Rail Accident Investigation Branch

Rail Accident Report

Collision on the Great Orme Tramway
15 September 2009

Department for Transport

Report 13/2010
August 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.

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Preface

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 The terms left and right relate to the uphill journey of a tram.

The Accident

4 At 12:15 hrs on 15 September 2009 two trams travelling in opposite directions collided at the passing loop on the upper section of the Great Orme Tramway, Llandudno (figure 1). One person suffered minor injuries in the collision.

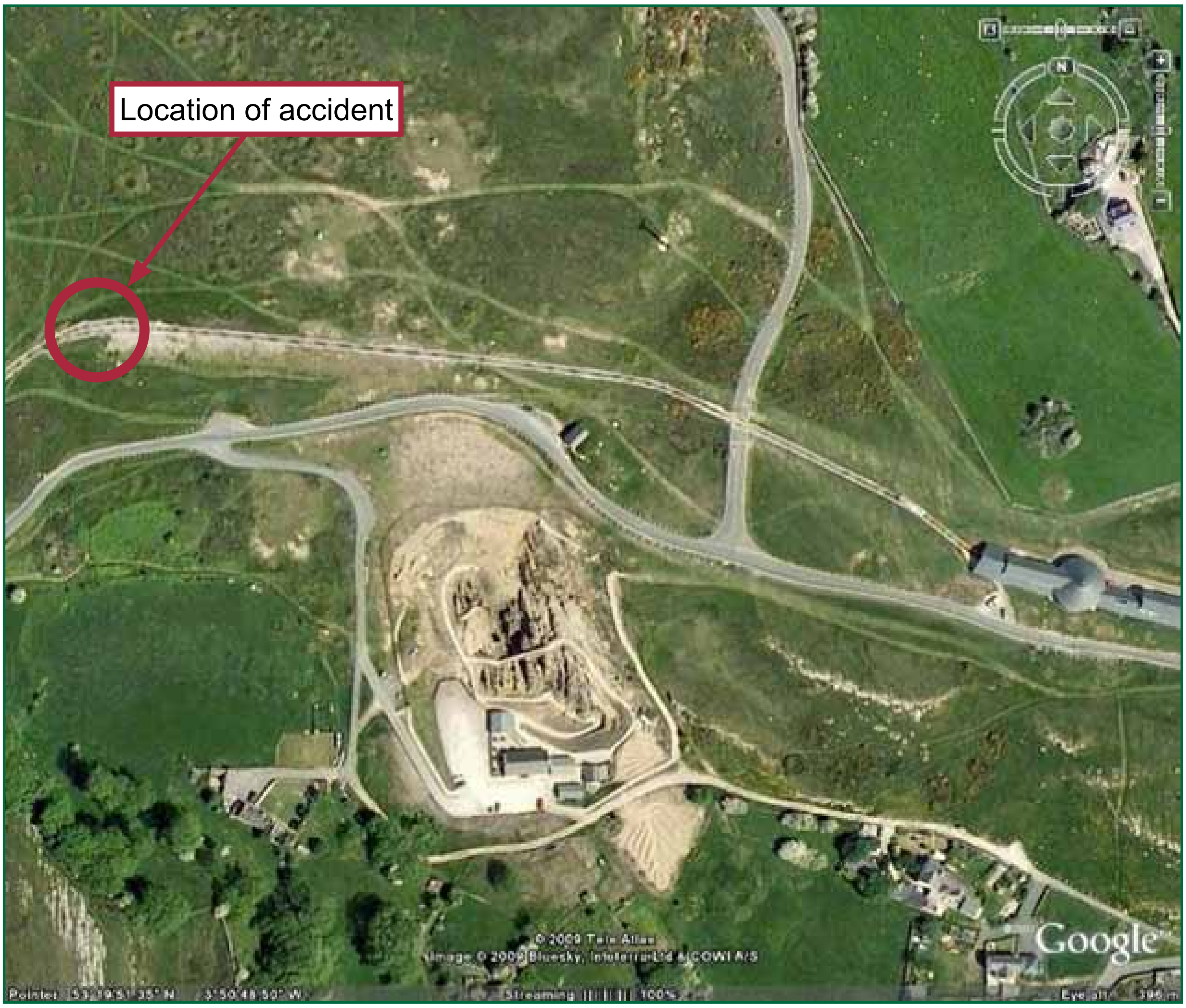

Figure 1: Aerial view of accident site showing location of accident (courtesy of Google Earth)

5 Tram 6 was travelling uphill and tram 7 downhill (figure 2). As tram 6 travelled over the lower *points* of the loop, its front *bogie* was correctly directed to the right-hand, north-side track, but its rear bogie was incorrectly directed to the left-hand, south-side track. Tram 7 was descending on the left-hand track and, although the braking systems of the winch and both trams were activated, the trams collided. The bodies of both trams were damaged in the collision (figure 3), but there was no damage to the infrastructure. The upper section of the tramway was closed for the remaining six weeks of the 2009 season.

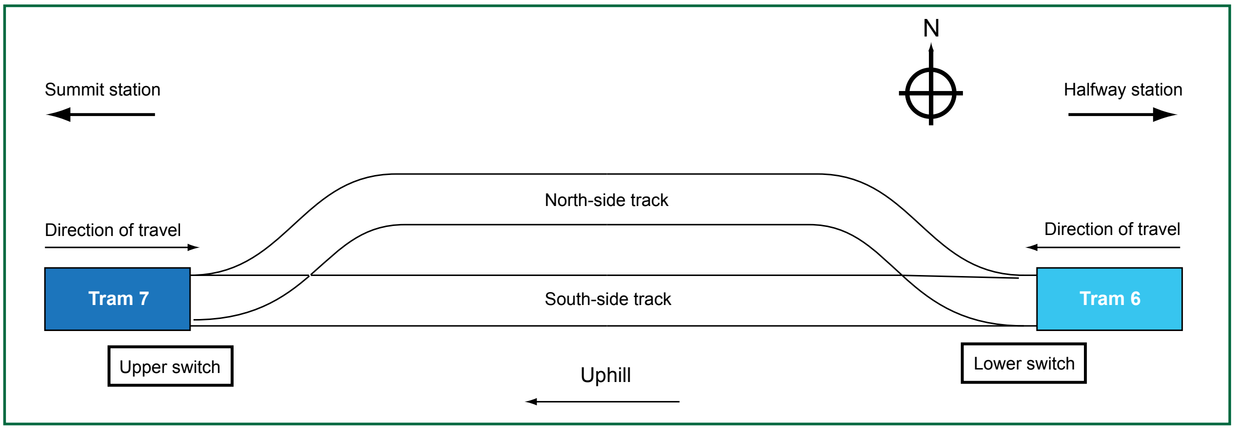

Figure 2: Plan of accident site

Figure 3: The trams after the accident

The organisations involved

6 The Great Orme Tramway is owned and operated by Conwy County Borough Council who also employed the tramway staff. There were eight full time staff including a Tramway Manager who led, directed and controlled tramway operations. The Tramway Manager reported to the Head of Engineering and Design Services within the Council who had the role of General Manager of the tramway.

7 Great Orme Tramway and Conwy County Borough Council freely co-operated with the investigation.

Location

8 The Great Orme Tramway is a cable-hauled heritage tramway which operates trams from Victoria station near Llandudno town centre to the summit of the Great Orme. There are two sections of the line: the lower section runs from Victoria station to Halfway station, and the upper section runs from Halfway station to the Summit station.

Equipment

9 Each section has its own winch and the two sections are functionally independent. Trams 6 and 7 operate on the upper section of the tramway and are connected by a cable running uphill from the trams which passes via the headwheel at the Summit station. Each tram also has a cable between it and a winch drum at Halfway station (figure 4). The trams are operated by a combination of the winchman and an attendant in each tram. The winchman controls the cable winch drums at Halfway station and the tram attendants control the manually operated tram brakes. There are cable compensators close to the winch drums which ensure that any cable slack is managed and protect the cable against shock loads.

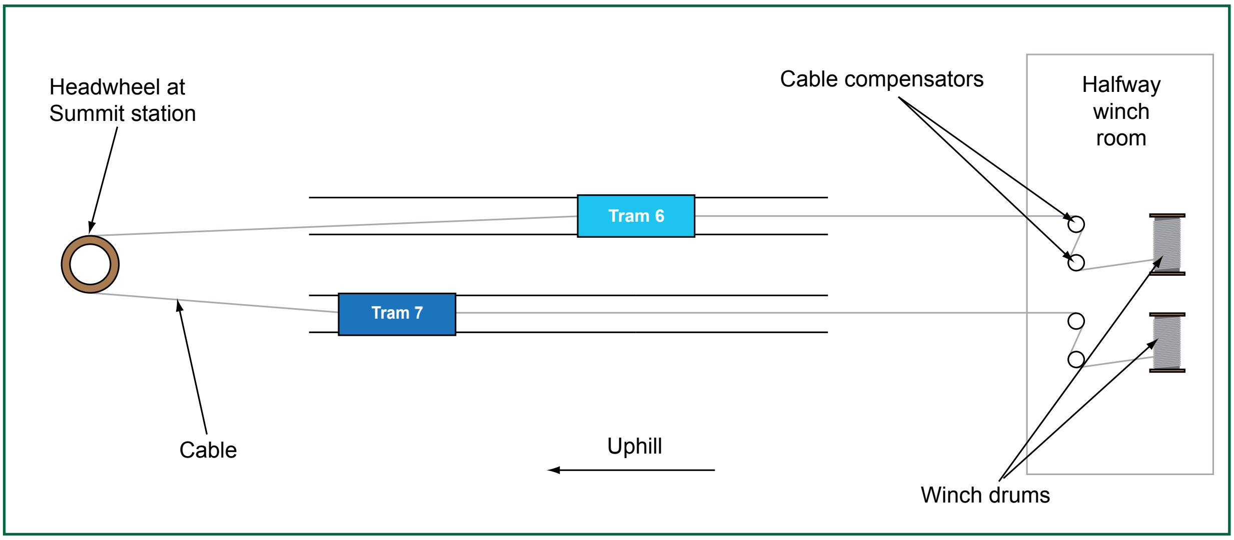

Figure 4: Schematic showing operation of the upper section

10 There are points at the upper and lower ends of the passing loop which allow the trams to enter and leave it. The loop is designed so that tram 6 always travels on the north-side track and tram 7 on the south-side track. This is irrespective of whether the trams are travelling in an uphill or downhill direction.

11 As the trams leave the loop the action of their wheels moves the points across. The points are then set in the correct positions for directing the trams to their correct tracks in the loop for their next return journeys (figure 5).

12 The passing loop and the points that were present at the time of this accident were installed between the 1999 and 2000 operating seasons. These replaced the existing track and points that had been identified as requiring renewal during an end-of-season inspection by the Council's insurance underwriter.

13 The points consisted of *loose heel switch* rails on timber *bearers*. A loose heel switch consists of switch rails that are hinged at the *heel*. This allows the rails' free ends (the toes) to be positioned for directing a tram to its intended route (figure 6).

14 The two switch rails of each point were connected together by a stretcher bar. The stretcher bar was connected to a track-side device, known as a tumbler, via a connecting rod. The tumbler was a mechanism that had a weighted lever. The lever was moved either side of its vertical position by the action of a tram leaving the loop (figure 7).

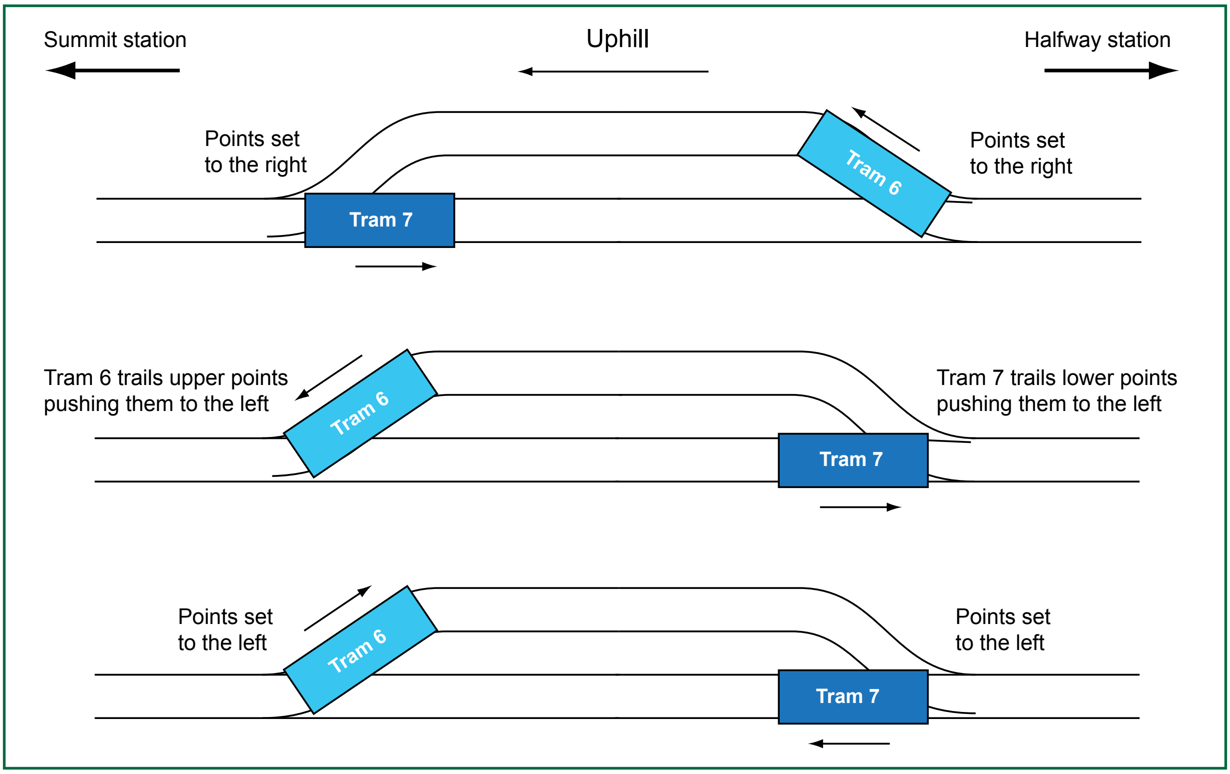

Figure 5: Operation of the upper section passing loop

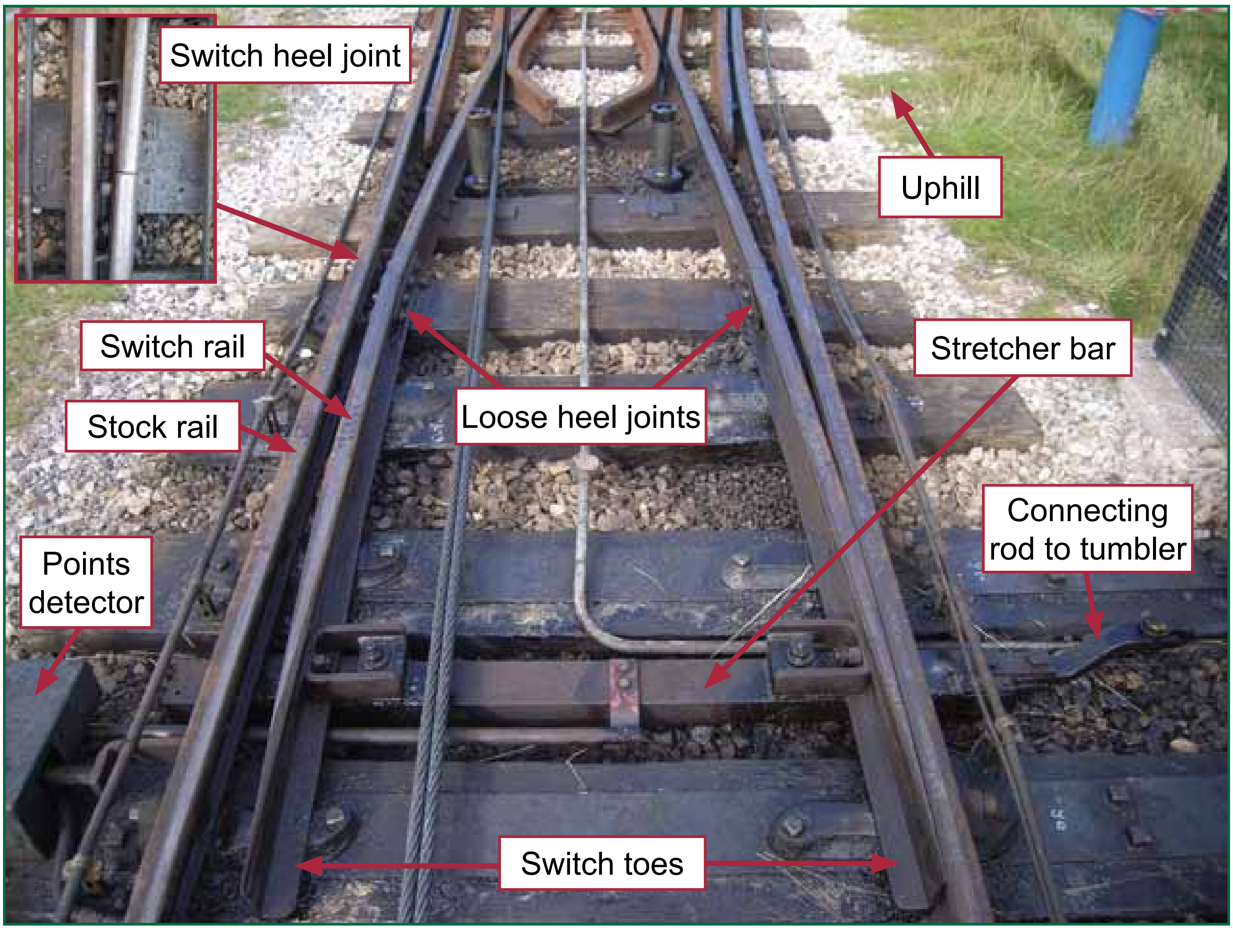

Figure 6: The lower points looking in an uphill direction

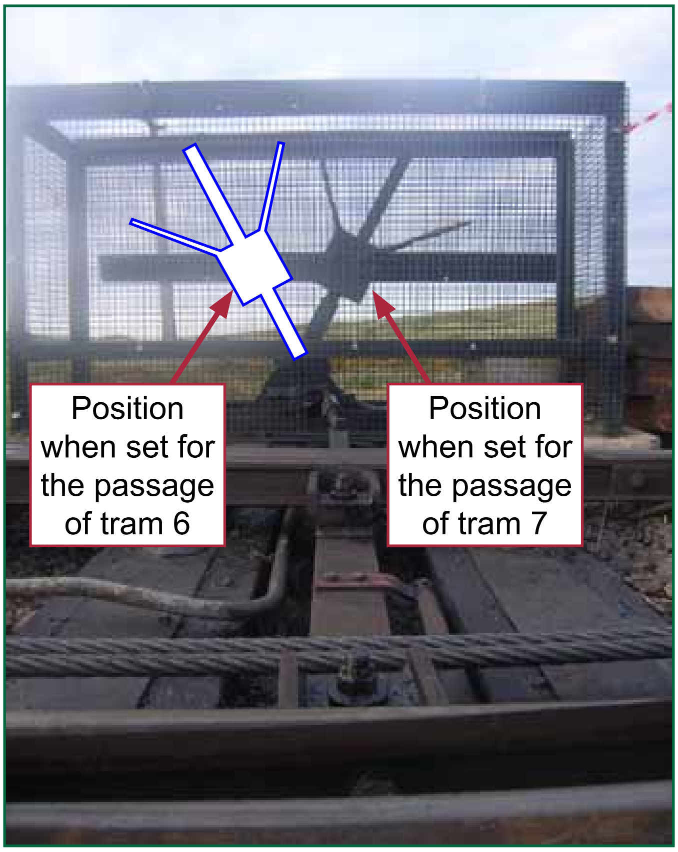

Figure 7: Tumbler weighted lever positions

15 The connecting rod was attached to an arm at the base of the tumbler. The tumbler applied a force, known as the holding force, to the points to keep them in position during *facing* tram moves.

16 When trams left the loop, the action of their wheels on the switch rails moved the tumbler lever to the other side of the vertical position and held the points for the next facing move.

17 Points position detectors were connected to each stretcher bar. These were electrically connected to a monitoring system. Their purpose was to ensure that both points were correctly set for the trams entering the loop. If the points were not in the correct position, the emergency brake on the winch would activate to stop the trams. The system had an inherent delay of approximately 1 second between the detection of an incorrect position of the points and the activation of the emergency braking.

18 Each tram was fitted with brakes which were operated by the tram attendant. These, together with the control of the winches, enabled the trams' speeds and the loading on the cable to be managed. Each tram was also fitted with an emergency stop button that when pressed activated the emergency stop of the winch. The winchman could also activate the emergency stop from his position in the winch room.

Events preceding the accident

19 The 2009 operating season began on 1 April, with no significant problems reported up to the accident on 15 September. Prior to the accident 4855 journeys had been made, a journey being one movement of the trams from downhill to uphill or vice versa.

20 On 15 September 2009 the trams had run for about two hours and there were no reported problems on the previous seven operations that day. On the incident journey there were 40 people in tram 6 and 24 people in tram 7. Each tram can carry up to 48 people.

21 As tram 6 approached the lower points in the uphill, facing direction, the tram attendant checked the position of the points. This consisted of looking both at the number '6' sign mounted on the tumbler lever (presented to him when the points were set for tram 6) and at the actual position of the points. This was a requirement of the tramway's operating procedures. The attendant was satisfied that the points were in the correct position and the journey continued.

Events during the accident

22 The trams were travelling at around 5 mph (8 km/h) as each approached the loop. Tram 7 entered the loop via the upper points and was correctly directed to the south-side track. The front bogie of tram 6 was correctly directed to the north-side track by the lower points, but its rear bogie was directed to the south-side track and into the path of tram 7 (figure 8).

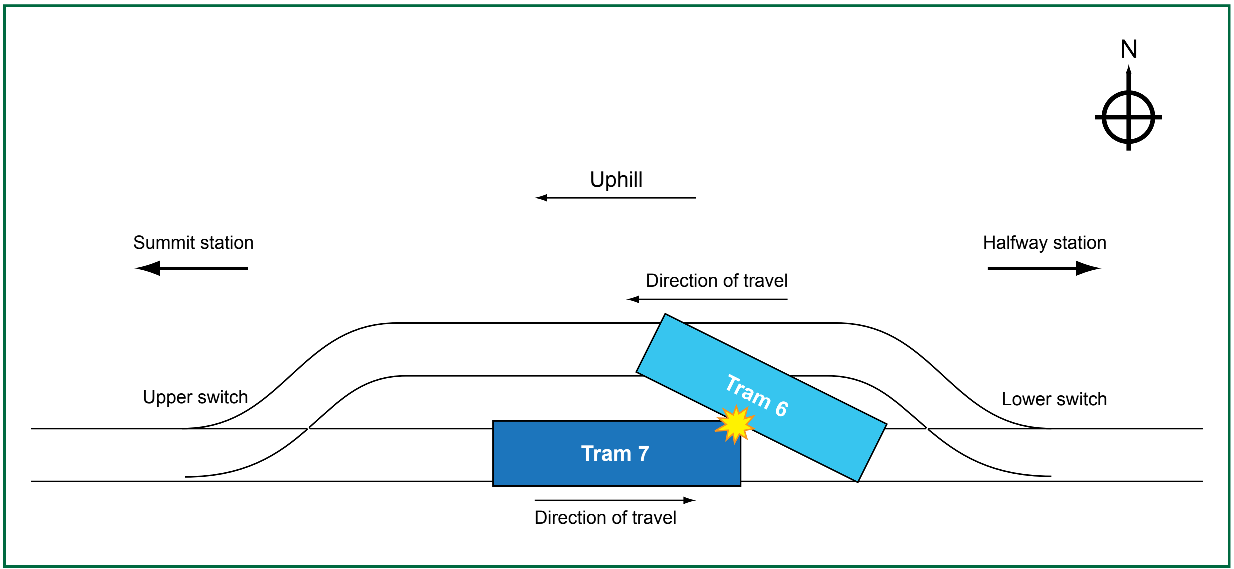

Figure 8: Positions of trams following the accident

23 The trams were braking prior to the collision. The emergency stop of the winch was activated by either the loss of correct switch position detection on the lower points (paragraph 17) or by the emergency stop buttons activated by both tram attendants and the winchman. The winchman had seen the rear of tram 6 was travelling on the wrong track on the CCTV system. Both tram attendants had operated the tram brakes as well as their emergency stop buttons.

24 The trams did not stop immediately due to the delay in the monitoring system (paragraph 17) and in the control of the cable slack by the compensators (paragraph 9). The speed of each tram was less than 5 mph (8 km/h) at the point of collision.

25 After the accident the points and the tumbler were found to be in a position set for an uphill journey of tram 7 (figure 7).

Consequences of the accident

26 There was a minor injury to one person caused by debris.

27 All wheels of both trams remained on the rails until the collision when the wheels of the front bogie of tram 6 were derailed by the impact. The bodies of both trams were damaged, but there was no damage to the infrastructure.

Events following the accident

28 The 64 passengers were evacuated by the tram attendants and the tramway personnel assisted their onward journeys by providing buses.

The Investigation

Sources of evidence

29 Evidence was obtained from the following sources:

- interviews and statements;
- evidence gathered on site;
- tests and measurements conducted by RAIB and the tramway;
- the tramway's consultant's technical report;
- photographs and videos taken by the RAIB;
- images from the tramway CCTV system, and
- procedures and records supplied by the Great Orme Tramway and Conwy County Borough Council.

Previous occurrences of a similar character

30 In April 2000 there was a collision between the same trams at the same location which injured 17 people. The track comprising the loop including the points had been replaced during the preceding closed season (paragraph 12).

31 Days before this accident tramway staff had noticed that trams leaving the loop were not moving the lower points to the correct position for their next uphill journeys. In order to keep the tramway operating before rectification works could be done a person was positioned at the lower points to ensure that they were moved to the correct position for uphill, facing movements.

32 The investigation by Her Majesty's Railway Inspectorate (HMRI) found that as tram 7 was ascending and tram 6 descending, tram 6 was correctly routed to the loop's north-side by the upper points, but the whole of tram 7 was incorrectly routed by the lower points also to the north-side. It was concluded that the person who had been drafted in from the Highways Department site security team together with the tram attendant (who was relatively new to operating on the upper section) had not noticed the incorrect position of the points immediately before the accident. The investigation identified that their training had been inadequate.

33 Subsequently the upper section was closed for repairs and modifications. These included adjustments to the points and the tumbler mechanism together with the addition of the monitoring system and the points position detectors (paragraph 17).

Key facts and analysis

Identification of the immediate cause[1]

34 **The immediate cause of the collision was the lower points moving under tram 6 directing the rear of the tram into the path of tram 7.**

35 The observations of the tram attendant (paragraph 21), together with post-accident tests of the detection and monitoring system, indicated that the points were set for the correct route prior to the arrival of tram 6.

36 Site examinations found no evidence that any of the wheels of tram 6 had derailed prior to the collision. For the front bogie of tram 6 to have been directed to the correct route, and its rear bogie to the incorrect route, the lower points must have changed position as tram 6 passed over them. This is supported by the points and the tumbler being found set for tram 7 after the accident (paragraph 25).

Identification of causal factors[2]

37 **A causal factor in the collision was the wheel forces overcoming the tumbler's holding force and changing the position of the points.**

38 The tramway CCTV images show that there was no one close to the points at the time of the accident. Movement of the points by manual intervention has therefore been discounted.

39 Following the accident, tests with empty trams indicated that forces from the wheels of tram 6 were attempting to change the position of the points whilst passing over them in a facing direction.

40 RAIB video images of the tests show that the toes of the lower points moved to the right by 10 mm when the leading bogie of tram 6 passed over the points in an uphill direction. During these tests the weighted tumbler lever moved towards the vertical position before falling back to its original position once the leading bogie had passed over the heel joints.

41 Tests conducted by the tramway's consultant found that the distance between the fully open switch rail and its *stock rail* was 98 mm (the toe opening). With the weighted lever moved from the position set for tram 6 to the vertical, the toe opening on the left-hand switch rail was recorded as 28 mm. With the weighted lever moved from the position set for tram 7 to the vertical, the toe opening on the right-hand switch rail was recorded as 43 mm. For a set of points and a tumbler which is balanced in both directions, it would be expected that these values would be approximately the same.

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

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

42 The force from the weighted lever tends towards its maximum when the lever is at one or other of its resting positions and reduces to zero when in a vertical position. The movement of the tumbler lever during these tests showed that there was sufficient energy from the wheels via the switch rails to accelerate the weighted lever towards a more vertical position and overcome its at-rest holding force.

43 RAIB observations showed that as the left-hand wheels of the leading bogie passed over the heel joint of the left-hand switch rail, the switch rail moved about a pivot formed by contact between the switch rail head and the adjacent stock rail head. This was at a point approximately half way along the switch rail (figure 9). The resulting switch rail deflection to the left at the heel led to the toes of the points moving to the right.

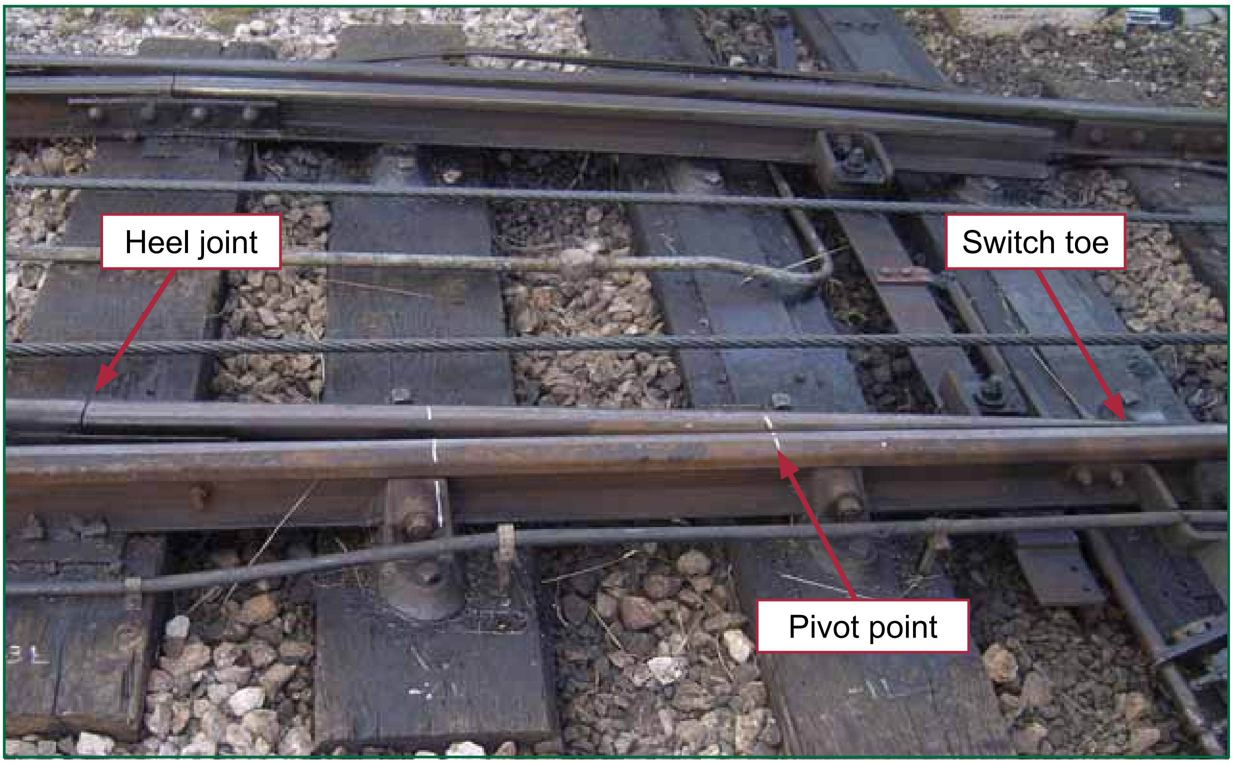

Figure 9: Left-hand switch and stock rails of the lower points

44 Although this lever action caused by lateral forces on the closed-side switch rail is considered to be the predominant mechanism in moving the points, vertical movements of both switch rails were observed as the wheels passed over the heel joints. These may have assisted the movement of the points by reducing any frictional resistance of the switch rails on the *slide chairs* near the toes of the points.

45 Although the tests did not reproduce a full reversal of the points, they demonstrated a plausible explanation for a change of position under the tram during the accident. Different conditions at the time of the accident to those during the tests, e.g. greater wheel loads due to carrying passengers and a speed that is likely to have been different, would change the level of energy given to the tumbler.

Wear and degradation of the points and the tumbler

46 **The effectiveness of the holding force on the points had reduced due to wear and degradation of the points and the tumbler. This is a causal factor.**

The points

47 The track geometry affected both the levels of rail forces and the way in which they overcame the holding force of the tumbler.

48 The alignment of the track changed significantly at the heel of the lower points in directing tram 6 to the right when travelling uphill, whereas the track for tram 7 followed a gentler left-hand curve. The RAIB video images of the tests showed that the left-hand leading wheel of the leading bogie was in flange contact with the left-hand switch rail before it reached the heel joint (figure 10). While flange contact is not an uncommon feature in tramway operations, it can result in high lateral rail forces. The change in geometry to the right at the heel area would have further increased this lateral force.

Figure 10: Flange contact between leading left-hand wheel and left-hand switch rail

49 The *track gauge* through the points was up to 13 mm wide with signs of lateral movement of some of the slide chairs. There was evidence of up to 5 mm of lateral movement of the left-hand *closure rail* at the bearer beyond the heel of the points. The track gauge at the heel changed from an excess of 8 mm to 0 mm over a distance of 670 mm in an uphill direction. This change in gauge over such a short distance would also have assisted in increasing the lateral wheel forces beyond those normally expected and hence those imparted to the switch rail. The widening of the track gauge was likely to be due to deterioration of the bearers within the points.

50 The rail heads of the points should be level across the track gauge by design. The RAIB measured up to 12 mm of *static cross-level* through the points between the switch toes and the heel. Cross-level is principally controlled by the support conditions of the bearers and the ballast. Gaps were observed under some of the chairs. This affected the support of the tram wheels, with the cross-level differences probably increasing under the weight of trams. This would have changed the vertical forces seen by the switch rails, altering the frictional forces between rails and the slide chairs and affecting the lateral forces on the tumbler (paragraph 44).

The tumbler

51 The holding force of the tumbler has to be sufficient to ensure that the points do not move when trams travel over the points in a facing direction. The force also has to be low enough to allow the trams to reposition the points when leaving the loop. There is no locking of the points in either position.

52 Measurements by the tramway's consultant after the accident found an imbalance between the holding forces from the tumbler in each of its resting positions, albeit this was measured at the tumbler and not at the switch rails. The holding force was less for the position set for tram 6 than for tram 7.

53 In both positions a lever was applied to manually open the closed-side switch rails. Although no force values were measured, the tramway's consultant found that the tumbler provided less resistance to moving the points away from the position set for tram 6 than that set for tram 7 ie they were unbalanced. This is probably due to one or a combination of the following:

- different stiffnesses of each switch rail and variations between the restraint conditions at each heel joint;
- variations in the friction conditions between each switch rail and its slide chairs. Gaps up to 3 mm were measured by the RAIB under the right-hand switch rail;
- differences in the angles between the two resting positions of the tumbler lever leading to unequal tumbler holding forces;
- differences in the angles of the arm at the base of the tumbler (paragraph 15) in each position affecting the forces delivered to the connecting rod in each direction, and
- the gauge widening of the stock rails at the switch toes would have led to changes in the holding forces of the switch rails.

Point locking

54 The points at the upper loop did not have a facing point lock. This is a causal factor.

55 Both points were of a trailable type ie their positions are changed by trams pushing the switch rails across as they leave the loop. For this reason conventional facing point locking, where the points are held in position by some form of positive mechanical engagement, was not employed. Office of Rail Regulation (ORR) guidance, in the form of Railway Safety Publication 2, Guidance on Tramways, does not require locking on points used on tramways.

Points Inspection and Maintenance

56 **The Great Orme Tramway did not routinely measure the condition of the points and the tumbler mechanism because they did not have procedures for such measurements and for associated remedial actions. This is a causal factor.**

57 The tramway had an operations manual which formed part of its safety management system (SMS). The operations manual was created in 2001 following the previous accident and the Tramway Manager had continued to develop it up to the accident.

58 The section of the operations manual relating to track maintenance gave instructions to the tramway staff to undertake daily visual checks of the track and the points before operations began. The RAIB has evidence that these daily checks were carried out.

59 The operations manual contained no procedures for track geometry and tumbler inspection and maintenance. Although the daily checks were done, they are solely visual and would only detect gross track geometry changes. As they did not involve measuring and recording pertinent track geometry features, they did not capture information relevant to the management of wear and degradation of the points.

60 There was instruction on general point oiling and greasing, and an annual detailed inspection on the tumbler to assess its wear. There was no means of adjusting the forces provided by the tumbler to account for wear. Wear within the tumbler mechanism was a known issue as the tumbler had been refurbished in the past, although no measurements of the mechanism had been recorded.

61 Although there were some dimensions defined for the plain line track geometry, there were none specific to points. There were no dimensional checks required to confirm the condition of the points and their holding mechanism. There were no records that indicated that maintenance had been carried out on the points since they were replaced in 2001.

Identification of underlying factors[3]

Risk assessment of the points

62 **The lack of a comprehensive risk assessment of the points was an underlying factor.**

63 A requirement of the Railways and Other Guided Transport Systems (Safety) Regulations 2006 (ROGS) is that all rail operators ensure the control of all categories of risk associated with the operation of the transport system and that this forms a part of the operator's safety management system.

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

64 The tramway's operations manual contained a risk assessment relating to the points on the upper section. At the time of the accident this contained three risks. Two of these related to the gross failures of the tumbler and the connection between the tumbler and the points. The third risk was loss of operation due to vandalism. A numerical risk ranking had been given to these risks although the effects of each were not documented. No other risks associated with the points had been identified.

65 The tramway had not carried out an analysis of the design of the points on its system and the potential modes of failure and their effects. In particular the potential for the points to malfunction due to the gradual wear and degradation of the points did not feature in the risk assessment.

Monitoring, audit and review

66 **The lack of competent audits was an underlying factor.**

67 *Duty holders* have a responsibility, under the ROGS regulations, to put in place a safety management system and ensure compliance with it. There is no requirement for the ORR to carry out audits of compliance with the SMS, unless they have specific concerns.

68 The Council's Health and Safety Policy for the tramway stated that safety audits by the Council must be carried out. The RAIB was provided with no evidence that any such audits had been carried out.

69 The tramway's operations manual summarised the roles and responsibilities of the Council. Included in this was a requirement to ensure that all maintenance procedures were in place and that a bi-annual safety tour was conducted. No evidence was made available to the RAIB that these duties had been carried out.

70 It is likely that a comprehensive and competent technical audit would have identified the lack of inspection and maintenance procedures for the track including the points.

Conclusions

Immediate cause

71 The immediate cause of the collision was the lower points moving under tram 6 directing its rear into the path of tram 7 (paragraph 34 and **Recommendation 1**).

Causal factors

72 A causal factor was the wheel forces overcoming the tumbler's holding force and changing the position of the points (paragraph 37 and **Recommendation 1**). This was a result of three factors:

- the effectiveness of the holding force on the points had reduced due to wear and degradation of the points (paragraph 46);
- the points did not have a facing point lock (paragraph 54), and
- there were no procedures in place to routinely measure the condition of, or undertake remedial actions upon, the points (paragraph 56).

Underlying factors

73 The underlying factors were that:

- there was a lack of a comprehensive risk assessment of the points (paragraph 62 and **Recommendation 1**), and
- there was a lack of competent audits by the tramway and the Council (paragraph 66 and **Recommendation 2**).

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

74 Over the closed period between October 2009 and March 2010, the tramway has undertaken remedial work on the upper loop, including:

- correcting the vertical alignment (cross-level and gradient) by lifting the track and adding approximately 70 tonnes of ballast;
- adding ballast retention boards to reduce the movement of ballast on the embankment;
- correcting the lateral alignment of the track;
- renewing deteriorated sleepers and bearers (paragraph 49);
- providing additional support to the heel areas of the points; and
- measuring and overhauling the tumblers, including adding a variable length arm to allow the output force from the tumblers to be adjusted.

75 The tramway has also investigated the operation of the monitoring system (paragraph 17) to understand possible failure modes and to inform future inspection and test procedures. The tramway is in the process of undertaking risk assessments and reviews of inspection and maintenance procedures.

76 On 20 March 2010 the upper section of the tramway was reopened following the works and a period of trial running.

Recommendations

77 The following safety recommendations are made[4]:

Recommendations to address causal and contributory factors

1 *The purpose of this recommendation is to identify and mitigate risks associated with the design, operation and maintenance of points installations.*

Conwy County Borough Council should conduct a competent technical evaluation of the points and crossings on the Great Orme Tramway. This should include an analysis of the failure modes and their effects. Risks identified should be documented and control measures incorporated in the safety management system and procedures. Control measures should include, but not be limited to, checks, measurements and inspections and their periodicity, limits on track geometry and other components which affect the operation of the points and actions to be taken on reaching those limits.

2 *The purpose of this recommendation is to promote effective monitoring of the condition of equipment, operations and maintenance of the Tramway.*

Conwy County Borough Council should ensure that comprehensive and competent audits are carried out to identify any deficiencies associated with the operation and maintenance of the Tramway. The audits should include checks of the condition of tramway equipment and surveillance of safety critical work activities.

[4] 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 ORR and Conwy County Borough Council 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.

Appendices

Appendix A - 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.

Bearers	Sleepers supporting the points.
Bogie	A metal frame equipped with two or three wheelsets and able to rotate freely in plan, used in pairs under rail vehicles to improve ride quality and better distribute force to the track.*
Closure rail	The rail between the heel of the switch and the crossing.
Duty holder	An organisation, or person which has a duty imposed on them by the law intended to protect the health and safety of employees and/or other persons.
Facing	The direction of travel of a rail vehicle approaching points from a single line towards the two diverging routes.
Heel	The point at which the switch rail of a loose heel switch pivots.*
Loose heel switch	Points in which the switch rails are not fastened to the stock rails, but pivot about a heel joint.
Points	A set of switches whose purpose is to divert rail vehicles from one line to diverging routes or vice versa.
Static cross-level	The difference in vertical level between the two running rails when there is no train present on the track.*
Slide chairs	A baseplate that supports the switch rails and has a flat surface to allow them to be moved laterally.
Stock rails	The fixed rails within a set of points.
Track gauge	The distance between the running edges of the running rails of the track.

This report is published by the Rail Accident Investigation Branch,
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