



Rail Accident Investigation Branch

Rail Accident Report



Passenger train derailments on the Ravenglass & Eskdale Railway 29 May & 5 July 2006

Department for
Transport

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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 accidents, and improve railway safety.
- 2 The RAIB does not establish blame, liability or carry out prosecutions.
- 3 Access was freely given by Ravenglass and Eskdale Railway (R&ER) to their staff, data, records and facilities for the purpose of this investigation.
- 4 Appendices at the rear of this report contain glossaries explaining the following:
 - acronyms and abbreviations are explained in Appendix A; and
 - certain technical terms (shown in *italics* the first time they appear in the report) are explained in Appendix B.
- 5 Throughout this report, vehicle and track components are described as ‘left’ and ‘right’ relative to the direction of travel.

Summary of the report

Key facts

- 6 On 29 May 2006, a diesel locomotive hauled passenger train was travelling from Dalegarth to Ravenglass when the leading bogie of the sixth coach derailed at 13:40 hrs, on the exit from a left hand curve (known as Spout House Curve) located approximately 5.75 miles (9.2 km) from Ravenglass. The derailment took place at 10-12 mph (16-19 km/h); there were no casualties and no significant damage to either the track or train.
- 7 On 5 July 2006 at 10:45 hrs, another diesel locomotive hauled passenger train, travelling from Dalegarth to Ravenglass was passing through Millwood Bank, located approximately 1.5 miles (2.4 km) from Ravenglass, when the leading bogie of the fifth coach derailed while travelling at 15-18 mph (24-29 km/h). The derailed coach, which was different in design from the coach in the first accident, was empty (*tare*) at the time. There were no casualties and no significant damage to the track or the train.

Conclusions

Derailed at Spout House Curve

- 8 The immediate cause of the derailment was *flange climb* of the leading right wheel of coach 134, due to the combination of a vehicle fault and the track condition. Derailment of the leading wheelset was followed immediately by the trailing wheelset.
- 9 The investigation found two causal, several contributory factors and one underlying factor.
- 10 The first causal factor was restricted movement of the leading left *axlebox* due to insufficient clearances between it and the bogie *horn guides* within which it slides. This led to excessive loading of the leading left wheel and a corresponding excessive unloading of the leading right wheel at the point of derailment (POD). The contributory factor which led to this was:
 - there was no specific requirement to check the clearances of axleboxes in their horn guides, or lubricate this interface, during periodic maintenance.
- 11 The second causal factor was *flange contact* between the leading right wheel and rail which gave rise to lateral forces on that wheel sufficient to cause flange climbing under the excessive wheel unloading condition arising from the first causal factor. The contributory factors which led to this flange contact were:
 - the presence of voiding below the right hand rail at the POD;
 - the normal curving behaviour of rail vehicles; and
 - the normal narrowing of the *track gauge* from the curve to the adjoining straight track.
- 12 The underlying cause of the derailment was that possible failure modes of the suspension and the sensitivity of vehicles to tolerances in track condition had not been adequately accounted for in existing maintenance procedures.

Derailment at Millwood Bank

- 13 The immediate cause of the derailment at Millwood Bank was flange climb of the leading right wheel of coach 110, due to a combination of vehicle, track and operational factors, which resulted in an excessive amount of vehicle *sway* and wheel unloading. The trailing wheelset derailed when the leading bogie struck the timbers of a level crossing, approximately 0.3 miles (0.5 km) further along the track.
- 14 The investigation found three causal, three contributory factors and one underlying factor.
- 15 The first causal factor was the lack of timely remedial action to known rough track conditions at Millwood Bank, where there were sufficient *voiding*, *alignment* and *cant* problems to cause excessive vehicle sway and pose a derailment risk when combined with the other prevailing conditions described below. The contributory factor which led to this was:
 - an existing system for reporting track faults had not been mandated and was not being used and therefore the urgency of repairs was not adequately conveyed to track maintenance staff.
- 16 The second causal factor was that the train speed was excessive for the track condition, causing resonance between the frequency of track input forces and the natural sway frequency of the vehicle. This led to an increasing sway amplitude and wheel unloading as coach 110 approached the POD. The contributory factor which led to this was:
 - there was no temporary speed restriction at Millwood Bank to alert drivers about the need for caution through the rough track.
- 17 The third causal factor was that the bogie suspension set up which, in the tare condition, reduced the leading bogie's tolerance to degraded track features and caused excessive wheel unloading. The contributory factor which led to this was:
 - a previous suspension modification to improve ride quality, had removed the flexibility between the bogie frame and wheelset in the unloading direction.
- 18 The underlying cause of the derailment was that the hazards caused by the rough track condition at Millwood Bank and the sensitivity of the saloon type coaches to excessive sway, particularly at speeds higher than about 15 mph (24 km/h), were not sufficiently recognised.

Recommendations arising from both accidents

- 19 Recommendations can be found at paragraph 107. They relate to the following areas:
- a fleet check of axlebox clearances and its inclusion in ongoing maintenance practice;
 - examination of the track to identify current and likely future areas of poor track condition and remedial work where necessary, particularly with regard to voiding;
 - development and implementation of a vehicle maintenance regime which is based on the assessment of hazards identified from both past experience and analysis of possible future failure modes;
 - briefing of operational staff on the signs of and risk from excessive vehicle sway;
 - review of the existing track fault reporting system, reaction to reported faults and mandating of the system;
 - implementation of a system to identify track faults liable to cause excessive sway and when mitigation measures should be triggered;
 - review of the existing suspension set up on ‘Severn Lamb’ type bogies to ensure it is consistent with track condition;
 - improving the lubrication at vehicle body/bogie interfaces.

Details common to both derailments

20 This report deals with two derailments that took place on 29 May 2006 at Spout House Curve and on 5 July 2006 at Millwood Bank. Following this section, which provides general details common to both derailments, each derailment is reported separately from paragraph 32 onwards, before common recommendations are made at paragraph 107.

The infrastructure

21 The R&ER is a seven mile long narrow gauge heritage railway which has been operating passenger trains on 15 inch (381 mm) gauge track since 1915. A route map is shown in Figure 1. The single line has three passing loops at Miteside, Irton Road and Fisherground, which divide the railway into four operating sections. Turntables are located at Ravenglass and Dalegarth to turn around locomotives.

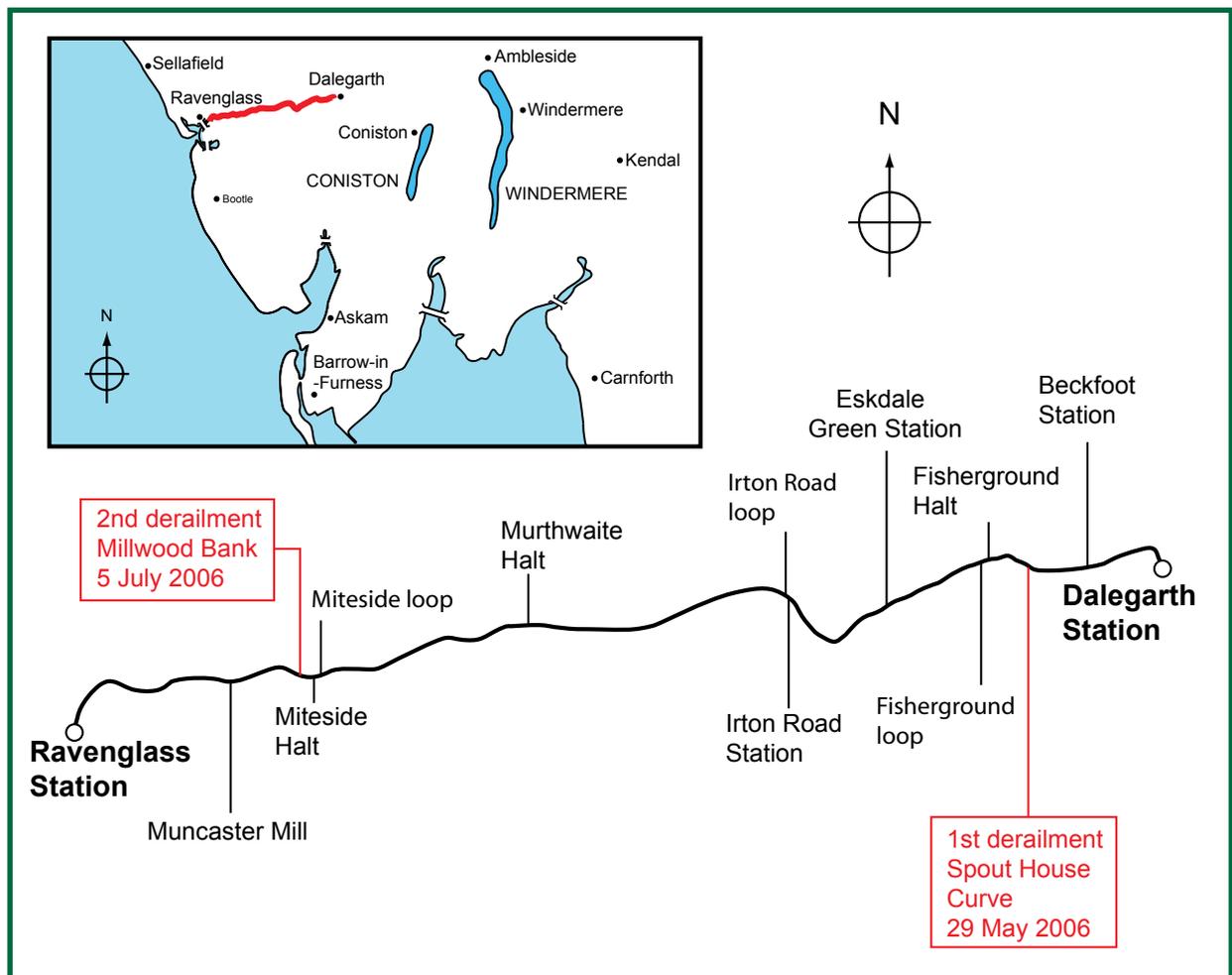


Figure 1: Location of Ravenglass & Eskdale Railway and route map showing derailment sites.

- 22 The track is constructed from 35 lb/yd (17.4 kg/m) rail fastened by *elastic spikes* or *coach screws* onto hardwood sleepers spaced every 3 ft (0.91 m) and laid on a foundation of limestone ballast.
- 23 The general maximum line speed was 20 mph (32 km/h). There are 10 mph (16 km/h) permanent speed restrictions (PSRs) at six locations including Spout House Curve and one 5 mph (8 km/h) PSR on the approach to Dalegarth station.
- 24 The left hand curve at Spout House Farm, the site of the first derailment, has a radius of 400 ft (122 m). Figure 2 shows the site of the derailment on the exit from this curve.



Figure 2: Site of derailment at Spout House Curve.

- 25 The curve at Millwood Bank, is a shallow right hand curve in the *Down* direction (ie towards Ravenglass) with a radius of approximately 1400 ft (427 m). Figure 3 shows the derailment site.

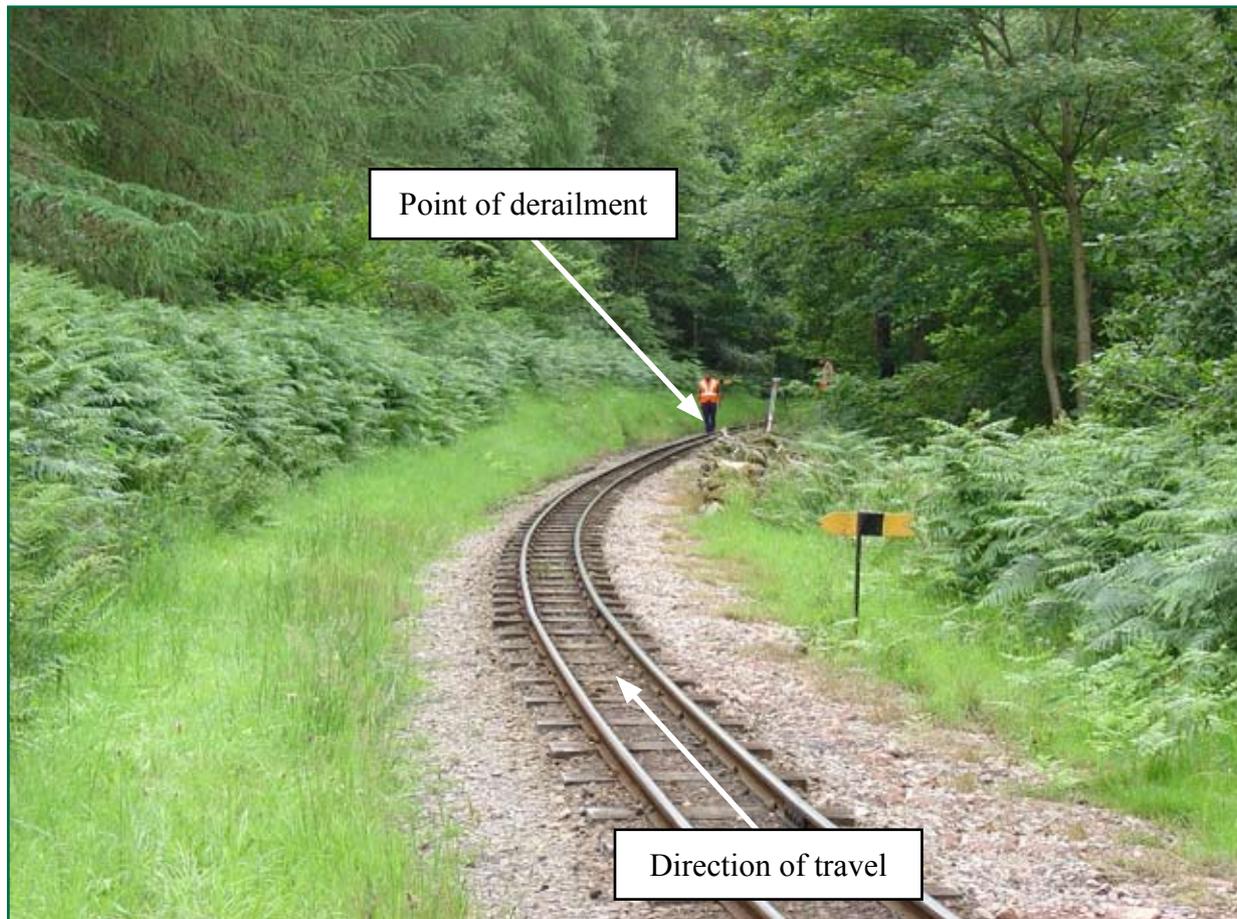


Figure 3: Site of derailment at Millwood Bank

- 26 Trains are controlled by radio communication between drivers and the duty controller located at Ravenglass signal box. Trains may only proceed from one section to another on the authorisation of the duty controller and pass each other at the passing loops.

The parties involved

- 27 The infrastructure and rolling stock are owned and operated by R&ER. All personnel involved in operating the railway at the time of the incidents were full time employees of R&ER, with the exception of the guards who were volunteers.

External circumstances

- 28 The weather at the time of both derailments was dry and warm. The rail head condition was clean and dry at both derailment sites.

Consequences of the accidents

- 29 There were no fatalities or injuries in either of these accidents.
- 30 There was no significant damage to the track in either accident. The derailed wheels at Spout House had marked the rail head and hardwood sleepers but these did not require repair. In the derailment at Millwood Bank, the derailed bogie caused minor damage to some sleepers and the timber crossing at Muncaster Mill.
- 31 Damage to the rolling stock in both accidents was also minor.

Accident details - Spout House Curve

- 32 On 29 May 2006, the 12:10 hrs departure from Ravenglass left on time and completed an uneventful journey to Dalegarth (Figure 1). Following a 40 minute lay-over, the train left Dalegarth at 13:35 hrs and proceeded to Spout House Curve without any indication of unusual vehicle behaviour.
- 33 The train comprised diesel locomotive ICL11 hauling two semi-open coaches (serial numbers 108 & 116) and 5 'Maxi' coaches (serial numbers 131, 132, 133, 134, 135). The derailed coach 134, which is one of six 'Maxi' coaches in the total passenger fleet of 46 vehicles, is shown in Figure 4.



Figure 4: 'Maxi' Coach No. 134

- 34 The train entered the left hand curve at Spout House Farm, located between the stations at Beckfoot and Fisherground (Figure 1) at a speed of 12-13 mph (19-21 km/h). As coach 134 exited the curve, its leading bogie derailed to the right hand side of the track. The bogie's right hand side suspension then collapsed and the equalising beam and springs (Figure 6) on that side came adrift. Both wheelsets remained sufficiently guided by the bogie frame for the wheels to continue running on the sleepers with the vehicle body upright. The derailment site is shown in Figure 2.
- 35 The guard, who was located near the middle of the train, noticed something was wrong and applied the train brake. In response to this, the driver also applied the train brake using his locomotive brake controller (part of the same system as the guard's train brake), bringing the train to a controlled stop approximately 35 m beyond the POD. The time of derailment was estimated at 13:40 hrs. There were 4 people riding in coach 134 at the time, two people over each bogie pivot.

- 36 The driver and guard inspected the derailed bogie, checked on the welfare of passengers and made arrangements for recovery. It was decided to split the train between coaches 133 and 132, and take the front portion forward to Ravenglass with the passengers. A brake facility remained at the rear of coach 132, where the guard sat, by means of an accessible brake valve which could have applied the train brake if required. Coaches 133 (brake saloon), 134 and 135 were left behind on site.
- 37 Re-railing of coach 134 commenced at approximately 14:15 hrs and was completed by 15:20 hrs. Coach 133 was pushed forward to Fisherground loop and coaches 134 and 135 were hauled back to Dalegarth by another locomotive. The line was open to traffic at 15:47 hrs.
- 38 R&ER stopped further running of the 'Maxi' coaches until the cause of the derailment was understood.

The Investigation - Spout House Curve

Sources of evidence

- 39 The derailment at Spout House Curve was notified to the RAIB at 09:12 hrs on 30 May 2006. The late notification occurred because the R&ER duty controller at the time had not been briefed about the requirement to notify the RAIB immediately in the event of a *schedule 1* type accident and those R&ER staff who were aware had become engrossed in the recovery and forgot to remind the duty controller. As a consequence the RAIB were not able to control the early collection of evidence on site.
- 40 Subsequently, the RAIB undertook examinations of the track and the derailed vehicle on 7 and 29 June 2006. Interviews with key personnel and running track tests were also carried out. For the running tests the derailed bogie was rebuilt with the same components and fitted back onto coach 134. The original train formation from 29 May 2006 was marshalled and run through the derailment site at Spout House Curve. A video record was made of the dynamic motion of the leading left and right axleboxes, flange contact of the leading right wheel and rotation of the leading bogie through the curve, in four separate passes through the derailment site. The reconstruction was valid because there was no relevant damage to the track at Spout House Curve or coach 134 which could have caused unrepresentative behaviour of the vehicle.

Key evidence

Train operation

- 41 The driver of the train had been a full time employee of R&ER since 1996 and with 20 years volunteer service prior to that. He had been retrained and passed to drive locomotive ICL11 in May 2006. He felt well on the day of the incident.
- 42 The operation of the train leading up to the accident was uneventful. The speed of entry into the left hand Spout House Curve was estimated at 12-13 mph (19-21 km/h). This entry speed was in excess of the 10 mph speed limit in that area, reportedly to allow for the expected speed reduction through the curve due to the uphill gradient.
- 43 As is usual driving practice with locomotive ICL11, the driver also had to maintain slight power through the curve to avoid the characteristic braking effect of the locomotive's hydrostatic transmission when power is off. The speed on exit from the curve is estimated to have been 10-12 mph (16-19 km/h).

Track

- 44 Details of the track marks on site and the position of the derailed bogie's suspension components which came adrift (paragraph 34) were obtained from track inspections and interviews with staff, who had been on site immediately after the accident. This provided sufficient information to locate the point of derailment (POD) at the exit from the curve and to determine that the mechanism of derailment had been flange climb of the leading right hand wheel of coach 134. Post derailment marks on the sleepers also indicated that the trailing wheelset had derailed almost immediately after the leading wheelset. Coil springs and the equalising beam from the right side of the bogie (Figure 6) were found in the ballast beyond the POD.

- 45 When inspected by RAIB, on 7 June 2006, the *track top*, alignment and general condition of the rails, sleepers and fastenings was satisfactory. However, some voiding below the right hand rail at the POD, estimated to be approximately 3 mm deep, had been found by R&ER and repaired on the morning after the accident, before the RAIB had been notified.
- 46 The track gauge narrowed from 15¼ inches (387 mm), 2 sleepers before the POD to 15 inches (381 mm) 1 sleeper before the POD. The cant varied from a maximum of ¾ inch (19 mm) 10 sleepers before the POD to zero (ie level) 4 sleepers before the POD. These values are generally in accordance with R&ER's standard track design parameters.

The derailed vehicle (coach 134)

- 47 The sliding interface between the body and leading bogie *bolsters* was devoid of grease in the load bearing areas (Figure 5) and there was evidence of metal pick up and scoring indicating a high level of friction between the surfaces.

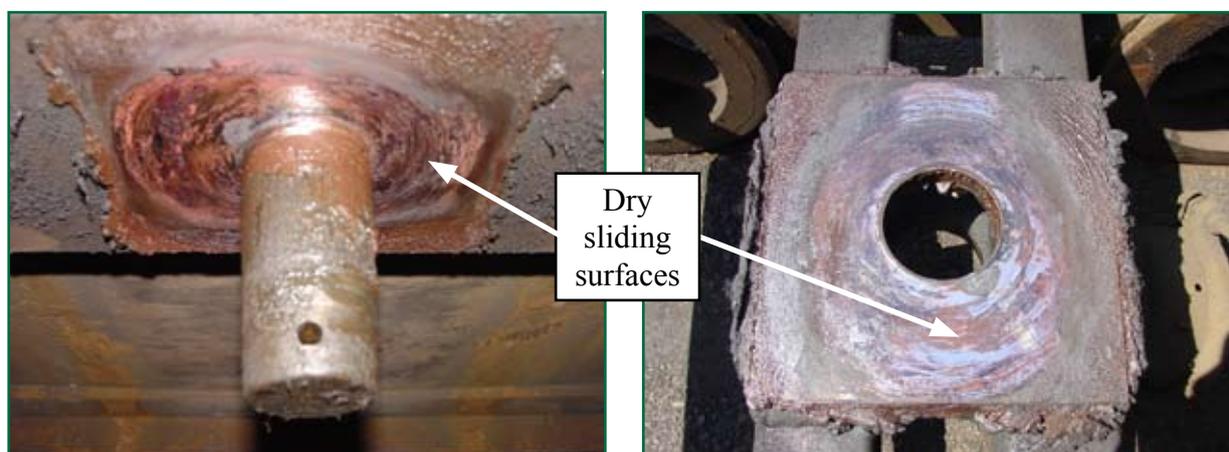


Figure 5: Vehicle body bolster (left) and bogie bolster (right)

- 48 On the leading bogie, the longitudinal clearance between the leading left axlebox and its horn guides (Figure 6) was 0.3 mm (ie 0.15 mm per side). This was much smaller than the corresponding clearances on the other three axleboxes, which varied between 1.7 mm and 4.3 mm. The lack of clearance on the leading left axlebox was due to a combination of the bearing and horn guide spacing being slightly bigger and smaller respectively, than at the other three axlebox positions. The sliding surfaces were dry, without any oil or grease lubrication. Parts of the inboard surface were also scored and pitted indicating that there had been high friction between the two surfaces and that free movement of the axlebox had been restricted. This was later found to be the case (paragraph 50).
- 49 The left leading axlebox had been changed around March 2001, when the previous one was found to be cracked, and had run without incident for several years.

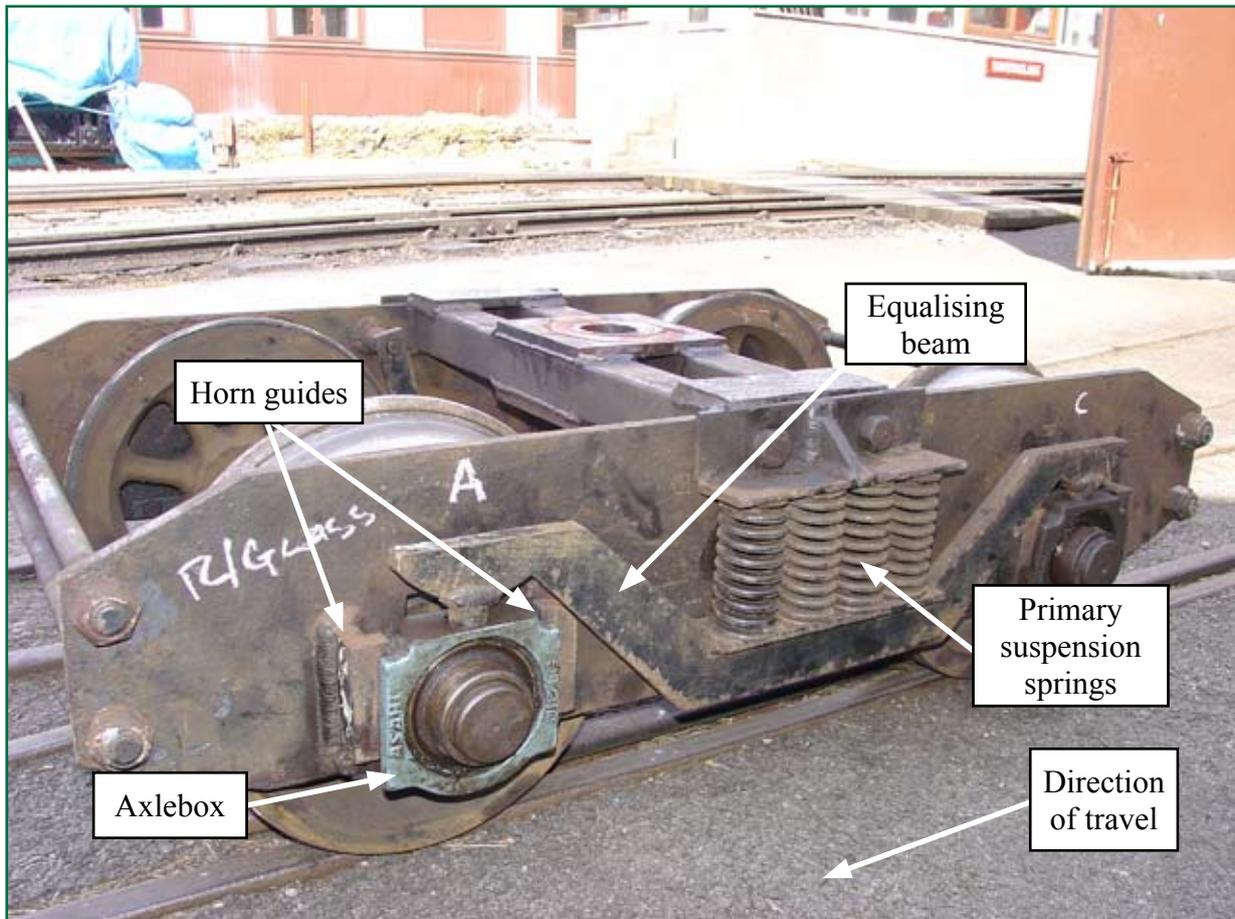


Figure 6: Derailed bogie of coach 134 (after reassembly)

50 Analysis of the video footage recorded in the running tests through Spout House Curve (paragraph 40) was undertaken to generally assess the motion of the axleboxes on the leading wheelset through the curve and quantify the amount of wheel unloading leading up to the POD. To obtain the latter, video analysis computer software was used to measure the vertical movement of each axlebox relative to the bogie frame on approach to the POD as the suspension springs compressed or extended. These measured deflections were then converted into proportions of the static wheel load using a calibration factor obtained when the vehicle body was lowered onto bogies during reassembly (paragraph 40).

These analyses revealed that:

- The vertical motion of the leading left axlebox was restricted, compared to the corresponding right axlebox, which moved freely throughout Spout House Curve;
- The leading right wheel was seen to unload by between 62 % and 72 % of its static wheel load at one sleeper before the POD, for curve exit speeds of 10 mph (16 km/h) and 12 mph (19 km/h) respectively. The corresponding leading left wheel load increases were 30 % and 41 %. Accounting for the 3 mm void which existed at the time of the derailment (but not during the running tests), the amount of right wheel unloading is likely to have risen from 62 % to as much as 87 % or from 72 % to as much as 97 % respectively, for the same curve exit speeds. The significance of this unloading is discussed later in paragraph 58;
- The leading right wheel was pushed into flange contact shortly after entry into the curve and remained in this position up to the POD;
- The leading bogie rotated normally through the curve, despite the lack of lubrication between the body and bogie bolsters.

- 51 R&ER's vehicle maintenance documentation comprises a checklist of eight tasks to be performed at the annual exam. The work done is signed off by the fitter together with any comments. The checklist does not include a specific requirement to check clearances between the axlebox and its horn guides, or to lubricate this interface.
- 52 Coach 134 was almost a month overdue on its annual maintenance check, which had been last performed on 28 April 2005. At that exam, inspection and greasing of the bogie bolster, axle bearings and couplings were carried out. The brakes were also tested. 'Maxi' coaches, normally operate together as a rake of vehicles and run approximately 1700 miles (2720 km) per year (mostly in the spring and summer months), compared to a fleet annual average of approximately 9,000 miles (14,400 km).

Previous occurrences of a similar character

- 53 There have been three previous derailments of rolling stock on plain track on the R&ER since 1992; in each case without injury.
- 54 The first was in 1992/93 when one bogie of a 'Maxi' coach derailed a short distance from Spout House Curve towards Ravenglass. The vehicle number is not known and there was no formal investigation to establish the cause.
- 55 The second derailment was in 1996 when 'Maxi' coach 130 derailed about a quarter mile (0.4 km) from Spout House curve towards Dalegarth. On that occasion some voiding was found over a short stretch of 4-5 sleeper bays. The depth of voiding was estimated to be between 3 and 6 mm. The accident was not investigated and the cause was not determined.
- 56 On 10 April 2006, a track maintenance train derailed at Eskdale Green station without injury. R&ER identified several causal factors, dry slip plates and dirt build-up at the body/bogie interface, curvature of the track and excessive speed.

Analysis - Spout House Curve

Identification of the immediate cause

- 57 Marks on the running rails and sleepers at the point of derailment indicated a flange climb type of derailment in which the leading right hand wheel of coach 134 rode up over the rail head causing the leading wheelset to derail to the right hand side of the track and pulling the trailing wheelset into derailment (paragraph 44).

Identification of causal and contributory factors

- 58 For a flange climb derailment to occur, there must be an increase in the ratio of lateral load to vertical load above a certain critical value, which is dependant on the friction and contact geometry between the wheel and the rail. Usually, this involves significant vertical wheel unloading (due to a track or vehicle fault or a combination of both) coinciding with lateral forces. If the amount of wheel unloading is high, even small lateral forces can induce a wheel into derailment.
- 59 Key evidence of a fault with the vehicle was the discovery that the clearance between the left leading axlebox and its bogie mounted horn guides was very small (paragraph 48). The physical evidence on the sliding surfaces and the results from the running tests (paragraph 50) confirmed that the lack of clearance had prevented free movement of the left axlebox and adversely affected the normal transfer of load from one side of the bogie to the other as coach 134 exited Spout House Curve. The result was that the leading right wheel unloaded excessively, probably by more than 80 % of the static wheel load (paragraph 50), leaving it vulnerable to flange climb.
- 60 There are no prescribed limits for wheel unloading on the R&ER. However, for indication only, the UK design standard, which is based on studies and derailment experience with heavy rail vehicles, sets the wheel unloading limit at 60 % of the static wheel load for a severe track twist design case (Railway Group Standard GM/RT2141). The wheel/rail contact geometry on the R&ER is not very dissimilar to heavy rail and the comparison indicates that the wheel unloading at Spout House Curve was sufficiently high to cause the derailment. The lack of adequate clearances on the leading left axlebox was a causal factor.
- 61 R&ER do not have a requirement in their maintenance procedures to check clearances at the axlebox and horn guides. Hence the lack of clearance was either never noticed or it was noticed and passed as acceptable because there was nothing in the form of documentation, practice or previous accidents to suggest it was a problem. The lack of prescribed tolerances for the axlebox/horn guide clearances in the maintenance documentation was therefore a contributory factor. That the annual maintenance exam was slightly overdue is not considered contributory because the problem had not been noticed and rectified during previous maintenance checks.

- 62 The lateral force necessary to induce the unloaded leading right wheel into derailment by flange climb was caused by flange contact of that wheel against the right hand rail. This flange contact was therefore a causal factor. Three factors contributed to the generation of lateral force:
- there had been some voiding below the right hand rail at the POD, which, although estimated to be relatively small in depth, would have created a twist in the track. This in turn would have contributed to both flange contact and wheel unloading. Therefore the voiding at the POD was a contributory factor;
 - the leading right wheel was seen, in the video evidence, to be in flange contact as it traversed the curve (paragraph 50). Such contact is normal when vehicles negotiate tight curves and generates the lateral forces required to steer the bogie. However; under wheel unloading conditions, these lateral forces act to promote flange climb. Therefore the normal curving behaviour of the vehicle was a contributory factor;
 - the track narrowed in gauge from 387 mm (the value used for curves) at 0.9 m before the POD to 381 mm (the value used for straight track) at the POD. Gauge widening in curves is standard design practice and is a normal condition, but the narrowing of the gauge at the POD would have tended to exacerbate the flange contact in these circumstances. The gauge narrowing on approach to the POD was therefore also a contributory factor.
- 63 Given that the above causal factors had been latent for some time, the question arises as to why the derailment had not occurred before. The reason is that the key factors were subject to variation with time. The effect of the restricted movement of the axlebox depends on the prevailing frictional forces at the axlebox/horn guide interface, speed of exit from the curve, passenger loading etc. Also the severity of the voiding increases gradually over time. It is therefore likely that at a particular time these factors would combine, in the presence of the other less variable factors, in such a way as to cause the derailment.

Identification of underlying causes

- 64 It was identified in paragraph 51 that R&ER's maintenance documentation did not have a requirement to check axlebox clearances. Maintenance practice on both its vehicles and track is based on custom and practice over more than 40 years of operation with the current owners. The axlebox clearance problem, which came to light during this investigation, was previously unknown. Therefore, an underlying cause of the accident was that possible failure modes of the suspension and the sensitivity of the vehicles to tolerances in track condition were not adequately taken into account in existing maintenance practices.

Conclusions - Spout House Curve

Immediate cause

- 65 The immediate cause of the derailment was flange climb of the leading right wheel of coach 134, due to the combination of a vehicle fault and the track condition. As it derailed to the right hand side of the track and the bogie yawed, the trailing wheelset was also pulled into derailment.

Causal and contributory factors

- 66 The first causal factor was restricted movement of the left leading axlebox due to insufficient clearances between it and the bogie horn guides within which it slides. This led to an excessive loading of the leading left wheel and a corresponding excessive unloading of the leading right wheel at the POD. The contributory factor which led to this was:
- there was no specific requirement to check clearances of axleboxes in the horn guides on assembly or at maintenance or lubricate this interface, which resulted in the lack of sufficient clearance going undetected (Recommendation 1).
- 67 The second causal factor was flange contact between the leading right wheel and rail which gave rise to lateral forces on that wheel and caused flange climbing under the excessive wheel unloading condition arising from the first causal factor. The contributory factors which led to this were:
- the presence of voiding below the right hand rail at the POD, due to degradation of the ballast foundation, which created some track twist and exacerbated the degree of wheel unloading (Recommendation 2);
 - the normal curving behaviour of rail vehicles, where wheel flanges make contact with the gauge face of outside rails as bogies steer through relatively tight curves;
 - narrowing of the track gauge from the curve to the adjoining straight track in line with standard R&ER track design practice, which contributed to the flange contact.

Underlying factor

- 68 An underlying cause of the derailment at Spout House Curve was that possible failure modes of the suspension and the sensitivity of vehicles to tolerances in track condition had not been adequately accounted for in existing maintenance procedures (Recommendation 3).

Additional observations

- 69 The body and bogie bolster plates, which support the weight of the body and which slide against each other as the bogie negotiates curves, were devoid of lubrication at the load bearing points. Although not causal or contributory to this accident, high friction at this interface can increase bogie rotational resistance and could be a hazard (Recommendation 8).

Accident details - Millwood Bank

- 70 On 5 July 2006, the 09:10 hrs departure from Ravenglass left on time and completed an uneventful journey to Dalegarth where it formed the 10:10 hrs departure back to Ravenglass. The train was also hauled by diesel locomotive ICL11, and consisted of a mixture of saloon, semi-open and open coaches (serial numbers, 117 nearest the locomotive, and 287, 169, 103, 110, 127, 136, 126). Saloon coach 110, which derailed, is shown in Figure 7. There are 17 of these saloon coaches in the fleet. Each vehicle is fitted with a pair of 'Severn Lamb' bogies (Figure 9) which are different in design from the 'Maxi' coach bogie (Figure 6).



Figure 7: Saloon Coach No. 110

- 71 On the return journey the train did not stop at Miteside Halt, as there were no passengers to get on or off there, and continued into the shallow right hand curve through Millwood Bank (Figure 3). The driver maintained slight power on the locomotive through the curve and the train speed reached 15-18 mph (24-29 km/h) as it passed through Millwood Bank. The maximum line speed over this stretch of track was 20 mph (32 km/h).
- 72 At around 10:45 hrs and at a location approximately 180 m from Miteside Halt, the leading wheelset of coach 110 derailed to the right hand side of the track. The derailment site is shown in Figure 3. Neither the driver nor the guard were aware of the derailment and the train continued towards Muncaster Mill in this condition. There were no passengers in coach 110.
- 73 Approximately half way between Millwood Bank and Muncaster Mill, the guard, who was located at the trailing end of coach 287 and facing towards Dalegarth, heard a screeching sound and smelled hot metal. He stood up and looked to see what was wrong but could not identify the source of the noise or smell. The driver started to brake for Muncaster Mill station and as coach 110 reached the timber level crossing just before the station, the guard saw the leading end of coach 110 lift up as the derailed wheelset struck the crossing timbers. The first indication to the driver of the derailment was a lurch as the train came to a stop, approximately 0.3 miles (0.5 km) from the point of derailment.
- 74 Arrangements were made to split the train and take the leading three coaches and the two remaining passengers to Ravenglass and this was completed by 11:30 hrs. Coach 110 was then re-railed and the remaining vehicles were moved to Ravenglass. The line was clear by 13:30 hrs.

The Investigation - Millwood Bank

Sources of evidence

75 Following the accident at Millwood Bank, which was notified to the RAIB immediately, the RAIB undertook examination of the derailed vehicle and a survey of the track at Millwood Bank on 5 and 6 July 2006. Coach 110 was tested in R&ER's workshops to determine its sway and wheel unloading characteristics. Subsequently, at the RAIB's request, R&ER provided video footage of a test train running through Millwood Bank at a speed of 15-18 mph (24-29 km/h) before and after track repairs. The test train formation was the same as the one which ran on 5 July 2006 but with the damaged coach 110 replaced by a similar saloon coach 103.

Key evidence

Train operation

- 76 The driver of the train was the track foreman of the R&ER (since 2000), and had driven various locomotives on the line since 1990. He was sufficiently rested on the day of the incident and felt well. A volunteer was also in the cab at the time.
- 77 The operation of the train from Ravenglass to Dalegarth and back to Miteside Halt was uneventful. The speed of the train through Millwood Bank at the time of the derailment was estimated at between 15 mph (24 km/h) and 18 mph (29 km/h). Even after the derailment the behaviour of the train felt normal to the crew who only identified something was wrong on the final approach to Muncaster Mill.

The track

- 78 The right hand rail head showed a clear wheel flange mark, starting at the POD and extending a distance of 1.8 m in the direction of travel, indicating that the mechanism of derailment had been flange climb. The length of the mark also indicated that the lateral force acting at the time had been relatively small.
- 79 Track voids were noted at 9 of the last 20 sleepers on the approach to the POD and their depth was measured using void meters. The recorded void depths varied from 1 mm to 7.5 mm; the deeper voids were further away from the POD.
- 80 Track levels were also taken from 20 sleepers before the POD to 10 sleepers beyond the POD and adjusted to include the measured void depths. From this data, the level of the (low) right rail relative to the (high) left rail (ie the cant) as seen by the passing train was obtained. The track gauge was also measured at the same sleeper positions and the results of both are shown in Figure 8, from which the following were noted:
- The cant varied from 24 mm at 20 sleepers before the POD to 5 mm at 9 sleepers before the POD. It then rose again to 12 mm at the POD. For the curve radius and line speed the *balancing cant* is 5 mm and therefore there was excess cant over most of the measured section, which would have caused a small net lateral force (up to 6 % of the static weight of about 1.5 tonnes) on the vehicle acting towards the inside of the curve;

- The variation in cant was not smooth, with rapid changes occurring, on average, every 4.5 sleeper bays or 4 m. The vehicle would therefore have been subjected to force inputs at a relatively regular frequency as it passed these positions. Taking a train speed at the middle of the estimated range of 16.5 mph (7.3 m/s), the regular force inputs would have occurred at a frequency of approximately 1.8 Hz, which is the same as the sway frequency of the vehicle (paragraph 85);
- The track gauge varied from 395 to 382 mm over the last 20 sleepers before the POD. The peaks and troughs in the gauge variation also showed a regular spacing in a similar manner to the changes in cant. This indicated that there were small variations in the lateral alignment of on one or both running rails. The effect of this would have been to apply additional lateral force inputs to the vehicle at a frequency close to the sway frequency.

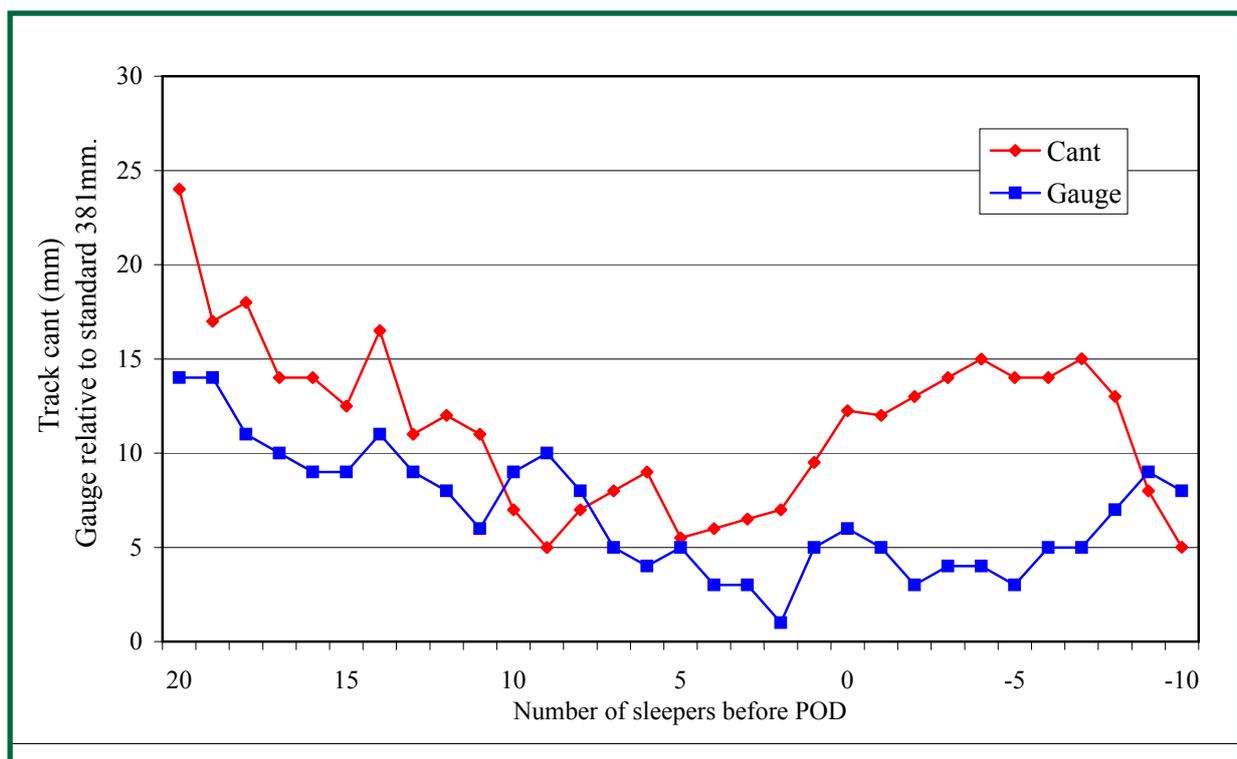


Figure 8: Cant (height of left rail above right rail) and gauge relative to standard 381 mm.

81 The track foreman and other drivers were aware of the degraded condition of the track at Millwood Bank, which has a history of similar degradation at this location. Monitoring of track condition is the responsibility of the track foreman, who walks the whole length of the track on average every 2 weeks to inspect it. In addition, he assesses track condition whilst carrying out his own driving duties and also relies on reports from other drivers to inform him of developing track problems. There are no standards or guidance on the R&ER that set out specific remedial actions to be taken when a track fault is identified. It is the responsibility of the track foreman, using his experience and judgement to decide the type and timing of any intervention (eg urgent remedial work or temporary speed restriction) to reduce risk.

The derailed vehicle (coach 110)

82 There were gouge marks at the bottom of the leading left primary suspension locking nuts on the bogie. This indicated that the leading end of the bogie had slid along the rail head, propping up the leading wheelset in the position shown in Figure 9, and preventing heavy contact with sleepers and ballast.

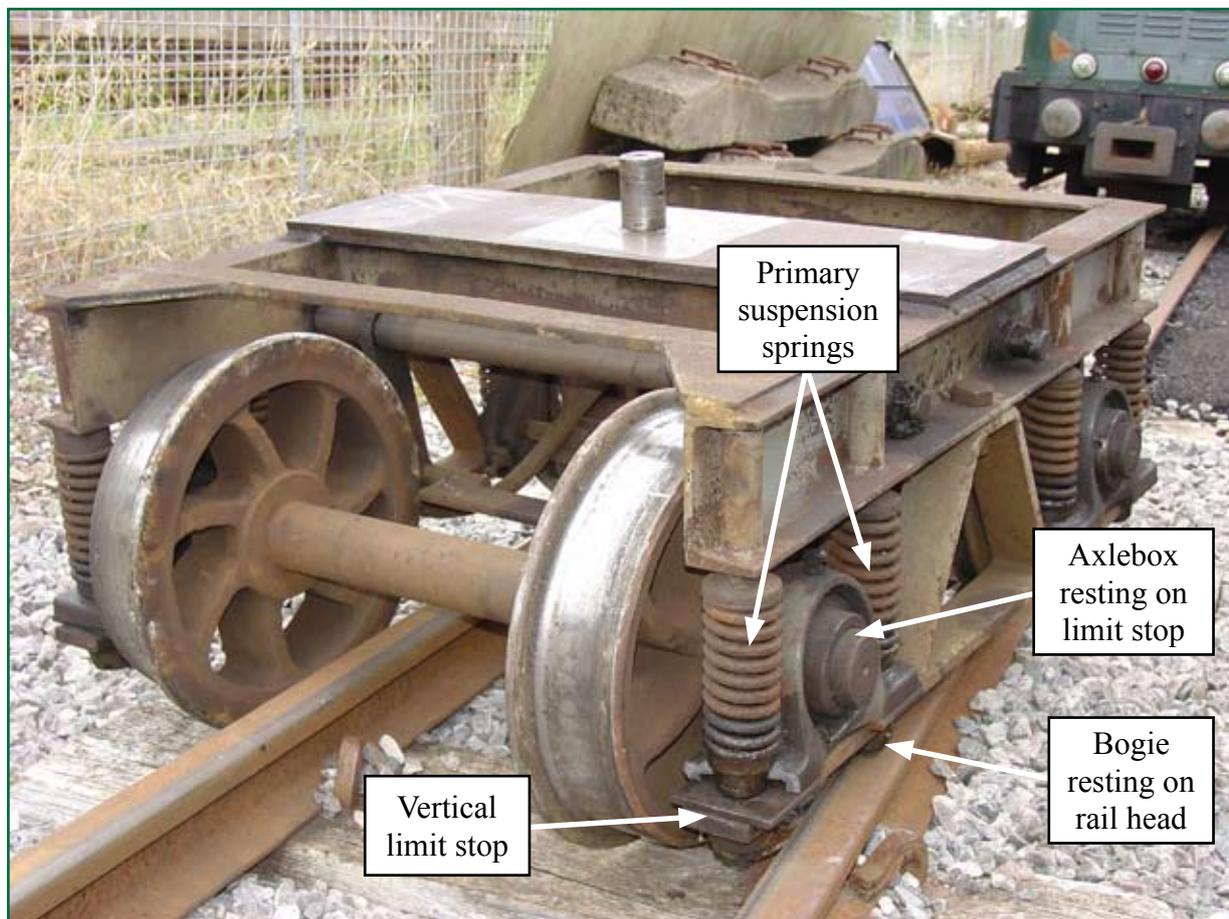


Figure 9: Leading bogie of coach 110 in initial derailed position.

83 The vehicle primary suspension comprises two vertically mounted springs either side of each axlebox which are located on two spring posts (Figure 9). When the vehicle is in tare condition, the axlebox sits directly on the vertical limit stop, which is fixed to the bogie frame. Hence the suspension has little or no flexibility in the wheel unloading (springs extending) direction and wheelsets will tend to unload excessively when traversing track with even moderate *twist faults* or dips caused by voiding.

84 There are no formal records or drawings of the bogie design or its optimum set up with regard to suspension clearances. Information available from the memories of R&ER staff indicated that when the bogies were first delivered in 1968, there was a clearance of 12 mm between the bottom of the axlebox and the vertical limit stop of the bogie in the tare condition, allowing that amount of flexibility in the unloading direction. However the ride performance at that time was unsatisfactory and vehicles were found to roll excessively. The decision was then taken by R&ER around 1970 to fit 12 mm spacers at the bottom of the springs. This spacer had the desired effect of improving ride quality, but flexibility in the unloading direction at tare had been virtually eliminated.

- 85 A dynamic sway test of coach 110 was undertaken in the tare condition to estimate the natural frequency of the vehicle. It was found that a sway oscillation could be easily induced by manually pushing the vehicle laterally at the *cantrail*. The sway frequency was measured at 1.8 Hz. The physical effort required to maintain the sway oscillation was low, indicating that there was relatively little damping at this frequency. The tests also showed that at a cantrail sway amplitude of approximately 100 mm, there was complete unloading of the wheels on the leading wheelset, which were noted to have just started lifting off the rail head.
- 86 During half the sway cycle, equivalent to a time period of 0.28 secs, the right hand side wheels would be unloading relative to their static wheel load. The distance travelled by the train in this time would be approximately 2 m which is close to the observed length of the flange mark on the right rail (1.8 m). This confirms that there was sufficient time for the wheel to unload and flange climb.
- 87 Video footage of the running tests through Millwood Bank (paragraph 75), showed that the fifth coach in the rake (the position occupied by coach 110 during the derailment) developed an increasing sway amplitude as it travelled towards the POD. Other saloon vehicles also swayed noticeably but not to the same extent. The amplitude of sway at the POD seen in the running tests was comparable to that required to produce complete wheel unloading in the workshop sway tests (paragraph 85). A significant amount of wheel unloading must have accompanied the excessive sway through Millwood Bank.
- 88 The running tests also showed evidence of lateral misalignment just before the POD. The hauling locomotive in particular, could be seen to receive a lateral impulse in the vicinity of the POD, most probably from the rail joint in the last sleeper bay before the POD. Therefore, coach 110 would also have suffered a similar lateral impulse.
- 89 Coach 110 was last maintained on 8 April 2006. During this exam the bogie was steam cleaned, inspected and greased (including the bolster and axle bearings), the brakes tested, couplings inspected and the wheels were turned.

Analysis - Millwood Bank

Identification of the immediate cause

- 90 Track marks around the POD gave clear indication that the immediate cause of the derailment had been flange climb of the leading right wheel of coach 110, which rode up over the rail head and derailed to the right hand side of the track. Intermittent marks on the sleepers beyond the POD and scoring on the leading left suspension indicated that the bogie had continued to run with the leading wheelset still held up by the locking nuts on the left axlebox (paragraph 82) as they slid on the left rail and with the trailing wheelset still on the rails. This was how the derailed bogie travelled a further 0.3 miles to Muncaster Mill without serious damage either to itself or the track.
- 91 The sway tests conducted in the workshop (paragraph 85) confirmed that high sway amplitudes could have caused significant wheel unloading. Evidence was also obtained from the running tests, of excessive vehicle sway through Millwood Bank in the tare condition at speeds greater than 15 mph (24 km/h). Combining these two pieces of evidence indicated that there had been ample scope for wheel unloading at Millwood Bank (paragraph 87) and that excessive sway was part of the immediate cause.

Identification of causal and contributory factors

- 92 The investigation identified three causes of the excessive sway and the resulting wheel unloading.
- 93 The survey of the track at Millwood Bank revealed voids, variations in gauge and cant and alignment problems at regular intervals on the approach to the POD. The track would have generated periodic force inputs to passing vehicles, which at a speed of 15-18 mph (24-29 km/h), excited the natural sway frequency of coach 110. The reason the track problems existed at the time of the derailment was that remedial work to correct this known problem had not been carried out. This was because the risk at Millwood Bank had not been recognised by the track foreman, although the deterioration of the track condition had been recognised and was being monitored by him. The lack of timely remedial action was a causal factor.
- 94 In addition to track inspections, reliance is also placed on the track foreman's assessment of track condition, and those of other drivers, during normal driving duties (paragraph 81). Although the deteriorating track condition at Millwood Bank was known by drivers, an existing system for reporting track faults had not been used to report it to the track foreman. This was because the system had not been formally adopted as a company procedure and therefore not mandated to drivers. Had it been, the issue of the poor track condition is likely to have been escalated sufficiently for timely action to have been taken. The lack a mandated track fault reporting system was a contributory factor.
- 95 The estimated train speed of 15-18 mph (24-29 km/h), whilst below the maximum line speed, was still high enough to cause coincidence of the track force inputs and vehicle sway frequencies. The resulting resonance increased the sway amplitude to excessive levels. That the train speed was excessive for the track condition was a causal factor.

- 96 Despite the track condition at Millwood Bank, a temporary speed restriction was not imposed, consequent to the lack of recognition of the risk there. Had it been, it would have provided a reminder about the track condition and the driver would most likely have reduced the speed of the train to comply. Therefore the lack of a temporary speed restriction was a contributory factor.
- 97 The suspension set up on the bogie fitted to coach 110, in common with similar ‘Severn Lamb’ type bogies on the R&ER, does not provide sufficient flexibility in the unloading direction, making it intolerant of track twist faults. Had there been some flexibility, the bogie would very likely have negotiated the track twists without derailment. Therefore the suspension set-up on coach 110 is also considered a causal factor. The removal of the flexibility that had existed in the original bogie design in order to improve the ride quality of the coaches was a contributory factor:
- 98 In addition to the wheel unloading, there must have been some lateral force to induce the flange climb. The investigation identified two sources of lateral forces both of which stem primarily from the rough track condition and therefore the first causal factor.
- excess cant over the last 20 sleepers before derailment which would have caused a small lateral force acting towards the inside of the curve.
 - lateral misalignment of the track on approach to the POD as observed from the variations in track gauge (Figure 8) and the video record (paragraph 88).

Identification of underlying causes

- 99 All three causal factors above and their contributory factors stem from a lack of recognition of the hazard from the rough track at Millwood Bank and the sensitivity of saloon coaches to sway inducing track features. The lack of recognition of the hazard is therefore considered an underlying factor.

Conclusions - Millwood Bank

Immediate cause

- 100 The immediate cause of the derailment at Millwood Bank was flange climb of the leading right wheel of coach 110, due to a combination of vehicle, track and operational factors, which resulted in an excessive amount of vehicle sway and wheel unloading.
- 101 The derailment of the trailing wheelset occurred 0.3 miles (0.5 km) further along the track from the POD when the leading bogie struck the level crossing at Muncaster Mill.

Causal and contributory factors

- 102 The first causal factor was the lack of timely remedial action to the known rough track conditions at Millwood Bank, where there were sufficient voiding, alignment and cant problems to cause excessive vehicle sway and pose a derailment risk when combined with the other prevailing conditions described below (Recommendations 2 & 6). The contributory factor which led to this was:
- an existing system for reporting track faults had not been mandated and was not being used and therefore the urgency of repairs was not adequately conveyed to track maintenance staff (Recommendation 5).
- 103 The second causal factor was that the train speed was excessive for the track condition, causing resonance between the frequency of track input forces and the natural sway frequency. This led to an increasing sway amplitude and wheel unloading as coach 110 approached the POD. The contributory factor which led to this was:
- there was no temporary speed restriction at Millwood Bank at the time of the accident to alert drivers about the need for caution through the rough track (Recommendations 5 & 6).
- 104 The third causal factor was the suspension set up which, in the tare condition, reduced the leading bogie's tolerance to degraded track features (eg track twist, voiding) which cause wheel unloading. The contributory factor which led to this was:
- a previous suspension modification to improve ride quality had removed the flexibility between the wheelset and bogie frame in the unloading direction and reduced the ability of the bogies to accommodate certain track faults and vehicle sway, thereby increasing the risk of flange climb derailments (Recommendation 7).

Underlying factor

- 105 The hazard caused by the rough track condition at Millwood Bank and the sensitivity of the saloon type coaches to excessive sway, particularly at speeds higher than about 15 mph (24 km/h), was not sufficiently recognised (Recommendation 4).

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

106 R&ER have carried out the following actions since these two derailments:

- the track at Millwood Bank and has been repaired and inspections have been carried of the whole line to determine if there are any other areas which need urgent maintenance;
- the general maximum line speed was permanently reduced from 20 mph (32 km/h) to 15 mph (24 km/h) on 8 July 2006;
- all duty controllers were briefed after the derailment at Spout House Curve on the need to notify the RAIB immediately if a schedule 1 event occurs on the line and an incident checklist has been drawn up and posted in the signal box;
- trials are being conducted on improved lubrication for vehicle body-bogie interfaces;
- a review of the suspension set up on Severn Lamb bogies has commenced;
- the existing track fault reporting system has now been mandated.

Recommendations

107 The following safety recommendations are made¹:

Recommendations to address causal and contributory factors from both accidents

Ravenglass and Eskdale Railway should:

1. Undertake a full fleet check to ensure that axlebox clearances are adequate to ensure free movement, carry out remedial work where necessary and mandate a requirement in maintenance documentation for periodic checks on these clearances to be made. An assessment should also be made of the safety benefits of introducing lubrication at the axlebox/horn guide interface and, where practicable, identified improvements should be implemented (paragraph 66).
2. Undertake a thorough examination of the track to identify existing and likely future areas of poor condition and implement a planned programme of remedial work. Particular attention should be paid to the presence of voiding. Until identified work is completed, appropriate temporary speed restrictions should be used (paragraphs 67, 102).
3. Develop and bring into use, a rolling stock maintenance regime which is based on the assessment of hazards identified from both past experience and analysis of possible future failure modes. This assessment should include consideration of allowable tolerances in track condition. The revised documentation should identify critical dimensional parameters and component conditions to be checked at maintenance (paragraph 68).
4. Ensure drivers, guards and track maintenance staff are made aware of the signs of excessive sway and the resulting risk of derailment, especially when running empty, so that future problems are reported and actioned early (paragraph 105).
5. Review the effectiveness of the existing system for reporting track faults, prioritisation of repairs and the use of temporary speed restrictions. Any identified improvements should then be implemented and the system formalised and mandated (paragraphs 102, 103).
6. Establish a system for routine inspection of the track condition and establish track standards such that temporary speed restrictions and/or remedial works are effected as appropriate to mitigate the risk of derailment due to excessive sway (paragraphs 102, 103).

continued...

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

7. Review the existing suspension set up and maintenance and inspection regime of the 'Severn Lamb' type bogies to determine whether it is consistent with the track condition resulting from implementation of Recommendation 6 (paragraph 104).

Recommendations to address other matters observed during the investigation

Ravenglass & Eskdale Railway should:

8. Develop and implement means of ensuring that the body/bogie bolsters remain lubricated between maintenance checks (paragraph 69).

Appendices

Glossary of abbreviations and acronyms

R&ER

POD

PSR

Appendix A

Ravenglass & Eskdale Railway

Point of derailment

Permanent speed restriction

Glossary of terms

Appendix B

| | |
|---------------------|--|
| Alignment (Track) | The lateral geometry of the track. |
| Axlebox | The axle bearing housing which connects the wheelset to the bogie via primary suspension. There is one axlebox at each end of a railway wheelset. |
| Balancing cant | The value of track cant, for a given speed and curve radius, at which there is no net lateral force on the vehicle. |
| Bolster | The main load bearing points between the vehicle body (body bolster) and the bogie (bogie bolster). |
| Cant (track) | The amount by which the high rail on a curve is raised above the low rail. |
| Cantrail | The point on a Rail Vehicle at which the side of the vehicle body meets the roof profile. |
| Coach screws | A form of rail fastener used on wooden sleepers. |
| Down (direction) | Direction of travel away from Dalegarth on the R&ER. |
| Elastic spikes | A form of rail fastener used on wooden sleepers. |
| Flange contact | The situation that occurs when the flange of a wheel contacts the gauge face of a rail. |
| Flange climb | A situation where the flange of a rail wheel rides up the inside (gauge) face of the rail head while rotating. If the wheel flange reaches the top of the rail head the wheelset is no longer laterally supported and this could result in derailment. |
| Horn guides | Guides attached to the bogie frame, on which the axleboxes slide vertically. |
| Schedule 1 | Types of accidents and incidents which must be notified to the RAIB immediately as defined in The Railways (Accident Investigation and Reporting) Regulations 2005. |
| Sway | The roll (side to side) motion of a rail vehicle. |
| Tare | Empty, without any people on board. |
| Track gauge | The specified distance between the rails of a railway track. On the R&ER this distance is 381 mm and 387 mm on straight and curved track respectively. |
| Track top | The vertical geometry of the track. |
| Twist fault (track) | An irregularity in the track top, resulting in a rapid change of cant over a defined distance. |
| Voiding | A track fault caused by gaps in the ballast reducing the vertical support provided to one or more sleepers. It manifests itself in the form of abnormally high vertical deflection of the rail when a train passes by. |

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