Report of investigation

into flooding of aft engine room

of passenger cruise ship

Queen Elizabeth 2

21/22 May 2002

Marine Accident Investigation Branch
First Floor, Carlton House
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Extract from

The Merchant Shipping

(Accident Reporting and Investigation)

Regulations 1999

The fundamental purpose of investigating an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 1999 is to determine its circumstances and the causes with the aim of improving the safety of life at sea and the avoidance of accidents in the future. It is not the purpose to apportion liability, nor, except so far as is necessary to achieve the fundamental purpose, to apportion blame.

This report is not written with liability in mind and is not intended to be used in court for the purpose of litigation. It endeavours to identify and analyse the relevant safety issues pertaining to the specific accident, and to make recommendations aimed at preventing similar accidents in the future.

CONTENTS

GLOSSARY OF TERMS

BST	:	British summer time
cm^2	:	square centimetre
EDX	:	energy dispersive X-ray
HAZ	:	heat affected zone
IACS	:	International Association of Classification Societies
IMO	:	International Maritime Organization
kW	:	kilowatt
LT	:	low temperature
MARPOL	:	The International Convention for the Prevention of Pollution from Ships
MCR	:	machinery control room
MSN	:	Merchant shipping notice
MW	:	Megawatt
m	:	metre
mm	:	millimetre
m^3	:	cubic metre
m^3/h	:	cubic metre per hour
UT	:	ultrasonic test
UTC	:	universal co-ordinated time

SYNOPSIS

At 1700 BST on 18 May 2002, the large passenger cruise ship *Queen Elizabeth 2*, left Southampton for a trans-Atlantic passage to New York. She had 1457 passengers and 973 crew on board.

At approximately 0200 UTC on 21 May, the senior watchkeeping engineer discovered a large sea water leak in the aft engine room. This was found to be caused by the perforation of a 250mm diameter sea water inlet pipe serving an evaporator used for producing fresh water.

Because the position of failure was between the isolating valve and the vessel's skin, the ingress of sea water could not be stopped by closing this valve. After several efforts at effecting emergency repairs, the ingress of sea water was stopped using an ingenious arrangement of a flexible bladder, inserted into the failed pipe and then filled with compressed air. This allowed the vessel to reach New York safely, where permanent repairs were made.

During the emergency repairs, large quantities of sea water entered the aft engine room. Although some of this water was pumped into the vessel's oily-water holding tanks, these were soon filled and several hundred tonnes were pumped directly overboard using the bilge injection system. In view of the direct risk to the vessel's safety caused by flooding, this was in accordance with the provisions of anti-pollution regulations.

The pipe's failure was found to have been caused by simple sea water corrosion. Although the pipe had been examined 2½ years previously, as part of an approved five-year survey cycle, the degree of corrosion was difficult to assess because of the presence of a welded flange. Thorough internal cleaning and examination was also difficult because of the length and relatively small diameter of the pipe.

Recommendations have been addressed to MCA, Cunard and Lloyd's Register of Shipping which, if implemented, should help to prevent a similar accident in the future.

Photograph courtesy of FotoFlite

Queen Elizabeth 2

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF VESSEL AND INCIDENT

Name	:	*Queen Elizabeth 2*
Type	:	Passenger cruise ship
Flag	:	UK
Port of registry	:	Southampton
IMO number	:	6725418
Gross tonnage	:	70327
Length	:	294m
Mean draft	:	9.51m
Year built	:	1969
Builder	:	Upper Clyde Shipbuilders Clydebank Glasgow UK
Main machinery	:	Nine 10500kW MAN diesel engines
Crew	:	973
Passengers	:	1457
Classification Society	:	Lloyd's Register of Shipping
Owner	:	Cunard Line Ltd Suite 400 6100 Blue Lagoon Drive Miami Florida 33126 USA
Type of incident	:	Partial flooding of aft engine room
Position	:	46° 43' N 31° 45' W

1.2 NARRATIVE

Note: All times quoted are ship's times. Where relevant, changes in clock settings are identified.

Queen Elizabeth 2 left Southampton at 1700 BST (UTC + 1 hour) on 18 May 2002, for a trans-Atlantic passage to New York. On board were 1457 passengers and 973 crew.

At approximately 0200 UTC on 21 May, the senior watchkeeping engineer found a large sea water leak into the aft engine room, during his routine inspection rounds. The leak was in the region of the starboard forward corner of the aft engine room. The alarm was immediately raised and assistance summoned.

Following the arrival of the chief and first engineers and other engineering staff, it was found that the leak was in a short length of 250mm diameter sea water pipe serving the starboard sea water evaporator **(Figure 1)**.

Figure 1

Leak from 250mm sea inlet

As this pipe, some 210mm long, was between the sea inlet isolating valve and the vessel's shell, it was impossible to isolate the leak by closing this valve.

Preparations were made to fabricate a clamp to hold a rubber seal over the leaking pipe. Using the bilge pumping system, water was pumped into the oily-water holding tanks.

The aft engine room 'Hi-Hi' bilge level alarm activated at 0315. Soon afterwards 'Echo' main engine, the port engine in the aft engine room, shut down automatically on 'Governor Fault'. This was attributed to floodwater being picked up by the rotating flywheel and soaking the electronic pickup for speed control.

At 0345 'Hotel' main engine, the starboard inner main engine in the aft engine room, was shut down manually because of the high floodwater level. No main engine remained running in the aft engine room.

At 0400, all oily-water holding tanks were full. Clocks were retarded 1 hour at 0400 to UTC - 1hour.

Owing to the rising water level in the aft engine room, the bilge injection valve on the main sea water circulating pump was partially opened and water was pumped overboard for 2 hours. An estimated 400m^3 of water was removed.

This reduced the water level, allowing work to be carried out on the leaking pipe. The clamp was fitted around the pipe, which reduced the ingress slightly. During this work, it was recognised that the leaking pipe might be very fragile and that care was needed not to cause total failure. To reinforce the pipe, stiffeners were welded between the flange and the surrounding structure.

The bilge injection valve was again partially opened at 1030 until 1230. An estimated 400m^3 of water was pumped overboard. This reduced the water level sufficiently to allow work on the leaking pipe to continue.

The lubricating oil sumps of the aft main engines were checked for water contamination, and their generators were checked for electrical resistance. All results were satisfactory and between 1040 and 1130 'Golf', 'India' and 'Hotel' main engines were started.

At 1200, the inboard main engine cooler in use began to show symptoms of being choked. This was attributed to the effects of bilge water being pumped through when the bilge injection was opened. To maintain engine temperatures, the outboard cooler was opened to operate in parallel with the inboard unit.

'Echo' main engine was prepared for starting at 1400 by turning it over on compressed air. Shortly afterwards, the sea water leak became noticeably worse and the bilge injection valve was opened again. 'Golf', 'India' and 'Hotel' main engines were again stopped because of high bilge water levels. From 1430 to 1730, an estimated 600m^3 of water was discharged overboard.

Following electrical checks on the generators in the aft engine room, all aft main engines were restarted between 1735 and 1739. Using rope, canvas, clamps and various blocking mediums, such as silicone and sawdust, efforts to restrict the rate of sea water ingress continued.

Meanwhile, work continued on the production of an arrangement that allowed an inflatable bag to be inserted in the leaking pipe. Inflation of this device stemmed the inflow at 2100.

At 0915 on 22 May, the inflatable bag failed and deflated. The rate of water ingress was again at its maximum. Again the aft engine room quickly became flooded and the bilge injection valve was opened between 0930 and 1030. An estimated 200m^3 of sea water was pumped overboard.

Using a repetition of the earlier technique, a second inflatable bag was inserted into the leaking pipe. This bag was longer than the first and, once inflated, stopped the inflow of water at 1015.

At no stage of the incident had the floodwater level risen above the engine room floor plate level, which is about 1m above the inner bottom or tank-top.

Throughout these operations, a secondary cofferdam was being fabricated and prepared for fitting, once water flow was reduced sufficiently to allow it to be welded to the adjacent structure.

During the remainder of 22 May, the cofferdam was welded around the failed pipe and the water ingress was totally arrested. This cofferdam remained in place until the vessel arrived in New York at 0830 (UTC –4) on 24 May. There, permanent repairs were undertaken.

1.3 THE MAIN MACHINERY SPACES

The vessel's main machinery is contained in two main engine rooms; namely the forward and aft engine rooms **(Figure 2)**. All nine main engines are nine cylinder, in-line, turbo charged diesels running on heavy fuel. Each drives a 10.5MW generator, the output from which can be used either for main propulsion or ship's services.

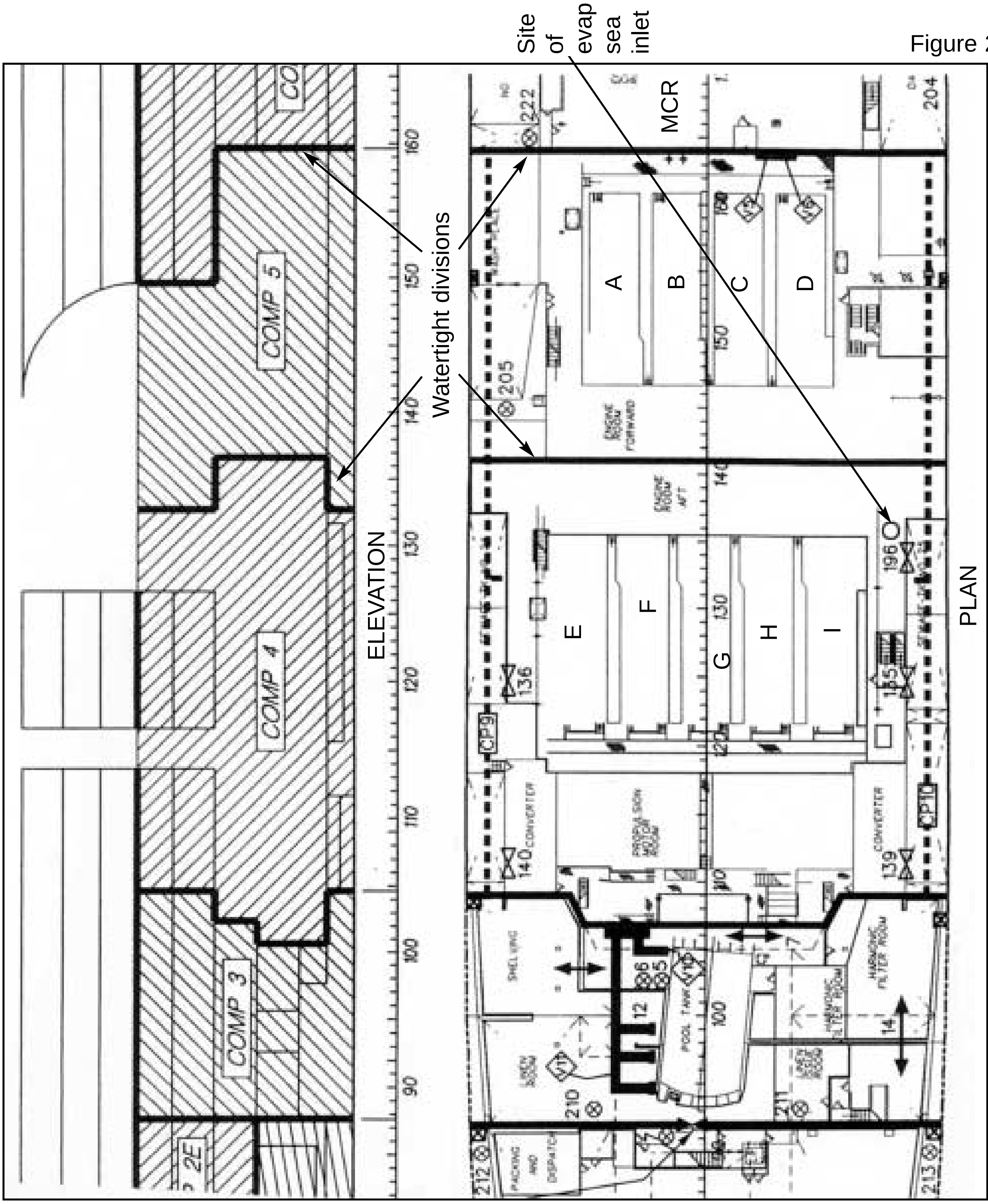
The forward engine room contains four main engines/generators. These are in line abreast and from port to starboard are designated 'Alpha', 'Bravo', 'Charlie' and 'Delta'. Forward of this space is the machinery control room (MCR).

Five main engines/generators are in the aft engine room. These are also arranged in a line abreast across the space and are designated 'Echo', 'Foxtrot', 'Golf', 'Hotel' and 'India' from port to starboard.

The two main engine rooms are separated by a watertight bulkhead.

Within the same watertight compartment as the aft engine room, although separated from it by a fire resistant division, are the two main propulsion motors. Each motor drives a controllable pitch propeller.

Figure 2



Main machinery spaces and watertight divisions

1.4 EMERGENCY REPAIRS

Early efforts to stem the ingress of water used clamps, rubber sheeting, canvas etc. Although these reduced the rate of inflow for a time, they proved largely unsuccessful.

The fragility of the failed pipe was also a concern. To reinforce the pipe, to prevent fracture and loss of the isolating valve, stays were welded between the upper flange of the valve and the surrounding structure **(Figure 3)**.

However, while these efforts were being made, ship's staff were fabricating a device to arrest the inflow completely.

The main component of this device had the form of a 'top hat' made of steel **(Figure 4)**. Its rim was a drilled flange suitable for bolting to the upper flange of the butterfly valve on the leaking pipe. The crown was a flat plate through which a tube was passed, and which could slide through the plate. Water leakage around this tube was prevented using a sealing gland arrangement.

To the lower end of the sliding tube was attached a flexible bellows, or bladder. To the upper end was a connection to the ship's compressed air system **(Figure 5)**. This bladder was a spare for the hydraulic system of the vessel's watertight doors.

The length of the cylindrical portion of the 'top hat' was such that with the tube fully withdrawn, the bladder did not protrude below the lower flange, or rim.

Once the inboard piping and strainer box were removed from the sea inlet valve, with the sliding tube in the fully withdrawn position, the 'top hat' was bolted to the valve's upper flange. The valve was then fully opened.

The sliding tube was then pushed down so that the bladder passed the valve's disc and into the leaking sea water pipe. Once the bladder was in position, compressed air was supplied to the bellows causing it to expand and fill the bore of the leaking pipe.

The technique successfully stopped the ingress of water.

The first bladder failed after several hours. However, the method was used again and proved effective until more permanent repairs were made. The second effort required some slight modification to the arrangements. The bladder used was longer than the first, and, to ensure it could be inserted into the leaking pipe lower than the area of perforation, and any sharp edges which might again cause a puncture, the sliding tube was increased in length.

Once the water inflow was completely stemmed, a steel box was built around the failed pipe. The tank top and sewage tank side were used as two sides of the box. To these, and the pipe's flange, were welded the other four sides of the box **(Figure 6)**. This totally enclosed the failed pipe and remained in place until the vessel's arrival in New York, where permanent repairs were made.

Figure 3

Reinforcing stays between valve flange and surrounding structure (inboard piping and strainer removed)

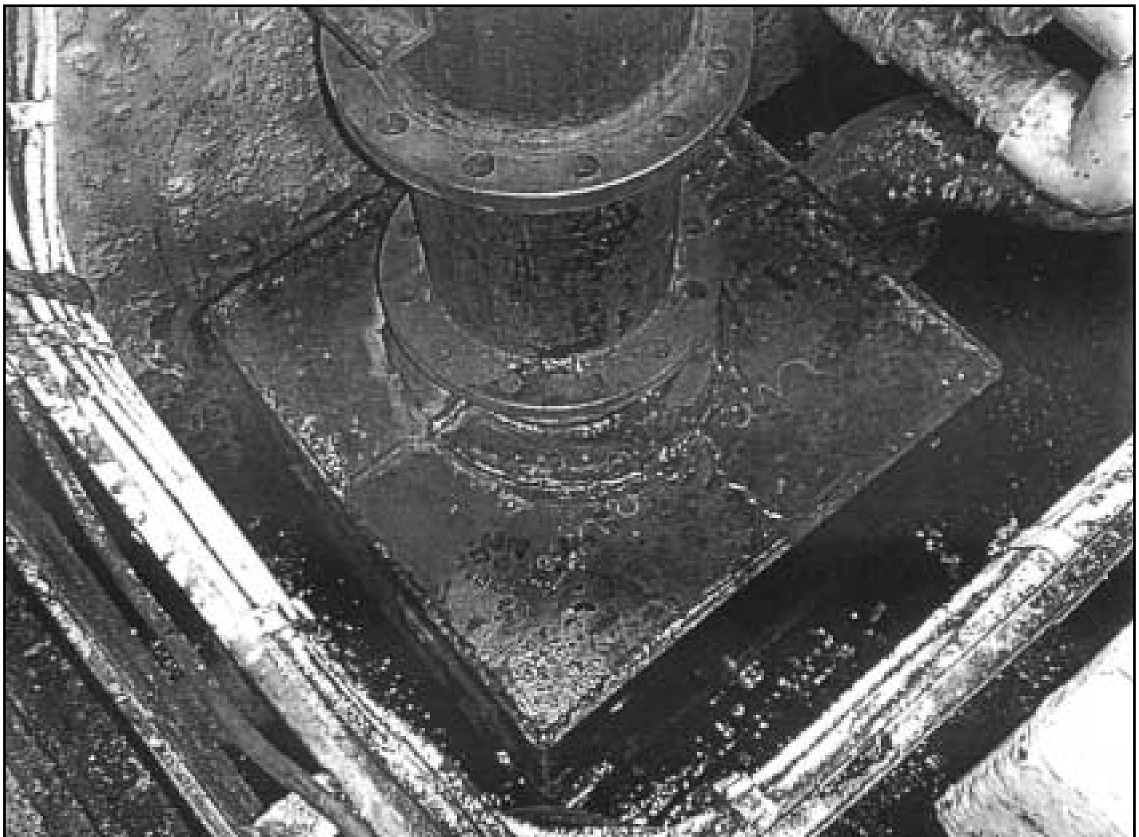
Figure 4

‘Top hat’ device to insert bellows into leaking pipe

Figure 5

Bladder used to stem flooding (compressed air connection at left hand end)

Figure 6



Box enclosing failed pipe

1.5 HISTORY OF THE FAILED PIPE

Queen Elizabeth 2 underwent a major conversion and refit in 1987, which included a complete change of propulsion machinery from steam to diesel main engines. The work was performed at Lloyd Werft Shipyard, Bremerhaven, Germany.

The pipework associated with the evaporator sea water system, including the length of pipe that failed in this incident, was installed during this work **(Figure 7)**.

Overall length of this pipe is about 1.4m. The lower end is welded to a short 460mm diameter tube, housing a filter grid or sieve. This tube is welded to the vessel's outer skin. About 210mm from the upper end of the pipe, it is welded to the tank top of the laundry fresh water tank. This tank is one of the vessel's double bottom tanks.

The upper end of the pipe is fitted with a flange. This is welded to the pipe top and bottom. A butterfly valve bolted to this flange is for system isolating purposes and safety.

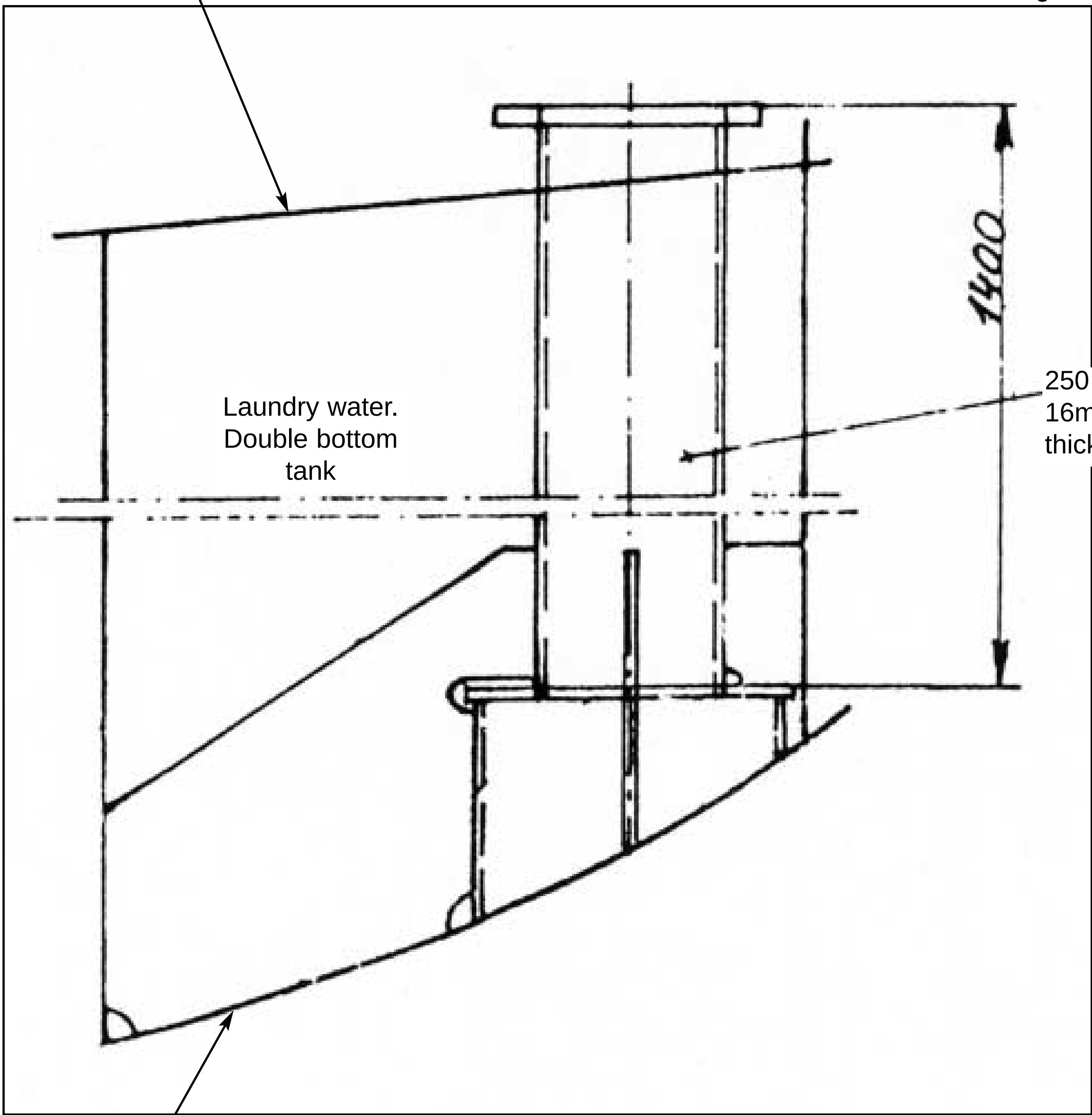
As one of the penetrations of the vessel's hull, this pipe and its associated isolating valve is the subject of survey by the vessel's classification society, Lloyd's Register of Shipping. To satisfy survey requirements, half the number of all such valves are surveyed during each biennial refit period. Thus, each valve and associated inlet is surveyed in accordance with regulation requirements of twice within a five-year period with no period between dry dockings exceeding 36 months. Maximum period between survey is five years.

This cycle of surveys resulted in the vessel's starboard side inlets and valves being surveyed during late November and early December 1999. This included the sea inlet to the starboard evaporator in the aft engine room.

Notes made by one of the vessel's own engineers record that this pipe appeared to be in poor condition and that access might be a problem. Other notes made by another engineer reported that the sea tube was badly corroded and was restricted with marine growth. He also mentions that thickness measurements are to be taken.

The corresponding sea inlet on the port side was surveyed during November/December 2001. Records show that the pipe was cleaned and ultrasonic tests carried out. The results were judged to be within acceptable limits.

Figure 7



Evaporator sea inlet

1.6 EXAMINATION OF FAILED PIPE

During repair in New York, the failed pipe stub was removed by cropping at tank-top level. It was retained on board and later landed at Southampton, UK, for examination by the MAIB.

The MAIB commissioned The Test House (Cambridge) to undertake material examinations.

The objectives of these examinations were:

1. to measure the area of the failure
2. to assess the effectiveness of the ultrasonic test (UT) principle for pipe thickness verification.
3. to identify the reasons for the pipe's failure

These objectives were achieved by means of two areas of study; dimensional assessment; analysis of specimens and corrosion products.

Dimensional assessment

Initial examination established the dimensions of the pipe and its area of failure. The pipe's outside diameter was measured as 272mm. Fabrication drawings give the pipe diameter as 273mm and evidence of a dimension within 1mm of the original specified size serves to confirm that only limited corrosion has occurred on the outer surface of the pipe. Its length is 210mm. One end is fitted with a welded slip-on steel flange of 29.5mm thickness.

Overall dimensions of the irregular perforated area are 161mm by 107mm. Area of this perforation was measured as approximately 72.65cm^2. A second small perforation is close by having overall dimensions of 6.5mm by 4mm **(Figures 8 & 9)**.

A small bore flanged compressed air line valve is fitted to a set-on boss. Internally, this connection is totally covered with corrosion products and marine growth.

Internal surfaces clear of the immediate leak sites are coated with heavy laminated corrosion products of up to 12mm thickness. The iron corrosion products are overlaid by hard marine fouling **(Figure 10)**. The pipe end, within the flange, is severely wasted.

Residual pipe thickness was measured at a selection of points around the pipe circumference **(Figure 11)**. All measurements were made from the outer diameter, with minimal surface preparation, using an ultrasonic thickness meter. Additional UT measurements were made around the pipe wall perforation **(Figure 9)**.

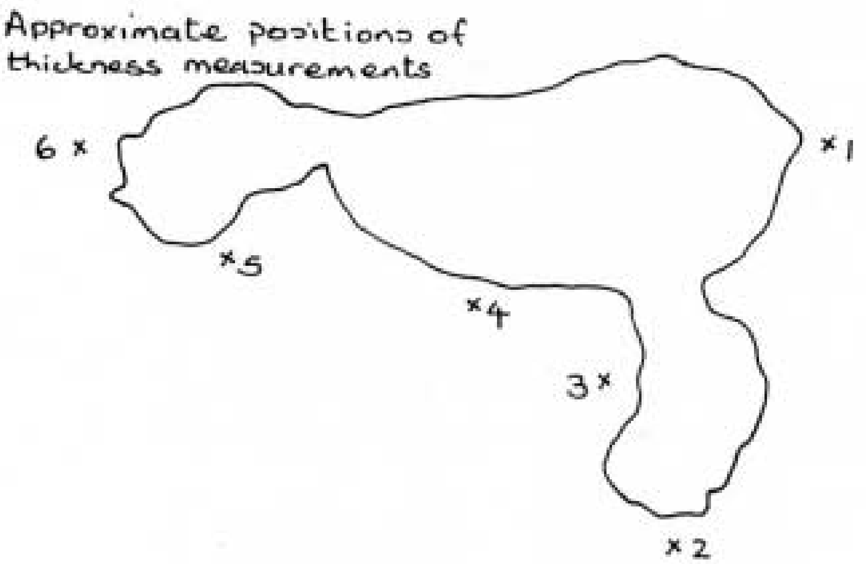
Figure 8

Detail of principal leak site showing corrosion of flange underside and local loss of the outer flange to pipe fillet weld. The figure also shows a close proximity secondary pipe wall perforation site (arrowed)

Figure 9

RESIDUAL WALL THICKNESS ADJACENT TO PIPE WALL PERFORATION

	POSITION					
	1	2	3	4	5	6
Thickness/mm	1.95	4.07	2.05	1.57	0.92	5.21



Outline of perforation

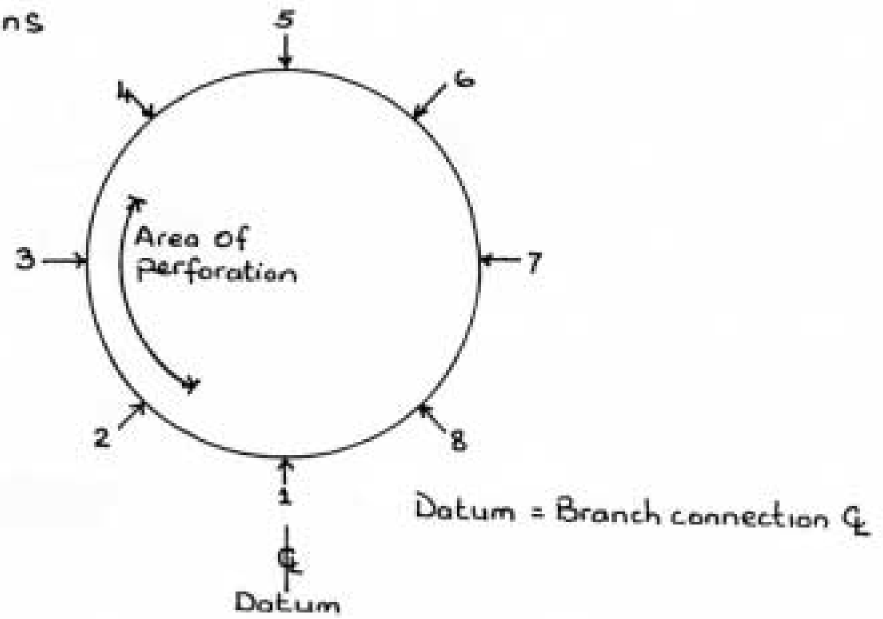
Figure 10

Corrosion damaged pipe end, and absence of any remnants of the inner flange to pipe sealing fillet weld. Heavy marine growth and corrosion products at top of picture

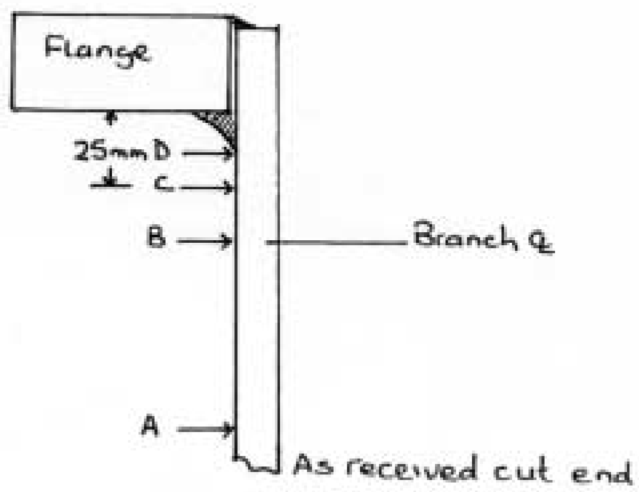
RESIDUAL PIPE WALL THICKNESS MEASUREMENTS AND KEY TO LOCATIONS AND POSITIONS

	LOCATION AND THICKNESS/mm							
POSITION	1	2	3	4	5	6	7	8
A	9.58	8.15	9.26	8.29	12.31	10.15	8.13	8.51
B	-	9.52	4.97	9.29	9.30	7.12	11.98	11.69
C	5.03	7.29	-	-	5.52	6.48	6.58	6.83
D	4.06	-	-	5.12	6.40	6.76	5.90	7.95

Locations



Positions



To confirm the validity of the UT readings, comparative vernier and UT measurements were taken at the open pipe end. Accepting the vernier readings as the reference measurement, UT derived values ranged from 0.05mm to 0.14mm above the comparative reference vernier values.

The pipe thickness data serve to confirm that the pipe had suffered heavy internal general corrosion wastage of up to 12mm and severe wastage local to the perforation site.

The comparative vernier and UT derived measurements serve to confirm the general suitability of the UT principle for remnant thickness determination, and identify only a very minimal overstating of residual thickness by the UT method.

Analysis of specimens

Four metallographic specimens were removed from the pipe; two from the pipe wall perforation edge and two from the flange-to-pipe connection.

<u>Pipe wall perforation edge specimens</u>

Perforation of the pipe wall had occurred by severe corrosion wastage. Pitting of both the inner and outer surfaces is also apparent. The corrosion products at both surfaces appear heavily laminated and are typical of a high chloride environment or sea water type corrosion.

<u>Flange-to-pipe connection specimens</u>

A specimen removed from the perforation site confirms that the pipe end, the pipe end to flange sealing fillet weld, and most of the flange underside to pipe fillet weld had been consumed by corrosion. Loss of the pipe's end over the full flange height had exposed the inner flange edge to sea water corrosion, resulting in significant and long standing end-grain corrosion into the flange. The underside flange-to-pipe fillet weld had been largely consumed by sea water corrosion.

Based on what remained of the flange underside weld metal and heat affected zone (HAZ), it appears that corrosion had proceeded from inside to outside and preferentially along the fillet weld fusion line.

The second specimen, removed remote from the pipe wall perforation site, serves to confirm both the direction of corrosion and the sequence of events that resulted in the final perforation. Sea water side corrosion had totally consumed the inner pipe-end-to-flange sealing fillet weld, exposing the flange-pipe interface to sea water and a phase of interfacial crevice corrosion. Progressive corrosion widening of the pipe to flange crevice then afforded sea water access to the root side of the underside fillet weld, which subsequently suffered preferential corrosion along both its fusion boundaries.

Analysis of corrosion products

Energy dispersive X-ray (EDX) analysis was completed on inner and outer bulk corrosion products and on in-situ corrosion products at the perforation edge.

Four samples of the inner corrosion products, one outer sample and four from the perforation edges appear very similar and typical of iron corrosion products from a high chloride sea water environment. Beyond the normally encountered sea water soluble metal salts, no other anomalous extraneous elements are present.

Conclusions of examination

The material analysis concludes that perforation of the pipe was the result of internal sea water corrosion. Although the pipe had suffered significant general internal corrosion, this alone had not caused the perforation.

Evidence suggests that the internal flange-to-pipe sealing fillet weld and pipe end had been consumed by general sea water corrosion. This then afforded sea water access to both the flange-to-pipe crevice and the outer fillet weld root. The outer fillet weld had, in turn, then experienced preferential corrosion along both its fusion boundaries, resulting in perforation and near total consumption of the weld at the leak site.

Presence of severe end-grain corrosion along the inner flange edge would suggest that the flange-to-pipe crevice had been open to sea water for a considerable length of time.

Evidence of heavy external pitting corrosion of the pipe immediately below the leak site, further suggests that a period of slow leakage or weeping through the flange-to-pipe interface might have preceded the catastrophic failure.

Comparative thickness testing confirmed the suitability of the UT principle for checking of pipe wall thickness. The nature of the progressive corrosion mechanism identified in this failure, however, suggests that checking of pipe wall thickness alone would not have identified the risk of pipe wall perforation and leakage.

No evidence of latent material defects was found in any of the samples examined.

1.7 WEATHER CONDITIONS

During 21 and 22 May 2002 the weather conditions recorded by the vessel's bridge watchkeeping officers were:

21 May

Time	Wind Direction	Wind Force (Beaufort)	Comments
0400	NWxW	9/10	Rough seas & swell
0800	WNW	8	Vessel rolling & pitching
1200	WNW	7	moderately, heaving
1600	WNW	6/7	at times.
2000	WSW	2	
2400	SW	7	

22 May

Time	Wind Direction	Wind Force (Beaufort)
0400	SW	8/9
0800	WSW	6
1200	NWxW	6
1600	NW	4
2000	WxS	3
2400	W	4

1.8 BILGE PUMPING SYSTEM

The vessel's bilge system consists of a bilge suction main, running along most of the length of the hull. This main is connected to the suctions of seven pumps and to each bilge well in the vessel.

The bilge suction main is normally kept isolated in six sections. The forward and aft sections are designated for clean water only. The centre sections, one of which serves the aft engine room, are treated as potentially contaminated.

The bilges served by the forward and aft sections of the systems may, if they contain only clean water, be pumped directly overboard. Those bilges served by the centre sections are pumped into oily-water holding tanks.

All routine bilge pumping operations are controlled from the vessel's safety control room, a continuously manned space separate from the machinery control room.

Emergency direct bilge suctions or injections, of 350mm diameter, and having no connection to the bilge main, are provided in the forward and aft engine rooms by one of the three sea water pumps in each space. These pumps normally supply sea water to the low temperature (LT) coolers for the main engines, and are intended for use as bilge pumps only as a last resort. Their drive motors are about 2m above engine room floor plate level and about 3m above the inner bottom of the vessel. All output from these pumps passes through one or other of two heat exchangers before going overboard **(Figure 12)**.

Nominal capacity of the aft engine room sea water pump having the emergency bilge injection facility, is 620m^3/h and 940m^3/h at each of its two running speeds of 1160rpm and 1750rpm, respectively.

1.9 MARPOL ANNEX 1

During the early stages of the flooding, the vessel's bilge pumping system was used to remove floodwater from the aft engine room. Because of the likelihood that this water was contaminated with oil from machinery, in accordance with the vessel's pollution prevention procedures, it was pumped into the vessel's oily-water holding tanks.

These tanks were quickly filled and the normal pollution prevention procedures could no longer be followed.

The International Convention for the Prevention of Pollution from Ships, 1973, was adopted by the International Conference on Marine Pollution convened by the International Maritime Organization (IMO) in October and November 1973. This convention was subsequently modified by the Protocol of 1978.

The Convention, as modified by the Protocol, is known more commonly as MARPOL 73/78.

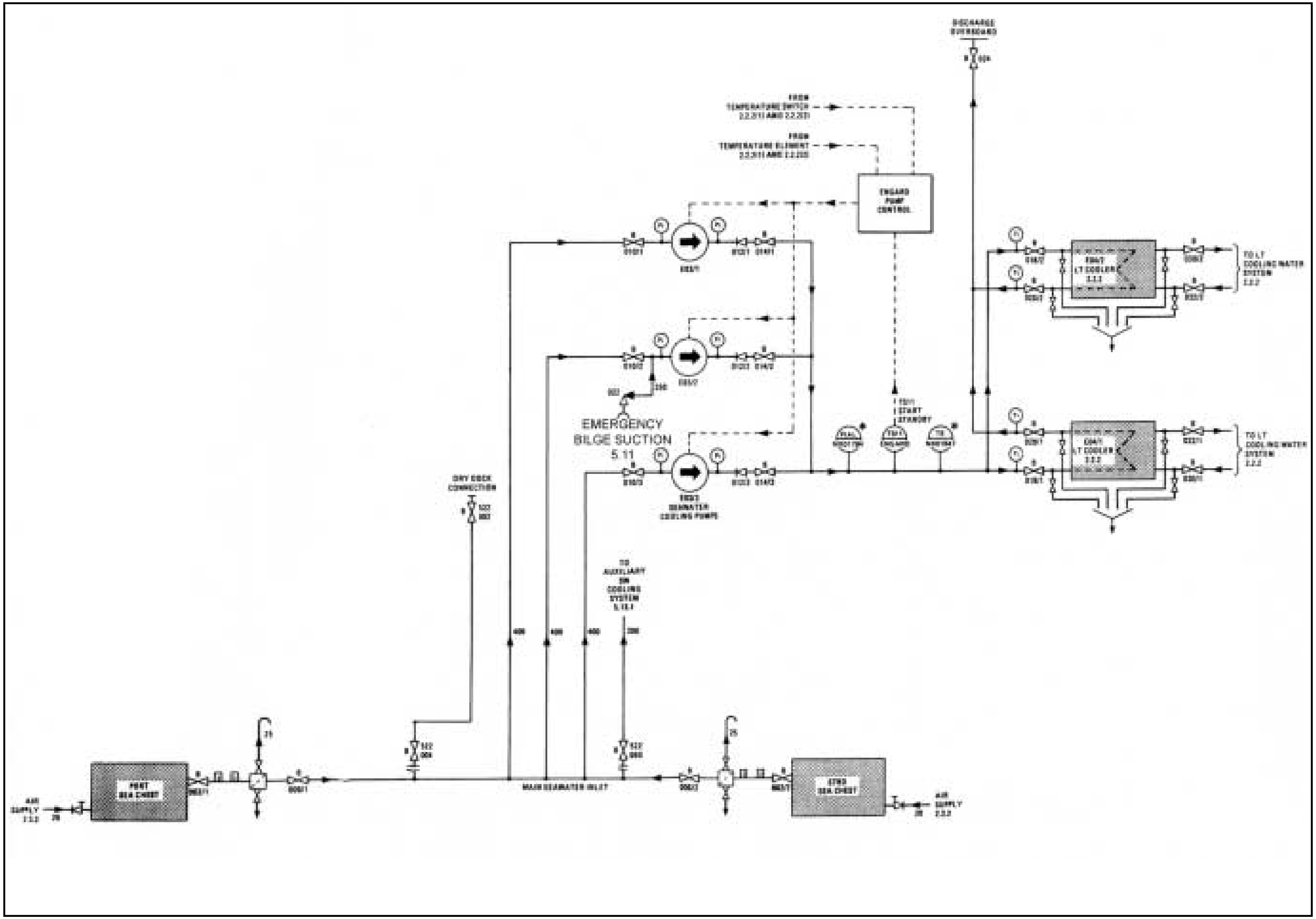
Annex 1 of MARPOL 73/78 covers the requirements for the Prevention of Pollution by Oil. It prohibits the discharge of oil and oil/water mixtures at sea, unless certain strict conditions are satisfied.

The annex contains an exception at Regulation 11, as follows:

Any discharge into the sea of oil or oily mixture necessary for the purpose of securing the safety of a ship or saving life at sea; or

the discharge into the sea of oil or oily mixture resulting from damage to a ship or its equipment, provided that all reasonable precautions have been taken after the occurrence of the damage or discovery of the discharge for the purpose of preventing or minimizing the discharge.

These requirements and exceptions of MARPOL Annex 1 are reflected in The Merchant Shipping (Prevention of Oil Pollution) Regulations 1996 at Part III, which is applicable to UK ships, wherever they may be.



Main SW circulating system and bilge injection

Figure 12

SECTION 2 - ANALYSIS

2.1 AIM

The purpose of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations to prevent similar accidents in the future.

2.2 RATE OF FLOODING

During the laboratory examination of the failed pipe, the area of the perforation was measured as $72.65cm^2$. The recorded mean draught of the vessel was 9.51m. As the pipe's perforation was approximately 2m above the keel, the static head of water above the perforation was about 7.5m.

Theoretical volumetric flow rate, corresponding to this head and area of flow, is $317m^3/h$. This figure is reduced by the effects of losses in the length of pipe beneath the perforation and within the very irregular shaped perforation. The actual figure was probably closer to $150m^3/h$.

Although this probably appeared a dramatic rate of ingress, the vessel's main sea water pump, used on its direct bilge injection, was comfortably able to lower the water level against this ingress.

A similar calculation made for inflow through the perforated pipe without the isolating valve being in place, as would have been the case had the pipe totally failed, gives an inflow in excess of $1000m^3$/hour.

It is questionable whether the vessel's bilge injection and bilge systems combined could have handled this rate of flooding. The vessel's engineers were thus correct in being concerned about the possibility of the flange and valve becoming detached from the pipe. The consequences of it doing so would have made the situation much more difficult to control.

2.3 THE EMERGENCY REPAIR

Apart from the obvious concern for the flooding of the aft engine room through the perforated pipe, ship's staff also recognised the possibility that the pipe might have been weakened sufficiently to fail completely, so effectively losing the isolating valve. Virtually unrestricted flow through the 250mm diameter pipe would have resulted, which would have been very difficult to stop.

Further, the rate of ingress would also, most probably, have been greater than the available pumping capacity. Free flooding of the aft engine room would have resulted, with consequent loss of the main propulsion motors.

These concerns proved largely unfounded, since post accident examination of the pipe found that, although corroded, it had reasonable strength to resist failure. However, the steps taken by the ship's staff to reinforce the pipe to avoid such catastrophic results were very prudent.

The initial efforts to control the inflow, using clamps, rubber sheeting etc. were the type of solution that most marine engineers are likely to have used.

However, the later efforts using inflatable bladders were particularly ingenious, in both conception and execution. The bladders were not part of the vessel's damage control equipment but were spare parts for watertight door hydraulic systems. To recognise that these parts could be of use in this situation and, to an even greater degree, devise a method for their insertion into the failed pipe was very ingenious.

Most marine engineers would hope to match this ingenuity under similar circumstances; it is probable that few would succeed.

As an example showing that all prodigious feats within the profession are not in the distant past, the details of the technique used, and the associated circumstances, should be brought to the attention of all who claim, or wish to be marine engineers.

2.4 CAUSE OF PIPE FAILURE

The mechanism that perforated the pipe was simple sea water corrosion. For a steel component permanently immersed in sea water, this finding is not very remarkable.

Of greater concern is the failure of the pipe, 2½ years after its most recent examination for Class, and 2 years before its next examination.

Although ship's records are unclear as to whether the wall thickness of this pipe was checked at its last examination in November/December 1999, it is probable that it was tested, using ultrasonic methods, and found acceptable.

Two of the vessel's own engineers recorded comments on the apparent poor condition of the pipe. Lloyd's Register conducted its own review of previous surveys held on the sea connections of QE2 and the incidence of failure in general. The distance piece was examined and hammer tested on 22 November 1999. Records indicate that the valve body was removed for the inspection, no substantial corrosion was noted and the general condition was reported to be satisfactory. The attending surveyors were unaware that the ship's engineers had recorded comments at the time on the apparent poor condition of the pipe.

Having qualified engineers observing and monitoring refit work and noting equipment condition, is a valuable resource for the vessel's owners. The reports they make should, to obtain greatest value from their services, be noted and made part of the material considered by the refit management team. This will ensure that any possible deficiencies that are noted are given full consideration.

All internal surfaces of the pipe had been affected by general sea water corrosion. However, much of the corrosion activity had taken place in the region where the pipe passed through the flange. The pipe end, inner face of the flange and upper and lower pipe-to-flange welds had all suffered from serious corrosion. No ultrasonic probe used for the pipe wall measurements could have detected the loss of material in these areas.

Much of the corrosion in this area was the result of the failure of the upper sealing weld, allowing sea water to gain access to the flange/pipe interface. Aggressive crevice corrosion resulted, together with sea water access to the lower weld. Clearly, the integrity of the upper weld is important to the long-term condition of the flange/pipe connection.

As the condition of the upper weld and pipe/flange connections cannot easily be assessed using common ultrasonic methods, it is necessary to remove the piping and valve inboard of the pipe for a visual examination. The owners of the vessel should be required, at the next opportunity, to perform visual examinations of all similar safety critical pipe/flange connections on the vessel to ensure their continued integrity.

2.5 SEA INLET ARRANGEMENTS

The evaporator sea water inlet consists of a length of piping passing through a double bottom tank and protruding into the aft engine room.

A more typical arrangement for sea inlets serving machinery is to mount the valve directly on to a sea inlet box attached to the shell, or directly on to the shell. The Merchant Shipping (Passenger Ship Construction: Ships of Classes I, II and II(A)) Regulations 1998 do, in the associated Merchant Shipping Notice MSN 1698 (M), Schedule 10, specify this arrangement. It is accepted that these Regulations did not apply to the vessel at the time of build in 1969 or modification in 1987.

Fabricated sea inlet boxes are normally of sufficient dimensions to allow easy access to their water side for the purposes of cleaning, inspection and painting. In contrast, a 1.4m long inlet pipe of 250mm diameter, as fitted here, is too long and too small in diameter to allow easy access for any of these purposes. The degree of accumulation of corrosion products and marine growth in the failed pipe is probably an indication of the difficulty of properly cleaning a pipe of that size.

Further, the extreme inboard end, that furthest from the dry dock during inspections, is the most difficult part to clean and examine from the dry dock.

This makes examination from within the ship the only practical option. The outer surface of the pipe, either from within the double bottom tank or the engine room, is comparatively simple to examine once access is arranged. However, unless some of the inboard piping system and isolating valve are removed, the bore at the inboard end of the pipe might never be properly cleaned or examined.

The condition of the extreme inboard end of the pipe, the stub within the engine room, may thus be uncertain, yet its failure has the potential for catastrophic consequences. This points to a need for greater consideration to be given to assessing the condition of these types of stub pipes thoroughly at the time of survey.

Alternatively, it might be possible to eliminate these short lengths of pipe in the engine rooms of the vessel by mounting the isolating valves on pads secured to the tank tops. Water ingress from a failure of the pipe would then be contained within the double bottom tank. This approach appears to be more in accord with the philosophy of the latest regulations.

In view of the apparently satisfactory working life of the existing arrangements, requiring major modifications of this nature might be unreasonable. However, the MCA and Lloyd's Register should require detailed examination of existing arrangements, where main sea inlet valves are mounted on pipes rather than on sea inlet boxes or to a vessel's shell plating.

2.6 SAFETY OF THE VESSEL

There was little difficulty in controlling the flooding of the aft engine room using the bilge injection line on one of the main sea water circulating pumps. However, had the flange totally separated from the pipe, the rate of ingress would have been much greater, and the ability of even the bilge injection system to control the flooding is questionable. The vessel's engineers recognised this possibility and took prudent preventative steps to ensure the flange remained attached to the pipe.

It must be recognised that had this flange become detached, the aft engine room would have been free to flood, with serious consequences.

Initially, all main engines in the aft engine room would have been disabled, followed by the main sea water pump being used on the bilge injection. By this stage, the water level would have been at a depth such that access to the failed pipe would have been impossible. Further corrective action to restrict the rate of ingress would then have been made far more difficult.

Loss of the bilge injection would have allowed the water level to rise at an uncontrolled rate. Flooding into the motor room, aft of the engine room, would have followed. In spite of the four main engines in the forward engine room continuing to run, loss of vessel propulsion would have resulted.

In this state, the vessel would have been disabled and drifted in poor weather conditions with a major compartment flooded. Even in this condition, the vessel would have retained sufficient freeboard and stability to remain a safe haven for those on board, but it was clearly a state that was undesirable and one having the potential for generating unforeseen risks.

Steps taken by engineering staff ensured that the situation did not deteriorate to this extreme. However, the gravity of these possible consequences undoubtedly introduced urgency into the task of stemming the flooding. It is further credit to the vessel's engineers that they produced such an effective and ingenious solution while subject to these pressures.

The potential consequences of failure of this type of inlet, particularly in the aft engine room of the vessel, are considered as unacceptable. The associated level of risk is, therefore, correspondingly high and indicates a need for suitable control measures to minimise the level of risk. In view of the 15 year working life of this pipe before failure, it is considered reasonable to ensure only that inlets of this design are thoroughly examined and their condition carefully monitored. Major modification to their design would probably be unreasonable and unjustifiable.

2.7 POLLUTION

Immediately following the discovery of the flooding, the bilges of the aft engine room were pumped into the oily-water holding tanks using the bilge system. This was in accordance with normal pollution prevention procedures.

Because of the rate of flooding, these tanks were filled to their capacity of $240m^3$ within two hours.

Ship's staff were left with little option other than to pump the floodwater directly overboard. To have done otherwise would have resulted in the loss of the engines in the aft engine room and, ultimately, the main propulsion motors.

This situation is covered by the provision of Regulation 11 of Annex 1 of MARPOL, where discharge into the sea, of oily mixture, is allowed for securing the safety of a ship.

SECTION 3 - FINDINGS

3.1 CAUSES AND CONTRIBUTING FACTORS

1. The pipe failure, which led to the flooding, was caused by simple sea water corrosion. [2.4]

2. The pipe/flange construction made detection of the severe corrosion difficult using ultrasonic methods. [2.4]

3. Pipe diameter and length made internal cleaning and visual examination difficult. [2.5]

3.2 OTHER FINDINGS

1. The maximum rate of flooding was in the order of 150m^3/hour. [2.2]

2. The emergency repair was a fine example of initiative and practical engineering problem solving. [2.3]

3. The failed pipe had been surveyed 2½ years before it failed. [2.4]

4. The rate of flooding was within the capacity of the bilge injection system and, until temporary repairs were complete, was easily controlled by this system. [2.6]

5. The vessel’s engineers took prudent steps to ensure the pipe’s flange did not become detached and cause the rate of flooding to increase substantially. [2.3, 2.6]

6. All discharges of water overboard were in accordance with the provisions of MARPOL. [2.7]

SECTION 4 - ACTION TAKEN

1. Interrogation of Lloyd’s Register of Shipping’s database has not revealed any similar cases of wasted and holed distance pieces to sea connections. However, Lloyd’s Register of Shipping will be advising its surveyors of this incident with guidance on the inspection of such distance pieces.

2. Lloyd’s Register of Shipping is discussing arrangements with the owners to assess the condition of other distance pieces to sea connections in any compartment of *Queen Elizabeth 2* whose flooding would seriously degrade the vessel’s safety.

SECTION 5 - RECOMMENDATIONS

The Maritime and Coastguard Agency and Lloyd’s Register of Shipping are recommended to:

1. Require, at the next reasonable opportunity, a detailed condition examination of this type of sea inlet in any compartment of *Queen Elizabeth 2* whose flooding would seriously degrade the vessel’s safety.

Cunard Line Ltd is recommended to:

2. Ensure that its management is satisfied that any condition report, made by technical staff, on safety critical equipment, is properly considered.

3. Employ the results of the required detailed examination of these inlet pipes, to amend the vessel’s safety management system to ensure the items are thoroughly and routinely inspected for condition.

Lloyd’s Register of Shipping is recommended to:

4. Bring this case to the attention of the IACS working party presently undertaking a review of engine room flooding incidents, with a view to offering surveyors standards against which they can assess the condition of safety critical sea water pipes.

Marine Accident Investigation Branch
March 2003