Rail Accident Investigation Branch

Rail Accident Report

Derailment at Long Millgate, Manchester
22 March 2006

Department for Transport

Report 08/2007
April 2007

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.

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Derailment at Long Millgate, Manchester 22 March 2006

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.

3 Access was freely given by Serco Metrolink to their staff, data and records in connection with the investigation.

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

- acronyms and abbreviations are explained in the glossary at Appendix A; and
- technical terms (shown in *italics* the first time they appear in the report) are explained in the glossary at Appendix B.

5 References to the left and right hand sides in this report refer to the sides as seen when facing in the direction of travel.

Summary of the report

Key facts about the accident

6 At 08:03 hrs on Wednesday 22 March 2006, two *wheelsets* of tram 1011, operating the 07:42 hrs Bury to Altrincham service on the Manchester Metrolink system, became derailed as the tram was entering the street running section of the network at Long Millgate, near Victoria Station. The derailed wheels remained close to the track, and the tram stopped 44 m from the point of derailment.

7 There were no injuries and no damage to the tram.

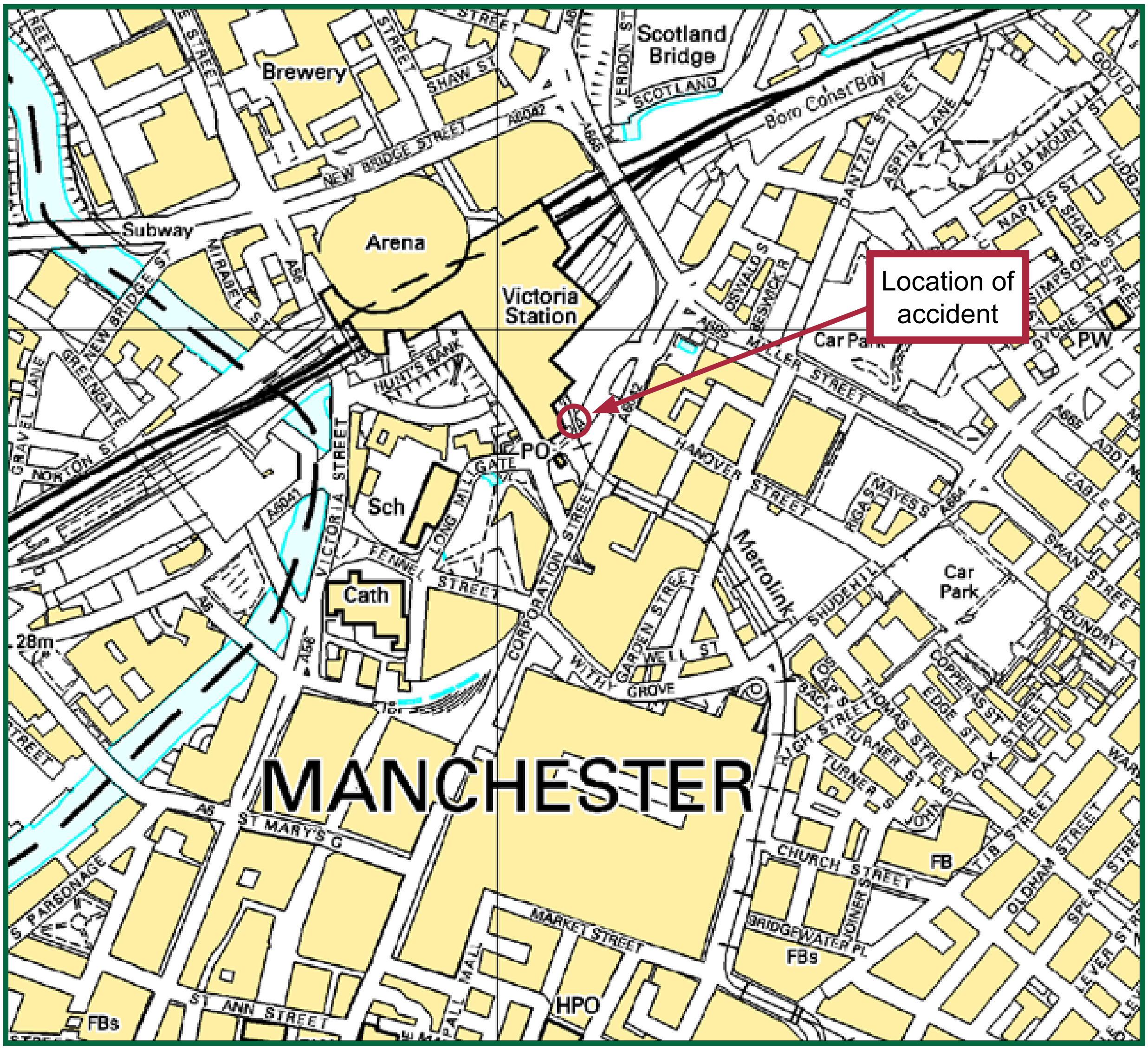

Figure 1: Extract from Ordnance Survey map showing location of accident.

Immediate cause, causal and contributory factors

8 The immediate cause of the accident was the failure of a repaired section of track at the transition between two types of rail, which allowed the wheels to ride up the inner face of the rail and become derailed.

9 The causal and contributory factors are described in paragraphs 76 - 78 of this report. They are related to the design of the transition, the amount of wear on the rails, and the way they had been maintained. The operation and driving of the tram did not contribute to the accident.

Recommendations

10 Recommendations can be found in paragraph 83. They relate to the following areas:

- development of a maintenance standard for street running track on the Metrolink system;
- examination of the feasibility of re-positioning the transitions from one type of rail to another onto straight sections of track;
- introduction of a planned renewal system.

The Accident

Summary of the accident

11 At 08:03 hrs on Wednesday 22 March 2006, two wheelsets of tram 1011, operating the 07:42 hrs Bury to Altrincham service on the Manchester Metrolink system, became derailed as the tram was entering the street running section of the network at Long Millgate, near Victoria Station. The derailed wheels remained close to the track, and the tram stopped 44 m from the point of derailment.

The parties involved

12 The tram was operated by Serco Metrolink, who hold the concession for the operation and maintenance of the Manchester Metrolink tram system, under contract to the Greater Manchester Passenger Transport Executive (GMPTE).

Location

13 The accident occurred on the section of the Manchester – Bury line of the Metrolink system where trams from Bury pass out of Manchester Victoria station and onto the streets of the city. The street, Long Millgate, carries pedestrian traffic only at this point. The speed limit approaching the location of the derailment is 15 mph (25 km/h), and the tram was travelling at just below this speed when the derailment took place.

14 At the location of the derailment point the track type changes from *flat-bottom rail* on conventional *baseplates* to *grooved rail* set into the pavement. This transition is on a right hand curve of about 170 m radius (Figures 2 and 3).

The tram

15 The tram, number 1011, was one of the fleet of 32 twin-car articulated units operated on the Metrolink system. It was built in 1991.

Events during the accident

16 On the morning of 22 March 2006 tram 1011, on the 07:42 hrs Bury to Altrincham service, left Victoria station at 08:03 hrs heading inbound towards Manchester city centre. The journey had been uneventful up until that point. This was a peak hour service, and was fully loaded with about 200 passengers.

17 Shortly after passing the transition from flat-bottom rail to grooved rail, as the vehicle entered the street running section, and travelling at approximately 15 mph (25 km/h), the driver of tram 1011 felt a bump and then heard a grinding sound. He then brought the vehicle to a controlled stop in Long Millgate shortly before the intersection with Corporation Street. The leading wheels had travelled 44 m from the point of derailment.

18 After liaising with the Metrolink control room the driver got out of the vehicle to assess the problem and discovered that the front axle of the centre bogie was derailed to the left.

19 Shortly afterwards tram 1013 departed from Victoria station on the following service. On sighting a tram stationary ahead, the driver of 1013 made a normal brake application and brought his vehicle to a stand approximately 3 metres from the rear of 1011, thus passing over the point of derailment. However, 1013 did not derail, and was removed from the scene before the pictures below were taken.

Figure 2: Derailed tram seen from the rear

20 The driver of tram 1011 went back to his cab and reported details to the Metrolink control room. He was advised to detrain passengers from the tram and await arrival of the emergency response team. Similar instructions were also given to the driver of tram 1013, and the passengers on both trams were assisted to leave the scene.

21 Subsequent examination of tram 1011 by Metrolink staff found that the leading axle of the rear bogie was also derailed. The wheels of both derailed bogies remained relatively close to the rail, with the leading axle of the centre bogie and leading axle of the rear bogie being 190 mm and 60 mm respectively out of alignment.

22 The weather throughout the day was clear and dry.

Consequences of the accident

23 There were no injuries to staff or passengers, and no damage to the tram. The track was damaged over a length of about 0.6 m (see Figure 4), and the right-hand rail in this area required replacement.

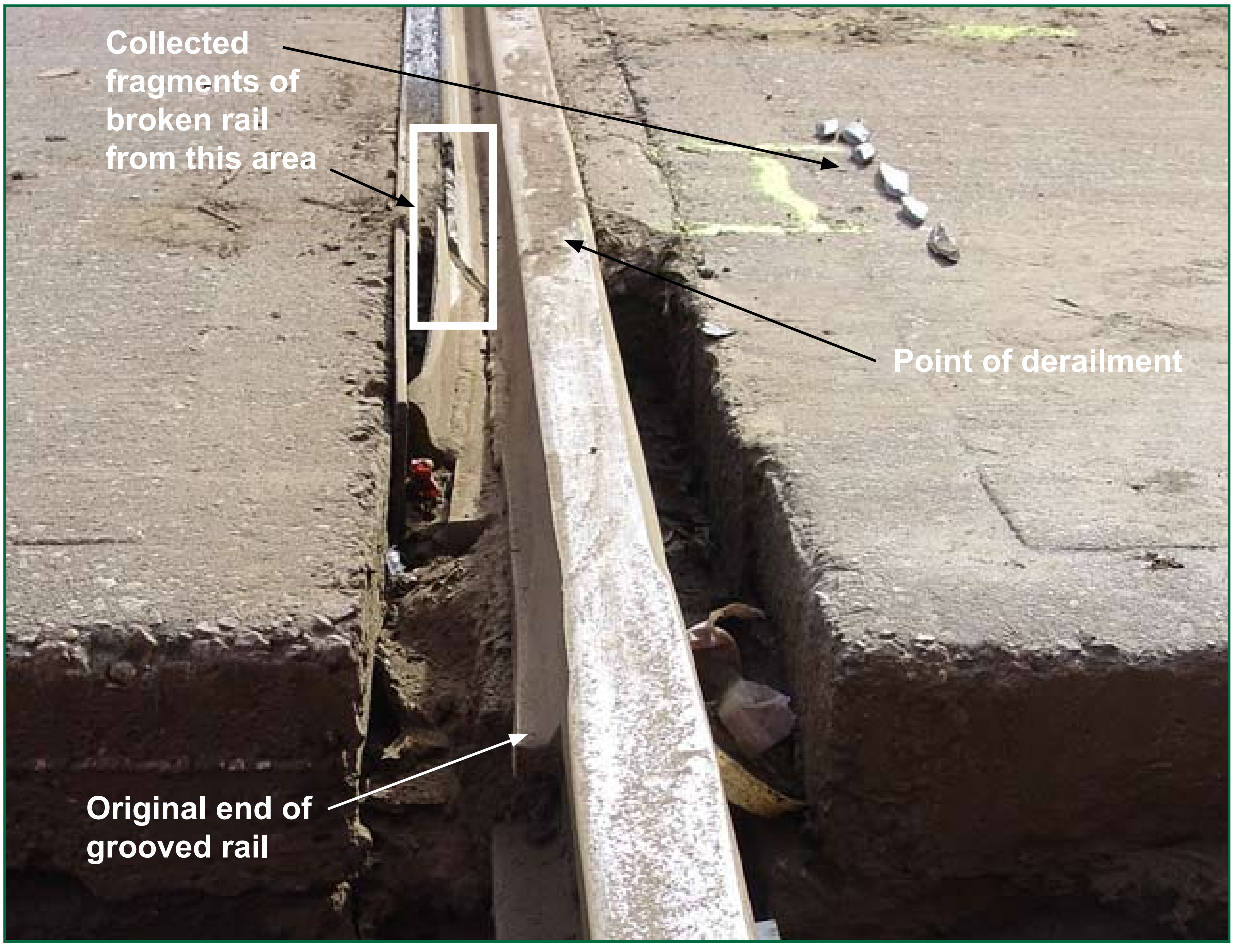

Figure 3: Right hand rail at transition showing extent of cutting-back from original end of grooved rail (see paragraph 27 for a description of the rail).

Events following the accident

24 The passengers were evacuated quickly and the Bury line tram service was suspended until the tram could be re-railed. This took place at 17:00 hrs, and following repairs to the track, services were resumed the next morning.

The Investigation

Investigation process

25 This report has been prepared using information gathered on-site by the RAIB, and information supplied by Serco Metrolink, and other tramway operators.

Analysis

Identification of the immediate cause

26 The derailment occurred at the point where the track changes from flat-bottom rail to grooved rail. The track through Victoria Station consists of a reinforced concrete slab with an 80 lb flat-bottom rail clipped into baseplates that are bolted to the slab. The track formation alters just outside the station entrance (known locally as the 'hole in the wall'), where the rails change to Ri59 grooved rail embedded in '*Edilon*' polymer and surrounded by a pavement surface.

27 The transition from flat-bottom to grooved rail is made by the use of transition pieces; these were originally fabricated by *flash butt welding* the two rail sections together and adapting the rail foot to create a tapered section. The transition pieces included a 'flared' arrangement to the end of the *keep* section of the rail to provide a wider groove where the wheel flange enters the grooved rail (Figure 4).

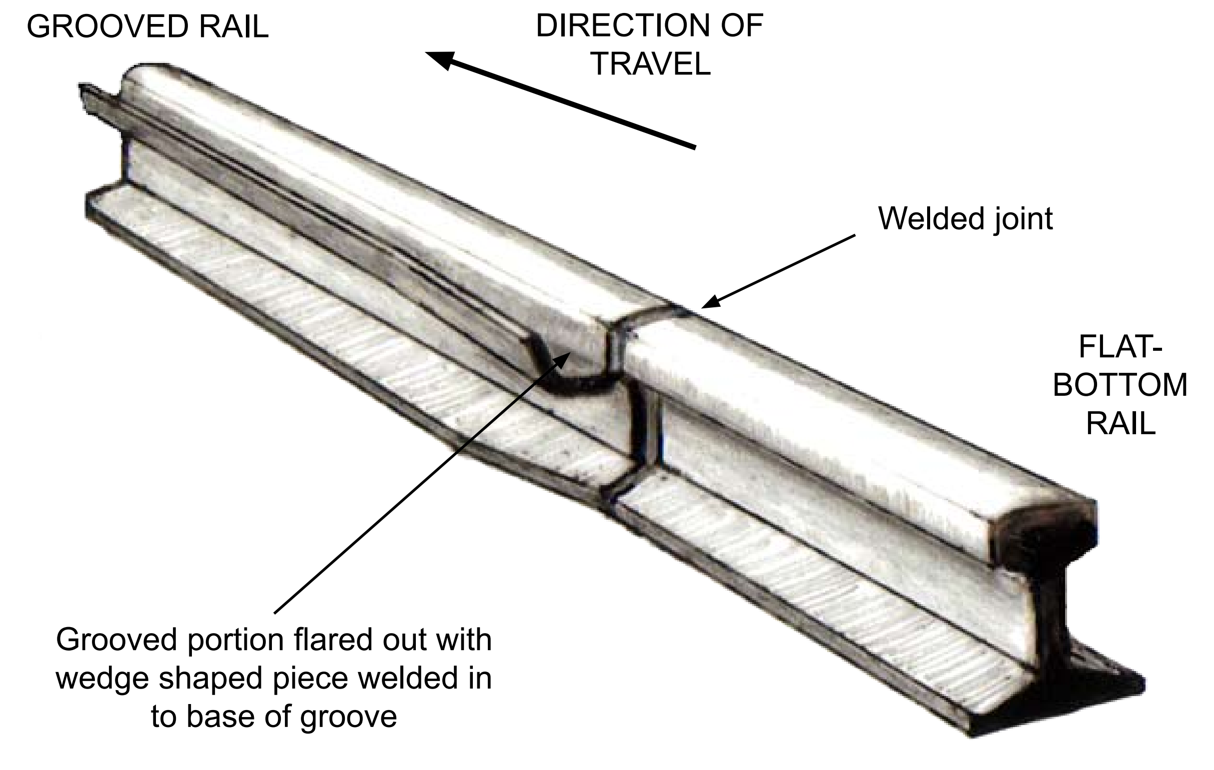

Figure 4: Simplified sketch of transition between rail profiles

28 As tram 1011 passed over it, the flared portion of the grooved right-hand (inner) rail broke away from the rest of the rail at the weld, and consequently the keep was shattered over a further length of 230 mm by the force exerted by wheel flanges which were no longer being guided and restrained by the flared portion. This permitted the flanges of the right-hand wheels of the leading wheelsets of the centre and trailing bogies to pass the wrong side of the keep, forcing the left-hand wheel over the railhead and into derailment (Figure 5).

Figure 5: details of broken rail

29 It is significant that the transition between the two types of rail occurs on a curve. As a wheelset runs round a curve, it moves outwards a distance y, which is given by the expression:

$$y = \frac{r_0 l}{R\lambda}$$

where r_0 = the wheel radius (0.37 m)

l = half the gauge (0.716 m)

R = the curve radius (170 m)

λ = the *conicity* of the wheel (0.05)

300 For the Manchester tram running round the curve at Long Millgate, y would be 31 mm if the wheel were not constrained, and if the wheel and rail were in the 'as new' condition. Flange contact with the inner face of the outer (in this case left hand) rail will normally occur before *flange back contact* with the keep rail, but quite small amounts of wear on the outer rail, leading to gauge spread of only 2 mm, will allow flange back contact to occur.

31 At the Victoria curve, the back of the flanges of the inner (right-hand) wheels of trams had been contacting the keep of the grooved rail, commencing at the point where the groove narrows in the flared portion of rail ('A' in Figure 5). This had placed a load on the flared portion, and the combination of the load and the consequent wear eventually caused the *flare* to break under the tram which derailed on 22 March. The flare had previously cracked and had been cut back and remade in October 2005. This work was not designed or carried out to a good standard (paragraph 54), and consequently the flare was weak and had a relatively short life before it failed again. The flare was not, however, intended to be of sufficient strength to withstand being struck by passing wheelsets.

<u>Previous derailments</u>

32 Metrolink have not previously experienced derailments at transitions. However, two previous derailments have occurred following failure of the rail keep on curves at other locations in the city centre. These occurred at Shudehill on 31 August 2004 and London Road on 11 January 2005.

The driving of the tram

33 The driver of tram 1011 joined Metrolink on 11 August 2003 and was passed competent as a driver on 20 October 2003. His last competence assessment prior to the incident was successfully carried out on 6 September 2004; assessments are undertaken every two years.

34 On the day of the derailment the driver had booked on duty at 07:05 hrs and had been driving for just over one hour. This was the sixth day that the driver had worked since his last rest day. The shifts worked were all morning shifts starting no earlier than 06:00 hrs with a maximum shift length of 8 hours 30 minutes. Fatigue is not considered to be an issue in this incident.

35 Analysis of the on-tram monitoring recorder (OTMR) data shows that acceleration of the tram on departure from Victoria was not unusual and that it was travelling within the permitted speed for the section of line.

36 The driving of the tram did not contribute to the derailment.

Control system – traction and braking

37 The review of the OTMR data following the incident shows that the vehicle was operating normally prior to the derailment. On departure from the Victoria tramstop it accelerated at a normal rate and reached a maximum of 14.91 mph (24 km/h). The permitted speed at this point is 15 mph (25 km/h). The tram also performed normally when braking following the derailment. It is therefore concluded that the tram's control systems did not contribute to the causes of the derailment.

Identification of causal and contributory factors

Track layout

38 There are three locations in Manchester City Centre where this form of transition arrangement has been installed: Victoria Station, Piccadilly Station and at the bottom of the G-MEX ramp where the Altrincham Line enters the city centre. These three transitions are all sited on curves, of radii 170 m, 100 m and 416 m respectively.

39 Metrolink have experienced problems with these transitions in recent years, with breaks occurring at the centre of the transition piece in the heat affected area associated with the welded joints. The broken transitions have been replaced with joints using bolted *fishplates,* because a welded repair was not considered to be reliable enough. The flash butt welded transitions of the type originally installed are no longer available as a replacement option. However, it is now possible for transitions to be machined from a single piece of metal. These would not include heat affected areas, and would be suitable for repair by welding as required. This design has not yet been used in Manchester.

40 The track layout contributed to the cause of the derailment, because the transition arrangement was located at a position on the curve where it was vulnerable to damage by wheel flanges.

Track design

41 The track system in Manchester was designed and constructed in the late 1980s, and was the first new generation tramway in the UK. The grooved rails in the city centre were originally located in shallow channels cast into a reinforced concrete slab. The rails were surrounded and electrically insulated with polymer, poured into metal formers held in place by the surrounding pavement or highway surface. There were no additional tie bars between the rails installed to hold the rails to gauge. The same arrangement can be found on other UK tramway systems. When renewal of rails has taken place, rails pre-coated with polymer have been used, held in place by concrete poured in the existing channels in the highway surface.

42 The grooved rails specified for Manchester are 900-grade steel. This is a harder rail than is normally used on main line railways, and was intended to minimise wear and extend the periods between re-railing. However, the use of these hard rails has made it difficult to build back any rail head wear by welding. 900-grade rails cannot be satisfactorily welded unless the metal is pre-heated, and this is not practicable if the rails are encased in polymer.

43 The use of transition rails (pre-assembled by flash butt welding, or more recently machined from solid) is common on tramways. It is, however, good practice to position these on straight track to reduce the stresses created in the transition and increase the life of the rails. Transitions between flat-bottomed and grooved rail sections have been constructed more recently on Manchester's Phase 2 line between Manchester and Eccles. At least two of these newer transitions are sited on curved track.

44 It is therefore concluded that the design of the track, and the choice of hard rails, contributed to the causes of the derailment by making it more difficult to maintain the gauge of the track **(Recommendation 2)**.

Track inspection and maintenance

45 Serco Metrolink staff carry out track inspections throughout the system on a weekly basis. The track patrollers are required to walk the ex-British Rail sections of track and report defects, in line with Network Rail standards for track inspection.

46 The same teams patrol the city centre sections, also weekly. For the street running (paved) areas, there is no detailed written guidance provided to the patroller on the scope of the patrol. Serco Metrolink's technical instruction for identification and prioritisation of defects (TI/002/Issue 01 November 03) does however list typical defects that the patroller might identify, including damage to switches & crossings, pavement defects, and drainage issues, but does not give guidance on defective transitions or rail keeps.

47 The inspections of the track at Victoria were found to be up to date; indeed the site of the derailment had been inspected the previous day. The records of the inspection indicate that the patroller had not identified any defects at this location.

48 There are a number of curved sections of grooved rail track in Manchester that have required attention because of the worn keep section of the rail. These were initially repaired by welding, but the limitations of this process when carried out without pre-heating (see paragraph 42) meant that the repairs had a short life and needed to be monitored until the rails were removed and replaced. This approach was revised following two derailments that were caused by weld repairs failing under passing trams. Further detailed analysis and '*Vampire®*' modelling by Manchester Metropolitan University caused the Serco Metrolink track engineer to determine that the keep could be removed completely on the tight radius curves, thus removing the derailment hazard.

49 The transitions on curved track between flat-bottom and grooved rail on the Eccles line required attention in 2005, after less than five years in use. The patrollers identified that wheel flanges were making contact towards the open end of the flare. The track gauge was tightened at the affected locations to improve the situation.

50 The track patrollers have received formal training in general track inspection, which provides direction on typical defects that may be identified on standard track. The training did not include any specific guidance on street running track.

51 The training and instructions provided for patrollers were not adequate to enable them properly to inspect the street running sections of track. However, any more suitable instructions that may have been provided would not have influenced the causes of this derailment because there was no visible defect in the track.

Track condition and repair

52 The condition of the track at the point of derailment was generally good. There was some *sidewear* on the outside rail of the curve but this was not excessive when compared with the levels of sidewear acceptable on standard rail sections. The gauge measurements taken at this location were within the tolerances listed in Serco Metrolink's technical instruction for identifying and prioritising defects (TI/002/issue 01 November 2003), which are in line with Network Rail's current track standard NR/SP/TRK/001.

53 One of the transition rails on the outbound line had been replaced with a fishplated arrangement following a rail break in May 2001. The transition rail where the derailment occurred had previously been modified in October 2005 following the identification of a cracked flare on the keep. The defective flare was cut off and another one fabricated by splaying the end of the keep rail and welding a metal wedge into the bottom of the flared groove to hold the keep open.

54 The welding-in of this wedge was sub-standard. The weld applied to the top of the wedge had not been sufficient to join the rails together, so the wedge was connected to the flare but not to the body of the rail. When the flare broke, it did so largely along this weld (Figure 3).

55 A member of the track maintenance team who was an experienced arc welder undertook the welding of rail keeps and the alterations to the flare at the transition. This welder had satisfactorily completed an assessment of competence to carry out this type of weld by Materials Engineering (UK) Ltd (a company approved by Serco for this purpose) in November 2005, after he made the repairs to the flare in October 2005.

56 The revised arrangement of the flare was not designed by the Serco Metrolink Track Engineer. The welder was required to devise a solution for himself, and concluded at the time of the work that welding a steel wedge into the bottom of the groove would help hold open the flared keep. There was no check carried out on the suitability of this solution or the quality of the welding **(Recommendation 4)**.

57 The general condition of the track was not considered to have directly influenced the derailment; however the ineffective repair to the keep would have reduced the potential life of the repaired section.

Vehicle condition

58 On returning to Queens Road Depot the vehicle was examined and wheel profile measurements taken, including *wheelset back to back* and flange width measurements. All dimensions were found to be within the appropriate specification limits.

59 The condition of the vehicle wheels is not considered to have contributed to the causes of the derailment.

Identification of underlying causes

Wheel-rail interface

60 The wheel profile adopted for the Manchester trams is a modification of the P8 profile defined in Railway Group Standard GM/RT 2466. The modification includes a thinner flange, for running in grooved rail, and a stepped flange back which makes contact with raised check rails on the ex-BR lines. This so-called 'tram/train' profile is suited to both grooved rails and the 'heavy rail' track found on the system's ex-BR lines.

61 The bogies of the Manchester trams are of typical heavy rail design, although they are set up to have low axle *yaw stiffness* compared to bogies of heavy rail vehicles. Even so, this stiffness is relatively high for the tight curves on the Manchester system and Serco have observed that the ability of the wheelset to *steer* around the city centre curved track is limited. The apparent width of the flange is increased when the wheel negotiates a curve. Wheel/rail interaction did not contribute to the derailment other than in respect of the increased wear rate of the rail and keep.

Standards

62 As described above (paragraph 52), the standards that Serco Metrolink has adopted for inspection and maintenance of the segregated sections of track on Metrolink are railway industry standards, in particular those of Network Rail. There were no construction standards available for grooved rail track that could be consulted regarding the position of the transition and no formal written inspection standard to dictate suitable intervention levels.

63 The permissible levels of wear of flat-bottomed rail are specified in Network Rail standards for main line railway applications. However, these levels of wear are not necessarily appropriate for grooved rail which is continuously supported and encased in polymer.

64 The absence of light rail standards has been acknowledged by HMRI, who commissioned a project to determine the specification and standards in use in the UK. A number of working groups, led by industry engineers, have been appointed to develop further guidance over and above that contained in the HMRI publication 'Railway Safety Principles and Guidance- part 2 section G: Guidance on Tramways' (RSPG). Key elements of this are due for delivery in mid-2007.

65 The lack of standards was therefore considered to have been a contributory factor to this and previous derailments on the Manchester system **(Recommendation 1)**.

Renewal strategy

66 Serco Metrolink had not, up to 2005, recorded levels of rail wear. Doing so could have enabled the rate of wear to be calculated and a renewals programme prepared. The rails that have been replaced in the last three years have been in locations where the keep section of the rail had worn excessively and/or failed completely.

67 A recent review by Serco Metrolink of wear to the city centre rails has produced a programme of work, both rail replacement and welding of side-worn rails, for grooved rail track. The transition at Victoria was not included in the review, because the curve radius of 170 m was not considered tight enough to warrant special attention (paragraph 70).

68 The current contract between GMPTE and Serco Metrolink does not provide for a renewals programme based on condition of the track. This contributed to the causes of the derailment by encouraging locally devised ad-hoc repairs to wear and failures. These repairs have a relatively short life. However, GMPTE has since let new contracts for track renewals during 2007 (paragraph 81) (**Recommendation 3)**.

Other factors for consideration

69 An investigation of sidewear and keep rail wear on the Manchester Metrolink system was carried out for Serco Metrolink by the Rail Technology Unit (RTU) of Manchester Metropolitan University during 2005, following two derailments and the discovery that, on tight radius curves in the street running section, the keep rail was starting to fail.

70 The emphasis of the RTU study was on keep wear in the very tight (25 m radius) curves on the Metrolink system, at locations such as High Street/Market Street and the Piccadilly Gardens triangle. The study concluded that the current level of sidewear was such that the structural integrity of the reduced sideworn rail section should be investigated to ensure safe levels of working stress. Serco Metrolink received this study in March 2005. In its response to the study, the company concentrated on repair and renewal of the very tight curves listed above. The curve at Long Millgate (radius 170 m) was not regarded as high-risk.

71 The study also predicted that it was very likely that a keep rail failure would cause a derailment. The predicted mechanism for derailment was the flange back of the low rail wheel climbing the face of the broken keep rail.

72 This was precisely the way in which the derailment of 22 March 2006 occurred, albeit on a larger radius (170 m) curve. The weakness of the flared portion of the transition was a factor in the breakage of the keep rail.

73 The RAIB asked operators of the other tramways in the UK about their experiences with transitions between flat-bottom and grooved rail. Apart from Manchester, no tramway has had a derailment at a transition. The systems that have been built since Manchester have, as far as possible, avoided transitions on curved track.

74 A study of the wheel/rail interface issues on all UK tramways was carried out for HMRI in 2006 (Appendix C - Ref. 1). This found that there is a need for standardisation in UK LRT systems to reduce the diversity of standards, reduce innovative features that may require corrective action, and promote cost effective operation. Funding to complete this research work (to aid the development of suitable standards (paragraph 64)) has been agreed, and the results are due to be delivered in the third quarter of 2007.

Conclusions

75 The immediate cause of the accident was the failure of a repaired section of track at the transition between two types of rail, which allowed the wheels to ride up the inner face of the grooved track and become derailed (paragraph 31).

76 The causal factor was:

- the repair to the transition area was undertaken without the use of a formal design change control process or quality control of the work done **(Recommendation 4)** (paragraph 56).

77 Contributing factors were:

- side wear on the outside rail of the curve in the transition area (paragraph 31);
- the positioning of the transition between two types of track on a curve, rather than on straight track **(Recommendation 2)** (paragraph 43);
- the choice of hard rail for track in the city centre area, making it difficult to make welded repairs to worn rails (paragraph 42).

78 Underlying causes were:

- the lack of construction and inspection standards for light rail grooved tracks, or guidance on intervention points **(Recommendation 1)** (paragraph 65);
- the absence of a defined renewal strategy based on the condition of the track on the Metrolink system **(Recommendation 3)** (paragraph 68).

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

79 Serco Metrolink removed the defective flare and the keep on the remainder of the curve, which had the effect of relocating the entry to grooved rail on to the straight section. The side worn rail opposite the new entry to the groove was built up by weld repair to tighten the gauge.

80 Serco Metrolink reviewed the other transition locations following the incident, and replaced two of the flares on curves facing oncoming trams, one at G-MEX and one at Piccadilly, with new fishplated joints; they also tightened the track gauge at these locations.

81 GMPTE has let a contract for renewals on the system separately from the operations and maintenance concession. This contract is for the renewal of more than 30 km of track (39 per cent of the existing system) during 2007.

82 HMRI have commissioned research into the wheel/rail interface on UK tramways, leading to the development of suitable standards. The results of this are due to be delivered during 2007 (paragraph 74).

Recommendations

83 The following safety recommendations are made:[1]

Recommendations to address causal and contributory factors

1 GMPTE[2] should ensure that a standard for Metrolink grooved rail track, including tolerances and limits for wear and gauge, is developed and implemented, and that there is guidance to inspection staff on appropriate levels and types of intervention corresponding to measured values and observations.

2 GMPTE should ensure that the risk of transitions between flat-bottomed and grooved rail on curves on the system is assessed, and that they are repositioned on to straight track where this is warranted and it is reasonably practicable to do so.

3 The infrastructure maintainer of Manchester Metrolink and GMPTE should jointly introduce a system for initiating, planning and implementing track renewals on the Metrolink system.

4 GMPTE should ensure that the infrastructure design change and quality control procedures for the Metrolink system are reviewed, to ensure the proper control of alterations made to the infrastructure during maintenance.

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[1] Responsibilities in respect of these recommendations are set out in the Railways (Accident Investigation and Reporting) Regulations 2005 and the accompanying guidance notes, which can be found on the RAIB web site at www.raib.gov.uk.

[2] The operation and maintenance contracts for the Metrolink system are being re-let from April 2007. Serco Metrolink is not among the companies short-listed for the contracts.

Appendices

Glossary of abbreviations and acronyms — Appendix A

BR	British Rail
GMPTE	Greater Manchester Passenger Transport Executive
HMRI	Her Majesty's Railway Inspectorate
OTMR	On Tram Monitoring Recorder
RAIB	Rail Accident Investigation Branch

Glossary of terms **Appendix B**

Baseplate	Metal casting which supports and holds a flat-bottomed rail on a sleeper or slab base.
Conicity	The taper of the tread of a railway wheel.
Fishplate	Steel plate used to align and secure together the ends of two rails in jointed track.
Flare	A tapered section formed at the end of a length of grooved rail.
Flange back contact	Contact between the inner (back) face of a wheel and the keep of a grooved rail.
Flash butt welding	Factory technique for joining lengths of rail.
Flat-bottom rail	A type of rail characterised by a broad and shallow base or ‘bottom’, used worldwide.
Grooved rail	Rail designed for use in streets, with a cross-section which incorporates a trough (or groove) in which the wheel flanges run.
Keep	In grooved rail, the wall of the groove opposite the rail head.
Sidewear	The reduction in railhead width due to wear caused by flange contact with the rails as trains run round a curved track.
Steer	The ability of a wheelset of a bogie vehicle to turn relative to the bogie frame when passing round a curve.
Vampire®	A proprietary software package that can simulate the interaction between railway vehicles and the track.
Wheelset	An assembly consisting of two wheels on an axle.
Wheelset back to back	The spacing apart of the two wheels on an axle.
Yaw stiffness	The ability of each axle to resist rotation in a horizontal plane relative to the bogie frame- a function of the suspension design.

References

Appendix C

1. A survey of UK tram and light railway systems relating to the wheel/rail interface FE/04/14:

   E J Hollis PhD CEng MIMechE. Health & Safety Laboratory, Buxton, 2006

This report is published by the Rail Accident Investigation Branch,
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