Rail Accident Investigation Branch

Rail Accident Report

Derailment of a freight train near Stewarton, Ayrshire
27 January 2009

Department for Transport

Report 02/2010
February 2010

This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC;
- the Railways and Transport Safety Act 2003; and
- the Railways (Accident Investigation and Reporting) Regulations 2005.

Any enquiries about this publication should be sent to:

RAIB
The Wharf
Stores Road
Derby UK
DE21 4BA

Email: enquiries@raib.gov.uk
Telephone: 01332 253300
Fax: 01332 253301
Website: www.raib.gov.uk

This report is published by the Rail Accident Investigation Branch, Department for Transport.

Derailment of a freight train near Stewarton, Ayrshire, 27 January 2009

Contents

Introduction

1 The sole purpose of a Rail Accident Investigation Branch (RAIB) investigation is to prevent future accidents and incidents and improve railway safety.

2 The RAIB does not establish blame, liability or carry out prosecutions.

Key Definitions

3 All mileages in this report are measured from a zero datum at the former Glasgow Gorbals Junction.

4 Appendices at the rear of this report contain the following:

- abbreviations, in appendix A; and
- technical terms (shown in *italics* the first time they appear in the report), in appendix B.

Summary of the Report

Key facts about the accident

5 At 06:12 hrs on 27 January 2009 the last six tank wagons of train 6B01, a ten-wagon dangerous goods train carrying a mixed consignment of gas oil, diesel and kerosene to a fuel depot south of Kilmarnock, derailed as the train crossed a metal *underbridge* south of Stewarton, Ayrshire (figure 1). The bridge, which takes the railway over the A735 road, collapsed and the derailed wagons overturned, coming to rest at various positions to the south of the bridge.

6 Fuel from four of the derailed wagons leaked into the local environment and watercourses, and there were localised fires. There were no fatalities or injuries.

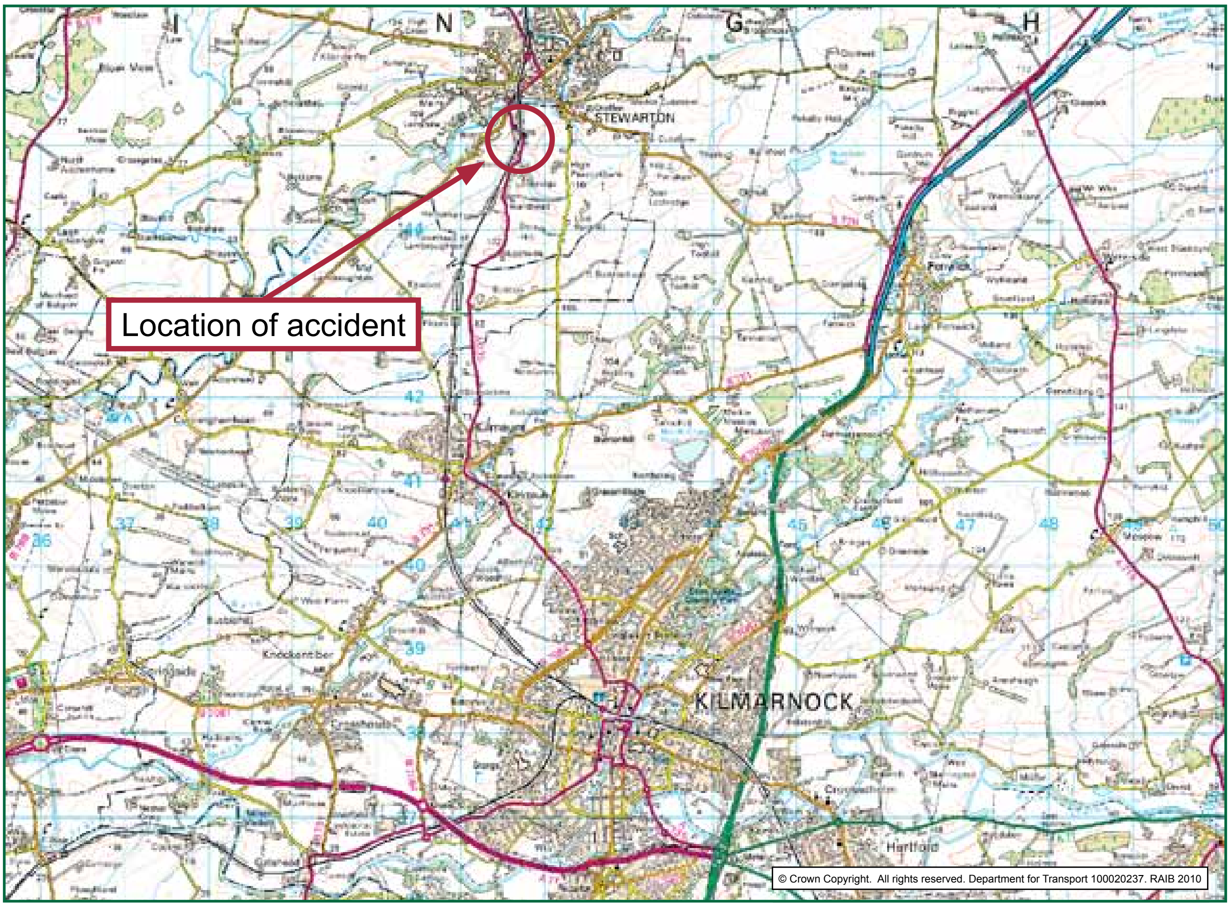

Figure 1: Extract from Ordnance Survey map showing location of the accident

Immediate cause, causal and contributory factors, underlying causes

7 The immediate cause of the derailment was the collapse of the bridge (known as Bridge 88) that followed the catastrophic structural failure of its east and centre *main girders*. Heavy corrosion had so significantly weakened these main girders that they were no longer able to carry the loading from trains that were permitted to run over the bridge.

8 The causal factors were:

- the form of construction of Bridge 88 that meant there was a hidden corrosion trap that affected the inner surfaces of the main girders; the corrosion resulted in a loss of thickness of the *web plates* of these girders, and in places holes formed; and
- the use of incorrectly assumed dimensions for the thicknesses of these web plates in the last two routine *assessments* of Bridge 88 (undertaken in 1982 and 1994), and no allowance for web plate corrosion loss; this meant that the calculated *live load capacity* of the east and centre main girders was higher than it should have been, and as a result, the reports of corrosion defects were not acted upon.

9 Contributory factors were:

- that no arrangements had been made to inspect the hidden parts of the east and centre main girders where the heavy corrosion on the web plates was occurring;
- that the web plates on the main girders were not fully repaired when the heavy corrosion would have been revealed when the east side of the bridge was waterproofed in 1987;
- that the bridge *superstructure* was not re-painted when the waterproofing work was done, or afterwards;
- the lack of any action in response to the web plate corrosion issues that were identified during the last routine *detailed examination* of the bridge, and highlighted immediately in an urgent defect report in October 2003; this could have initiated work that could have led to the structural significance of the web condition being fully appreciated;
- the lack of any response to the continued reporting of web corrosion defects in the routine annual *visual examinations* that followed the last detailed examination;
- the lack of a formal means of alerting Network Rail (the railway infrastructure owner) to urgent findings arising from special assessment calculation work that was undertaken in response to work that Network Rail did nationally in order to verify the live load capacity of all its underbridges (the *route availability* verification exercise) because of a legal notice issued by the *Office of Rail Regulation* (ORR);
- the decision to bring forward the replacement of Bridge 88, because of an upgrade scheme, in that it resulted in information being overlooked that was potentially relevant to the condition of the bridge while it remained in service; and
- the belief that Network Rail continued to have in the incorrect results of the last routine assessment when evaluating the ongoing safety of Bridge 88 until it was replaced, possibly exacerbated by deterioration that had occurred since that assessment was done.

10 An underlying factor was the ongoing reliance on unverified critical information by those responsible for the routine management of Bridge 88.

Severity of consequences

11 The derailed wagons, track and local infrastructure were all badly damaged as a result of the accident. The tanks on three of the wagons were punctured, and a valve was damaged on another when it overturned. Altogether around 220,000 litres of diesel and kerosene leaked from these wagons. The last wagon caught fire.

12 The spilt fuel contaminated local land and entered a tributary of the River Irvine, which flows into Irvine Harbour. It resulted in a major pollution incident that had serious impact on the ecology of the watercourses – killing fish and invertebrates, and affecting birdlife.

13 The main girders that supported the east side of Bridge 88 failed and fell to the A735 road below, together with other debris and masonry from the south *abutment*, a major part of which was destroyed.

14 Because it was already planned to replace Bridge 88, and the new bridge deck had been made, it was possible to reopen the railway within a month of the accident.

Recommendations

15 Recommendations can be found in paragraph 267. They relate to the following areas:

- checks and intervention action with regard to other Network Rail bridges that may be at risk because of similar hidden corrosion issues or erroneous assessment findings;
- improvements to Network Rail's methods and processes for the examination of hidden critical parts of structures;
- improvements to the management of the information used for making decisions about the structural safety of Network Rail's bridges;
- improvements to Network Rail's structures assessment procedures;
- evaluation of the use of track geometry recordings as a means of identifying structural issues with railway underbridges;
- improvements to the construction of existing tank wagons registered in Great Britain; and
- evaluation of improvements to international regulations concerning tank wagon design.

The Accident

Summary of the accident

16 At 06:12 hrs on 27 January 2009 the last six tank wagons of train 6B01, the 05:20 hrs Mossend Down Yard to Riccarton freight service, derailed as the train crossed southwards on Bridge 88, which takes the railway over the A735 road south of Stewarton. The ten-wagon train was carrying a mixed consignment of gas oil, diesel and kerosene to a fuel depot at Riccarton, to the south of Kilmarnock.

17 Bridge 88 collapsed when the train was on it and all the derailed wagons overturned, coming to rest at various positions to the south of the bridge (figure 2). The derailed wagons, and the track and associated infrastructure, were badly damaged.

18 A major part of the fuel on the train leaked into the local environment and watercourses, and there were localised fires. There were no fatalities or injuries.

The parties involved

19 DB Schenker Rail (UK) Ltd (DB Schenker) operated the train, employed the driver and maintained the locomotive. The fuel consignment was being carried for its customer, BP Oil.

20 BP Oil was also the owner of all the wagons, apart from the eighth, which was leased from VTG Rail UK Ltd (VTG Rail). Axiom Rail (Stoke) Ltd (Axiom Rail) was contracted to maintain all of the wagons.

21 Network Rail owns, operates and maintains the railway infrastructure on which the accident occurred. It was part of its Scotland Territory.

22 In its Scotland Territory, Network Rail contracted consulting engineers to carry out specific activities to support Network Rail's management of its bridges. At the time of the accident, it contracted Jacobs Engineering UK Ltd (Jacobs) to do directed assessment work (determining the safe load carrying capacity of a bridge). It also employed Atkins to undertake visual and detailed examinations in order to provide information on the physical condition of its bridges. (The key activities involved in Network Rail's processes for the routine management of bridges are outlined in paragraph 50.)

23 Jarvis Rail Ltd (Jarvis) was contracted to undertake infrastructure improvement works that were ongoing in the area at the time of the derailment.

24 DB Schenker, BP Oil, VTG Rail, Axiom Rail, Network Rail, Jacobs, Atkins and Jarvis freely co-operated with the investigation.

Location

25 Stewarton is on the Glasgow and South Western line, which runs from Glasgow to Carlisle. The railway is a secondary route that duplicates the West Coast Main Line. At the location of the derailment it mainly carries local passenger traffic, with occasional heavy freight trains. Bridge 88 is between Stewarton station (18 miles 20 chains) and Kilmaurs station (21 miles 48 chains) on the Glasgow-Barrhead-Kilmarnock section. The *up* direction is for trains running south, towards Carlisle.

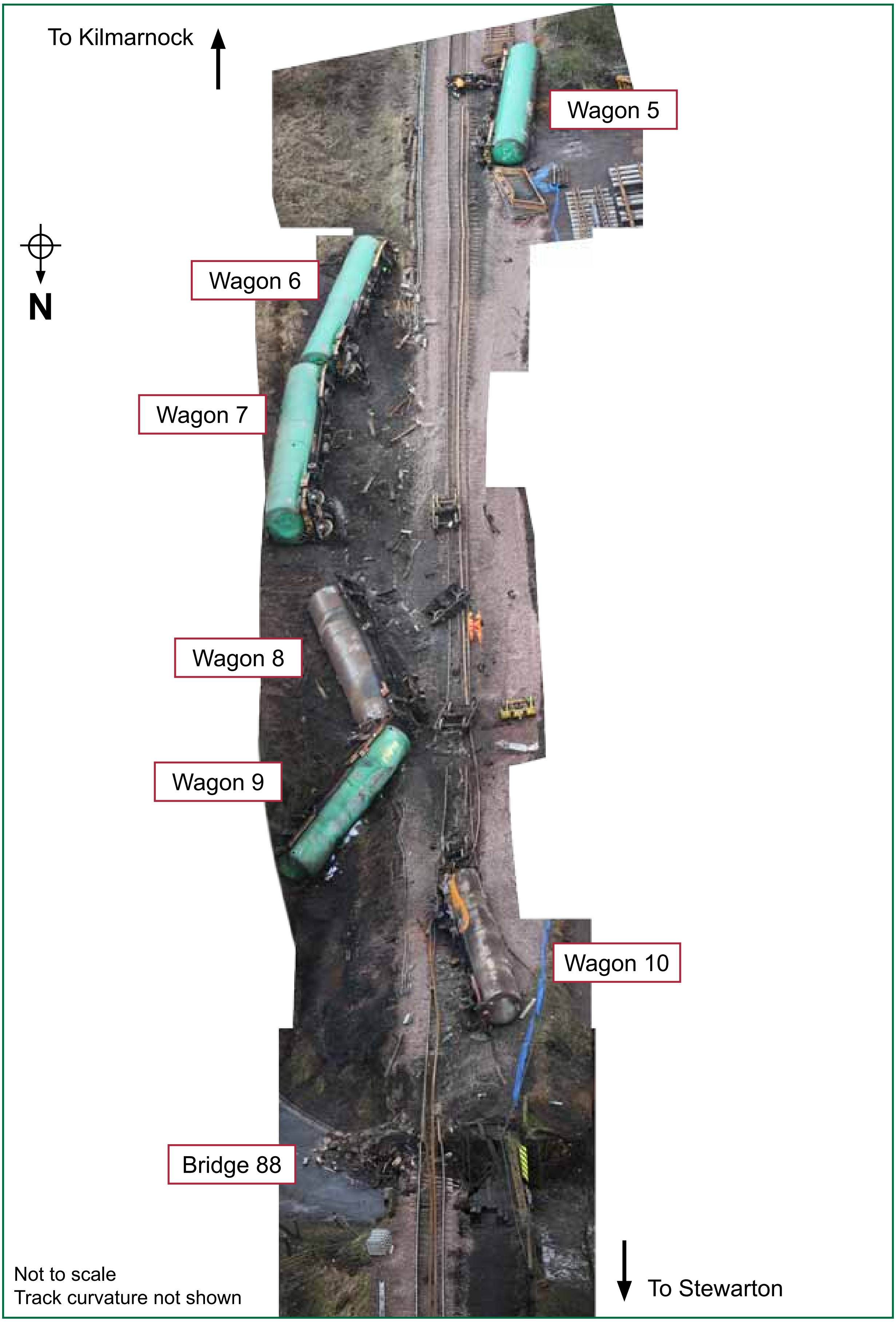

Figure 2: Composite aerial photograph showing the collapsed bridge and the location of the derailed wagons on the southern side (photographs courtesy of Network Rail)

26 South from Stewarton station, the railway crosses Annick Water Viaduct (Bridge 87), reaching Bridge 88 at 18 miles 60 chains. The track is curved towards the right and is on a falling gradient of 1 in 131, at the end of Annick Water Viaduct, reducing to 1 in 722 at Bridge 88's north abutment. The permitted speed of trains, in both directions, is 65 mph (105 km/h) to just north of Bridge 88, increasing to 70 mph (113 km/h) on crossing the bridge and beyond.

27 The railway was constructed as a double track line. Along with other secondary lines around this time, it was reduced to a single track in the 1970s, between Barrhead and Kilmarnock, by removing the former *down* line. The up line was left in place on the east side of the original double track *formation*. A *loop* was provided at Lugton (13 miles 50 chains) to allow trains to pass each other.

28 An upgrade scheme (the Lugton loop scheme) was underway at the time of the derailment to improve the capacity of the single line by extending the loop at Lugton. The work included reinstating the track on the bed of the former down line in the vicinity of Bridge 88.

29 Figure 3 is a diagram of the railway between Barrhead and Kilmarnock, showing key features relevant to the investigation.

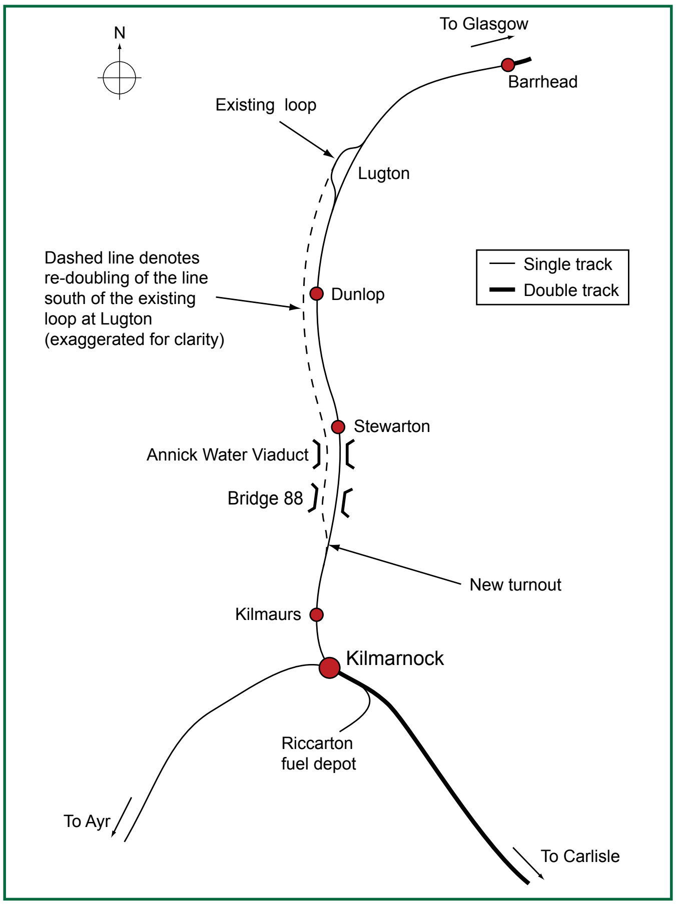

Figure 3: Diagram of the railway between Barrhead and Kilmarnock (not to scale)

External circumstances

30 The weather in the area on 27 January 2009 was light drizzle, with a temperature of 7°C. It played no part in the accident.

Train

31 Train 6B01 was formed of a class 66 diesel electric locomotive, number 66067, and a mixture of ten TEA and TEB type tank wagons; figure 4 shows one of the TEA wagons from the train. The train carried a combined volume of around 866,700 litres of fuel, which had been loaded at the Grangemouth refinery. Table 1 is a summary of the wagons forming the train.

	Wagon number	Wagon type	Owner	Consignment	
Wagon 1	BPO 80566	TEA	BP Oil	Gas Oil	86,000 litres
Wagon 2	BPO 87580	TEB	BP Oil	Gas Oil	86,100 litres
Wagon 3	BPO 87261	TEA	BP Oil	Gas Oil	86,300 litres
Wagon 4	BPO 80565	TEA	BP Oil	Gas Oil	86,000 litres
Wagon 5	BPO 87577	TEB	BP Oil	Gas Oil	86,000 litres
Wagon 6	BPO 87164	TEA	BP Oil	Diesel	85,900 litres
Wagon 7	BPO 87566	TEB	BP Oil	Diesel	86,600 litres
Wagon 8	VTG 87516	TEA	VTG	Kerosene	88,300 litres
Wagon 9	BPO 87188	TEA	BP Oil	Kerosene	87,700 litres
Wagon 10	BPO 80564	TEB	BP Oil	Kerosene	87,800 litres
				Total	**866,700 litres**

Table 1: Formation of the wagons on train 6B01

32 TEA and TEB tank wagons are of a similar construction. They both consist of a single steel tank cylinder on a steel underframe, 17.753 metres long over buffer faces, supported on a pair of *three-piece bogies*. They are fitted with *drawhooks* and *Instanter* couplings.

33 The RAIB found no evidence that any of the laden tank wagons exceeded the permitted gross laden weight limits specified in TOPS*,* the computer system DB Schenker uses to manage and authorise the operation of its freight trains. For wagons 6 and 7 this limit is 102 tonnes; for all the other wagons it is 101.95 tonnes.

34 The tank wagons on train 6B01 were built between 1967 and 1968 by a variety of manufacturers including Pickering, Powell Duffryn and Metro Cammell.

35 Axiom Rail had carried out a regular programme of maintenance on the wagons at its outstation in Grangemouth. It comprised a *vehicle inspection and brake test* (VIBT), done every 12 months, with two *planned preventative maintenance* (PPM) activities done approximately four and then eight months later. Although the RAIB found that TOPS reported that the VIBT for wagon 5 was overdue, paper records showed that both the VIBT and PPM were in date. This discrepancy is most likely due to an oversight with the TOPS data input, and was not of significance to the derailment.

36 The RAIB found nothing untoward with the last VIBT and PPM records of any of the wagons, or in the defect repair book of locomotive 66067, to indicate a pre-existing fault on the train that could have contributed to the derailment or its consequences[1].

37 Because it was a *class 6 train*, 6B01 was not permitted to exceed 60 mph (97 km/h).

Figure 4: TEA tank wagon

Infrastructure

Signalling

38 Signalling on the line between Barrhead and Kilmarnock is by the *Scottish Region tokenless block* system, controlled from signal boxes at Barrhead, Lugton and Kilmarnock. Neither the signalling system, nor its operation, played a part in the derailment.

Track

39 The track over Bridge 88 consisted of continuously welded rails on concrete sleepers with granite ballast. It had a nominal *cant* of between 70 and 80 mm.

Bridge 88

40 Bridge 88 was a single span metal underbridge, designed to carry the original double track railway over a single carriageway road. The road and railway are at an acute angle to one another and, as a result, the bridge was skewed at an angle of 39 degrees to a horizontal line at right angles to the railway. The clear square span[2] (the perpendicular distance between the supporting abutments) was 9.2 metres and the clear skew span (the distance between the abutments, parallel to the track) was 11.8 metres.

41 The metal superstructure of the bridge was of the *half-through* design (a bridge where the floor of the bridge, carrying the load from the track, is supported by main girders located either side of the track) and comprised an east and west deck with two outer main girders (the east and west main girders) and a common centre main girder. All three main girders ran parallel to the track.

[1] The RAIB also physically examined the tank wagons with reference to the cause of the derailment and the leakage that occurred. This is discussed in paragraphs 235 to 249 and appendix F.

[2] Dimensions are based on the survey undertaken as part of the Inspection for Assessment done in November 2007 (paragraph 65).

42 *Cross girders* spanned between the main girders, except at the ends of the bridge where, because of the skew angle, the cross girders were cut short and partly supported by the abutments. Figure 5 shows a plan of the bridge superstructure and the principal bridge dimensions.

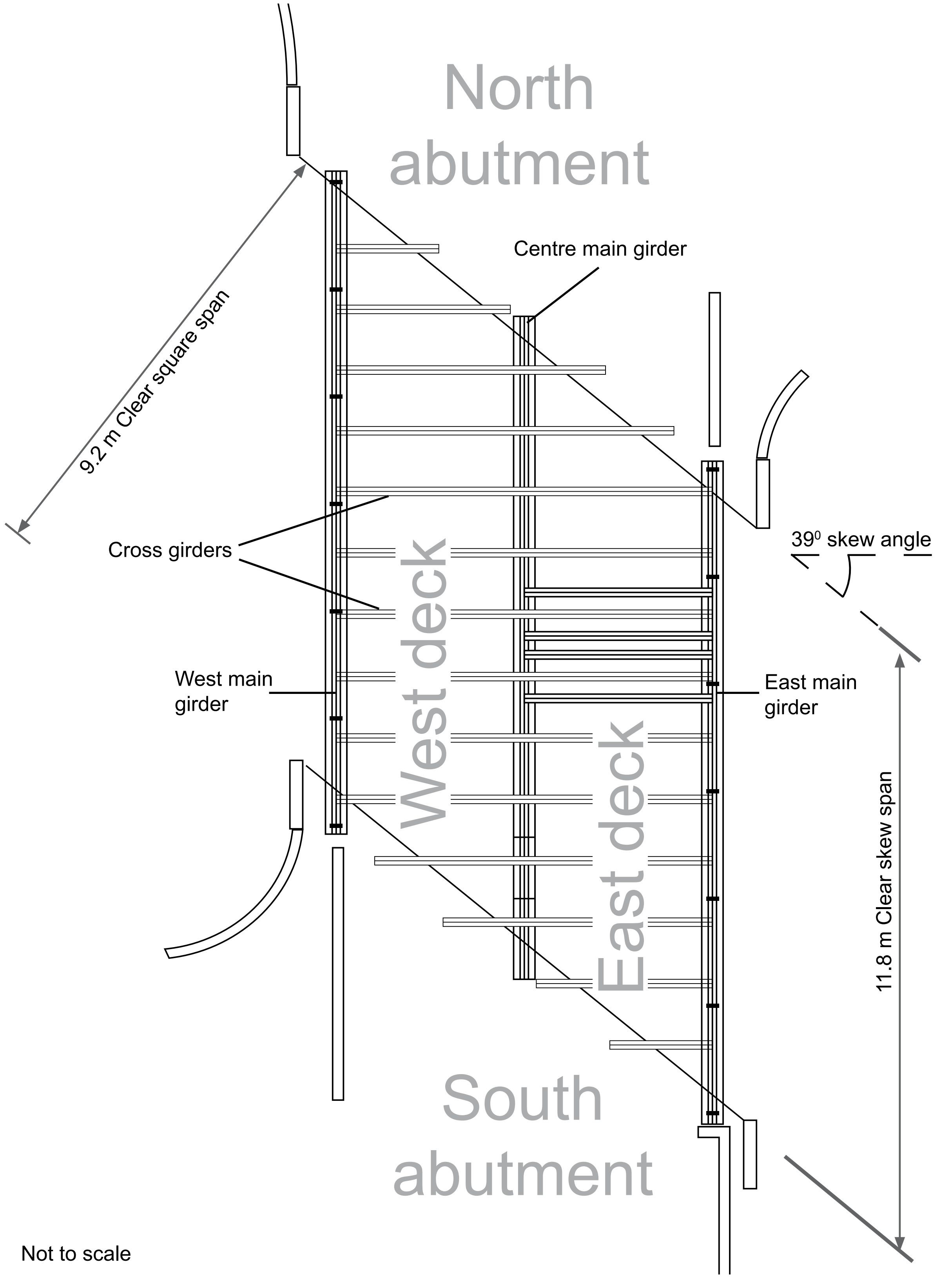

Figure 5: Plan view of Bridge 88 superstructure

43 All the girders were fabricated from *wrought iron* plates, angles and T-sections, held together with wrought iron rivets. The supporting abutments were of stone masonry. The railway approached these, from both the north and south, on earth embankments. Figure 6 shows a photograph of the east elevation of the bridge at the time of the last routine examination in February 2008; train 6B01 was crossing from the right when it derailed.

Figure 6: East elevation of Bridge 88 in February 2008 (photograph courtesy of Network Rail)

44 Network Rail's records do not show when Bridge 88 was constructed, but it is believed to date from the building of the line in the 1870s.

45 The tracks over the bridge originally had the rails directly supported and fastened on *longitudinal timbers* that spanned the cross girders. Figure 7a shows the likely arrangement.

46 The London Midland and Scottish Railway (LMSR - the owners of the line from 1923 to railway nationalisation in 1948) replaced the longitudinal timbers with a timber deck. The deck timbers also spanned the cross girders, but now supported the rails on ballast and sleepers. The ballast was kept in place by timber boards mounted on edge (timber upstands), one on each side (figure 7b). The record drawing showing this as a proposed arrangement was dated 1935, but there is no record of the actual date of implementation.

47 In 1984, British Rail decided to waterproof the east deck of the bridge because it was concerned about the condition of the timber deck; the line had been reduced to single track by this time and the west deck was redundant (paragraph 27). British Rail did this work in 1987. It involved removing the track and ballast, fitting a proprietary waterproofing system (the detailed application of which was designed by British Rail), and then replacing the ballast and track on top.

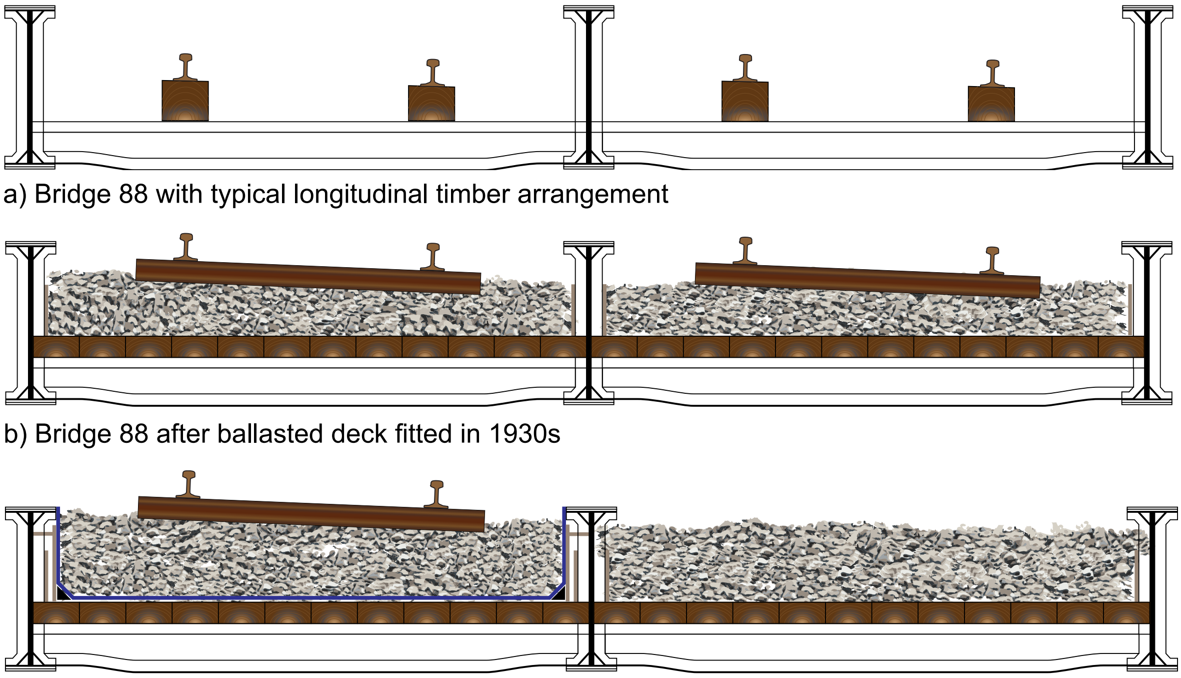

Figure 7: Cross-section of the deck of Bridge 88 showing the modifications made since it was constructed

48 The waterproofing system comprised a 6 mm thick layer of bituminous board on the timber deck, with a neoprene waterproof membrane laid on top. The membrane was protected by a further two layers of bituminous boarding, each 12 mm thick. At the sides of the deck, the waterproofing membrane was brought up to the top of the main girders. Figure 7c shows the arrangement fitted.

Routine management of bridges

49 Network Rail's company standards NR/CS/CIV/032 'Managing Existing Structures' and NR/CE/S/080 'Management of Existing Bridges & Culverts' define the overall process used by Network Rail for the identification and mitigation of risks associated with bridges on its infrastructure.

50 These standards identify four key activities:

- Listing and identification: capturing the key details of each bridge, such as its unique identity, construction and safe load capacity;
- Examination: periodic inspection of each bridge to determine structural condition and monitor changes, including those to loading and environment;
- Assessment: work to determine, and review at periodic intervals[3], the safe load capacity of each bridge; and
- *Evaluation*: an appraisal of available information for each bridge, including findings from examinations and the results of assessments, to decide if intervention actions are required to ensure an acceptable level of safety; evaluations are carried out in response to a variety of events, such as the reporting of a significant defect or the receipt of an assessment report (paragraph 167).

[3] Since the implementation of Railway Group standard GC/RT5141 in 1995, it has been the aim that bridge assessments should be no older than 18 years.

51 Network Rail required implementation of both NR/CS/CIV/032 and NR/SP/CIV/080 from 1 July 2004. Prior to this, *Railway Group standard* GC/RT 5100 'Safe Management of Structures' was applicable; it defined a similar process. British Rail had similar process requirements before this.

52 There are two types of regular examination. These are defined in Network Rail's company standard NR/SP/CIV/017 'Examination of Bridges & Culverts'[4]:

- Detailed examination: a close-up examination of a bridge to record, in sufficient detail, the condition of all its parts and its use, and to make recommendations for remedial works. Special consideration is required to be given to verifying the condition of load bearing parts that are hidden or obscured. The normal interval between detailed examinations is 6 years[5]; the standard requires a risk assessment to justify an increase beyond this.
- Visual examination: an examination to identify changes in the condition of a bridge, which is carried out from a safe location without the use of temporary access equipment. There is no specific requirement to gain access to hidden parts. However, representative samples of obscured parts should be examined where reasonably practicable, for instance by lifting ceiling panels to see the bridge structures above or using other simple non-disruptive means. Visual examinations are normally carried out annually, but can be omitted if they coincide with a detailed examination.

53 Network Rail's Structures Engineer for its Scotland Territory was responsible for the routine management of Bridge 88 at the time of the derailment, and had records to show that it was an identified structure and was subject to a regular programme of examination and assessment.

54 Atkins, whom Network Rail had contracted to do routine bridge examinations in the Scotland Territory (paragraph 22), did the last detailed examination of Bridge 88 on 7 October 2003 (the 2003 Detailed Examination).

55 Atkins also did the last visual examination, which was undertaken on 25 February 2008, as well as visual examinations on 1 March 2007, 20 March 2006, 21 February 2005 and 19 October 2001. There are records of visual examinations done by others on 9 January 2001, 9 December 1999 and 13 January 1999. With the exception of the 24 months between October 2001 and October 2003, for which the RAIB could not find a record of an examination being done, and the period from October 2003 to February 2005, which was beyond the 15-month limit between visual examinations, routine examinations were being undertaken in general accordance with the intervals required. As well as undertaking routine detailed and visual examinations, Atkins carried out special examinations to monitor the condition of the masonry abutments. Records show that these examinations were carried out on 2 May 2001, 15 September 2002, 15 February 2004, 17 October 2004, 24 April 2005 and 10 December 2005.

---

[4] The defined requirements in issue 1 of the standard, current at the time of the 2003 Detailed Examination, and issue 2, current at the time of the derailment, are not significantly different regarding the aspects highlighted.

[5] Except for bridge parts submerged in a watercourse. The normal interval for these is 3 years.

56 Records show that the last routine assessment of Bridge 88 was undertaken in August 1994 (the 1994 Assessment). Railtrack, the infrastructure owners at that time, did the work in-house. The previous routine assessment was done in 1982 (the 1982 Assessment), when British Rail owned the infrastructure. This assessment was contracted to an engineering consultancy. Although there was no specifically defined requirement at the time, the period between the 1982 and 1994 Assessments was compliant with the maximum 18-year interval in Railway Group standard GC/RT5141 that was implemented shortly afterwards (paragraph 50 and associated footnote). Network Rail's processes did not require another routine assessment before the date of the derailment.

Bridge strikes

57 Road vehicles frequently strike railway underbridges that cross highways. Network Rail record around 2000 such strikes every year.

58 Network Rail's records show that Bridge 88 had been struck on at least 18 occasions between 1966 and the date of the accident. The actual number of occasions is likely to be greater, as not all bridge strikes are reported.

59 In 1992 British Rail wrote to the highways authority, Strathclyde Regional Council, and asked for height restriction signs to be put up, on either side on the bridge, prohibiting vehicles over 4.1 metres or 13 ft 6 in. In 1994, at a bridge strike liaison meeting with Strathclyde Regional Council, Railtrack agreed to additionally fit reflective yellow and black hatching road signs. Bridge 88 was fitted with both types of sign at the time of the accident.

Route availability verification exercise

60 In March 2006 the ORR issued a legal notice[6] on Network Rail under section 57C of the Railways Act 1993 for its 'failure to publish accurate information about the capability of the network in documents that are used to define the network available for train operators …'. This action was in relation to Network Rail's operating documents declaring that it was possible to operate trains on lines where other records detailed infrastructure limitations that should have restricted this. It arose because of a discrepancy with records relating to a line in the Manchester area, but it was found that the issues were more widespread.

61 Network Rail took action in response to the ORR notice by commencing a project to verify published infrastructure capability, including the live load capacity in terms of route availability[7] (RA), of all its underbridges. Within Network Rail, this project was known as the route availability verification exercise. The exercise covered bridges that had a documented live load capacity less than the RA of the line on which they were located. In its Scotland Territory, Network Rail contracted Jacobs to carry out directed work on the assessment studies that were required (paragraph 22).

---

[6] ORR imposed a financial penalty on Network Rail as a result. Further information regarding the notice can be found on the ORR's website at www.rail-reg.gov.uk.

[7] Route availability is the standard measure used by Network Rail, and its predecessors, to describe the structural ability of its underbridges to carry live load; it is a measure of the train load that can be safely carried. Trains are allocated one of 10 standard load classes, RA1 through to RA10; train 6B01 was allocated RA10, the heaviest. Assessments are used to determine the maximum RA value that each key structural element of a bridge can carry, for example, cross girder or main girder. See appendix D for further information on route availability and BSUs, the standardised measure on which it is based.

62 In the 1994 Assessment report (paragraph 56) certain structural elements of Bridge 88 had a live load capacity below that published in operating publications[8]. There were three issues:

- the cross girders, a significant number of which were corroded, or were damaged due to strikes from road vehicles;
- the east main girder because of excessive *shear stress* in some of its rivets; and
- the east main girder because of vehicle strike damage to its bottom *flange*.

63 Initially, on 18 January 2007, Network Rail asked Jacobs to review the discrepancy issues in the 1994 Assessment to check if they were due to analysis conservatisms now addressed by refinements to Network Rail's *assessment codes*. Network Rail required Jacobs to review and report on all three discrepancy issues. There is, however, evidence that Network Rail's primary concern was with the cross girders and that the issues with the east main girder were not considered significant:

- Network Rail knew that the criterion for rivet shear stress was overly conservative in the version of the assessment code (the document that describes how the live load capacity of a bridge is to be calculated in an assessment) that was used for the 1994 Assessment and had adopted a principle that this criterion should not dictate live load capacity decisions. Subsequent research has led to more realistic rules for shear stress in rivets.
- The damage to the east main girder bottom flange was repaired sometime after the 1994 Assessment report was issued (appendix F and figure F2).

64 On 23 March 2007, Jacobs advised Network Rail that it considered that application of the new assessment codes would offer little or no scope for improvement to the RA of this structure. In the light of this, Network Rail considered replacing the superstructure of Bridge 88 and entered a proposal in its business plan. On 19 June 2007, after undertaking an evaluation, Network Rail asked Jacobs to undertake additional assessment work. This included consideration of the load from real trains (using train types defined by Network Rail together with results from the 1994 Assessment) and a new 'further rigorous assessment' of the bridge (the 2007 Assessment). The detailed requirements for the 2007 Assessment were defined on the 'Approval in Principle for Assessment' form, which was agreed later. It stated the assessed capacity of the bridge as 'RA1 at 70 mph' with the critical issue defined as rivet shear stress in the east main girder.

65 Jacobs arranged to have the calculations for the 2007 Assessment done in an overseas office. In November 2007 an engineer from Jacobs' Glasgow office inspected the bridge and collected the information on the bridge and its condition that was required (the *Inspection for Assessment*).

Lugton loop scheme

66 The work to extend the existing loop at Lugton (paragraph 28) involved reintroducing the double track southwards through Dunlop and Stewarton stations to a new turnout located south of Bridge 88 (figure 3).

67 Network Rail reviewed the implications of Bridge 88 having to carry two tracks, and taking into consideration issues raised as part of the route availability verification exercise, decided to replace the complete superstructure before laying the new second track over it.

---

[8] In the case of the Scotland Territory this was 'Loads Tables and Associated Instructions - Scotland'.

68 Jarvis, the contractor engaged to carry out the improvement works (paragraph 23), was undertaking work in the vicinity of Bridge 88 on the days before the derailment in connection with the track relaying and bridge renewal. The bridge superstructure was planned to be replaced on 7 and 8 February 2009.

Events preceding the accident

69 In carrying out the improvement works, Jarvis laid the new second track from the north (Lugton) working progressively through Dunlop and Stewarton stations to the location of the new turnout. The work involved the mechanical excavation of the old formation, followed by laying new ballast and track with *steel sleepers.* Jarvis used *engineering trains* to bring in new materials and take away spoil.

70 During work undertaken on the night of 16-17 January 2009, Jarvis removed the old ballast on the redundant west deck of Bridge 88 in preparation for the superstructure replacement. It used excavators, positioned over the north and south abutments, and on the track of the east deck, to reach over and scoop off the spoil.

71 On the night of 26-27 January 2009, Jarvis excavated the old formation immediately north of Bridge 88. It did this with tracked excavators, digging spoil from the formation and loading it into two-axle spoil wagons on the adjacent single line. A pair of class 66 locomotives, one on each end of the engineering train, brought the empty spoil wagons into the worksite at the start of the planned *possession*. The train came in from the north, passing Barrhead signal box at 23:35 hrs on 26 January. It stopped at the northern end of Bridge 88 while the wagons were loaded. There is no record of precisely where the train stopped; however, there is witness evidence that the locomotive may have stood partly on Bridge 88, but it did not cross it. Jarvis had prepared a general plan for the work that was being done, which it refined and briefed on site before starting work. The RAIB found no evidence of a documented restriction in the plan that should have prevented the engineering train going onto the bridge.

72 The excavators used for the work on the night of 26-27 January were *road-rail vehicles*. They entered the worksite from south of Bridge 88, crossing it on the track of the east deck on their rail wheels. The excavation work started 20-30 metres north of the bridge, and worked northwards, over the Annick Water Viaduct, towards Stewarton. On completion of the excavation work, they transferred back onto the track and returned over the east deck of Bridge 88 to leave the worksite.

73 The loaded train departed northwards out of the worksite, without crossing Bridge 88. It passed Barrhead signal box at 05:31 hrs on 27 January. The *Engineering Supervisor* checked that there were no obstructions so that the line could be opened for normal traffic.

Events during the accident

74 Train 6B01 was the first train through after the line was reopened. The driver booked on for duty at Mossend Yard, near Motherwell, at 04:24 hrs on 27 January 2009. The train was ready for him and he departed the yard about 10 minutes early. He was familiar with the route and had made the journey to the fuel depot at Riccarton many times before.

75 The journey through to Stewarton was reported as uneventful. The train passed Barrhead signal box at 05:55 hrs, ahead of schedule, and the CCTV at Stewarton station showed the train passing with nothing untoward apparent.

76 After leaving Stewarton, the driver made repeated brake applications to control the train speed as it ran down the gradient over Annick Water Viaduct. The *on train data recorder* (OTDR) recorded 6B01 travelling at 56.7 mph (91.3 km/h) as it approached Bridge 88 – within its permitted speed of 60 mph (97 km/h) (paragraph 37).

77 The driver reports that the locomotive crossed Bridge 88 without him being aware of anything unusual. He then noticed a rapid reduction in *brake pipe* pressure and the brakes automatically applied bringing the train to a halt, 1.2 km south of the bridge.

78 The driver called the signaller at Kilmarnock to explain that he had had an unsolicited brake application and that he was going to walk back along the train to investigate. On doing so, he discovered that the train had separated and that the rear six wagons were missing. Air was escaping from the brake pipe at the rear of the four leading wagons. He closed the local cock to retain pressure. He reports that he then called the signaller to update him, and he walked on to investigate further.

79 It was dark, and the curvature of the track obscured the view back. However, after about 100 metres the driver reports seeing an orange glow in the sky, and he realised the rear portion of the train, which had separated, was on fire. He contacted the signaller again to notify him that it was a dangerous goods incident and that the emergency services were required.

80 The driver states that he then secured the front part the train and called his duty manager who told him 'to remain safe' and wait for further instructions.

81 By 06:26 hrs, the signaller had blocked the line, called the emergency services and notified Network Rail control.

Consequences of the accident

82 The rear six tank wagons of train 6B01 derailed as they crossed Bridge 88. The first of these, wagon 5, ran derailed for over 100 m, damaging the concrete sleepers and unfastening the right-hand (west) running rail. It finally overturned, its leading bogie becoming detached, and it came to rest on the west side of the track, to the inside of the curve.

83 Wagons 6, 7, 8 and 9 initially followed wagon 5, running derailed and damaging railway infrastructure, but then overturned to the outside of the curve. They came to rest, also after losing bogies, on the east side of the track and embankment. Wagon 10 overturned and came to rest close to the south abutment, in debris that had accumulated in the *four-foot*.

84 Figures 2 and 8 show the locations of the six rear wagons after derailment.

85 The tanks of wagons 6, 8 and 10 were all punctured by the drawhooks of adjacent wagons, and a *pressure and vacuum valve* was damaged on the top of the tank on wagon 7. Kerosene leaking from wagon 10 ignited.

Figure 8: Derailed wagons

86 Site recovery records indicate that, altogether, around 220,000 litres of fuel was lost to the environment - including that which burnt from wagon 10. The spilt fuel contaminated adjacent land and entered the Garrier Burn, a tributary of the River Irvine, which flows into Irvine harbour. It resulted in a major pollution incident that had serious impact on the ecology of the Garrier Burn, killing all fish and invertebrates; dead invertebrates were also found in the River Irvine and birds were affected by the spilt fuel in Irvine harbour.

87 Both the east and centre main girders of Bridge 88, which supported the east deck that carried the railway, failed, and a major part of the south abutment was destroyed. The failed superstructure, masonry and other debris from the bridge fell onto the A735 road below (figure 9).

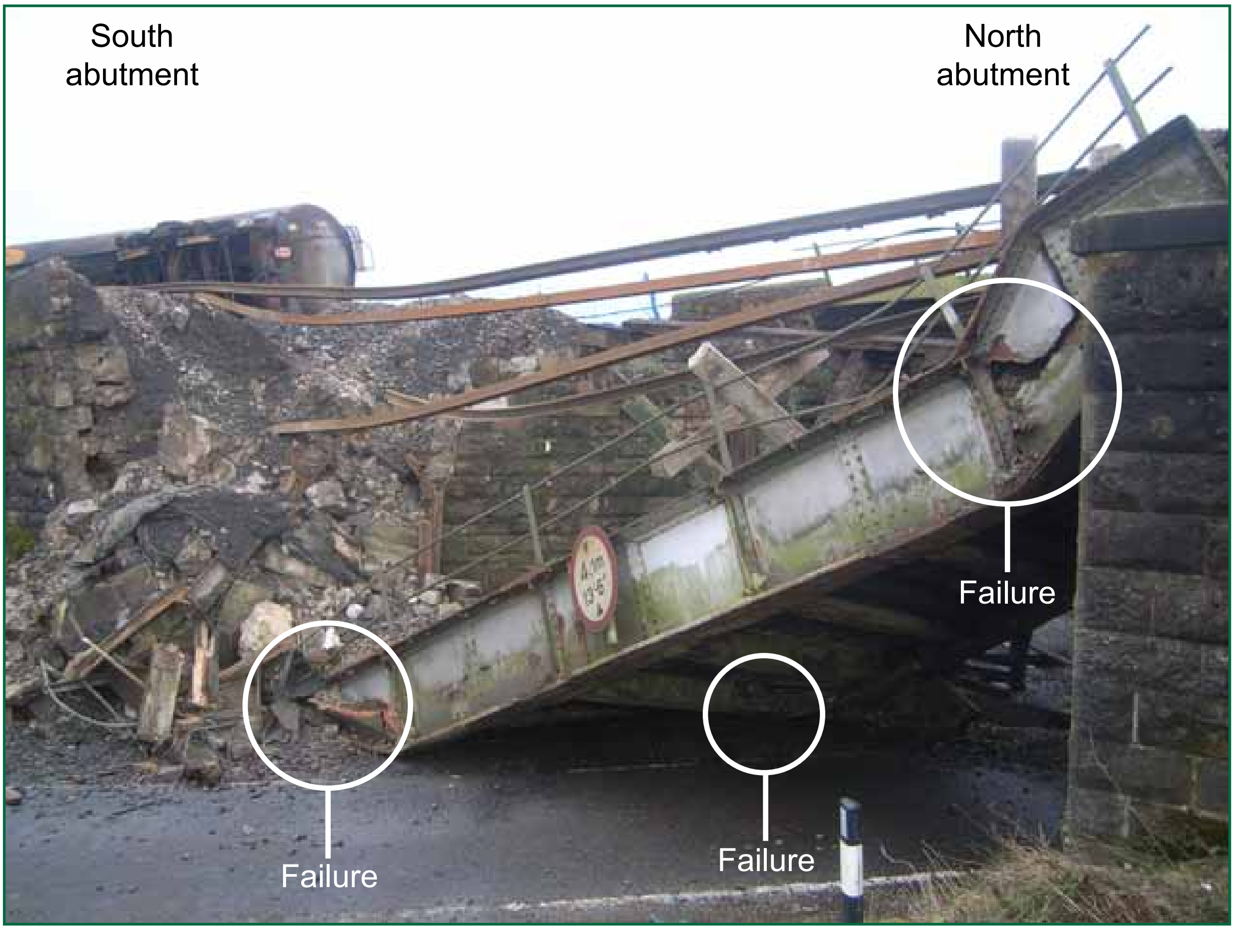

Figure 9: Bridge 88 after the derailment - east side (reflective yellow and black hatching road sign has been removed to reveal the condition of the east main girder)

88 The running rails, and two rails that had been laid in the four-foot in preparation for the double-tracking work, remained in place, but were left hanging across the gap between the two abutments. The right-hand running rail fractured over the south abutment, but the left-hand rail remained intact.

89 There was no damage to the track or infrastructure on the approach to Bridge 88 from the north.

90 The locomotive and the leading four wagons remained on the track. No-one was injured.

Events following the accident

91 Strathclyde Fire and Rescue were at the scene by 06:31 hrs and by 07:08 hrs Network Rail's rail incident officer had arrived. Strathclyde Police declared the accident a major incident at 07:12 hrs and set up site cordons. British Transport Police officers also attended.

92 Network Rail notified the RAIB of the accident at 06:55 hrs, and inspectors were deployed. An inspector from the ORR[9] also attended.

93 At 09:00 hrs, following notification from Strathclyde Fire and Rescue, the Scottish Environment Protection Agency (SEPA) sent officers to the site, and at 09:44 hrs, Network Rail requested the attendance of its environmental spillage contractor.

94 At 11:45 hrs, Strathclyde Fire and Rescue confirmed that it had extinguished the fire, and by 12:00 hrs allowed access to the inner cordon surrounding the overturned wagons and collapsed bridge.

95 At 15:30 hrs the following day, British Transport Police took over full control of the site cordons.

96 SEPA, Strathclyde Fire and Rescue's environmental protection unit, Network Rail's spillage contractor and environmental contractors brought in by BP Oil, the fuel consignment owners, worked together to minimise the effect of the spillage into local watercourses, contain further spillage and to evacuate the fuel remaining in the overturned tank wagons.

97 Both the railway line and the A735 road were blocked as a result of the accident. The bridge was re-constructed, using the superstructure that was planned to be installed as part of the Lugton loop scheme (paragraph 67), and the line reopened on 16 February 2009.

[9] The inspector was representing the part of the ORR that is responsible for safety regulation. The notice ORR issued regarding infrastructure compatibility information (paragraph 60) was from the part of the organisation that is responsible for economic regulation.

The Investigation

Sources of evidence

98 The RAIB has used the following key sources of evidence in its investigation:

- from its activities on site:
  - visual and photographic examination of the locomotive and leading four wagons, the in-situ condition of the six overturned wagons and damage to the railway infrastructure;
  - examination and survey of the undamaged track on the northern approach to Bridge 88;
  - examination and survey of the in-situ remains of the collapsed bridge;
  - excavation of the debris from the collapsed bridge including recording the final locations of the dressed stone blocks, which had formed the facing to the south abutment – it was possible to identify the original location of a number of these stones using photographs from Network Rail's routine examination records; and
  - identification of the key pieces of metalwork from Bridge 88, and other parts, such as the running rails that were on it.
- data from the locomotive's OTDR;
- CCTV recordings from Stewarton station;
- off-site examination, testing and measurement of the four wagons that did not derail;
- off-site examination and measurement of the six wagons that derailed;
- track geometry data recorded by Network Rail's track measurement trains;
- vehicle dynamic modelling studies;
- examination of the bridge deck components recovered from Bridge 88, including metallurgical and corrosion surveys;
- testing of timber samples taken from the deck of Bridge 88;
- a survey of the marks on the running rails recovered from Bridge 88;
- witness testimony; and
- information, photographs and documents provided by Network Rail, Atkins, Jacobs, Jarvis, DB Schenker, BP Oil, Axiom Rail, SEPA, Strathclyde Fire and Rescue, Strathclyde Police and the British Transport Police.

Analysis

Identification of the immediate cause[10]

99 **The immediate cause of the derailment of train 6B01 was the collapse of Bridge 88 that followed the catastrophic structural failure of its east and centre main girders. Heavy corrosion had so significantly weakened the main girders that they were no longer able to carry the loading from trains, like 6B01, that Network Rail had permitted to run over the bridge.**

100 The main girders on Bridge 88 were *I-beams,* comprising a vertical web plate with thicker horizontal plates (flanges) attached at top and bottom. The web plate is critical to an I-beam's ability to support load. It connects the flanges together by carrying the shear stresses that are required for the beam to work as an effective structural member.

101 The RAIB found evidence that the integrity of the web plates on the east and centre main girders was so impaired due to corrosion that they were no longer able to carry the shear stresses required - the girders failed as a direct result. In summary:

- On surveying the superstructure of Bridge 88, a horizontal band of heavy corrosion was identified, at mid-height, on the web plates of both the east and centre main girders. This had significantly reduced the web plate thickness.
- The deformed shape of the collapsed main girders, and the fractures of them, were consistent with them failing because the shear stresses in the web plates were too great.
- Industry standard structural assessment calculations, done specifically for this investigation using measured un-corroded girder dimensions, predicted live load capacities due to shear stress (shear failure) that were below the load class for the train. Accounting for material loss due to corrosion would increase the shear stress and reduce the calculated capacity further.
- Track data, recorded three days before, showed a significant vertical dip had formed on Bridge 88. This matched the bridge span and was an indication of recent structural deterioration.
- Marks and damage on the wagons from 6B01 indicated that they encountered a discrete vertical track irregularity on the bridge that got progressively larger as the train passed. This was evidence that the bridge was collapsing as the train passed over.

Web plate corrosion

102 The web plates on both main girders were made up of 12, almost-square, individual web panels that were riveted together at alternating *splice plates* and *T-section stiffeners.* The RAIB numbered these '1' to '12', web panel 1 being at the north abutment (figure 10).

[10] The condition, event or behaviour that directly resulted in the occurrence.

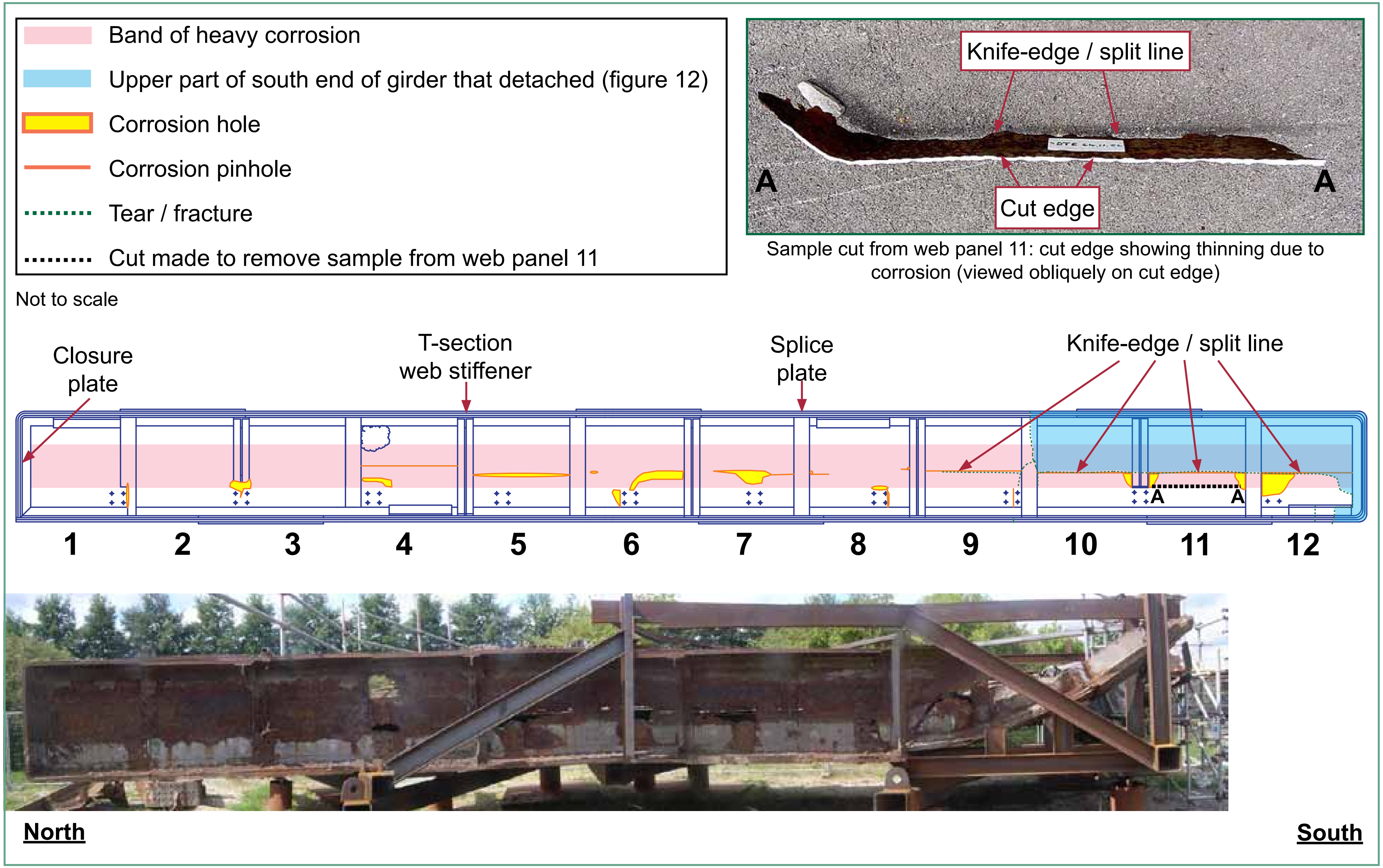

Figure 10: Condition of the centre main girder. Inset shows sample cut from web panel 11 (Note: due to the damage that occurred as a result of the bridge collapse and the limitations in recording the nature of the corrosion, the shape and size of the defects are shown for illustrative purposes only)

103 The horizontal band of heavy corrosion affected both surfaces of the centre main girder web plate - there was material loss throughout its length. At mid-span, web panels 4 to 7, the corrosion was so severe that significant holes had formed. At the south end, the web thickness had reduced to a knife-edge that extended along a horizontal line, at mid-height, from the centre of web panel 9 through to panel 12. Pinhole-like perforation had occurred along the knife-edge and both panels 11 and 12 had holes in them. The key features of the centre main girder condition are illustrated in figure 10. The inset shows a sample cut from the web plate at panel 11. It is from just below the horizontal knife-edge line and illustrates the thickness reduction that had occurred.

104 On the east main girder, the corrosion band was most evident on the inner surface (west face) of the web plate. This may have been due to the outer surface being more accessible for repainting, though the RAIB found no evidence to show that such painting had been carried out since 1966, or it may have been due to the inner surface being in a more corrosive damp environment. There was evidence of significant holes at mid-span (web panels 7 and 8) and likewise a similar knife-edge condition to that found on the centre main girder at the south end (web panels 10 through to 12).

105 The findings of RAIB's survey of the metal superstructure of Bridge 88 are summarised in appendix E.

Main girder failures

106 There were three failures in the main girders. The east main girder failed at its south end, and also, in web panel 2, at a point close to its north end. The centre main girder only failed at its south end. The failures at the south end resulted in the girder ends coming off the abutment and falling to the road below. Figure 9 shows the locations of the failures.

107 The failure at the south end of the centre main girder was of particular interest. Here, the girder had split along the horizontal knife-edge line (paragraph 103), and a section, comprising the upper parts of web panels 10 to 12, became detached (figure 10). One of two samples taken from this interface showed evidence of slip, of a microscopic scale, along this line (figure 11). This indicates that horizontal movement had been occurring along the split, and therefore that the web plates were no longer carrying the shear stresses required for the upper and lower parts of the I-beam to work together as a single effective structural member.

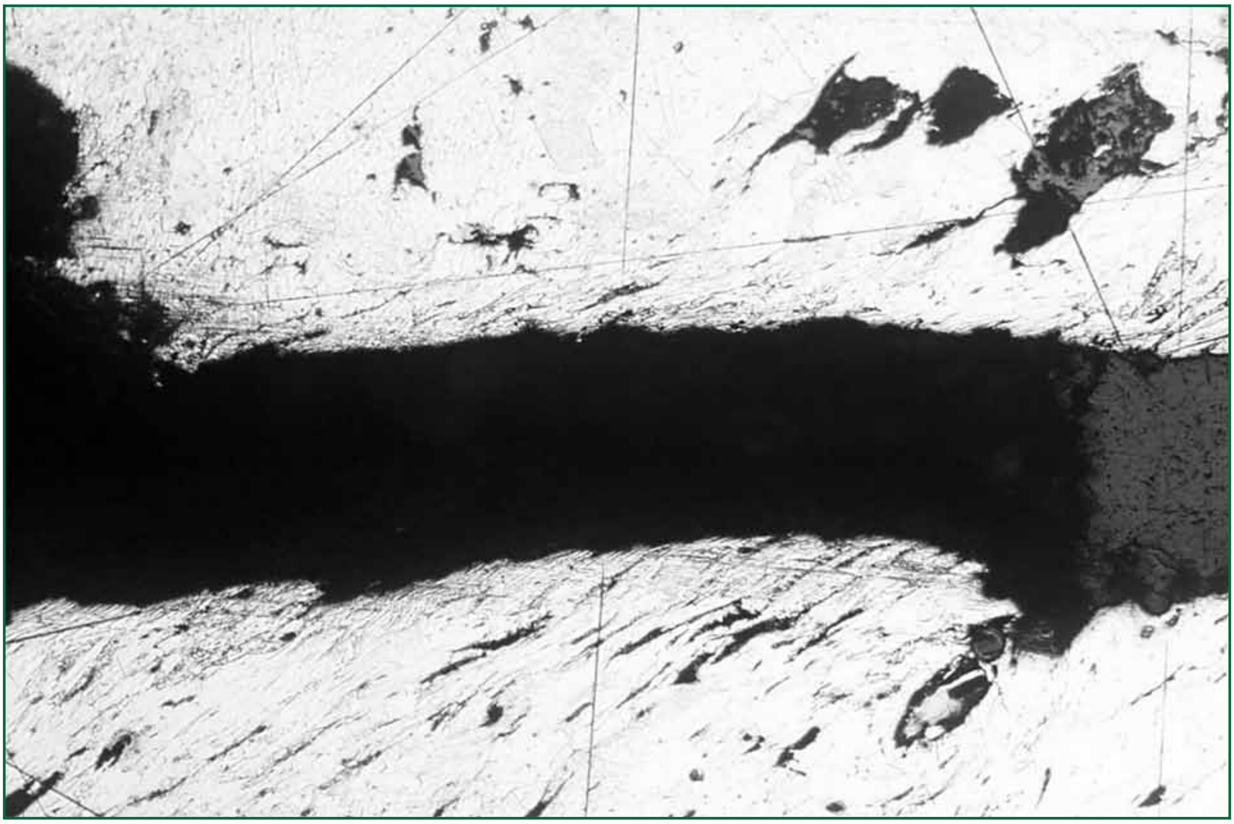

Figure 11: Micro-section through the mating surfaces along the knife edge line that had formed on the web plate on the south end of the centre main girder - sample taken from web panel 11

108 On the section that detached, the *closure plate* (the vertical plate at the end of the girder) had folded to form an acute angle with the top flange. To accommodate this, the web tore to the upper corner, and the outer layers[11] of the flange fractured and parts broke off (figure 12). There was a strike mark on the flange material freshly exposed by this de-layering that was consistent with impact from the train (figure 12 inset); there was no corresponding mark on the part that broke off. This supports the scenario of the flange fracturing suddenly, and while the girder was still in an elevated position - exposed to the passing train. The folding is therefore unlikely to be a consequence of the girder falling and then hitting the road. It is, however, consistent with upper and lower parts of the beam flexing independently, because the web plate could not carry the required shear stress, and then the flanges, suddenly having too much load transferred to them, fracturing, resulting in catastrophic failure. There was no evidence to indicate failure due to pre-existing fractures on the flanges – for instance, due to *fatigue* crack growth.

Structural calculations

109 The RAIB measured the sizes of the main girders and calculated their live load capacity against shear failure. The results are summarised in table 2 (paragraph 165). For reference purposes, the calculations were done according to the method used for the 1994 Assessment (paragraph 162), likewise no allowance was made for corrosion loss.

[11] Wrought iron (paragraph 43) has a microstructure comprising alternate layers of iron and chemical impurities. These layers can separate in failure situations.

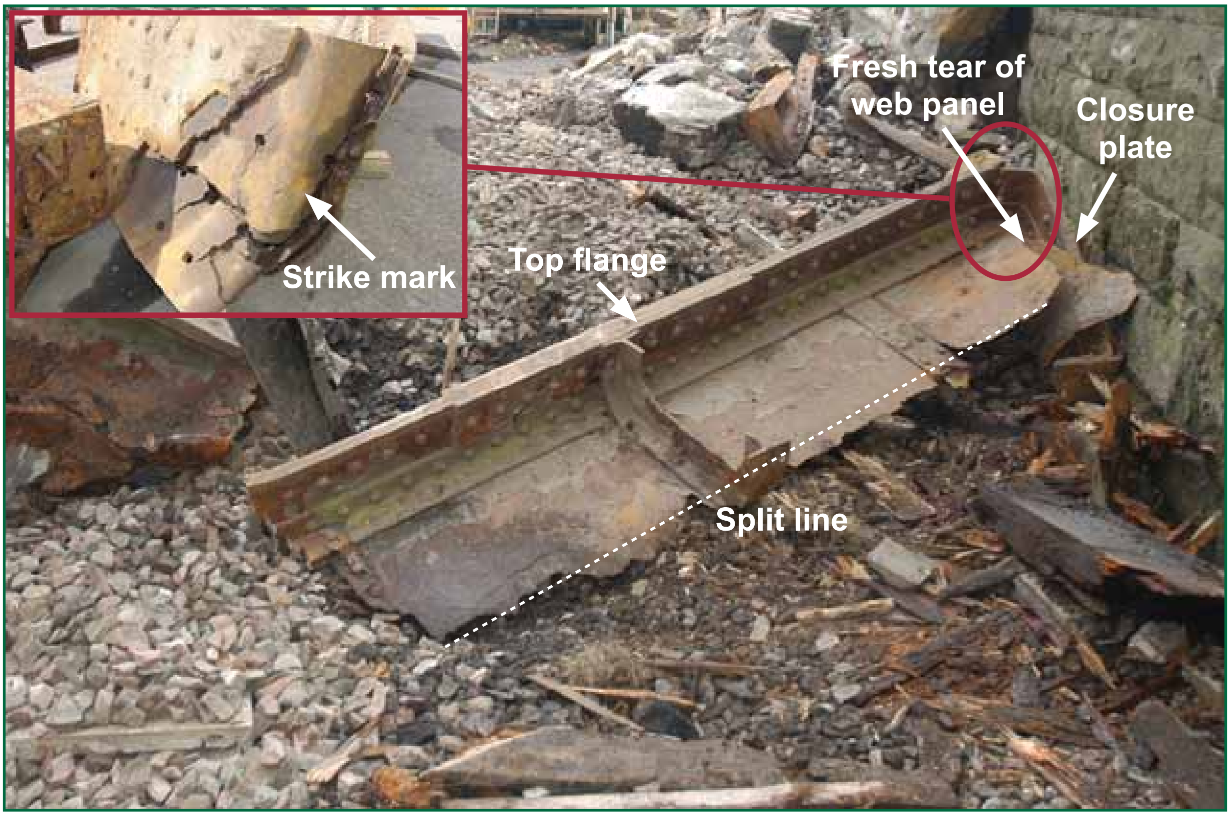

Figure 12: Upper part of the south end of the centre main girder showing the horizontal split line, the folded closure plate and fractured flanges (main photograph courtesy of British Transport Police)

110 Train 6B01 was an RA10[12] train, but against shear failure the RAIB calculations indicate dynamic capacities of RA6 and RA8 for the east and centre main girders respectively (paragraphs 155 to 166 explain the reasons for this difference). Calculations in accordance with assessment codes are generally conservative (they are based on simplifications that mean, for instance, not all of the load carrying capability of the structure is taken into account), but, like the 1994 Assessment, these re-worked calculations ignored corrosion losses that in practice were severe, particularly for the centre main girder. That the calculations show the main girders to have insufficient live load capacity, even if corrosion losses are ignored, is further evidence that the shear stress in the web plates was high.

Track geometry

111 Network Rail has a fleet of special trains that regularly run over its network recording the geometry of the track for routine track inspection and maintenance purposes. One of these trains ran over Bridge 88 on 24 January 2009, three days before the accident. It recorded a dip on the bridge, which subsequent analysis showed was not present on runs in July 2008 and January 2008 (figure 13). The extent of the dip is coincident with the bridge span. The relatively rigid make-up of the elements supporting the rails on the bridge deck (concrete sleepers and granite ballast with no obvious source of *voiding*) means that this is likely to be an indication of increased deflection of the bridge superstructure. It suggests that, since the last run in June 2008, there had been a change in the structural performance of the bridge. A loss of web plate integrity would explain this. There is no record of recent track maintenance activity in the area to explain otherwise.

[12] The maximum load of a four-axle wagon, for it to be classified as RA10, is 100 imperial tons (101.6 metric tonnes), sometimes rounded to 102 tonnes (paragraph 33).

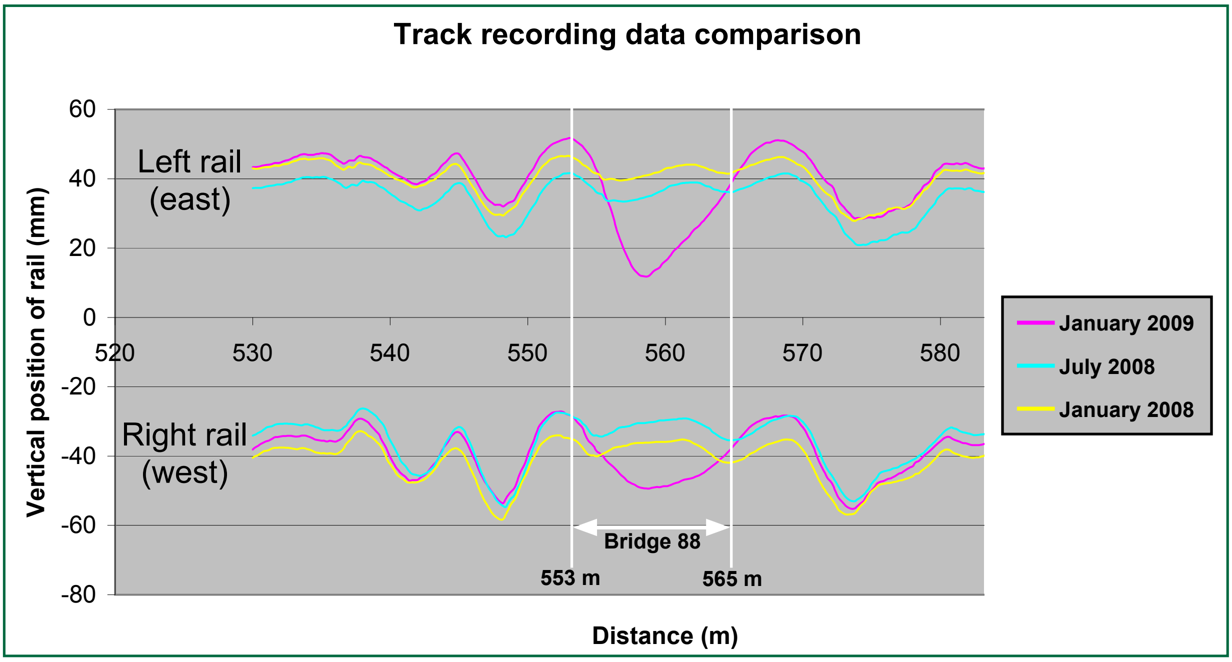

Figure 13: Vertical geometry of the track measured in the vicinity of Bridge 88

Wagon witness marks and damage

112 Examination of the first four tank wagons from train 6B01 identified several examples of damage. These showed that the wagons, when crossing the bridge, encountered a vertical dip that got progressively larger. For instance, on wagon 1 there was evidence of minor movement between the tank body and its support bracket (figure 14a). By the time wagon 4 crossed, the vertical dynamic response was sufficient to both deform the tank (figure 14b) and cause the axles to contact underframe brake equipment (figure 14c).

113 The same pattern of developing movement continued onto wagon 5 and the wagons that followed, with the motion becoming so severe that the adjacent ends of the wagons started to *override*. This resulted in a number of the buffers getting knocked off, and tanks being punctured by drawhooks (paragraph 85). The drawhook on wagon 7 cut a gash in the tank of wagon 6 that was over 1 metre high (figure 15) providing further evidence of the size of the dip that had developed.

114 The only explanation that the RAIB found that is consistent with this evidence was that Bridge 88 was progressively collapsing beneath train 6B01. The damage to the south abutment (paragraph 87) was most likely a consequence of impact damage from the wagons that then went on to overturn.

Discounted causes

115 The RAIB has been unable to find any record for over a century of a previous occurrence of a railway underbridge collapse that was due solely to the load of a permitted train.

116 There were a series of collapses involving underbridges with cast iron beams in the 19th Century, but records indicate that the last of these was in 1891. The use of railway underbridges made of cast iron carrying *tensile stresses* was subsequently curtailed and those existing were gradually replaced. The cast iron railway bridges that remain in service today are generally of the arch form. In these bridges load is carried mainly as *compressive stress*. Bridge 88 was made from wrought iron (paragraph 43), not cast iron.

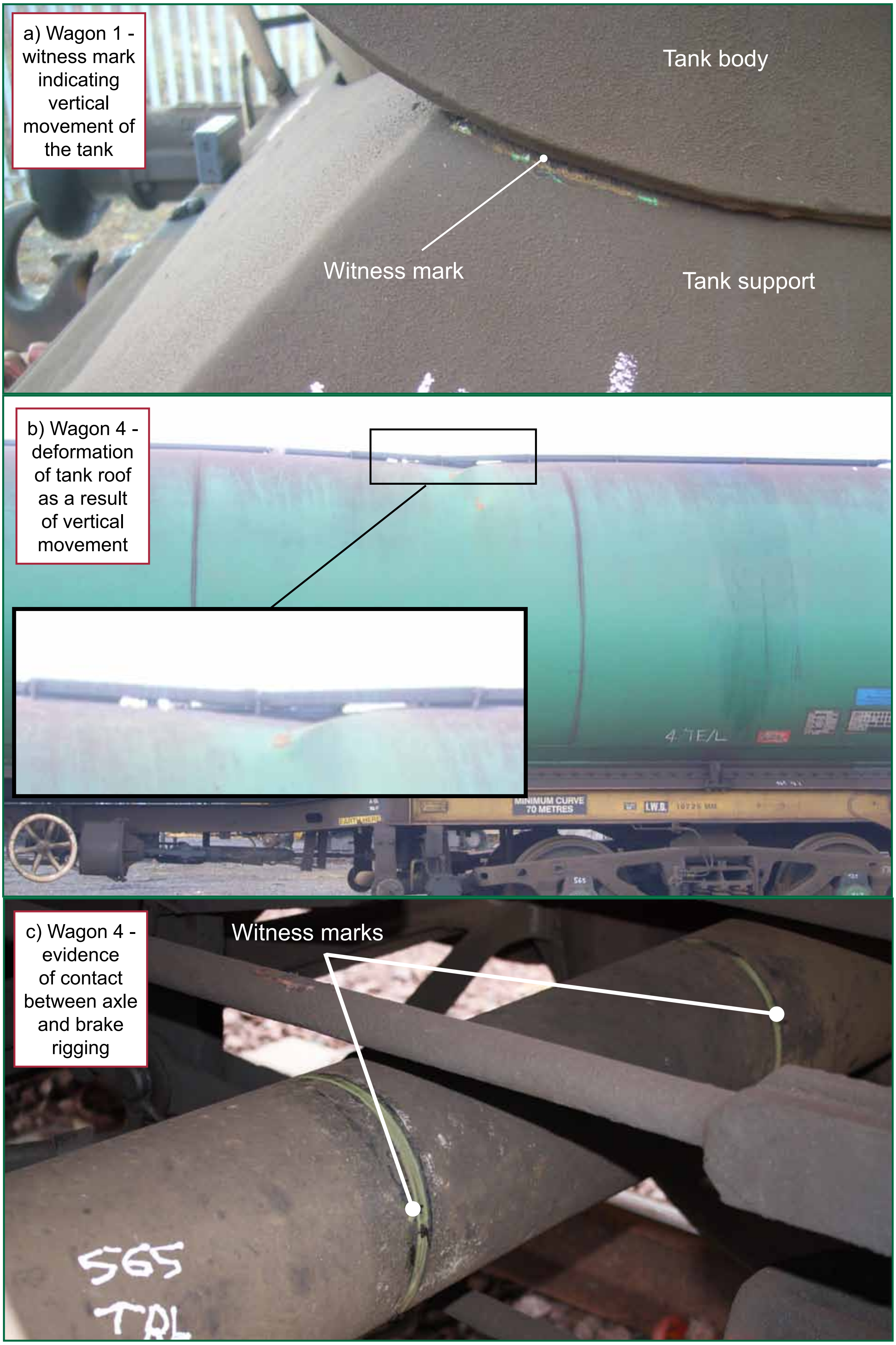

Figure 14: Witness marks and damage on the wagons that did not derail

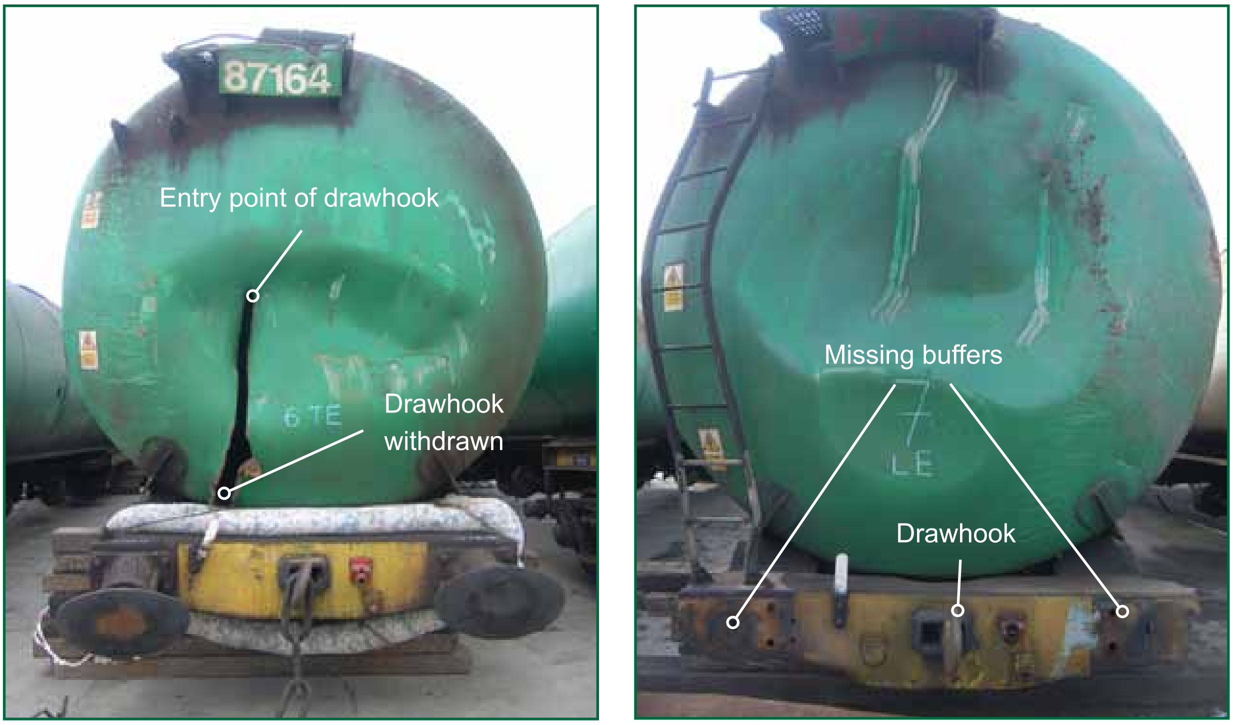

Figure 15: Vertical gash on the tank of wagon 6 (left) caused by the adjacent drawhook on wagon 7 (right)

117 More recent railway underbridge collapses have occurred, but these have generally been the result of weakening due to external factors such as *river scour*, which resulted in the fatal collapse of the Glanrhyd underbridge in Carmarthenshire on 19 October 1987, or as a consequence of an accident, usually a derailment.

118 Bridge 88 did not have submerged foundations. Therefore damage from river scour was not a precursor.

119 The RAIB confirmed that the accident was not the result of the train derailing before the bridge collapsed, or any other factors to do with the bridge or the nearby upgrade work. It investigated the following alternative causes, and found no supporting evidence for them:

- train derailment resulting from:
  - a *wheel flange* climbing over the *rail head* and then running derailed (flange climb derailment) – the vertical track feature that was recorded on 24 January (paragraph 111) resulted in the formation of a *twist fault* and the RAIB particularly wanted to determine if this could have initiated derailment by this mechanism;
  - a wheel lifting over the rail head, without climbing, for instance due to large vertical dynamic suspension movement or encountering an obstacle (wheel lift derailment);
  - the track gauge spreading, allowing the wheels to drop into the four-foot (gauge spread derailment);
  - a rail failure; or
  - a *wheelset or* gross mechanical suspension failure (wheelset or suspension failure).
- a road vehicle striking the bridge and causing significant damage (bridge strike).

- work undertaken in connection with the Lugton loop scheme that may have damaged the bridge (upgrade works).
- a failure of the south abutment masonry that resulted in the south ends of the east and centre main girders falling to the road below (abutment failure).
- a train load that should not have been permitted on the bridge (excessive train load).

120 Appendix F summarises the related findings, which have enabled the RAIB to discount all of the above possibilities.

Identification of causal[13] and contributory[14] factors

121 The east and centre main girders of Bridge 88 failed because:

- of heavy corrosion on the web plates of the main girders; and
- Network Rail's processes for the routine management of bridges did not result in effective intervention action.

122 The RAIB also considered opportunities that were outside Network Rail's routine management processes, and why these did not result in effective intervention action. Of these, the new assessment work done in 2007 as part of the route availability verification exercise (paragraphs 64 and 65) was the most significant. The RAIB identified a number of additional factors as a consequence, although as these were associated with opportunities that were not designed to prevent Bridge 88 collapsing, their causal significance is secondary.

Heavy corrosion on the main girders

123 The reasons why the web plates had been allowed to become heavily corroded relate to:

- the construction of the bridge, and how this led to a corrosion trap that was difficult to see;
- that the corrosion trap was not reported as being hidden, and was not inspected;
- that the corroded web plates were not fully repaired; and
- the poor condition of the paint on the bridge, which was intended to protect against corrosion.

Construction of Bridge 88

124 **The form of construction of Bridge 88, as modified by the LMSR and British Rail, meant there was a hidden corrosion trap that affected the inner surfaces of the main girder web plates. The corrosion resulted in a significant loss of web plate thickness, and in places holes formed. This was causal to the collapse of the bridge.**

---

[13] Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

[14] Any condition, event or behaviour that affected or sustained the occurrence, or exacerbated the outcome. Eliminating one or more of these factors would not have prevented the occurrence but their presence made it more likely, or changed the outcome.

125 There are two primary reasons for the hidden corrosion trap:

- The LMSR's replacement of the longitudinal timbers, which originally supported the track, with a ballasted timber deck (paragraphs 45 and 46). This led to a void where debris, dirt and ballast, which retained moisture, could accumulate next to the inner surfaces of the main girder web plates on both east and west decks. The level of the ballast alone made this critical area of the main girders almost impossible to see.
- The waterproofing arrangement that British Rail fitted in 1987 because of concerns with the condition of the timber deck (paragraph 47). This effectively sealed in the accumulated moist debris and made the inner surfaces of the main girder web plates on the east deck, the side that collapsed, even more difficult to see.

Ballasted timber deck

126 The timber upstands, which the LMSR fitted to keep the ballast in place on the timber deck (paragraph 46), formed pockets with the T-section stiffeners and the timber deck adjacent to the web plates. On dismantling the bridge, the RAIB found that debris, dirt and ballast had accumulated in these pockets. From observation and analysis of the condition of adjacent timbers (there was evidence of wet rot and damp), it was evident that this debris would have been wet. The location of the resulting moist environment corresponds with the horizontal band of corrosion found on the inner surfaces of the east and centre main girder web plates (paragraphs 103 and 104). It helps explain why the corrosion in this area was so severe. These features are shown in figure 16.

127 Photographs from the routine assessments done in 1982 and 1994, and the inspection done for the 2007 Assessment, show how high the ballast had been on the deck of Bridge 88 (figure 17). In 1982 it buried the centre main girder. The ballast on Bridge 88 would have made the corrosion band very difficult to see from above the deck; the proximity of the timber deck to the web plates would have made the corrosion difficult to see from below.

Waterproofing arrangement

128 The construction of the waterproofing arrangement fitted to the east deck was generally in accordance with the design drawing. The main exception was that the drawing does not show the LMSR timber upstands; British Rail left these in place together with the accumulated debris that was behind.

129 Where the neoprene membrane was brought up the sides of the deck (paragraph 48 and figure 7c), it was wrapped over a plywood sheet that was supported off the inside of the main girders by a softwood frame, shown diagrammatically on figure 16. The frame was clamped to the centre and east main girder flanges, a sealing compound applied, and covered by an aluminium capping strip.

130 The membrane, therefore, effectively sealed in the LMSR timber upstands, the moist debris and the band of heavy corrosion. The photograph in figure 18, taken during dismantling, is a view behind the membrane fitted to the centre main girder – so much ballast had accumulated that the timber upstand is buried. There was no provision in the design or installation of the waterproofing arrangement to facilitate inspection of this critical area.

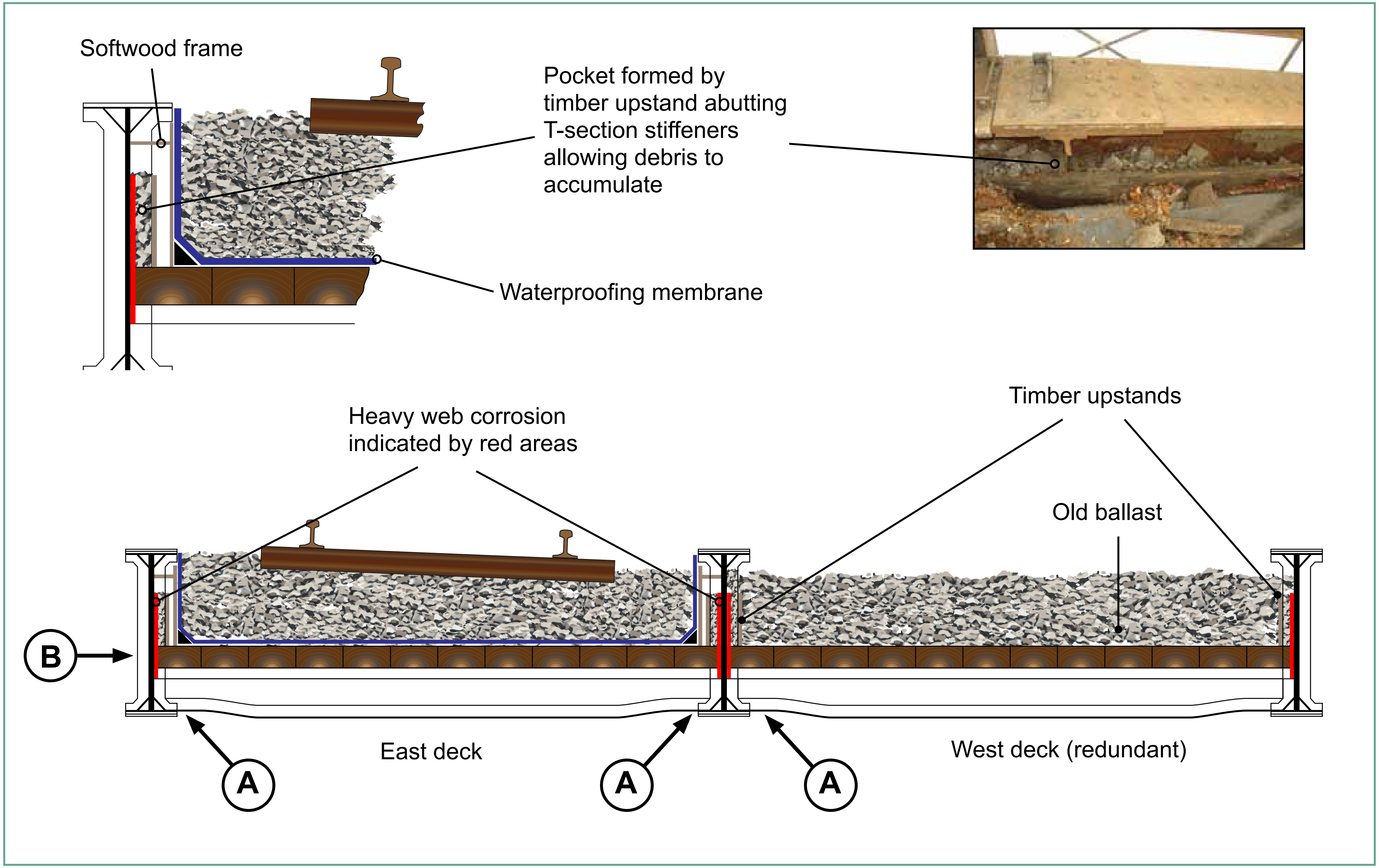

Figure 16: Cross-section of Bridge 88 showing areas of debris accumulation and heavy web corrosion

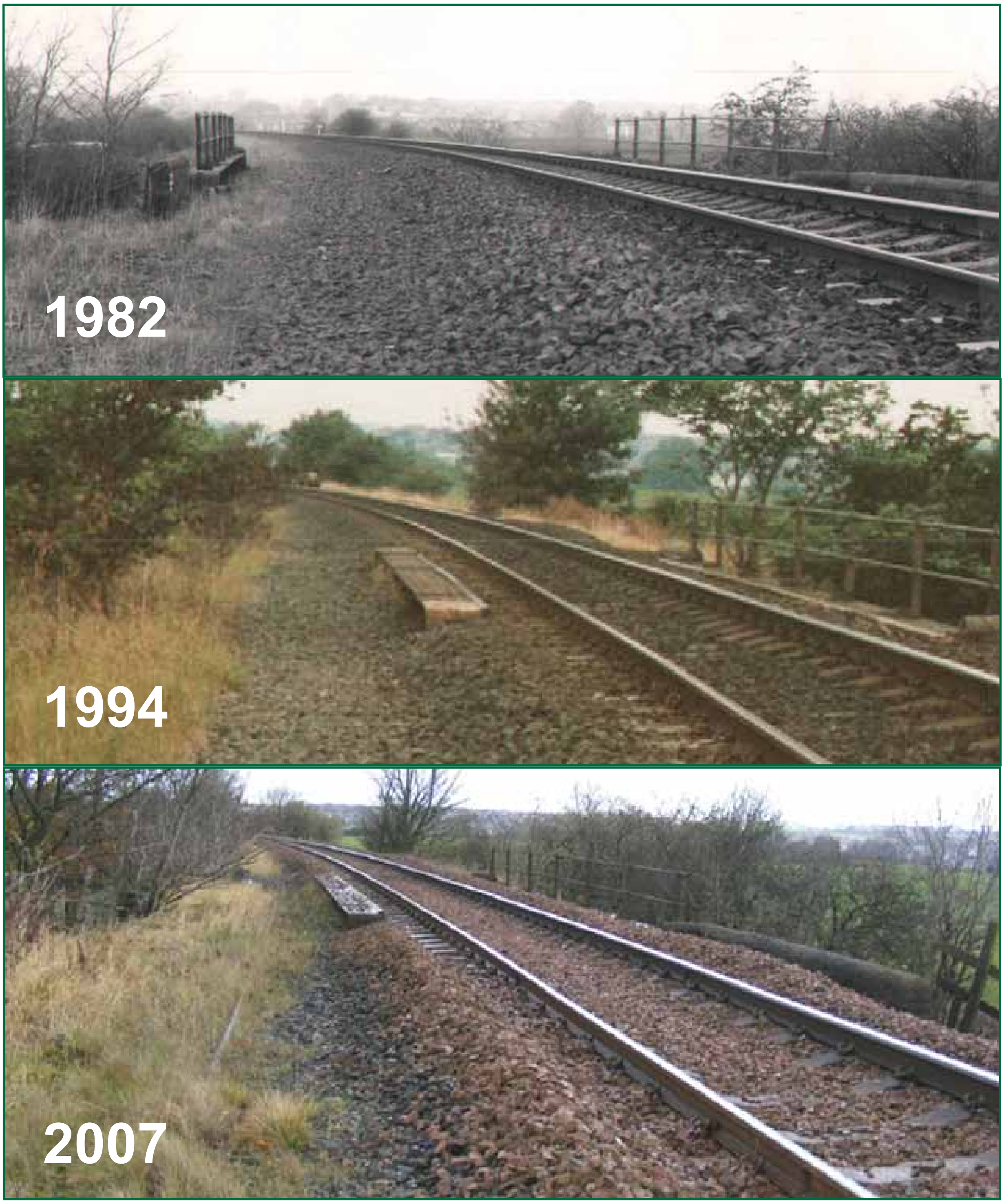

Figure 17: The level of ballast on Bridge 88 when photographed for assessments in 1982, 1994 and 2007 (photographs courtesy of Network Rail)

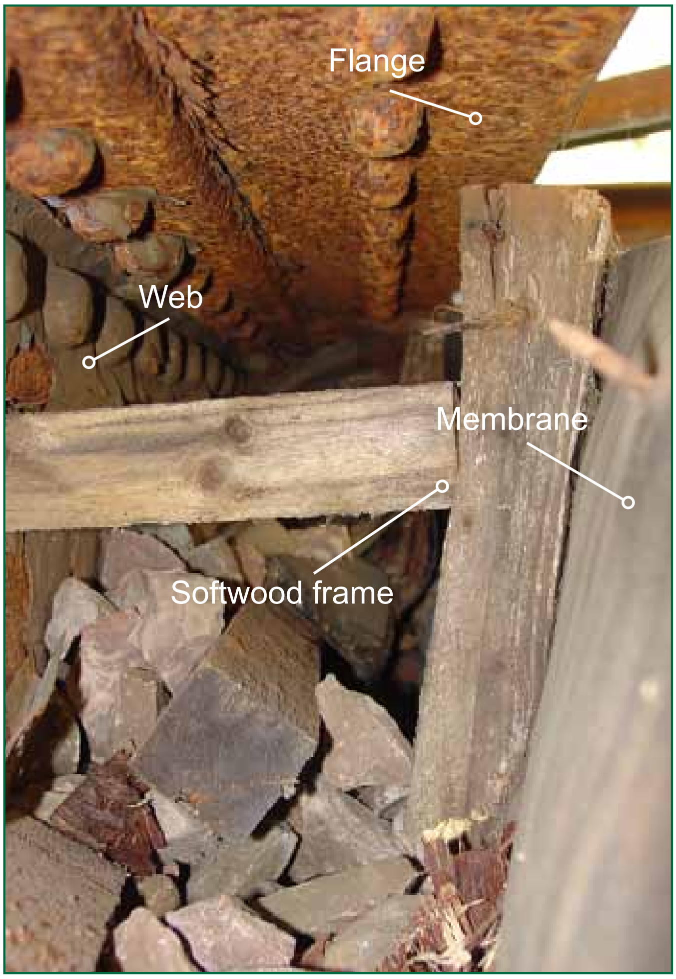

Figure 18: Accumulated ballast and debris found behind the waterproof membrane of the centre main girder

Inspection of hidden critical areas

131 **There were no formally reported concerns regarding access to the hidden parts of the main girders where the heavy corrosion was occurring. Furthermore, no remedial work, or management action, was implemented, or planned, to gain access to these parts. The fact that no arrangements were made to inspect the hidden parts of the east and centre main girders where the heavy corrosion was occurring was contributory to the collapse of the bridge.**

132 The RAIB identified two previous accidents involving the collapse of railway structures that were the result of corrosion of hidden parts. Both involved *overbridges*.

133 The first was the failure of a footbridge at Bury Knowsley Street station on 19 January 1952. The floor fell from the footbridge when it was loaded with around 200 people leaving a football match. Two people were killed and 173 injured.

134 The bridge consisted of timber *trusses* with a wooden floor. The joints between the timber members were made using wrought iron plates and some of these were partially hidden. Corrosion of these plates led to the failure of the timber connections and collapse of the bridge floor.

135 The second accident occurred at Clapham Junction on 10 May 1965. One of the signal boxes at Clapham Junction was supported on an overbridge consisting of two steel trusses with connecting steel cross girders. A diagonal member at the end of one of the trusses failed. The end of the bridge dropped 4 feet (1.2 m), fouling the railway below. No-one was injured, but lines were blocked causing widespread disruption.

136 The collapse occurred due to corrosion of the lower part of the diagonal member. At this location, one side of the steel member was concealed by timber. The diagonal member was made of two steel plates that were closely spaced. The narrow gap between them made painting difficult, and a corrosion trap formed.

137 Network Rail's structure management standards draw specific attention to issues associated with the type of hidden corrosion trap that was found on Bridge 88. For instance, when undertaking routine detailed examinations, Network Rail's company standard NR/SP/CIV/017 'Examination of Bridges & Culverts' (paragraph 52) refers to the need for the examination to 'be sufficient to enable the condition of the (hidden and critical) part to be verified', unless a considered justification is made and recorded. Elsewhere it states that 'all metalwork shall be examined for corrosion'. Before the issue of this standard, similar reference was made in other published documents, for instance BR Civil Engineering Handbook 6.

138 Without special arrangements (like the removal of ballast or the waterproofing membrane), the only places where it would have been possible to see evidence of the heavy corrosion on the east and centre main girder web plates were:

- the small area on the underside of the bridge, where, in places, the corrosion extended just below the timber deck (A on figure 16) – both main girders; and
- on the east elevation of the bridge, where, in some areas, corrosion was so severe that it had perforated the web plate (B on figure 16) – east main girder only.

139 The last routine detailed examination of Bridge 88 was undertaken for Network Rail in October 2003 by Atkins (paragraph 54). It reported significant concerns about the corrosion that could be seen, but the only recorded concern regarding access to hidden parts was with the east main girder, stating 'Severe corrosion and lamination leading to (loss of section) at back of web plate. Back face could not be examined at this height due to ballast.' (The examiner was so concerned by the condition of the east main girder and, to a lesser extent, the cross girders, that he raised an urgent defect report to this effect. This is discussed further in paragraphs 172 to 189.)

140 The detailed examination report was prepared on a standard template; the cover sheet has a number of boxes, three of which are titled:

- 'Part examined';
- 'Hidden parts not examined as part of detailed examination (excluding foundations)'; and
- 'Reasons not examined'.

141 These boxes provide a formalised way of recording concerns about the completeness of the detailed examination. However, none contained any information. An adjacent box titled 'Complete Examination' recorded 'Yes'.

142 Witness evidence indicated that those doing detailed examination work at the time would not have regarded the hidden inner surfaces of the web plates as being a critical part of the structure that needed to be recorded as 'not examined'. The types of feature that might be recorded would be parts hidden by signs or advertising hoardings, or where a girder end is buried in masonry. Furthermore, contrary to NR/SP/CIV/017, Network Rail had told Atkins that it did not require it to remove ballast when examining timber decks. Although the intent of this instruction was to avoid disturbing a waterproof membrane, if present, not requiring ballast removal probably led the examination contractor to understand that it was acceptable practice to leave the adjacent inner surfaces of the web plates covered.

143 There are other reasons, to do with the structure management standards, which could have led to a similar understanding. When the 2003 Detailed Examination was done, issue 1 of Network Rail standard NR/SP/CIV/017 was current, and this implemented the mandatory requirements of the Railway Group standard GC/RT5100. An accompanying approved code of practice, GC/RC5511, gave non-mandatory guidance on meeting the requirements of GC/RT5100. GC/RC5511 stated that 'unless there are significant signs of deterioration (e.g. water seepage, distortion, rust staining etc.) it is not necessary to expose either the surface of structural elements which form part of composite structures … or to expose the surface of elements adjacent to ballast or other surfacing…'.

144 Visual examinations do not require the same consideration regarding the need to verify the condition of hidden parts (paragraph 52), for instance by revealing concealing features. Despite this, two of the four visual examinations undertaken since the 2003 Detailed Examination (paragraph 55) reported concerns with access to hidden parts in the descriptive part of the report: the last one, 25 February 2008, and the one before, 1 March 2007. With reference to a hole on the web plate of the east main girder, they both state '50 mm x 50 mm visible with remainder of hole hidden by deck and chevrons'. However, neither formally reported anything in the aforementioned template boxes (paragraph 140).

145 In summary, the inner surfaces of the main girder web plates were not formally reported as a potential hidden corrosion trap. No-one made any special arrangements, or modified the bridge, so that they could be inspected.

Repair of the corroded web plates

146 **When British Rail revealed the inner surfaces of the web plates in 1987 to fit the waterproofing arrangement, it is almost certain that there had already been a significant loss of plate thickness through corrosion. However, there is no evidence that any repairs were then done to fully restore lost material. Not repairing the web plates, when the waterproofing work was done, was contributory to the collapse of the bridge.**

Figure 19: Repair plate welded to web panel 5 of the east main girder

147 The RAIB's survey of Bridge 88 found that web repairs had been considered necessary in the past. Web panels 1, 5, 10 and 12 of the east main girder all had steel repair plates welded to their external surface:

- panel 1 had a part plate repair that covered the lower half of the panel;
- panel 10 had a part plate repair that was full height, but half-width; and
- panels 5 and 12 had a full-sized repair plate that covered the whole panel; figure 19, shows the repair done to panel 5.

Physical evidence points to the repairs being in response to holes that had formed from established corrosion on the inner surface of the web plate.

148 Although there is no record of when these repairs were done, a metallurgical analysis found that the repair plate steel was no more recent than the 1950s or 1960s[15]. The repairs, then, were almost certainly historic, and were done a significant number of years before the waterproofing work.

149 The evidence in paragraphs 147 and 148 indicates that it is likely that material loss on the inner surfaces of the web plates would have been observable when the track and ballast were removed to fit the waterproofing arrangement. A decision could have been made to do repairs that fully restored the lost material - for instance, by attaching repair plates to other web panels[16]. However, there is no evidence that any repairs were done, or considered necessary. Furthermore, because the waterproofing and ballast replacement then enclosed the inner surfaces, the options for future repair work were reduced.

[15] Based on a comparison of the manganese content with that required in historic UK standards for structural steel and the level of phosphorus, which was considered too high for modern steel making practice.

[16] Metallurgical examination showed the welds on the historic web repairs retained their strength where the plates were full-sized. Such repairs might have been effective in fully restoring lost material, though welding to wrought iron is widely considered difficult. On the part plates, some of the welds were to corroded and thinned wrought iron web material that had subsequently fractured. These repairs are unlikely to have been fully effective.

Corrosion protection

150 **The inner surfaces of the main girders could have been re-painted to protect against further corrosion loss, particularly at the time of the waterproofing, but also afterwards (although the waterproofing arrangement would have made full re-painting impossible). Not re-painting the metal superstructure was contributory to the collapse of the bridge.**

151 On dismantling the bridge, it was evident that any paint that had been applied to inner surfaces of the main girder web plates had long since deteriorated and disappeared. Based on the typical life of paint systems used in studies done for Railtrack[17] and that Bridge 88 was almost certainly last painted over 40 years ago (March 1966[18]), and that there had been reports of concerns with the paint condition since 1981, this was also most likely the situation when the waterproofing work was done.

152 Pieces of a bitumastic compound, thought to have been used during the waterproofing work, were found in direct contact with the corroded inner surfaces of the web plates. There was no intermediate layer of paint to indicate that any painting had been done.

153 Network Rail's records include a British Rail works proposal, dated 10 May 1983, that stated 'paint all steel work after bridge deck has been waterproofed'. Although the waterproofing would have prevented painting of the inner surfaces of the east and centre main girder web plates, access to the west side of the centre main girder would have been possible by removing ballast from the redundant (west) deck. Painting this alone could have helped arrest the corrosion loss on the centre main girder web plates. However, although proposed, no painting was done. The RAIB found no evidence to indicate why this was not done.

Routine management of Bridge 88

154 Network Rail's routine management processes did not prevent the collapse of Bridge 88 because:

- the results of the last routine bridge assessments led to a misunderstanding of the significance of reports concerning the condition of the main girder web plates;
- the findings of the last detailed examination did not result in immediate action that could have led to a full understanding of the criticality of the identified web plate corrosion defects; this was despite the fact that the examiner was so concerned that he issued a related urgent defect report; and
- the findings of subsequent annual visual examinations did not result in any action with respect to the corroded condition of the web plates.

[17] A study done for Railtrack in 1995 on bridge maintenance strategies assumed a typical paint life of 10 years.

[18] The date the bridge was last fully painted was not recorded at the time. However, there was an inscription on the west main girder that reads '3/66'. The RAIB believe this to be evidence of this date. It is consistent with notes subsequently made by Network Rail in the bridge records.

Routine bridge assessment

155 In the assessment of a railway underbridge, Network Rail use structural calculations to determine the loads that it can safely carry. However, the calculations done for the last two routine assessments of Bridge 88 (in 1982 and 1994) were based upon key dimensions of the main structural elements that were inaccurate: the as-built web thicknesses for the east and centre main girders were both incorrectly assumed as 1/2 inch (12.7 mm) instead of 1/4 inch (6.4 mm) and 3/8 inch (9.5 mm) respectively. In addition, no allowance was made for corrosion losses that had further reduced these thicknesses. Together, this meant that the calculated live load capacity of the east and centre main girders was considerably higher than it should have been. It resulted in the significance of web corrosion reports being overlooked. The use of this incorrectly assumed web plate dimension was causal to the bridge collapse.

156 Furthermore, the last routine assessment for Bridge 88 (1994) raised concerns regarding over-stress of the cross girders. There is evidence that this focussed management action on condition issues with these elements of the bridge.

157 The RAIB has been unable to establish why British Rail commissioned the 1982 Assessment.

158 The consultants who undertook the assessment inspected the bridge and prepared a drawing of it. This drawing showed the sizes of the structural members that were used in the assessment calculations. The cross section showing the east and centre main girders had the note '1/2" assumed' against the web thickness dimension. Figure 20 includes an extract from the drawing showing the cross section.

159 The RAIB measured the dimensions of the east and centre main girders and found the actual uncorroded thickness of their webs was 1/4 inch (6.4 mm) and 3/8 inch (9.5 mm) respectively (appendix E includes further details). Both were significantly less than those used in the calculation, resulting in an over-prediction of live load capacity.

160 Other incorrect assumptions were made. Some of these also meant that the 1982 Assessment calculation over predicted live load capacity, for instance:

- The main girder material was assumed to be early steel. This has an allowable shear stress 15% higher than the actual material, wrought iron (paragraph 43).
- The stiffeners on the main girder webs were assumed to line up at every cross girder – they actually lined up at only two locations on the centre main girder and one on the east girder. Each of these locations was on a different cross girder. The effect of this was to make the permitted stress for the top flange of the main girder higher than it should have been as the stiffening benefits from *U-frame action* would be reduced.

161 The resulting calculations from the 1982 Assessment found that the east and centre main girders and the cross girders all had sufficient live load capacity[19] for a RA10 train travelling at 75 mph. Against shear failure the margin is very significant. The calculations used un-corroded sizes for the metal structural elements.

[19] There was a rivet shear stress discrepancy issue on the east main girder, but for reasons relating to the significance of similar results in the 1994 Assessment (paragraphs 63 and 164), this is not discussed further here.

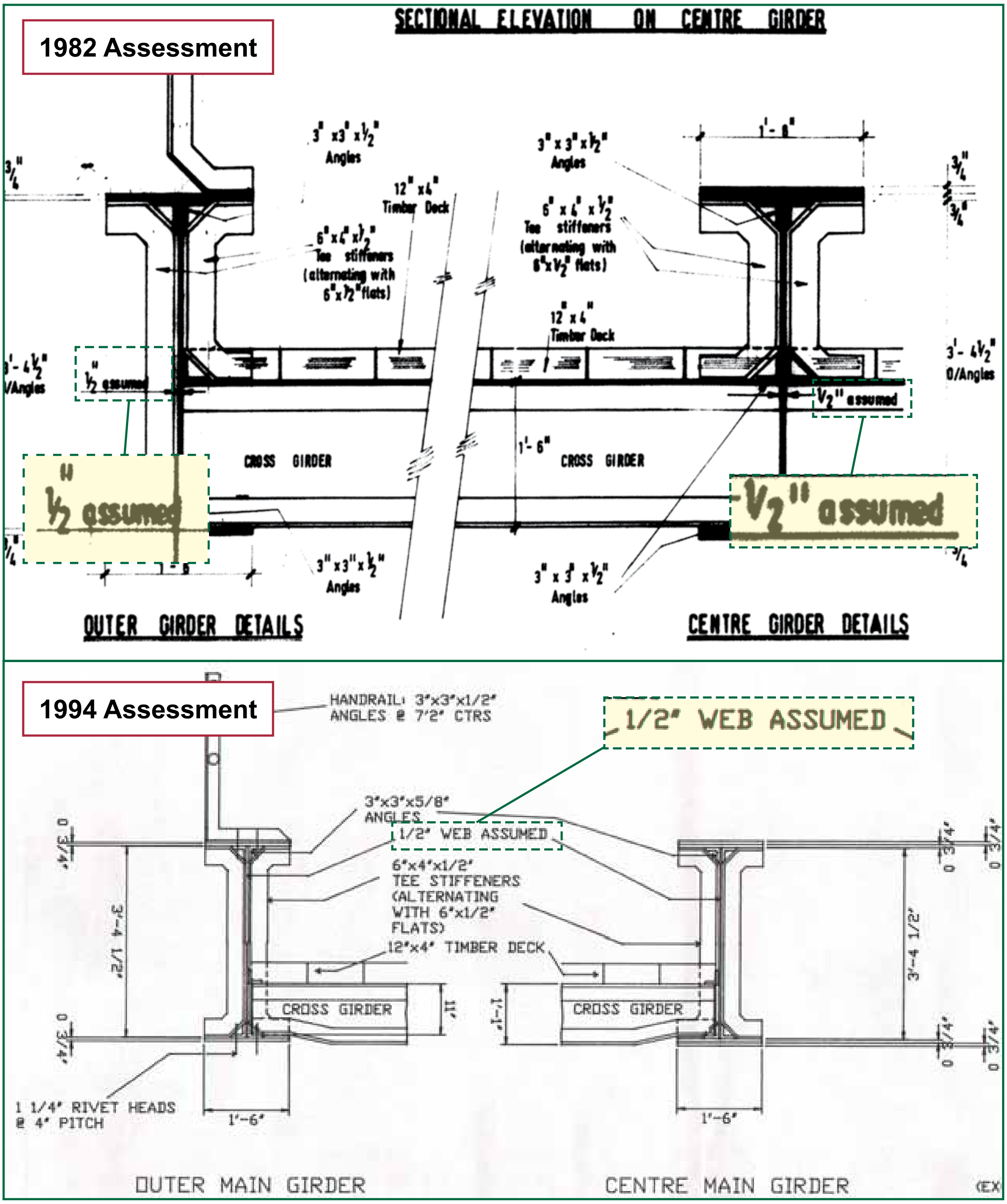

Figure 20: Extracts from the drawings prepared for the 1982 and 1994 Assessments showing the cross-section of the main girders (images courtesy of Network Rail)

162 Witness evidence indicated that the 1994 Assessment was commissioned because of concerns with the condition of the bridge. It was done to the 1983 version of British Rail's assessment code (BR36840).

163 Railtrack inspected the bridge and prepared a new drawing of it for use in the assessment. This included a similar note regarding the web plate thickness, '1/2" web assumed', showing that the same assumption had been made (figure 20). However, most of the other incorrect assumptions made in 1982 were amended. Consideration was also given to material lost through corrosion and strike damage from road vehicles, but this was only insofar as it related to the flanges of the cross girders and of the east main girder. All the webs, and all of the centre main girder, were treated as un-corroded.

164 The resulting calculations showed that the centre main girder still had sufficient live load capacity for an RA10 train load (but now assumed to be travelling at 70 mph (113 km/h)). On the east main girder there were discrepancy issues due to rivet shear stress and damage to the bottom flange (paragraph 62), but there is evidence these issues were considered insignificant (paragraph 63). With these discounted, the east main girder also had sufficient live load capacity. Although reduced compared to the 1982 findings, the margin against shear failure was still significant.

165 The RAIB re-worked the 1994 Assessment calculations using the same calculation method but with the correct as-built web dimensions. This indicated that the main girders had insufficient live load capacity for an RA10 train (see table 2). Against shear failure the centre main girder is calculated to have a live load capacity of only around 65% of that shown in the 1994 Assessment; the east main girder, only around 41%. Furthermore, if allowance had also been made for loss of web plate thickness due to corrosion – the effects of which were identified at the time of the 1994 Assessment (paragraph 195) - the calculated live load capacity of the main girders would have been even less.

	Live load capacity [20] – dynamic load [21]		
Structural element/failure mechanism [22]	1982 Assessement BSUs	1994 Assessement BSUs	Re-worked 1994 Assessement (measured web) BSUs
Centre main girder/shear	35.8 (RA10)	27.68 (RA10)	18.10 (RA8)
East main girder/shear	46.8 (RA10)	40.48 (RA10)	16.67 (RA6)
Centre main girder/bending	32.5 (RA10)	29.45 (RA10)	26.12 (RA10)
East main girder/bending	23.8 (RA10)	21.79 (RA10)	17.73 (RA7)

Table 2: Comparison of calculated live load capacity of the east and centre main girders, based on as-measured web dimensions, with the results from 1982 and 1994 Assessements.

[20] Live load capacity is given in terms of BSU to show the full assessed capacity of the structural element. The equivalent RA number is also given. Note that a ceiling of RA10 was applied to the 1982 and 1994 Assessments, which means that any residual live load capacity above RA10 is not apparent from the RA number. See also appendix D.

[21] Dynamic load relates to the loads imposed by a train that is moving. For the 1982 Assessment a speed of 75 mph was used; for the 1994 Assessment, including the re-worked assessment, 70 mph was used.

[22] For comparison, all elements are considered in their un-corroded and undamaged condition. Two principal failure mechanisms are presented: bending and shear. For shear, assessment is against the limiting shear stress in the web (paragraph 100). For bending, assessment is against the limiting tensile or compressive stress in the flange.

166 The calculations in both the 1982 and 1994 Assessments, including the dimensional information used as input, were signed off at the time as checked.

167 The evaluation part of Network Rail's routine management process is used to decide if intervention action is needed to ensure the continuing safety of a bridge (paragraph 50). Network Rail's company standard NR/SP/CIV/080 'Management of Existing Bridges & Structures' defines the events that should result in evaluations being done[23]. They include:

- when 'the report of a significant[24] defect, change in condition or situation that is likely to affect the safety or serviceability of the structure' is received;
- the 'receipt of a detailed examination …report'; or
- the 'receipt of a visual examination report indicating a significant change in condition'.

168 Company standard NR/SP/CIV/080 also outlines the evaluation methodology[23]. It lists the results of the last assessment report as one of the key pieces of information that needs to be considered during the evaluation in order to 'confirm or otherwise the continuing structural safety' of the bridge. This is prior to deciding on any intervention action. Witness evidence confirmed that this was adopted practice in Network Rail's Scotland Territory, specifically reporting that the assessment should be examined when determining the seriousness of a reported defect.

169 In effect, therefore, the results from the last assessment act like a gate during an evaluation. If they incorrectly show there is adequate live load capacity, then the significance of reports of defects or poor condition may be overlooked, and therefore, so may the need for intervention action. This is a possible explanation why no action was thought necessary following reports of corrosion on the main girder web plates: for instance, in relation to the corrosion defects identified in the 2003 Detailed Examination report (paragraph 139), but also a hole in the web of the centre main girder that was illustrated in the 1994 Assessment report itself. The RAIB found no documented reasoning supporting such evaluation decisions.

170 The only main girder discrepancy issues in the 1994 Assessment concerned the east main girder, and these were considered insignificant (paragraph 63). However, the assessment raised particular concern about the live load capacity of the cross girders. With allowance for damage and corrosion, the dynamic capacity[25] of these was calculated to be RA1; it was RA4 without.

171 Although not directly causal to the accident, the 1994 Assessment is likely to have focussed management attention on the live load capacity issues with the cross girders. On reviewing it during an evaluation, the results could have led to the conclusion that the main girders were not of primary concern, but that intervention action regarding the cross girders was.

[23] Its predecessor, Railway Group standard GM/RT5100 'Safe Management of Structures', contained similar requirements

[24] Network Rail define this as 'anything that measurably changes the safety or performance of a structure'

[25] The RA numbers are derived from the BSU number by subtracting 10 and rounding down to the whole number (as described in appendix D). In the 1994 Assessment report, a convention of rounding up was used.

Urgent defect report and findings from the last detailed examination

172 **The examiner who did the 2003 Detailed Examination (paragraph 54) was so concerned about the condition of the web plates on the east main girder that he raised an urgent defect report. However, the RAIB found no evidence that Network Rail took any action in relation to these specific corrosion issues, such as investigations that could have led to the structural significance being fully appreciated, and intervention action being taken. The lack of any action in response to the web plate corrosion issues detailed in the urgent defect report, and later in the 2003 Detailed Examination report, was contributory to the bridge collapse.**

173 The detailed examination undertaken on 7 October 2003 would have been the last opportunity, as part of Network Rail's routine management processes, to do a close-up and thorough examination of Bridge 88 (paragraph 52).

174 The examination was done by a bridge examiner from Atkins on the night of 7-8 October 2003. It was done at night as a road closure was necessary to get to the underside of the bridge deck. The examiner used ladders and an elevating access platform to gain access, and floodlights for illumination. He took with him the previous visual examination report, but not the report of the previous detailed examination, which was done by another contractor and was not available to him.

175 During the detailed examination, the examiner became particularly concerned with the condition of the east main girder. On the external surface of the web plate he found corrosion holes and what, at first, he believed to be a longitudinal fracture, but later realised was a series of corrosion holes. The holes, which ran along a line at the top of the timber deck, were only visible when the reflective yellow and black hatching road sign (paragraph 59) was lifted. He also had concerns regarding holes in the webs of several cross girders.

176 His concerns led him to call his on-call manager that night for advice. It was decided that the examiner would submit a report at the end of the shift, which he duly emailed to his manager. The report described six defects that the examiner was most concerned about: five related to corrosion of the east main girder that resulted in holes and severe thinning of its web plates. The other defect concerned corrosion of the webs of several cross girders. Appendix G includes a transcript of the defect description and the photographs that it refers to.

177 Company standard NR/SP/CIV/017 requires the *structures manager* to be notified 'as soon as practically possible', either verbally or electronically, 'where the condition of any part of a structure is such that urgent action is likely to be required'. Since the examiner's manager agreed with the assessment of the severity of the defects, he submitted the report he had been emailed as an urgent defect report for Network Rail's attention.

178 The report was submitted electronically via the Atkins *'Pronet'* system on 8 October 2003. Atkins and Network Rail used the Atkins Pronet system as a means of managing shared information, in this case examination reports. The system was available to designated Network Rail staff via the internet.

179 Since Network Rail staff needed to be logged into Pronet to access information, Atkins notified them of the presence of this new urgent defect via an email. This was sent at 09:15 hrs on 8 October 2003 to a list of recipients that Network Rail had defined. It included a structures maintenance engineer and a number of project managers. The email stated:

> *'Subject: Urgent Defect No 45*
>
> *Dear all,*
>
> *Following examination of structure 222/088 on the GBK line last night please find posted on pronet Defect No 45 for your information.*
>
> *Regards …'*

The email gave no detail on the defect: the recipient needed to read the report on Pronet to find this out.

180 The log kept by Pronet showed that no-one in Network Rail accessed the report until 26 November 2003, when a project manager retrieved it; no Network Rail engineer retrieved it until 17 June 2004[26] (although this would have been after 2003 Detailed Examination report was available, which contained similar information (paragraphs 182 and 183)). The report was not accessed again until after the derailment of train 6B01.

181 It is unclear whether Atkins alerted Network Rail to the details of the defect by another means, for instance by telephone. This is possible, but no formal record was found of this and it did not result in anyone from Network Rail immediately accessing Pronet to read the report.

182 After the urgent defect report was issued, the Atkins examiner completed his report for the 2003 Detailed Examination. On 4 December 2003, following review, it was issued to Network Rail.

183 The report described all the defects that were covered in the urgent defect report (although different wording was used) together with those on other parts of the bridge. It drew attention to the fact that 'an urgent defect report was submitted 8-OCT-03' (although no other reference was made to urgency). It gave Bridge 88 an overall condition of 'very poor', and also individually cited the main girders, cross girders, waterproofing and painting as 'V/P' (very poor). It recommended eight actions; three are key:

- 'Major steelwork repairs throughout. Alternatively consider superstructure replacement';
- 'Steelwork repairs to be prioritised in accordance with urgent defect report'; and
- 'Painting superstructure after repairs'.

184 Network Rail entered the details from the detailed examination report into the database that it used for the management of structures in its Scotland Territory (examination database). Network Rail used the examination database to record the intervention actions that it proposed to carry out in response to routine examinations. In response to the eight Atkins recommendations for Bridge 88, the record of what Network Rail decided to do is ambiguous: in the data field 'recommended minor works', it recorded 'as raised'.

---

[26] Although it is possible that, after the report was first accessed (on 26 November 2003), the Network Rail recipient circulated it within the engineering team responsible. Network Rail advised that this was not uncommon at the time.

185 Nothing was entered in any other relevant data field, including, significantly, the field titled 'Assessment Required'. One explanation is that the reported defects were not considered significant enough to initiate a new assessment, which could have revealed the inaccuracies in the 1994 Assessment (paragraph 155). However, not entering anything could also have been an oversight.

186 The RAIB found no evidence that any action was planned in direct response to the above three key recommendations that Atkins made; no record was found that explained why.

187 Records show that, in November 2003, Network Rail arranged for a steel sub-contractor to visit Bridge 88 with a scaffold 'to provide access to the entire underside of the structure for inspection by a Network Rail representative'. While there is no supporting documentary evidence linking this to the urgent defect report, Network Rail feel that, in view of informal practices that were then in place, its timing makes it likely that it was in response to it. Although there was no record of what the inspection found, in January 2004 arrangements were made to install supplementary steel beams either side of the damaged cross girders on the east deck (see also appendix F). The RAIB could not establish the reason for this remedial work being done at this time. It is possible it was related to the findings from the 2003 Detailed Examination report, from conclusions of the inspection arranged in November 2003, or for some other reason. However, it is evident that the repairs did not address the main girder web plate corrosion issues that both the urgent defect report and the 2003 Detailed Examination highlighted. Furthermore, as the work done would have gone some way to addressing the concerns highlighted with the cross girders in the 1994 Assessment (paragraphs 170 and 171), recommendations for work in other routine examinations may well have been considered lower priority.

188 In summary, RAIB found no evidence that Network Rail took any action in relation to the main girder web plate corrosion defects identified in the urgent defect report that Atkins submitted on 8 October 2003, or in the 2003 Detailed Examination report that followed – neither to repair them, nor to initiate investigative actions that could have led to their structural significance being fully appreciated. The RAIB found no process in place to highlight that issues raised in urgent defect reports remained open, and there is no record of the urgent defect report on Network Rail's examination database that might have shown what action it had decided to take.

189 In June 2000, Railtrack introduced a system of scoring bridges according to their condition. The system, known as the Structures Condition Marking Index (SCMI), is described in Network Rail guidance note NR/GN/CIV/041 'Structures Condition Marking Index Handbook for Bridges'. Atkins collected the data necessary to calculate the SCMI score for the main elements of the bridge when they did the 2003 Detailed Examination. It sent these to Network Rail, in spreadsheet form, and the data were aggregated to generate an overall score for the bridge, which was used for general reporting purposes. It was not used to determine SCMI scores for the individual bridge elements. The RAIB arranged for SCMI scores for the individual elements to be calculated after the accident; it gave a score of 50 (out of 100[27]) for the centre main girder and 10 for the east. This information, if it had been determined after the 2003 Detailed Examination, could have been useful when considering intervention action.

Response to subsequent visual examinations

190 **Subsequent annual visual examinations continued to raise concerns regarding the corroded condition of the main girder webs. However, these also did not result in any investigative actions that could have led to the structural significance being appreciated. As a result, no intervention action was taken. The lack of action in response to the continued reports of web corrosion was contributory to the bridge collapse.**

191 The first visual examination after the 2003 Detailed Examination, undertaken on 21 February 2005 and done by the same bridge examiner, reported similar findings with regard to the corrosion of the web plates of the east main girder. It repeated the same key recommendations: major steelwork repairs, prioritised to the urgent defect report, followed by re-painting. The examiner gave the bridge an overall condition of 'poor'.

192 With regard to the intervention actions that Network Rail proposed, its examination database (paragraph 184) recorded that the 'steelwork' repairs were '…prioritised in system'[28]. However, by reference to Network Rail's minor works records, it was seen that these steelwork repairs did not involve work relating to the main girder webs. Instead, they referred to the supplementary steel beams fitted next to the damaged cross girders in January 2004 (paragraph 187). No reason was recorded why no action was planned regarding the main girder web plates.

193 Two other examiners carried out the next two visual examinations, on 20 March 2006 and 1 March 2007. They both raised similar concerns regarding corrosion on the web plates of the east main girder and recommended steelwork repairs. They both gave the bridge an overall condition of 'poor'. This time Network Rail's recorded intervention proposal was limited to pointing work (of the masonry abutment) that was already 'prioritised on the system'. Again, no reason was recorded why no action was planned regarding the main girder web plates.

---

[27] SCMI is used to rate the condition of visible elements on a structure; it is not, however, a safety index. Network Rail's guidance note (NR/GN/CIV/041) states only that a score of 100 is representative for a bridge in perfect condition. From this it can be inferred that a score of 0 is representative of a bridge that is visibly in as bad a condition as can be envisaged.

[28] There is no explanation what is specifically meant by 'prioritised in system', the RAIB has presumed it relates to work that Network Rail planned to carry out either as a result of this examination, or for some other reason.

194 The last visual examination of Bridge 88 was carried out on 25 February 2008. It too identified corrosion issues with the web of the east main girder, but did not recommend any related action. It gave the whole bridge an overall condition of 'fair'.

195 None of the above visual examinations, nor the 2003 Detailed Examination, identified the corrosion hole in the web plate at the south end of the centre main girder that was shown in the 1994 Assessment report (paragraph 169) (figure 21). This is the hole in web panel 12 that is identified in paragraph 103. It is on the split line where the upper part of the centre main girder became detached as Bridge 88 collapsed (paragraph 107).

Figure 21: The web plate corrosion hole at the south end of the centre main girder that was illustrated in the 1994 Assessment report (photograph courtesy of Network Rail)

Other opportunities for intervention – route availability verification exercise

196 The route availability verification exercise (paragraphs 60 to 65) resulted in Network Rail needing to re-appraise around 300 bridges in its Scotland Territory because of discrepancies between calculated live load capacity and permitted train loading. The work started in 2006. In January 2007, with a batch of other bridges, Network Rail asked Jacobs to start looking at Bridge 88 with respect to the discrepancies in the 1994 Assessment (paragraph 62).

197 After determining that the 1994 Assessment calculations were not overly pessimistic (paragraph 64), Network Rail began to consider replacing the bridge and initiated an evaluation. In June 2007 this resulted in it asking Jacobs to undertake a new 'further rigorous assessment', the 2007 Assessment. The calculations for the 2007 Assessment, which were done by a Jacobs assessment engineer overseas, were based on revised measurements of the bridge made at the Inspection for Assessment done in November 2007 (paragraph 65). The revised measurements included, significantly, the centre main girder web thickness.

198 The new assessment calculations showed that the centre main girder had insufficient live load capacity against shear failure. The Jacobs office in Glasgow received a report containing draft findings on 4 April 2008[29]. However, because Jacobs understood that Network Rail had de-prioritised the need for calculation work, Jacobs' staff in Glasgow did not read the draft report or forward it to Network Rail until after the derailment of train 6B01.

199 If Network Rail had been made aware of certain findings from the 2007 Assessment, it would have been alerted to the seriousness of the condition of the main girders on Bridge 88. This would have enabled it to take action before train 6B01 crossed on 27 January 2009. The RAIB indentified two reasons to do with the 2007 Assessment calculation work why this did not occur:

- there was no formal process for alerting Network Rail of urgent findings from work done for assessment calculations; and
- the decision to replace the bridge earlier than was originally being considered, which resulted in the 2007 Assessment work being given lower priority.

200 The RAIB also identified reasons why other work done in connection with the route availability exercise did not result in effective intervention action. These ultimately related to the significance attached to information in the 1994 Assessment report.

Urgent findings from assessment calculations

201 **Work relating to the 2007 Assessment calculations provided a number of indications that the main girders were likely to be weaker than the 1994 Assessment indicated. However, there was no formal process for raising such urgent concerns and no-one did so. If concerns had been raised, Network Rail could have taken action to prevent the collapse of the bridge. The lack of a formal means of alerting Network Rail of urgent findings from assessment calculation work was contributory to the collapse of Bridge 88.**

202 Jacobs' office in Glasgow collated a set of information (assessment pack) for the overseas office that did the assessment calculation. Amongst other information it included:

- the Inspection for Assessment report – which included amended dimension information for the main girders that was marked on copies of drawings from the 1994 Assessment report;
- a copy of the 1994 Assessment report - detailing the most up-to-date calculation of the bridge live load capacity and the main girder sizes on which it was based; and
- a copy of the 2003 Detailed Examination report documenting the corrosion defects of the web plates of the east main girder.

[29] The report that was received was a draft that represented work in progress. Engineers in Jacobs' Glasgow office had yet to review, check and approve the results and findings.

203 The marked-up drawing of the 1994 Assessment that detailed the main girder cross sections in the Inspection for Assessment report correctly recorded the centre main girder web thickness as ‘3/8” ’ (9.5 mm)[30] (figure 22). This was an early indication of a significant inconsistency with the 1994 Assessment – which had assumed ½ inch (12.7 mm) (paragraph 163).

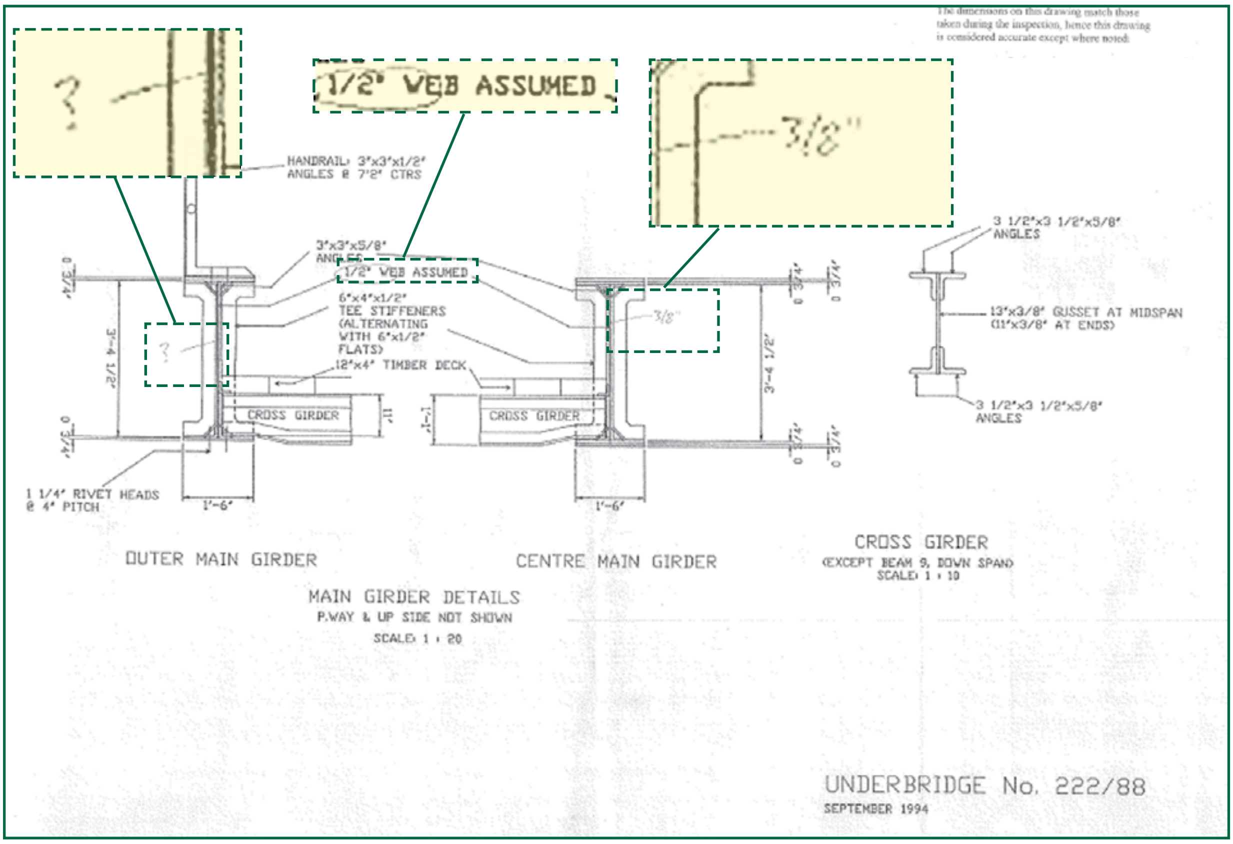

Figure 22: Extract from the bridge drawing used for the 2007 Assessment (image courtesy of Network Rail)

204 Other indications of concern with the 1994 Assessment were that:

- Severe web plate corrosion was recorded in the 2003 Detailed Examination and the 1994 Assessment reports, and yet the main girder capacities calculated in the 1994 Assessment were based on un-corroded web plate thicknesses. (The Inspection for Assessment report described similar corrosion defects; this was so that the assessment engineer could make allowance for corrosion in the new calculations.)
- The new calculations, the findings of which were included in the draft 2007 Assessment report, showed the live load capacity against shear failure of the centre main girder was considerably less than that calculated in 1994.

205 None of these indications resulted in Network Rail being made aware of any urgent findings from the 2007 Assessment calculation work. Although the RAIB have not been able to confirm this, it is possible that the assessment engineer may have been led into thinking that, because a number of the concerns raised were old and known, Network Rail was already aware and had action in place.

[30] Jacobs reported that it attempted to measure the east main girder web thickness at the Inspection for Assessment. However, the dimension was recorded as “?” on the marked-up drawing (figure 22). There is evidence that the overseas assessment engineer sought to verify this dimension with Jacobs’ office in Glasgow; it confirmed that a thickness of 3/8 inch should be used. This is greater than the ¼ inch measured by RAIB (paragraph 159).

206 There were no formal processes in place that required Network Rail to be alerted to critical issues arising from assessment calculation work - although there were processes for alerting Network Rail of urgent issues identified during Inspections for Assessment.

Priority given to the 2007 Assessment – decision to replace Bridge 88

207 **When it was decided to replace the bridge earlier than previously planned, Network Rail told Jacobs that it no longer required it to examine requested options for engineering remedial work. The consequence was that assessment work on other bridges was allowed to continue ahead of Bridge 88 to the extent that the draft calculations for the 2007 Assessment had not been reviewed or finalised at the time of the derailment. De-prioritising information that was potentially relevant to the condition of Bridge 88 while it remained in service was contributory to its collapse.**

208 When Jacobs advised that the 1994 Assessment for Bridge 88 was not overly pessimistic Network Rail began to consider major renewal work. Network Rail's main concern was with the cross girders and the timber deck. Mindful of the large number of structural members that would probably need renewing, Network Rail felt that superstructure replacement was the only practical option (paragraph 64). Initially this decision was made so that budgetary provision could be allocated, and a scheme developed. A financial proposal was made in March 2007 for replacement in 2010-2011.

209 Network Rail and Jacobs kept each other appraised of the assessment work requested for the route availability verification exercise at regular liaison meetings. These were 'technical meetings' (dealing with technical aspects of assessment work - also referred to as 'ORR review meetings'), 'pre-feasibility design meetings' (dealing with engineering remedial work) and general contract meetings. Since June 2006, there had been discussion within Network Rail regarding the Lugton loop scheme and its implications for Bridge 88 (paragraph 66). It was felt that the bridge would need replacing if it was to carry a double track. The minutes of the 'pre-feasibility design meeting' of 25 October 2007 showed that Network Rail asked Jacobs to look into options for strengthening Bridge 88 to take a double track, but on 13 December 2007 it revised this and asked for the work to be based on the existing single line arrangement. This indicates that it was no longer considering the option of doubling over the existing bridge. When the initial budget proposal for replacement was made in March 2007, it was not known whether the Lugton loop scheme would definitely go ahead. However, with the planned implementation of the scheme confirmed as being in 2008-2009, towards the end of 2007 there was greater confidence, and it was decided to replace the bridge as part of the scheme - two years earlier than the original budget proposal.

210 In the pre-feasibilty design meetings on 10 January and 7 February 2008, Network Rail advised Jacobs that superstructure replacement was likely to be the 'solution'. At the meeting on 6 March 2008, Network Rail confirmed that pre-feasibility work was no longer required. In reality, Jacobs had yet to start any work in connection with the earlier requests as it required the finalised results from the 2007 Assessment. Network Rail did not intend that cancelling the pre-feasibility work would mean that the 2007 Assessment work was no longer required, and Jacobs were aware that the work was to be finished as it was on a list of outstanding work for completion in Network Rail's next financial year (April 2008-April 2009). However, Jacobs understood that Network Rail had now placed a lower priority on the work. There was a substantial volume of assessment work that needed to be completed in 2008-2009, and Jacobs reported that there was more concern with progressing the assessment of other bridges at technical meetings (status reports of this period recorded that assessment work on other bridges was allowed to continue ahead of Bridge 88). The draft 2007 Assessment calculation report arrived at Jacobs' Glasgow office on 4 April 2008 (paragraph 198). No-one opened the report (probably because the work was understood to have lower priority), and it was not forwarded to Network Rail.

Belief in the 1994 Assessment

211 **The 1994 Assessment would have led Network Rail to believe that the main girders of Bridge 88 had sufficient live load capacity; it understood that the main issues raised were to do with the cross girders, and that there were no significant capacity concerns with other parts of the structure (paragraph 63). The belief Network Rail had in the incorrect results of the 1994 Assessment (because it was based on incorrect web thickness assumptions) when evaluating the ongoing safety of Bridge 88 in response to the route availability exercise, possibly exacerbated by deterioration since the 1994 Assessment was done, was contributory to the bridge collapse.**

212 The work in connection with the route availability verification exercise was focussed on the live load capacity discrepancy issues arising from the results of the last valid assessment. The 1994 Assessment led Network Rail to consider the cross girders as the open risk (paragraph 63). Its staff did not recall having concerns regarding the live load capacity of the main girders, and while there were discrepancy issues in the report (for instance with rivet shear stress on the east main girder), these, for the reasons discussed in paragraph 63, were not considered significant[31].

213 On 16 May 2007, as part of the evaluation done following the initial review of the 1994 Assessment discrepancy issues (paragraph 197), Network Rail engineers went to examine the bridge to see the condition of the cross girders. They saw the supplementary beams that had been inserted in January 2004 (paragraph 187) and recorded that the 'condition was not as significant as reported. Added to 07/08 programme … for subsequent re-assessment' (the 2007 Assessment).

[31] The survey of the recovered superstructure found there was some justification in this reasoning; there was no evidence of main girder failure associated with rivet shear stress or damage of the bottom flange.

214 The 1994 Assessment found the cross girders to have an un-corroded live load capacity of RA4. However, Network Rail recorded that it believed there was 'sufficient scope to get the cross girder to an acceptable assessed category pending major works'. Bearing in mind that most of the corroded cross girders were on the redundant west deck, and supplementary beams had been fitted to the most damaged ones on the east (paragraph 187), it judged that the bridge was safe for the freight trains that were using it for the time being. It declared the bridge a 'marginal discrepancy' (meaning that although the assessed live load capacity was below the published RA for the line, an evaluation had considered that it could remain in service).

215 Bringing forward the replacement of the bridge is likely to have led Network Rail to accept that there was insufficient time for it to be worthwhile strengthening Bridge 88 and therefore that pre-feasibility work was not required (paragraphs 209 and 210).

216 While waiting for the bridge to be replaced, a routine visual examination took place on 25 February 2008. It failed to trigger any relevant intervention action, probably since it did not identify that the bridge metalwork was in a significantly worse condition than when examined the year before. It recommended no related action (paragraph 194).

217 Although not related to the incorrect live load capacity results, the RAIB observed that condition information in the 1994 Assessment report may also have influenced intervention action decisions during the route availability verification exercise.

218 On 27 November 2007 Jacobs sent an engineer to carry out the Inspection for Assessment on Bridge 88. The inspection was done during the day using two half-road closures. Network Rail engineers were present when Jacobs inspected the north side of the bridge.

219 The Inspection for Assessment report identified general concerns about the condition of the bridge superstructure. It also detailed specific relevant defects on the east and centre main girders.

220 On the east main girder, web plate holes are described and illustrated (figure 23a). The report goes on to state that these are 'likely to have been caused by water pooling on the timber deck…'; in effect, they were thought to be due to the corrosion trap that was observed when the bridge was dismantled (paragraph 126). The holes are those indentified in the 2003 Detailed Examination.

221 On the centre main girder, a corrosion hole in the web plate above the south abutment is described and illustrated (figure 23b). It reported the corrosion as severe and that the hole 'extends for at least 10 inches in height', beyond this it could not be seen[32] (the Network Rail engineers were not on site when this part of the bridge was inspected). The Jacobs engineer was particularly concerned about this defect and, on 19 December 2007, Jacobs emailed photographs of it to Network Rail. Network Rail staff do not recall what direct action was taken as a result of this notification.

[32] In relation to the centre main girder it also stated 'A full inspection of the centre girder web could not be taken. It is therefore highly possible that there are other defects present that are not visible'.

222 At Network Rail's request, on 11 February 2008, Jacobs forwarded a copy of the of the Inspection for Assessment report, together with the defect photographs. In both the report synopsis and the conclusion in the inspection summary, although declaring 'the structure is in a very poor condition', Jacobs reported that the bridge was considered to be 'serviceable'[33].

223 Network Rail stated that on receiving the report, it acknowledged the defects described and undertook an evaluation, which involved consulting both the 2003 Detailed Examination and the 1994 Assessment (although contrary to company standard NR/SP/CIV/080, the results were not recorded). Although the web plate defects on the east main girder were reported in the 2003 Detailed Examination, there was no report of the hole in the centre main girder. However, the 1994 Assessment report (paragraph 195) recorded this. On the basis that all the defects were long-standing, Network Rail were satisfied with Jacobs conclusion in the report that the bridge was 'serviceable'. Network Rail has stated that on receipt of the Inspection for Assessment report it asked Jacobs to expedite the 2007 Assessment, and for the supporting 'Approval in Principle for Assessment' form to be sent to it for review (paragraph 64); this was before the pre-feasibility work was cancelled on 6 March 2008 (paragraph 210). Although there is no documentary evidence to support this statement, it is known that Jacobs sent the 'Approval in Principle for Assessment' form the following day, 12 February 2008. The form was later agreed and signed on behalf of Network Rail at a meeting on 26 February 2008.

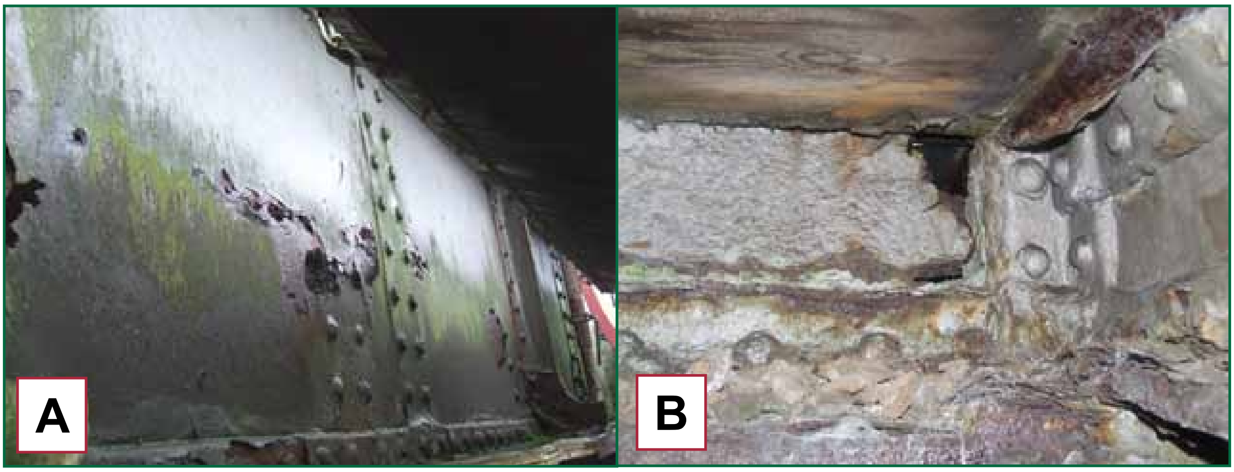

Figure 23: Photographs of web corrosion from the Inspection for Assessment undertaken 27 November 2007 (photographs courtesy of Network Rail)

[33] Jacobs reported that the only alternative categorisation was 'unserviceable'; this would only be used if the inspector felt it necessary to report an immediate danger to the operational railway during the inspection. He would have done this by notifying Network Rail control.

Identification of underlying factors[34]

224 It was evident that the 1994 Assessment findings dominated the decisions made by those responsible for the management of Bridge 88. In the absence of any other evidence, the RAIB believes that the assessment repeatedly led those responsible to wrongly conclude that there was sufficient margin in the live load capacity of the main girders of the bridge, and therefore that they did not need to respond to defects that were, in practice, critical to its structural integrity (paragraph 169).

225 This was because two key dimensions in the supporting structural calculations were wrongly assumed: the web plate thicknesses of the east and centre main girders. Exactly the same thicknesses were used in the previous 1982 Assessment. It is therefore likely that for over 25 years, decisions regarding the management of the bridge – such as painting, metalwork repairs, access to hidden parts, superstructure replacement and load restrictions – were all affected by these incorrect assumptions.

226 The ongoing reliance on unverified critical information in the routine management of Bridge 88 was an underlying factor.

Other factors for consideration

Track inspection

227 The vertical track geometry feature that Network Rail's track recording train recorded on 24 January 2009 showed that there had been a change in the structural behaviour of Bridge 88 since the last recording six months previously (paragraph 111). This is likely to have been an indication of change in its structural behaviour.

228 There were two primary means by which those responsible for Network Rail's track inspection (the local track maintenance organisation) could have identified that this track feature was significant to the bridge, and, if they had notified the relevant parties, enabled intervention action to be considered. In practice, however, neither would have ultimately prevented the bridge collapse.

229 The first was if the geometry data recorded by the train had been analysed and compared with data recorded on previous runs. The RAIB did this to recreate the vertical track geometry plot in figure 13. However, this involved data analysis that cannot readily be done by those doing routine track inspection work - and there is currently no requirement for it. Bridge 88 collapsed three days after the track geometry was recorded. To have been of use, the analysis would have had to have been done and reported within this timeframe – in practice, an unreasonable expectation.

[34] Any factors associated with the overall management systems, organisational arrangements or the regulatory structure.

230 The second means was that the vertical track geometry feature on Bridge 88 manifested itself as a discrete track twist fault (appendix F). The fault was automatically reported to the local track maintenance organisation, and, if it had been realised that it was on an underbridge, those responsible for the routine management of bridges could have been informed. However, the locations of underbridges are not specifically recorded or shown on the fault reports given to the local track maintenance organisation. It is therefore difficult to determine whether a reported fault is coincident with a bridge.

231 Network Rail's procedures required that the twist fault should be repaired within 14 days. By the date of the collapse, there is no record that anyone was considering how to repair the twist fault on Bridge 88, or how it may have formed – therefore potentially realising that the bridge had weakened.

232 The RAIB has investigated other accidents where trends from track geometry recording runs identified early indications of safety-critical issues, for instance the derailment on 25 January 2008 at Santon near Foreign Ore Branch Junction, Scunthorpe (RAIB report 10/2009[35]).

233 Network Rail company standard NR/SP/TRK/001 'Inspection and Maintenance of Permanent Way', requires *patrollers* to look out for track geometry faults on their regular visual inspections of the track condition. Records show they reported none in the vicinity of Bridge 88 for the six months prior to the bridge collapse. The recorded track geometry feature would, in the main, have been the result of the bridge deflecting under the load of the recording train. As patrollers do not generally observe the track under load, they are unlikely to have seen anything obviously untoward.

234 Patrollers are asked to look wider than the track when doing their regular visual inspections. With regard to bridges, they are asked to look out for new cracks on structures and the growth of existing cracks. They do their inspections from track level. From here, they would not be able to see any crack, or other defect, that was a sign of the structural condition of Bridge 88.

Severity of consequences

235 The records of the oil that was recovered on site showed that around 220,000 litres were lost from the derailed wagons. The RAIB identified that:

a. around 50,000 litres of diesel leaked from a pressure and vacuum valve on the top of the tank of wagon 7 as a result of damage that occurred when the wagon overturned; and

b. around 170,000 litres of diesel and kerosene were lost from punctures to the tanks of wagons 6, 8[36] and 10 that were the result of impacts from the drawhooks of adjacent wagons; this includes the fuel that burnt from wagon 10.

236 The RAIB examined each of the overturned wagons for other sources of fuel leakage but none was found.

[35] RAIB reports are available at the RAIB website, www.raib.gov.uk

[36] Recovery records partly combined the volumes recovered from wagons 8 and 9. However, an off-site inspection found no evidence of leakage sources on wagon 9 to suggest it was likely that a significant amount of kerosene spilt from it (paragraph 249).

Damaged valve on wagon 7

237 Two pressure and vacuum valves are mounted on the top of each wagon, and the rearmost valve on wagon 7, a TEB tank wagon, was severely damaged. The valve's head was pushed back causing the valve body to be torn open around its threaded section. There was evidence that it had struck a timber post from the railway boundary fence (figure 24). All of the fuel lost from wagon 7 leaked from the broken valve.

Figure 24: Damaged pressure and vacuum valve on wagon 7

238 The type of pressure and vacuum valves fitted to the TEA and TEB tank wagons were first produced in 1974, at the request of British Rail. The valves are designed to provide adequate pressure relief capacity if the tank wagon is fully engulfed in fire, preventing catastrophic rupture of the tank. The vacuum relief provided by the valve protects against implosion when fuel is extracted from the tank or the ambient temperature falls sufficiently.

239 The wagons involved in the accident were originally built in 1967 and 1968, so these valves had been retrofitted to them. The valves have a thread fitting for attaching to the top of the tank, and depending on the type of fitting, the valve can protrude 41 mm to 60 mm once seated. This means the valve's head is proud of the walkway on the tank roof, making it vulnerable to damage if overturning occurs.

240 Fittings like these on new tank wagons, which are designed to comply with the requirements of Railway Group standard GM/RT2101 'Requirements for the Design, Construction, Test & Use of the Tanks of Rail Tank Wagons', need to be protected against damage to ensure they remain leak tight when wagons overturn or derail. The international regulations, RID[37], which will replace the requirements of GM/RT2101, make similar demands. The RAIB has identified no requirement to retrospectively provide such protection to the valves that were fitted to the tanks on train 6B01.

241 In this accident, protection of the pressure and vacuum valve would have reduced the likelihood of it being damaged, and fuel leaking out.

Punctured tanks on wagons 6, 8 and 10

242 The wagons made significant override movements as the train passed over the collapsing bridge, causing the tanks on wagons 6, 8 and 10 to be punctured by the drawhooks of adjacent wagons; the punctures on wagons 6 and 10 can be seen in figures 8 and 15. All of the fuel lost from these wagons leaked through these holes.

243 There have been previous occurrences of tanks carrying dangerous goods, being punctured by drawhooks. The RAIB has identified a least four such accidents since 1980.

244 In 1984, a train carrying dangerous goods derailed in Summit Tunnel and the accident report praised the effectiveness of *override beams* that were fitted in preventing tank punctures. Railway Group standard GM/RT2101, which was first issued in 1996, requires that all new tank wagons designed to carry dangerous goods must have end protection override beams if the distance from the tank to the buffer face is less than 920 mm. British Rail had similar requirements before this. There has been no requirement to retrospectively provide such protection for other than liquefied gases, unless certain wagon conversion[38] work is being carried out. In 2003, a UK research project[39] concluded that there was no safety justification for such a retrofit. However, this work did not consider the costs of environmental damage or the associated clean-up.

245 None of the wagons on train 6B01 was built with, or was modified to have, end protection, and there was no requirement for them to be. Furthermore, the type of override protection that has been fitted to comply with GM/RT2101, a plain beam mounted above the buffers, is unlikely to have provided significant benefit in this accident due to the very high vertical movements that occurred.

246 The current version of RID (2009) requires end protection for new tanks carrying highly hazardous substances. The regulations call for at least one of the following: an override prevention system, an increased thickness of tank ends, or 'sandwich covers' or 'protective shields' to protect the tank ends. Some of these measures may have helped prevent the puncturing that occurred. However, for the type of flammable liquids on train 6B01 none of these measures is required.

---

[37] Regulations concerning the International Carriage of Dangerous Goods by Rail (RID).

[38] If a new tank is fitted to a 'Class A' tank wagon (carrying flammable products with flashpoint below 23ºC), or a 'Class B' tank wagon (carrying flammable products with flashpoint between 23ºC and 61ºC) is converted to carry 'Class A' products.

[39] 'Review of tank wagon end protection' carried out for the Rail Safety and Standards Board in 2003.

Discounted sources of leakage

247 The RAIB examined, off site, the six wagons that overturned for any other sources of leakage, especially where fittings were attached.

248 Two *foot valves* are installed at the bottom of each tank and attached to them are the pipes through which the fuel is discharged. These valves are opened manually using a lever mechanism when the tanks are about to be discharged; they are left in the closed position when the tanks are in transit. The external portion of the valve body is designed to break off under impact loads but leave the valve sealed in the body of the tank. The foot valves on all six wagons were damaged to varying degrees. However, with the exception of the front valve on wagon 10, which suffered fire damage, all of them remained seated and sealed.

249 There are two manhole closure units on the top of each tank that provide access into it. On wagons 5, 6, 7, 8 and 10, the units were all either undamaged or had sustained superficial damage. One unit on wagon 9 showed signs of being struck but the lid and its mechanism were intact and showed no obvious signs of leakage.

Fire on wagon 10

250 Only wagon 10, which was carrying kerosene, caught fire (paragraph 85).

251 CCTV images of train 6B01 passing through Stewarton station at 06:11 hrs did not show anything untoward on the train and, in particular, no evidence of fire on wagon 10. The derailment occurred shortly afterwards (around 30 seconds). It is therefore unlikely that the kerosene on wagon 10 ignited prior to the train passing over Bridge 88. The fire was therefore almost certainly not due to a pre-existing fault on the train.

252 The main release of flammable liquid started when the wagons were punctured as they crossed the collapsing bridge (paragraph 242), the leaking wagons trailing spilt fuel to their ultimate resting positions.

253 The RAIB did not determine the precise source or location of the ignition. However, given the nature of the damage that occurred during the derailment, there are a number of possibilities. Of particular interest is the evidence of metal removal on the *foot* of the east (left) running rail on the bridge. Visual inspection suggested that this was probably the result of frictional metal-to-metal contact that would have resulted in sparks and locally high surface temperatures. It occurred in an area where leaking fuel fell.

Conclusions

Immediate cause

254 The immediate cause of the derailment of 6B01 was the collapse of Bridge 88 that followed the catastrophic structural failure of its east and centre main girders. Heavy corrosion had so significantly weakened these main girders that they were no longer able to carry the loading from trains, like 6B01, that Network Rail had permitted to run over the bridge (paragraph 99).

Causal factors

255 Causal factors were:

a. the form of construction of Bridge 88 that meant there was a hidden corrosion trap that affected the inner surfaces of the main girder web plates; the corrosion resulted in a significant loss of web plate thickness, and in places holes formed (paragraph 124 & Recommendations 1, 3 and 4); and

b. the use of incorrectly assumed dimensions for the thickness of the web plates of the east and centre main girders in the last two routine assessments of Bridge 88 (in 1982 and 1994), and no allowance for web plate corrosion loss; this meant that the calculated live load capacity of these two main girders was higher than it should have been, and, as a result, the reports of material loss due to corrosion on the web plates were not acted upon (paragraph 155 & Recommendations 7 and 8).

Contributory factors

256 Contributory factors were:

a. that no arrangements were made to inspect the hidden parts of the east and centre main girders where the heavy corrosion on the web plates was occurring (paragraph 131 & Recommendations 2, 3 and 5);

b. that the web plates on the main girders were not fully repaired when heavy corrosion on them would have been revealed as part of the waterproofing work that was done in 1987 (paragraph 146 & Recommendation 5);

c. that the bridge superstructure was not re-painted when the waterproofing work was done in 1987, or afterwards (paragraph 150 & Recommendation 5);

d. the lack of any action in response to the web plate corrosion issues identified during the last routine detailed examination of the bridge, and highlighted immediately in an urgent defect report in October 2003; this could have initiated work that could have led to the structural significance of the web condition being appreciated (paragraph 172 & Recommendations 5, 6 and 9); and

e. the lack of any response to the continued reporting of web corrosion defects in the routine annual visual examinations that followed the last detailed examination (paragraph 190 & Recommendations 5 and 6);

257 The following contributory factors were also identified relating to activities that were in addition to the routine management of Bridge 88:

a. the lack of a formal means of alerting Network Rail to urgent findings arising from the assessment calculation work undertaken by Jacobs as part of the route availability verification exercise (paragraph 201 & Recommendations 5, 7 and 8);

b. the decision to bring forward the replacement of Bridge 88 that resulted in information being overlooked that was potentially relevant to the condition of the bridge while it remained in service (paragraph 207 & Recommendation 5); and

c. the belief that Network Rail continued to have in the incorrect results of the 1994 Assessment (because it was based on incorrect web thickness assumptions) when evaluating the ongoing safety of Bridge 88 in response to the route availability verification exercise, which was possibly exacerbated by deterioration since the 1994 Assessment was done (paragraph 211 & Recommendations 5, 7, 8 and 9).

Underlying factor

258 The underlying cause was the ongoing reliance on unverified critical information by those responsible for the routine management of Bridge 88 (paragraph 226 & Recommendations 7 and 8).

Other factors affecting the consequences

259 The following factors affected the severity of the accident:

a. the damage that was done to the pressure and vacuum valve on the roof of the tank on wagon 7 when the wagon overturned; this resulted in the spillage of around 50,000 litres of diesel (paragraph 235a & Recommendation 11); and

b. the punctures to the tanks of wagons 6, 8 and 10 that were caused by impacts by the drawhooks on adjacent wagons; this resulted in the spillage of around 170,000 litres of diesel and kerosene (paragraph 235b & Recommendation 12).

Additional observations[40]

260 The RAIB's analysis of information from the last track recording run over Bridge 88 identified a change in the structural condition of Bridge 88 that was a precursor to its collapse. If Network Rail was to develop the analysis and reporting of this information, particularly with respect to fault location and track geometry deterioration trends, it may be possible to use it for the routine identification of potential structural defects (paragraphs 227 to 232 & Recommendation 10).

[40] An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the accident but does deserve scrutiny.

Actions reported as already taken or in progress relevant to this report

261 Following the accident at Stewarton, Network Rail has been investigating the condition of its metal bridges that are of similar construction to Bridge 88: half-through or *through* form, where ballast or other details prevent easy examination of the main girders. Other types of bridges having key similarities to Bridge 88, for instance ballasted timber decks, are also being considered.

262 An approach using risk-based criteria, which includes the condition of visible parts of the structure, has been used to select priority bridges for investigation. For each of these a review is undertaken: to gain assurance on the condition of parts that are difficult to see, or potentially hidden. The review is staged, involving the following activities as emerging findings dictate:

- desk top review of available relating information and records;
- a special engineering site inspection; and
- work to reveal and inspect hidden details, for instance the removal of ballast.

263 Network Rail are using the findings from the above site inspections to develop and undertake a programme of extended checks of all centre main girders with buried concrete-metal interfaces or with potential debris traps that are similar to that found on Bridge 88 (paragraph 126).

264 Network Rail has started a review of the assessments of its railway bridges to verify dimensional information used for critical structural members.

265 Network Rail has completed a review of urgent defect reports raised in its Scotland Territory to confirm that appropriate action has been taken.

266 Since 2003, Network Rail has implemented a number of changes to its processes for the routine management of underbridges that are relevant to the investigation findings:

a. Where examination reports recommend remedial action with respect to an identified defect, the engineer undertaking the examination is required to include a risk score that quantifies the criticality of the defect. This is to aid the engineer undertaking the evaluation to decide the intervention action required.

b. A new asset register and reporting information system – the Civil Asset Register and electronic Reporting System (CARRS) – has recently been implemented nationally. Network Rail is using this to manage the receipt of examination reports, record the outcomes of evaluations, and manage intervention actions raised to address identified defects.

c. A new national process has been introduced for managing and recording safety-related events, such as reports of urgent defects, involving structures.

d. A risk-based interval between detailed examinations has been recently introduced with the objective of improving the effectiveness of the routine examination regime. Network Rail states that this will allow a more regular detailed examination of structures that are deemed to have a greater number of higher-risk features.

e. Enhancements have been made regarding how the condition of structural elements is to be considered when assessing the live load capacity.

f. When undertaking a new assessment, engineers are now required to compare their findings with the results of the previous assessment and comment on the differences.

Recommendations

267 The following safety recommendations are made[41]:

Recommendations to address causal and contributory factors

1 *The purpose of this recommendation is to establish whether there are other bridges with construction features similar to Bridge 88 that are in an unsafe condition, and to take appropriate action (paragraph 255a).*

Network Rail should identify metal bridges having features that could conceal corrosion occurring on critical structural parts. It should take intervention action as necessary to secure the safety of trains and the public.

Paragraphs 261 to 263 outline work that Network Rail has reported it is currently doing regarding this.

2 *The intention of this recommendation is to prevent hidden critical structural elements of bridges remaining unexamined where there is a risk of deterioration in structural integrity (paragraph 256a).*

Network Rail should develop criteria for when hidden critical structural parts of bridges should be examined, and apply them to its processes for the management of bridges.

3 *The intention of this recommendation is to develop effective and practical methods for examining the hidden parts of bridges (paragraphs 255a and 256a).*

Network Rail should produce and implement guidance on what methods should be routinely used to examine parts of metal bridges that are permanently hidden by ballast, waterproofing arrangements, or other similar construction features (such as work to remove concealing features or use of remote inspection probes). It should require those undertaking bridge examinations to use such methods, as appropriate, when examinations are demanded by the criteria developed in response to Recommendation 2.

continued

[41] Those identified in the recommendations, have a general and ongoing obligation to comply with health and safety legislation and need to take these recommendations into account in ensuring the safety of their employees and others.

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail Regulation (Recommendations 1 to 11) and the Department for Transport (Recommendation 12) to enable them to carry out their duties under regulation 12(2) to:

(a) ensure that recommendations are duly considered and where appropriate acted upon; and

(b) report back to RAIB details of any implementation measures, or the reasons why no implementation measures are being taken.

Copies of both the regulations and the accompanying guidance notes (paragraphs 167 to 171) can be found on RAIB's web site at www.raib.gov.uk.

4 *The intention of this recommendation is that new structures should not be constructed, nor existing structures modified, in a way that prevents access to parts that need routine inspection or examination (not all hidden parts may need to be inspected; in certain situations it may be possible to put alternative arrangements in place to verify structural integrity) (paragraph 255a).*

Network Rail should review its standards and procedures for the design and approval of new and modified bridges, and their implementation, and make necessary changes to confirm that:

- the designer identifies the parts that need to be periodically inspected in order to verify structural integrity;
- the designer designs the works with access to permit examination of such parts;
- the checker of the design confirms that the design includes suitable provision for the routine examination of such parts;
- designs that do not meet the criteria listed above are not approved for construction; and
- procedures for the examination of such works take into account the inspection needs identified by the designer, and the access means provided.

5 *The intention of this recommendation is to make improvements to ensure that those responsible for making decisions regarding the structural safety of Network Rail's bridges are suitably informed and have access to a single collection of valid information for each bridge (paragraphs 256a, 256b, 256c, 256d, 256e, 257a, 257b and 257c)*

Network Rail should review its processes for the management of bridges, and their implementation, and make changes to confirm that:

- a single list referencing the most up-to-date information regarding the history, condition and assessed capacity of each bridge is made available, in an appropriate format, to those making decisions regarding its structural safety;
- there is a formal means of alerting Network Rail to urgent findings arising from assessment work;
- all decisions regarding exposing hidden critical structural parts during examinations, and the justification supporting these decisions, are included in the bridge records;
- the evaluation process includes consideration of the corroded condition of load bearing members, and guidance so that the effects of corrosion are understood and taken into account;

continued

- all decisions regarding intervention actions critical to the structural integrity of the bridge, made as a result of an evaluation, or otherwise, are recorded with the bridge records, including a record of the justification for the decision;
- the implementation status of any intervention actions that are critical to structural integrity, and any outstanding risk issues, are included in the bridge records; and
- any urgent defect reports and the action taken as result, together with the supporting justification, are included in the bridge records.

Paragraphs 266a, 266b, 266c and 266f outline improvements that Network Rail has reported it has already made regarding this.

6 *The intention of this recommendation is for Network Rail to ensure that the condition of previously recorded outstanding defects in critical structural elements continues to be monitored by the appropriate subsequent examination or inspection (paragraphs 256d and 256e)*

Network Rail should review its processes and make necessary changes so that previously reported defects affecting structural integrity that are not reported in subsequent examinations and inspections are identified; the revised processes should be such that all such discrepancies are resolved.

7 *The intention of this recommendation is to establish if the assessment results of other bridges are incorrect because of critical dimensional assumptions, or inadequate allowance for material loss on load bearing members due to corrosion (paragraphs 255b, 257a, 257c and 258).*

Network Rail should identify all underbridge assessments where, for load bearing members, there have been reports of severe corrosion that has not been accounted for, or critical dimensions have been assumed, and take suitable steps to secure the safety of trains and the public.

Paragraph 264 outlines work that Network Rail has reported that it is currently doing with regards to this.

continued

8 *The intention of this recommendation is to prevent there being errors in the assessment results of bridges in the future because of critical dimension assumptions or inadequate allowance for material loss on load bearing members due to corrosion (paragraphs 255b, 257a, 257c and 258)*

Network Rail should review its procedures for the assessment of structures, and make necessary changes, to:

- forbid the use of key dimensional information for load bearing members that has not been verified, either on site, or from as-built drawings; and
- specify the criteria for when the corroded condition of load bearing members must be assessed.

Paragraph 266e outlines enhancements that Network Rail has reported it has already made regarding this.

9 *The intention of this recommendation is that appropriate action is taken in the event of future reports of urgent defects on bridges (paragraph 256d and 257c)*

Network Rail should review its procedures for the management of structures, and their implementation, and make changes to confirm that reports of urgent defects are:

- reliably delivered to the correct personnel; and
- used to develop and implement appropriate actions.

Paragraph 266c outlines improvements that Network Rail has reported it has already made regarding this.

Recommendations to address other matters observed during the investigation

10 *The intention of this recommendation is to take advantage of information that is already recorded for track maintenance purposes so that Network Rail can use the information to alert its staff to potential structural issues with railway underbridges; this recommendation is a extension of recommendation 4 that RAIB made following its investigation of a freight train derailment on 25 January 2008 at Santon, near Foreign Ore Branch Junction, Scunthorpe[42] (paragraph 260)*

Network Rail should evaluate the feasibility of using the track geometry data recorded by its track measurement trains so that trends can be seen that could be used to identify underbridges that may have degraded to an unsafe condition. If reasonably practicable, it should develop and implement appropriate analysis tools and processes and make these available to engineers responsible for the management of structures and track.

continued

[42] RAIB report 10/2009 (paragraph 232)

11 *The intention of this recommendation is to improve the construction of existing tank wagons registered in Great Britain in order to mitigate the risk of leakage resulting from damage to external fittings in accident scenarios (paragraph 259a).*

Network Rail's Private Wagons Registration Agreement Management Group, and the owners of other dangerous goods tank wagons registered in Great Britain (DB Schenker) should review the design of tank wagons, for which they are responsible, to evaluate measures (including shrouding) that could be taken to protect external equipment, such as pressure and vacuum valves, against damage in the event of overturning and derailment. Where reasonably practicable, Network Rail's Private Wagons Registration Agreement Management Group and DB Schenker should take action to ensure that the external equipment is adequately protected in the event of overturning and derailment.

12 *The intention of this recommendation is to improve the construction of new tank wagons in order to mitigate the risk of leakage resulting from tank damage in accidents (paragraph 259b).*

The UK competent authority for dangerous goods, the Department for Transport, should evaluate the case for extending the requirement for end protection measures on rail tank wagons to cover a wider range of liquid products. The combined benefit to both safety and the environment shall be taken into consideration when assessing the cost implications of this extension. If the case is valid, the Department for Transport should make a proposal for a requirement change to the committee responsible for the RID regulations.

The requirements in the current version of the RID regulations regarding end protection are outlined in paragraph 246.

Appendices

Appendix A - Glossary of abbreviations and acronyms

LMSR	London Midland and Scottish Railway
ORR	Office of Rail Regulation
OTDR	On train data recorder
SEPA	Scottish Environment Protection Agency
TOPS	*Total operations processing system*
VIBT	Vehicle inspection and brake test
PPM	Planned preventative maintenance

Appendix B - Glossary of terms

All definitions marked with an asterisk, thus (*), have been taken from Ellis's British Railway Engineering Encyclopaedia © Iain Ellis. www.iainellis.com.

Abutment	The structure that supports the extreme ends of a bridge deck.
Assessment	The determination of the safe load carrying capacity of a structure taking into account its physical condition and location. The term includes site inspection with site measurements and the carrying out of any calculations and checks.
Assessment code (of practice)	A document that describes what is required in a calculation for a bridge assessment and gives guidance on how the calculations are to be performed.
Brake pipe	On a train fitted with air operated brake system, this pipe runs through the length of the train and is de-pressurised to apply the brakes.
Bending moment	A type of load applied to a structural element (comprising a force multiplied by its distance from a support point) that causes the element to sag or hog.
Cant	The amount by which one rail on the track is raised above the other.
Class 6 train	Freight train authorised to run at a maximum speed of 60 mph.
Closure plate	In this report, the section of metal that forms the flanges of an I-beam where it is bent round the end of the beam. See also figure 10.
Compressive stress	The force carried by a section of solid material divided by its cross-sectional area, where that force is acting toward the material centre - pushing the material together.
Cross girder	A smaller lateral structural member spanning between the main girders of a bridge.*
Cyclic top	Regular vertical, medium wavelength variations from design level of a section of track.*
Detailed examination	A close examination of all accessible parts of a structure, generally within touching distance, of sufficient quality to produce a record that includes the condition of all parts of the structure, the uses to which the structure is being put, recommendations for remedial action, and any other relevant facts.
Down	In the direction of Glasgow, away from Carlisle and London.
Drawhook	The hook on the end of a wagon by which it is coupled to the next wagon in the train.
Engineering train	A train that is run for the purpose of carrying material to or from a site of engineering work on the railway.

Engineering Supervisor	Person that manages the safe execution of work within a worksite on the railway.
Evaluation	An appraisal of all relevant information and circumstances relating to a structure including its condition, use and location to establish whether action is required to ensure that the level of safety and serviceability remains acceptable.
Fatigue	Phenomenon by which a material may fracture under cyclic stresses, even by those below its ultimate breaking strength (called tensile strength).
Flange	The thicker horizontal part (or plate) of an I-beam, see figure E1.
Foot	The lowest part of a rail cross-section.
Foot valve	Valve fitted to the underside of rail wagon tanks through which the liquid in the tank is discharged.
Formation	The prepared surface of the ground, on which the ballast and the track is laid.*
Four-foot	The area between the two running rails of a standard gauge railway.*
Half-through	A bridge deck construction where the floor of the bridge, carrying the load of the track, is supported by main girders located either side of the track. Rigidity is provided by utilising the lower lateral members as part of a U-frame.
I-beam	A beam with a cross section in the shape of the letter 'I'.
Inspection for Assessment	A close examination of a bridge carried out with the purpose of obtaining information that will be used in the calculation of the bridge's live load capacity.
Instanter	A chain-like assembly of two standard oval links connected by a special pear- shaped link, used to connect the coupling hooks (drawhooks) of two adjacent rail vehicles. The special middle link allows the chain to be shortened once it is fitted, which reduces slack in the coupling thereby reducing buffing and draw loads.
Live load capacity	The capability of a bridge to carry the loading from vehicles and pedestrians, that cross it (as distinst from its self-weight and other permanent load effects).
Longitudinal timber	A timber bearer parallel to and supporting a rail and its fastenings.
Loop	A parallel length of track connected, at both ends, to a single line railway that allows trains to pass one another.
Main girder(s)	The larger load bearing member(s) on certain types of bridge deck, usually running parallel to the span of the bridge.

Office of Rail Regulation	Independent statutory body responsible for economic and safety regulation of railways in Great Britain.*
On train data recorder	A data recorder fitted to a train that collects information about its performance and the status of systems on board, such as speed and brake control.
Overbridge	A bridge that goes over the railway.
Override	The movement of a railway vehicle that results in one end lifting and contacting an adjacent vehicle at a higher level.
Override beam	A horizontal beam located above the buffers on a tank wagon that is designed to give protection to the tank once overriding has initiated.
Patroller	A trained member of staff who carries out a pedestrian visual inspection of the track (and superficial inspection of other lineside items) on a regular basis.*
Planned preventative maintenance	Maintenance activity planned to take place on a regular basis to reduce the incidence of failures in service.*
Point load	A concentrated force applied to a structure.
Possession	Period of time that a section of the railway is blocked to service trains so that engineering work can be safely carried out.
Pressure and vacuum valve	Valve fitted to the roof of a rail wagon tank to vent gas in the event of over-pressure and provide vacuum relief to protect against tank implosion.
Pronet	A proprietary computer system used to share information among a group of people.
Rail head	The upper part of a rail cross-section.
Railway Group standard	Mandatory technical or operational document which sets out what is required to meet system safety responsibilities on Network Rail's infrastructure.
River scour	The removal of material from under or adjacent to structural supports, foundations or earthworks by the action of flowing water.*
Road-rail vehicle	A vehicle that can travel under its own power on the roads and also, by virtue of a rail guidance system, on railway track. Such vehicles are not allowed to operate outside a possession.
Route availability	Standard measure used by Network Rail to describe the capability of an underbridge to carry live load, see also appendix D.
Scottish Region Tokenless Block	A system of signalling single track lines that was developed for use in the former British Rail Scottish Region.

Shear force	A force applied to solid material that results in displacement in the direction of the force, and deformation in which parallel planes remain parallel.
Shear stress	Shear force divided by the area of the plane on which the force acts.
Splice plates	A plate designed to join two other plates together (figure E1).
Steel sleeper	A railway sleeper made from a C-shaped rolled steel section.*
Structures manager	Person nominated by Network Rail for the safe management of a structure or group of structures.
Superstructure	The assembled structural elements of a bridge deck that carries the track and is supported on the abutments.
Tensile stress	The force carried by a section of a solid material divided by its cross-sectional area, where that force is acting away from the element centre – pulling the material apart.
Three-piece bogie	A bogie, used on freight wagons, made up of three main frame components: ● two side frames, to which the axle ends are connected; and ● a horizontal beam on which the body pivots. The beam is supported off the side frames by suspension springs.
Through	A type of bridge deck where lateral members, both below the track and overhead, brace the main girders.
Total operations processing system	A computer system used to track movement of rail vehicles and manage other information, for instance regarding their maintenance condition.
Truss	An arrangement of individual structural members that carry load in tension and compression.
T-section stiffener	A metal section in the shape of the letter 'T ' that is attached to a plate in order to give it rigidity. In the case of Bridge 88 it also joined the web panels together, figure E1.
Twist fault	A change in track cant over a certain distance that exceeds limits defined for track maintenance purposes.
U-frame action	The structural action in a half-through bridge by which the cross girders and web stiffeners form a stiff U-shaped section which stabilises the top flanges of the main girders.
Ultrasonic testing	A system using ultrasound to detect flaws in rails.
Underbridge	A bridge that carries the railway over an obstruction.
Up	In the direction of Carlisle and London, away from Glasgow.
Vehicle inspection and brake test	A periodic maintenance activity to ensure that a rail vehicle is in a serviceable condition and its brakes are functional.

Visual examination	An examination to identify changes in the condition of a structure carried out from a safe observation location, without using special access equipment but using permanent access ladders and walkways, binoculars and hand held lighting where necessary.
Voiding	A track fault consisting of spaces under sleepers, that results in vertical displacement of the track when trains pass over.
Web plate	The thinner vertical part (plate) of an I-beam.
Wheel flange	The extended portion of a rail vehicle's wheel that contacts the rail head and thus provides the wheelset with directional guidance.*
Wheelset	Two rail wheels mounted on their joining axle.*
Wrought iron	An early type of iron alloy characterised by the way it is mechanically worked during manufacture.

Appendix C - Key standards

International standards

RID	Regulations concerning the International Carriage of Dangerous Goods by Rail

Railway Group standards

GC/RT5100	Safe Management of Structures
GC/RC5511	Recommendations for the Safe Management of Structures
GC/RT5141	Assessment of Structural Capacity
GM/RT2141	Resistance of Railway Vehicles to Derailment and Roll-Over
GM/RT2101	Requirements for the Design, Construction, Test & Use of the Tanks of Rail Tank Wagons
GM/RT2466	Railway Wheelsets

Network Rail company standards and other documents

NR/CS/CIV/032	Managing Existing Structures
NR/SP/CIV/080	Management of Existing Bridges & Culverts
NR/SP/CIV/017	Examination of Bridges & Culverts
NR/SP/TRK/001	Inspection and Maintenance of Permanent Way
NR/GN/CIV/041	Structures Condition Marking Index Handbook for Bridges

Appendix D - Route availability

The route availability (RA) system was devised in the 1940s as a simple way of controlling the loading from trains on underbridges. British Rail, Railtrack and Network Rail have used it since for this purpose.

The system consists of two parts, the calculation of an RA number for the train and the calculation of an RA number for the bridge. The essential principle of the system is that the RA number of the train does not exceed the RA number of any of the bridges on a route with which the train is compatible. If this check is not satisfied further checks are required to demonstrate compatibility.

Derivation of the RA number for a bridge

The main girders on bridges of the same type as Bridge 88 at Stewarton are considered in such a way that the *bending moment* at the supporting abutments is zero. The maximum bending moment in the main girders therefore occurs somewhere towards the centre of the span. By the same consideration, the *shear force* in the main girders is a maximum at the abutments (end shear). These two effects (bending moment and end shear) are the main ones considered in calculating the load carrying capacity of the main girders. Checks are then made on other factors that might limit the capacity, such as splice plate joints and riveted connections, to confirm that these are capable of carrying the same load that the main girder is capable of.

The load applied to the girder is considered to be uniformly distributed across the whole span (uniformly distributed load – UDL). The maximum UDL that the girder can safely carry is calculated in accordance with Network Rail's code of practice for bridge assessment. It is calculated for both bending moment and end shear.

The UDL capacity of the girder (its load carrying capacity) is converted to a standardised form by expressing it in terms of the number of units of a standard load train that it represents. This standard load is taken from a historic British Standard (BS153) for bridges. One unit of this standard BS load is applied to a beam with the same span as the girder under consideration and the maximum bending moment and end shear are calculated. An equivalent UDL that results in the same bending moment and end shear is then calculated. This is the UDL that represents one unit of the standard BS load (referred to as a 'BSU'). To simplify calculations, the UDLs for one BSU are tabulated, in Network Rail's code of practice, for the range of likely spans found on Network Rail underbridges.

The assessed capacity of a bridge girder is expressed in BSU terms by dividing the calculated UDL capacity by the UDL representing one BSU. The derivation of the RA number from the BSU capacity is done by subtracting 10 and rounding down to a whole number. For instance if the girder had an assessed capacity of 18.6 BSU, it would be assigned an RA number of 8 (RA8).

In BS153, the full loading for a bridge was 20 BSU and bridges that were assessed to have capacities of 20 BSU or more were therefore assigned an RA number of 10 (RA10). Network Rail has since removed the ceiling of RA10 and their assessment codes now allow numbers above RA10.

If the assessed capacity is less than 11 BSU, the bridge is regarded as having zero load capacity and further work is required to determine which vehicles can safely run over it.

Derivation of the RA number for a train

The train is represented as a series of *point loads*, with each point load representing the maximum weight for that axle. This series of point loads is then moved across the bridge span to determine the maximum bending moment and end shear. The UDL that would produce the same bending moment and end shear on that same span is then calculated. The UDLs representing one BSU are again tabulated for a range of likely bridge spans.

The resulting BSU values for the bending moment and end shear are plotted against the span to give an overview of how the loading from the train compares with the BS standard loading – this is done for a range of spans. The maximum value of BSU for the train within the span range 1.22 metres to 50 metres is then taken. The RA number of the train is the maximum BSU value, rounded up to a whole number, minus 10.

Trains are only assigned RA numbers between 1 and 10. If the calculated RA number is less than 1 then it is assigned an RA number of 1 (RA1). If the calculated RA number is above 10 then the train is regarded as an exceptional load and special arrangements have to be made before it can run.

Appendix E - Survey of the recovered superstructure from Bridge 88

East main girder

The RAIB surveyed the east main girder and recorded key features found on each web panel (paragraph 102) and the associated parts (figure E1).

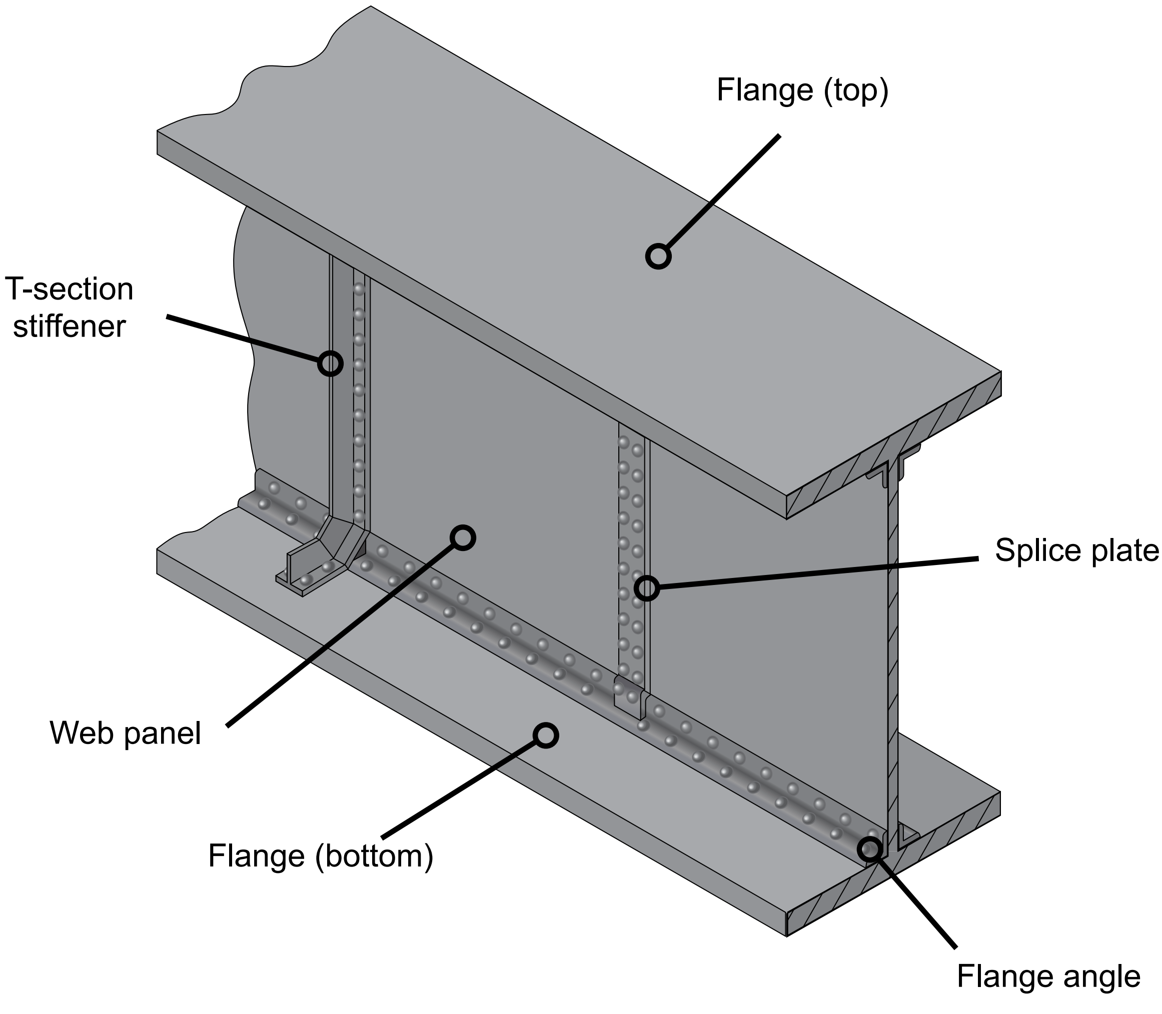

Figure E1: Diagram showing a typical main girder web panel and associated parts

Web panel 1 (at the north abutment) was found to be in good condition with only light corrosion along the lower flange angles. It had been repaired at some time by adding a steel repair plate that covered the lower half of the outer face of the panel. This repair panel was welded to the tips of flange angles along two of its sides, to the web splice plate along a third and to the original web panel material along the remaining upper edge.

Web panel 2 had failed in shear and was torn along a horizontal line just below mid-height as well as vertically at each end. The vertical fracture faces of the tears were seen to be crystalline. They showed the thickness of the panel to vary from a knife-edge, at mid-height, to the original full thickness at top and bottom. The top and bottom flanges had grossly distorted (bent) when the panel failed but had remained intact. However, the adjacent flange angles had fractured.

Web panels 3 and 4 were in a similar condition with patches of corrosion along the bottom edge, close to the flange angles. One of these patches had been repainted with a single coat of paint, but the corrosion was now appearing through. The centre part of both panels was corroded along a line close to mid-height. This line of corrosion was present throughout the girder and corresponded to the level of the top of the floor timbers. In web panel 3 there was a small hole at this height, and in web panel 4 there was a line of pinholes.

Web panel 5 had been previously repaired by welding on a steel plate that covered the full outer face of the panel. The original web panel was left in place behind and could be seen from the inside of the bridge once the deck timbers were removed. The original panel was corroded right through for half of its length.

Web panel 6 was not as badly corroded as other web panels on the east main girder.

Web panels 7 and 8 had pinholes throughout their length, again at mid-height, and also two significant corrosion holes.

Web panel 9 had pinholes at its northernmost end; it had been extensively deformed in the accident.

Web panel 10 had a line of pinholes throughout its length at mid-height. It had been repaired by adding a steel plate that covered the southernmost half of the outer face of the panel. This plate was welded in along all four of its edges. This panel had been extensively damaged in the accident and the repair plate had torn from the original wrought iron material. Sections were cut through the vertical welds at three positions: at one position the weld failed where it was attached to much-thinned wrought iron, at another the weld was good (although the fit-up was poor), and at the third the weld had fractured, but after there had been initial significant distortion on the plates it was joining. The strength of welds onto wrought iron is largely governed by the length of the fusion line and the quality of the wrought iron itself. The only place where the weld itself had failed was where the repair plate was welded to thinned wrought iron. If a repair plate had been fitted that covered the full web panel (as on panel 5) such welding would not have been necessary.

Web panel 11 was torn in a similar way to web panel 2, and it had also failed in shear. The web panel was corroded to a knife-edge at mid-height along its entire length. In the accident, the top flange fractured at both ends of the panel and parted from the main girder together with the upper part of the web panel. The bottom flange fractured at the splice plate between web panels 10 and 9 and partway along web panel 12. It too parted from the girder, and a section of the lower part of web panel 11 remained attached to it.

Web panel 12 had been repaired by welding on a steel plate that covered its full outer face. The original web panel behind this repair plate was corroded right through, throughout its length, just above the lower flange angle. There was also a line of corrosion at mid-height.

In general, the paint was intact on the outer surface of the east main girder, except where corrosion holes had formed, which had started from the inner surface. The paint on the inner surface of the girder was mainly intact below the level of the deck timbers. Above this level the paint system had completely broken down and there was extensive heavy corrosion.

Centre main girder

The RAIB found that, in general, the centre main girder was in a worse condition than the east main girder. All web panels had heavy corrosion over a horizontal central band that extended from the underside of the deck timbers to a line around 14 inches (355 mm) below the top flange, a line roughly corresponding with the top of the timber upstands (paragraph 46).

Web panels 1, 2 and 3 had corrosion holes in them close to where cross girders attached. The heads of the rivets in the bottom flange at panels 1 and 2 had almost totally corroded away.

Web panel 4 had a corrosion hole above where a cross girder attached. There was also a line of pinholes at mid-height. The heads of the rivets in the web splice plate at the north end of this panel were badly corroded. The T-stiffener at the south end was badly corroded at mid-height.

Web panel 5 was corroded right through at mid-height, throughout its length.

Web panel 6 had a corrosion hole which started above a cross girder attachment point and ran, at mid-height, through half the length of the panel. There were other smaller holes at mid-height.

Web panel 7 was corroded right through at mid-height through half of its length, with pinholes through the remainder.

Web panel 8 was holed above a cross girder attachment point. At mid-height, there were two short lines of pinholes, one at each end of the panel.

Web panel 9 had a line of pinholes at deck level throughout the panel. It was torn along this line in the accident.

Web panels 10, 11 and 12 were corroded to a knife-edge at mid-height and were torn along this line during the accident. The upper part of these panels detached from the rest of the main girder along with the top flange. There were holes above two cross girder attachment points, one between panels 10 and 11, the other adjacent to the splice plate between panels 11 and 12 (this is the corrosion perforation shown in figures 21 and 23). The heads of the rivets in the bottom flange at web panels 11 and 12 were badly corroded.

A sample of the web plate was cut from the web panel 11. It showed how the corrosion had attacked the plate from both sides (this is the section shown in figure 10).

The bottom flange was part-fractured at the north side of the splice plate joining web panels 9 and 10. At web panel 12, the bottom flange was also fractured in two places, and a short section of the flange was detached.

The closure plate at the south end of the girder remained connected to the upper part of web panels 10, 11 and 12. The top flange folded and fractured in the accident, the wrought iron de-layered and parts became detached (this is shown in figure 12).

West main girder

The RAIB observed a similar horizontal band of corrosion on the inside surface of the west girder to that found on the east and centre main girders. However, the RAIB did not undertake a detailed survey of this girder as it was not subject to the train loads and did not fail in the accident.

Main girder web thickness

The web panel thickness was measured at several places within the length of the east and centre main girders. Additionally, a detailed set of thickness measurements was made by drilling holes on a grid pattern in panel 8 of the centre main girder and panels 4 and 7 of the east main girder.

The web panels near the ends of the span were examined closely to determine web thickness, and this was 1/4 inch (6.4 mm) at all locations on the east main girder (web panels 1, 4, 7, 9 and 11 were measured).

The centre main girder thickness was surveyed in the most undamaged panel near the centre of the bridge. There was still paint adhering to parts of this panel and the thickness measurements included this. The RAIB believe that the original thickness of this panel was 3/8 inch (9.5 mm). The distance between the flange angles was measured in panel 12 at 3/8 inch, confirming the original web panel thickness at the location of the failure.

The RAIB did not find any evidence of variation in original web panel thickness along the length of either of the main girders.

Cross girders

The cross girders that supported the east side of the deck were of two types:

- The original cross girders, which were fabricated from a wrought iron web plate with wrought iron angles riveted on to form flanges.
- Supplementary steel I-beams, which were installed as part of bridge strike repairs done in 2004 (paragraph 187).

The original cross girders had suffered extensive breakdown of their paint system and, consequently, widespread corrosion. The corrosion was most prevalent on the bottom surface of the bottom flanges, where impact from over height road vehicles had also caused damage.

Some of the cross girders were found to be heavily deformed after the accident. The damage to these cross girders was, however, fully consistent with them either having been struck by the derailed train, or as a consequence of the already failed bridge collapsing. The RAIB did not find evidence of a cross girder failure leading to the bridge collapse.

Where the cross girders remained attached to the intact parts of the main girders they were found to be largely undamaged.

Appendix F - Summary of investigation to eliminate alternative causes of the accident

Derailment initiated causes

The RAIB found no witness marks or damage on the track on the northern approach to Bridge 88 to indicate that the train was running derailed before it crossed the bridge (paragraph 89). The investigation therefore concentrated on mechanisms that could have caused the train to derail on the bridge itself.

Flange climb derailment

The most likely cause of a derailment involving the flange climbing over the rail head would be as a result of a track twist or wagon feature that, on their own or in combination, could result in a significant reduction in wheel load. If such were to occur at a time when the lateral force on the wheel were high enough, for instance as a result of the wheelset negotiating a curve, the flange on the wheel could start to climb the rail.

On 24 January 2009, Network Rail recorded a track twist fault on Bridge 88 (paragraph 230). Its magnitude meant that, according to Network Rail's track maintenance procedures, it needed to be repaired within 14 days. As no repair had been done before train 6B01 passed over the bridge (it was not required to have been by this time) the RAIB investigated whether it could have had led to a derailment condition.

Examination and testing of the first four wagons, those that did not derail and were relatively undamaged, did not identify any untoward factors that could have caused wagons 5 and 6 to derail. When measured in the laden condition, as they were at the time of the accident, none of the wheel loads on the non-derailed wagons was significantly lower than the rest - all were within 7% of the mean. Measurements of the wheel unloading performance on two sample wagons, wagons 1 and 4, showed them both to be significantly within the requirement of Railway Group standard GM/RT 2141, Resistance of Railway Vehicles to Derailment and Roll-Over; this standard is used to assess a new vehicle's fitness to run on Network Rail's infrastructure. Furthermore, measurements of critical wheelset dimensions on wagons 5 and 6 showed compliance with the appropriate standard, GM/RT2466, Railway Wheelsets.

A vehicle dynamic simulation study was undertaken, using a wagon model validated using results from the above wagon testing, and other sources of information including track geometry inputs recorded by Network Rail on 24 January, and speed information recorded on the train's OTDR. The results showed that the wagons on train 6B01 were not at risk of flange climb derailment when they passed over the recorded track twist fault on Bridge 88, or any other geometric track feature in the vicinity.

Wheel lift derailment

Certain vertical track features have the potential of exciting vertical dynamic suspension movements sufficient to cause total wheel unloading, which in turn could result in a wheel lifting off the running rail and into derailment. Network Rail track standards refer to these as '*cyclic top*' faults.

Network Rail also recorded cyclic top faults in the vicinity of Bridge 88 on 24 January. Again these had not been repaired before the passage of train 6B01 because they were not of a significantly high magnitude to require immediate action.

The vehicle dynamic simulation study indicated that the wagons on train 6B01 were not at risk of a wheel lift-type derailment due to the cyclic top faults.

The other means by which the wagons could have derailed through wheel lift are if they had encountered obstructions that could physically cause their wheels to lift. The RAIB found no evidence of this. Wagon 5 was the first to derail and the preceding vehicles on the train would also have encountered any such obstruction. None of the preceding vehicles showed signs of derailment.

Gauge spread derailment

Network Rail recorded the track gauge in the vicinity of Bridge 88 on 24 January 2009. It showed nothing untoward. Similarly, measurements showed that the distance between the backs of the wheels on the wheelsets of wagons 5 and 6 were correct[43]. It is therefore not likely that the wheels on the derailed wagons could have dropped into the four-foot.

Rail failure

No failures of the running rails occurred on Bridge 88. The closest failure was on the right-hand (west) rail, approximately 2 metres beyond the bridge over the south abutment (paragraph 88). It is unlikely that this could have been the cause of a derailment that resulted in Bridge 88 becoming so seriously damaged. Evidence from derailments caused by rail failures, such as at Bushey in 1980, shows that consequential damage is unlikely to develop behind the point of derailment. Furthermore, no witness marks were found on the wheels of either wagon 5 or 6 to indicate they had run over a rail that had fractured. The left-hand running rail remained intact.

Network Rail's records of routine *ultrasonic testing* for the most recent period, years 2006 to 2008, showed no history of rail defects in the vicinity of Bridge 88.

Wheelset or suspension failure

Examination of the bogies from wagons 5 and 6 showed that there were no signs of failure to any wheel, axle or axle box. There was no damage to suspension components that was not likely to be consequential.

Other bridge-related causes

Bridge strike

The RAIB found no evidence that the collapse of Bridge 88 was the result of an impact from a road vehicle.

Like many railway underbridges, Bridge 88 had a history of being struck by road vehicles (paragraph 58) and RAIB's survey of the underside of the bridge superstructure found evidence that supported this.

The bottom flanges of all three main girders showed evidence of damage from road vehicles. Damage to the cross girders varied, some, near the ends of the bridge, had not been struck at all, while others had experienced extensive damage.

[43] Compliant to Railway Group standard GM/RT2466

On the east side of the deck, one of the cross girders had been replaced in the past (date not recorded). Two other cross girders on the east side, whose bottom flanges were badly torn by a strike incident, had supplementary steel beams inserted each side of them. Records show the supplementary beams were installed in January 2004, probably in response to recommendations arising from the routine structures management process (paragraph 187) The RAIB found the repair work was intact when it surveyed the bridge (figure F1).

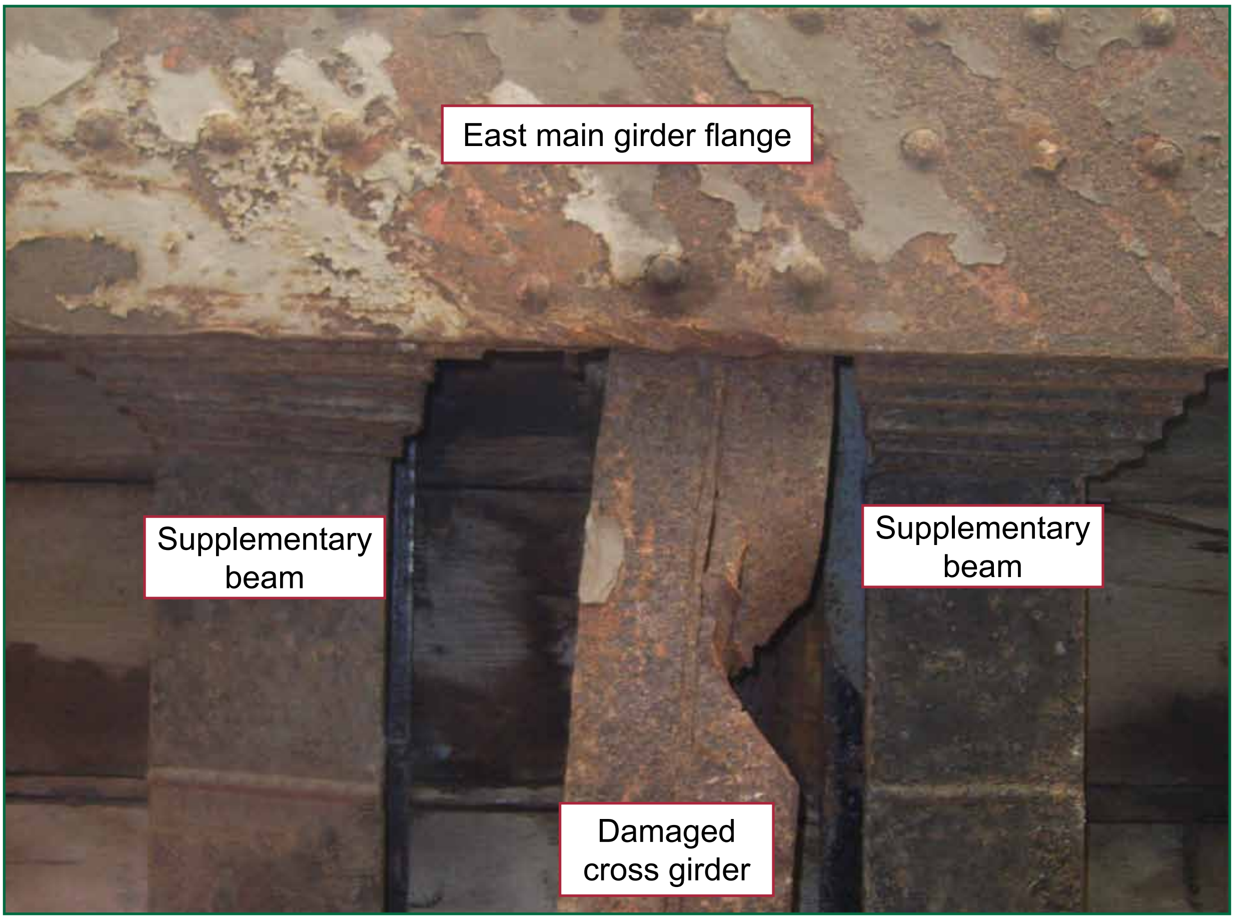

Figure F1: Repair done in 2004 to supplement cross girders damaged by vehicle strikes

As would be expected, the strike damage to the main girder flanges was most severe on the outer faces of the east and west main girders - these would be struck first if an over-height vehicle attempted to pass underneath. The damage inflicted on the flanges of both outer main girders was of such magnitude that repairs had been considered necessary. These repairs involved the welding on of steel plates to the existing flanges (the date is not recorded, however the repairs are not shown on photographs in the 1994 Assessment report). The RAIB found the repair work was intact when it surveyed the bridge (figure F2).

Most of the bridge strike damage on the bridge was long-standing, as evidenced by it being painted over or showing signs of corrosion. There was one small scrape on the north end of the east main girder bottom flange, which was still shiny after the derailment, that was probably more recent, but it would only have been the result of a light impact.

Figure F2: Repair to bottom flange of the east main girder

In summary, none of the damage done to Bridge 88 as a result of vehicle strikes was consistent with the gross structural failure of the centre and east main girders that resulted in its collapse. It was either longstanding, and either stable or repaired, or of a nature that would have not have resulted in the failures that occurred.

Upgrade works

The RAIB identified two aspects of the upgrade work, which Jarvis was doing in the vicinity of Bridge 88 during the weeks before the accident, that were of interest (paragraphs 69 to 73): the removal of the old spoil from the redundant west deck on the night of 16-17 January, and the loading of spoil into an engineering train on the night before the accident. However, it found no evidence that either would have directly resulted in the collapse of the bridge, or damage that significantly weakened it.

The manner in which the work was reported as being done to remove the old ballast on 16-17 January, indicated that there was only limited disturbance to the bridge. There is witness evidence that neither of the road-rail excavators went onto the redundant west deck of the bridge. The ballast was removed by reaching from positions on the abutment and, while on rail wheels, from the track on the east deck. Both machine operators were instructed to keep clear of the main girders. There is no evidence of damage to the centre main girder on the site photograph that was taken after the ballast was removed (figure F3).

The work done during the night before the accident was reported as the removal of spoil from the old formation north of the bridge. No work was done on the bridge itself. The spoil was loaded into two-axle wagons on an engineering train. The train came in from the north and it is possible that it stopped with the leading locomotive partly on the bridge. The train did not cross the bridge.

The locomotive was of the same type as that on train 6B01, but it was moving at a much lower speed. Given this, even if it had been partly on Bridge 88, it is highly improbable that any loading from it could have been the cause of the collapse.

Figure F3: Site photograph of the west deck after the ballast was removed on 16-17 January 2009 (photograph courtesy of Network Rail)

Abutment failure

A major part of the south abutment was found in a failed condition but the RAIB found no evidence that this was the initiating failure.

The south abutment was constructed of sandstone blocks but it had been repaired in the past. There was a vertical crack in the face of this abutment which ran from close to the centre main girder bearing diagonally downwards towards the east side. This crack was first reported in 1975 and had been regularly monitored since then. Results of this monitoring were available for the period from 1998 to 2005; they showed that the crack was stable over this time.

At site, debris from the failed abutment was found on top of the collapsed south end of the east deck (figure F4). The underside of the east and centre main girders were in direct contact with the tarmac surface of the A735 road beneath, showing that these must have failed, and fallen, before the abutment. The most likely reason for the failure of the south abutment is impact damage from the wagons that went on to derail (paragraph 114).

The north abutment was in good condition and remained standing after the accident, effectively undamaged.

Excessive train load

Train 6B01 was loaded in accordance with defined gross laden weight limits (paragraph 33). Network Rail operating procedures allowed trains of this weight to operate without restriction over this route.

Figure F4: Photograph of debris from failed south abutment

Appendix G - Urgent defect report issued by Atkins in October 2003

Transcript of 'Defect Description', referenced photographs are shown on figure G1:

MAIN GIRDERS

MGE1

HOLES IN WEB, OUTER/EXPOSED FACE WITH SEVERE THINNING TO INTERNAL WEB FACE. THICKNESS AROUND HOLES 2mm MAX.(THIN 8 – 10mm)

SEVERITY OF THINNING COULD ONLY BE DETERMINED BY TAPPING OF WEB SECTIONS WITH HAMMER – BALLAST SITS AT HEIGHT OF TOP FLANGE DENYING ACCESS TO REAR FACE OF WEBS.

1ST HOLE AT 2ND WEB PANEL IN FROM ES2 – ABT1.1400mm FROM END SUPPORT, 400mm

FROM BOTTON FLANGE. L=80mm H=35mm. PHOTO 1.

EVIDENCE OF H/L FRACTURE ABOVE THIS HOLE WITH ISOLATED PIN HOLES IN PLACES

ALONG H/L FRACTURE (MOSTLY PAINTED OVER) APPARENT BY BULGING AT THINNED AREA

OF WEB PLATE 460mm FROM BOTTON FLANGE, 500mm FROM ES2 – ABT1.

2ND HOLE AT 5TH AND 6TH WEB PANELS IN FROM ES2 – ABT1. L=620mm H =220mm.

WIDESPREAD THINNING TO THESE WEB PANELS VISIBLE FROM HOLE AND APPARENT FROM HAMMER TAPPING. PHOTO 2.

CROSS GIRDERS

SEVERAL CROSS GIRDERS SHOW ISOLATED HOLES IN WEB AT ENDS NEXT TO

CONNECTIONS TO MAIN GIRDERS. PHOTO 3 + 4 + 5.

Figure G1: Photographs from Atkins urgent defect report (photographs courtesy of Network Rail)

This page is left intentionally blank

This report is published by the Rail Accident Investigation Branch, Department for Transport.

Any enquiries about this publication should be sent to:

RAIB
The Wharf
Stores Road
Derby UK
DE21 4BA

Telephone: 01332 253300
Fax: 01332 253301
Email: enquiries@raib.gov.uk
Website: www.raib.gov.uk