of the welds. All the sections of welds that have been made show some distributed porosity, but not of a severity to influence significantly the properties of the weld. The microstructures of the sections taken were satisfactory.

The keel plate, the tank top and plate C7 all had low values of toughness at 5C (less than 15J, CV). The low toughness of C7 is not relevant, since fracture was largely in the region of the weld. The low toughness of the keel plate undoubtedly gave rise to the brittle fracture of the keel plate, but since a ductile fracture had already grown 220mm into the plate, it is unlikely that an improved toughness of the keel plate would have prevented its fracture. An improved toughness in the material of the tank top may have influenced the course of events. Bearing in mind the heavy weather, it is not possible to predict whether it would have prevented the complete fracture of the hull.

Low values of toughness in hot rolled mild steel are not unusual, and are more likely in thicker plate. Unless the toughness of the plate is specified in the original order, the buyer must take it as it comes. Thus unless toughness was specified in this case, the metal of the plates must be regarded as satisfactory.

6.5 Brittle fractures are accompanied by loud reports, of an intensity depending on the level of stress and the size of the fracture. Thus, the fracture of B7 and A7 would have been accompanied by relatively small reports, the fracture of C7 by a louder report, and the fracture of the keel plate by the loudest report. Fracture of the tank top would have been accompanied by one or more reports. "Eye-witness" evidence may throw some additional light on the exact sequence of events.

7. SUMMARY

7.1 The general sequence of events can readily be deduced from the evidence obtained. A large scale transverse fracture of the bottom plates on the starboard side of the vessel developed along the line of the weld between frames 66 and 67. This fracture extended across the A7 plate (starboard) along the line of the rivet holes at frame 66, and into the keel plate. A sudden brittle failure of the keel plate then followed (including the keel itself and the duct keels). Further extension of the fracture to port through the rivet holes at frame 67 then took place leading to a complete fracture of the bottom of the vessel. After the bottom fracture, the plates of the tank top were bent "upwards" (relative to the plane of the tank top in the stern of the vessel) about a transverse axis in the region of frames 66-68. This resulted in a brittle fracture of the tank top in the region of frame 66 (starboard side) and frame 68 (port side). With both the bottom and the tank top fractured, the resistance of the vessel to further longitudinal bending moments was destroyed, and the vessel foundered.

These events all took place close to the part of the vessel subject to maximum bending moment as loaded.

7.2 The specific sequence of events leading to the fracture of the bottom on the starboard side cannot be resolved precisely from the evidence obtained. It is considered most likely that fracture started on the starboard side, either at the intersection of the transverse butt weld at the overlap between A7 and B7, or at the intersection of the longitudinally welded angle with the transverse butt weld between plates B7 and B8. Fracture at these points may have been essentially contemporaneous.

Another possible initiation point, the heavily wasted region on the port side of the B plate, we consider to be less probable as the source of fracture.

7.3 The steels used in the construction of the bottom and the tank top were found to be of an appropriate composition and mechanical properties which complied with BS4360, Grade 40A. The compositions of the steels were such that the steels were readily weldable by standard techniques and commonly used electrodes.

7.4 No undue heat affected zone hardening or weld cracking was discovered. All welds examined showed some distributed minor porosity. It is unlikely that any deficiency of the welding played a role in the fracture of the vessel.

7.5 The microstructures of the sections of the plates showed them to have microstructures typical of hot rolled mild steel.

A R Entwisle, MA, PhD, CEng, FIM

EXTRACTS FROM THE BUREAU VERITAS

"STUDY OF THE LONGITUDINAL STRENGTH CHARACTERISTICS OF DREDGERS - BOWSPRITE AND BOWBELLE"

DATED 15 MARCH 1989

1. INTRODUCTION

Following the loss of the hopper dredger BOWSPRITE, the longitudinal strength properties of the two sister ships BOWBELLE and BOWSPRITE are studied in the present paper, and compared to some criteria issued from BUREAU VERITAS RULES, Section 9-1, 1987.

2. CONCLUSIONS

The following conclusions can be drawn:-

- stress levels and all longitudinal strength criteria are satisfactory at deck and at bottom, with scantlings and thicknesses given on drawings.
- safety margins are high (106N/mm^2 at deck, 63N/mm^2 at bottom).
- depending on the hypothesis taken into account for still water bending moment evaluation, stresses at top coaming (compressive) could be equal or slightly above the 1987 Rules limits, but still acceptable.

As a general conclusion, breaking of the ship cannot be due to insufficient designed scantlings. Calculations according to reduced thicknesses cannot explain the breakage of the vessel, if we consider that BOWSPRITE remaining scantlings were equivalent to those measured aboard BOWBELLE.

EXTRACT FROM FURTHER BUREAU VERITAS REPORT DATED 3 AUGUST 1990

INTRODUCTION

Following the loss of the hopper dredger, samples of bottom and double bottom tank top plating have been removed from the wreck and thickness measurements have been undertaken.

The longitudinal strength properties of the BOWSPRITE are calculated from the measured thicknesses and compared to relevant criteria issued from Bureau Veritas Rules, Section 9-1, 1987.

MEASURED THICKNESS

The following thicknesses have been used:-

Strake	Thickness (mm)	OriginalThickness (mm)
strake "A"	12	13.21
strake "B"	10	13.21
strake "C"	10	13.21
strake "D"	9	10.92
keel	17	19.05
tank top	17	19.09

CONCLUSIONS

The following conclusions can be drawn:-

-stress levels and all longitudinal strength criteria calculated for estimated remaining thicknesses at loss time comply with the Bureau Veritas Rules requirement for deep sea notation, at deck and bottom.

Safety margins are high (112N/mm^2 at deck, 75N/mm^2 at bottom).

F I G U R E S

Marine Accident Investigation Branch

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M.V. "BOWSPRITE" ARRANGEMENT OF CARGO, ACCOMMODATION, STORES AND TANK SPACES

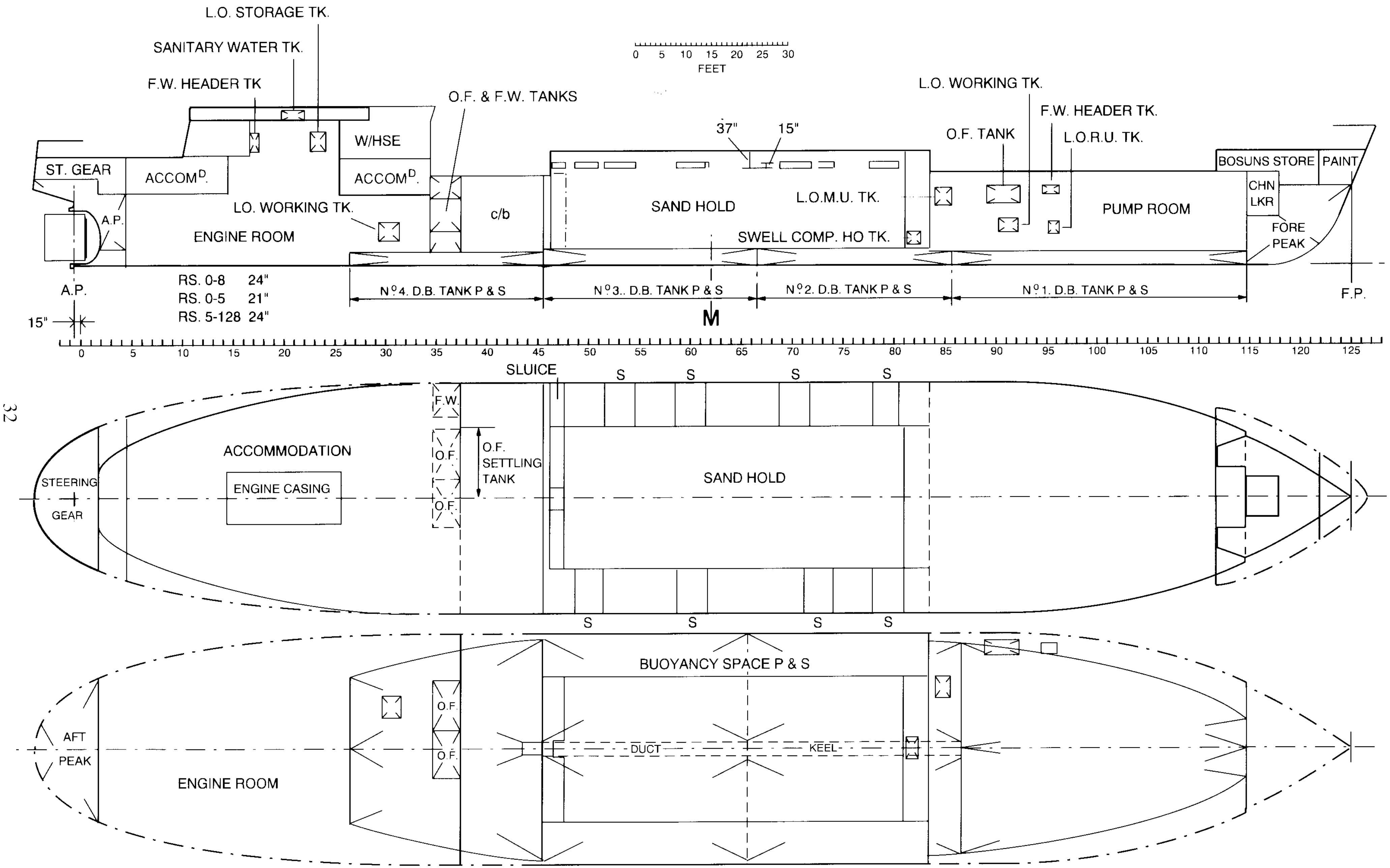

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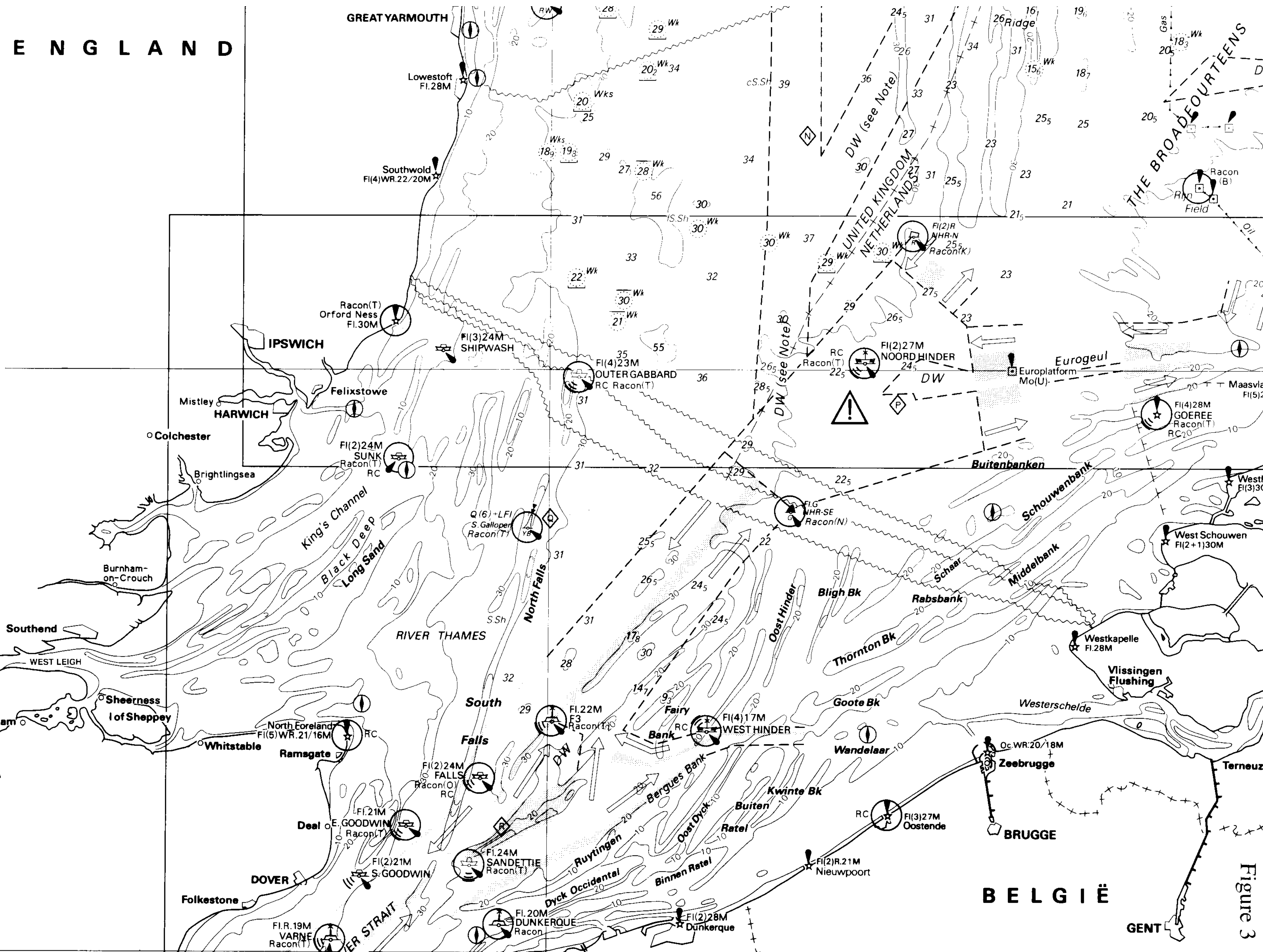
Figure 2



Extract from Admiralty Chart No. 2182

Figure 3

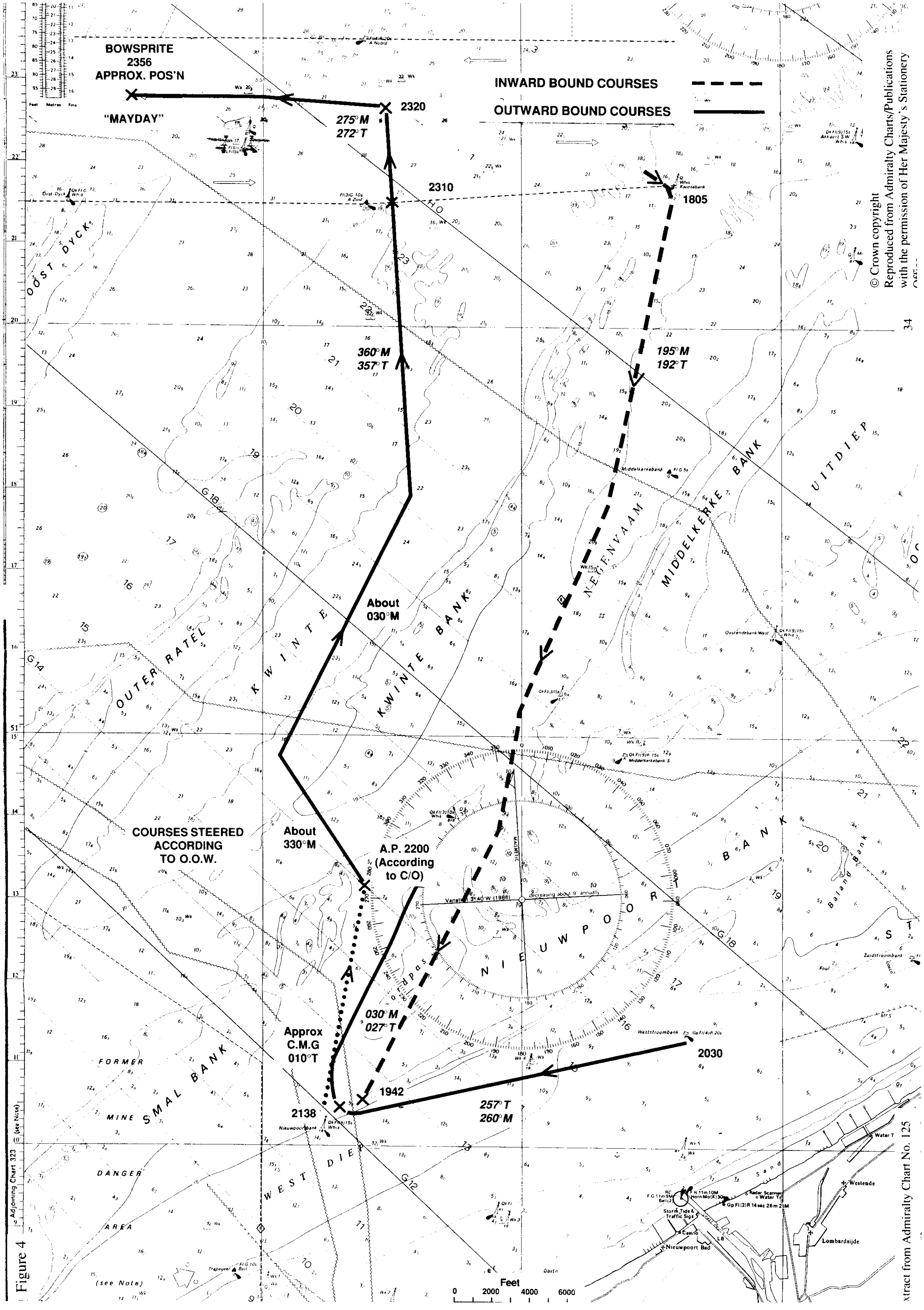


Figure 4

Extract from Admiralty Chart No. 125

Stern section after the accident

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General view of the stern part of vessel

Figure 7

Oblique view of fracture

Part of A7 (starboard) and part of keel plate.

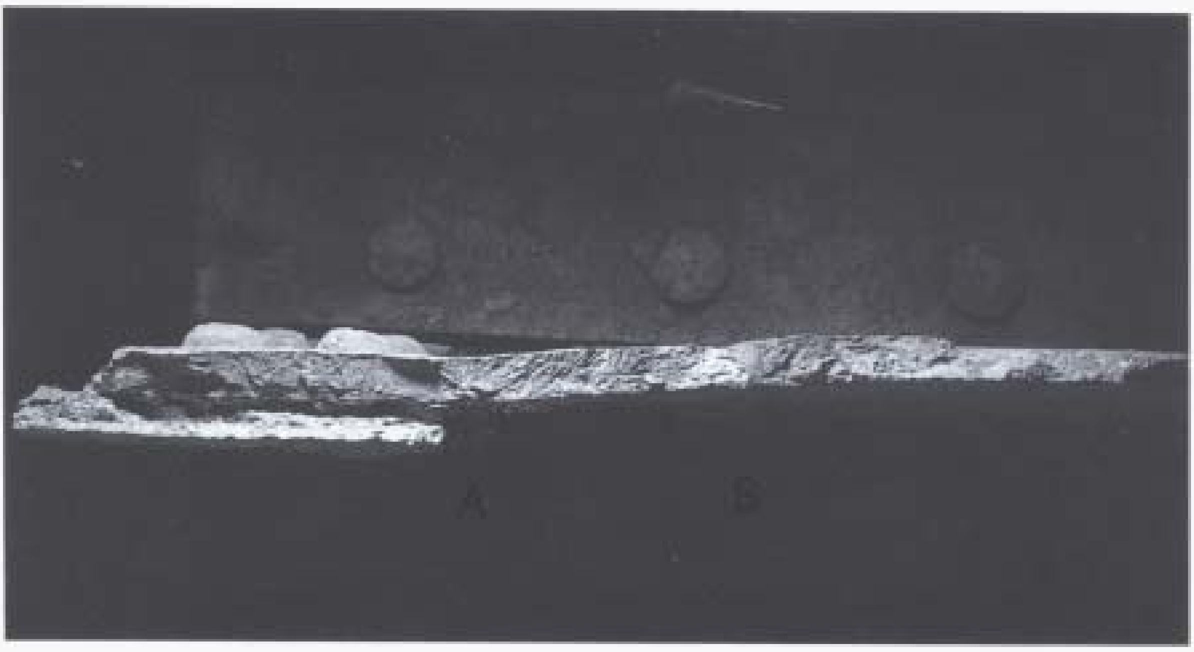
Figure 9

Detail of fracture in keel plate, showing transition from ductile fracture to brittle fracture at A. Fracture has progressed from left to right (starboard to port).

Figure 10

Oblique view of fracture of B7, A7. Note wastage of B7 and sources of fracture A and B.

Figure 11



Detail of fracture in A7, showing souces A and B.

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