Rail Accident Investigation Branch

Rail Accident Report

Derailment at Starr Gate, Blackpool
30 May 2006

Department for Transport

Report 15/2007
May 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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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 Blackpool Transport Services (BTS), Blackpool Borough Council (BBC),Tram Power and HM Railway Inspectorate (HMRI) to their staff, data and records in connection with the investigation.

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

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

Summary

5 At 12:00 hrs on 30 May 2006, tram 611 was traversing the curve on the *loop* at Starr Gate on Blackpool Tramway when it became derailed. The location of the incident is shown on Figure 1.

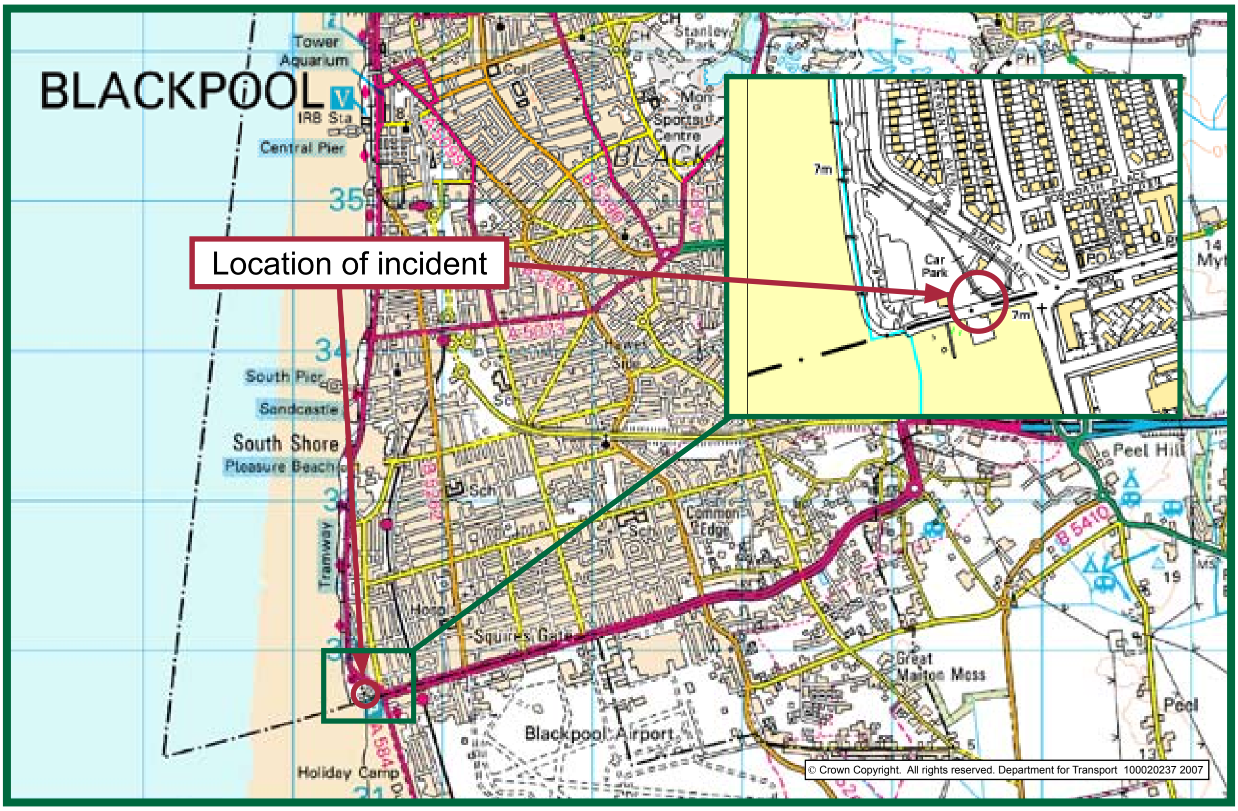


Figure 1: Extract from Ordnance Survey map showing location of incident

6 Tram 611 was a prototype design and was undertaking a series of test runs. It was a two car *articulated vehicle* and had a running gear arrangement under the connecting central *articulation module* which included an *independent rotating* wheel design. Independently rotating wheels have been used on trams in service on other tramways; however, the type of running gear used on tram 611 was significantly different to that used on other trams operating in Blackpool. The derailment occurred at low speed and involved only the pair of wheels under the articulation module. They derailed to the centre of the curve. There were no injuries or significant damage.

7 The immediate cause of the incident was the tip of the *flange* on the wheel under the central articulation module, and on the inner radius of the curve, contacting a worn portion of the rail, and hence promoting it to climb onto the *rail head*.

8 The derailment risks associated with the operation of a tram having a new type of running gear on the type of worn rail and curved track found on the loop, were not previously identified and therefore not mitigated.

9 Recommendations can be found at paragraph 49. They relate to the following areas:

- a need to understand more fully the derailment behaviour of tram 611; and,
- control of the pattern of wear on the rail *gauge face*.

The Incident

10 At 12:00 hrs on 30 May 2006, tram 611 was traversing the curve on the loop at Starr Gate on Blackpool Tramway when it became derailed. The tram was a prototype design and was undertaking a series of test runs.

The infrastructure

11 Blackpool Tramway runs along the coast between Starr Gate, in the south of Blackpool, and the town of Fleetwood to the north. Sections of the route are open to pedestrians and, in places, also road vehicles; other sections are reserved for trams only. Trams are electrically powered from an overhead supply.

12 The track and infrastructure is owned and maintained by BBC.

13 Passenger tram services on Blackpool Tramway are operated by BTS.

14 The loop at Starr Gate is used so trams can reverse direction at the southern end of their journey without the need to change *driving positio*n. The curve on the loop has a nominal radius of 25 m. The track comprises *95 lb bull head rail* installed on timber sleepers with a *cant* of between 60 and 80 mm. A *check rail* is fitted to the inside running rail.

15 The loop is on a section of the route which is reserved for trams.

The tram

16 Tram 611 was owned and being developed by Tram Power. Other organisations were involved in the earlier stages of design and construction.

17 The tram comprises two car bodies which are connected together by a central articulation module. The outer end of the each car body is carried by a single four wheel *driven bogie* which incorporates automotive axle components. The articulation module is carried on a pair of wheels which are free to rotate independently of each other. Neither of these wheels is driven. All the wheels on the tram include rubber elements between the outer rim and wheel centre. The principal arrangement of the tram is shown in Figure 2. It is designed to be capable of traversing curves of radius 15 m and greater.

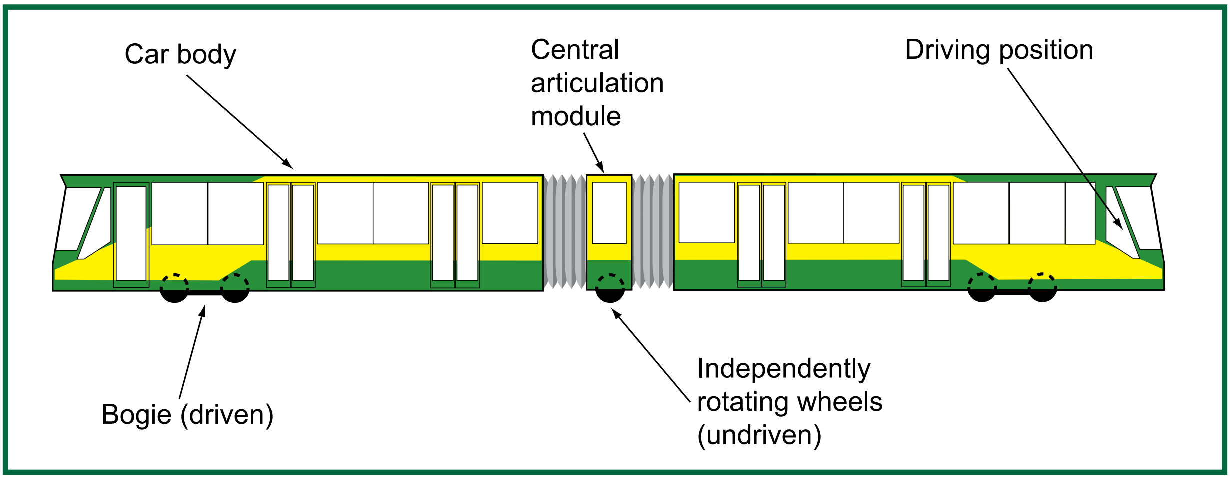


Figure 2: Principal arrangement of the tram

18 The tram was originally constructed in 1997 as part of a part of a development project, and early tests were conducted in Blackpool between 1998 and 2000.

19 In 2004 there was a change of the project investors; the tram was rebuilt and refurbished. New tests were initially conducted on the short Birkenhead Tramway prior to the tram being moved back to Blackpool to undertake a larger scale programme of testing and trials. No derailments were reported as result of the test running at Birkenhead.

20 HMRI provided guidance to Tram Power in respect of the approval process for the tram. In a letter dated 24 February 2005, they highlighted the benefit that would be obtained from Tram Power developing a safety management plan which led to a technical case for safety. They specifically felt that the independent assessment of the critical features of the tram was desirable; one such feature was the central articulation module. In the same letter of 24 February, they also offered help in putting Tram Power in contact with a consultancy that could assist in developing the technical case for safety.

21 Tram Power advised that, prior to the incident, a proposal was received from a consultancy to independently assess the overall design of the tram. This proposal was not pursued as it was considered prohibitively expensive for that phase of the tram development.

22 Tram Power undertook simplified derailment calculations prior to the incident; however, no detailed dynamic study of the derailment risks of the tram operating on Blackpool Tramway was made. Tram Power considered that conventional railway vehicle dynamic analysis tools were not able to reliably model the behaviour of the running gear arrangement.

23 HMRI had been notified of the tests at Birkenhead and Blackpool. After discussion with BTS, they had received an assurance that the experimental tram would be scrutinised under BTS's safety management system - which had already been used to assess new trams entering service – before it was tested. As BTS were a known operator, HMRI was content for them to undertake the responsibility for ensuring the safe operation of the tram under their safety management system; on 10 August 2005 HMRI gave consent to the duty holders, Metropolitan Borough of Wirral and BTS, the respective tramway operators, for a six month period of testing and trials. On 22 February 2006, BTS were given consent for an additional six month period of testing. Both consents were given under Regulation 4(4)(b)(i) of Railways and Other Transport Systems (Approval of Works, Plant and Equipment) Regulations 1994. The consent for testing given to BTS on 22 February 2006 required that HMRI be presented with a risk assessment based on the results of these tests before passenger trials could be conducted.

24 The tram was moved to Blackpool in December 2005 to undertake the larger scale programme of tests (paragraph 19). The tests and trials were seen as a means of providing validation and verification evidence that could support the approval process.

25 During testing at Blackpool the tram was stabled at BTS's depot at Rigby Road. BTS provided a member of staff to drive the tram.

Events during the incident

26 At 11:40 hrs on 30 May 2006, the tram departed the depot in order to carry out brake tests on the section of line between Blackpool Tower and Starr Gate. Three people were on board: BTS's driver, and two technical members of the tram development team. The weather was dry, fine and clear.

27 The tram arrived at the loop at around 12:00 hrs. It was travelling at approximately 5 mph (8 km/h) when, about two-thirds of the way around the curve, a loud noise was heard by those on board. One of the development team members saw that the inner and outer wheels under the central articulation module had derailed toward the curve centre. He alerted the driver, who then brought the tram to a stop. Figure 3 shows the position of the inner wheel after the derailment.

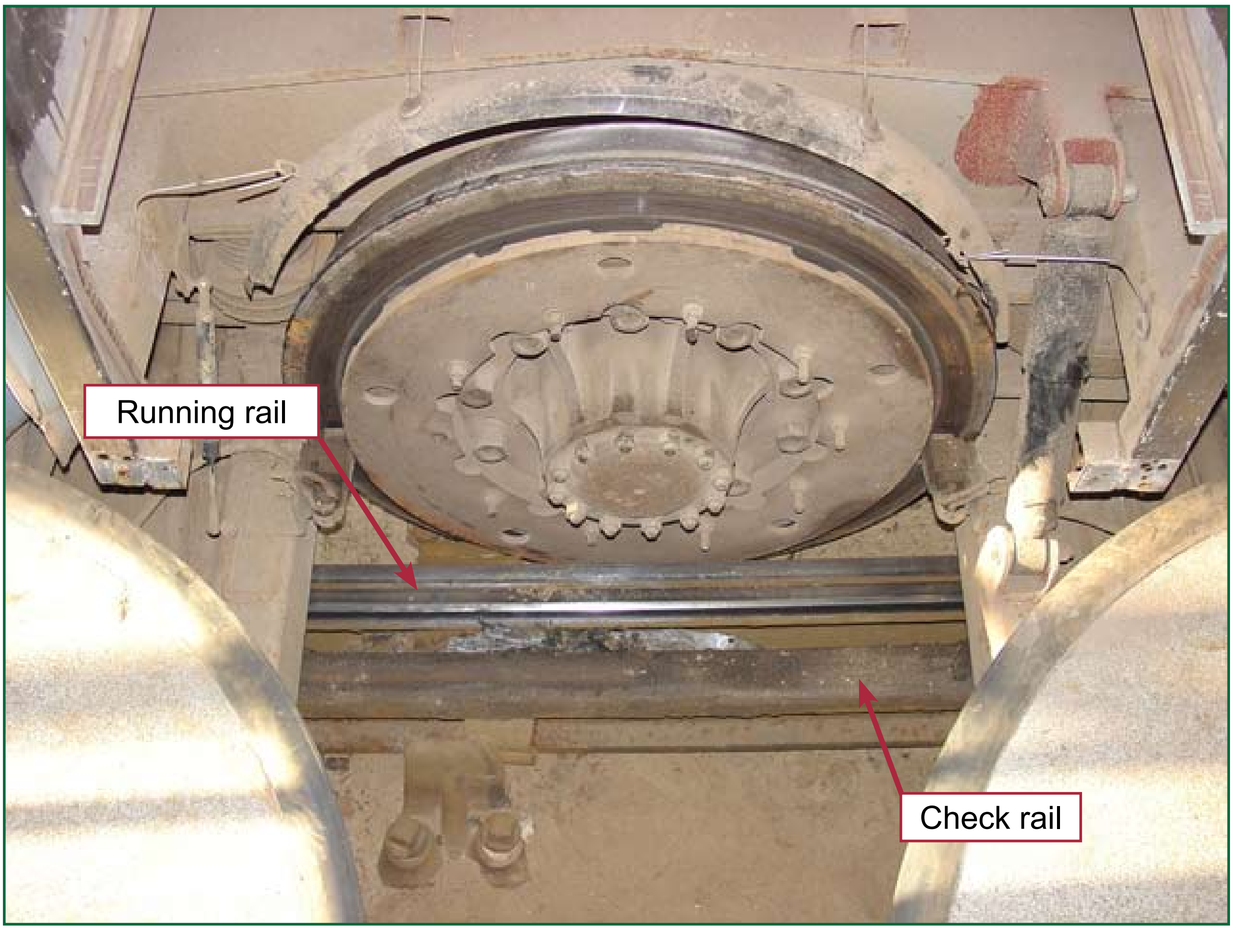


Figure 3: View from inside the articulation module showing the location of the inner derailed wheel

28 The tram remained upright and no other wheels were derailed; see Figure 4. There were no injuries and only minor marking of the track. There was no significant disruption to passenger service as arrangements were made to enable service trams to turn back at a *crossover* immediately north of the loop and continue running.

Figure 4: Derailed tram

29 Tram 611 had previously negotiated the curve on the loop a number of times since January 2006 without incident. Those on board felt that the tram was being driven at a significantly lower speed on this occasion than on previous ones, although there was no particular identified reason for this.

The Investigation

30 The investigation included:

- examination of the track on the loop including the rail profiles;
- examination of tram 611 including the wheel profiles;
- consideration of information provided by BTS, BBC and Tram Power, including tram design documentation and track maintenance standards;
- consideration of information from HMRI regarding approval matters; and
- interviews with key persons involved.

Analysis

31 The point at which the inner wheel of the central articulation module had become derailed was evident from marks on the rail head and *rail fastenings*. These indicated that the wheel flange had been running on top of the rail head before eventually dropping onto and running over the fastenings toward the inside of the curve.

32 Marks on the rail showed that the wheel flange had initiated its climb onto the rail head 13.5 m before the derailment point. The wheel flange had sustained its travel on the rail head through being guided by a low ridge which had formed on the rail head (paragraph 37), see Figure 5.

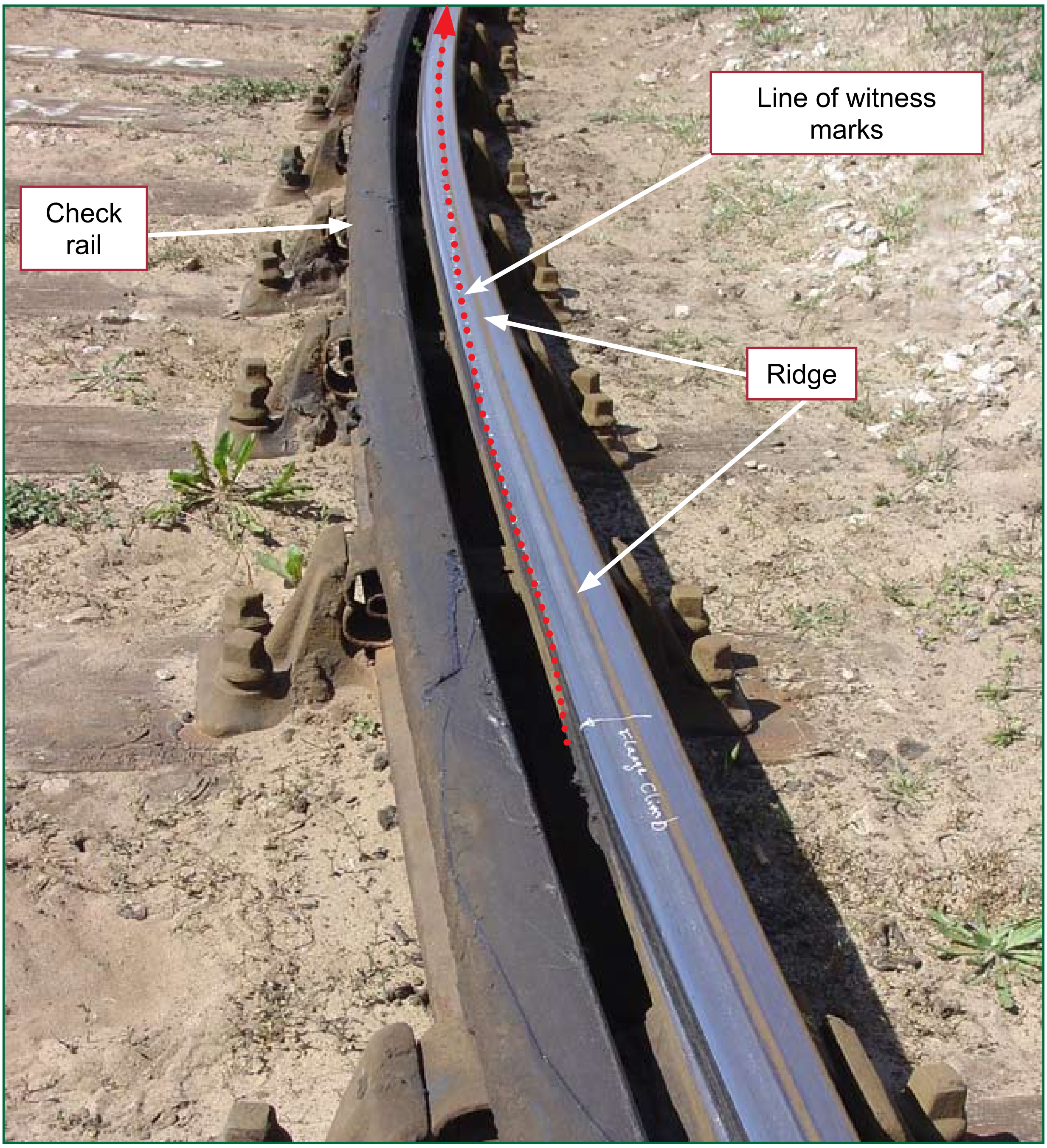


Figure 5: Witness marks on the inner rail showing the path of the wheel flange climb and its sustained running on the rail head

33 A *rail joint* was located immediately prior to the place where the wheel flange had started to climb the inner rail. Wear was evident on the gauge face of the rail, see Figure 6.

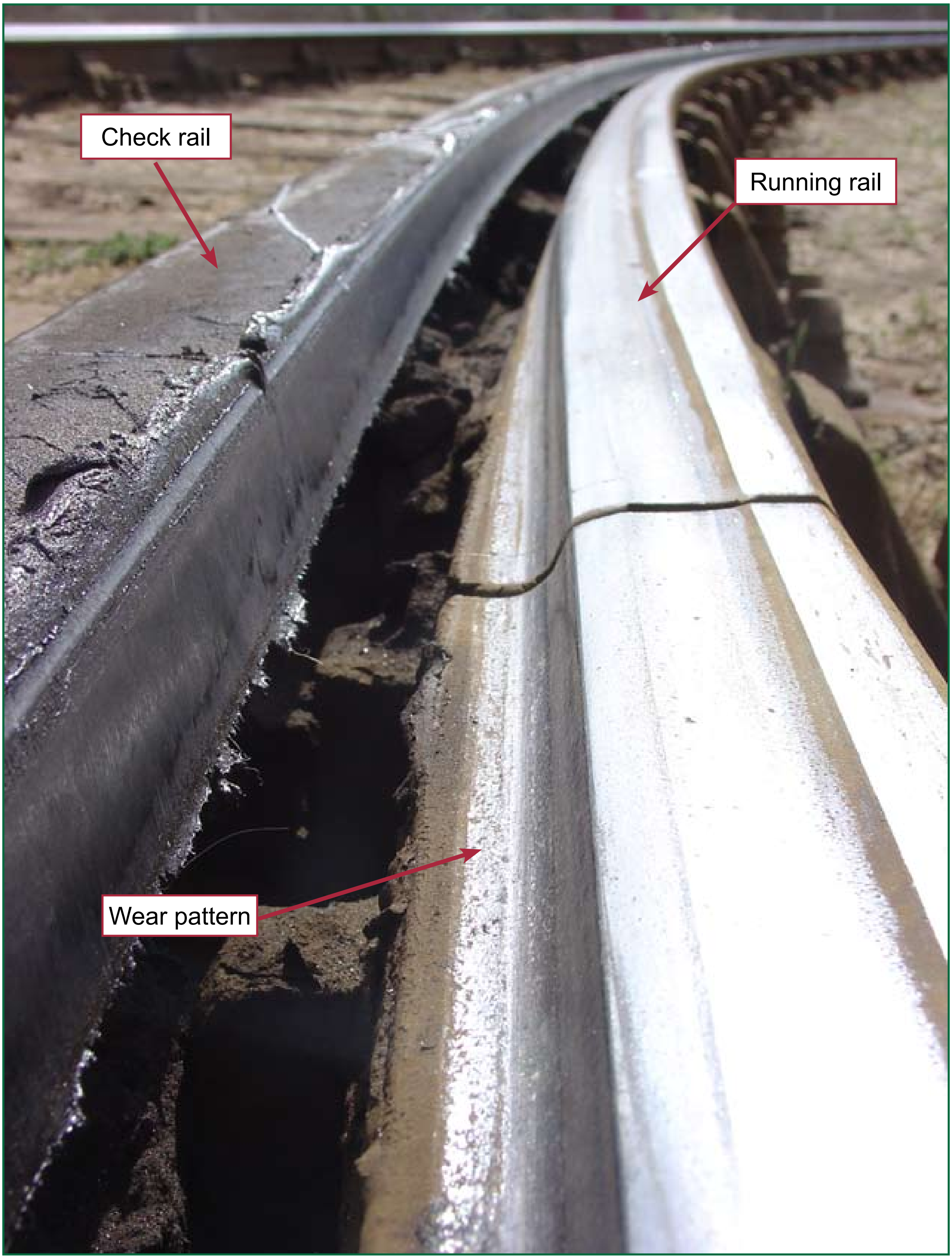


Figure 6: Pattern of wear observed on the gauge face of the rail

34 An overlay of the rail profile, measured at the joint, and that of the wheel, indicates the potential for the tip of the wheel flange to come into contact with the worn rail; this is shown on Figure 7. Also shown is the associated angle of contact made between the flange and the rail. The risk of derailment is increased when this angle is low, since only relatively small horizontal forces – occurring as a result of negotiating the curve – are needed to start the flange climbing the rail. The shallowness of the angle at this location indicates a risk of derailment.

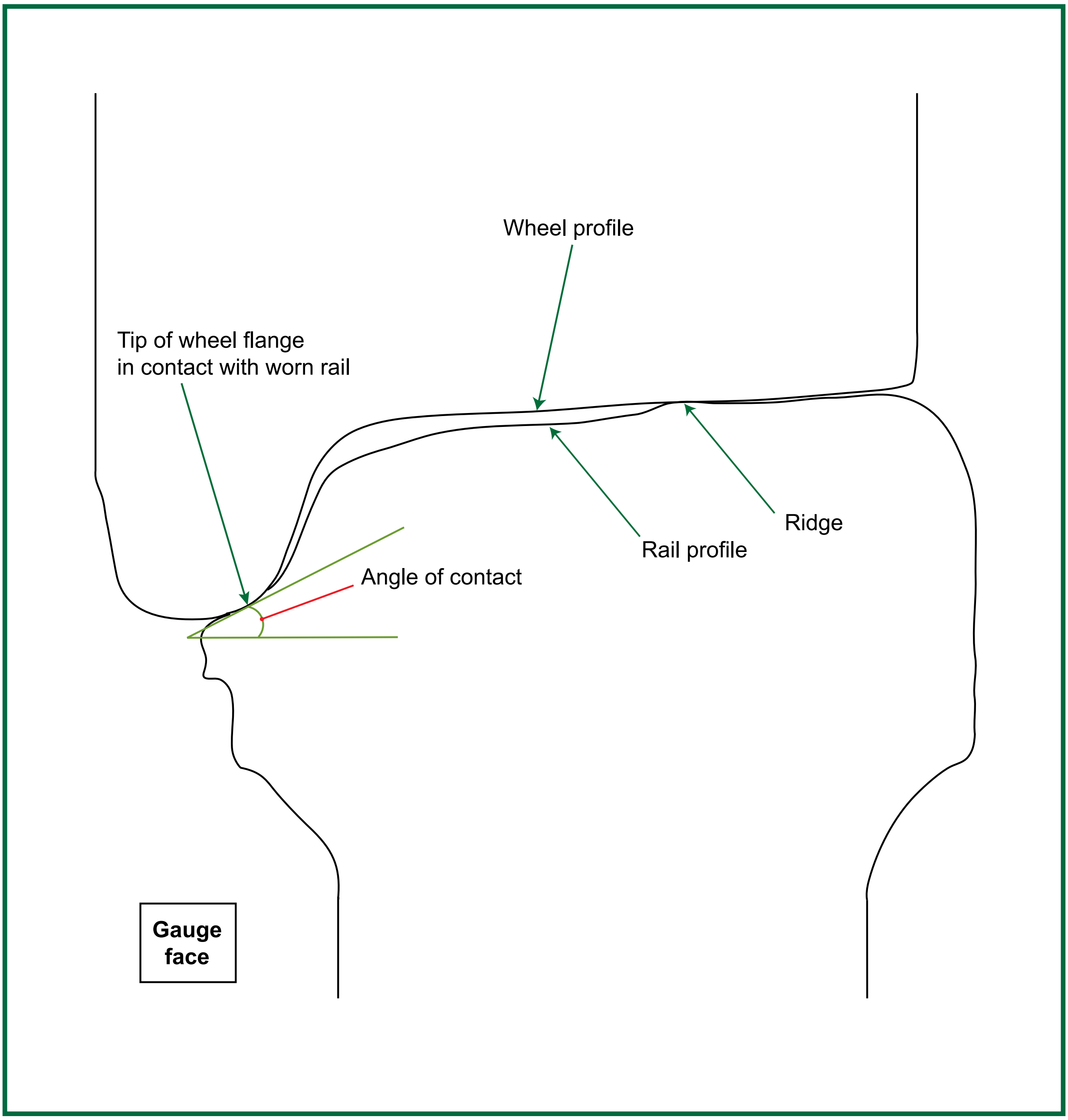


Figure 7: Overlay of measured rail and wheel profile showing the potential for wheel flange tip contact

35 The above shows the immediate cause of the derailment was that the tip of the wheel flange came into contact with the worn profile of the rail gauge face whilst a sufficiently high horizontal force was acting toward the centre of the curve. The check rail provides no protection for a wheel derailing in this direction.

36 BTS's trams running in passenger service have conventional wheelsets with an axle coupling each pair of wheels together; in the last 5 years, there have been no reports of derailments involving these trams on the loop. Following recovery of tram 611, the passage of three service trams was monitored over the track where the derailment occurred. None evidenced any tendency for the type of flange climbing identified in the derailment of tram 611.

37 The monitoring also showed that the *bogies* adopted a *yaw* attitude when running around the curve on the loop – the outer flange on the first wheelset in contact with the outer rail and the inner flange on the second wheelset in contact with the inner rail. This running behaviour is not unusual on small radius curves. It evidences that the repeated passage of service trams had led to the wear on the rail gauge face of the inner rail (due to the running position of the flange on the second wheelset) and the development of the ridge on the rail head (due to the difference in lateral position of the wheels on the first and second wheelsets).

38 Neither BTS nor Tram Power undertook a dynamic study of tram 611 to assess the risk of derailment of the new type of running gear when operating on the Blackpool Tramway (paragraph 22); this could have enabled an assessment of the behaviour of the tram on track similar to that found, and over the likely ranges of service speed and other parameters.

39 A dynamic study could have formed part of an independent assessment of the tram design, especially if this had considered the novel features of the central articulation module and the running gear. However no such assessment had been made by the time of the incident (paragraph 21) nor was it a direct requirement of the consent for test running that it should have been. The test running itself was considered a part of validating the performance of the tram and providing the evidence for its approval (paragraph 24).

40 In summary, the specific derailment risk to tram 611 that was posed by the combination of its new design of running gear, the rail sidewear, the curve radius and the range of different speeds and other operating parameters (such as traction and brake demands), was not identified before the incident; this precluded any ability to mitigate the risks now known. This is considered to be causal to the derailment.

41 The Blackpool Tram Track Maintenance Handbook, issued by BBC as their maintenance standard, gives guidance to the maintenance teams responsible for the track on the operational sections of Blackpool Tramway. It identifies rail sidewear as a defect which should be identified during normal track inspection. However, no quantitative limit or guidance is given to determine when sidewear has become so severe that rectification is required. An extract of the part of the handbook relating to sidewear is included in appendix C.

Conclusions

42 The immediate cause of the incident was the tip of the flange on the wheel under the central articulation module, and on the inner radius of the curve, contacting a worn portion of the rail, and hence promoting it to climb onto the rail head.

43 The causal factor was that the derailment risks of operating a tram, having a type of running gear which was new to operations in Blackpool, on the type of worn rail and curved track found on the loop at Starr Gate, were not previously identified and therefore not mitigated against.

44 The above causal factor is unlikely to present a derailment risk to BTS's passenger trams.

45 The track maintenance standard issued by BBC gives no quantitative limits or guidance for when action is needed to address rail sidewear defects. This is contributory to the derailment.

Actions already taken or in progress

46 HMRI has put Tram Power in contact with a specialist consultancy having the capability and experience of analysing the dynamic behaviour of the type of running gear fitted to tram 611. Proposals for a study of the dynamic behaviour tram 611 have been discussed.

47 Tram Power has also been in discussion with other tram operators regarding their experience of the behaviour of independent rotating wheels.

48 BBC has re-profiled the rail gauge face on the loop by grinding.

Recommendations

49 The following safety recommendations are made[1]:

1. BTS, in association with Tram Power and BBC, should undertake an assessment of operational and derailment behaviour of tram 611 in order to identify the mitigation measures necessary to allow its safe operation on the Blackpool Tramway. In conducting this assessment consideration should be given to the combined influence of the tram design (including the configuration of the running gear), operating parameters and the track design and maintenance (including rail head profiles).

2. BBC should take measures to control the pattern of wear on the rail gauge face throughout the Blackpool Tramway. This should include the definition of quantitative limits and guidance for the management of rail sidewear in the relevant track maintenance procedures and documentation.

[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 RAIB's web site at www.raib.gov.uk

Appendices

Glossary of abbreviations and acronyms — Appendix A

BBC	Blackpool Borough Council
BTS	Blackpool Transport Services
HMRI	HM Railway Inspectorate

Glossary of terms **Appendix B**

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

95 lb bull head rail	A type of rail characterised by a narrow and deep base or 'bottom', little used outside the UK.
Articulated vehicle	A rail vehicle arranged so that two or more adjacent cars share a common bogie or axle.*
Articulation module	A flexible part of a tram which allows relative rotational movement between two coupled cars.
Bogie	A metal frame equipped with two or three wheelsets and able to rotate freely in plan, used under rail vehicles to improve ride quality and better distribute forces to the track.*
Cant	The design amount by which one rail of a track is raised above the other rail, measured over the rail centres.*
Check rail	A rail or another special section provided alongside a running rail to give guidance to flanged wheels by restricting the lateral movement of the wheels.*
Crossover	Connection between two tracks which allow trains to pass from one to another.
Driven bogie	A bogie having mechanically driven wheels.
Driving position	The location of the driving controls on a rail vehicle.
Flange	The extended portion of a rail wheel that provides it with directional guidance.*
Gauge face	The side of the rail head facing toward the opposite running rail.*
Independent rotating	Typically used to describe a pair of wheels which are free to rotate relative to each other.*
Loop	Length of track which allows trams to change direction without the need to use an alternative driving position.
Rail fastenings	Fastenings to fix rails to sleepers.
Rail head	The bulbous upper part of a rail section.*
Rail joint	The connection between individual lengths of rail.
Yaw	The rotation of a body (for example a car body or bogie) about a vertical axis.

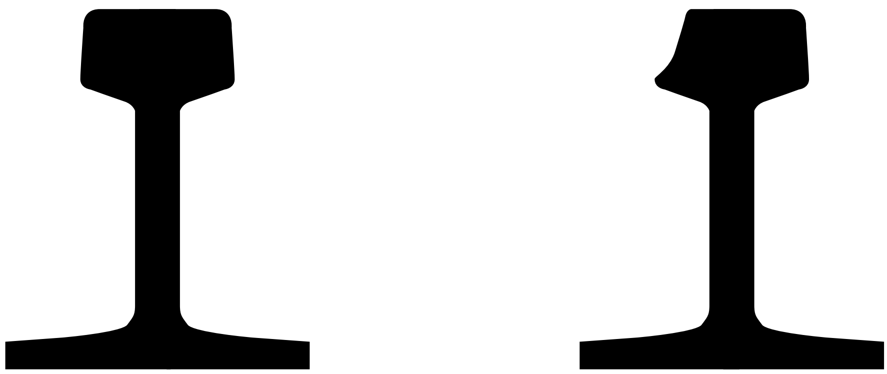
Extract from Blackpool Tram Track Maintenance Handbook Appendix C

The extract below, relating to rail sidewear defects, is taken from Blackpool Tram Track Maintenance Handbook, Version 2, September 2004.

The term "Action" refers to the period within which the defect is to be rectified (D = 1 month, E = 3 months, H = monitor).

Sidewear is loss of section to one side of the rail head, it is similar to normal progressive rail wear but occurs on the outside rail of a curve or where dips in the track allow the flange of a wheel to be forced onto the rail either by centrifugal force or acceleration.

Rectification of any severe sidewear identified should be by replacing or (if possible) transposing the rails.



a. Full rail profile *b. Profile with sidewear*

Figure 9: *Side Wear*

Category	Tolerances	Action
Sidewear	No wear	H
	Minor wear on curves	H
	Significant wear on curves	D
	Minor cyclic sidewear on straight	H
	Significant cyclic sidewear on straight	E

Version 2, September 2004
Blackpool Tram Track Maintenance Handbook

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