Walkway collapse at

PORT RAMSGATE

A report on the investigation into the walkway collapse at Port Ramsgate on 14 September 1994

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Front cover: *Gap walkway spanned - shore end sideways to pontoon (used by kind permission of the Kent Police)*

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PREFACE

1 Shortly before 01.00 on the morning of Wednesday 14 September 1994, part of the passenger walkway at No 3 Berth, Port Ramsgate, collapsed. One end of the walkway fell 10 m, embedding itself in the deck of the pontoon that had provided the floating seaward support for the structure. Six members of the public were killed and seven received multiple injuries.

2 Following an exhaustive investigation, the Health and Safety Executive (HSE) brought legal proceedings against the operating company, the designers/contractors and the independent approval organisation. All were convicted of serious offences under the Health and Safety at Work etc Act 1974 and record fines and costs were imposed.

3 Much of the technical information in this report has already been made widely available as a result of the legal proceedings taken, articles in the technical press and lectures to professional bodies. However, HSE has published this report to draw attention to a set of circumstances in which large organisations with professional and technically well qualified staff and managers allowed a series of errors to lead to disaster. Lessons learned are included in the report.

3 The incident provides a salutary lesson about what can happen if insufficient attention is given to managing a project of this nature. The issues involved and the lessons to be learnt go far beyond the field of maritime transport systems. It is important that the widest possible audience should benefit from the lessons of this tragic incident. This will include client organisations and others who initiate structural projects, designers, manufacturers, contractors, operators, and those who advise, approve or verify such projects. The application of these lessons to future projects will be one positive testimony to those who died and were injured.

4 Since the incident, interested parties in the ferry ports industry (including the independent approval organisation which was prosecuted) have published a number of documents which address the procurement, operation and maintenance of linkspans. These include:

(a) new rules for the classification of linkspans[1] produced by Lloyd's Register of Shipping (LR)(referred to in this report as the LR *Linkspan Rules*); and

(b) best practice guide for the procurement, operation and maintenance of linkspans[2] prepared by the Construction Industry Research and Information Association (CIRIA).

SUMMARY

1 At 00.47 on 14 September 1994, part of the passenger walkway at No 3 Berth, Port Ramsgate, collapsed. One end of the walkway fell 10 m, causing the death of six passengers and severe multiple injuries to seven others.

2 The walkway was part of a berth facility which served vehicle and passenger ferry ships. The berth had recently been upgraded by the provision of an additional upper vehicle bridge and a separate passenger walkway which had been brought into use four months before the accident. The walkway was in three sections, spanning from shore to a floating pontoon, across the pontoon supported on a portal frame, and from the pontoon to the ferry ship (see Figure 1).

3 The end of the section leading from the shore to the pontoon fell when its only secured connection to the pontoon portal frame failed (see Figures 2a and 2b). This section of the walkway had been supported using four stub axles, one welded to each corner of the walkway. Each stub axle rested in a bearing sleeve that formed part of a support foot. The four support feet were designed to rotate on the stub axles and were of the same design, with the following exception: the seaward right-hand support foot (viewed along the walkway from the shore) was attached to the walkway support platform on which the feet rested at the pontoon end by a vertical pintle. The other three support feet rested on flat support surfaces and had been designed to slide as the pontoon moved relative to the shore. The two at the shore end rested in slideway guides.

4 Investigating HSE inspectors quickly found that the immediate physical cause of the collapse was failure of the weld securing the end of the right-hand seaward stub axle to the walkway. It was clear from visual examination that the weld was poorly executed and that there had been fatigue cracking. Subsequent metallurgical examination confirmed this. Complete separation of the stub axle was likely to have occurred several days before the accident. The left-hand seaward stub axle showed evidence of poor welding and fatigue cracking but failure occurred when it hit the pontoon deck during the collapse.

5 Review of the design revealed that it did not provide the support and articulation necessary to match the overall design concept. The walkway was designed such that it was likely to be torsionally stiff. As such the design did not allow for the roll of the pontoon and the design calculations of the loadings on the cantilevered support stub axles were inadequate. It appeared that the designers had failed to visualise how the static and dynamic loadings would be carried and therefore failed to consider the effects of fatigue on the support stub axles. No fatigue calculations were made.

6 The investigation traced these physical failings to the absence of effective arrangements for the management of the project by the port operator, the

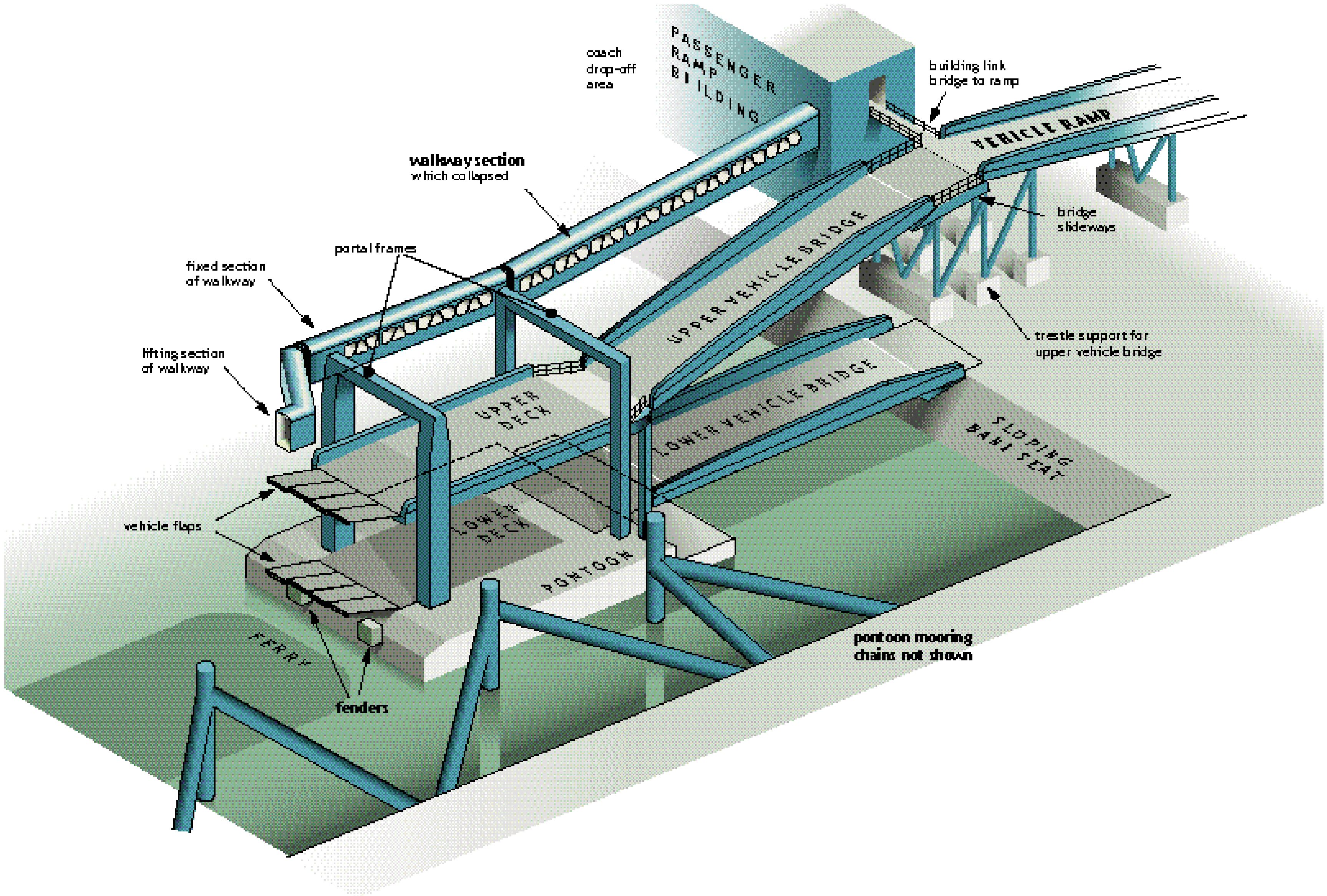

Figure 1: *Berth 3 - the double deck project 1994*

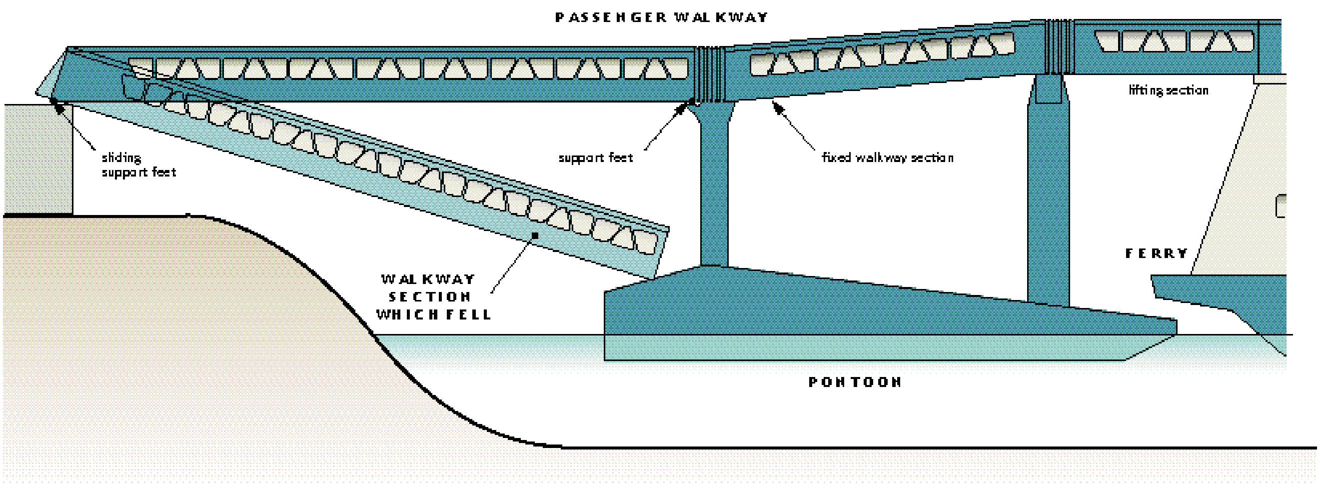

Figure 2a: *Diagram showing the walkway from shore to ferry*

designer of the upgraded facility and the manufacturer.

7 The upgrade project had originated in 1991, had been shelved in 1992, and was resurrected in the second half of 1993. It then proceeded with such haste that no contract papers were completed and the port operator failed to provide vital information to the designer, eg a design brief, specification for the project and environmental data. The lack of environmental data was significant, since it should have been used by the designers to calculate the stresses on the berth structures. The designers did not pursue such information and the design calculations were based on inadequate assumptions, were inaccurate and failed to provide a safe design.

8 A classification society was engaged by the manufacturer to certify the upgraded structure. The role of the society was never apparently clear to the parties involved in the upgrade contract. There was lack of liaison between offices of the society both in the UK and in Sweden. The environmental conditions, the design concept and the assumptions used by the designer were not checked by the society. A risk assessment which would have shown the effects of safety-critical component failure was not carried out. Faults in fabrication and during installation were not identified. The society failed to follow its own rules. Calculations made by the society to check the stub axle welds which failed were inaccurate, and inadequate to identify basic design deficiencies.

9 During on-site fabrication, commissioning and early operation of the upgraded berth, warning signs that indicated serious failings in design and fabrication were not adequately heeded by the main parties involved.

10 Finally, no provision was made for continuing maintenance of the upgraded structure, lubrication facilities were not installed, suitable access for maintenance was not incorporated and no manual or other written instructions were provided.

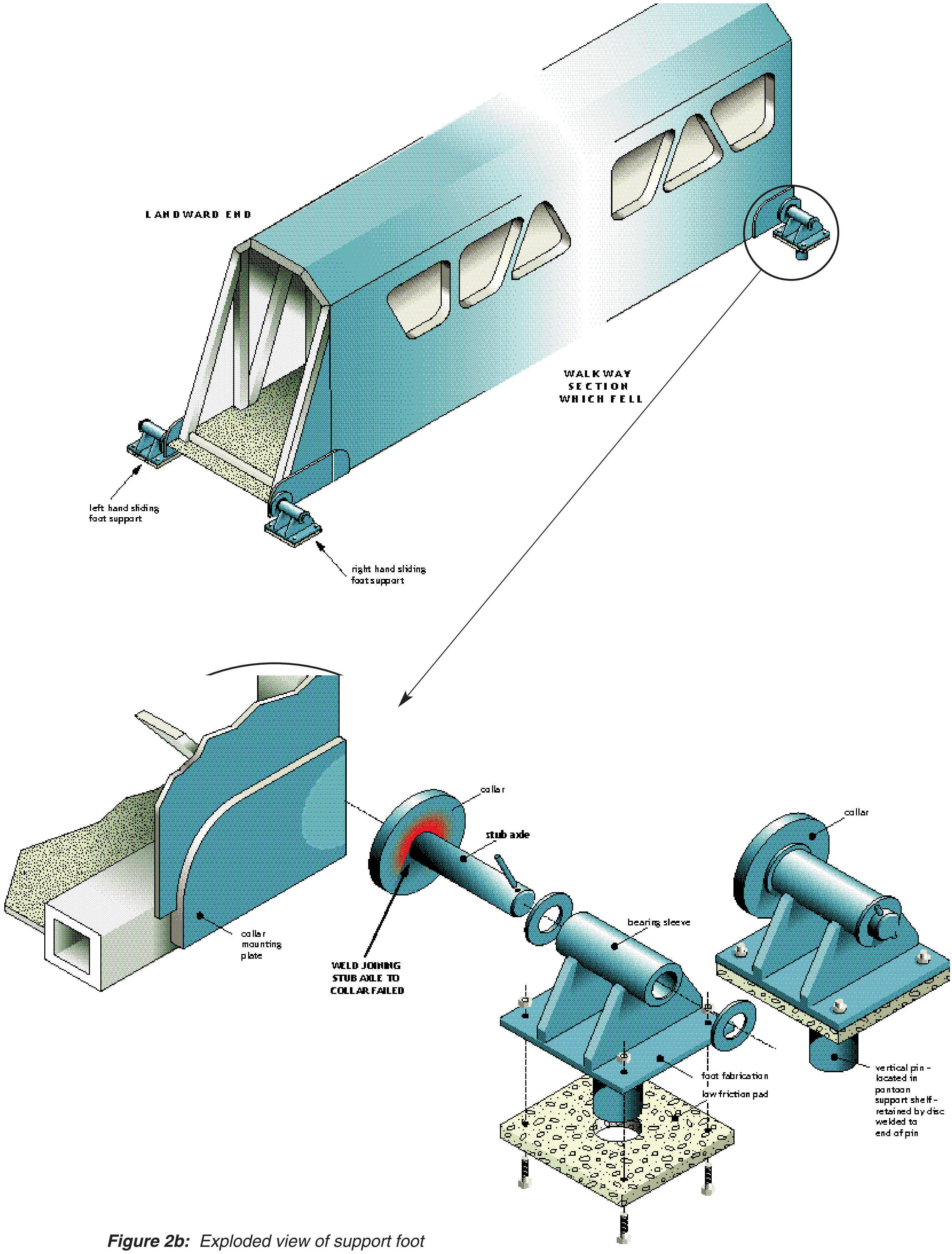

Figure 2b: *Exploded view of support foot*

11 Serious deficiencies with the upper vehicle bridge structure at the berth were found early in the investigation and a prohibition notice was served on the port operator to prevent use of this facility until remedial action was taken. This report addresses the major deficiencies.

12 As a result of the investigation the port operator, the designer, the major fabrication contractor and the classification society were prosecuted by HSE. All were convicted and fines totalling £1.7 million were imposed. HSE costs of £0.7 million were awarded against the defendants.

13 The report concludes that the collapse was caused by a series of errors in the design; some of which were gross. These were compounded by defective fabrication work and a lack of adequate maintenance procedures. All these resulted from the absence of organised project management. The classification society failed to apply its rules sufficiently rigorously to detect the design, fabrication and installation deficiencies. These errors made the collapse inevitable. In fact it could have failed in a number of ways in addition to that which led to the collapse. The report also concludes that compliance with the legislation and technical guidance already in place would have ensured that the project was safely completed.

14 Nothing new was learnt about the nature of technical failures of structures. However, anyone involved with the procurement, design, fabrication and installation of such structures will benefit from reading this report, which in particular illustrates the need for:

(a) effective project management;

(b) procurers of structures to understand the wide extent of their statutory duty to exercise control over the work of their contractors, where it forms part of the conduct of their own undertaking and it is reasonably practicable for them to do so; and

(c) classification societies to make their role clear to major parties in a project.

BACKGROUND

The port of Ramsgate

15 In September 1994 the port of Ramsgate was a busy cross-channel ferry port with a variety of services running to Ostend and Dunkirk. Traffic comprised foot passengers, cars, coaches, lorries and unaccompanied freight containers on trailers. Some of the services used freight-only dedicated ferries. Others carried a variety of passengers and freight. All the conventional ferries operating from the port were roll-on, roll-off (known as ro-ro ferries) with lorries and cars driving on to a vehicle deck.

16 The port had gone through several recent stages of development. In the early 1980s, a new harbour had come into use at Ramsgate. This was built on reclaimed land next to the 200-year-old Royal Harbour (see Figure 3). Ferry services were operated by Sally Lines Ltd and the harbour operated by a sister company, Port Ramsgate Ltd (subsequently known as Port Ramsgate in this report). More than one million passengers each year were using the port by the late 1980s. Appendix 1 gives a short history of the port.

17 During the 1980s, a number of ship berths were built within the new harbour. Piled structures were built out from the shore for ferries to moor against. Steel structures called 'linkspans' were installed to bridge the gap between the ferry and the shore so that vehicles and passengers could enter each ferry. Appendix 2 provides an outline of the development of different types of linkspan. During the mid-1980s three floating, pontoon-based linkspans were installed at Ramsgate. These were single-deck linkspans. The stern of each ferry was held just clear of the pontoon by mooring lines and a vehicle ramp was lowered on to the pontoon deck from the ferry. The berths were numbered: 1, 2 and 3. Figure 4 shows Berth 3 as a single-deck linkspan.

18 The three linkspans were of similar construction, comprising a pontoon 31 m long by 22 m wide providing a large deck for vehicles to move across. Each pontoon had a ballast water tank at each corner so that its position in the water could be adjusted. The pontoon deck was linked to the shore by a vehicle bridge supported on four feet. One of these was connected to the pontoon by a vertical pin known as a 'pintle'; the others were free to slide in runners. Using a 'single point' connection meant that the bridge and pontoon could articulate (move) independently. The vehicle bridge was of open construction - having a base and sides - and was torsionally flexible, being able to twist to accommodate the roll of the pontoon.

19 One side of the pontoon rested against two vertical piles driven into the sea bed and was held against the piles by chains secured to a fixed mooring structure alongside the pontoon. The tidal range at Ramsgate can exceed 7 m between lowest and highest height of water and the chains were so fixed as to permit the

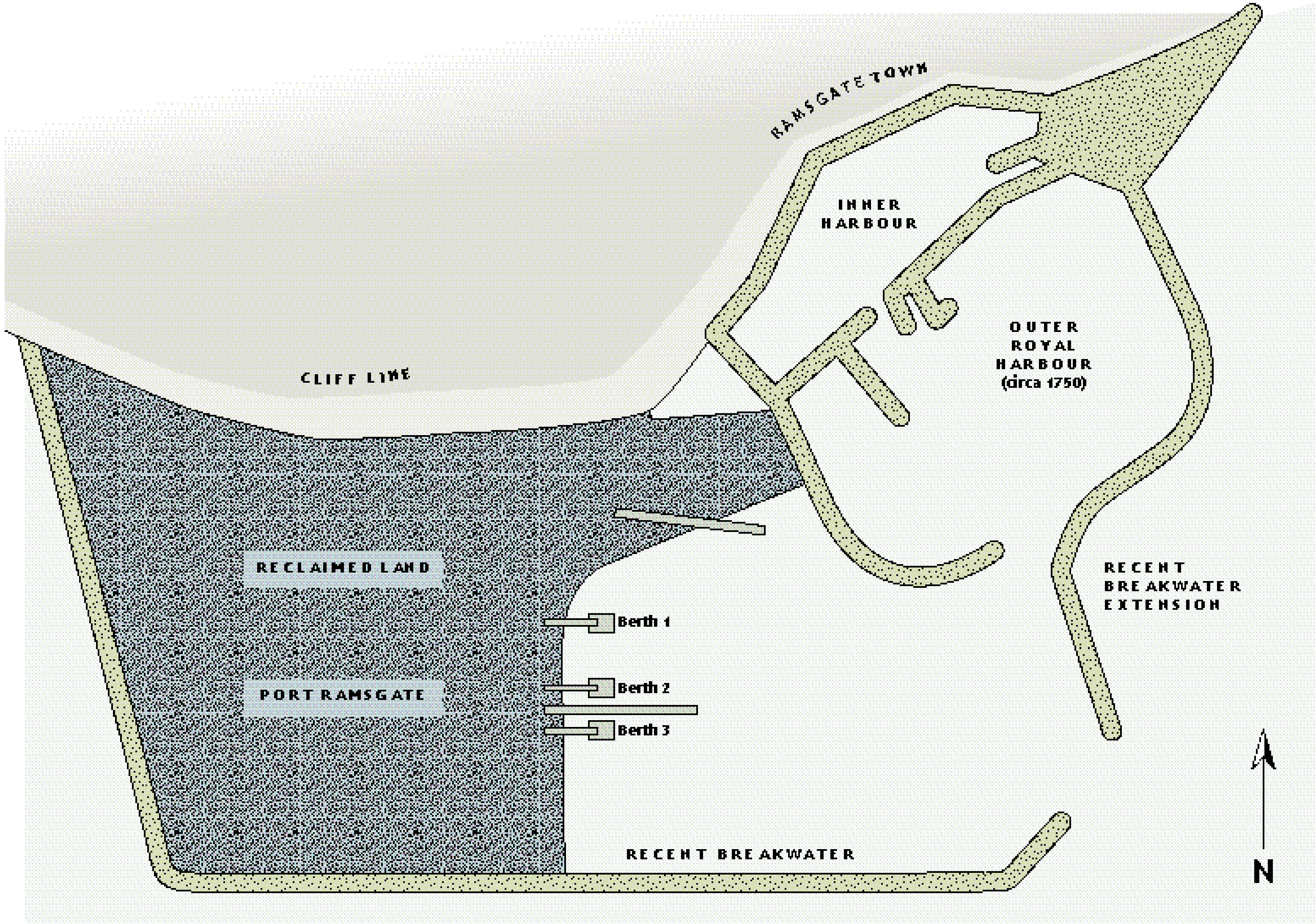

Figure 3: *Ramsgate harbour - map showing layout in 1994*

pontoon to rise and fall with the tide. Another set of chains connected the pontoon back to the shore. These chains were attached close to each end of the vehicle bridge (see Figure 4). Therefore the shoreward sliding feet under the vehicle bridge needed to slide only a short distance to accommodate the change in position. Metal plates were set into the sloping shore (known as the bankseat) to facilitate sliding.

20 During the early 1990s, the cross-channel ferry companies were reshaping their structure and operations to prepare for competition as the channel tunnel neared completion. Port Ramsgate was negotiating for an additional ferry company to use Ramsgate. This was Regie voor Maritiem Transport (RMT) the Belgian state-owned operator. RMT vessels did not have internal vehicle ramps. They needed to use a double-deck linkspan fitted with flaps to give access to both decks of these ferries. A project was undertaken by Port Ramsgate to achieve this at Berth 3.

The main organisations involved

21 The main organisations involved in the expansion work at the port of Ramsgate which led up to the collapse of the walkway were Port Ramsgate, two Swedish companies (Fartygsentrepenader AB and Fartygstionstructioner AB) and Lloyd's Register of Shipping (LR). A brief outline of each follows.

PORT RAMSGATE ?
The operating body and main contractor

Port Ramsgate had operated the port since the early 1980s, having leased the bare site from the local authority who owned the land. Port Ramsgate had responsibility for port facilities from procurement through operation and maintenance to liaison with commercial and public users of the facilities. During the early 1990s - the period of preparation for expansion - Port Ramsgate employed 100-150 people.

Management structure included a managing director who had an office and staff on-site; a port manager who had day-to-day operational responsibility, and other hands-on managers who operated the port facilities. A consultant port engineer was also retained. His job involved liaising with contractors and statutory authorities regarding development of the port as well as carrying out inspection of structures and devising maintenance programmes. His services were dispensed with before the Berth 3 project got under way.

In taking over operation of the new harbour facilities in 1980, Port Ramsgate had to create a management structure that could handle a wide range of development projects. By the time the Berth 3 upper-deck project was considered it had considerable experience of these. It also had a wide range of outside specialist contacts from whom to seek advice. The executive control of commercial and technical issues conferred the opportunity and responsibility to organise and manage

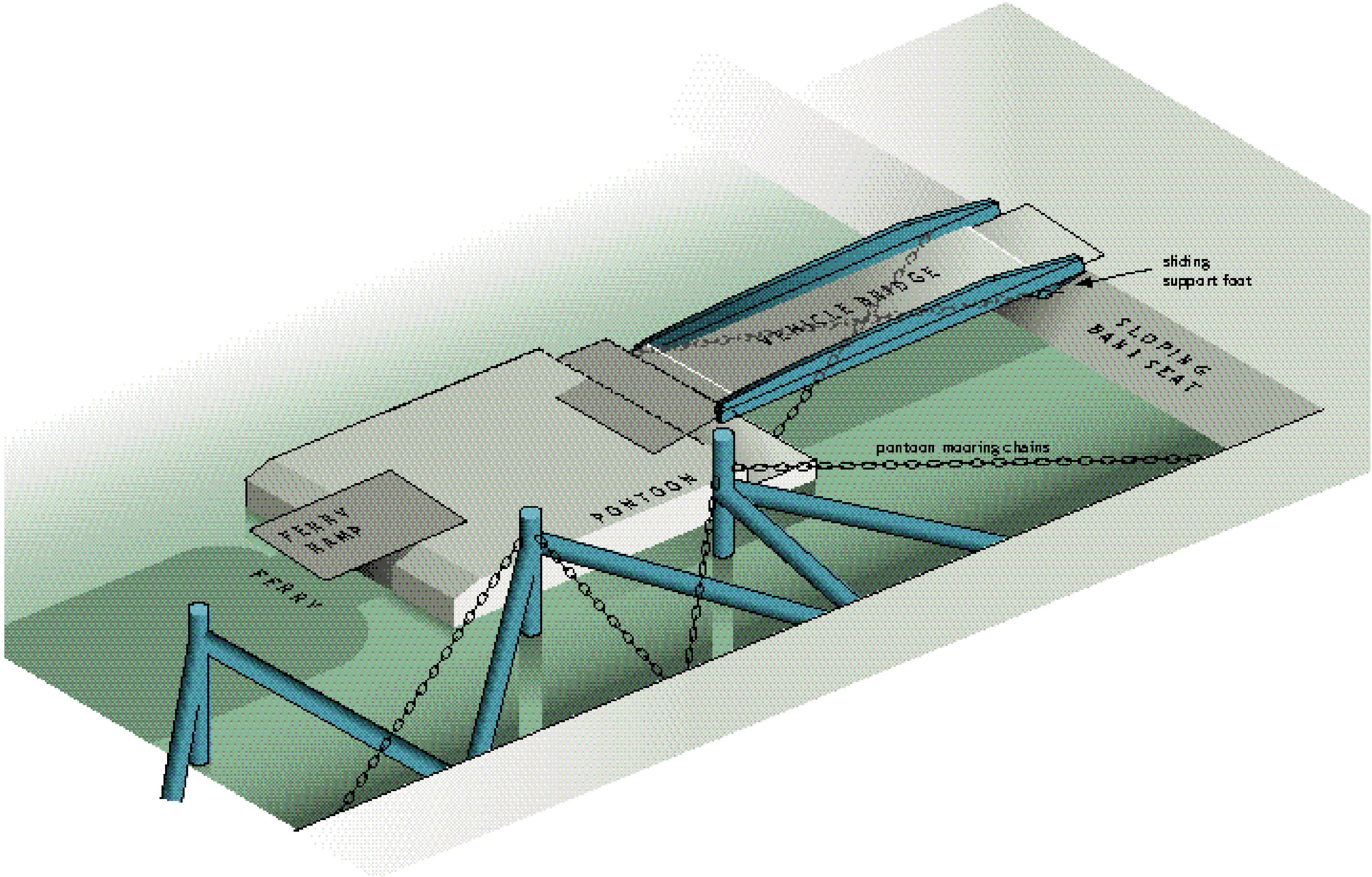

Figure 4: *Berth 3 1985-1994 single-deck linkspan*

design and procurement of facilities that would be safe and easy to operate and maintain. It could decide the basis on which contracts would be placed and decided to obtain the upper-deck steelwork from one contractor on a ‘design and build’ basis. It directly arranged the involvement of many other contractors on associated work. In effect, as well as being the client for the project, it retained the role of ‘main contractor’ and was best placed to set and demand the standards to be followed by all the parties involved. As the port operator it had overall responsibility for the safety of the travelling public using the port facilities.

FARTYGSENTREPRENADER AB ?
The contractor

Fartygsentreprenader AB (FEAB) was a shipbuilding company based in Uddevalla, Sweden employing about 100 people. During the 1980s, FEAB supplied all three of the single-deck pontoon-based linkspans used at Ramsgate. FEAB was approached by Port Ramsgate to carry out feasibility design work to add a second vehicle deck to the single-deck linkspan at Berth 3. This involved liaison with Port Ramsgate senior management and the ferry operator. Port Ramsgate’s consultant port engineer provided a number of ideas. When the contract was awarded on a design-and-build basis, FEAB made arrangements for local companies to carry out installation work at Ramsgate. It provided a director/contracts manager who remained on site at Ramsgate co-ordinating and overseeing installation work through to handover.

FARTYGSKONSTRUCTIONER AB ?
The designer

Fartygskonstructioner AB (FKAB) was a sister company to FEAB specialising in naval architecture (design of ships) and employing about 30-35 people. It shared offices in Uddevalla, Sweden and was owned by Mattsson Group AB. FKAB had designed the single-deck pontoon-based linkspans supplied to Port Ramsgate and was subcontracted by FEAB to design the upper deck and walkway additions to its earlier work.

It designed the walkway supports and the weld detail that failed, causing the collapse. It liaised directly with LR and with contractors brought in by Port Ramsgate on other parts of the development, eg the passenger ramp building through which passengers reached the walkway.

LLOYD S REGISTER OF SHIPPING (LR) ?
The classification society

LR is a classification society (see Appendix 3) established over 200 years ago. About 4000 people are employed worldwide. The main office at Croydon and the LR offices at Crawley (UK) and Gothenburg and Helsingborg (Sweden) were all

involved in the contract.
The single-deck linkspans at Ramsgate had been built under survey and were maintained in class with LR by Port Ramsgate. This involved annual surveys by LR. Port Ramsgate decided to keep the modified Berth 3 structure in class with LR. Accordingly FEAB contracted LR to classify the upgraded berth. LR did not appoint a project leader or lead office to handle the whole contract. Checking of the upper-deck project plans was a head office (LR Croydon) function because of the hydraulically actuated parts of the design. The Swedish offices of LR saw it as their function to visit fabrication yards and the Crawley office's function to survey the installation work at Ramsgate. Port Ramsgate was in contact only with the LR Crawley office but FEAB and FKAB, at various stages, were in contact with each of the LR offices.

The project

22 In early 1994 the single-deck Berth 3 linkspan at Port Ramsgate was substantially modified to provide an upper deck with a new upper vehicle bridge, and a separate high-level walkway was installed to lead from a new shore building to the passenger deck of a ferry. The latter served to completely segregate foot passengers from vehicle traffic. These modifications are referred to as the 'upper-deck project'. The single-deck linkspans had been designed so that an upper deck could be added at a later date. Figure 1 shows Berth 3 after completion of the upper-deck project.

23 The idea for the type and location of the walkway had come from Port Ramsgate and was seen as an 'add-on' part of the design to provide the most versatile arrangement for the different designs of ferry ships which might use the berth.

Description of the walkway

24 The walkway was in three connected sections. The first, from the passenger ramp building at the shore to a portal frame on a floating pontoon, was designed to articulate about its support points at the portal frame and slide to adjust to movement of the sea at its shoreward end; a second, fixed section crossed the portal frame; and a third, lifting section pivoted at the portal frame making the final link to a ferry ship (see Figures 1, 2 and 10).

25 The walkway was made of steel and comprised a rigid frame made up of box section trusses connected by flat bars. The frame was clad with 6 mm thick plate. Window openings were formed between the frame members on both sides. The design length of the shore to pontoon section was 33 m and the walkway was 2.1 m wide and 2.5 m high. The design weight was 21 tonnes. This section of the walkway was secured to the pontoon portal frame at about 10 m above the pontoon deck. Figures 1 and 5 illustrate the layout and structural form of the walkway section.

Figure 5: *Shore end of collapsed walkway photographed from inside passenger ramp building*

26 The ‘passenger ramp building’ connected the walkway to ground level on the shore.

27 The shore-to-pontoon section had four support feet. These had been slid on to stub axles projecting horizontally from each lower corner of the walkway. Each stub axle had been welded into a collar which itself was welded to the lower corners of the walkway. The support feet were designed to rotate on the stub axles. All four support feet had a low-friction pad bolted to their underside. Three of them were designed to slide freely. One - the seaward right foot on the pontoon - had an additional vertical pin (called a pintle) that connected the walkway to a high-level support platform on the pontoon. Figure 6 shows a support foot with the major parts labelled. Figures 7 and 8 show sectioned views of the support feet. When the pontoon moved due to tide, wave, wind and traffic, the feet were designed to adjust position and accommodate any motion. Any motion that the feet could not accommodate was intended to be absorbed by the torsional flexibility of the structure. Figure 9 illustrates how the walkway pivoted and moved as a result of tidal motion.

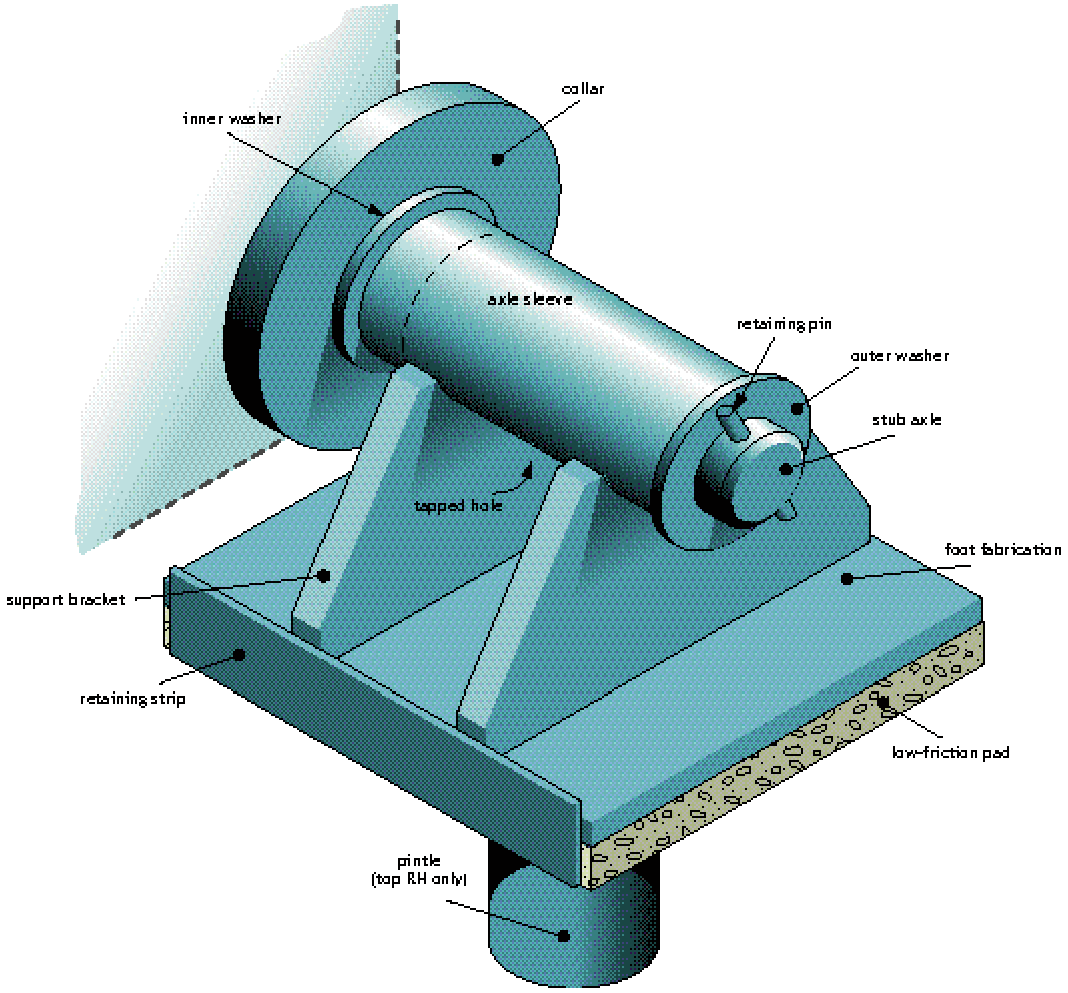

Figure 6: *Three-dimensional diagram of a support foot with parts labelled*

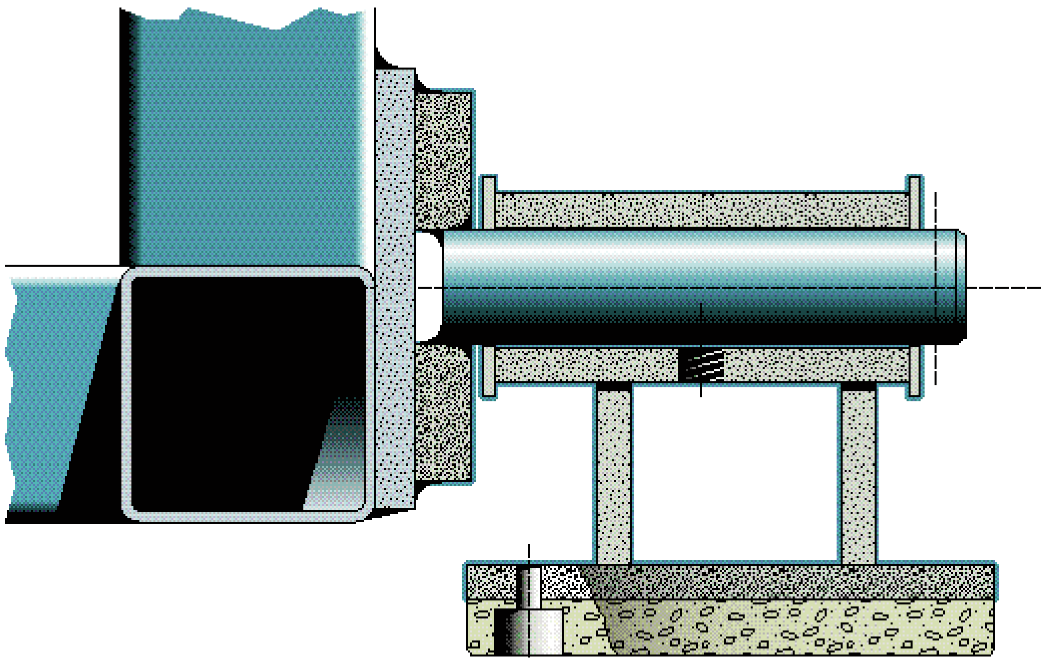

Figure 7: *Sliding support foot - sectioned end view*

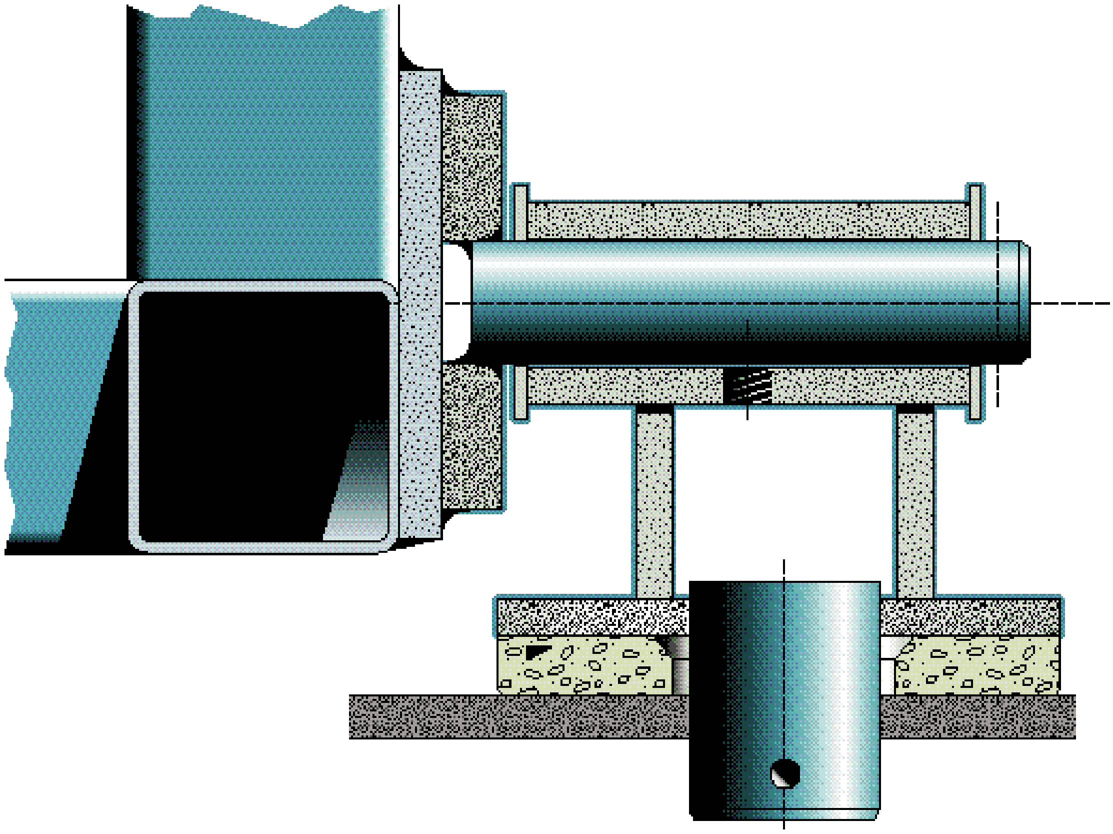

Figure 8: *Pintle support foot - sectioned end view*

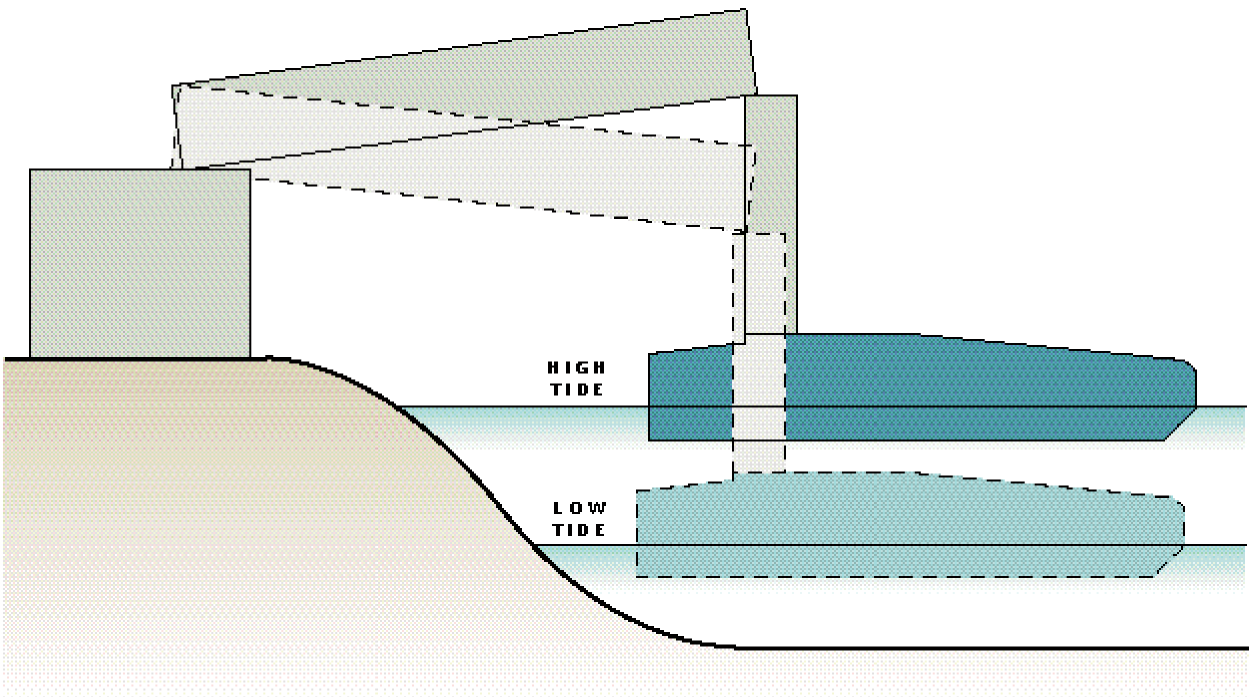

Figure 9: *Diagram showing walkway pivoting with tide*

28 Twenty-four hours before the accident, a port foreman walked the length of the walkway checking for vandalism to the weatherproofing fabric bellows linking the sections. He later reported that the metal flap plate covering the small gap between the shore to pontoon section and the section crossing the pontoon was correctly positioned at that time and that there were no signs of the sections separating.

29 Ten hours before the accident, the port maintenance supervisor walked through the walkway and noted nothing that gave him cause for concern.

30 Just before midnight the ferry *Prins Filip* performed a textbook berthing in calm weather on a falling tide. Vehicle loading proceeded and immediately before the accident, two heavy trailers pulled by port vehicles crossed the lower deck and entered the vessel. This would have caused the pontoon to move in the water.

31 At 00.45, the last remaining foot passengers had walked to the top of the ramp in the passenger ramp building and were about to enter the walkway and board the *Prins Filip*. Several hundred had already boarded. Sea conditions were calm. It was then slack water with low tide due in less than one hour. There was no appreciable wind. A Japanese tourist described walking along the first section of walkway, hearing a noise, being showered with water (rain-water released from the top of the fabric bellows which linked the sections as this was torn) and then running on to the ship knowing that the walkway had fallen behind him. He was the last foot passenger to reach the ship.

32 On the shore side, a security officer was seeing the last of the foot passengers on to the ferry. She heard a terrible noise, the lights went out, and at first she was not sure what had happened. She then saw that the other end of the walkway had fallen from its support platform on to the pontoon below.

33 The duty port foreman was standing on the upper vehicle deck on Berth 3 and heard the walkway collapse. He raised the alarm and called for the attendance of the emergency services at 00.49.

34 Figures 10 and 11 show the fallen walkway. Figure 12 shows the support platform from which the walkway fell. Figure 5 shows the collapsed walkway at the shore end. Figure 13, taken after the walkway had been lifted clear, shows the slideways at the shore end looking towards the pontoon fixed section of walkway. This is the gap the walkway had spanned. These photographs were taken during the night and early morning following the collapse.

Major incident

35 Rescue and emergency services deployed very rapidly and declared a major incident. The ship's manifest was checked and an initial discrepancy with the

Figure 10: *Berth 3 from south west - walkway span in fallen position*

Figure 11: *Collapsed walkway from pontoon deck*

Figure 12: *Pontoon support platform and fixed section of walkway*

Figure 13: *The gap the walkway spanned to the pontoon - and showing ends of passenger ramp slideways*

passenger count indicated that up to 20 passengers could be missing. The Royal National Lifeboat Institution's (RNLI) assistance was requested as it was feared that passengers could have been thrown out of the end of the walkway and into the water. This did not prove to be the case.

36 About 80 emergency personnel attended the rescue, many remaining on site most of the night. These included staff of the Kent Fire Brigade, Kent County Constabulary, Kent Ambulance NHS Trust, a Mobile Medical Team from Thanet District Hospital, the RNLI and the Sussex Police Underwater Search Unit. Employees of Port Ramsgate, the crew of the port safety boat and a doctor from among the passengers were also involved. All the seriously injured were lying where they fell in the walkway. Access was difficult and the lighting had failed. The fallen walkway was inclined at an angle of 30-35^{o} with the shoreward end still resting in the passenger ramp building. The fallen end was embedded in the pontoon. The screeching sound of metal moving on metal heightened concerns that further collapse could occur. Efforts were made to secure the shoreward end of the walkway. Casualties were taken to the Kent and Canterbury Hospital in Canterbury. All casualties and bodies of those who died were recovered by 02.11.

37 Of the estimated 20 passengers who were on the walkway as it fell, approximately one-third walked away with minor injuries or uninjured, one-third were hospitalised with serious back and leg injuries (7) and one-third suffered fatal injuries (6).

38 Locally based HSE inspectors attended the scene from 03.30 and a specialist engineering inspector was on site from 08.30.

39 What proved to be the immediate cause of the collapse was identified within hours by the combined efforts of Port Ramsgate staff, their engineering consultants and HSE inspectors.

40 When dawn arrived a Kent Police 'scenes of crime' photographer and a Kent Fire Brigade video cameraman remained on site to help record the scene.

THE INVESTIGATION

Organisation

40 To minimise duplication of effort, the responsibilities of the Kent police and HSE for investigating the incident were agreed at an early stage. The police pursued the enquiries necessary for HM Coroner's inquest and to address any possibility of manslaughter charges. They interviewed many of the 500 passengers on the *Prins Filip* and some shore personnel and crew before allowing the ferry to sail.

40 HSE inspectors investigated all aspects of the collapse related to the

enforcement of health and safety legislation.

HSE's investigation team

40 The investigation started under the immediate direction of the principal inspector who was responsible for inspecting Ramsgate Harbour. He was at the site from 03.30 on the morning of the incident. He and inspectors of his group spent several weeks at the site over the following months. The team, and support for it, was expanded as the need for varied types of expertise was identified, as follows.

(a) A principal specialist inspector (engineering) was at the site from 08.30 on the day of the incident, confirmed the likely cause of failure, authorised the removal of the walkway and identified items of physical evidence for removal for laboratory examination. Afterwards, he co-ordinated the technical inputs to the investigation.

(b) HSE's Health and Safety Laboratory (HSL) provided a team of engineers and scientists to undertake the collection and detailed analysis of physical evidence and to assess the design of the walkway and the design calculations. Metallurgical examination of critical parts of the walkway was carried out in the HSL laboratories.

(c) The Docks National Interest Group (NIG), which serves as HSE's centre of expertise for dealings with the docks industry, co-ordinated a national check with inspectors and dock operators to ensure that similar incidents could not happen at other facilities. They also provided information from national and international organisations about the design and operation of ships' berths.

(d) Inspectors of HSE's Offshore Safety Division (OSD), who inspect the offshore oil sector, provided expert advice on marine structures, projects involving their construction and the role of classification societies.

(e) HSE's Solicitor's Office engaged leading and junior counsel to provide legal advice to the investigation team when it became apparent that legal proceedings for serious contraventions of health and safety legislation were likely.

(f) Two independent engineering consultants were engaged early in 1995 to report and advise on practices current within the field of maritime structural engineering; they gave evidence at the trial.

The initial approach to investigation

41 As in many investigations, HSE inspectors needed to satisfy themselves that any continuing hazard at the site was addressed. They also had to consider whether operation of similar installations at other locations needed early warning of a serious potential hazard. So the following questions needed to be addressed:

(a) Was the upper vehicle deck safe to remain in service?

An examination of the upper vehicle deck and bridge caused such major concern that a Prohibition Notice was served on Port Ramsgate on 15 September 1994 to stop commercial use of Berth 3 until an independent competent person had examined the design and construction work and declared the structure free from design or operational defects. Port Ramsgate appointed consulting engineers to carry out the assessment. A number of defects were identified and rectified over the months that followed. A summary of these defects and remedial action taken is included in Appendix 8.

(b) Were there other walkways of similar construction in use in the UK and at risk of collapse?

Rapid enquiries by the Docks NIG and other inspectors across the country established that there were none.

(c) What caused the collapse?

Answering this question involved recovering and formally taking possession of physical evidence including the failed parts from the scene, locating and collecting plans and paperwork associated with the berth and taking statements from eye-witnesses, Port Ramsgate employees and people involved with the design and fabrication of the walkway. Scientific work was undertaken to determine the technical causes of the failure and assessment of the walkway design and calculations were made.

(d) Who was responsible for the collapse?

This line of enquiry considered the role of the various organisations and individuals involved in the project to determine their responsibilities and assess compliance with their duties under the Health and Safety at Work etc Act 1974 (HSW Act) and associated legislation.

Forensic investigation

The HSL investigation was commissioned to examine two main issues:

(a) The causes of the stub axle weld failure

This involved examination and photographic recording of the recovered pieces; taking samples for chemical analysis to determine grades of steel involved; microscopical examination and testing to determine metallurgical condition, hardness etc; and fractographic examination to establish mode of failure. Representatives of all parties involved were invited to see the recovered parts before laboratory dismantling or destructive examination.

(b) The design of the support arrangements for the walkway section

This involved consideration of the berth, forces of the sea and weather acting on it and examination of the design drawings to allow calculation of in-service stresses in the stub axle welds. FKAB and LR design assumptions and calculations were also assessed.

Evidence from the scene

42 It was quickly apparent that failure of the welded joint attaching the right-hand seaward stub axle to the walkway had allowed the walkway to fall from its support platform at the portal frame. Figure 2 shows this joint in relation to the rest of the structure. The collar into which the stub axle had been welded remained attached to the walkway. The support foot with the vertical pin/pintle remained attached to the pontoon support platform with the stub axle seized in its bearing. The left-hand stub axle at the pontoon end, together with its sliding support foot, were also detached and were missing. They were later recovered from the seabed by police divers.

43 After the collapse, the walkway was resting in a precarious position and there was a risk of further collapse and damage. Two mobile cranes were used to support the fallen section during initial investigation (see Figure 10) then to recover and place it on the upper vehicle bridge. Parts of the walkway were identified for further detailed examination, marked, cut away from the structure and placed in secure storage. Viewed from the shore, the support feet at the pontoon end were called the 'seaward left' and 'seaward right' feet. Those at the shore end were called the 'shore end left' and 'shore end right' feet. The seaward right foot is the one with the vertical pin or 'pintle' that attached the walkway to the pontoon.

Condition of the walkway structure

44 Damage to the walkway structure from its fall was slight. None of the windows were broken.

The condition of the seaward support feet

45 Following the accident, the seaward right support foot was still connected to the support platform by the vertical pin/pintle. It was found rotated at an angle of approximately 45° about its vertical axis, suggesting that it had been pulled into this position as the walkway moved towards the edge of the platform.
The broken-off stub axle protruded from the support foot and the fracture surfaces on the axle and collar were dark and rusted over much of their surface. A recent indentation/burr in the support foot base plate immediately below the end of the stub axle was the only other obvious damage. This 'notch' suggested contact with the edge of the disconnected walkway. Figure 14 is a photograph of the seaward right support foot following the accident. Figure 16 shows the collar to which it had been welded.

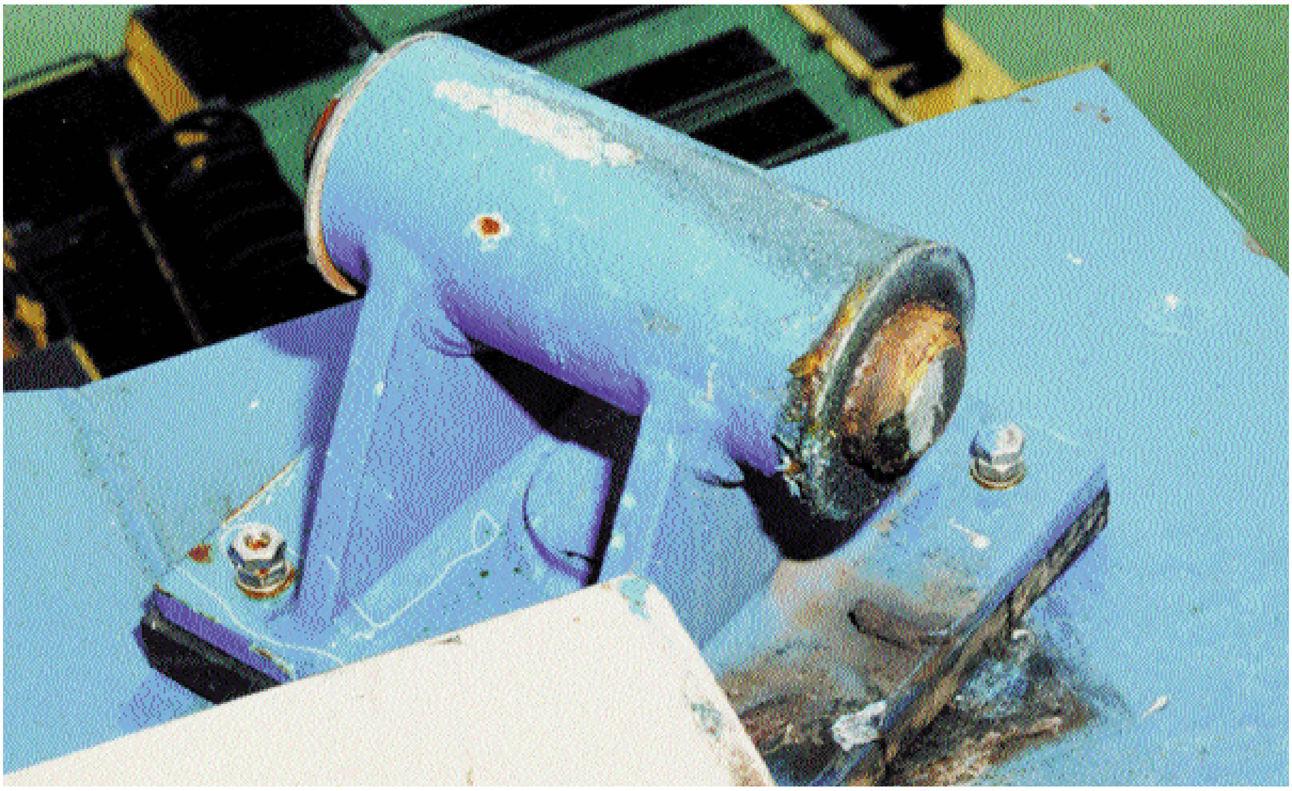

Figure 14: *Seaward right support foot as found*

46 A retaining ring had been welded on to the pintle on the underside of the platform. The weld was ground out in the laboratory to remove the ring and release the support foot. The contact surface of the plate was found to be free of lubricant and lightly rusted on the edge adjacent to the walkway. Figure17 shows the contact surface after removal of the support foot.

47 The section of support platform on which the seaward left foot had rested showed rust-coloured 'prints', indicating this support foot had rested in at least two positions before the collapse, whereas it was required to constantly slide to

Figure 15: *Seaward right stub axle - fracture surface - seized in support foot*

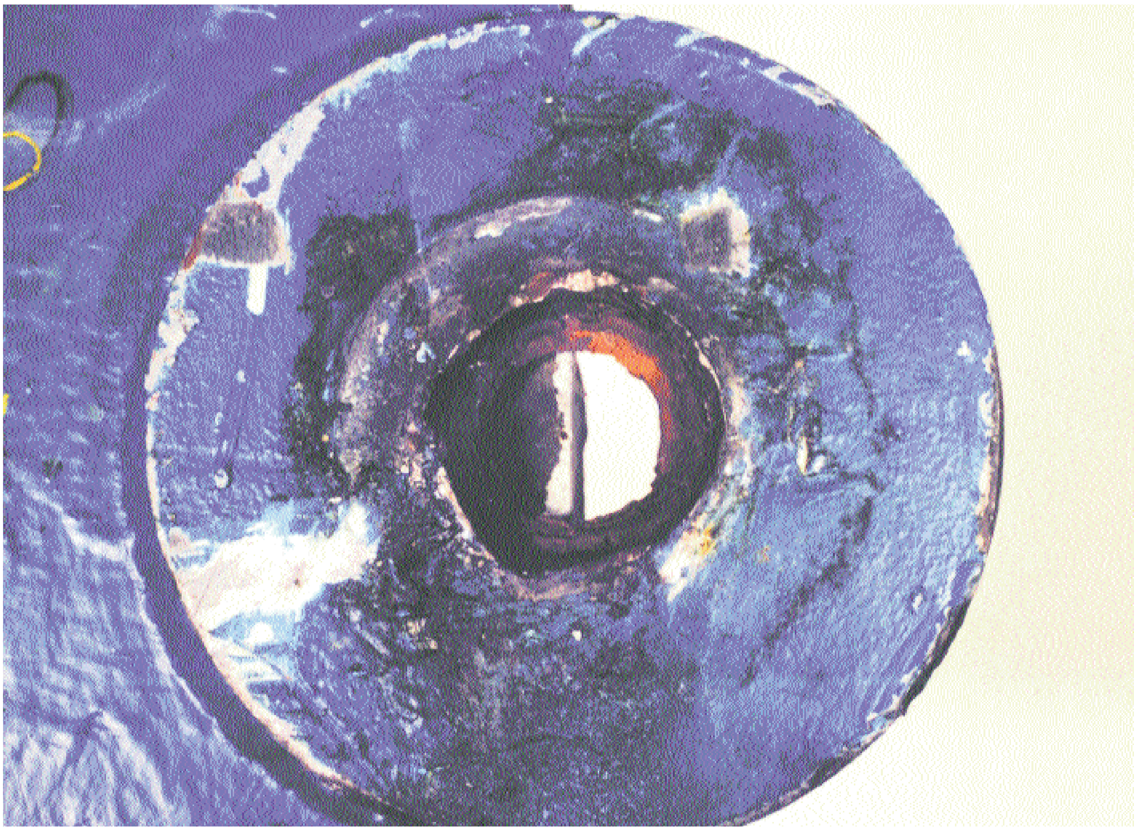

Figure 16: *Seaward right collar welded to corner of walkway*

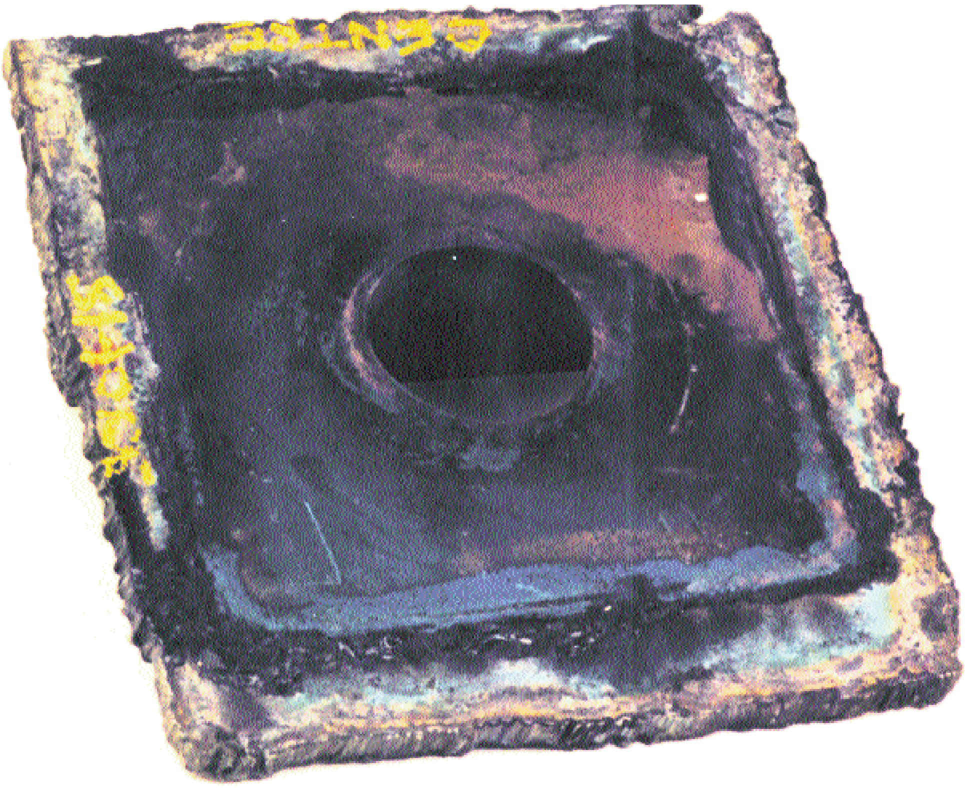

Figure 17: *Seaward right support platform after dismantling and removal of seaward right foot*

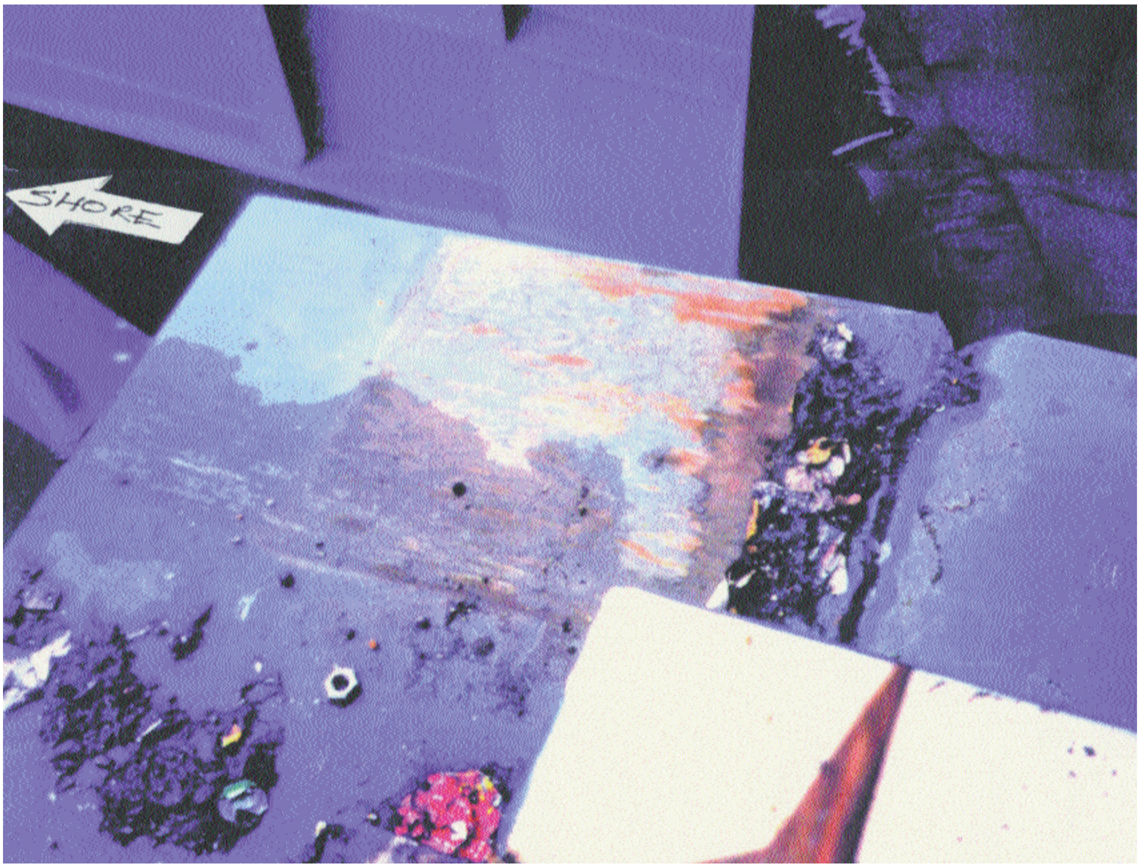

Figure 18: *Support platform showing position of seaward left-hand foot assembly*

allow for pontoon movement. The painted finish below the low-friction contact area was also much worn away and the base metal rusted, especially on the seaward edge of the contact zone. Figure 18 is a photograph taken the day after the accident, showing the top left contact area of the support platform.

48 In the laboratory, the top right stub axle was found to be partially seized in its support sleeve; application of a torque of 400 Newtons (Nm) achieved a rotation of 5-10^{o} of arc, this being roughly equivalent to the rotation necessary for the walkway to adjust for the tide. The stub axle was then driven out for detailed examination.

49 The seaward left support foot was submerged in sea water for approximately 12 hours before recovery by a police diving team. The fracture surfaces on the stub axle and collar were rusted over two-thirds of their circumference but not as heavily as on the seaward right. The stub axle was in the support sleeve. The low-friction pad was not attached and was never found.

50 The seaward left stub axle was seized within the support sleeve. Figure 19 shows the failed seaward left stub axle protruding from its support foot. Dismantling required machining the support sleeve into two pieces to free the stub axle. The grease distribution groove at the bottom of the sleeve bore was found to be completely blocked with rust and metal debris. Despite its immersion in sea water, it is likely that the seaward left support foot was not rotating on its stub axle before the accident.

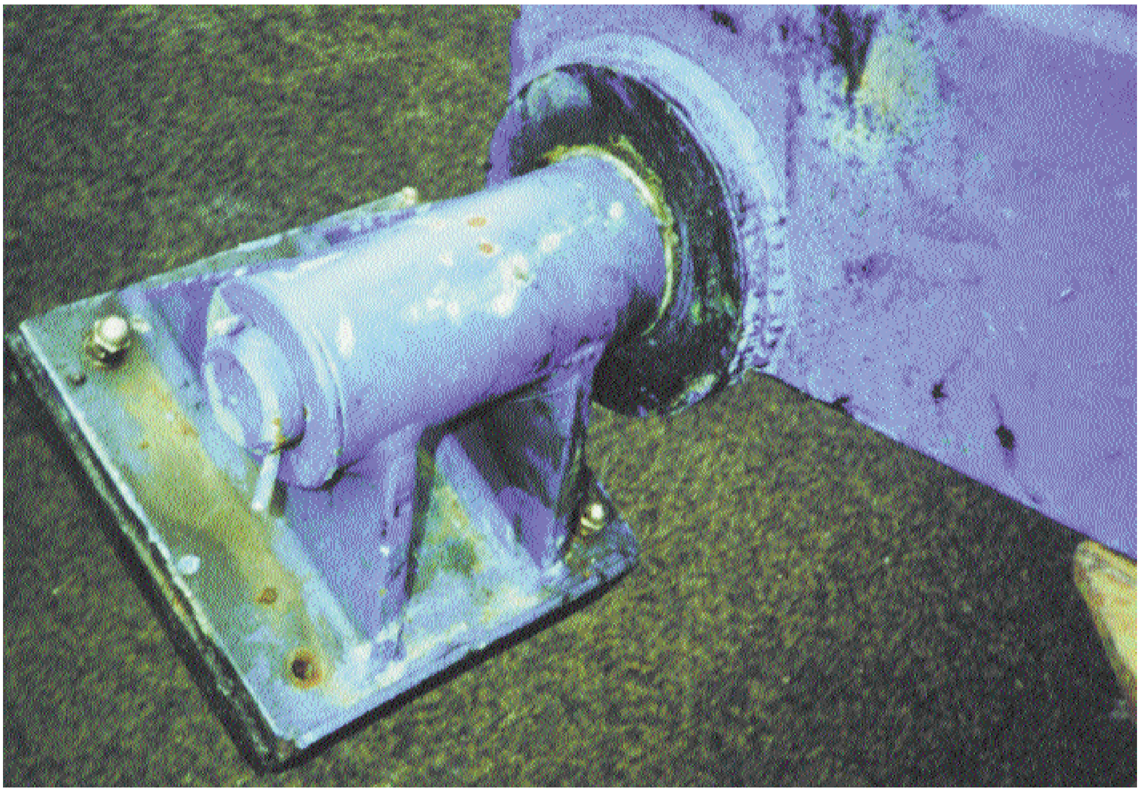

Figure 19: *Shore end right support foot still attached to walkway*

Shore end support feet

51 The shore end left and right support feet were on their stub axles which were still attached to the walkway. Both these support feet were free to rotate.
Figure 20 shows the shore end right foot following recovery of the walkway.
One fixing bolt for the shore end right low-friction pad was lying side-on and embedded in, but protruding from, the underside of the pad. The other bolts were loose.

Figure 20: *Seaward left stub axle - fracture surface - partially seized in support foot*

The underside of the pad was coated in grease apart from a dry area extending across the inner third of the pad. This area was scored by sliding contact with the slideway. Figure 21 shows these features.

52 All four support feet had been manufactured with a threaded hole in the underside of the stub axle support sleeve as shown in the fabrication drawing. These were all capable of taking a grease nipple or ‘Greas-o-Matic’ automatic grease dispenser. There were no indications that these holes ever had anything fitted to them.

Figure 21: *Shore end right support foot - underside of low-friction pad*

Shore end slideways

53 The ‘U’ channel slideways fitted in the passenger ramp building were photographed and examined but not removed. The sliding surfaces had grease on them and build-up of grease and debris less than 500 mm from the edge of the building indicated the seaward limit of recent sliding action. The slideways had been galvanised but both sliding surfaces had areas free from grease where rusting had occurred. This extended from their inner sides across approximately one-third of their width. The right-hand slideway was visibly in worse condition in this respect. The galvanising in these areas had been worn away. Figure 22 shows the right-hand slideway in the passenger ramp building.

Technical defects ? metallurgy

54 Photographs were taken before cleaning and dismantling work at HSL. Figure 15 shows the seaward right stub axle protruding from its support foot and Figure 16 is the corresponding seaward right collar. Figure 19 shows the seaward left stub axle protruding from its support foot and Figure 23 is the corresponding seaward left collar.

Figure 22: *Right-hand slideway in passenger building showing rusting*

55 The four support foot assemblies were examined to determine the materials, method of manufacture and mode of failure. A technical account of the metallurgical examination and findings is given in Appendix 4. The following section summarises this work.

56 Each stub axle had been engaged approximately 16 mm into its 25 mm thick collar. The parts had been welded together using two circular welds around the circumference of the stub axle.

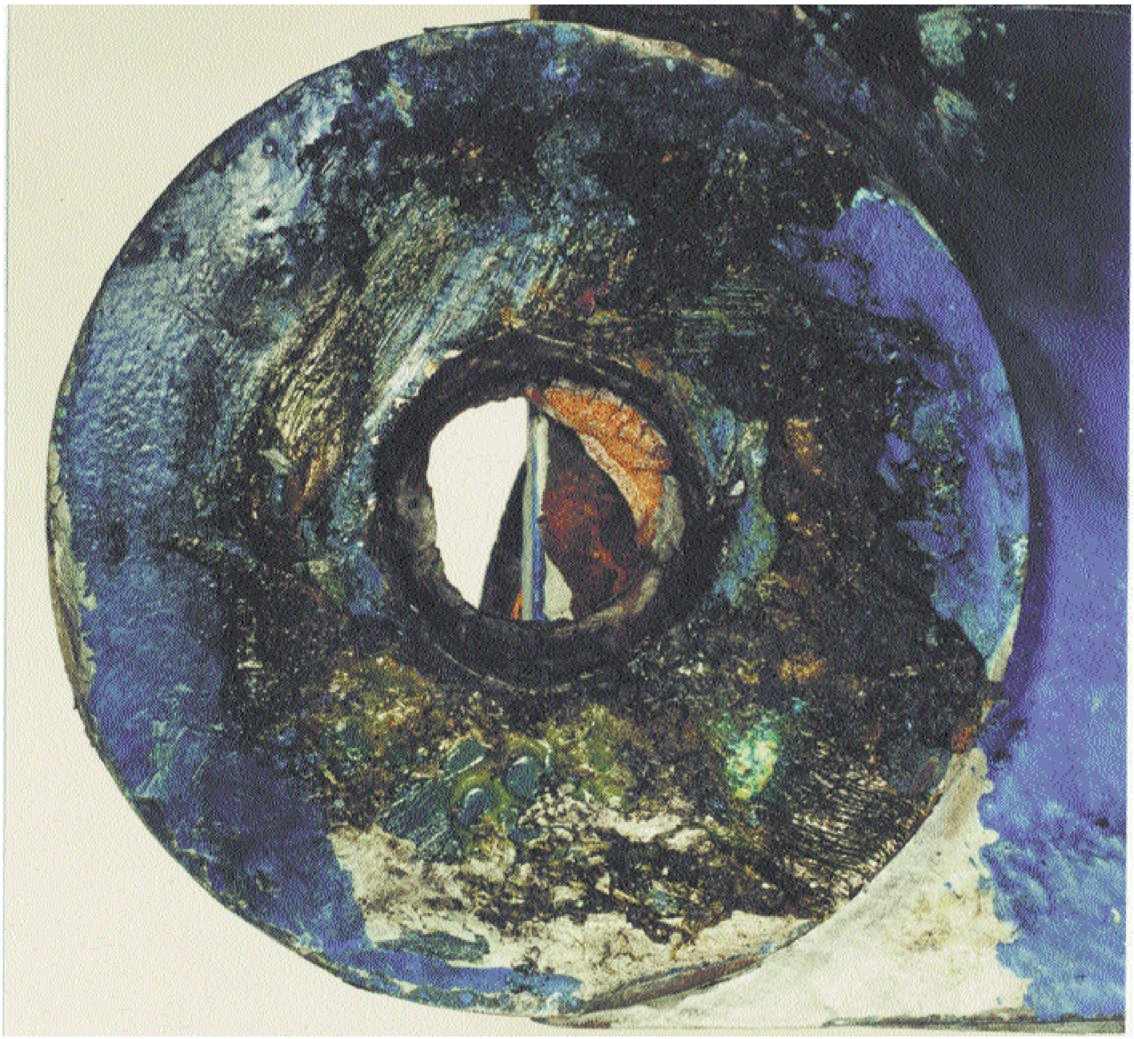

Figure 23: *Seaward left collar welded to corner of walkway*

57 Failure of both axle/collar joints at the pontoon end of the walkway had occurred at, or close to, both welds. The stub axles were found to have been made of medium carbon steel as specified on the fabrication drawing. Laboratory examination of the fracture surfaces showed that the failure occurred as a result of fatigue cracking followed by overload.

58 Fatigue cracking occurs in a structure when a small but significant force is applied to it cyclically. It is akin to bending a piece of wire backwards and forwards until it breaks. The force involved each time the wire is bent is not enough to break the undamaged wire in one go. After a number of bending cycles, a crack starts to grow from the weakest point. At each further bending cycle the crack grows a bit more (ie propagates). Eventually the force involved is enough to break the remaining intact metal. In essence this is what had happened to the stub axle welds although the plastic deformation which occurs in a piece of wire did not occur. Fatigue failure in an engineering structure can involve large numbers (ie millions) of load cycles and a variety of loading conditions. The dangers of

fatigue cracking are widely known where structures are subject to cyclical loading. Because of this, it is normal practice for designers to ensure that fatigue will not lead to structural failure within the operating life of the structure.

56 The seaward right stub axle welds (this being the support with the pintle) had completely separated some time - possibly days - before the accident. The seaward left stub axle welds had failed around much of their circumference by fatigue cracking, with the final ligament of attachment breaking during the accident. Because the stub axles were made of medium carbon steel, they required a special welding procedure including preheating of components before welding and heat treatment after welding. None was used. The welds were of very poor quality and contained many defects including:

(a) lack of fusion - weld metal failing to join to the base metal - typically caused in arc welding by insufficient power;

(b) lack of penetration - the weld does not go deep enough into metal to be joined - a result of insufficient heating or working too fast;

(c) intergranular cracking - cracks formed as the weld metal contracted on cooling;

(d) porosity - caused by gas bubbles remaining in the liquid weld metal. This frequently occurs when damp materials are used; and

(f) high-hardness zones - areas in the heat-affected zone of the stub axle were hard and therefore brittle due to lack of heat treatment after welding.

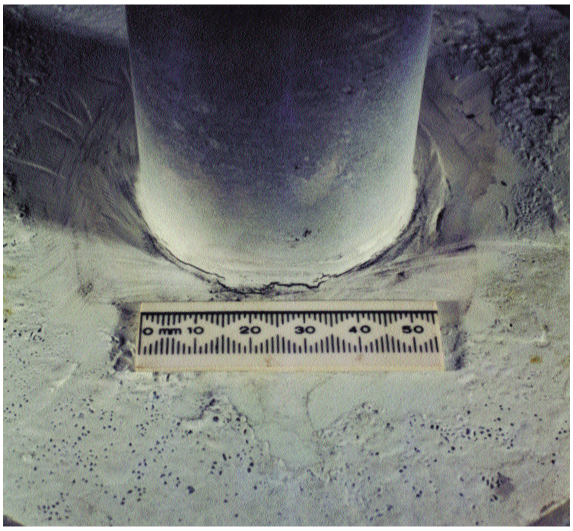

Figure 24: *Shore end right stub axle/collar joint from below - fatigue cracks*

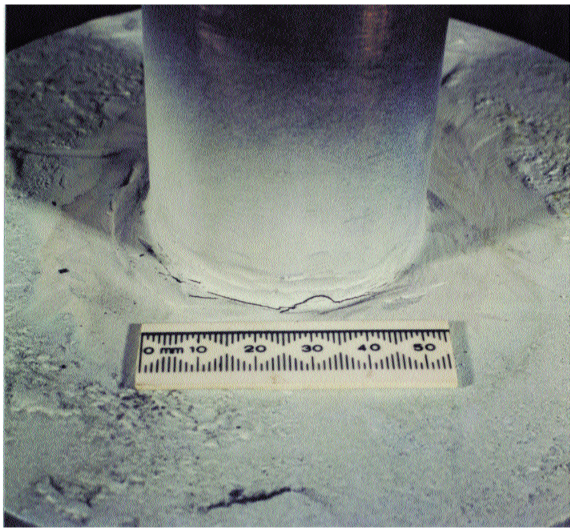

Figure 25: *Shore end right stub axle/collar joint from above - fatigue cracks*

60 In addition, in all cases, grinding carried out on the outer weld had left scratches on the surface of the weld and the stub axle. On a microscopic scale these formed sharp surface irregularities from which multiple fatigue cracks had initiated. The presence of the other defects had assisted crack growth.

61 Although intact, the shore end stub axle to collar welds also had well advanced fatigue cracks. Figures 24 and 25 show the fatigue cracking

found on the shore end right stub axle assembly.

62 The necessity for special precautions to be taken during welding of medium carbon steel should have been recognised from the outset by the designers. The fabrication drawing should have included, or referred the welder to, a weld procedure document. This should have been a straightforward procedure that is suitably dealt with by LR Rules (see Appendix 3). In this case the LR *Welding rules*[3] were not followed by FKAB, FEAB or LR.

Technical defects ? design

63 HSL reviewed the walkway design from two perspectives:

(a) Was the design defective and, if so, in what respects?

(b) How should the designer and those responsible for checking the design have assessed the design?

64 A summary review of design calculations carried out by FKAB and LR and further details of the HSL design assessment can be found in Appendix 5. Appendix 6 provides a comparative table of results of stress calculations carried out by FKAB, LR and HSL.

By considering the design concept it was clear that:

(a) The walkway was subject to environmental forces such as tide, wind and wave; and operational forces such as vehicle movements and heavy berthing of ferries.

(b) The structure was subject to dynamic forces in that it led from a static shore structure to a moving pontoon.

(c) The walkway structure was likely to be torsionally stiff.

(d) The design would need to provide support and articulation to allow movement in all directions. Figure 26 illustrates the six degrees of freedom - three linear directions of motion and three rotations. The height of the walkway above the pontoon would have the effect of amplifying small movements (rotations) of the pontoon.

(e) The support feet were cantilevered from the walkway sides and the load path would not be in a simple vertical line. The load acted on the stub axle/collar joints to create a bending force, so that the stress was increased in proportion to the length of the stub axles acting as a lever (known as the moment arm). Figure 27 illustrates the concept of a 'load path'.

65 Based upon the assessment of the walkway support concept, HSL concluded that:

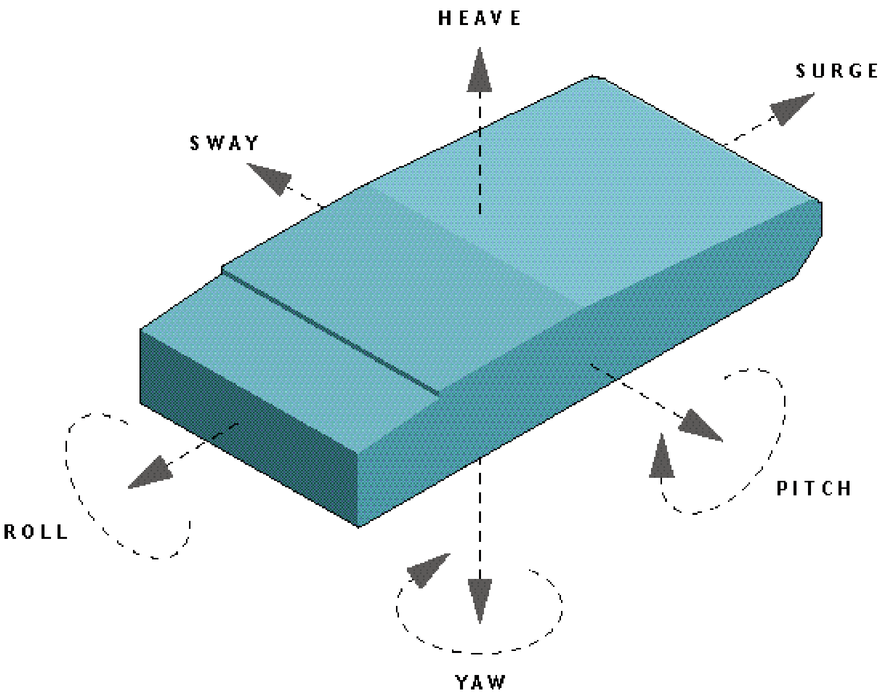

Figure 26a: *Six degrees of freedom explained*

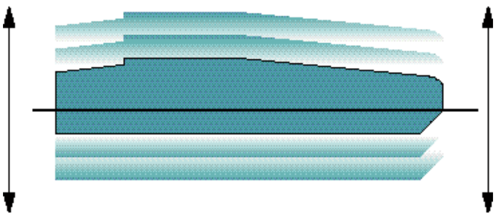

Figure 26b: *Pontoon heave*

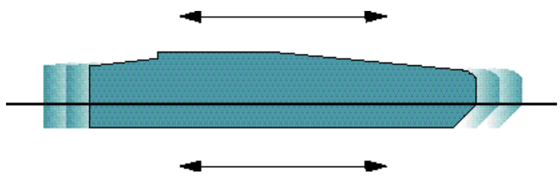

Figure 26c: *Pontoon surge*

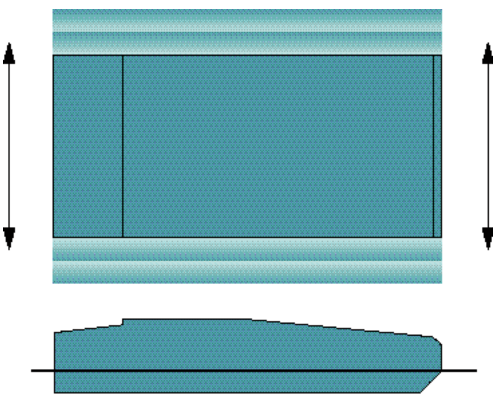

Figure 26d: *Pontoon sway*

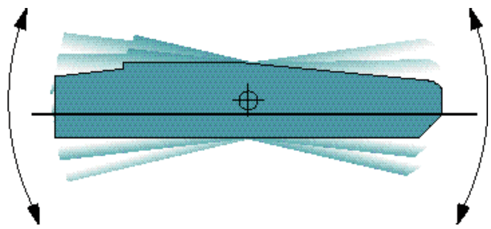

Figure 26e: *Pontoon pitch*

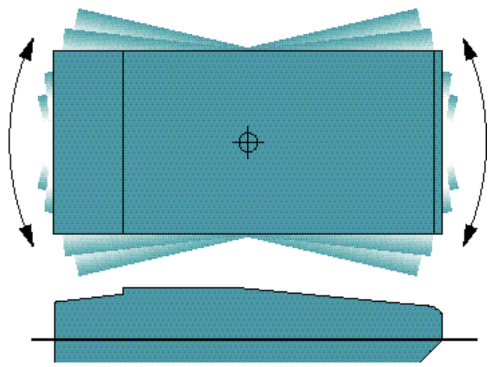

Figure 26f: *Pontoon yaw*

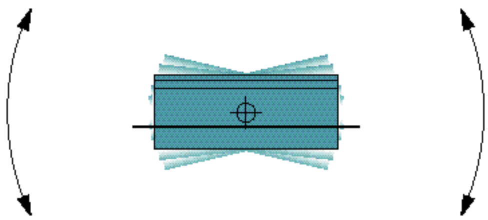

Figure 26g: *Pontoon roll*

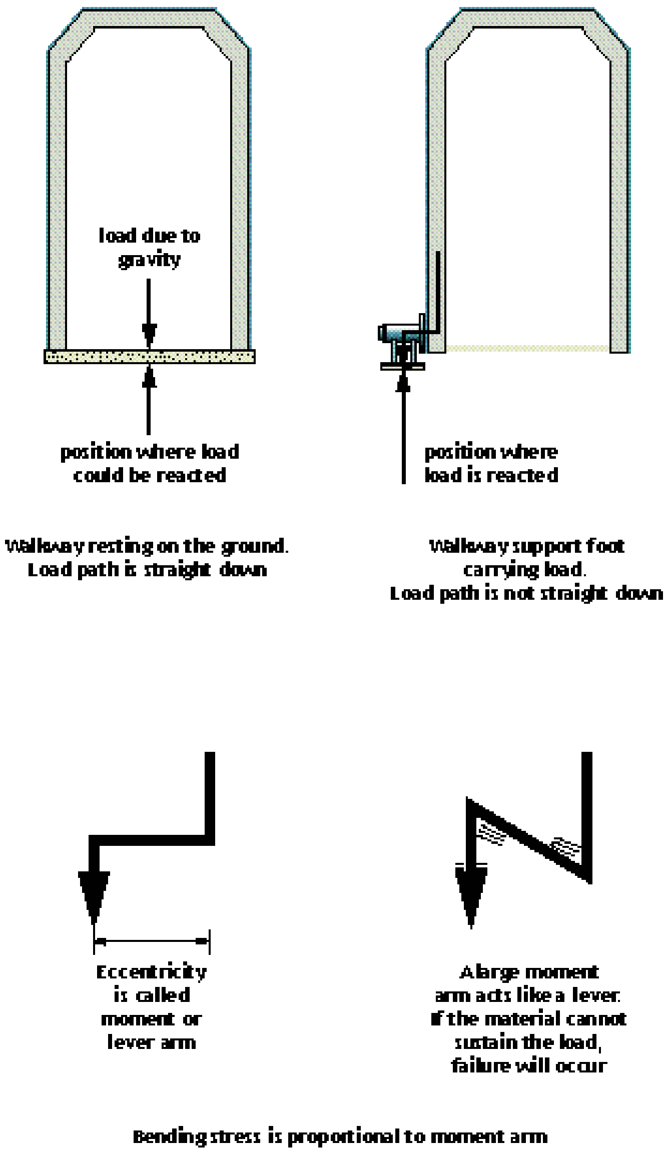

Figure 27: *The concept of load path eccentricity and moment arm*

(a) The design of the supports did not provide for roll of the pontoon.
(b) At times, because the walkway was torsionally inflexible, it would be supported on just one foot at each end. This is referred to as 'two-foot support'.

(c) Even if this fundamental design deficiency had not been identified, the design calculations should have assessed at least a reasoned 'worst case' option of the vertical load acting less than evenly on all four support feet.

(d) A design relying on four welded, horizontal stub axles was going to be very susceptible to errors of stub axle and support surface alignment. This is illustrated in Figure 28.

66 HSL engineers made calculations based on static and dynamic loadings derived from visualising how the load paths from the stub axle collars would be transferred

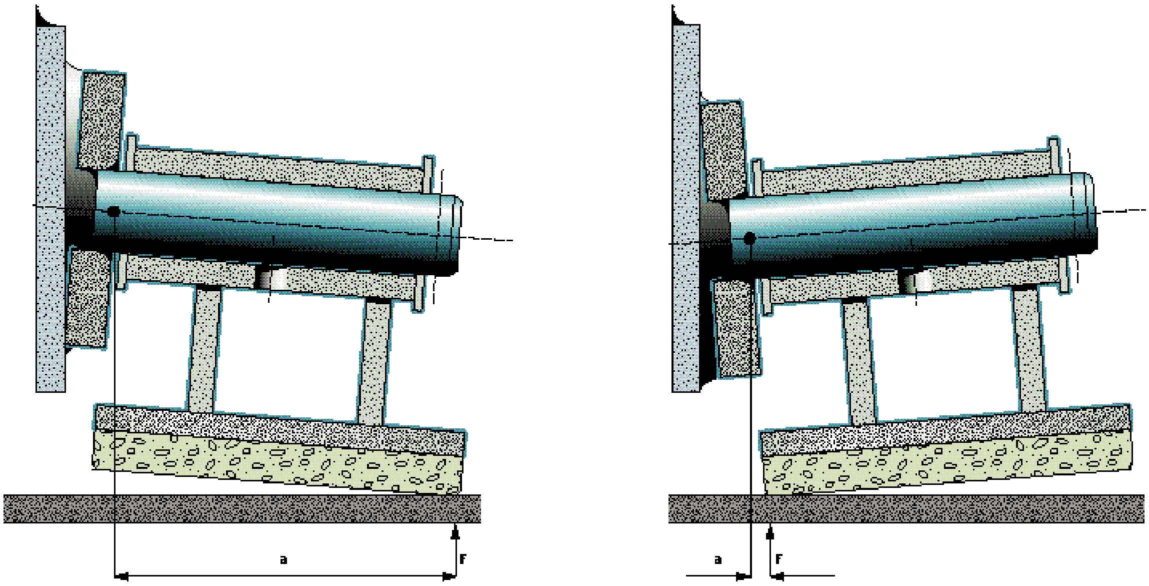

Figure 28: *Effect of stub-axle misalignment on bending arm moment - exaggerated to demonstrate principle*

through the stub axles and the support feet. Two scenarios were tested:

(a) with four-foot support and one-quarter of the load carried evenly through each foot (best case); and

(b) with two-foot support and half the load carried evenly through each of these feet.

67 For each of these two scenarios, HSL assessed the moment arm as 115 mm. Both sets of calculations covered the design static loading and dynamic loadings based on reasoned assumptions. *(Static* loading takes account of the dead load of the walkway; for convenience of calculation the weight of the passengers was included as static load. *Dynamic* loading takes account of other forces caused by movement of structure due to motion of the sea, heavy vehicle movements, ship berthing impacts, and the friction of the support feet's sliding pads in their channels; it would also include loading associated with passenger movement through the walkway.)

68 The horizontal stub axles carried the load in a cantilever mode such that the actual load transferred increased in proportion to the length of the stub axle acting as a lever (known as the moment arm).

69 The above calculations, together with a range of assumptions and calculations of the number of cyclic loadings, enabled fatigue calculations for the stub axles to be made and probability of failure to be assessed. In both cases failure was predicted in alarmingly short timescales. Even where the 'best case' scenario was calculated (all four feet evenly loaded), failure by fatigue cracking was predicted within a small fraction of the presumed 20 years design life of the walkway. Failure was certain to occur; the only question was 'when?'

FKAB and LR calculations

70 The FKAB and LR calculations suggest that both the designer and those checking the design had difficulty visualising the structure and how it would be subjected to dynamic loading. In particular, FKAB failed to realise that the support feet and axle bearing sleeves would tilt under static and dynamic stresses and this would result in a variable length of axle moment arm (see Figure 28). FKAB apparently assumed a 65 mm moment arm. LR seriously erred in considering the moment arm and assessed it as 25 mm although the assumption on which this was based was not given. **No fatigue calculations were made by FKAB or LR.**

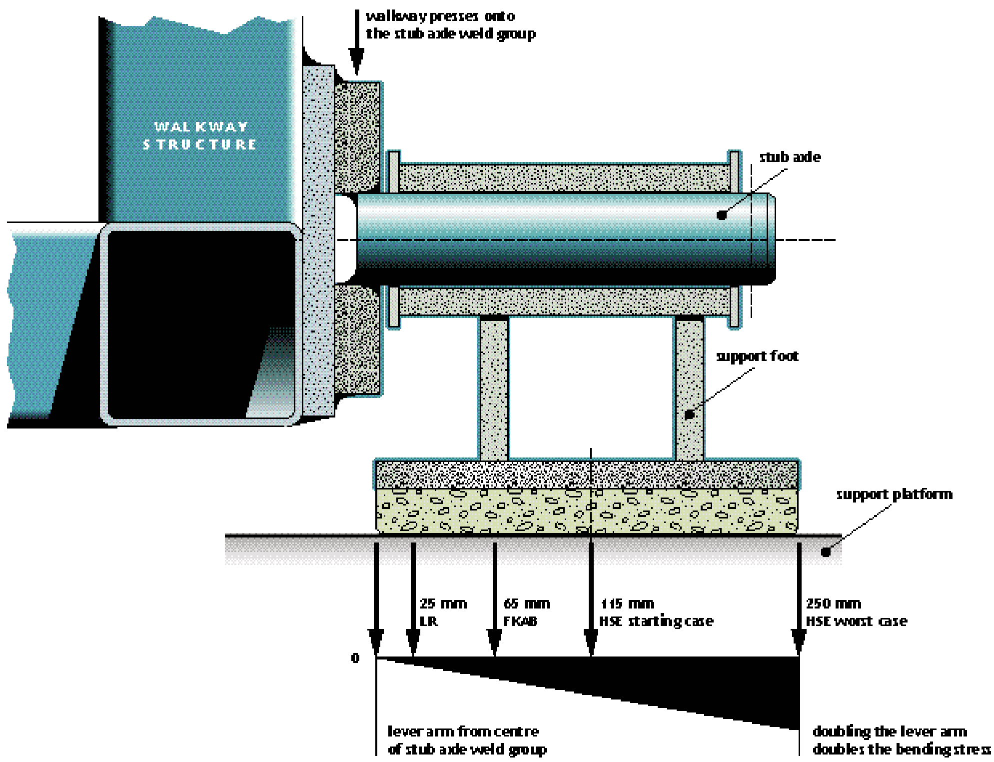

Figure 29: *Stub axle lever arm load path through support foot*

71 Neither had assessed a realistic loading scenario, let alone one that would have proved the long-term structural viability of the walkway. FKAB did not provide a layout drawing showing how the walkway was to be supported. However, the support foot fabrication drawing shown in Figure 30 contains sufficient visual information which, when combined with knowledge of the length, weight and positioning of the walkway, would have allowed a professional engineer to reject the support concept. Calculations should only have been needed to provide formal endorsement of such a rejection.

72 Appendix 6 contrasts the outcome of HSL and independent expert static stress calculations with those carried out by FKAB and LR.

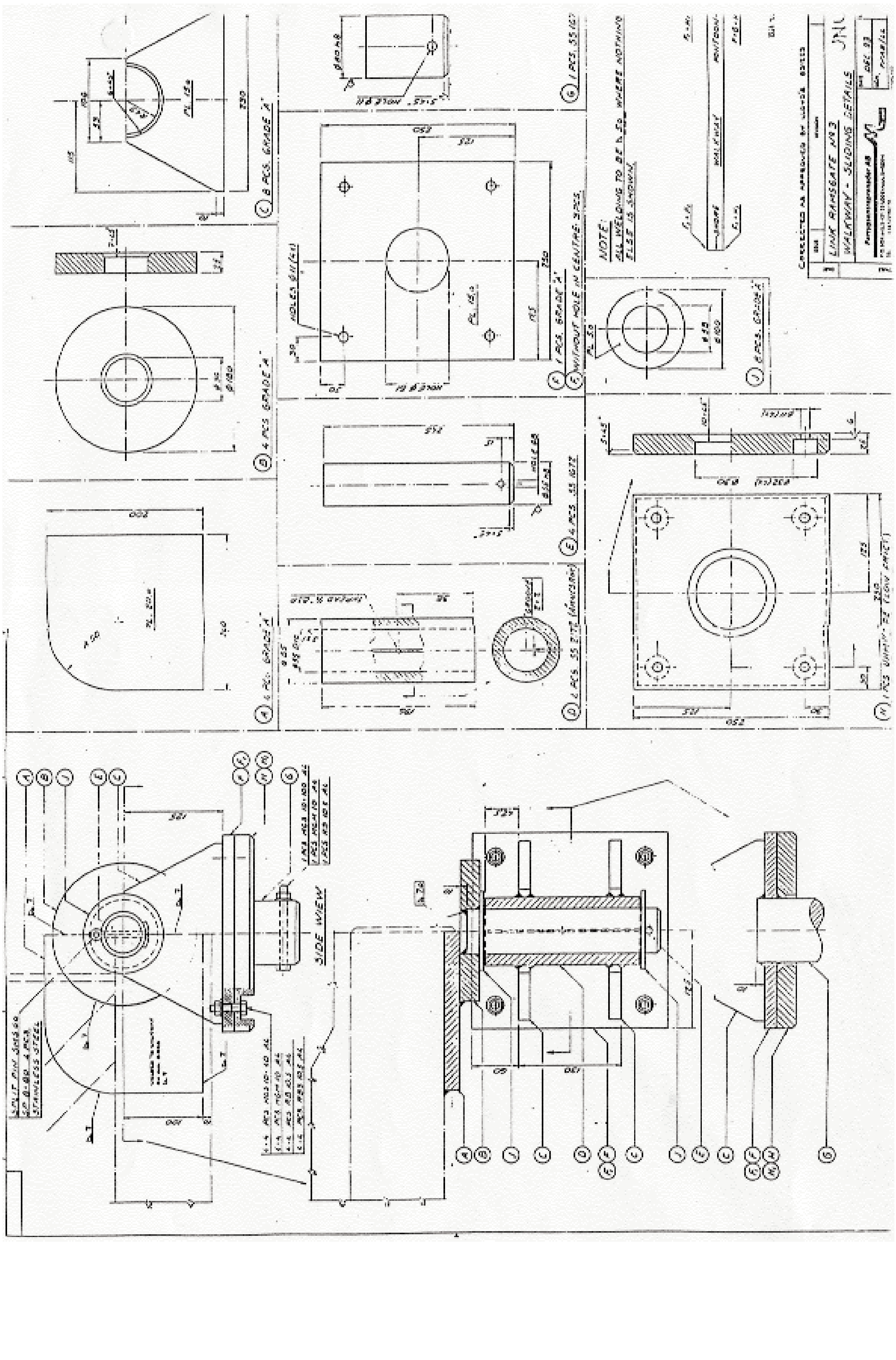

***Figure 30:** Reduced size copy of foot fabrication drawing*

73 This section outlines the stages in the development of the Berth 3 upper-deck project and outlines failings uncovered by the investigation.

The single-deck linkspans

74 The original Berth 3 structure, built in 1985, is described on page 6. The original design work by FKAB included specialist computer-aided studies to predict wave heights at the berths and assess a variety of loading conditions and mooring forces.

75 In the light of experience, Port Ramsgate made alterations to the single-deck berth to aid operation and maintenance. Among these were the addition of safety chains to link the pontoon to the seaward end of the bridge. They were intended to prevent complete disengagement in the event of a heavy berthing. **An inspection and maintenance schedule was also devised but not formally recorded.** This recognised the importance of inspecting and maintaining the bridge support feet, and in particular the more heavily designed foot fitted with a vertical pin (pintle) that connected the low-level bridge to the pontoon. This had bearing shells with wear indicator marks to show when they needed replacing.

The double-deck project

76 The double-deck project was proposed in 1991. The existing Berth 3 single-deck vehicle linkspan and pontoon at Ramsgate had been designed so that the pontoon was substantial enough to allow for installation of an upper deck at a later date. Port Ramsgate also proposed that vehicles and pedestrians could be segregated by the provision of a separate passenger walkway. This was to link the shore to the vessel via the pontoon - a novel idea.

77 Because the original Berth 1, 2 and 3 linkspans at Ramsgate had been built by FEAB during the 1980s, Port Ramsgate asked it to co-ordinate design work for the upper-deck project. A quote by FKAB for design work was accepted on the basis that work could be stopped at any stage. This was followed by FEAB's quotation which included fabrication, delivery and installation and the estimate that six months would be required from order date to completion. FEAB and FKAB agreed to proceed with design work for the walkway and take the project to a stage where fabrication drawings could be produced quickly if the RMT contract was secured and an order placed.

78 The upper-deck project was shelved in June 1992 when discussions with RMT collapsed.

79 Discussions reopened in mid-1993 and the project was resurrected.

80 1 January 1994 was proposed as the start date for RMT services from Ramsgate. A new quotation for the whole project was requested by Port Ramsgate on 19 August 1993. This was provided the next day, including ‘Lloyd’s test and certificate’ and stated that the walkway would be quoted separately. The papers from FEAB were accompanied by a quote from FKAB for design work. The walkway proposals were received by Port Ramsgate on 7 September.

81 During August 1993, Port Ramsgate dispensed with the services of its consultant port engineer. He had considerable experience with the single-deck linkspans and had been working closely with FEAB on the upper-deck proposals. Port Ramsgate chose not to recruit a comparable replacement or to appoint an engineering consultancy to oversee the project on their behalf. **It therefore had nobody competent to exercise technical control or co-ordination of the project.**

82 In early November, Port Ramsgate appointed a retired civil engineer to the part-time post of consultant port engineer starting on 1 January 1994 at 26 hours per month. He worked on the upper-deck project at Berth 3, but his role was limited to progress chasing. He had little experience of structural steelwork and none with floating structures.

Contract secured for additional traffic

83 On 23 September, Port Ramsgate confirmed by fax to FEAB that it had the contract with RMT. The amended price for the main works was accepted and a visit requested ‘with the appropriate contract’ to formalise matters. The copy of this fax supplied to HSE is interesting as it contains the hand-written addition: ‘(Contract) waived in view of time constraints’. **Apart from company order forms, no contract papers were used by FEAB/Port Ramsgate for the Berth 3 upper-deck project.**

Order for the main works

84 Port Ramsgate placed the main order for the works with FEAB on 29 September 1993. A 12-week delivery/installation schedule was required. The lower deck was to be ready for use on 1 January and the upper deck by 21 January 1994. RMT services out of Ramsgate were due to start on 1 January 1994. During this period, Port Ramsgate was also negotiating contracts to extend the fixed mooring structures at Berth 3, to dredge the approach channels to the port and for the design/installation of civil engineering groundworks for the shoreside facilities at the berth.

85 **On 6 October 1993, Port Ramsgate’s former port engineering consultant sent a fax to both Port Ramsgate and separately to FEAB. He warned that his original concept for an independent walkway span between the pontoon and the shore was not a sound idea after all. He proposed that the walkway should be physically attached to the upper vehicle bridge which, he pointed out, would be safer and cheaper.**

Contract for classification services

86 In early October, arrangements were made between LR Gothenburg office and the LR Croydon Lifting Appliances and Materials Handling Department for meeting the contract with FEAB for classification services. LR quality assurance procedures required LR Croydon to perform design approval on structures such as Berth 3.

87 LR Gothenburg informed LR Croydon that plans had been received from FEAB/FKAB but as the project time schedule was tight LR Gothenburg offered to carry out preliminary approval. It also informed LR Croydon that the owners wanted certification to the LR *Code for lifting appliances in a marine environment*[4] (referred to in this report as the LR *Code for lifting appliances*). This Code is part of the system of Rules published by LR and is used for designing and checking cranes, lifting decks and ramps, associated machinery and fittings intended to be used or carried at sea. Where linkspans have lifting parts, this Code could be applied to those parts and is used in conjunction with other more general design codes.

88 LR Croydon replied to LR Gothenburg informing it that approval of the project should be to a different LR design code[1] (the LR *Linkspan rules*) as well as the LR *Code for lifting appliances*.[4] Many linkspans incorporate lifting equipment and the *Linkspan rules* deferred to the LR *Code for lifting appliances* for design stress data and survey procedures. The first technical paragraph of the LR *Linkspan rules* was particularly relevant:

'The scantlings [size and material used for each part] *and arrangements are to be consistent with the method of support, the environmental conditions prevailing at the operating location, berthing conditions and the specified vehicle loading data.'* (Section 1.1.2)[1]

89 These Rules provided a brief but sufficient list of issues that needed to be considered in the design of a linkspan. Walkways were not dealt with separately. Information required by LR from the designer was listed and included:

(a) environmental data for wind, wave and current;

(b) model test results, particularly where the installation is of novel design;

(c) vehicle loading data;

(d) berthing forces;

(e) details of fenders and ramp-to-ship connection;

(f) site and structural plans; and

(g) materials specification.

90 LR Croydon agreed that LR Gothenburg could carry out preliminary plan approval but that formal approval of the plans had to come from LR Croydon.

91 On 27 October 1993, FEAB placed the order for plan approval with LR using the LR standard form. The service requested was: ‘Plan approval…… in accordance with the Lloyd’s Register Code for Lifting Appliances in a Marine Environment’.[4] **This was not the most suitable code.**

92 On 5 November 1993, LR Gothenburg wrote to LR Croydon stating that it would act as though giving full approval due to the urgency of the project.

Walkway ordered

93 FEAB quoted for the supply and installation of the walkway on 15 November 1993. This was accepted and a order placed by Port Ramsgate on 18 November.

94 On the same day, the latter ordered the passenger ramp building from a local steel fabrication company; this was the covered ramp leading from a coach drop-off point up to a landing platform on which the walkway was to rest.

95 The next day Port Ramsgate informed both contractors that the walkway position should now be changed to the right of Berth 3 (viewed looking seaward). FEAB agreed with Port Ramsgate that the walkway could be moved to the right-hand side of the berth and quoted an additional price for the alteration work. The structural engineer commissioned by the local contractors to design the passenger ramp building was able to mirror image his design to place the building in the new position.

96 FKAB, the designer, sent the local contractor a drawing showing requirements for the landing area where the walkway entered the passenger ramp building. This contractor had been told by FEAB that the walkway would place a vertical load of 20 tonnes on to this building, that it would slide in the building as the tide changed but that the design did not need to allow for this as there would be very little friction. The contractor’s structural engineer did not accept this and provided bracing in the building in anticipation of walkway wind loading. The FKAB drawing indicated that it intended to use cantilevered supports for the walkway, but no detail was given.

97 On 22 November 1993, FEAB placed an order with the same local contractor for the internal strengthening of the pontoon. This company agreed with FEAB to supply labour and consumables on a daily basis for as long as required for the upper-deck installation. Port Ramsgate engaged an engineering consultancy to design foundations for the passenger ramp building and the shore-based vehicle approach ramp.

Installation starts

98 Work on the pontoon began at the end of November 1994. Shortly afterwards a

senior employee of FEAB arrived in Ramsgate to supervise the installation work.

99 On 7 December 1993, FKAB sent walkway design drawings to LR Gothenburg for approval. Included was a drawing *Sliding details* Issue 0 dated December 1993. This is the fabrication drawing for the support feet and is referred to as the ‘support feet fabrication drawing’ in this report. The stub axle welds are shown on this drawing. A later, though little-changed update is shown in Figure 30. FKAB calculations to ‘prove’ the walkway support design were not carried out until 13 December 1993 - several days after the drawings had been sent to LR.

LR gives walkway supports preliminary approval

100 LR Gothenburg replied on 23 December informing FKAB that three project drawings showing walkway components - including the support foot fabrication drawing - had been given preliminary approval. A number of changes were requested, including increasing the size of the welds that subsequently failed. FKAB incorporated these and issued a drawing as a replacement which was marked ‘corrected as approved by Lloyd’s (Register) on 931223 (23 December 1993)’. A copy of this drawing was marked ‘preliminary approved’ and forwarded to LR Croydon who later endorsed the LR Gothenburg changes and in turn stamped the drawing ‘Approved 18/3/94’. Figure 30 is the reduced-size copy of this drawing.

101 During fabrication, LR Gothenburg surveyors visited FEAB yards to witness material conformity and fabrication. Where components were checked, this was recorded and a fabrication certificate issued with reference to the design drawing numbers. Four such certificates were issued. None refers to the support feet fabrication drawing. LR surveyors did not witness fabrication of these parts.

102 On 18 January 1994, a surveyor based at the LR Crawley office made his first visit to Port Ramsgate to survey installation of the upper-deck project.

Berth 3 brought back into use

103 RMT began operating a limited service from the Port of Ramsgate at the start of 1994. Berth 3 was not ready for several weeks and ferries used one of the other single-deck linkspans. As none of the RMT ships were fitted with loading ramps, a crane had to lift a temporary ramp on to the ferry’s lower deck at each docking.

104 By mid-January, pontoon strengthening was nearly completed and the portal frame to carry the upper deck was in place. FEAB provided training to Port Ramsgate’s foremen who would be operating the berth. Berth 3 came back into use in late January with considerable work still required to fit the upper structures. During January, the ramp leading to the upper vehicle bridge was being installed.

105 In late January, LR Croydon sent LR Crawley two general arrangement (GA) drawings for Berth 3. These show the plan and side views of the whole project.

They had been stamped 'Noted 14/1/94' by LR. LR does not 'approve' general arrangement drawings even though they are vital to show the overall concept of the scheme. These drawings had been out of date since mid-November and showed the walkway running down the centre of the pontoon. **LR Croydon who approved the design did not receive the correct general arrangement drawings until after the accident. Design approval had been carried out without a clear understanding of the layout of the project.**

The upper vehicle bridge

106 The upper vehicle bridge was lifted into position on 2 February. There was a delay as the crane controller refused to order the lift when he saw that the steel trestle which was to support the shore end of the bridge was not secured to its base. After remedial work, the lift was completed. Further problems came to light immediately, and during a ferry berthing that night the trestle and its foundations were damaged. The bridge was taken down and after redesign work by the engineering consultants for the foundations, the trestle and foundations were modified. The upper vehicle bridge was lifted back into place on 14 March. Further details about these problems are given in Appendix 9.

107 The upper vehicle ramp and bridge were load tested on 21 March and the upper deck of the pontoon was load tested on 22 March. The upper vehicle structures were brought into use on 23 March 1994. FEAB provided port foremen with further training in their operation.

The walkway

108 FEAB contracted the fabrication of the walkway sections to Junoverken AB, a sister company, also based in Uddevalla, Sweden and owned by the Mattsson Group AB. This work was witnessed by LR Gothenburg.

109 The walkway sections were shipped to Harwich and delivered to the site by road. The longest section - to reach from shore to pontoon - arrived in three pieces that were butt-welded together by a local subcontractor working under the direction of FEAB.

110 The stub axle assemblies and support feet for the shore to pontoon section were fabricated in Sweden but the investigation team could not discover in whose yard this was done.

111 At Ramsgate the collar for a stub axle assembly was welded to each corner of the walkway. The support feet, with plastic low-friction pads made of high-density polyethylene on their underside, were then slid on to the stub axles and secured in place by a split pin. Each foot was able to rotate on its stub axle so as to accommodate changes in angle caused by tidal and other vertical motion. The right-hand seaward support foot had a vertical pin/pintle that went through the

portal frame platform to positively secure the walkway in place.

112 The LR Crawley site surveyor asked the Port Ramsgate consultant port engineer to arrange a non-destructive examination (NDE) by a specialist organisation of welding carried out at Ramsgate. However the port engineer assumed that the walkway had arrived ready for lifting into place. The LR surveyor assumed the lines of unpainted welding had been checked by his colleagues in Sweden. **The requested examination was not carried out.**

Walkway lifted into place

113 On 22 March the walkway was lifted into place to link the passenger ramp building and the fixed walkway section that crossed the pontoon. The LR Crawley site surveyor spent most of this day on site. For part of the day he was accompanied by the LR Croydon structural engineers who had carried out approval of the design.

Problems

Four problems were found once the walkway had been lifted into place:

(a) The walkway seemed to be too short.

(b) The pintle of the seaward right support foot was made to have a bolt assembly pass through it to stop it lifting out of the portal frame platform. Although the bolt could be inserted through the pintle, there was not enough clearance underneath the platform to rotate the nut on to the thread. The bolt was left loose in the hole overnight.

(c) The local contractor who had designed and built the passenger ramp building had expected contact between the walkway and the building to take place under the walkway and not outboard in the form of cantilevered stub axles and support feet. This meant that the floor beams intended to support the walkway vertical load were in the wrong position. The contractor had also assumed the walkway would be supported on rollers that could run on the floor plate of the building. The guides he had provided could not be used.

(d) In addition, the same contractor had not appreciated that FKAB wished the floor of the passenger ramp building to incorporate a 4° slope under the walkway. This was to prevent the underside fouling the building when the tide was out (the walkway traversed a vertical arc of approximately +7° to -3° on the tide). The building had not been provided with this slope.

FEAB decided not to lift the walkway down for alteration.

114 To prevent the walkway falling off the unfinished building by moving to left or right, the shore end sliding feet were removed from the stub axles and the walkway was temporarily supported on wooden sleepers protruding from the building. Under the

supervision of FEAB, restraint blocks were made up and bolted to the edge of the ramp building to prevent sideways movement. To provide maximum overlap between the walkway and the building, the pontoon water ballast was also adjusted to tilt the portal frames towards the building.

Damage

115 During the night, the stub axle collars at the shore end came up against the temporary lateral restraints preventing the pontoon from moving seaward when the tide was in. The vertical pin/pintle in the seaward top foot was pulled upwards so that the low-friction pad was raised by 10-15 mm at its seaward edge. The retaining bolt was severely damaged and FEAB instructed that a steel ring be permanently welded around the pintle to hold it in place. As the end of the walkway had slid so close to the edge of the building it was now very obvious that it was too short by 0.75 m. As its dimensions were found to be in accordance with the drawings this was discussed with FKAB, the designer, who faxed details of an extension using available materials. FKAB also faxed the design alteration to LR Gothenburg for approval. The walkway was extended. This involved grinding off and re-fitting the shore end stub axle assemblies. **LR Croydon who approved the design, and LR Crawley who carried out installation surveys, did not know of the extension until after the collapse.**

116 During the days that the walkway rested on wooden sleepers, friction due to tidal motion wore away up to 20 mm thickness of timber. The forces involved would have imposed additional load on the seaward stub axles welds.

117 It does not appear that removal of the walkway for inspection of critical components was contemplated following this overstressing. **FEAB was fully aware of all the problems listed above and those that follow were also brought to its attention.**

118 Following completion of the extension, the sliding feet were provided with temporary guides. It was not until 15 April that the final ‘U’ channel slideways were fitted. These were of galvanised mild steel and were not fitted with stainless steel sliding surfaces to receive the low-friction plastic pads attached to the underside of the sliding feet, as is normal with this type of design. FEAB accepted the galvanised surfaces at the shore end. It also allowed the support feet low-friction pads at the seaward end to rest on the painted surface of the support platform. There is no indication that FKAB even considered this issue. The sliding and support contact surfaces had deteriorated considerably by the time of the collapse.

Heavy berthing

119 Seven heavy berthing incidents were logged at Berth 3 between the installation of the walkway and its collapse, the heaviest involving the pontoon being trapped between the ship and its guide piles, causing it to move shorewards violently by

approximately 2 m.

Additional problems

120 FEAB/FKAB expected the sliding feet to be able to run on a dry surface. However, employees working for the local contractor who erected the passenger ramp building found that structural bolts holding it together were working loose. This is expected on a small scale with galvanised steelwork that has to be ‘bedded in’. The problem here was much more severe; some 50-60 bolts in the vicinity of the walkway were coming loose every two or three days.

121 A director of the steel fabrication company found that the building was vibrating in time with wave action. His consultant structural engineer, while at the site on 18 April, suggested that all bolts securing structural components in the building be checked for tightness and those found to be loose, paint-marked for monitoring. He wrote to his client, the steel erection contractor, on 20 April asking that his comments be passed on to Port Ramsgate. He had originally been told that FEAB expected no lateral load to be applied by the walkway sliding in and out of the passenger ramp building. This was obviously not the case and in his letter he suggested consideration should be given to changing the sliding feet to rollers or some other means of support. A copy of his letter was handed to Port Ramsgate and the issue discussed with it. Subsequently, twice-weekly greasing of the slideways in the passenger reception building started, with the agreement of FEAB.

122 At about the same time the low-friction pads at the shore end were found to be damaged and coming loose from the support feet. Each low-friction pad was retained by four nuts and bolts. An employee of the local steel fabricator frequently picked up and replaced nuts that had fallen off. He also found that the bolts were occasionally falling out from the underside of the pads. He usually managed to find and replace them, but noted that one had disappeared completely. After the accident this was found embedded in, but protruding from, the contact surface of the low-friction pad (see photograph in Figure 21). FEAB instructed that steel restraint strips be welded to the front and rear edges of the feet. A welder did this on the seaward edges but was moved to other work before finishing the task. **No one checked that this job had been completed and it was not mentioned again.**

Support foot lifting off

123 Employees of the same local contractor saw the shoreward bottom left support foot of the walkway lifted clear of its slideway for hours at a time on several occasions, indicating ‘two-foot support’. One of the men sighted along the walkway in this condition and noted no twist in the structure at all (ie there was no visible torsional flexibility). FEAB was verbally informed of this on a number of occasions and at first attempted to settle the feet by adjusting the ballast water in the pontoon. The articulation design did not cater for roll of the pontoon and the walkway was not sufficiently torsionally flexible to settle. This factor was a major influence on the time taken for the stub axle welds to fail. **It is not known whether FKAB was**

informed that two-foot support was occurring.

124 The walkway was load tested on 19 April at the request of, and witnessed by, the LR Crawley site surveyor. Using a loading based upon 0.4 tonnes per metre^2 plus 10% he recorded a maximum vertical deflection of only 2 mm over the length of the walkway. The LR Croydon design approval surveyor had anticipated about 35 mm deflection from full passenger loading. **The low deflection test result was not referred to the design approval surveyor.** (It should be noted that proof load testing cannot provide any assurance that a structure is safe from fatigue failure.)

Project completed

125 On 28 April 1994, two LR Crawley surveyors signed the completion certificate for the Berth 3 upper-deck project. A copy was sent to FEAB. This meant that the appropriate LR committee would be informed and a recommendation made that Berth 3 should ‘remain in class’. Port Ramsgate believed that the involvement of LR in the project meant that nothing had been left to chance. However, LR plan approval surveyors had not considered that their Rules required them to assess the following details, all of which were crucial to the safe operation of the walkway:

(a) suitability of the stub axle material;

(b) tolerance of fit between the axle/bearing;

(c) ease of carrying out non-destructive examination during fabrication or in use;

(d) lubrication system;

(e) maintainability;

(f) accessibility; and

(g) operability.

126 The passenger walkway was brought into use on 12 May 1994. As RMT operations from the Port of Ramsgate built up through the summer season, several thousand passengers a day used the walkway.

Walkway maintenance

127 Some time before the end of installation work, FEAB’s site project engineer verbally offered to give Port Ramsgate’s technical supervisor a maintenance tour of the new work, to be followed up with a written maintenance schedule. Several weeks later the tour took place, at the technical supervisor’s insistence. It comprised a walk along the upper vehicle deck. The technical supervisor received the impression that maintenance would be straightforward and similar to

maintenance of the (much simpler) single-deck linkspans.

128 Most lubrication of moving parts was by disposable Greas-o-Matics. These screwed into place and supplied grease from a small reservoir under chemically induced pressure. FEAB intended each one to last about three months. FEAB's project engineer pointed out two of them on the seaward lifting section of the passenger walkway and several others on the sliding feet of the upper vehicle bridge but no reference was made to the feet assemblies on the walkway.

129 **The maintenance schedule that had been promised was never provided by FEAB, nor was it requested by Port Ramsgate.** FEAB left the site about two days later. Port Ramsgate organised routine greasing of slideways and Greas-o-Matics changeover following their existing procedures. Previous evidence of grease was used to indicate areas where routine greasing was required. The part-time consultant engineer was not consulted about maintenance procedures.

130 FEAB did not fit any form of lubrication system to the walkway support feet axles and support feet sleeves. After assembly, no further greasing of the stub axle sleeves took place. This contributed to the seizure of the exposed bearings at the pontoon end of the walkway.

131 The fabrication drawing for the walkway support feet shows a threaded hole in the stub axle support sleeve, presumably intended for a greasing point to be screwed into place. The drawing does not say what this is for, or mention lubrication. This can be seen in Figure 30 on part 'D'. (The designer apparently intended that grease was injected into the vicinity of the highest bearing load. This is contrary to normal good practice. Calculation checks have shown that even if fitted, the Greas-o-Matic system would not have worked.)

132 The FKAB design did not provide for access for inspection and maintenance. The walkway support feet at the shore end were readily accessible but those at the pontoon end were not, nor even readily visible. The crucial top right support with the pintle could only be reached using a cradle suspended from a crane.

133 On 5 July 1994 an insurance company engineering surveyor carried out a brief visual inspection of Berth 3 as part of a routine periodic inspection of equipment at the Port. He detected nothing untoward.

Problems during operation of Berth 3

134 In the weeks before the accident, a number of faults with the upper vehicle bridge came to light (these are included in Appendix 9). Various *ad hoc* remedies were implemented but possible underlying causes related to their design were not investigated by Port Ramsgate. It did not consider the nature of the design or contrast the support arrangements with other bridge supports at the port. FEAB sent two sets of steelwork drawings to Port Ramsgate. These proved invaluable to the investigation team after the accident, but had not been

previously looked at by port staff.

CONCLUSIONS

Immediate causes of the collapse

135 The immediate cause of the collapse of the walkway was the fatigue cracking and then overload failure of the remaining ligament of material of the seaward right stub axle to collar welds. Separation of the stub axle from the collar occurred some time, probably several days, before the collapse.

136 This failure separated the walkway from the vertical pintle which was the only means by which it was positively attached to the pontoon portal frame. This allowed the seaward end of the walkway to slide off its support platform on the portal frame.

137 The design of the welds and the quality of the welding were both poor and totally inadequate for the application.

138 The overall design of the walkway support arrangements was totally inadequate for normal operating conditions and should have been rejected. It failed to take account of weather and sea conditions and foreseeable events such as heavy berthing. Even without the faults in fabrication and welding, collapse of the walkway would have been inevitable.

Underlying causes of the collapse

139 Underlying the mechanical causes of the collapse were the failures of major parties engaged in the project to carry out their respective functions adequately. These organisations, which were well respected in their industry and which employed professional managers and technical staff, did not operate to standards which are commonly recognised and in some instances set out in commonly used codes of practice. In particular:

(a) failure of any of the parties to carry out a risk assessment for the project allowed safety-critical design failures to be made;

(b) failure to have a project plan which provided for effective monitoring of the project allowed defects in design and fabrication to remain undetected;

(c) even when defects became patent to certain individuals, the lack of adequate systems of liaison and communication prevented effective action being taken to remedy them, and, more importantly, prevented any fundamental consideration of a series of defects and problems which might have led to the questionning of the underlying technical causes of these defects.

140 The speed with which the project was finally undertaken probably contributed, but the failure to respond to patent problems continued after the completed

upper-deck works were taken into use.

141 The failures of the major parties to address the above issues and the more detailed issues recorded below involved serious contraventions of their legal duties under health and safety legislation. See the Legal proceedings section for details of the prosecutions which resulted.

Port Ramsgate failed as the port operator and main contractor to:

(a) provide for any overall competent management of the project;

(b) provide a specification for the project which took into account foreseeable operating conditions and set down contractual conditions;

(c) provide for any checks on the standards of design being applied by FKAB;

(d) react competently to the warnings that there were serious technical deficiencies in the overall Berth 3 project during fabrication and erection work on site;

(e) to question the lack of information from FKAB and FEAB about the maintenance needs of the walkway; and

(f) to react to obvious problems which became quickly apparent during operational use of the walkway.

FKAB did not provide a safe design for the walkway and is primarily responsible for the technical design defects that caused the accident. Its failure was comprehensive in that it:

(a) failed to obtain any specification for the project from Port Ramsgate to address expected operating conditions or seek information from elsewhere, eg on weather and sea conditions;

(b) failed to make anything like adequate assumptions on stresses which would result from their design;

(c) worked with calculations which were inadequately set out, inaccurate and dangerous;

(d) failed to provide any back-up support mechanism for the seaward end support unit;

(e) designed inadequate welds for the stub axles/collar joints and failed to specify adequately welding processes and standards to be used;

(f) failed to make provision for adequate lubrication of the stub axles in their support foot sleeves and for the support feet friction pads in their slideways; and

(g) failed to make provision for fixed means of access for maintenance.

FEAB failed to:

(a) correctly carry out critical welds such as the stub axle/collar joints;

(b) address the design inadequacies which became obvious during fabrication and refer them to FKAB, Port Ramsgate or LR for systematic appraisal;

(c) ensure that the lubrication arrangements of the walkway support units were understood by their own site engineer;

(d) install any lubrication system to the stub axle sleeves; and

(e) provide adequate maintenance instructions or a manual to Port Ramsgate.

LR failed to properly exercise its function as a classification society and ‘approved’ the walkway when it should have found it unsafe in design and construction In particular it failed to:

(a) identify the inadequate design concept as set out in the plans submitted to it;

(b) request any specification or explanation of the design from FKAB/FEAB (despite there being a requirement for this in its own Rules for the assessment of ship-to-shore ramps and linkspans);

(c) identify the faults in the detailed design for the support feet;

(d) to make correct assumptions for the basis of its own calculations;

(e) identify the significance of the forces imposed on the walkway by the design of its support arrangements;

(f) take account of how pontoon motion would affect the walkway;

(g) respond to the problems with the design, revealed during installation of the walkway; and

(h) realise the significance of the extremely small deflection during its proof load test of the walkway which would have led it to question its earlier calculations.

142 There was confusion about LR’s role among all major parties to the project,

including apparently LR itself. The other parties apparently derived a sense of security from LR's involvement despite deficiencies in design procedure and fabrication, which should have been obvious to them. LR saw its role as somehow being limited to carrying out checks and recording design and fabrication to enable classification of the structure according to its Rules. It did not equate this with ensuring fitness for purpose. LR did not spell out its interpretation of its role to the other major parties, which allowed the sense of security engendered by its involvement, to persist.

The framework of legislation and guidance

143 The general duties of the Health and Safety at Work etc Act 1974 (HSW Act), the Management of Health and Safety at Work Regulations 1992 and the Supply of Machinery (Health and Safety) Regulations 1992 provided an adequate framework in which parties to projects of the type undertaken at Ramsgate's Berth 3 had legal duties which, if complied with, would have ensured safety. The duties laid on an employer conducting an undertaking by the HSW Act 1974 section 3(1) extend to all activities which are part of an employer's undertaking. However, the employer may invoke the defence that it is not reasonably practicable to comply.

144 As the operator of its port facilities, Port Ramsgate had a duty to to ensure that new facilities were procured and installed in such a way that they were safe for passengers. Although it engaged contractors for the walkway element of the Berth 3 project, this civil contract did not relieve it of its statutory duty to ensure that the walkway it procured was safe. It was reasonably practicable for such a company to be aware of the available standards and guidance for the design and fabrication of the walkway (see References section). As a client, as a major port operator and as the main contractor for the overall project, it was able to require, monitor and supervise the implementation of such standards and guidance.

145 Port Ramsgate failed to appreciate the extent of its duties under the HSW Act, section 3(1). As the conductor of an undertaking (ie the operation of its port facilities) it had a duty to protect the public using them, not only in its day-to-day conduct of the port facilities, but also in the overall conduct of the business. This included the specification, design and procurement of the walkway. HSE's case against it on this issue was specifically addressed and upheld at the prosecution trial.

146 This framework has now been reinforced by the Construction, Design and Management Regulations 1994 (CDM Regulations) which came into force from 31 March 1995 as a result of a European Community directive. These would have applied to the project if they had been in force and would have provided a clear line of responsibility from the client to the designers and fabrication and installation contractors.

147 The failings of Port Ramsgate, FEAB, FKAB and LR gave rise to clear and serious breaches of their legal duties under health and safety legislation (see

Legal proceedings section).

LEGAL PROCEEDINGS

148 A summary of health and safety legislation applicable to the procurement and operation of linkspans is given in Appendix 11.

149 The investigation of the technical causes of the collapse and the management of the project covered the conduct of many organisations and individuals. After careful scrutiny of the knowledge, awareness and action of each individual, the investigating team concluded that there were no grounds for prosecuting individuals. It decided that corporate failings within four organisations had led to the accident. Other organisations referred to in this report were either not involved closely enough to be held culpable or had done everything that could reasonably have been expected to warn of their concerns.

Charges laid

150 In March 1995 - less than six months after the collapse - charges were laid against four organisations (Port Ramsgate, FKAB, FEAB and LR) alleging a breach of section 3 of the HSW Act for failing to take all reasonably practicable steps to safeguard members of the public who used the walkway. Port Ramsgate faced an additional charge under the Docks Regulations 1988 regulation 7(1) for failing to maintain safe access to the *Prins Filip*.

151 The bases of the cases under the HSW Act 1974 section 3(1) against the defendants were as follows:

152 ***Port Ramsgate Ltd*** Failure to ensure so far as reasonably practicable that the project to provide a walkway at Berth 3 was arranged and managed in a way that would minimise the risk of structural failure in use. Failure to provide or require a specification for the project. Failure to detect or act upon signs that the project was not completed satisfactorily, including failure to carry out inspection and maintenance.

153 ***FEAB*** Failure to ensure so far as reasonably practicable that the project to provide a walkway at Berth 3 was arranged and managed in a way that would minimise the risk of structural failure in use; including poor installation methods, failure to detect lack of lubrication to safety-critical bearings and failure to pass critical information to the designer once problems had been recognised.

154 ***FKAB*** Failure to consider the type and range of motion the walkway would experience; failure to carry out detail design of safety-critical bearings in line with good practice, with the result that the bearings were severely underdesigned; failure to use calculation methodology that would encourage faults to be detected; failure to provide back-up, such as safety chains, to

protect against disconnection of the bridge from its supports.

155 ***LR*** Failure to ensure so far as reasonably practicable that the client, fabricator and user were made adequately aware of the extent of checking of design, fabrication and installation work that LR would carry out. Failure to consider the nature and range of motion that the structure could experience and its ability to cope with this motion. Failure to conduct check calculations that were both sensible and sufficient. Failure to identify safety-critical elements for detailed checking from design through fabrication to use.

156 The two Swedish companies did not have an office or assets in the UK, so they were approached and asked whether they would submit to UK jurisdiction. They declined. The Criminal Justice (International Corporation) Act 1990 was used as a vehicle to serve the summonses on FEAB and FKAB in Sweden.

157 Pleas of 'not guilty' were entered by Port Ramsgate and LR. FEAB and FKAB were not represented at any of the hearings and the judge entered 'not guilty' pleas on their behalf.

158 The trial began on 13 January 1997 at the the Central Criminal Court in London. At the last minute, LR changed its plea to one of 'guilty'. FKAB and FEAB did not attend. The trial lasted 26 days, including a site visit to Ramsgate to allow the jury to examine Berth 3 and the dismantled walkway. This was the first known instance of a criminal case being heard against a foreign company in its absence.

Verdict

159 The jury were asked to deliver a 'special verdict'. The trial judge wished to know whether they considered that, under the single HSW Act section 3 charge, Port Ramsgate could only have delayed the collapse, for example by carrying out maintenance, or whether it could have prevented the collapse (for example by conducting the project differently).

160 The jury returned unanimous verdicts of 'guilty' on all counts against Port Ramsgate, FEAB and FKAB. They indicated by special verdict that Port Ramsgate could have conducted the project in a manner that would have prevented the collapse.

In summing up the trial judge said:

'One of the purposes of the Health and Safety at Work etc Act 1974 is to ensure that the public is safe, that it is protected from all risks of this kind. It is unacceptable that ordinary members of the public going aboard a ferry in the course of their ordinary lives shall be exposed to the risk of death or serious injury. The purpose of these fines is, in part, to bring it home to the boardrooms of companies and to the controlling minds of other entities who may be employers that the safety of the public is paramount'.

161 Fines totalling £1 700 000 were imposed on the four defendants, together with prosecution costs of £723 500. The fines and costs awarded against the defendants are listed in Appendix 10.

CONTACT WITH THE INJURED AND FAMILIES OF THOSE WHO DIED

162 Those killed included three Belgians, two Britons and a French person. The seriously injured included four Americans, an Austrian, a Japanese and a Briton.

163 HSE has established procedures for keeping seriously injured people and the next of kin of those killed in accidents, informed about the outcomes of its investigations and about any consequent legal proceedings. Throughout the investigation and the preparation and conclusion of the legal proceedings which followed, HSE tried to keep the seriously injured and next of kin informed by a series of letters. These were forwarded through the office of HM Coroner for Kent Thanet District who took on the responsibility for maintaining these contacts. HSE gratefully acknowledged her help and that of her staff.

LESSONS LEARNED

164 There are many lessons to be learned from this accident. They are relevant to people and organisations engaged in the procurement, design, design reviewing, fabrication and operation of structural projects. They are also relevant to classification societies and other bodies who manage, quality assure and insure the conduct of such projects and/or the resulting structures. These lessons are set out here in the order in which the issues have been addressed in this report. This section ends with a series of positive and reasonably practical steps which the major parties in the walkway project could have covered by project planning.

165 HSE sees the need to promote effective project management as the most important lesson to be learned.

Technical issues

166 The technical issues involved were neither new or remarkable. The designer and the fabricator made a series of gross errors in carrying out work for which there were adequate technical standards and guidance. Aspects of their failures which merit particular attention by others are:

(a) the design of articulated parts of structures and the need to involve adequate mechanical engineering expertise in their design and appraisal;

(b) the need for back-up measures for safety-critical support elements in walkway/linkspan structures; and

(c) the need to provide for lifelong maintenance and appropriate fixed access to do this.

167 Although the failed walkway proved to be the only example of its type in the UK, HSE and the UK ferry port operators have researched into good practice in the procurement, operation and maintenance of linkspans and other ferry access installations, and have published new guidance.[2]

168 Failure of the walkway could have been avoided if Port Ramsgate had adequately responded to defects which became apparent during operation of the walkway. All port operators should ensure that risk assessments on such installations are reviewed if unexpected findings arise from inspection and maintenance work, particularly after any heavy berthing of vessels. Such inspection and maintenance needs to be commensurate with the forces of the sea and weather acting on these installations.

The role of classification societies

169 Classification societies should make clear their role to clients in performing their function of 'approving' designs, fabrication and installation of structures. Clients should be informed of:

(a) the published standards against which the 'approval' is given;

(b) other criteria against which the 'approval' is given, eg the specification of operational requirements and the environment in which the structure will operate; and

(c) the purposes for which the various stages of 'approval' can be used, eg to independently check the work of designers or fabricators in a positive manner or to record design and fabrication standards for future insurance purposes.

170 Clients should ensure they understand the function of classification societies in any project for which they engage them, for example, whether they form an active part of the project management system or whether they provide 'approval' for a separate purpose (eg licensing of an installation or its insurance).

Promotion of effective project management

171 This incident amply demonstrates the need for effective project management. This lesson should be applied by all who engage in such projects. Without sound initial specification, careful application of reasoned assumptions, systematic checks and monitoring of the processes of a project, with responsibilities for each function clearly allocated, serious defects can be introduced and remain undetected. Risk assessment should be a standard technique used in initial design work and any design review. Without such management frameworks, there is a clear risk that individuals will fail to perform to the professional standards to which they have been trained.

172 Educational establishments responsible for the training of civil and structural engineers and professional bodies who represent the interests of these disciplines should develop and emphasise the role of effective project management to ensure the safe completion of projects.

Duties of employers conducting undertakings

173 The verdict against Port Ramsgate at its trial confirmed that employers are under a duty to exercise control over an activity if it forms part of the conduct of their undertaking and it is reasonably practicable for them to do so. This

interpretation of section 3(1) of the HSW Act had been clearly established by the House of Lords' judgement in *Regina v Associated Octel Co Ltd*. All employers contracting out work related to the conduct of their businesses need to be aware of this judgement and to operate systems for controlling work done for them by contractors, according to their capacity to do so.

Reasonably practicable measures which could have been taken

***Port Ramsgate** could have:*

(a) organised a management structure or systems that enabled control of the project to be established and maintained from inception through procurement to operation;

(b) used in-house expertise or appointed a consulting engineer to set up and manage the project;

(c) arranged for either a design brief or a specification to be drawn up for the project; and

(d) kept thorough records of meetings, discussions and decisions connected with the project.

During the early stages of the project Port Ramsgate could have:

(a) specified, or asked for, relevant standard/s to be used by the designer;

(b) arranged for environmental data to be obtained or provided;

(c) specified in-service life;

(d) specified maintainability;

(e) specified access requirements for inspection and maintenance;

(f) required provision of inspection and maintenance manuals;

(g) required, or carried, out a risk assessment at any stage;

(h) insisted on, or checked, quality assurance provisions from contractors; and

(i) approached LR directly to establish its precise role.

Many of these provisions could have been covered by a contract with the other parties involved.

During fabrication, installation and early use Port Ramsgate could have:

(a) arranged co-ordination of all contractors involved and questioned the competence of FEAB and the FKAB design in the light of faults which were revealed;

(b) established the cause or implications of incidents as one after another occurred, eg serious damage to the vehicle bridge trestle foundations, redesign of the vehicle bridge slideways and malfunction of the vehicle deck flaps;

(c) responded to indications that all was not well with the walkway design, eg the need to extend the walkway, the need to re-tighten structural bolts in the passenger ramp building every few days and the concerns raised by a structural engineer (with another contractor) about the design of the shore end sliding feet;

(d) tried to obtain the maintenance manual verbally promised by FEAB; and

(e) assess maintenance requirements of the walkway mechanical parts and sliding surfaces.

A combination of all or some of the measures should have led to the discovery of the fault that directly caused the walkway to collapse.

***FEAB** could have:*

During design and fabrication:

(a) insisted on a design brief and then a specification being provided or commissioned by its client;

(b) insisted on contractual papers being used to formalise arrangements with Port Ramsgate;

(c) ensured that its contract with LR was for the design to be assessed in accordance with the correct LR Rules;

(d) provided other contractors with sufficient information or checked their work - eg the walkway landing area in the passenger ramp building;

(e) used its own principle that low-friction pads should run on polished stainless steel slideways;

(f) ensured that the support feet were fabricated as ‘safety-critical’ items, and used welding procedures suitable for medium carbon steel;

(g) employed a quality concept and quality control procedures to ensure good detail design and compliance with suitable welding procedures;

(h) consulted the designer before changing the design of the support feet, ie adding a weld preparation chamfer to the stub axles and machining a taper into washers that covered the stub axle outer weld; and

(i) ensured that fabrication of the support feet was witnessed by LR.

During installation work at Ramsgate:

(a) ensured welding that had been carried out on the walkway component parts on site at Ramsgate was drawn to the attention of the LR site surveyor;

(b) checked that the walkway would fit before lifting it into position;

(c) lifted the walkway down for remedial work when it was found to be too short;

(d) acted on knowledge that the pintle support foot had been wrenched shorewards hours after installation;

(e) fitted automatic lubricators (Greas-o-Matics) to the stub axle bearings supporting the walkway;

(f) taken suitable action when the walkway was seen on many occasions to be supported on two feet;

(g) informed the designer (FKAB) that the walkway was lifting off and being supported on two feet;

(h) located the cause and taken suitable action when the passenger ramp building structural bolts were working loose;

(i) acted when the low-friction pads fitted to the underside of the walkway support feet were working loose;

(j) advised the designer or client of potential maintenance difficulties which would result from the lack of access to the seaward support feet;

(k) informed LR of problems during installation;

(l) instructed Port Ramsgate staff properly on the maintenance requirements of the walkway; and

(m) provided written maintenance instructions to meet a verbal promise.

***FKAB** could have:*

(a) worked from relevant design standards instead of relying on the limited criteria set out in the LR *Code for lifting appliances;*[1]

(b) selected a sound principle/concept for support design;

(c) taken steps to understand the operating environment;

(d) carried out a risk assessment;

(e) provided a layout drawing (intermediate between general arrangement and fabrication drawing);

(f) consistently updated drawings, issued amendment details or entered dates after altering design drawings;

(g) produced a sound detail design;

(h) carried out calculations on a sensible basis to assess the design of the walkway support feet; and completed them before sending the design drawings to LR;

(i) stated assumptions on which calculations were based, presented them clearly and ensured their accuracy;

(j) assessed the torsional flexibility of the walkway;

(k) designed the walkway supports to cater for roll of the pontoon, assessing limits of motion and the consequences of their being reached;

(l) assessed worst case loadings;

(m) carried out a fatigue assessment;

(n) provided back-up to support the structure in the event of disconnection;

(o) provided a workable lubrication design (for the plain/sliding bearings on the new structure);

(p) designed to provide for inspection, maintenance and access for these;

(q) considered the implications of major design changes made following installation problems - eg vehicle bridge slideways altered to include a sloping section and walkway extended *in situ*; and

(r) sought out the causes of many problems occurring in use.

***LR** could have:*

During design appraisal:

(a) explained its role to the other parties;

(b) required environmental data;

(c) carried out a risk assessment;

(d) assessed the technical concepts of the design;

(e) formally identified the safety-critical nature of the top right (pintle) support foot;

(f) considered limits of motion;

(g) checked the walkway support design, taking into account its awareness of the inevitability of the stub axle deflection, using suitable and accurate calculations which needed to be clearly presented, together with the assumptions on which they were based;

(h) assessed worst case loadings on the support feet;

(i) assessed friction and dynamic loadings;

(j) assessed susceptibility to fatigue;

(k) considered back-up to support the structure in the event of disconnection;

(l) considered the suitability of the design of the support feet to allow non-destructive examination (NDE) of the welds during fabrication or in-service;

(m) assessed maintainability of the design together with access for this;

(n) assessed lubrication need or provision; and

(o) identified critical areas for site surveyors to check.

During fabrication and installation:

(a) organised and implemented effective communications between surveyors (nine surveyors in four offices);

(b) applied sensible quality assurance and monitoring procedures, eg to safety-critical welds;

(c) passed on knowledge about walkway extension from its Gothenburg office to site surveyors; and

(d) passed on knowledge from the site to the design approval surveyor that the walkway position had been moved from the centreline of the pontoon to the right of the pontoon.

In many respects LR did not comply with its own Rules.

APPENDIX 1: MARITIME RAMSGATE

1 Ramsgate did not have a natural harbour but had been a port for several hundred years. Construction of a stone-built harbour of refuge began in about 1750. This was built out from a small bay and named the Royal Harbour, as the town developed into a prosperous trading and then a holiday location. Following this early development, layout of the port remained essentially the same until the late 1970s, comprising an inner non-tidal harbour approached through lock gates, and an outer harbour that provided quayside moorings for trading and fishing vessels. Ferry operations began about 1850 with a short-lived, twice-daily service to Ostend. In 1965 hovercraft crossings to Calais started from a pad constructed within the outer harbour. The introduction of larger hovercraft led to this operation being moved to a new site several miles along the coast. Two berths were installed within the outer harbour for ferry traffic - mainly the importation of cars. There was no scope for expansion and both shipping and dockside traffic problems resulted.

2 During the 1970s, the local authority developed proposals for a sea defence project to halt erosion of cliffs to the west of the Royal Harbour. Following the initial breakwater scheme, it was suggested this could be combined with a reclamation project by building the breakwater offshore. The layout and use of this reclaimed area was upgraded in consultation with the private sector. A ferry company - Sally Lines Ltd - eventually took an option on the site. The reclaimed area became the new Port of Ramsgate and was operated by a sister company to Sally Lines Ltd - Port Ramsgate. Several development phases ensued, each reclaiming more land. In order to berth a number of ferries on a limited frontage, mooring structures were built into the sea so that each ferry would berth bow- or stern-on to land. Figure 3 shows the harbour layout in 1994.

3 By the late 1980s, over one million passengers each year were passing through the port on their way to and from the continent. Freight - in the form of lorries and containers - expanded too. This was all driven on to ferries, giving the name ‘roll-on roll-off’ (ro-ro) to this activity.

APPENDIX 2: DEVELOPMENT OF FERRY BERTHS AND ROLL?ON ROLL?OFF (RO?RO) FERRIES

1 Traditionally, cargo was unloaded by lifting it manually or by crane from the hold of a ship. This generally meant that the vessel berthed side-on to a quay or transferred cargo to smaller craft from an anchorage. The development of assault/supply landing naval vessels and development of trade with areas where a conventional quayside was not available led to the construction of ships fitted with bow or stern doors that could lower to form a ramp suitable for vehicle traffic. Many of these ships could unload directly on to a beach. This involved wheeling rather than lifting the cargo and could be carried out very quickly, so time in port was minimised.

2 Ro-ro port facilities developed from both extremes. Where development was based around existing port facilities, there was a tendency to build ships' berths that comprised a large land-based structure with vehicle bridge/s and sometimes a passenger walkway; all of which would be raised and lowered to match the height of the tide and the position of the ferry in the water. Port structures including a bridge linking a ship to the shore became known as 'linkspans'. Frequently, this type of structure has a series of flaps fitted to the end of each linkspan bridge. These lower on to the ferry deck, meaning that the ferry does not need to have its own ramps.

3 Where development was at a new or untried site, an alternative approach was available. This design tended to develop the beach landing concept but avoided the tidal and shallow draught limitations this imposes. Port Ramsgate followed this option and used a floating pontoon to follow the tide. This was linked to the shore by a vehicle bridge. The ferry's ramp lowered on to the pontoon deck and traffic drove across the pontoon and bridge to the shore. This avoided the need for large lifting machinery to follow the tide and meant that an operator did not need to adjust the position of the bridge every few minutes. This type of basic facility is more compact and tends to cost less than comparable land-based linkspans. It is also easy to install, requiring minimal civil engineering groundwork (foundations) and can remain in use through a good range of tidal conditions. In addition, a pontoon-based linkspan is easily moved to a different location when no longer needed; the bridge is either lifted or hauled on to the pontoon which is then towed to the new mooring.

APPENDIX 3: CLASSIFICATION SOCIETIES

1 There are several major classification societies carrying out 'classification' work throughout the world. They work with, and alongside, the legislation of individual countries, and that set by international bodies such as the International Maritime Organisation. Each has their own set of 'Rules' covering design, fabrication and survey of ships. The involvement of an independent classification society and its record of achievement remains a major influence on the premium an insurance company may apply to a vessel or cargo.

2 Classification is a process of checking designs, materials and fabrication to ensure the standard of construction of ships and structures against a set of rules published, and regularly updated, by a classification society. Ships and structures are 'maintained in class' with a classification society by being submitted to periodic inspections and examinations to prove that they continue to conform to the society's rules. In the UK, classification of port structures is a voluntary independent check used by owners as part of their management of the procurement and operation process. It helps them to comply with their legal duties under health and safety legislation and is taken into account when insurance premiums are set.

3 LR is internationally renowned as the oldest classification society. It has provided a service to ship owners and others since 1760. Traditionally, this involved surveying a ship to determine condition. In simple terms, the better the 'class' of vessel, the greater the chance that the vessel would survive a voyage. In sea-going vessels, factors such as competence of captain and crew and the weather were not so easy to predict and good structural condition did not guarantee safe arrival. Classification still involves a check on condition during the working life of a vessel or structure. But condition is more than ever determined by quality of design, materials and fabrication. This now means that most vessels or structures placed 'in class' with LR have been surveyed from the design stage onwards.

4 LR remains a non-profit making organisation (although it also owns several limited companies that carry out various specialist aspects of its business). The constitution of LR[8] defines its role:

> *'To secure for the benefit of the community high technical standards of design, manufacture, construction, maintenance, operation and performance for the purpose of enhancing the safety of life and property both at sea and on land'.*

5 The first stage of putting this into practice is to:

> *'approve the design of, survey and report on....shipping;....land or sea or seabed installations, structures, plant etc;.....for the purposes of testing their compliance with plans, specifications, rules, codes of practice etc or*

their fitness for particular requirements'.

6 The experience gained in surveying vessels led LR to develop a set of ship Rules and 'Codes of practice' that govern the design and fabrication standards it will accept. Classification is exclusively a scheme that deals with maritime structures but has included those at the 'water margin' such as linkspans. Although frequently land-based, linkspans are categorised by LR as a type of ship. This is because all linkspans have an interface with shipping, and some have a floating or submerged pontoon that will often involve towage and a sea journey to the port of use. LR is the only classification society to have devised a set of Rules dealing with the design and classification of linkspans. LR offers a similar service for land structures. This is known as 'certification' and entails a more flexible approach involving greater reference to standards drawn up by other bodies.

7 The classification process has developed into a well-established procedure which typically involves the following:

Classification society rules

8 These are a set of design, fabrication and survey 'Ship Rules' that provide a minimum standard that designers, ship yards and LR surveyors use. Traditionally they relied heavily on the 'scantlings' (literally the 'size and material' intended to be used for a piece of the ship). The Rules are divided into sections each dealing with a different type of vessel or process. More recently the Rules have incorporated a mixture of requirements, relationships (including stress data), and most recently goal setting standards. The Rules also include sections about classification and the steps that need to be followed in order to obtain and maintain classification. They are updated on a regular basis with supplements usually issued annually.

Plan approval

9 This is the examination of plans by comparison with LR Ship Rules or another agreed standard. The designer submits sets of plans to the relevant LR department. These are checked for compliance with the agreed standard and, following any changes deemed necessary by LR, are approved. Checking 'fitness for purpose' at the design stage is an obvious and essential part of the management of a project.

Survey of fabrication

10 Local LR surveyor/s visit the fabrication yard and, using a set of LR approved plans, witness proof of material quality, proof of fabricator skills - eg by testing welders - and observe fabrication. Certificates identifying which drawings have been checked are issued.

Survey of installation

11 Where fabrication is followed by installation - as against sailing away - the installation work is also witnessed. Proof load testing may be carried out. Operation is also observed and a completion certificate is then issued.

12 A committee then formally ascribes a ‘class notification’ and the vessel or structure is ‘in class with LR’.

Annual survey

13 To maintain class, a survey to determine condition is carried out by a local LR surveyor at prescribed intervals. Failure to carry out regular surveys or to carry out work deemed necessary would result in the vessel or structure being taken out of ‘class’.

1 The seaward left stub axle/collar fracture surfaces were less discoloured and appeared more recent than the seaward right parts. The top left fracture surfaces are discussed first.

2 The fabrication drawing (a reduced-size copy is shown in Figure 30) implied that both welds should have a 7 mm throat. The stub axle is shown square ended with no weld preparation to its edge. The collar is shown with a 45° chamfer to the bore of the hole at its outer face. The welds are referred to as the ‘inner’ and ‘outer’ welds. The inner weld is a fillet weld - effectively a ‘weld at the bottom of a hole’. The outer weld joined the stub axle to the outer face of the collar and is best described as a partial penetration butt weld between materials of different thickness.

3 In fact, contrary to the design drawing, each stub axle had a weld preparation chamfer. After welding, each of the outer welds had been ground back, probably with an angle grinder, in an attempt to match the joint design profile - a 90° internal angle with no specified radius. Designers usually avoid sharp changes of section as these are known to cause stress concentration. The fabricator was unwilling or unable to achieve the design radius and the outer welds were left with a radius in the region of 3 mm. This is still a sudden change of section for a design of this nature and scale. A section cut from one of the shore end intact welds showed that, at worst, the outer weld had been reduced to a 3 mm throat by grinding. At the pontoon end the failed welds had a throat dimension of approximately 7 mm.

Seaward left-hand stub axle/collar assembly (sliding support foot at pontoon end)

4 Failure of the seaward left foot assembly had occurred as a result of the separation of the stub axle from the collar. The collar remained in position, welded to the walkway structure. The fracture surface on the stub axle is shown in Figure 19.

5 Examination of the external surface of the failed outer weld revealed that, except for areas where gross welding defects had affected the fracture initiation or where the fracture had been produced by the final overload, the fracture edge had a ratcheted appearance consistent with multiple initiation of many cracks at locations around the circumference of the stub axle, but predominantly in the lower seaward quadrant. This form of multiple crack initiation results from fatigue loading. Multiple initiation of fatigue cracks is likely if the geometry of the component, or the presence of surface defects, produces relatively high stress concentrations. In this instance, the cracking had initiated at a welded joint with a 90° included angle. The initiation of the cracks had been significantly

influenced by the presence of grinding marks on the outer surface - ie the cracks are all parallel to the grinding marks. Figure 31 shows an area of the external surface of the outer weld, where pre-existing cracks originating from grinding

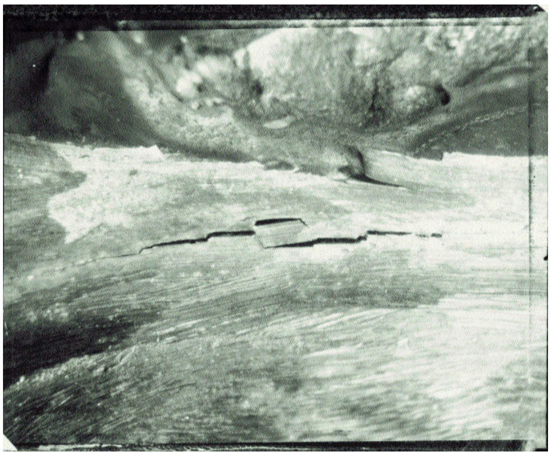

Figure 31: *Seaward left outer weld stub axle - fatigue cracks originating from grinding marks*

Figure 32: *Seaward left outer weld stub axle - beach marks*

marks have been opened up by the final overload failure of this part of the joint.

6

Figure 33: *Seaward left inner weld stub axle - beach marks*

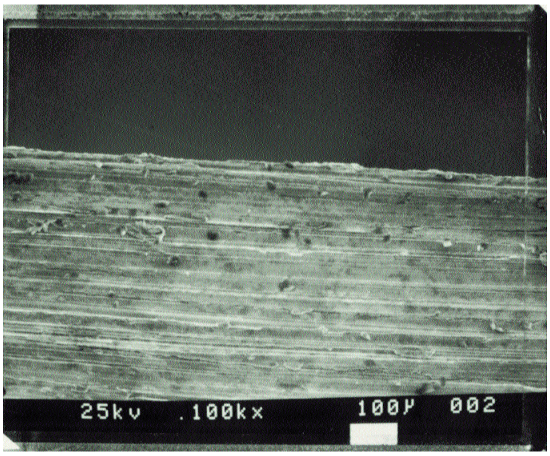

Figure 34: *Seaward right stub axle - coincidence between grinding marks and fatigue cracks*

On the fracture surface of the outer weld there are many areas where, under low magnification optical and scanning electron microscopy, beach markings are clearly visible. An example of these areas is shown in Figure 32. Beach marks are an important feature in identifying fatigue failure.[5] They are a result of changes in the magnitude or frequency of loading, or of oxidation during periods of arrested crack development.

7 The failure of the inner weld was also the result of fatigue cracking followed by overload. The fatigue cracking was centred approximately 15° to seaward of bottom dead centre. It had propagated around 50% of the circumference when final overload failure occurred. A significant crescent-shaped area of the inner weld exhibited beach markings; part of this is shown in Figure 33. The shape and extent of the fatigue-cracked area and the beach markings on it indicated that the cracking on the inner weld was typical of that produced under a moderate nominal stress and a severe stress concentration in bending.

8 Fine radial steps in the fatigue-cracked region suggested that there may have been some torsional element to the fatigue loading. Resistance to rotation (ie seizure) of the stub axle within the axle sleeve would have provided such a torsional load.

9 Welding defects within the joint including lack of fusion, lack of penetration and porosity assisted the propagation of fatigue cracking. Final fracture of the joint was due to ductile shear failure of remaining ligaments of weld metal close to top dead centre. Overload failure in the inner weld had occurred partly through the stub axle parent material where it showed a more brittle form of transgranular brittle cleavage. This indicates poor welding practice. The overload failure had a recent appearance. It probably occurred at the time of the incident, possibly when the walkway hit the pontoon deck.

Seaward right-hand stub axle/collar assembly (the support with vertical pin)

10 Failure of the seaward right-hand foot assembly had also occurred as a result of the separation of the stub axle from the collar, which remained in position welded to the walkway structure. The failure on the stub axle is shown in Figure 15. The fractures were again at or close to the welds between the stub axle and the collar. Initiation of fatigue cracking of the outer weld was again closely associated with the grinding marks produced by the surface dressing operation. Multiple crack initiation sites were visible and the ratcheted nature of the fracture extended over a greater proportion of the outer weld surface than on the seaward left side. Only where there were other welding defects was this absent. There were no visual signs of overload failure in the outer weld. This indicates that it had been completely cracked by fatigue action before complete failure of the inner weld. Figure 34 shows the coincidence between grinding marks and the fatigue cracks.

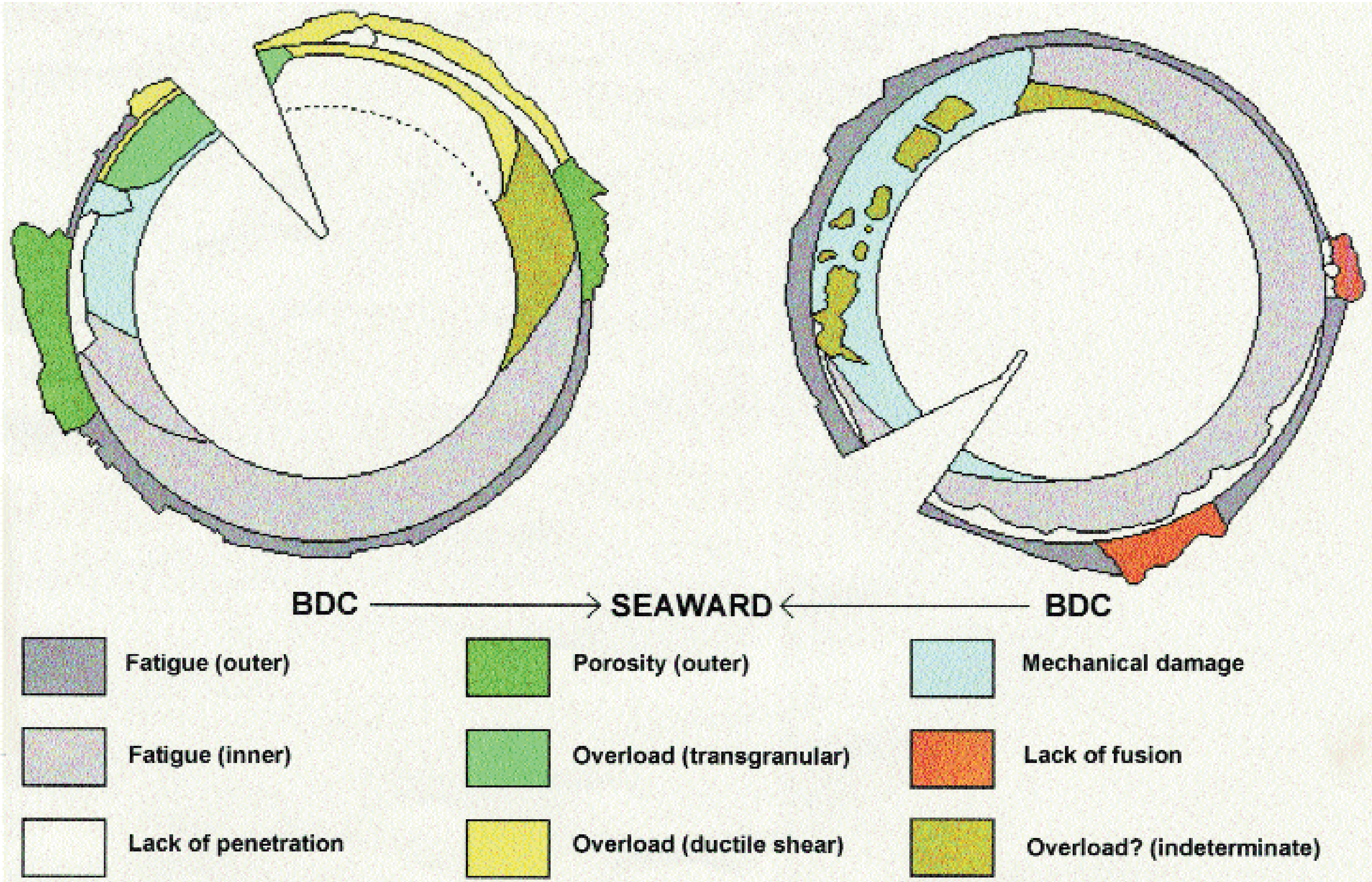

Figure 35: *Schematic view of seaward left and seaward right stub axle fracture surfaces showing failure modes*

11 The inner weld had failed as a result of fatigue cracking followed by overload failure. The fatigue cracking was centred approximately 45° to shoreward of bottom dead centre in an area where there was significant lack of penetration of the weld metal to the root of the weld preparation. The fatigue cracking had propagated around approximately 75% of the circumference of the stub axle at which point overload failure occurred. None of the fracture surfaces, including the final overload region, appeared to be recent. The overload failure region had been quite heavily damaged by repeated contact between the fracture surfaces. Separation of the stub axle from the collar may have occurred several days before the accident.

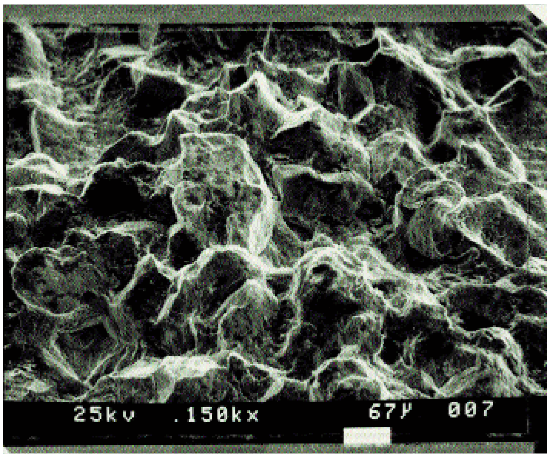

Figure 36: *Seaward right stub axle - interangular cracking at the root of the inner weld*

12 A schematic representation of the fractures of both seaward stub axles including modes of failure is given in Figure 35. The poor quality of the welding and the problems associated with welding to the medium carbon stub axle meant that propagation of the surface-initiated cracks was aided by welding defects, including intergranular cracking in the stub axle material. An example of intergranular cracking at the root of the inner weld is shown in Figure 36.

Shore end stub axle assemblies

13 Magnetic particle inspection of the outer welds on the shore end stub axle/collar assemblies revealed significant cracking in these welds on both the left-hand and right-hand sides. Figures 24 and 25 show this cracking on the shore end right stub axle to collar welds. No cracking was found at the external surfaces of the inner welds. However, cracking in the seaward inner welds started at the roots of the welds. Scanning electron microscope examination of the opened crack surfaces from the shore end right outer weld showed that this outer weld cracking was a combination of fatigue cracking and pre-existing intergranular cracking due to poor welding practice. The poor practice may have included failure to use 'low hydrogen' welding rods. Microscopical examination through the welds from the shore end right-hand assembly revealed many other defects in the welds; particularly in the outer weld. The defects included lack of penetration, lack of fusion, entrapped slag and surface-breaking porosity. The propagation of cracks through the outer weld would have been aided by these defects. The surface-breaking porosity would have been detectable by visual examination, probably being visible after the grinding had been performed.

14 The section taken through the welded joint between the stub axle and the collar from the shore end right hand-assembly is shown in Figure 37.

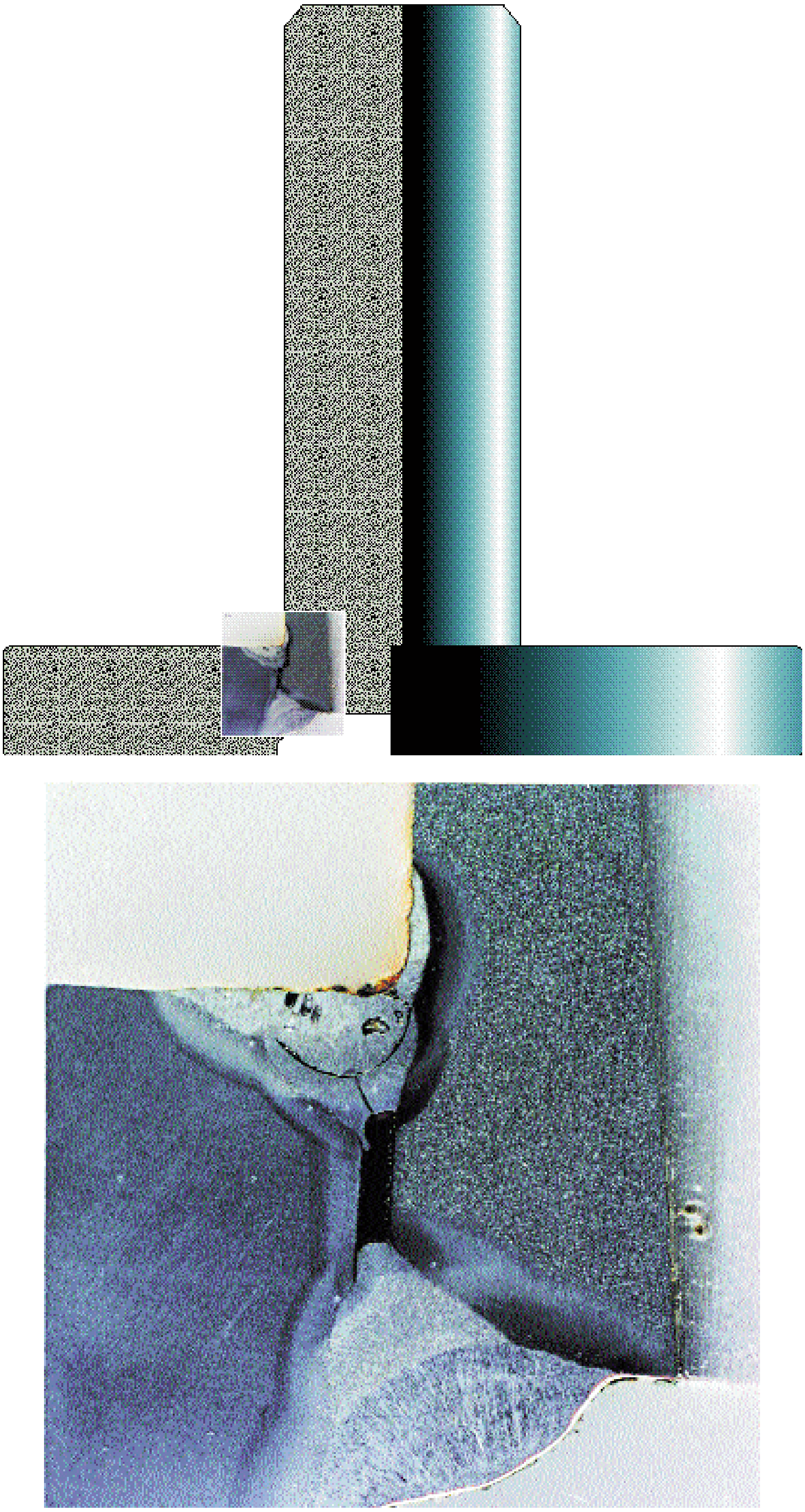

Figure 37: *Section through the shore end right stub axle to collar weld with location schematic*

Materials and condition

15 Chemical analysis showed that the stub axles had been made from a hot rolled medium-carbon steel (0.4-0.5% carbon) in the normalised condition. The collars had been made from hot rolled low-carbon steel containing 0.1-0.2% carbon. The welding of medium to low-carbon steels is known to present difficulties. Unless special procedures are followed (pre-heating of items to be welded and stress relieving after welding) cracking after welding is likely, particularly in the heat-affected zones (HAZ).

16 Vickers hardness tests in accordance with BS 427:1990 *Method for Vickers hardness test*[6] were performed on all the sections used for microscopical examination. These tests gave values consistent with the observed microstructures, material compositions and confirmed they were not heat-treated.

17 The hardness values obtained in the various HAZ were very variable, which is to be expected because of the multi-pass nature of the welding where earlier HAZ may be altered by subsequent weld passes. Values obtained from the HAZ indicated no post-weld stress relieving heat treatment had been carried out. The stub axles were much too hard in the HAZ. This would have made them 'brittle'. The stub axle to collar assemblies should have been heat treated in a controlled manner after fabrication to relieve stresses and increase toughness. The LR *Welding Rules*[3] begin by requiring that:

> *'The plans to be submitted for approval are to indicate clearly details of the welded connections of main structural members, including the type and size of welds....The information to be submitted should include the following:*
>
> *(a) whether weld sizes given are throat thicknesses or leg lengths;*
>
> *(b) grades and thicknesses of materials to be welded;*
>
> *(c) location, types of joints and angles of abutting members;*
>
> *(d) reference to welding procedures to be used; and*
>
> *(e) sequence of welding of assemblies and joining up of assemblies.'*
> (Ship Rules, Part 3, Chapter 10, section 2.2.1)[3]

18 The Rules go into further detail of procedures suitable for the welding of medium-carbon steels and mixed assemblies (which was the case with the stub axle/collar assembly). Procedures for the inspection of work by LR site surveyors are covered and also detailed in associated LR Rules and internal LR manuals.

19 The fabrication drawing showing the walkway support feet and the stub axle welds that failed does not state whether the welds are sized by throat thickness

or leg length, but the grade of medium-carbon steel used for the axles is shown. This should have alerted all those involved with design, fabrication and checking to the need for special procedures. Welding procedures and sequence of fabrication are not shown on the drawing or any of the project documentation provided to HSE.

20 Some surface-breaking porosity would have been visible after grinding of one of the outer welds. Careful visual inspection of all welds is normal practice. For components that are going to be highly stressed or are safety critical - as was the case here - inspection of the welds should have included sub-surface non-destructive examination. This is a normal procedure within the civil engineering industry. In this case the stub axle to collar welds are particularly difficult to check. It is normal practice for designers to try to make the fabrication as easy to check as possible. This includes in-service checks which may be needed at intervals throughout the life of the structure.

21 Fatigue cracks will grow from areas of greatest weakness in an overstressed design. Even if the stub axle welding had been exemplary, the structure would have failed.

22 The LR Ship Rules allow the large-scale use of low-grade mild steel plate that has not been tested for impact resistance during manufacture. LR material specification Rules allocate the grade designation ‘Grade A’ to this material. Safety-critical components on the walkway were designed and manufactured from this grade - including the collars into which the stub axles were welded. Without being tested, the ability of this material to avoid brittle fracture at low temperatures is not known. BS 5400:1978-1990 *Steel, Concrete and Composite Bridges*[7] does not permit the use of steel with unknown impact resistance in bridges for structural members that work in tension. This form of failure was not involved in the collapse of the walkway.

APPENDIX 5: ASSESSMENT OF THE DESIGN: CALCULATION METHODOLOGY

FKAB design calculations

1 Under vertical loading, HSL had shown that the stub axle moment arm was an indeterminate variable between the limits of zero and 250 mm (support anywhere from the inner edge to the outer edge of the support foot). FKAB knew that the stub axle was subject to a bending force and it assumed that the load would be carried on all four support feet. The only safety margin (ie spare load carrying capacity) built into its bending calculations relied on keeping the calculated stresses below the maximum allowed in the LR *Code for lifting appliances*[4] design code. However, FKAB mistakenly assumed that the axle sleeve (part D on Figure 30) would restrain the stub axle and prevent it bending. The axle sleeve was a much more substantial component than the stub axle. FKAB calculated the bending effect on the axle sleeve using a moment arm of 65 mm. This completely missed the point that under load the axle sleeve and the complete support foot would rotate with the stub axle. FKAB's resultant bending stresses were too low by a factor of ten when compared to the HSL optimistic support situation with even loading and two-foot support. FKAB derived a horizontal loading by applying the relatively high coefficient of friction of 0.3 to its vertical load results. It did not consider dynamic or cyclic loading likely to result in fatigue.

LR's design check calculations

2 LR Croydon carried out calculations which may have anticipated that stub axle deflection would lead to a small moment arm under static vertical load. It assumed four-foot support and selected a moment arm of 25 mm in order to calculate the bending effect on the stub axle and welds. This is ten times smaller than the worst case situation even under four-foot support. Again the only safety margin applied was to accept results within design code allowable stress figures. The result of this crucial calculation was just within the allowable bending stress for this class of material given in the LR *Code for lifting appliances.*[4] The stresses calculated in the stub axle welds exceeded the allowable limit and the size of the welds was increased at the request of LR. LR did not calculate the effects of horizontal loading or dynamic effects. It is ironic to note that increasing the moment arm selected by LR from 25 to 26 mm, an increase of just 4%, would have resulted in this aspect of the design being rejected. This serves to illustrate how sensitive the variables are and how crucial it is to select appropriate assumptions when performing safety critical calculations. Structural engineers frequently use a 'sensitivity study' to test the effects of altering variables in the calculations. There is no evidence that this had been done.

3 In addition, neither the FKAB nor the LR calculations took account of the effects of the low-friction pad wearing over time. The area of the pad subject to highest

pressure would be most susceptible to wear which would tend to increase the moment arm, leading to further deformation and increasing the likelihood of collapse due to overload. Calculations carried out to prove a design must consider influences through the life of the structure.

4 It is also surprising that both failed to check the wind loading on the walkway section that collapsed. It would have overturned under the effects of side-wind loading during storm force winds likely to be experienced once in every ten years. In this respect, BS 5400[7] specifies a considerably higher stability.

Finite element analysis

5 To consider the combined effects of vertical and horizontal loading on the stub axles, HSL used a complex 'finite element analysis' computer modelling technique. To keep nominal bending stress levels below the ultimate strength of the material, a moment arm of 48 mm was assumed. This enabled the zones of highest stress to be predicted. These predictions matched the general area where fatigue cracks were found to have initiated.

Fatigue assessment

6 The metallurgical investigation of the fracture surfaces showed that fatigue cracking had led to the collapse. Where a structure is subjected to a number of repeated load cycles, cracks can start (be initiated) and spread (by propagation). Eventually the structure can fail, even though the stress generated by the applied load is below that required to cause failure in a static load situation. This type of failure is known as a fatigue failure. The two important factors in fatigue design of welded structures are the range of stress experienced at any point and the number of times this stress range is applied. The investigation needed to explain how these fatigue cracks could have occurred.

7 Rising and falling stresses in the stub axles and welds would have been caused by several different load cases. The highest cyclic loading occurred under vertical load as the walkway rocked from two diagonally opposed feet on to the other two. However, it would be extremely difficult to make assumptions about how frequently this occurred and the moment arm to apply.

8 Stresses induced by horizontal loading were not as large but could be much more readily assessed. Pitching of the pontoon due to vehicles passing over the pontoon and wave action would have caused push-pull sliding of the walkway (ie a fully reversing loading). Small movements at sea level were amplified by the rotation of the pontoon. The walkway was at high level and even motion that did not lead to the support feet sliding would have caused stress levels to rise and fall in the stub axles/welds.

Stress range

The estimate of stress range assumed:

(a) mass of the walkway (excluding passengers who used the walkway for short periods each day);

(b) two-foot support and four-foot support cases considered;

(c) co-efficient of friction of 0.08 (derived from manufacturer's data);

(d) moment arm of 115 mm (outer face of collar to centre line of pintle); and

(e) torsional effects due to misalignment or seizure of the stub axles were not included.

Number of cycles

The estimate for the number of service cycles assumes:

(a) about 150 000 heavy goods vehicles crossing the Berth 3 pontoon per year;

(b) maximum wave height within the harbour would be in the region of 0.7 m - storm waves would therefore be significant;

(c) wave period could be in the region of 6 seconds (ie 10 waves per m = 14 400 load cycles per day; figures derived from information supplied by Port Ramsgate;

(d) all sliding would lead to the pintle contacting the support platform. In practice, stick-slip effects would determine a minimum effective cycle for the full moment arm to apply;

(e) the decay effects of pitching were not included - only the first cycle of each event was considered; and

(f) tidal and wind effects were not considered.

9 Fatigue assessment is not intended to predict when a structure will fail. In the design situation, fatigue studies are used to consider whether fatigue damage could become a problem during the service life of a structure. Although often appearing to give 'precise' figures for the life of a structure, these are subject to a 'probability of failure' and in actual life can vary dramatically - even in test specimens in a laboratory.

10 BS 7608:1993[5] specifies a methodology for fatigue assessing a range of standard joints. Once the type of joint and stress range are known, the allowable number of service cycles can be calculated or read off a chart. Designers usually work using a 2.3% probability of failure (ie how many joints of this type would fail at a given stress range before reaching the given number of load cycles - 2.3% is 23 failures in every 1000 tested and is used as the standard design curve based upon accurate or worst case loadings). The number of load cycles predicted to give a 50% probability of weld failure is akin to matching prediction to what happens in practice (ie half the samples will probably have failed at that stress and number of cycles). Note that BS 7608[5] assumes reasonable quality welding which was not the case with the walkway stub axle welds.

Fatigue assessment results

11 Using the two-foot support case and a probability of failure of 50%, failure of the stub axle/collar welds was predicted in 100 000 service cycles. This was equivalent to several months of known use by heavy goods vehicles and a small amount of wave action.

12 Even if all four support feet had shared the load equally, the 50% failure rate predicted a fatigue life of approximately 3 million service cycles. This was alarmingly low for a structure with an unspecified, but likely service life intended to be in the region of 20 years.

13 Using the design case based on a 2.3% probability of failure and support on four feet gives a life of only 800 000 cycles. At worst, even this is equivalent to only 56 days of full wave action.

Conclusions of the HSL design assessment

(a) The design concept of a high-level, independent walkway was a dubious choice due to the vulnerability of the berth and the mobility of the pontoon and should have been rejected unless detailed assessment proved it to be safe within a carefully set operating envelope.

(b) The design concept of the walkway supports - based on four-foot support, single-point attachment, welded cantilevered stub axles and sliding feet should have been rejected in the absence of an equally detailed assessment.

(c) The design detail of the walkway supports - using inappropriate materials, weld geometry, and lubrication/protection - should have been rejected.

(d) The design detail of each end of the walkway structure could not develop sufficient strength to resist deformation and should have been rejected.

(e) Stresses in the stub axle welds due to vertical and horizontal loadings for both static and fatigue load design cases were greatly in excess of the allowable stresses according to current design codes.

(f) The moment arm of the support stub axles under vertical loading was an indeterminate figure, meaning that only the worst case condition should have been assessed. Under horizontal loading it was a fixed value at the critical pintle support bearing. Neither FKAB nor LR assessed the proposed design accurately or sufficiently. Because they did not understand the nature of the support concept they failed to consider the effects of fatigue.

(g) The design review, including the results of post-accident calculations, concurs with the metallurgical evidence.

Comparison of stress calculations by FKAB/FEAB, LR and HSL, based upon weld throat of 7 mm

	FKAB/FEAB	*LR*	*HSL*
Bending calculations			
Design tensile stress for stub axle material	not stated	**188 N/mm²**	300 N/mm²
Design shear stress for weld material	not stated	**109 N/mm²**	140 N/mm²
Horizontal bending stress	82 N/mm² (sleeve)	not stated	436 N/mm² (stub axle)
Vertical bending stress	136 N/mm² (sleeve)	**184 N/mm²** (stub axle)	725/1450 N/mm² (stub axle)
Vertical bending stress weld	not stated	**96 N/mm²**	440/880 N/mm²
Sheer stress calculations			
Design shear stress for stub axle material	not stated	**109 N/mm²**	180 N/mm²
Horizontal shear stress	26 N/mm²	not stated	26 N/mm²
Vertical shear stress	43 N/mm²	**51 N/mm²**	43/87 N/mm²
Vertical shear stress (outer weld)		**130 N/mm²**	

Where two figures are quoted, they refer to stresses calculated assuming equal support by all four feet or by only two feet (Note: 100 N/mm² = 6.475 tonf/in² = 100 MPa)

Design stress = allowable stress

APPENDIX 7: WALKWAY DESIGN DEFECTS

1 The walkway supports were highly stressed under static loads. Additional cyclic loading led to fatigue cracks growing in the most susceptible area of the design - the welds connecting the top right stub axle to the collar. There were other failure modes and the following hierarchy indicates how design review should have suspected and located sufficient of these for rejection of the design to have taken place.

(a) The high-level independent walkway was in a very vulnerable position and was not part of an integrated design. The entire concept was flawed.

(b) The ends of the walkway were not designed to form an 'end ring frame'. This meant that the loading imposed on the walkway through its supports could not be carried into the structure without deformation.

(c) The walkway was likely to be torsionally inflexible. The supports would therefore have to accommodate roll of the pontoon.

(d) Use of cantilevered stub axles would prevent a near linear load path being used.

(e) For horizontal loadings the moment arm or eccentricity was set in the region of 115 mm on the top right (pintle) support foot.

(f) The stub axle and welds were too small for the anticipated loadings and the welds were susceptible to elastic and plastic deformation which would prevent immediate collapse. For vertical loading this degree of deformation was impossible to predict, with the result that in-service stresses in the stub axle and weld were not predictable.

(g) Mounting of the stub axles was very susceptible to errors of alignment and no tolerance was given for this or fabrication twist within the walkway itself.

(h) The geometry and size of the supports made them highly susceptible to fatigue loadings.

(i) The outer weld could not be fabricated as designed. The design called for zero radius at a major change of section. Fabrication introduced a radius and, despite very poor welding procedure and results, the radius may actually have delayed the collapse.

(j) Detail design of the stub axle to collar welds is extremely poor, making it very difficult to use non-destructive examination (NDE) techniques to check the sub-surface quality of welding (even by radiography) during fabrication and impossible by any method after fitting to the walkway.

(k) Tolerance given for the stub axle to bearing support sleeve clearance was designed as a stated minimum of 0.1 mm. (Stub axle diameter 55 mm over 196 mm contact length). This is much too tight a tolerance for this type of detail and encouraged seizure.

(l) Design for lubrication of the stub axle bearings relied on injecting grease from a Greas-o-Matic at low pressure along the line of highest bearing pressure. There was no guarantee that grease would enter the bearing; no means for keeping grease in the bearing; and no means of keeping grit and salt spray out. (In the event, nobody remembered to fit the Greas-o-Matics anyway.)

(m) The 25 mm thick low-friction pads were 15 mm thinner than the minimum recommended by the manufacturer for this type of use. Attachment of the pads should not have relied on just nuts and bolts. Other options include using load-spreading inserts and bonding. Sliding on a galvanised or painted surface is also totally inappropriate.

(n) Each stub axle was retained in its support foot by an 8 mm diameter pin. Failure of this pin could also have led to disengagement.

(o) A serious corrosion trap was created by designing only half the collar to overlap the walkway without continuous welding to seal all gaps.

(p) Access for inspection and maintenance was not provided.

(q) The effects of wind loading were not considered - the walkway would have blown over in a side-wind of a strength experienced, on average, once in every ten years.

APPENDIX 8: BERTH 3 UPPER?DECK PROJECT ? DESIGN DEFECTS IDENTIFIED AND CORRECTED FOLLOWING THE WALKWAY COLLAPSE

1 The collapse of the walkway raised concerns about the safety of the upper vehicle structures at Berth 3 at Port Ramsgate. Following examination of the remaining structure, commercial use of the berth was formally prohibited by HSE. The enforcement notice required that an assessment of the berth and completion of any necessary modifications be carried out before ferry operations could start again. Consulting engineers were appointed by Port Ramsgate. This section summarises the design defects and corrective action taken.

Heavy berthing

(a) Heavy berthing involving impact between an approaching ferry and the berth created the greatest risk of damage or displacement leading to immediate or delayed collapse of the upper vehicle bridge.

(b) In addition, the single-deck linkspans had been designed to ‘fold up’ and move shorewards during a heavy berthing. Installation of the upper bridge support trestle placed a mass concrete foundation in line with the lower vehicle bridge. Heavy berthing could have led the lower bridge to crash into this foundation.

Action taken: *Shoreward motion of the pontoon and bridges was limited by installing buffer piles between the shore and the pontoon. This system incorporated a large fender placed between the pontoon and the buffer piles to absorb impact. In addition, piles were placed to the open water side of the pontoon to prevent side-on collision.*

Upper vehicle bridge - support feet problems

(a) The 20 mm thick steel slideways had deformed - been pushed downwards - between the centre and cross webs that supported the slideways. This left them with a scalloped appearance.

(b) Following foundation damage, alterations to the original horizontal design of the slideways had introduced a sloping section of slideway. This meant that the support feet had to rock over a change of angle at some states of tide. This had been done to provide clearance for the bridge diagonal bracing members that had caused foundation damage during installation.

(c) At the change of angle, poor fitting up and finishing had left a lip between the sloping and horizontal sliding surfaces. At its worst this was 3 mm high.

(d) The two Greas-o-Matics supplying each sliding surface on the shore end feet were empty after three days rather than lasting the three months expected by FEAB.

(e) There was nothing to prevent grit entering the sliding contact surfaces.

(f) Despite the support feet axles being attached to the bridge in double shear and having lubrication grooves away from the line of highest bearing pressure, grease from Greas-o-Matics was not covering the contact surfaces and corrosion was occurring.

(g) No means had been provided for lubricating the contact surface between the support platform and the upper vehicle pintle support foot.

(h) No means for lubricating the pintle itself had been provided. When dismantled, the pintle was found to have worn and rusted such that an alarming reduction in diameter had occurred during the seven months it had been in place.

(i) The off-the-shelf spherical bearing linking the pintle support foot to the bridge was not suitable for a maritime environment.

(j) No means of access had been provided for inspection and maintenance of the seaward support feet.

Action taken: *Modifications included radical redesign of the slideways to remove the change of angle; fitting replaceable slideway wear plates; installing a remote greasing station with fixed and flexible pipe work to reach all lubrication points and fitting telescopic covers to the slideways to keep grit out. The pintle bearing was completely redesigned and the seaward end of the upper vehicle bridge adapted so that in situ bearing replacement could be safely carried out. Access ladders and working platforms were provided to all areas of the berth requiring inspection.*

Upper vehicle deck (upper deck on the pontoon)

(a) This was hinged to the pontoon towers at the landward end and adjusted by two hydraulic cylinders at the seaward end with shot bolt locking. The landward hinge pins ran in spherical bearings. The bearings and the pins were not accessible for inspection and were not maintainable. There was no backup in the event of failure.

(b) Twisting of the upper vehicle deck on to the right-hand seaward pontoon tower was being caused by asymmetric pressure on the deck as the roadway turned to the right at the start and finish of the upper vehicle bridge.

(c) Grounding of long vehicles on the ramp leading to the upper bridge and when crossing the flaps linking the pontoon to a ferry had been a problem.

Action taken: *Retention assemblies were welded to the pontoon towers to support the upper deck in the event of bearing/pin failure. A number of alterations were made to ensure smooth changes of gradient on the roadway and to refine pontoon ballasting and deck adjustment procedures.Provision was made for improved lubrication and removal of grit trapped between contact surfaces.*

Berth to ferry flaps - edge interface

(a) Interference between adjacent 7 m long flaps hinged off the upper and lower decks was being caused by wear of the plain hinge bearings. These comprised 100 mm diameter stainless steel hinge pins mounted in 40 mm thick hinge plates. No lubrication had been provided and the hinge plate holes had become enlarged by up to 12 mm, largely due to deformation. This resulted from the flaps being very wide - some over 2 m - and poor hydraulic control that prevented free motion of the flap hydraulic cylinder. When a heavy goods vehicle moved on to the ferry end of the flap, one corner of which may have been clear of the ferry deck, the flap acted as a giant lever pivoting around the locked-out hydraulic cylinder. The hinge pin was repeatedly levered up and hinge plate deformation resulted.

Action taken: *It was not cost-effective to reduce the width of each flap to a sensible dimension so a combination of measures was adopted. These included preventing hydraulic cylinder lockout; increasing the thickness of each hinge plate; and adopting a rigorous inspection and replacement regime for parts subject to wear or displacement. On the upper deck this required installation of an access gantry where previously there had been none.*

Operation and maintenance

2 In consultation with the berth operators - mainly port foremen - an operating manual was drawn up.

3 A detailed inspection and maintenance manual was written to cover day-to-day involvement of non-technical operations staff through technical maintenance from routine greasing to major *in situ* dismantling and replacement work.

Passenger walkway

4 All traces of the walkway route have been removed from the passenger ramp

building and the pontoon. Alternative enclosed routes were available. Before RMT ferry services stopped, foot passengers used the passenger ramp building to gain access to the top of the vehicle ramp. The upper deck and bridge was then closed to vehicles and the passengers used the vehicle route to walk on to the ferry. The landing platform within the passenger ramp building has had the walkway slideways removed and the opening covered to match the rest of the building. Only a window remains, looking out to the pontoon tower where the walkway support platform used to be.

APPENDIX 9: PROBLEMS DURING INSTALLATION OF THE BERTH 3 UPPER BRIDGE DECK

1 The new upper vehicle bridge was supported on four feet in a similar way to the 1985 lower vehicle bridge. One of them - the seaward right-hand foot - was attached to the pontoon by a vertical pin (pintle). Unlike the walkway supports, these feet were mounted below the bridge structure on axles that were held rigidly at both ends.

2 The upper vehicle bridge was prepared for lifting into position on 2 February 1994 by a floating crane. Installation of the shoreside steel trestle on which the bridge would rest was under the control of FEAB. The foundations had been installed by a contractor working for Port Ramsgate. The crane controller refused to start the lift as he could see that the trestle was not secure. No one present knew who was supposed to grout in the trestle hold-down bolts and the steelwork baseplates. The hold-down bolts were fixed in position by Port Ramsgate employees using quick-setting epoxy grout. Following this delay, the lift went ahead with the steelwork base plates resting on packing shims. This was not a satisfactory situation as the trestle was expected to cope with immediate motion of the bridge due to tidal and mid-winter wave action.

3 It was then discovered that the diagonal braces fitted below and forming part of the upper vehicle bridge were preventing the shore end sliding feet from resting on the horizontal slideways on top of the trestles. The ends of the box section braces were cut away to clear the slideways.

4 During the night, loud noises were heard while an after-dark berthing test involving the ferry *Prins Filip* was in progress. There had been further contact between the diagonal bracing members on the underside of the bridge and the support trestle. Under tidal and wave motion the trestle had been pushed shorewards, causing substantial foundation damage. The upper vehicle bridge had to be lifted down.

5 The engineering consultancy who had designed the foundations for Port Ramsgate investigated this incident, reporting to Port Ramsgate on 8 February. The foundations had been designed using loading data supplied by FEAB/FKAB. Although not linked to the cause of the vehicle bridge incident, this data was checked and doubts raised about its suitability. Rebuilding the foundations to a modified design was proposed. The report also highlighted the result of checks on the trestle hold-down bolts. These showed they had been designed by FKAB with a safety factor of 1.3 - much lower than that normally used by UK designers. After consulting FKAB, the engineering consultancy also suggested redesigning the trestle by adding bracing steelwork. FKAB responded, indicating the reliance placed on LR's role in the project: 'As the trestle structure is approved by Lloyd's we consider the additional bracing entirely as (your)

improvement of the foundations'. This work was carried out.

6 Redesign of the foundations incurred more delay and substantial cost. In an attempt to prevent further contact between the fixed trestle and the moving bridge, the seaward ends of the previously horizontal slideways were lowered. The slideways now comprised a sloping surface, a change of angle and the remaining horizontal length. This meant that under some tidal or heavy berthing conditions, the sliding support feet would have to rock over the change of angle. This poorly thought-out design change was badly executed. The bridge was lifted back into place on 14 March.

APPENDIX 10: CRIMINAL FINES AND COSTS AWARDED AGAINST THE ORGANISATIONS PROSECUTED

Organisation	*Fine £*	*Costs £*
Port Ramsgate Ltd (The port operator who conceived and placed the project)	**200 000** (no separate fine under the Docks Regulations offence)	**219 500**
Fartygsentreprenader AB (FEAB) (Contracted by Port Ramsgate Ltd to design and build the upper vehicle deck and walkway)	**750 000**	**251 500** (awarded jointly against FEAB/FKAB)
Fartygskonstruktioner AB (FKAB) (Sister company to FEAB, subcontracted by FEAB to design the upper deck and walkway)	**250 000**	
Lloyd's Register of Shipping (LR) (Contracted to check the design, manufacture and installation of modifications to the berth which included the walkway)	**500 000**	**242 500**

1 The total fines and costs, amounting to £2.4 million, was the largest criminal penalty awarded for health and safety offences arising from one incident in the UK at that time.

2 FEAB and FKAB have no office or assets within UK jurisdiction. There is no mechanism for recovering the penalty awarded against these companies. At the time of writing they have declined all requests from the court for payment. This means that neither company will be able to bid for work in the UK. It also means that senior representatives of either company will be unable to visit the UK without risk of being arrested for non-payment of criminal fines.

APPENDIX 11: CURRENT LEGISLATION

Health and safety legislation applicable to the supply and use of a walkway in a port includes the Health and Safety at Work etc Act 1974, in which:

(a) section 2 places a duty on each employer to take reasonably practicable steps to ensure the health and safety of his employees;

(a) section 3 places a similar duty on each employer to safeguard members of the public - and people employed by other employers - who could be affected by the work activity;

(c) section 6 places a duty on the supplier of equipment to ensure it is safe to use and accompanied by suitable information - such as operating and maintenance instructions; and

(d) section 37 makes provision for senior managers to be personally prosecuted for the same offence as the organisation employing them.

The Docks Regulations 1988 place specific duties on port operators. In particular, regulation 7 makes it an absolute duty to provide suitable safe and properly maintained means of access to a ship.

In addition the following legislation sets standards or procedures that are relevant:

(a) the Supply of Machinery Regulations 1992 may apply in full or in part where the linkspan or walkway is defined as a machine or incorporates machinery;

(b) the Management of Health and Safety at Work Regulations 1992 require work activity to be risk-assessed and rigorously organised using a hazard identification and risk reduction methodology;

(c) the Workplace Regulations 1992 set requirements to provide safe means of access and prevent hazards such as falls from open edges; and

(d) the Provision and Use of Work Equipment Regulations 1992 require the prevention of entanglement or trapping between moving parts and a proposed amendment will place maintenance requirements on the organisation or person responsible.

APPENDIX 12: LIST OF FIGURES

Note: *In diagrams showing motion, the degree of motion has been exaggerated to assist clarity*.

REFERENCES

1 *Lloyds Register Rules and Regulations for the classification of ships Part 7*, Other ship types and systems, Chapter 6 Ship-to-shore ramps and linkspans Lloyd's Register of Shipping

2 *Safety in ports: ship-to-shore linkspans and walkways, a guide to procurement, operations and maintenance* Construction Industry Research and Information Association (CIRIA) 1999

3 *Lloyds Register Rules and Regulations for the classification of ships Part 3*, Ship structures, Chapter 10 Welding and structural details, Lloyd's Register of Shipping

4 *Code for lifting appliances in a marine environment* Lloyd's Register of Shipping 1987

5 *Code of Practice for fatigue design and assessment of steel structures* BS 7608:1993

6 *Method for Vickers hardness test and for verification for Vickers hardness testing machines* BS 427:1990

7 *Steel, concrete and composite bridges* ISO 2395 and BS 5400: Parts 1-10C: 1978-1990

8 *Rules relating to the constitution of Lloyd's Register of Shipping* Lloyds Register of Shipping

British Standards are available from:
British Standards Institution Sales and Customer Services, 389 Chiswick High Road, London W4 4AL Tel: 0181 996 7000 Fax: 0181 996 7001

Lloyds Register publications are available from:
Lloyds Register of Shipping, 71 Fenchurch Street,
London EC3M 4BS Tel: 0171 709 9166 Fax: 0171 488 4796

CIRIA publications are available from:
CIRIA, Storey's Gate, Westminister,

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