Rail Accident Investigation Branch

Rail Accident Report

Freight train derailment at Angerstein Junction 2 April 2014

Report 11/2015
August 2015

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

The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents or by mitigating their consequences. It is not the purpose of such an investigation to establish blame or liability. Accordingly, it is inappropriate that RAIB reports should be used to assign fault or blame, or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

The RAIB's findings are based on its own evaluation of the evidence that was available at the time of the investigation and are intended to explain what happened, and why, in a fair and unbiased manner.

Where the RAIB has described a factor as being linked to cause and the term is unqualified, this means that the RAIB has satisfied itself that the evidence supports both the presence of the factor and its direct relevance to the causation of the accident. However, where the RAIB is less confident about the existence of a factor, or its role in the causation of the accident, the RAIB will qualify its findings by use of the words 'probable' or 'possible', as appropriate. Where there is more than one potential explanation the RAIB may describe one factor as being 'more' or 'less' likely than the other.

In some cases factors are described as 'underlying'. Such factors are also relevant to the causation of the accident but are associated with the underlying management arrangements or organisational issues (such as working culture). Where necessary, the words 'probable' or 'possible' can also be used to qualify 'underlying factor'.

Use of the word 'probable' means that, although it is considered highly likely that the factor applied, some small element of uncertainty remains. Use of the word 'possible' means that, although there is some evidence that supports this factor, there remains a more significant degree of uncertainty.

An 'observation' is a safety issue discovered as part of the investigation that is not considered to be causal or underlying to the event being investigated, but does deserve scrutiny because of a perceived potential for safety learning.

The above terms are intended to assist readers' interpretation of the report, and to provide suitable explanations where uncertainty remains. The report should therefore be interpreted as the view of the RAIB, expressed with the sole purpose of improving railway safety.

The RAIB's investigation (including its scope, methods, conclusions and recommendations) is independent of any inquest or fatal accident inquiry, and all other investigations, including those carried out by the safety authority, police or railway industry.

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Freight train derailment at Angerstein Junction 2 April 2014

Contents

Summary

At about 12:15 hrs on Wednesday 2 April 2014, two wagons of a nominally empty freight train derailed on the approach to Angerstein Junction, near Charlton in south east London. The derailed wagons were pulled over the junction and stopped on the Blackheath to Charlton line, with the two wagons partly obstructing the line used by trains travelling in the opposite direction. No other trains were involved in the accident and no-one was injured, but there was significant damage to the railway infrastructure.

The wagons derailed because the leading right-hand wheel on one of them was carrying insufficient load to prevent the wheel climbing up the outer rail on a curved section of track. The insufficient load was due to a combination of a track defect, an unevenly distributed residual load in the wagon, and an uneven distribution of load associated with a twisted bogie. The unevenly distributed residual load comprised finely crushed rock which adhered to the side of wagon, and was not discharged by unloading procedures. These procedures had been developed without recognising the derailment risk associated with carrying relatively small, but significantly unbalanced, loads. This combination of factors illustrates the derailment risk which arises when imperfect freight wagons are operated on imperfect track in circumstances where both wagon and track are compliant with relevant railway standards.

The RAIB has made six recommendations, several of which could be informed by work undertaken as part of a cross-industry programme already initiated by the ORR after previous RAIB investigations identified derailment risks associated with operation of wagons and track which are imperfect, but nevertheless compliant with relevant standards. A recommendation addressed to Aggregate Industries seeks improved wagon load discharge arrangements. Two recommendations addressed to RSSB are intended to mitigate risks associated with imperfect wagons, carrying unevenly distributed loads, on imperfect track. Three recommendations, addressed to Network Rail, seek appropriate control of derailment risk in sidings where derailed vehicles can affect running lines, provision to wagon operators of wagon defect information collected by trackside equipment, and possible modifications to the method of collecting track twist data in order to reflect the effect of this track defect on modern rolling stock.

Introduction

Key definitions

1 Metric units are used throughout this report, except for speeds and locations which are given in imperial units, in accordance with railway industry practice. Where appropriate, the equivalent metric value is also given.

2 All mileages are measured from London Charing Cross Station.

3 The report uses ‘left’ and ‘right’ with reference to the direction of train travel at the time of derailment.

4 The report contains abbreviations and technical terms (shown in *italics* the first time they appear in the report). These are explained in appendices A and B.

The accident

Summary of the accident

5 At about 12:15 hrs on Wednesday 2 April 2014, two wagons of a nominally empty freight train derailed as it was exiting the sidings onto the running lines at Angerstein Junction, near Charlton in south east London (figure 1). The train came to a stand with the two wagons partly obstructing the opposite line, which was open to traffic (figure 2). No-one was injured in the accident, but there was significant damage to the railway infrastructure.

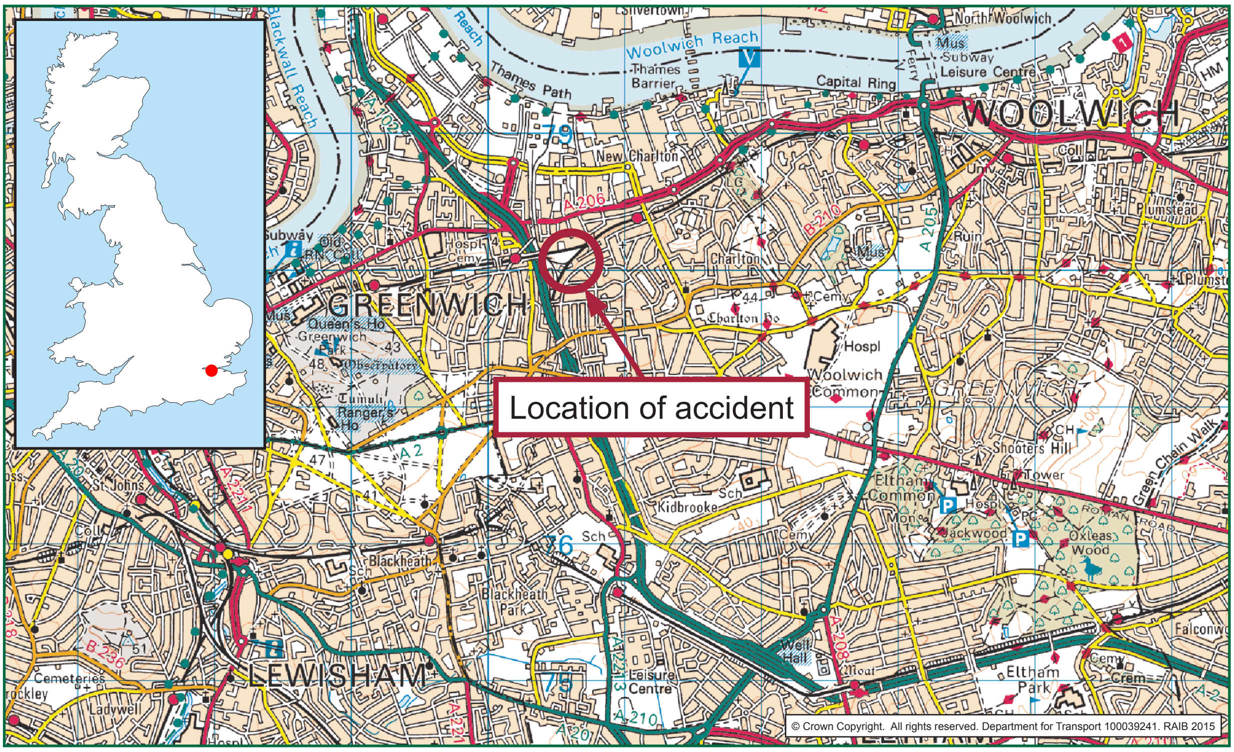

Figure 1: Extract from Ordnance Survey map showing location of accident

Context

Location

6 The derailment occurred within the length of a set of curved *trap points*, approximately 50 metres before reaching the point where the line from Angerstein Wharf sidings joins the North Kent lines at Angerstein Junction. The train finally stopped after travelling approximately 180 metres beyond the point where the derailment occurred, with two derailed wagons on the North Kent lines.

7 Angerstein Junction is at 8 miles 46 *chains* on the North Kent lines, which connect Blackheath and Charlton (figure 3). At Charlton Junction, at 8 miles 63 chains, the North Kent lines join with the Greenwich lines.

Figure 2: Derailed train after stopping, showing derailed wagons at the bridge

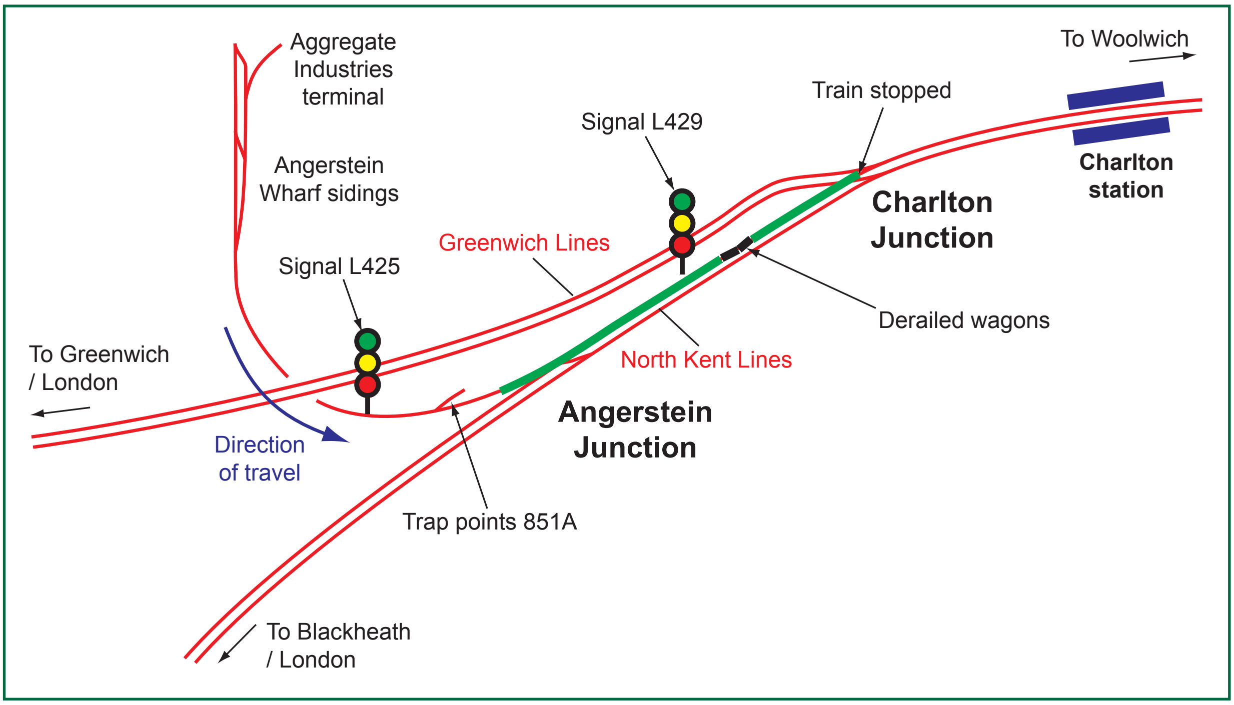

Figure 3: Track layout and selected signals (showing train location after stopping)

8 The North Kent and Greenwich lines are primarily used by trains from London towards Woolwich and beyond. The Aggregate Industries terminal at Angerstein Wharf sidings is used by freight trains that arrive loaded with *aggregate*, unload, and then depart empty. Some trains that use an adjacent terminal arrive at Angerstein Wharf sidings empty and depart loaded.

9 The permitted speed limit for trains departing from Angerstein Wharf sidings was 15 mph (24 km/h), increasing to 50 mph (80 km/h) after Angerstein Junction.

10 Trains departing from Angerstein Wharf sidings descend a 1 in 211 gradient from approximately 200 metres before the junction, which then increases to 1 in 168 after joining the North Kent lines.

11 The line from the sidings is single track and not electrified, while the North Kent and Greenwich lines are both double track with *third rail DC electrification*. The signalling is controlled from London Bridge Signalling Centre, and the electrification is controlled from Lewisham Electrical Control Room.

Organisations involved

12 Network Rail owns and operates the railway infrastructure in the area where the train derailed, which is within Network Rail's Kent route. It employs the staff who were responsible for the maintenance of the track.

13 Freightliner was the operator of the train that derailed, and employs both its driver and the *shunter* who prepared it for departure.

14 Aggregate Industries owns and operates the terminal at Angerstein Wharf, where the train was unloaded, as well as a similar unloading terminal at Tinsley, in Sheffield, and a loading terminal at Bardon Hill quarry in Leicestershire. It employs the terminal operators who load and unload the trains at these locations. It also owned the residual load (paragraph 94) that was being carried when the derailment occurred.

15 VTG Rail UK (subsequently referred to in this report as VTG) owns the wagons that derailed, and leases these to Aggregate Industries. VTG is responsible for the maintenance of the wagons.

16 All of the above organisations freely co-operated with the investigation.

Train involved

17 The train involved in the accident was 6M79, the 11:56 hrs service from Angerstein Wharf sidings to Bardon Hill quarry, in Leicestershire. It consisted of a Class 66 locomotive hauling 20 aggregate *hopper wagons* (a mixture of types JRA and JGA - figure 4).

18 The two wagons that derailed were both JRA hopper wagons which were built in France in 1990.

External circumstances

19 The weather was overcast but dry at the time of the derailment. There is no evidence to suggest that abnormal external circumstances influenced the accident.

Figure 4: JRA hopper wagon 546, with JGA wagon behind it

Events preceding the accident

20 During the week before the accident, the set of wagons, that included those that derailed, made three return trips carrying mixed grades of aggregate (including both *crushed rock fines* and larger grade stone) from Bardon Hill quarry to the Aggregate Industries terminal at Tinsley. These journeys were on 28 March, 31 March and 1 April 2014.

21 On the morning of the derailment, the incoming train carried various grades of aggregate, but not crushed rock fines, from Bardon Hill quarry to the Aggregate Industries terminal at Angerstein Wharf sidings.

22 On arrival at Angerstein Wharf sidings, the locomotive *ran round* the train, before pushing it in to the terminal, where the wagons were unloaded.

23 After unloading, the train departed from Angerstein Wharf sidings, at 11:54 hrs, to return to Bardon Hill quarry.

Events during the accident

24 On approaching Angerstein Junction, the train was stopped by a *red aspect* at signal L425 (figure 3). This signal is positioned before the trap points, and controls entry on to the North Kent lines.

25 Signal L425 then changed to show a proceed aspect, and the train proceeded onto the *Down* North Kent line, reaching a maximum speed of 5 mph (8 km/h), towards signal L429, which was showing a red aspect. This signal controls entry onto the Greenwich lines at Charlton Junction.

26 At 12:08 hrs, as the train was slowing, a *wheelset* on the 9th wagon (number 7069050546 – henceforth referred to as wagon 546) derailed to the outside of the fixed outer rail on the curve within the trap points (851A). The train then continued for approximately 20 metres before stopping at signal L429.

27 When signal L429 changed to a proceed aspect, the train started to move, dragging the derailed wheelset over Angerstein Junction, consequently derailing the remaining wheelsets on the same wagon and those on the rear *bogie* of the preceding wagon (number 7069050611 – henceforth referred to as wagon 611).

28 After starting from signal L129, the train travelled for approximately 160 metres before stopping due to an automatic emergency brake application triggered by separation of the *brake pipes* linking the two derailed wagons. The train stopped with the locomotive on Charlton Junction and the rear of the train approximately 8 metres beyond the point of the derailment.

Events following the accident

29 The train driver contacted the signaller by radio and told him that he suspected a fault with the train, and that it was standing with the locomotive on Charlton Junction. The signaller stopped train movements on the North Kent and Greenwich lines, and arranged for the power to be isolated to allow the driver to inspect the train. The driver then contacted the signaller by mobile phone to advise him that the train was derailed and obstructing the Up North Kent line.

30 The front seven wagons were later detached from the rest of the train and removed from the site, allowing the Greenwich lines to reopen by 17:00 hrs on the same day.

31 The remaining wagons were rerailed and pushed back into Angerstein Wharf sidings by 06:30 hrs on 4 April 2014. This allowed repairs to the track and associated infrastructure to be completed for reopening of the North Kent lines later that day.

The investigation

Sources of evidence

32 The RAIB used the following sources of evidence in this investigation:

- track surveys carried out by both the RAIB and Network Rail after the derailment;
- track maintenance records;
- site photographs and measurements;
- the train's *on-train data recorder* (OTDR) data;
- wagon survey carried out by the RAIB;
- results from wagon *wheel unloading* tests undertaken on behalf of VTG at Angerstein Wharf in August 2014, and at Derby in March 2015;
- results from bogie rotational resistance tests undertaken on behalf of VTG at Derby in March 2015;
- wagon maintenance records;
- *WheelChex* data;
- *TOPS* data for the trains included in the above WheelChex data;
- wagon weight data from Bardon Hill quarry;
- RAIB observation of aggregate wagons unloading at the Angerstein Wharf terminal;
- witness statements;
- weather data; and
- a review of previous RAIB investigations that had relevance to this accident.

Key facts and analysis

Background information

Track twist

33 *Track twist* is a measurement of the change in the relative heights (or *cant*) of the two *running rails* between two positions along the track. It can be expressed as an absolute measure of the difference in cant between the two measuring points. It can also be expressed as an average gradient, where the difference in cant is related to the distance between the two measuring locations.

34 Railway Group Standard GC/RT5021 'Track System Requirements', and Network Rail's track maintenance standard NR/L2/TRK/001 'Inspection and Maintenance of Permanent Way', refer to track twist over a measurement base of three metres. As an example, a change of cant from 20 mm to 30 mm over a base distance of three metres is expressed as either a track twist of 10 mm or as a twist gradient of 1 in 300 (10 mm in 3000 mm).

35 Track twist can exist as part of the track design. On straight track, there will normally be no cant, whereas curves can have a cant installed, with the outer rail positioned higher than the inner rail, to reduce the forces exerted by wheels on the outer rail. The cant therefore needs to progressively change where track transitions from a straight to a curve, and vice versa. This results in an intended track twist, known as a *cant gradient*. Track twist can also result from movements in the track over time away from its 'as-designed' position. This should be detected by measurement during maintenance inspection activities and corrected if it becomes excessive. Track twist can cause uneven loading of the wheels on a wagon, and therefore increase the risk of derailment (paragraph 75).

36 It is possible for the amount of track twist to change when trains pass over it. The twist without the effect of the weight of a train is known as the *static twist*, while that with the effect of the weight of a train is known as the *dynamic twist*. Dynamic twist includes any change in cant arising from the compression of *voids*, or gaps under the track, as a train passes over them.

37 Movable *switch rails* (shown in figure 5), such as the inner rail at the derailment location, can also contribute to dynamic twist. This is because there can be gaps between the underside of the movable switch rail and the surfaces that are intended to provide vertical support to the rail. These gaps, known as *hogging*, close when a train passes over the rail.

38 Dynamic track twist is usually measured using a *track recording vehicle* (TRV), which records the track geometry as it passes over the track. If a TRV is not used, equipment, such as *void meters* and *step gauges*, is needed to identify any dynamic twist effects due to voiding or hogging respectively.

Wagon design, suspension characteristics and modelling

39 The body of wagon 546 consists of a three compartment hopper supported on an underframe. The underframe is mounted on two bogies, each of which is supported on two wheelsets (figure 4).

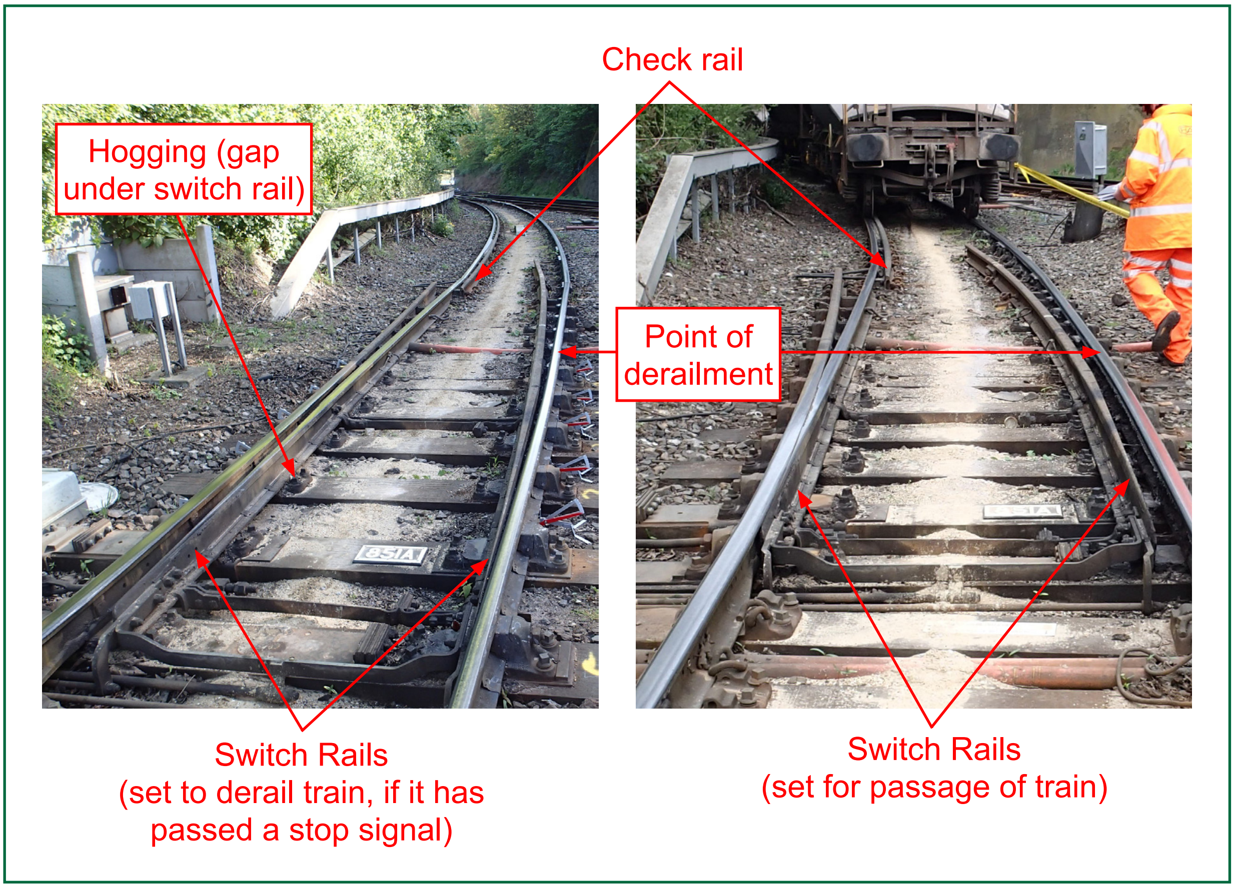

Figure 5: Trap points 851A

40 There are spring assemblies mounted between the bogie frame and the end of each wheelset (figure 6) which provide *primary suspension*. Each assembly consists of two nested springs of different lengths. This arrangement means that the primary suspension has a softer characteristic when it is lightly loaded, because only one spring is in use. When the load on the spring assembly is increased, compressing the outer spring enough to bring the second spring into use, the combined springs provide a stiffer suspension characteristic. The suspension spring arrangements are referred to as 'tare', when only the softer characteristic is acting, and 'loaded', when the stiffer combined characteristic is acting. RAIB calculations, based on the spring details given in the wagon construction drawings, show that the changeover from the tare characteristic to the loaded characteristic occurs at a wheel load of approximately 3.25 tonnes, equivalent to a total uniformly distributed wagon payload of 3.4 tonnes.

41 The bogie frames are relatively rigid, compared to the primary suspension springs, but there is some torsional flexibility associated with the wagon body and the connection to the bogies.

42 The RAIB developed a simple model of the suspension of wagon 546, in order to calculate the effects of track twist on the loading of the wagon's wheels, and to assess the equivalent effect of any distortion of the bogie frame. This model uses primary springs to represent the primary suspension and secondary springs to represent the combined effect of torsional flexibility in the wagon body and in the connection between the body and the bogies. The model is represented in figure 7.

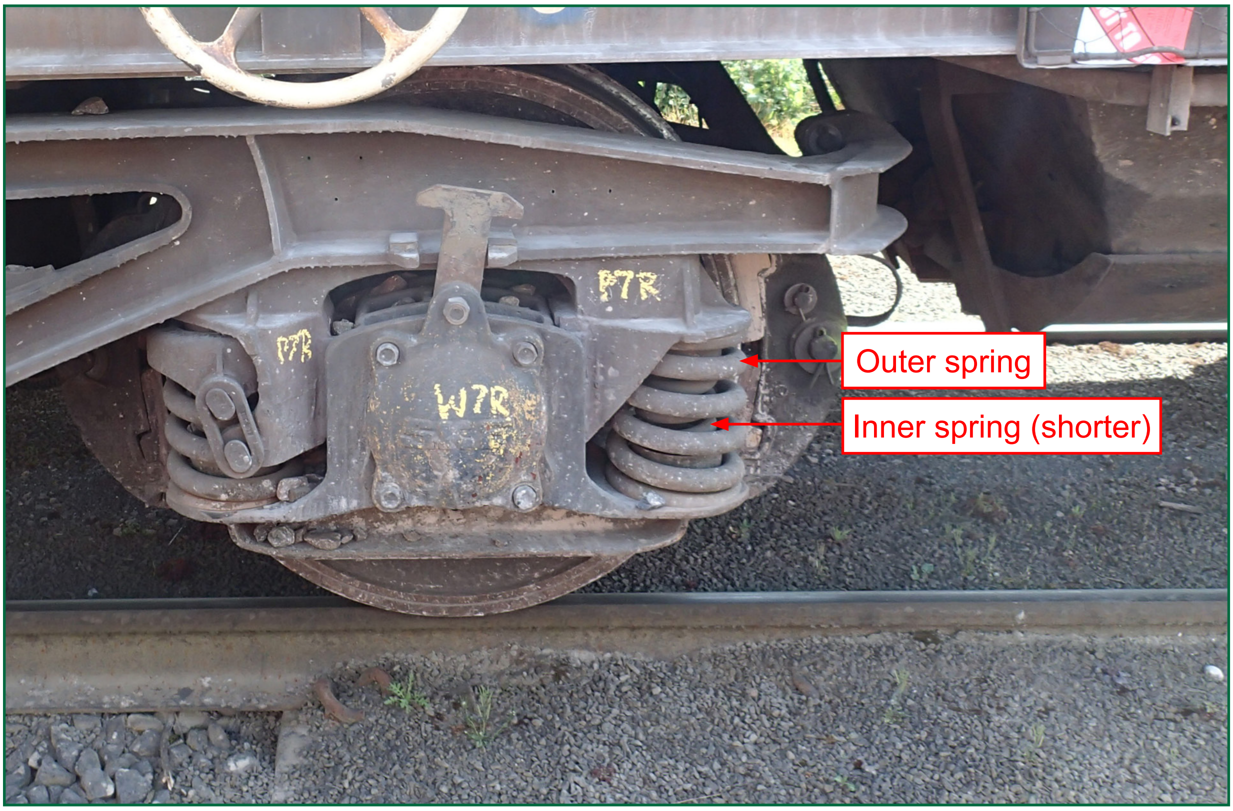

Figure 6: Wagon primary suspension spring arrangement

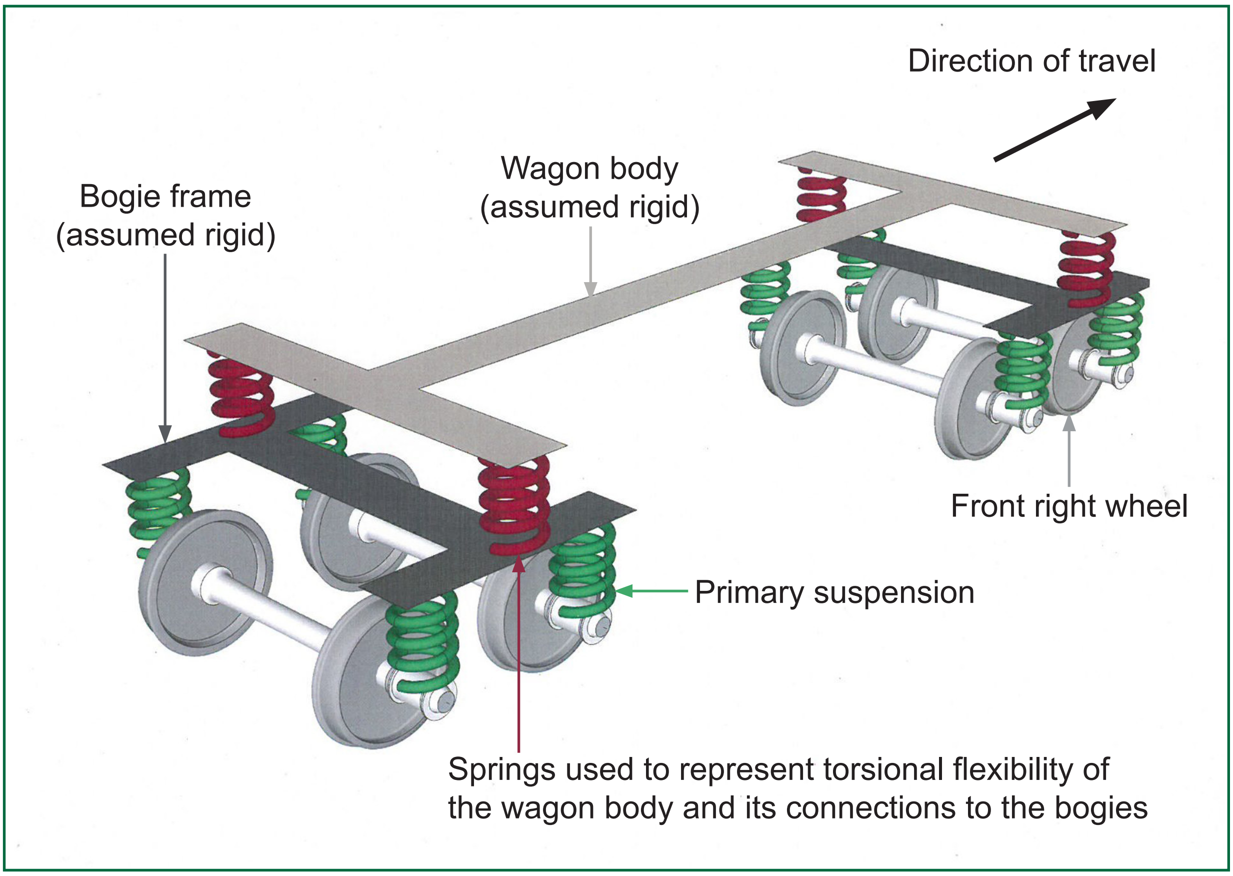

Figure 7: Simplified wagon model used in calculations

43 The model uses the primary suspension spring stiffnesses given on the manufacturer's drawings, and applies either the tare or the loaded spring characteristic at each wheel depending on the load being carried on the wagon wheel. The secondary spring stiffness used in the model was derived by the RAIB using results from the *ΔQ/Q testing* undertaken at Angerstein Wharf (paragraphs 51 and 52).

44 The model calculates the effect of track twist on wheel loading, and allows the effects of track twist along the bogie wheelbase to be separated from that along the wagon length. It also allows the effect of *bogie frame twist* to be evaluated. In this context, bogie frame twist relates to the relative position of the interfaces between the bogie frame and the top of the suspension springs. The interface is the underside of any packing pieces inserted to correct the effects of bogie distortion due to manufacturing inaccuracies etc.

Wheel unloading

45 The derailment mechanism considered in this report is known as *flange climb* (paragraphs 58 to 63) and occurs when the vertical load on a wheel is insufficient to prevent lateral forces pushing the wheel up the sloping interface between the *wheel flange* and the rail (figure 8). The likelihood of derailment increases as the ratio between the lateral force and the vertical load increases. Consequently, the probability of a given wheel derailing increases as the vertical load on it decreases. In some circumstances, such as an unevenly distributed payload, wheels on the same axle can carry differing loads. The difference between the average wheel load (Q) on an axle and the actual load on a wheel is conventionally designated ΔQ. The likelihood of derailment, in adverse conditions, tends to increase as the ratio ΔQ/Q increases.

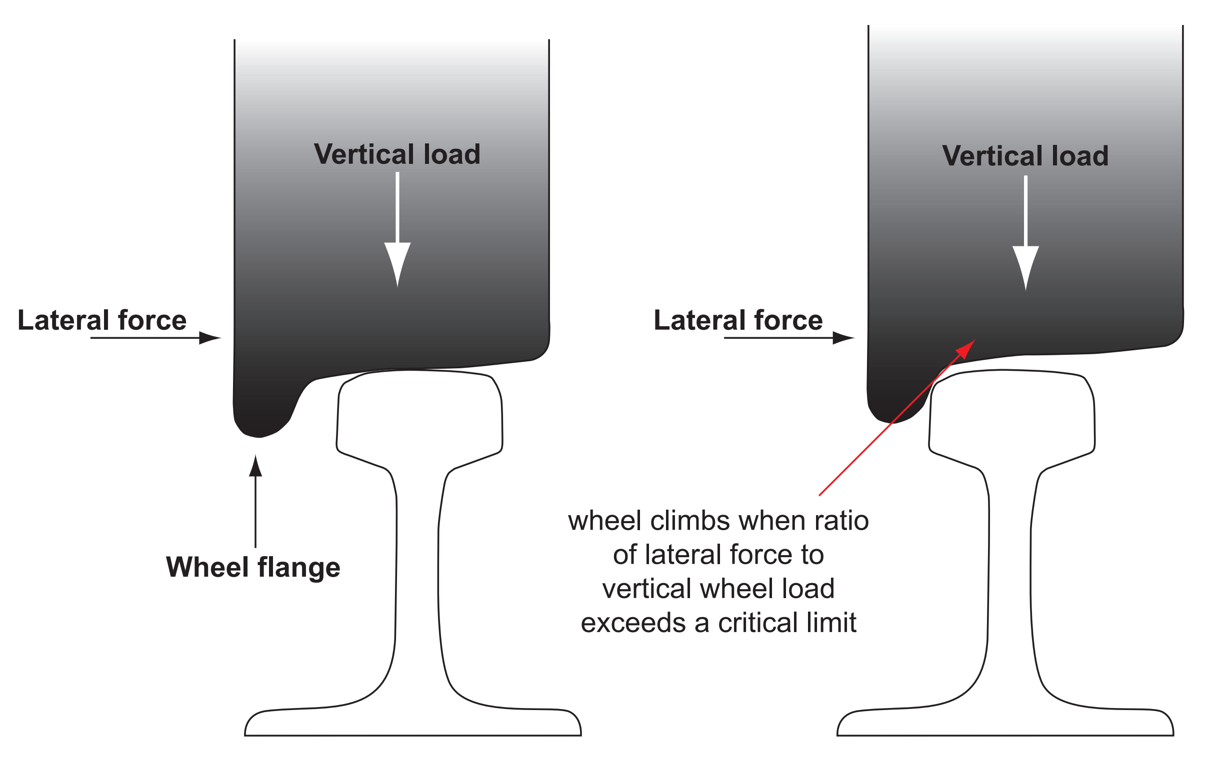

Figure 8: Flange climb

46 The propensity for a flange climb derailment depends on both the track geometry at the point of derailment and the geometry on the approach to this point. This is because the rail wheel has to travel sufficient distance along the track (typically up to two metres[1]) for it to be able to climb fully onto the rail head. The RAIB's model (paragraph 42) considers only the track geometry at the point of derailment, but the RAIB has given subjective consideration to the curvature, twist and gauge on the approach (paragraphs 78 and 139) and concluded that this is consistent with a flange climb derailment.

47 During the derailment at Angerstein Junction, lateral forces were present due to the track curvature and other effects, such as the gradient and the controlled deceleration of the train, but there is no evidence to suggest that these were abnormal. Other similar wagons in this train, and in other trains, would have been subject to similar lateral forces and passed over the incident location without derailment. No suspension abnormalities relevant to the cause of the derailment were identified on wagon 546. As a result, vertical wheel loadings, particularly the reduction of loading on the leading right-hand wheel, are considered most relevant to the cause of the derailment.

48 Three sets of $\Delta Q/Q$ tests were carried out on wagon 546 after the derailment. These tests were in accordance with Railway Group Standard GM/RT2141 'Resistance of Railway Vehicles to Derailment and Roll-Over' and showed the overall response of the wagon to a track twist defined in this standard. The first set of $\Delta Q/Q$ tests was undertaken while wagon 546 was still at Angerstein Wharf terminal, and the subsequent tests were carried out after the wagon had been moved by road transport to a testing facility at Derby. The Angerstein tests took place in a siding with uneven track so, before undertaking the GM/RT2141 testing sequence, packing was introduced under one of the wheels on each axle so that each axle was made level. This was not required at Derby as the testing was carried out on level track.

49 The GM/RT2141 testing sequence required the load on each wheel to be measured before packing was inserted, in four steps, to achieve the standard track twist defined in GM/RT2141. The packing was first placed under the wheels on one side of the wagon, and the resulting effect on the wheel loading was measured. This test was then repeated for packing under the wheels on the opposite side of the wagon, to simulate the same track twist in the opposite direction.

50 The $\Delta Q/Q$ test forms part of the *acceptance process* for new wagons given in GM/RT2141. In this process, the intent of the tests is to demonstrate that the wagon will give acceptable performance in service. Satisfactory completion of the tests requires that no wheel loses more than 60% of its nominal wheel load[2] when carrying a range of payloads over a defined track twist. As the nominal wheel load is the average wheel load on the wheelset, the reported wheel unloading is affected by any uneven wheel loading due to wagon twist, bogie twist, and uneven weight distribution within the wagon.

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[1] Paragraph C2 in Appendix C of Railway Group Standard GM/RT2141 (Resistance of Railway Vehicles to Derailment and Roll-Over) refers to use of a two metre length.

[2] This 60 % $\Delta Q/Q$ limit in GM/RT2141 (paragraph 53) is taken as a pass/fail threshold for wagon acceptance. It is generally accepted that, in the presence of significant, but normal, lateral forces (paragraph 50), a wheel unloading ratio ($\Delta Q/Q$) that is considerably in excess of the GM/RT2141 limit of 60 % is likely to be necessary before there is a significant risk of flange climb derailment.

51 The first set of ΔQ/Q tests was undertaken at Angerstein and recorded a ΔQ/Q value of 61 % for the front right wheel of wagon 546 (the first wheel to derail). This included the effect of an unbalanced partial load of about 11.7 tonnes (paragraph 94), the effect of a twist in the bogie frame (paragraph 98) and the effect of a spring that had become dislodged during the derailment[3]. The secondary suspension in the wagon model (paragraph 43) was calibrated using data from this test.

52 The second and third sets of ΔQ/Q tests were undertaken at Derby after the RAIB had completed the analyses used to obtain the wheel loadings given in this report. Both these sets of tests were undertaken with the wagon empty and the twisted bogie in place. The first set was undertaken before the dislodged spring was corrected and so did not reflect the condition of the wagon when it derailed. The spring was seated correctly before the third set of tests which gave a ΔQ/Q value of 46% for the front right wheel[4].

53 During repairs to the wagon undertaken after completion of the wheel load analyses detailed in this report, VTG found that an inner (laden) suspension spring on the second right wheel of the leading bogie was of the incorrect type, and that an inner spring on the rear bogie was broken. RAIB analyses have shown that including the incorrect spring would have only a small effect on the calculated wheel loads, and the broken spring would have no effect because loads on this wheel were small so only the tare (outer) spring was in use.

WheelChex Data

54 WheelChex is a type of Wheel Impact Load Detector (WILD) system that is installed at key locations on Network Rail's infrastucture. Both rails on a section of straight and level track are instrumented to measure the load imparted by moving wheels. The primary function of WheelChex is to identify vehicles with wheels that are generating excessive dynamic loads on the railhead, such as wheels that have flat spots or are out-of-round, so that these vehicles can be stopped before they damage the infrastructure. WheelChex can also provide data that indicates the weights of individual wheels on passing trains, an issue considered by previous RAIB reports relating to derailments at King Edward Bridge and Ely Dock Junction (paragraph 160).

55 The set of wagons that included wagon 546 had not passed any WheelChex sites on its journey from Bardon Hill quarry to Angerstein Wharf sidings on the day of the derailment. However, it had passed a WheelChex site at Thurmaston, just north of Leicester, on each of the three round trips to Tinsley in the five days prior to the derailment. Because the WheelChex system on the lines used in the northbound direction was out of service due to track maintenance, only the data for the southbound empty journeys was available.

[3] This incorrectly seated spring was identified while the wagon was at Derby. Comparison of the wheel load distribution on the leading bogie during the ΔQ/Q testing at Angerstein with the corresponding Wheelchex data showed that this spring had become unseated after the derailment.

[4] The third set of tests was analysed using the RAIB model and this demonstrated that the model was providing a reasonable representation of the wagon behaviour.

56 This meant that three sets of data were available for the same nominally empty service[5] that included wagon 546. The individual wheel loads recorded by WheelChex were increased by approximately six percent to obtain consistency with the total wagon weights recorded at Bardon Hill quarry. The wagon weights recorded at the quarry are considered by the RAIB to be more accurate as they were provided by calibrated equipment that was designed for weighing wagons. Track geometry records provided by Network Rail confirmed that the track in the vicinity of the WheelChex site was free of significant defects that could have influenced the recorded wheel loads.

57 The order of the wagons shown in TOPS did not correlate with the order of the wagons seen at the derailment site. The RAIB established the correct order of the wagons seen in the WheelChex data by using Aggregate Industries' loading documentation for the trains, practical shunting options for the train at the terminals and patterns in the sequence of *diagonal wheel unloadings* (such as those caused by bogie twist) recorded by WheelChex for each of the bogies in each train (paragraph 56).

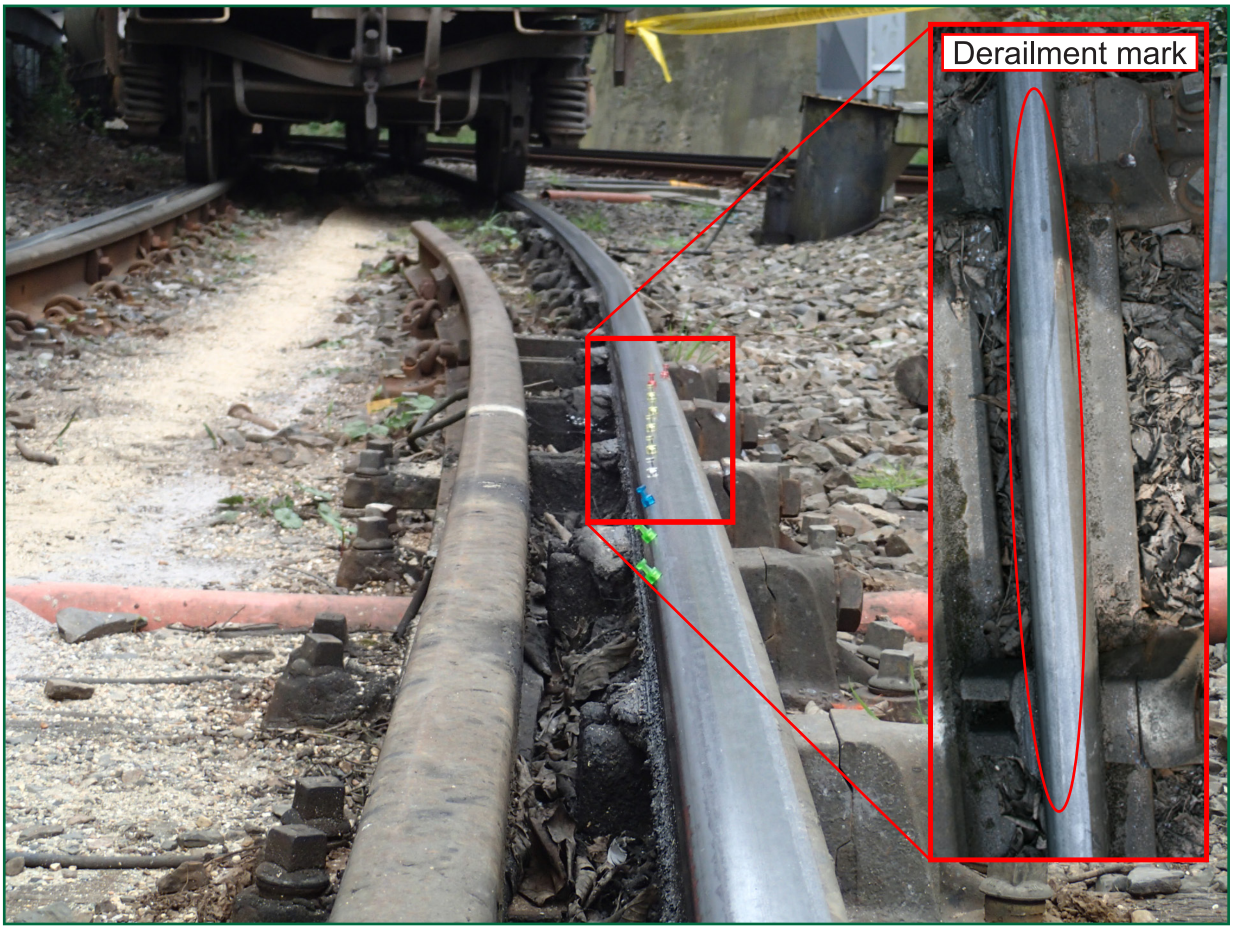

Figure 9: Derailment mark (position marked by coloured magnets placed on the rail) (Inset courtesy of Network Rail)

[5] Each train contained a different set of wagons, but each one included wagon 546.

Identification of the immediate cause

58 **The immediate cause of the accident was that there was insufficient load on the front right-hand wheel of the leading bogie on wagon 546 to counteract the lateral forces at the wheel-rail interface, and thus to prevent the flange climbing over the railhead in the vicinity of trap points 851A*.***

59 The marks on the rails at the point of derailment indicate that a single wheel flange climbed onto the head of the outer rail before derailing to the outside of the curve (figure 9).

60 The RAIB considers that it was the right-hand leading wheel on the leading bogie of wagon 546 that derailed first. The RAIB's experience of flange climb derailments is that the leading wheel on a bogie is much more likely to climb the outer rail on a curve than the trailing wheel. This is due to the more likely increased *angle of attack* of that wheel flange to the rail. The RAIB calculated the wheel unloadings for the three bogies that ultimately derailed, with each bogie positioned at the point of derailment. This showed that the front right wheel on the leading bogie of wagon 546 would have experienced approximately 20% more wheel unloading than the equivalent wheel on each of the other bogies. As a result it would have been more likely to derail than the others.

61 The marks on the *buffers* of the 8th and 9th wagons are consistent with this derailment sequence, because they indicate that the front wheelset of the 9th wagon (wagon 546) derailed to the right-hand side of the train and dropped off the rails while the 8th wagon (wagon 611) was still on the rails (figure 10). This is evidenced by the buffer face marks being concentrated on the top left-hand corner of the front left buffer of the 9th wagon and on the bottom right corner of the rear left buffer on the 8th wagon.

62 The RAIB has concluded that the rest of the wheels on the 9th wagon were dragged into derailment, along with those on the rear bogie of the 8th wagon, as the derailed wheelset was pulled across the junction and crossover *points* at Angerstein Junction. This is because the wheels that were already derailed would have been pulled over the rails at the pointwork, and this would have dragged the other wheels off the rails.

63 Marks on the back of the left side buffers on both the 8th and 9th wagons indicate that these locked together (image 4 in figure 10). This is discounted as a cause of the derailment because the marks on the front faces of the buffers show that the buffer on the 9th wagon dropped relative to that on the 8th wagon (ie the 9th wagon derailed) before locking occurred (paragraph 61). The *buffer locking* resulted in the rear left buffer on the 8th wagon being levered off to the left by the front left buffer on the 9th wagon (image 1 in figure 10). This buffer was found upside down between the running rails, about 70 metres after Angerstein Junction (image 2 in figure 10).

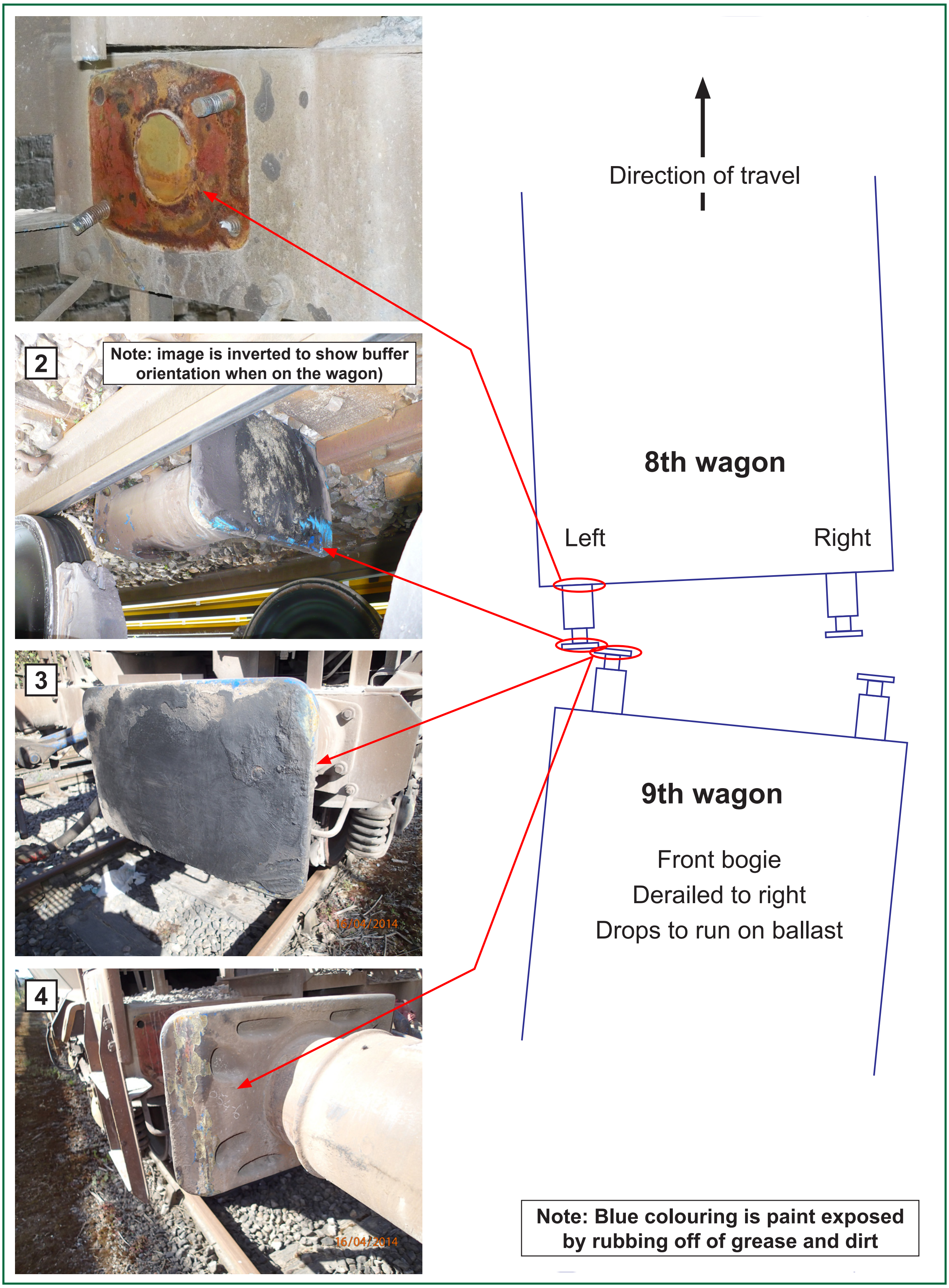

Figure 10: Buffer marks on 8th and 9th wagon (1st and 2nd insets courtesy of Network Rail)

Identification of causal factors

64 The accident occurred due to a combination of the following factors (acting in conjunction with the normal operational conditions described in paragraph 67):

a) A track fault at the trap points resulted in significant unloading of the leading right-hand wheel of wagon 546 (paragraph 68).

b) The track fault at the trap points was not detected and corrected by Network Rail's inspection and maintenance regime (paragraph 82).

c) Wagon 546 contained an uneven residual load that was sufficient to bring some of its loaded primary suspension springs into play, concurrently with relatively low wheel loads (paragraph 93).

d) The leading bogie on wagon 546 had an unbalanced diagonal wheel loading, associated with a twisted bogie (paragraph 98).

e) Procedures to release materials in the wagon during discharge at Tinsley and Angerstein allowed an uneven partial load to remain in the wagon (paragraph 113).

65 The following underlying factors also possibly contributed to the accident:

a) The potential for residual loads, particularly uneven residual loads, to increase the risk of derailment had not been recognised (paragraph 121).

b) Compliance with existing railway standards does not eliminate the risk of derailment (paragraph 129).

66 Figure 11 summarises the calculated wheel unloadings due to the relevant causal factors. Each of these factors is considered in turn in paragraphs 68 to 111.

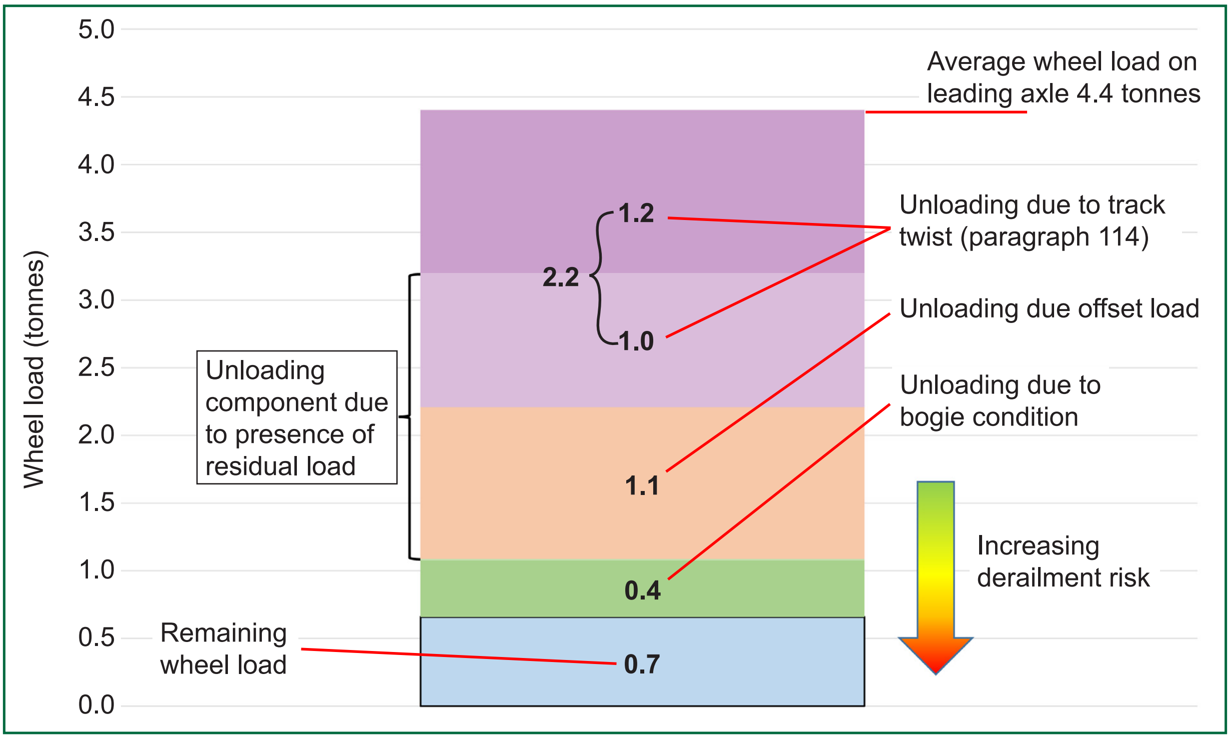

Figure 11: Indicative distribution of wheel unloading due to relevant causal factors

67 Several additional possible contributors to the derailment were considered, and either discounted or categorised as a normal condition. These were as follows:

a) **High lateral force, due to track curvature:** the derailment took place on a tight curve with a radius of approximately 130 metres. This was within the 70 metres minimum negotiable curve radius of the wagon reported by VTG. The RAIB considered this to be a normal operational condition.

b) **High lateral force, due to bogie rotation:** testing and examination at Derby showed that both bogies on wagon 546 had rotational resistances exceeding the upper limit given in GM/RT2141 for acceptance of a new wagon. The leading bogie (the first to derail) exceeded the acceptance limit by 50%. Once stripped down, evidence of significant damage at the bogie pivot was revealed, which would have increased rotational resistance. This was consistent with being a consequence of the derailment. The trailing bogie exceeded the acceptance limit by approximately 20%. Examination of the friction components of both bogies showed that these were still within the wear specification. As normal wear and tear on a properly maintained wagon can result in some degradation below criteria applicable to a new wagon, it is likely that, at the time of the derailment, the rotational resistances of the bogies on wagon 546 were not abnormal for this wagon type.

c) **Absence of check rail:** there was no *check rail* fitted at the point of derailment at trap points 851A. Railway group standard GC/RT5021 (Track System Requirements)[6] did not require a check rail at this location because the inside rail was located in the movable section of the trap points. As a result, this was considered to be a normal operational condition. A continuous check rail was provided on the rest of the curve, both before and after the trap points, and would have been required at the point of derailment if it had been on a section of plain line.

d) **High wheel/rail friction:** there was no visible evidence of high rail/wheel friction, such as the presence of metallic particles that had been worn from the rail, at the point of derailment. The curve was fitted with several lubricators intended to provide lubricating grease on the rail wheel interface of both the outer and check rails[7]. Network Rail's maintenance documentation indicated that the lubricators had undergone a two-monthly inspection, which showed that they contained sufficient grease and were operational, about a week before the derailment, with no outstanding faults recorded.

e) ***Cant deficiency/excess*:** the cant excess when the leading wheel was at the point of derailment, with the train travelling at 5 mph (8 km/h) was calculated to be 5 mm. This was very small compared to the limit of 110 mm permitted in Network Rail standard NR/L2/TRK/2049 (Track Design Handbook). The RAIB considered this to be a normal operational condition.

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[6] Section 3.2.11.1 states – 'All passenger lines, and freight only lines adjacent to passenger lines, with a horizontal radius of 200 metres or less shall be fitted with a continuous check rail to the inside rail of the curve, except where the design of S&C prevents this from being provided.'

[7] Network Rail states that the primary purpose of rail lubrication is infrastructure asset protection (ie reduction of wear at the rail/wheel interface) and not mitigation of derailment risk (See RAIB report 07/2014 – March 2014: Locomotive derailment at Ordsall Lane Junction, Salford, on 23 January 2013)

f) **Wheel/rail profile:** the side of the rail and the wheel flange both showed signs of wear. Such wear is normal, particularly on curved track. Wheel and rail profiles measured by the RAIB indicated that the *contact angle* between the front right wheel of wagon 546 and the right hand rail at the point of derailment was approximately 65 degrees, compared to approximately 60 degrees that would be expected for an unworn wheel of the same type on unworn rail. This higher contact angle would have acted to reduce the risk of a flange climb derailment occurring.

g) **Buffer locking:** the evidence from the buffer marks (paragraph 63) indicates that the buffers between the 8th and 9th wagons did not lock together until after the first wheelset had derailed.

h) **Buffing forces:** there was no evidence of any abnormal buffing forces between the wagons at the buffers. The buffer faces were well lubricated and there were no marks on the central area to indicate any high contact forces.

i) **Support of the rails:** there was an orange pipe containing electrical cables crossing the track at the point of derailment (figure 9). This was positioned between sleepers, and near to the surface, and so would not have affected the vertical track support at that location.

j) **Train braking and track gradient:** the train was braking gently on a left-hand curve with the front 18 wagons on a downhill gradient (figure 12), at the time of derailment, and this could have affected the lateral forces between the wheels and the outer rail. This was a normal operational practice for any train that was required to stop at signal L429. This scenario, with a train braking to stop at signal L129, was also present in a similar derailment that occurred at the same location on 3 June 2015 (paragraph 169).

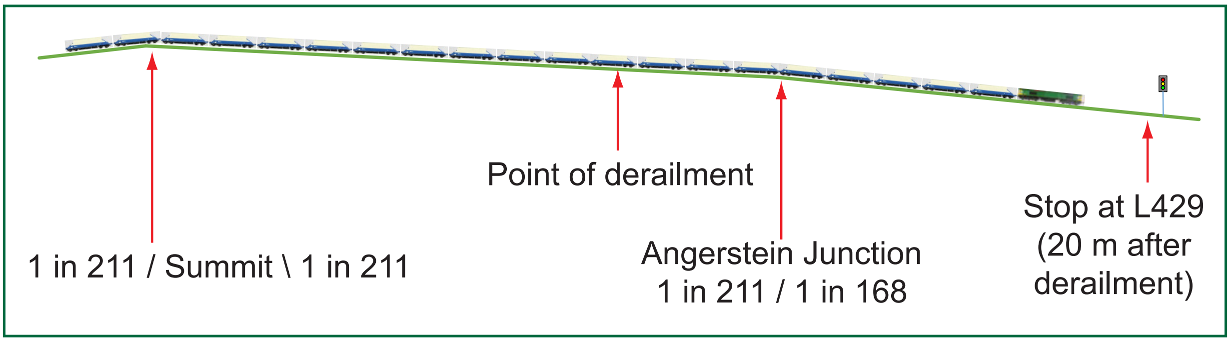


Figure 12: Gradient profile relative to the train position at derailment

Factors relating to the track condition

68 A track fault in the vicinity of the trap points resulted in significant unloading of the leading right-hand wheel of wagon 546.

69 The RAIB and Network Rail both carried out track surveys after the derailment. The RAIB also measured the amount of voiding in the vicinity of the point of derailment and incorporated this into the track survey data, along with switch hogging information measured by Network Rail after the derailment, to determine the dynamic twist in the vicinity of the point of derailment (paragraphs 33 to 38). This information is presented in figures 13 and 14, which include cant and track twist (change of cant) measured over a 3 metre base.

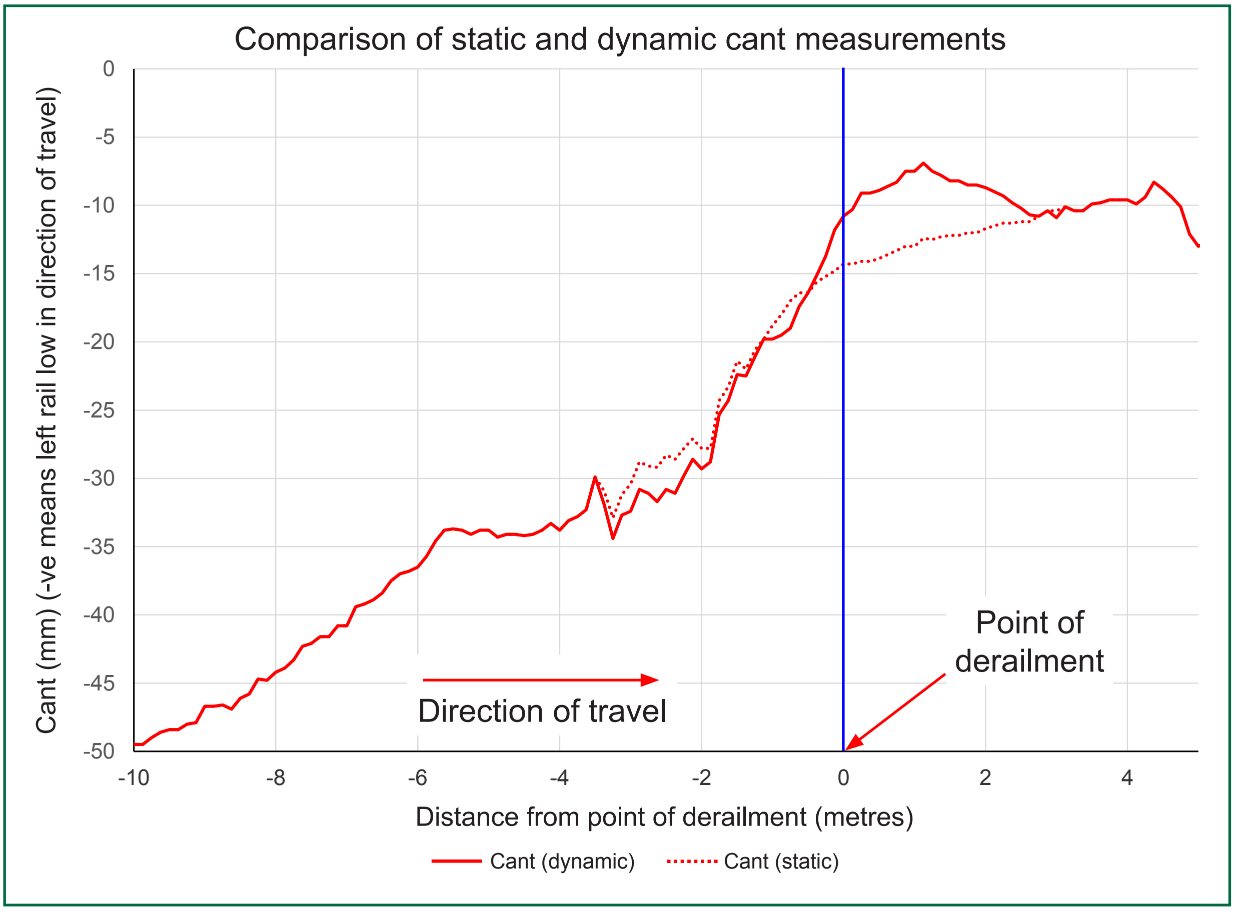


Figure 13: Track cant in the vicinity of the derailment location

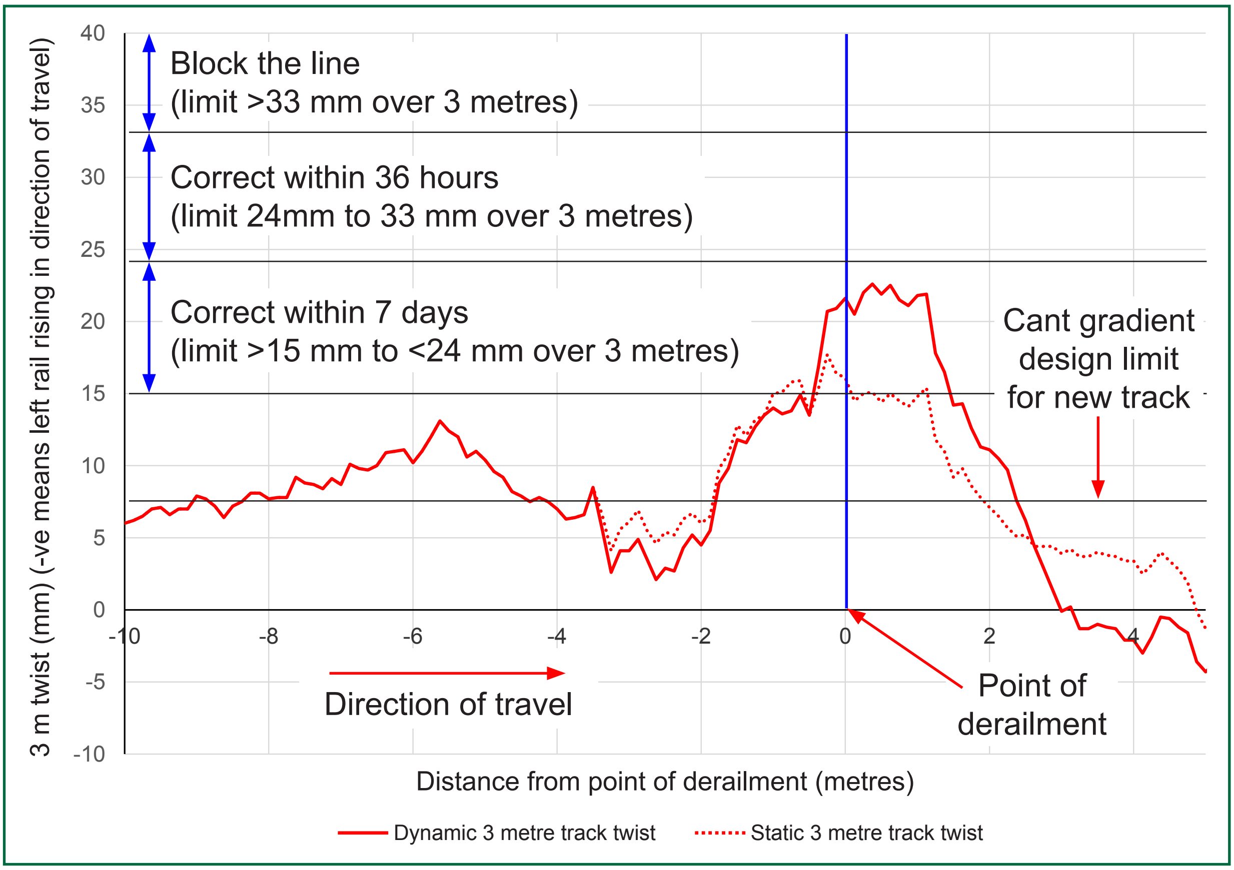


Figure 14: Track twist in the vicinity of the derailment location

70 The survey data showed that over the 10 metres on the approach to the point of derailment, the average cant gradient was close to the maximum design limit of 1 in 400 (7.5 mm change in cant every 3 metres) that is allowed by railway group standard GC/RT5021 (Track System Requirements) for new track. This design limit was significantly exceeded at some locations, including in the immediate vicinity of the point of derailment, probably due to track bed deterioration.

71 The inclusion of the voiding and switch hogging data showed that there was localised track movement in the vicinity of the point of derailment which increased the track twist. At the point of derailment, the measured 3 metre dynamic twist was 22 mm, or an average gradient of 1 in 136. The static 3 metre twist at the same location, which would not include the effects of voiding or hogging, was measured as 16 mm, or an average gradient of 1 in 187.

72 Network Rail standard NR/L2/TRK/001 'Inspection and maintenance of permanent way' places limits on the amount of track twist that is allowed to be present on the network, and defines timescales within which track twists that exceed those limits should be corrected. Table 1 shows the three metre dynamic track twist limits, and the actions required, for track with the curvature and speed limit present at the derailment location. The standard does not define separate limits applicable to static track twist.

Fault	Speed range	Limiting value	Immediate action	Remedial action
Twist (3 m)	All speeds	> 33 mm (1 in 90)	BLOCK THE LINE (train movements to be stopped)	Correct before opening to traffic
Twist (3 m)	Up to 75 mph	33 mm to 24 mm (1 in 91 to 1 in 125)		Correct within 36 hours
Twist (3 m) – curve radius <400 m	Up to 65 mph	> 15 mm to < 24 mm (1 in 126 to 1 in 199)		Correct within 7 days

Table 1: Three metre twist limits and corrective actions for the derailment location (from NR/L2/TRK/001)

73 Comparison of the measured site twist in figure 14 with the twist limits in table 1 shows that the static three metre twist at the point of derailment was slightly above the threshold that would trigger a requirement for corrective action within 7 days of detection. However, the measured dynamic three metre twist was significantly into the zone that would trigger corrective action within 7 days of detection.

74 The track survey data, incorporating the switch hogging and voiding information, was used to determine the track cant at each of the wheelsets of wagon 546, when its leading wheelset was at the point of derailment. This is summarised in table 2.

Wheelset	1st (Leading)	2nd	3rd	4th
Dynamic cant (+ve is right wheel high)	11 mm	29 mm	48 mm	53 mm

Table 2: Track cant at wagon 546 wheelsets, when at the derailment location

75 The track twist data in table 2 was input to the RAIB wagon model, described in paragraphs 39 to 44, to calculate the wheel unloading that the wagon, as loaded at the time[8], would have experienced due to the track twist at the derailment site (figure 15). The model predicted that the front right-hand wheel load on wagon 546 would have been reduced by approximately 1.8 tonnes due to the track twist present between the wheelsets of the leading bogie, and by approximately a further 0.4 tonnes due to the track twist present between the two *bogie pivot* centres. The total reduction in wheel load due to the track twist was therefore approximately 2.2 tonnes (equivalent to a ΔQ/Q of about 51%).

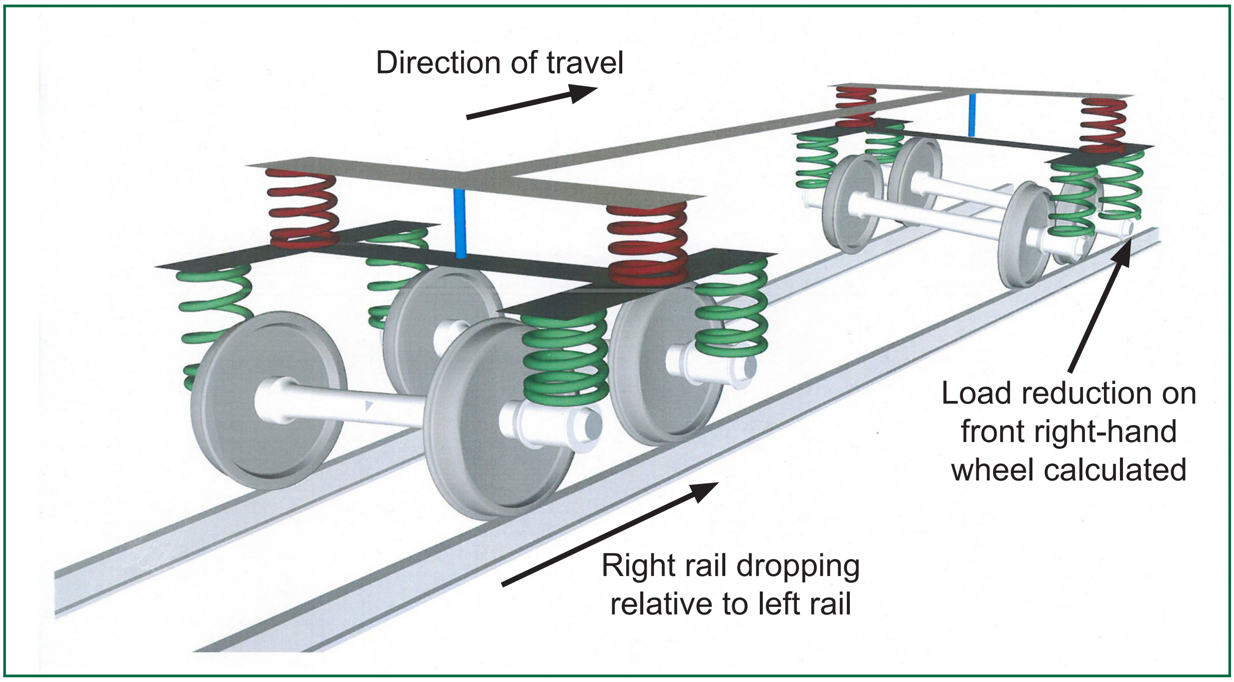


Figure 15: Model with track twist applied (exaggerated for illustration)

76 The RAIB assessed the effect on the wheel unloading of wagon 546 if the track approaching the point of derailment had experienced proportionally less deterioration from its designed profile[9], such that it was just clear of the limit where the 3 metre twist would require maintenance action (ie if 3 metre twist was less than 15 mm). In this scenario the front right wheel unloading is likely to have been approximately 1.6 tonnes under the same wagon loading conditions (equivalent to ΔQ/Q of about 36%). Similarly the RAIB calculations showed that, if the track had been allowed to deteriorate further than found at the time of derailment, the front right wheel unloading could have reached approximately 3.2 tonnes (equivalent to ΔQ/Q of about 72%) before the maintenance standards required train movements to be stopped (ie when 3 metre twist reached 33 mm).

Gauge widening

77 The nominal *track gauge* for a curve of radius between 126 metres and 150 metres is defined in Network Rail standard NR/L2/TRK/2102 (Design and construction of track) as being 1444 mm.

[8] The wagon load, and its distribution, affected the wagon suspension characteristics (paragraph 109).

[9] The RAIB made the assumption that the designed geometry profile on the approach to the point of derailment had a uniform cant gradient.

78 The track survey data, recorded immediately after the derailment, showed that the maximum static track gauge was 1466 mm, with this occurring approximately 0.5 metres before the point of derailment. Similarly, at the point of derailment the static track gauge was 1464 mm, showing that the wide gauge would have been sustained as the wheel flange was climbing towards derailment. Both of these measured values exceed the 1460 mm limit for dynamic gauge, defined in NR/L2/TRK/001 as the value that triggers a corrective action within 28 days.

79 The RAIB recorded video footage of a train passing over the trap points, which showed that approximately 5 mm of additional gauge widening was present close to the point of derailment under dynamic loading. This meant that the dynamic gauge at the widest point, approximately 0.5 metres before the point of derailment, is likely to have been approximately 1471 mm, which exceeds the 1470 mm threshold that would trigger a corrective action within 36 hours. Similarly the dynamic gauge at the point of derailment would have been approximately 1469 mm, which is close to the same threshold.

80 The presence of gauge widening increases the available angle of attack (see appendix B) of the leading wheel flange on the outer rail of the curve. The effect of this is to increase the lateral flange climb forces, and thus to increase the risk of a derailment. This effect is discussed in more detail in the RAIB report into a locomotive derailment at Ordsall Lane Junction, Salford, on 23 January 2013 (RAIB report 07/2014 – March 2014).

81 The RAIB considers that the effect of the gauge widening, although contributing to the lateral flange climbing forces at the leading right-hand wheel, is likely to be small compared to the effects of the other factors which contributed to the derailment.

Track maintenance

82 **The track fault at the trap points was not detected and corrected by Network Rail's inspection and maintenance regime.**

83 Network Rail's requirements for track inspection and maintenance are defined in standard NR/L2/TRK/001. The inspection and maintenance regime applied depends on the *track category*, which in turn depends on the speed and annual tonnage of traffic that uses the track. The standard includes special provisions for sections of track that are classified as sidings.

84 NR/L2/TRK/001 places responsibility for specifying which track category applies to each section of track with the relevant Route Asset Manager (Track). However, the standard does not define what makes a section of track a siding and does not define who has responsibility for making that decision. Witness evidence indicated that the track from Angerstein Junction to Angerstein Wharf sidings is treated as a siding for maintenance purposes because this connection is shown as a siding in the *Sectional Appendix*.

85 NR/L2/TRK/001 specifies that sidings for through traffic, such as the line at the point of derailment, are inspected at a frequency in accordance with the appropriate track category. Here the track category was 'Cat 6', which required a *basic visual inspection* (BVI) once every two weeks, and more detailed inspection every 13 weeks. The BVI includes a visual inspection of the condition of track and components, but does not include any measurements of track geometry. The inspection regime that had been put in place by the local Track Maintenance Engineer (TME) was compliant with this requirement.

86 NR/L2/TRK/001 states that sidings do not normally require routine track geometry measurement, including measurement of twist and gauge, unless they are within 10 ft (3 metres) of a running line or carry dangerous goods. Neither of these conditions applied at the location of the derailment. The TME recognised that there was no routine track geometry measurement being undertaken by a track recording vehicle on the line between Angerstein junction and Angerstein Wharf sidings, but considered that there was a need to monitor track geometry. As a result, he operated a maintenance regime where a manual trolley was used annually (as would be required if this was a Cat 6 line that was not a siding) to measure static cant and gauge data. This was additional to the minimum actions that NR/L2/TRK/001 required him to implement.

87 The manual trolley was unable to record the dynamic effects of voiding, hogging and gauge widening, because it was much lighter than a track recording vehicle, and so the track did not move under its weight as it passed. As a result the data from the manual trolley could only include static track geometry.

88 NR/L2/TRK/001 states that where manual trolleys are used to record geometry, the dynamic effects will need to be measured using void meters and dynamic track gauges. However, this can only be done in the presence of passing trains, and the infrequency of traffic on this line made this impractical. In addition, Network Rail restricts the use of void meters in regions where third rail electrification is used, due to the risk of staff receiving an electric shock from contact with the third rail when using them. This meant that the TME did not have local access to any void meters, despite the line at the derailment location itself not being electrified.

89 In the absence of being able to routinely observe passing trains to visually assess track movement, the TME relied on visual inspection of the track to identify any signs that it had been moving under load. No visible evidence of such movements had been identified in any of the basic visual or supervisory inspection records, and the RAIB was also not able to identify any visible signs of voiding, such as wet spots, at the derailment location in the absence of a passing train. Voiding is normally very difficult to identify during a BVI. Gauge widening due to dynamic effects can often be identified by scuff marks on the sleeper, but the amount of movement was small at the derailment location.

90 The manual trolley data was recorded by the local technical team. This data included a record of the geometry profile along the track and identifies locations where corrective maintenance limits had been reached or were being approached. The Section Manager, who was responsible for implementing track repairs, only routinely received from the technical team the list of locations where static twist and gauge values exceeded the maintenance limits applicable to dynamic measurements. This meant that the Section Manager did not have information from the manual trolley that could have alerted him to areas that were deteriorating towards the maintenance limits.

91 The last manual trolley recording for the line to Angerstein Wharf sidings, made 10 months prior to the derailment, did not identify any static twist or gauge faults at the derailment location that would have required corrective action when assessed against the dynamic maintenance limits. However, if a geometry recording with the manual trolley had been made at the time of the derailment, it is likely that a twist fault with a 7 day response time and a gauge fault with a 28 day response time would have been identified.

92 If a dynamic track geometry measurement had been undertaken 10 months before the derailment, it is possible that an actionable dynamic twist and/or gauge fault could have been present and identified. Similarly, if this had been undertaken at the time of the derailment, a twist fault with a 36 hour response time and a gauge fault with a 36 hour response time would have been identified.

Factors relating to the load and wagon

Load magnitude and distribution

93 **Wagon 546 contained an uneven residual load that was sufficient to bring some of its loaded primary suspension springs into play, concurrently with relatively low wheel loads.**

94 Weighing records from Bardon Hill quarry show that, before loading on 1 April 2014, wagon 546 contained 13.3 tonnes of crushed rock fines that had been retained after the previous cargo had been discharged at Tinsley. The wagon was then filled from above with 50.3 tonnes of 10 mm stone, which was subsequently discharged at the Angerstein terminal, via the hopper bottom doors. Weighing records from the Angerstein terminal show that, during unloading of the 10 mm stone, about 1.6 tonnes of the retained crushed rock fines was also released, leaving about 11.7 tonnes of the fines in the wagon hoppers. This material was still in wagon 546 when it derailed later that day.

95 This crushed rock fines material would have been located on the sides of the hopper, because most of it remained in the wagon throughout the loading and during unloading. The ability of crushed rock fines to hang in position on the side of wagons is illustrated in figure 16, which shows the material hanging in position on the sides of a wagon not involved in the derailment. Figure 17 shows the retained crushed rock fines material in one of wagon 546's three hoppers, after it had been shaken off the wagon sides and down to the bottom of the hopper during the derailment. The material could not have been in this position during unloading at the Angerstein terminal because it would have been discharged when the hopper bottom doors were opened.

96 Wagon 546 was capable of carrying a payload of 67.4 tonnes, and the retained load of 11.7 tonnes was well within its intended capacity. However, the RAIB observes that the wagon would normally be expected to run either empty or close to fully loaded, and not with a relatively small load such as this.

97 The actual distribution of the retained payload of 11.7 tonnes of crushed rock fines (paragraph 94) at the time of derailment is not known, as it was displaced during the derailment (paragraph 95). In the absence of better information, the RAIB has assumed that the load distribution at the time of the derailment was similar to the distribution of the 13.3 tonnes of material recorded by WheelChex when the wagon passed Thurmaston on 1 April 2014. The wheel loadings at the time of derailment, with the residual load, are estimated to have been as shown in appendix E.

Figure 16: Crushed rock fines hanging up in a similar hopper wagon

Figure 17: Retained material in the wagon (after derailment)

Wagon condition

98 **The leading bogie on wagon 546 had an unbalanced diagonal wheel loading, associated with a twisted bogie, before the derailment. Although this is not considered to be unusual, it would have increased the probability of derailment.**

99 Analysis of the available WheelChex information from three previous trips (paragraph 56) showed that the leading bogie on wagon 546 was displaying a consistent diagonal wheel unloading[10] of approximately 0.4 tonnes (table 3) as it passed the WheelChex site at Thurmaston.

Date	28 March 2014	31 March 2014	1 April 2014
Residual load in wagon (nominally empty on all runs)	0 tonnes	18.4 tonnes	13.3 tonnes
Bogie diagonal wheel unloading (per wheel)	0.38 tonnes	0.43 tonnes	0.41 tonnes

Table 3: Bogie-related wheel unloading on wagon 546 bogie

100 The diagonal wheel unloading on the leading bogie of wagon 546 means that the front right-hand wheel would have been unloaded by approximately 0.4 tonnes before any further unloading due to track twist and the residual load in the wagon. This is equivalent to $\Delta Q/Q$ of about 9%, as loaded at the time of derailment.

101 Bogie frame twist (illustrated in appendix B) is one possible cause of diagonal wheel unloading. Other possible causes of diagonal wheel unloading include incorrect packing inserted between the suspension springs and the bogie frame, and differences between the suspension springs used at each wheel. Measurements, taken at the top of the suspension springs after the bogie had been removed from the wagon, showed a bogie frame twist of approximately 13 mm on the leading bogie, oriented so as to unload the leading right-hand wheel at the time of derailment. The inspection of the leading bogie did not identify any packing, or other visible anomalies in the bogie, and did not reveal any visible damage to, or differences between, the springs.

102 The RAIB calculations indicate that the diagonal wheel unloading recorded by WheelChex was equivalent to the effects of a twist in the bogie frame of approximately 7 mm. This was less than the 13 mm that was measured during the inspection. At least a small part of this difference is because the RAIB model assumes a fully rigid bogie frame and, as the bogie frame is actually slightly flexible, a greater frame twist is needed to give an equivalent diagonal wheel unloading. It is also possible that some of the measured bogie twist was the result of damage sustained during the derailment. The diagonal wheel unloadings used this report are based on pre-derailment WheelChex data and so are unaffected by these uncertainties. The RAIB consider it probable that this diagonal wheel unloading was partly, or entirely, a consequence of bogie twist.

[10] The calculation method for diagonal wheel unloading is explained in appendix E.

103 The leading bogie of wagon 546 was surveyed several times by the RAIB, after the derailment, while still fitted to the wagon, to try to identify any twist in the bogie frame. Measurements were taken at several accessible points on the bogie frame. However, due to difficulties in accessing the top of some of the suspension springs with the bogie attached to the wagon, the RAIB did not obtain all the necessary data to obtain an accurate measurement of bogie frame twist. Measurements taken during these surveys were inconsistent and gave bogie frame twists of between 0 mm and 15 mm, depending on the frame position used for the measurements. None of the maintenance instructions for the wagon identified a defined point on the frame at which the twist could be measured. As a result of these difficulties, it was not possible to measure bogie frame twist by this method.

104 An SNCF bogie maintenance document, dated 2006 (ITR 72 002 – RG1 RG2 Des Bogies Type Y25 et leurs dérivés), describes a method for measuring bogie frame twist in bogies of the type fitted to wagon 546. This requires the bogie to be removed from the wagon and disassembled. The bogie frame is then positioned on four equal height stands, and the twist is indicated by the size of the gap between the frame and any stand that it is not touching. The document specifies that the maximum permissible bogie frame twist, measured in this way, is 5 mm (equivalent to a wheel unloading of about 0.3 tonnes for wagon 546 if calculated using the RAIB model assuming a rigid bogie). The RAIB was unable to identify any equivalent UK documents, including the maintenance documents for the JRA wagons, that described a limit for permissible bogie frame twist.

105 The maintenance regime for the JRA wagons in this train was defined in document WHD/BACR/01 'Maintenance schedule for Bardon Aggregates 90t JRA Aggregate Hopper Wagons'. This was prepared by the previous owner of the wagons, and was adopted by VTG. As part of this regime, the wagons were subject to Planned Preventative Maintenance (PPM) and to Vehicle Inspection and Brake Test (VIBT) alternately every three months. This maintenance was up to date, with the last PPM taking place on 10 March 2014, three weeks before the derailment. No defects were recorded during the last four maintenance activities.

106 A wagon receives maintenance and repair based on the findings of the PPM and VIBT. It is also subject to overhaul every 7 years, and this includes a more detailed inspection, including removal of the bogies and measurement of dimensions between wearing surfaces. Some checks on wearing parts are also carried out on the bogie when its wheels are changed between overhauls.

107 The PPM, VIBT and overhaul procedures require the bogie frame to be visually examined for '*security, damage, bending, fractures and weld failures*'. This does not require any measurement of the bogie frame to identify any distortion that is not visible. This is consistent with *Rail Industry Standard* RIS-2702-RST 'In-Service Examination and Reference Limits for Freight Wagons', which is maintained by *RSSB* and requires the wagon to be examined '*where visible, for damage, distortion, defects, weld failures and security of attached components*'.

108 VTG stated that wagon bogies are only dimensionally checked for frame twist if the wagon is involved in a collision or a derailment. VTG was unable to provide any evidence to confirm whether or not the wagon had been involved in any previous derailments or collisions which could have caused any damage to the bogie frame. This was partly because the wagon had passed through multiple owners since manufacture in 1990, and VTG did not have historic incident records.

Overall wheel load distribution

109 The combined effect of diagonal wheel unloading associated with bogie twist (paragraph 98), the residual load, and the tare weight of the wagon resulted in the wheel load distribution shown in table 4. This distribution meant that, before encountering the track twist at the derailment site, the leading right wheel was unloaded by approximately 1.5 tonnes compared to the average load on that axle (the 1.5 tonnes includes diagonal wheel unloading and lateral imbalance). It also meant that five of the wheels had a load of above 3.25 tonnes (paragraph 40), meaning that they were using the stiffer loaded primary suspension springs, thus increasing the unloading effect of track twist.

Wheel loads/unloading		**Axle (1 is Leading)**			
		4	**3**	**2**	**1**
Left wheel	Tare weight	2.8 tonnes	2.8 tonnes	2.8 tonnes	2.8 tonnes
	Load weight (averaged across axle)	1.3 tonnes	1.1 tonnes	1.9 tonnes	1.6 tonnes
	Diagonal wheel unloading	-0.1 tonnes	0.1 tonnes	-0.4 tonnes	0.4 tonnes
	Lateral load imbalance	1.0 tonnes	1.0 tonnes	1.1 tonnes	1.1 tonnes
	Total wheel load	5.1 tonnes	5.0 tonnes	5.4 tonnes	5.9 tonnes
Right wheel	Tare weight	2.8 tonnes	2.8 tonnes	2.8 tonnes	2.8 tonnes
	Load weight (averaged across axle)	1.3 tonnes	1.1 tonnes	1.9 tonnes	1.6 tonnes
	Diagonal wheel unloading	0.1 tonnes	-0.1 tonnes	0.4 tonnes	-0.4 tonnes
	Lateral load imbalance	-1.0 tonnes	-1.0 tonnes	-1.1 tonnes	-1.1 tonnes
	Total wheel load	3.2 tonnes	2.9 tonnes	4.0 tonnes	2.9 tonnes

Table 4: Wheel load distribution and breakdown on level track, prior to derailment (Mathematical discrepancies are due to rounding errors)

110 The RAIB calculated that, with the primary suspension springs in this condition, the track twist at the derailment location would have caused the front right wheel to carry 2.2 tonnes less that it would have done on level track. This unloading is equivalent to $\Delta Q/Q$ of about 51%.

111 If the wagon had been empty after unloading then all of the wheels would have been resting on the softer tare primary suspension springs. In this condition, the RAIB calculated that the wheel unloading due to the track twist would have been 1.2 tonnes (equivalent to ΔQ/Q of about 27%). This is 1.0 tonne less than the wheel unloading due to track twist calculated for the wagon as loaded at the time of the derailment. Figure 11 therefore subdivides the 2.2 tonnes wheel unloading effect of track twist into two components; 1.2 tonnes associated with an empty wagon and an additional 1.0 tonne associated with the residual load.

Lateral imbalances on other wagons

112 The WheelChex data for the nominally empty train that included wagon 546 and passed Thurmaston WheelChex site on 1 April 2014 (when travelling from Tinsley to Bardon Hill quarry), is shown in figure 18. This shows the lateral imbalance (per wheel)[11] of most of the wagons is less than 0.2 tonnes, but exceeds this value on ten wagons. In all ten instances, the load is biased to the same side (the left side when related to the direction of travel at the time of derailment), and is associated with wagons that are carrying residual loads in excess of 4 tonnes. RAIB analysis of additional WheelChex data for two earlier nominally empty trips between Tinsley terminal and Bardon Hill quarry shows that between 40% and 85% of the wagons in each train contained a residual load in excess of 1 tonne, and that this load was always significantly biased towards the same side.

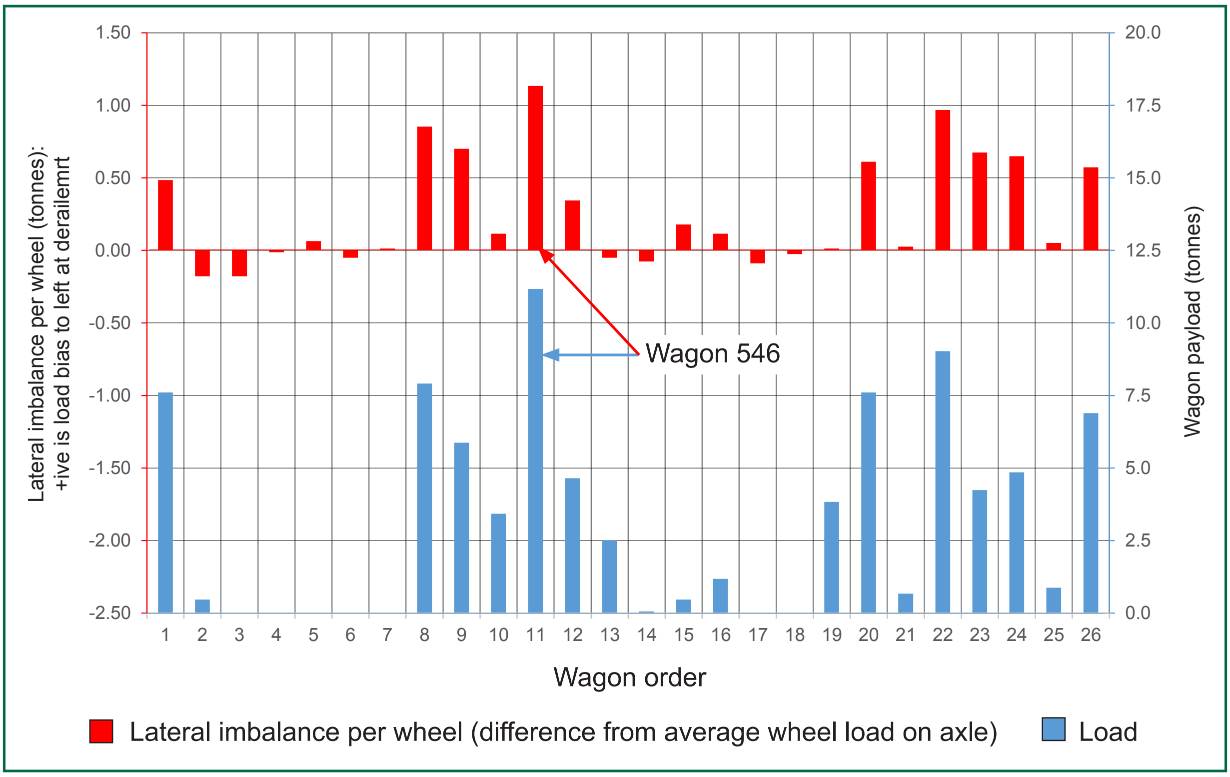


Figure 18: Graph of unbalanced loads in other wagons (from Thurmaston WheelChex on 1 April 2014)

11 Lateral imbalance (per wheel) is defined as the difference between the total weights on all the left side wheels and all the right side wheels, divided by the total number of wheels. This represents the average load difference per wheel between uneven and even loading.

Unloading procedures

113 **Procedures to release materials in the wagon during discharge at Tinsley and Angerstein allowed an uneven residual load to remain in the wagon.**

114 Aggregate Industries has stated that crushed rock fines are prone to hanging up in hopper wagons during discharge (figure 16), and that this has been a long term problem. It explained that the small, angular granite particles appear to lock together to form bridges between surfaces in the wagon, rather than flowing freely when the doors in the bottom of the hopper are open.

115 Aggregate Industries had a procedure in place at the Angerstein terminal that involved use of a CCTV camera, positioned above the unloading pit, to check the inside of wagons that were being emptied to identify if the load had been fully discharged (figure 19). If load was seen to hang up, the operator was required to use a sledgehammer to strike the side of the wagon in order to release it. If the material was not released after a reasonable amount of hammering, the procedure required this to be recorded and the wagon returned with the retained load in situ. The RAIB has seen no evidence to indicate that the presence of retained loads was being recorded.

Figure 19: Operators view of wagon interior on CCTV screen

116 When travelling to Angerstein, immediately before the derailment, the load in the wagon was 10 mm stone particles. The RAIB noted, while observing unloading of a similar train, that this material does not hang up in wagons, and flows freely from the hopper when the bottom doors are opened (figure 20). It is not known whether the operator checked to see if there was a retained load in wagon 546 after the 10 mm stone had been discharged at Angerstein, shortly before the derailment, or attempted to release the retained load that was hanging up on its sides.

Figure 20: Larger particle rock freely discharging from a hopper wagon

117 The unloading process is a one person operation at both Angerstein and Tinsley terminals. A shunter is also present, but his role is to control train movements during unloading, and not to assist with emptying wagons. The unloading operator connects a compressed air supply to the wagon to be unloaded, to provide power to operate the hopper bottom doors (figure 21). He then controls the opening of the hopper doors to discharge the material from the wagon onto a conveyor system in a pit under the train. After the wagon is unloaded, the operator records the weight of material that was unloaded, closes the hopper doors and disconnects the air line. The train is then moved forward to bring the next wagon into the unloading area.

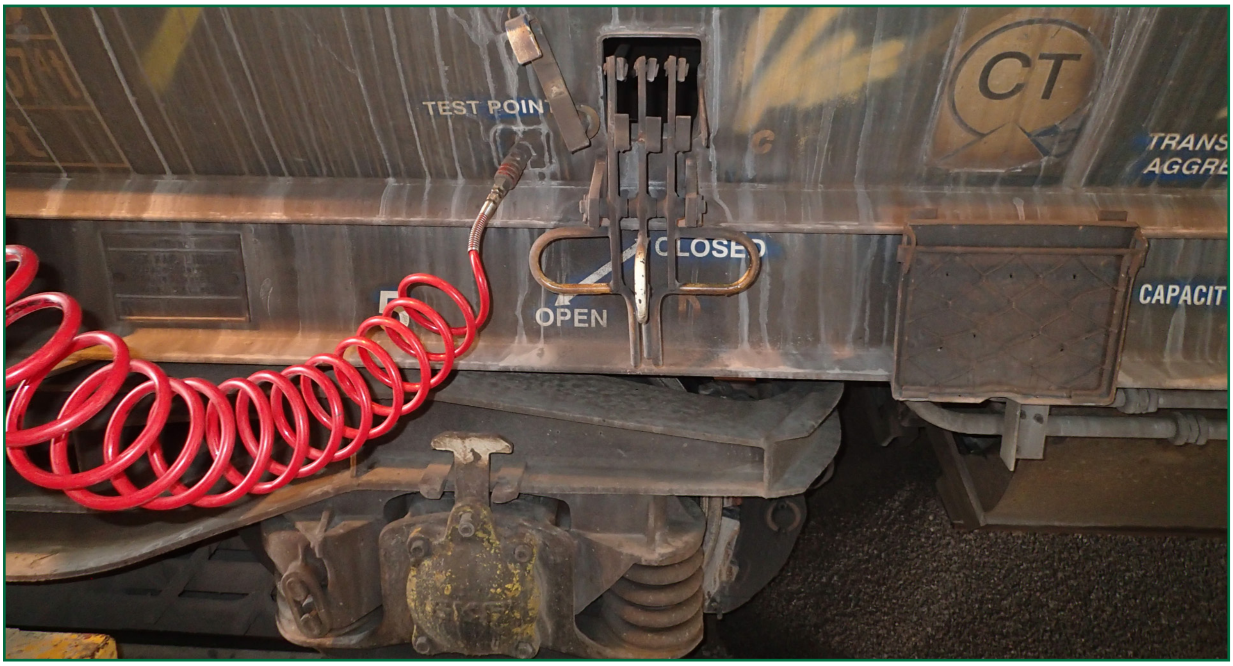


Figure 21: Wagon air connection and door controls

118 At all times during this operation, the operator is situated on one side of the wagon, where the air supply, the CCTV system and the conveyor controls are located. This means that, in practice, the operator only uses the sledgehammer on one side of the wagon, and release of hanging material is more effective on that side than on the other.

119 When travelling between Bardon Hill, Tinsley and Angerstein, the wagons followed routes that meant that the operators were positioned on the right side of the wagons (related to the direction of travel at derailment) during unloading at both Tinsley and Angerstein terminals. This meant that the sledgehammers would not have been used on the opposite side of the wagons, thus making it more likely that material would be retained on the left side for consecutive journeys.

120 Aggregate Industries recognised that the use of sledgehammers introduced manual handling risks to the unloading procedure and had attempted to minimise their use by trialling other methods of releasing retained material in wagons. These methods included non-stick coatings in the hopper, vibration pads attached to the wagon sides and the use of *slide-hammers* instead of sledgehammers. Although all of these reduced the manual handling risks, sledgehammers were more effective and so continued to be used at the Angerstein terminal.

Identification of underlying factors

Aggregate Industries' recognition of load imbalance risk

121 **The potential for residual loads, particularly uneven residual loads, to increase the risk of derailment had not been recognised.**

122 Granite stone from Bardon Hill quarry has been transported by rail for more than 160 years, and the crushed rock fines material has been prone to hanging up in hopper wagons for as long as it has been transported in them. Aggregate Industries was unable to identify for how long this material has been transported in hopper wagons, but it did indicate that it had been for several decades.

123 As the operator of the train, Freightliner was responsible for safe operation of the train on the network. Its processes intended to achieve this included a written working agreement with Aggregate Industries, which defined each organisation's operational responsibility at Angerstein terminal.

124 Under this agreement, Freightliner retained operational responsibility for train movements and for preparing the train for departure from the terminal. A Freightliner shunter at the terminal ensured that train movements were undertaken safely when requested by Aggregate Industries' staff. The shunter also monitored the condition of trains and carried out pre-departure inspections before trains left the terminal.

125 This pre-departure inspection is described in Railway Group Standard GO/RT3056/C 'Principles of Safe Freight Train Operation' section C3 'Operational pre-departure check'. This checks the mechanical condition of the train, including couplings, brakes, hopper doors and presence of a tail lamp. It does not include any inspection of the internal loading of the wagon.

126 Also under the agreement, Aggregate Industries took on operational responsibility for carrying out the unloading activities. The Aggregate Industries terminal operator liaised with the Freightliner shunter to control train movements, so that each wagon was positioned over the unloading pit in turn. The operator also undertook the unloading activity (paragraph 117) in line with the unloading procedure, which was part of Aggregate Industries' site safety management system for the Angerstein terminal.

127 The unloading procedure identified that a failure to fully discharge a load was possible, but only required this to be recorded and the wagon returned as if it was empty. The risk assessment associated with Aggregate Industries' unloading procedure was focused on the unloading activity, and did not consider the possibility of retained loads exporting risk onto the railway. As a result, it did not consider the possibility of uneven loads being present in nominally empty wagons, and thus did not place any limits on the extent to which an uneven residual load was acceptable.

128 Aggregate Industries did, in its procedure for loading wagons at Bardon Hill quarry, identify the importance of ensuring lateral and longitudinal balance of the load. It stated that it had not considered that, after unloading, wagons could still contain a load that would require a similar assessment.

Derailment risk with current standards

129 **Compliance with existing railway standards does not eliminate the risk of derailment.**

130 The derailment at Angerstein involved a wagon that had been accepted as compliant with standards intended to control derailment risk (paragraph 50), was reported as being maintained in accordance with standards (paragraph 105) and was running over track which standards permit to remain in service (paragraph 73). The potential for derailment to occur in these circumstances was recognised by the railway industry and led to RSSB undertaking research, published in 2006 as RSSB Research Report T357 'Cost effective reduction of derailment risk: initial data analysis'[12].

131 This research considered wagons compliant with derailment resistance standard GM/RT2141 running on track compliant with design standard GC/RT5021 and maintained to standard NR/L2/TRK/001. RSSB research recognised that a finite risk of derailment remained when complying with these standards, but concluded that such derailments were uncommon and normally involved factors, such as wagon loading, that were outside the direct control of these standards. As a result, the report stated *'Our analysis does not suggest that a change to mandatory standards would be effective in managing the residual derailment risk and therefore no action to amend Railway Group Standards is proposed'*.

132 The RAIB has investigated a previous derailment that occurred when both track and wagons were 'compliant' at King Edward Bridge (paragraph 150). In addition, the RAIB investigation into a locomotive derailment at Ordsall Lane Junction (paragraph 80) considered the management of derailment risk and identified that even when the vehicle and track are compliant with relevant standards, there is a residual risk of derailment.

[12] http://www.rssb.co.uk/research-development-and-innovation/research-and-development/research-project-catalogue/t357.

133 The risk of derailment is usually greater for lightly loaded wagons and bogies because wheel loads are still relatively low but the suspension is relatively stiff as the load is just sufficient to bring the loaded springs into play. In this situation a relatively small extension of a suspension spring in response to a track defect can cause a relatively large load reduction compared to the wheel load. Lightly loaded wagons and bogies are therefore more likely to be associated with derailments in 'compliant' circumstances and wagon 546 is an example of this. The effect of the relatively light load in wagon 546 is shown on figure 22 which is based on the RAIB model. The centre bar shows the leading right-hand wheel ΔQ/Q value of approximately 85% which occurred during the Angerstein derailment. If the same track defect had been encountered when the wagon was empty, the ΔQ/Q value would have been approximately 56%. If carrying a full load, with an offset comparable to the incident load, the ΔQ/Q value would have been approximately 42%. It is improbable that the derailment would have occurred in either of these instances.

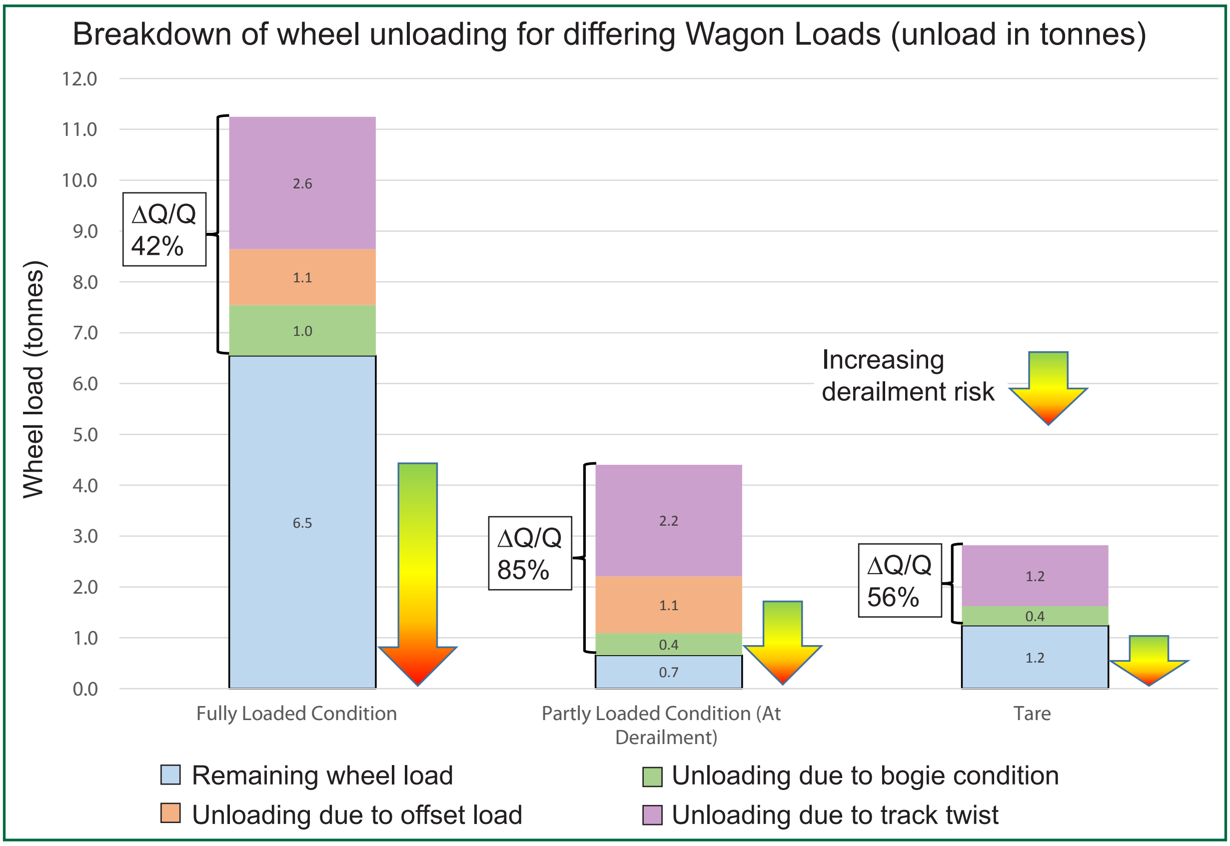


Figure 22: Illustration of effect of track twist, and unbalanced residual load on differently loaded wagons

134 The RAIB has observed comparable effects when investigating derailments of container wagons carrying uneven loads due to:

- asymmetric loading within a container; and/or
- longitudinal asymmetry due to the distribution of weight along the length of a wagon.

135 These investigations related to derailments at Duddeston, Reading West Junction and Primrose Hill/Camden Road West Junction (paragraph 150).

Observations

Twist measurement length

136 **The twist measurement used for track maintenance related to a base of 3 metres, which differed significantly from the wheelbase of, and hence the twist that affected, the bogie on wagon 546.**

137 Network Rail and Railway Group Standards relating to track design and maintenance refer to track twist measured over a base length of three metres. These include Network Rail standards NR/L2/TRK/001 'Inspection and maintenance of permanent way' and NR/L2/TRK/2102 'Design and construction of track'. They also include railway group standard GC/RT5021 'Track system requirements', which is maintained by RSSB. Standards that are specific to recording of track geometry using rail vehicle mounted equipment also specify an additional measurement base of 5 metres, but this is not used by Network Rail for specifying track maintenance. These include Network Rail standard NR/SP/TRK/042 'Track Geometry Recording' and railway group standard GC/EH0038 'Track recording handbook' (now withdrawn).

138 On wagon 546, in common with the majority of the wagons that use the line to Angerstein Wharf, the spacing between the wheels on each bogie is 1.8 metres. That means that the wagon bogies will react to track twists with a base length of 1.8 metres. If twist is measured over a length of 3 metres, it is possible for the measurement to bridge greater changes in cant that occur within that distance.

139 At the derailment location, the measured 3 metre dynamic twist was 22 mm, which is equivalent to a gradient of 0.73% (1 in 136). However, the measured 1.8 metre dynamic twist was 18 mm[13], which is equivalent to a gradient of 1.00% (1 in 100). This means that the twist gradient experienced by every wagon bogie passing over that location, acting to unload the front right wheel, was 35% higher than that which would have been detected by using a 3 metre measurement base (figure 23). The potential for derailment due to track twists that are not able to be identified using a measurement base of 3 metres was previously considered in the RAIB report into a derailment at Primrose Hill/Camden Road West Junction, North London (paragraph 162).

140 The European Union 'Commission Regulation on the technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union' (1299/2014 of 18 November 2014)[14] requires track twist to be assessed using at least one measurement base between 2 metres and 5 metres, with no restriction on the use of additional bases outside this range. However, no criteria are provided for deciding which base(s) to choose within this range. The current system used on Network Rail is compliant with this requirement. This standard allows infrastructure operators to use more than one measurement base within this range and additional bases outside this range.

[13] A 1.8 metre twist of in excess of 12 mm was sustained over the 1.5 metres on the approach to the point of derailment, during which the flange would have been starting to climb onto the rail head (paragraph 46).

[14] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014R1299.

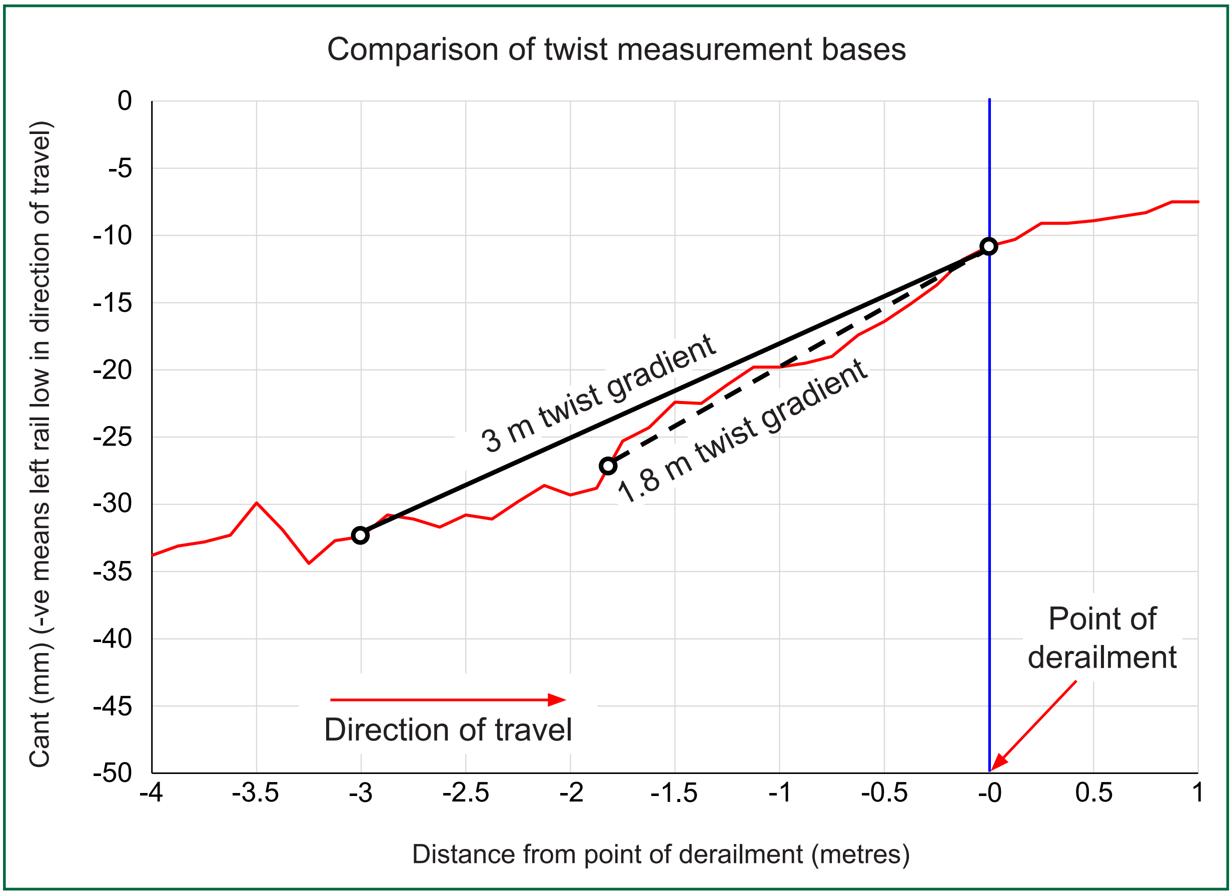


Figure 23: Measurement of site dynamic twist using different base lengths

141 While the RAIB cannot be certain, it is possible that a maintenance regime using a twist length comparable to the bogie wheel spacing could have avoided the derailment. This would depend on the maintenance limit that would be specified for the shorter twist length, the time period between measurements and the time periods within which corrective actions would be required.

142 **A small, but not insignificant, proportion of freight wagons operating on Network Rail infrastructure have significant diagonal wheel unloadings on their bogies.**

143 The RAIB's analysis of three sets of Thurmaston WheelChex data indicates that the leading bogie of wagon 546 had a diagonal wheel unloading of approximately 0.4 tonnes (paragraph 99), both when the wagon was empty and when it had a residual load of up to 13.6 tonnes. The RAIB believes that this was associated with bogie frame twist.

144 Figure 24 shows the diagonal wheel unloadings for the train containing wagon 546 at Thurmaston on 1 April 2014. This shows that four other bogies in that train had comparable or greater diagonal wheel unloadings to that on wagon 546. Three of these had the effect of unloading the leading right wheel, while the fourth would have unloaded the leading left wheel.

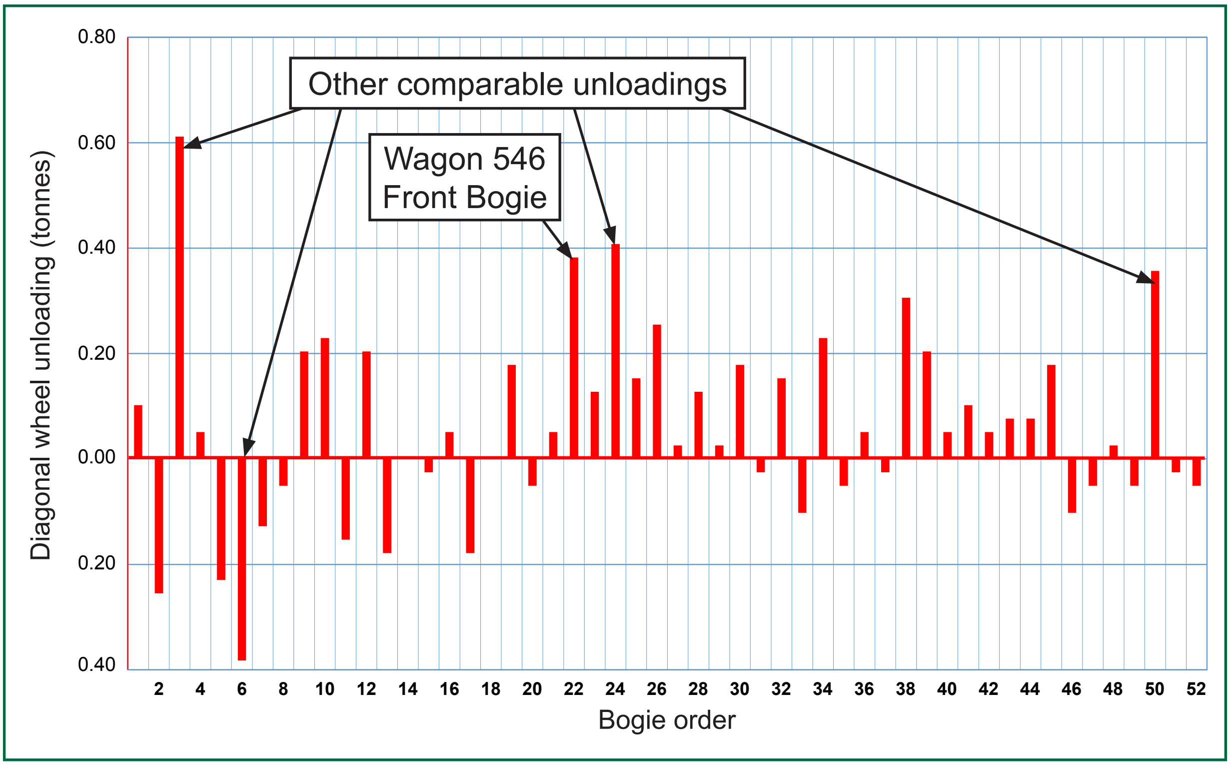


Figure 24: Bogie diagonal wheel unloading for train containing wagon 546 (from Thurmaston WheelChex on 1 April 2014)

145 Two of the four bogies were fitted to JRA wagons and two were fitted to JGA wagons (also a hopper wagon with Y25 type bogies similar to those on wagon 546, but from a different manufacturer). Three of these four bogies exhibited approximately 0.4 tonnes of diagonal wheel unloading. The fourth bogie, one of those fitted to a JGA wagon, exhibited approximately 0.6 tonnes of diagonal wheel unloading. The unloading on wagon 546 was associated with bogie twist but the cause of the other diagonal wheel unloadings is uncertain. If they were caused by twist in the bogie frames, the RAIB model shows that unloadings of 0.4 tonnes and 0.6 tonnes correspond to approximately 7 mm and 11 mm of twist on a rigid bogie (paragraph 102).

146 The RAIB obtained further wheel load data from Network Rail, for other recording locations and other types of wagon. Because much of the data was for loaded wagons, and the types of bogies on the wagons varied, the RAIB acknowledges that the data cannot be used to draw detailed conclusions about the prevalence of bogie diagonal wheel unloading.

Number of trains reviewed	11
Number of wagon bogies on these trains	582
Number of bogies with diagonal wheel unloading exceeding 0.3 tonnes when tare or lightly loaded, or exceeding 0.6 tonnes when loaded (The higher value for loaded wagons reflects the expected stiffer suspension characteristics)	20

Table 5: Summary results from survey of bogie diagonal wheel unloadings

147 Among the 582 bogies surveyed, 20 bogies showed diagonal wheel unloadings comparable to, or worse than, those on wagon 546. However, 7 of those bogies were recorded in a single train of 24 open box wagons. This compares to 6 bogies out of 52 on the JRA and JGA hopper wagons seen in the Thurmaston WheelChex data for the trains that included wagon 546 (paragraph 56). The data suggests that the bogies on some types of wagon are more susceptible to diagonal wheel unloading due to bogie frame twist, or other abnormal bogie suspension characteristics, than others. The data also indicates that the diagonal wheel unloading seen on wagon 546 was not unusual (table 5).

148 An earlier industry investigation into a derailment at Westbury in 2006[15] makes reference to some work that Jarvis Rail had carried out in 2005 to survey the extent of bogie frame twist in the Y25 type bogies fitted to the fleet of YFA and YXA wagons it operated. This work identified that, in the fleet of 132 bogies, six were found to have a bogie frame twist in excess of 10 mm (equivalent to a diagonal wheel unloading of approximately 0.5 tonnes if analysed using the RAIB model, which assumes a rigid bogie). Of those, three were found to have in excess of 20 mm of frame twist, and one of those had 42 mm of frame twist. The RAIB has been unable to identify any industry actions that took place as a result of this work. RSSB has reported that uneven wheel loading due to frame twist on Y25 type bogies has been known about since 1987.

149 The RAIB asked a number of wagon owners and operators if they routinely measured bogie frame twist, or diagonal wheel unloading, and if they knew what levels were present in operational wagon bogies. All replied that they do not routinely measure such twist, and would only do so after a derailment or collision (paragraph 108). None of the wagon owners or operators were able to identify any more recent work on the extent of bogie frame twist present on wagons operating on the rail network.

Previous occurrences of a similar character

150 The RAIB has investigated several previous derailments in which a combination of track twist and uneven wagon loading has led to derailment (table 6). Recommendations and actions arising from them that were relevant to this derailment are given in paragraphs 156 to 163.

Accident	Date	RAIB Report
King Edward Bridge, Newcastle-upon-Tyne	10 May 2007	02/2008 – January 2008
Ely	22 June 2007	02/2009 – January 2009
Duddeston	10 August 2007	16/2008 – July 2008
Birmingham Moor Street	25 March 2008	07/2009 – March 2009
Reading West Junction	28 January 2012	02/2013 – January 2013
Primrose Hill/Camden Road West Junction, North London	15 October 2013	21/2014 – October 2014

Table 6: Previous related derailments

[15] Network Rail (West Country), English, Welsh & Scottish Railways and Jarvis Rail - Report of a Formal Investigation into a derailment - Date: Thursday 13 April 2006 - Location: Westbury South - Train: 6C41 15.05 Alexandra Dock Jcn. to Westbury - SMIS reference: QGW/123712 - Local reference: 06/RGW/023.

151 The RAIB has not investigated a previous derailment where diagonal wheel unloading across a bogie, or bogie frame twist, has been identified as a causal factor. However, twist on a 2-axle wagon (a wheel unloading mechanism similar to that for twist on a bogie frame, but affected by track twist over different lengths) was recognised as a factor in the derailment at King Edward Bridge and one recommendation from the RAIB investigation into this accident is relevant to the Angerstein Junction derailment (paragraph 160).

Summary of conclusions

Immediate cause

152 The immediate cause of the accident was that there was insufficient load on the front right-hand wheel of the leading bogie on wagon 546 to counteract the lateral forces at the wheel-rail interface, and thus to prevent the flange climbing over the railhead in the vicinity of trap points 851A (**paragraph 58**).

Causal factors

153 The causal factors were:

a) A track fault in the vicinity of the trap points resulted in significant unloading of the leading right-hand wheel of wagon 546 (**paragraph 68, Recommendation 3**).

b) The track fault at the trap points was not detected and corrected by Network Rail's inspection and maintenance regime (**paragraph 82, Recommendations 3 and 4**).

c) Wagon 546 contained an uneven residual load that was sufficient to bring some of its loaded primary suspension springs into play, concurrently with relatively low wheel loads (**paragraph 93, Recommendations 1 and 6**).

d) The leading bogie on wagon 546 had an unbalanced diagonal wheel loading, associated with a twisted bogie (**paragraph 98, Recommendations 2 and 5**).

e) Procedures to release materials in the wagon during discharge at Tinsley and Angerstein allowed an uneven residual load to remain in the wagon (**paragraph 113, Recommendation 1**).

Underlying factors

154 The underlying factors were:

a) The potential for residual loads, particularly uneven residual loads, to increase the risk of derailment had not been recognised (**paragraph 121, Recommendations 1 and 6**).

b) Compliance with existing railway standards does not eliminate the risk of derailment (**paragraph 129, Recommendation 6**).

Additional observations

155 Although not linked to the accident on 2 April 2014, the RAIB observes that

a) The twist measurement used for track maintenance related to a base of three metres, which differed significantly from the wheelbase of, and hence the twist that affected, the bogie on wagon 546 (**paragraph 136, Recommendation 4**).

b) A small, but not insignificant, proportion of freight wagons operating on Network Rail infrastructure have significant diagonal wheel unloadings on their bogies (**paragraph 142, Recommendations 2, 5 and 6**).

Previous RAIB recommendations relevant to this investigation

156 The following recommendations, which were made by the RAIB as a result of its previous investigations, have relevance to this investigation.

Recommendation that could have affected the factors

Accident at Birmingham Moor Street, 25 March 2008, RAIB report published March 2009

157 Recommendation 2 of the RAIB report into the derailment at Birmingham Moor Street[16] is relevant to the Angerstein Junction derailment because it includes consideration of how track deterioration on lightly used lines is identified. The recommendation states:

Network Rail should develop methods to improve the identification of voids in lightly used track and provide this as guidance to their inspection staff. Where this is a critical factor, consideration should be given to other methods of determining voids by measurement. This may include use of a track recording vehicle or void measurement using void meters.

158 The ORR (see appendix A for definition) has reported to the RAIB that the recommendation had been addressed by the following measures:

The first part of the recommendation was not implemented because it was already covered by existing processes to identify voiding on running lines.

The second part of the recommendation was addressed by compiling a track register of locations susceptible to voiding and by identifying a dynamic strategy for each.

159 At the Angerstein derailment site, inspection staff had been unable to visually identify the presence of voiding in the absence of trains, and the system that was in place for dynamic measurement of track movement did not identify that track twist maintenance limits had been reached. The TME was unaware of a separate register of locations susceptible to voiding, but knew that such locations had routine additional inspections scheduled in Network Rail's maintenance system. The derailment site at Angerstein was not identified for additional inspections, other than the manual trolley geometry measurement that had been instigated by the TME (paragraph 86).

[16] Report 07/2009, available on the RAIB website.

Recommendations that are currently being implemented

Accident at King Edward Bridge, Newcastle-upon-Tyne, 10 May 2007, RAIB report published January 2008

160 Recommendation 2 of the RAIB report into the derailment at King Edward Bridge, Newcastle-upon-Tyne[17], is relevant to the Angerstein Junction derailment because it includes consideration of using WheelChex (or similar systems) to identify wagons with excessive wheel load imbalances. This recommendation was reiterated in the RAIB report into a derailment at Ely Dock Junction on 22 June 2007[18]. The recommendation states:

Network Rail should investigate the capability for WheelChex data to be used to identify out-of-balance lateral wheel loading on vehicles and if practicable to instigate a warning system using WheelChex to minimise the risk to the network.

161 The ORR reported to the RAIB, in August 2014, that implementation of this recommendation was ongoing, as part of Network Rail's nationwide programme to install 'Gotcha' (paragraph 170). The ORR also reported that it expected to be able to provide a further update in August 2015. Network Rail reported to the RAIB, in April 2015, that replacement of 'WheelChex' with 'Gotcha' was virtually complete, with 28 systems installed, one system still to be installed, and four additional sites planned.

Accident at Primrose Hill/Camden Road West Junction, 15 October 2013, RAIB report published October 2014

162 Recommendation 2 of the RAIB report[19] into the derailment at Primrose Hill/Camden Road West Junction, North London, is relevant to the Angerstein Junction derailment because it includes consideration of the derailment risks arising from uneven loads on freight wagons (although focusing on container wagons). The recommendation states:

Freightliner and Network Rail should jointly request that RSSB:

a) researches the factors that may increase the probability of derailment when container wagons are asymmetrically loaded, and in particular:

i) sensitivity to combinations of longitudinal and lateral offsets in loads that can reasonably be encountered in service;

ii) the predicted performance of wagons with high torsional stiffness along their length (using the FEA type as an example); and

iii) the effect of multiple twist faults, track twist over distances other than 3 metres (as commonly specified and measured by Network Rail) and lateral track irregularities.

b) updates and amends as necessary the risk assessment contained within the RSSB and Transport Research Laboratory joint report ('Potential risks to road and rail transport associated with asymmetric loading of containers'); this should take into account the results from the research referred to in a) and additional evidence presented in this investigation report; and

[17] Report 02/2008, available on the RAIB website.

[18] Report 02/2009, available on the RAIB website.

[19] Report 12/2008, available on the RAIB website.

c) *works with industry stakeholders to use the outputs of a) and b) to identify, evaluate and promote adoption of any additional reasonably practicable mitigations capable of reducing the risk from asymmetric loading of wagons.*

163 The ORR has reported to the RAIB that it wrote to Network Rail and freight operators, on 5 December 2014, to promote cross-industry work to assess and address the derailment risk in freight wagons, particularly in relation to container wagons. The RAIB is aware that a cross-industry group (chaired by RSSB) has been established to address this risk, and a programme of work is now being developed which includes research into the issues raised in the ORR's letter.

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

Other reported actions

164 The RAIB issued an Urgent Safety Advice (USA) to the railway industry (appendix D), which was also issued as a National Incident Report (NIR3061 – 29 July 2014). This highlighted the scenario where uneven retained loads were present in nominally empty wagons, giving rise to an increased derailment risk in degraded track conditions. Freightliner has prepared a code of practice for ‘Inspection of hopper wagons with uneven residual load’. This was accepted as good practice by the Rail Freight Operators Group, and shared with its members, in December 2014.

165 Aggregate Industries has continued its work to identify possible alternative methods for releasing retained loads from hopper wagons. This has included consideration of techniques such as sonic vibration, mechanical flails and alterations to the existing sledgehammering procedure.

166 Aggregate Industries is now using a foam spray, instead of a water spray, to damp down dust at Bardon Hill Quarry. It reports that initial results indicate that this has improved the discharging of crushed rock fines at unloading terminals, and reduced the number and magnitude of residual loads being returned to the loading point.

167 Network Rail carried out maintenance work to rectify the gauge and twist faults that were present on the line between Angerstein Junction and the Angerstein terminal. This included replacement of trap points 851A. However, a second derailment occurred at the same location in the replacement trap points during the days leading up to 5 February 2015. The wheel that derailed on that occasion rerailed itself at Angerstein Junction, and so the fact that there had been a derailment was not recognised until track damage was found at the next visual inspection. Subsequent measurement of the track geometry by Network Rail identified that the replacement points had not been installed with the required cant, and so had introduced a twist fault. The trap points have since had the geometry corrected to remove this twist fault.

168 The RAIB has not investigated the February 2015 derailment but notes that Recommendation 3 of the present report covers effective management of assets such as the trap points involved in these derailments. Network Rail has reported to the RAIB in April 2015 that it is proposing to use a track recording vehicle to routinely measure dynamic track geometry on the line between Angerstein Junction and the Angerstein terminal from June 2015.

169 A third derailment occurred at trap points 851A on 3 June 2015. The RAIB is currently examining the circumstances of this event and will, if appropriate, publish its findings in due course.

170 Network Rail is also considering the circumstances of the Angerstein derailment as part of its ongoing work to develop monitoring criteria for wheel weight distribution. This is part of the wider project which has replaced WheelChex equipment with the ‘Gotcha’ system. This system is capable of greater analysis of the available wheel weight data and can provide an alarm where load imbalances exceed thresholds (paragraph 161).

Recommendations

171 The following recommendations are made[20]:

1 *The intention of this recommendation is to prevent wagons operating on the network with unacceptable uneven retained loads after unloading.*

Aggregate Industries, in consultation with relevant train operators, should review its processes for discharging aggregate hopper wagons, and for inspection of train loading and condition prior to despatch, to ensure that the risks arising from uneven residual loads are identified and effectively managed. Aggregate Industries should then implement appropriate control measures to mitigate this risk so far as is reasonably practicable (paragraphs 153(c), 153(e) and 154(a)).

2 *The intention of this recommendation is to manage the contribution that diagonal wheel unloadings, due to twisted bogie frames or other defects, make to derailment risk. The RAIB notes that action taken in response to this recommendation could be informed by work undertaken as part of the railway industry's response to the ORR's letter of 5 December 2014 (paragraph 163).*

RSSB, in conjunction with freight wagon operators, freight operating companies and entities in charge of maintenance for freight wagons, should review the extent to which diagonal wheel unloadings are present within freight wagon bogies that are operating on Network Rail infrastructure, and the contribution that this makes to derailment risk. This review should consider:

- identifying the magnitude and prevalence of diagonal wheel unloadings caused by bogie frame twist (and other possible causes);
- proposing criteria for acceptable levels of diagonal wheel unloading, or for bogie frame twist; and
- proposing proportionate measures for identifying, and then managing, unacceptable diagonal wheel unloadings (paragraphs 153(d) and 155(b)).

continued

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

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail Regulation (also known as Office of Rail and Road) to enable it to carry out its 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 200 to 203) can be found on RAIB's website www.gov.uk/raib.

3 *The intention of this recommendation is to ensure that the control of derailment risk in sidings takes account of the possibility of exporting that risk onto running lines.*

Network Rail should review the processes by which track geometry is managed in sidings and connections on the approach to running lines, in order to identify and implement any changes necessary to ensure that the export of risk to running lines is effectively managed. This should include consideration of how dynamic track geometry is assessed on infrequently used lines (paragraphs 153(a) and 153(b)).

4 *The intention of this recommendation is to review whether the historic track twist measurement base (3 metres) is still a sufficient control for track twist risk applicable to current rolling stock. The RAIB notes that this recommendation could be informed by the joint industry action taken in response to ORR's letter of 5 December 2014 (paragraph 163).*

Network Rail should liaise with RSSB to review whether the existing 3 metre measurement base used for identification of track twist is sufficient for managing the derailment risk applicable to rolling stock currently operating on Network Rail infrastructure. If found to be inadequate or insufficient, Network Rail should:

- update its process for assessing track twist by the inclusion of additional and/or alternative measurement bases; and
- implement a time-bound plan to apply the new process to all of its infrastructure (paragraphs 153(b) and 155(a)).

5 *The intention of this recommendation is to encourage use of available monitoring data from wheel impact load detection systems, such as Gotcha, to inform rolling stock maintenance.*

Network Rail should review the potential to use wheel impact load detection system data to provide information about possible defects, such as uneven wheel loading or uneven load distribution, relating to specific wagons. The review should include consideration of how this information could be used to improve control of overall derailment risk (such as identifying the need for entities in charge of maintenance to check the condition of suspect wagons and take appropriate remedial action). Network Rail should seek inputs from relevant entities in charge of maintenance as part of the review. If justified by the review, Network Rail should implement track side and reporting processes needed for collecting and disseminating this information (paragraphs 153(d) and 155(b)).

continued

6 *The intention of this recommendation is to ensure that the distribution of loads in wagons, including partly loaded wagons, is controlled in a manner compatible with wagon and track characteristics. The RAIB notes that action taken in response to this recommendation could be informed by work undertaken as part of the railway industry's response to the ORR's letter of 5 December 2014 (paragraph 163).*

RSSB, in consultation with industry, should review the risks associated with the uneven loading of wagons, with particular reference to partial loads, and propose any necessary mitigation, so that the extent of permitted load imbalance is effectively controlled (paragraphs 153(c), 154(a), 154(b) and 155(b).

Appendices

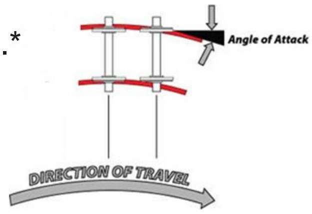
Appendix A - Glossary of abbreviations and acronyms

BVI	Basic Visual Inspection
CCTV	Closed Circuit Television
DC	Direct Current
ORR	Until 1 April 2015 ORR was known as the ‘Office of Rail Regulation’. It has used the name ‘Office of Rail and Road’ for operating purposes with effect from 1 April 2015. Legal force is expected to be given to this name from October 2015
OTDR	On-Train Data Recorder
PPM	Planned Preventative Maintenance
Q	Cross-axle average vertical wheel load on a wheelset
RAIB	Rail Accident Investigation Branch
SNCF	Société Nationale des Chemins de Fer Français (French railway operator)
TME	Track Maintenance Engineer
TOPS	Total Operations Processing System
TRV	Track Recording Vehicle
USA	Urgent Safety Advice
VIBT	Vehicle Inspection and Brake Test
WILD	Wheel Impact Load Detector

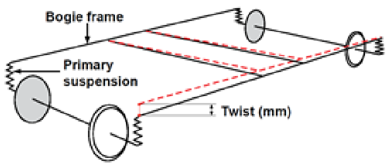
Appendix B - Glossary of terms

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

Acceptance process	The process whereby conformance of railway vehicles to the mandatory requirements of industry standards is scrutinised and certificated.*
Aggregate	Pieces of broken or crushed stone or gravel.
Angle of attack	The angle between the running edge of the rail and the plane of the wheel flange.*



Basic visual inspection	A visual inspection of the track, carried out on foot, which aims to identify any immediate or short term actions that are required. Often referred to as a track patrol.
Bogie	An assembly of two wheelsets in a frame which is pivoted at the end of a long vehicle to enable the vehicle to go round curves.
Bogie frame twist	Distortion of the structural frame on a bogie that results in the one of the primary suspension connection points being out of plane with the others. Measured at the top of the suspension springs and sometimes corrected by inserting packing pieces above these springs.



Bogie pivot	The vertical pin about which a bogie rotates.*
Brake pipe	A pipe running the length of a train that controls, and sometimes supplies, the train's air brakes. A reduction in brake pipe air pressure, as happens when the pipe is separated or ruptured, applies the brakes.
Buffers	Impact absorbing devices fitted to rail vehicles to accommodate changes in alignment between adjacent vehicles and to prevent them from colliding heavily during braking.*
Buffer locking	When the buffer of one vehicle has passed behind that on an adjacent vehicle.
Buffing forces	The dynamic loads imposed on rail vehicles through buffer contact with adjacent vehicles.*
Cant	The amount by which one rail is raised higher than the other rail on the same track.

Cant deficiency/ excess	The amount that the track cant needs to increase/decrease in order to balance the centrifugal force acting on a rail vehicle when running at speed on a curve.
Cant gradient	The rate at which cant changes in a specific length. This is equivalent to twist, but can refer to an intentional feature of the track design.
Chain	An imperial unit of length measurement that is equivalent to 22 yards (approximately 20 metres).
Check rail	A rail or other special section provided alongside a running rail to give guidance to flanged wheels by restricting lateral movement of the wheels.*
Contact angle	The angle between the tangential plane at which the wheel makes contact with the rail and that of the track.
Crushed rock fines	Finely crushed granite, with a particle size ranging from 4 mm to less than 63 μm.
Diagonal wheel unloading	The unloading on the wheels of a bogie due to distortion or other conditions affecting the frame or suspension, manifesting itself as an uneven sharing of the load between the wheels on the leading and trailing wheelsets.
Down line	A track on which the normal passage of trains is in the down direction, ie away from London, the capital, the original railway company's headquarters or towards the highest mileage.*
ΔQ/Q test	A test by which the effect of track twist on wheel loads is verified.
Dynamic twist	The change of cant along a track measured over a specific distance, while the track is under load from a train. This differs from static twist, which is the measure when the track is not loaded.
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 constrained and this usually leads to derailment.
Hogging	The gap under a rail that is closed up when a train passes over it.
Hopper wagon	A wagon which discharges its load through doors in the bottom area of the wagon.
Nested springs	A spring arrangement where two springs of different stiffness and of different diameter and length are arranged one inside the other, so that the overall stiffness increases when the applied load is sufficient to compress the longer spring to the length of the inner spring.

On-train data recorder	A data recorder fitted to a train that records information on the status of train equipment, including speed and brake applications.
Points	A section of track with moveable rails that can direct a train from one track to another.
Primary suspension	Those components of a suspension system that are connected to the axles.*
Rail industry standard	A document which defines technical standards, for use by the UK railway industry.
Red aspect	The red light on a colour light signal that means stop.
RSSB	A cross-industry organisation, formerly known as the Rail Safety and Standards Board, undertaking safety and standards related activities.
Run round	The process of detaching a locomotive from one end of a train, running it to the opposite end and reattaching it to enable the train to travel in the reverse direction.*
Running rails	Rails that support and guide the flanged steel rail wheels of a rail vehicle.*
Sectional Appendix	An operating publication produced by Network Rail that includes details of running lines, permitted speeds, and local instructions.
Shunter	A person who carries out operational activities such as coupling and uncoupling vehicles and forming vehicles into train consists.
Slide-hammer	A tool that allows an impact force to be imparted to a surface using a sliding action, rather than the swinging action of a normal hammer.
Static twist	The change of cant along a track measured over a specific distance, while the track is not under load from a train. This differs from dynamic twist, which is the measure when the track is loaded.
Step gauge	A measuring device with one straight edge and a series of steps cut into the other, each one creating a known dimension to the long straight edge.* This is used to measure gaps by identifying how many steps will fit into it.
Switch rail	A movable rail in a set of points.
Third rail dc electrification	A general term used to cover the type of electrification that involves the supply of DC traction current to trains by means of a conductor rail laid along one side of the track, known as the third rail.*

TOPS (Total Operations Processing System)	A computer system used to track rail vehicles. It deals with destination, load, location and maintenance information for all vehicles on the network. Vehicle data is entered for every movement, allowing virtually real time updates.*
Track category	A description of the amount of use a track gets, ranging from 6 (little used, low speed) to 1a (very high speed, very high annual tonnage).*
Track gauge	The distance between the inside faces of the rails.
Track recording vehicle	A rail vehicle which gathers quantitative data about the track geometry.*
Track twist	The change in cant, along the track, measured over a specific distance. This is equivalent to ‘cant gradient’, but is normally referring to unintentional track features.
Trap points	An assembly of switches or points intended to derail rail vehicles in the event of their unauthorised movement, such as conflicting movements onto passenger lines.*
Voiding	A track fault consisting of spaces or soft ground under sleepers, that results in vertical displacement of the track when trains pass over.
Void meter	A piece of equipment used to measure voids by recording the vertical rail movement when a train passes.
Wheel flange	The extended portion of a rail wheel that contacts the rail head and thus provides the wheelset with directional guidance.
Wheel unloading	A reduction in downwards force of a rail wheel. This reduced force can be a factor that permits a rail wheel to derail.
WheelChex	A track-mounted monitoring system designed to measure the vertical wheel loads of passing trains and identify those with the potential to cause excessive damage to the infrastructure.
Wheelset	Two rail wheels mounted on their joining axle.

Appendix C - Key standards current at the time

GC/RT5021 (Track System Requirements)	Issue 5, published by RSSB, December 2011
NR/L2/TRK/001 (Inspection and maintenance of permanent way)	Issue 6, published by Network Rail, December 2012
NR/L2/TRK/2049 (Track Design Handbook)	Issue 12, published by Network Rail, March 2010
NR/L2/TRK/2102 (Design and construction of track)	Issue 6, published by Network Rail, March 2010
RIS-2702-RST (In-Service Examination and Reference Limits for Freight Wagons)	Issue 1, published by RSSB, March 2011

Appendix D - Urgent Safety Advice (USA) issued by the RAIB

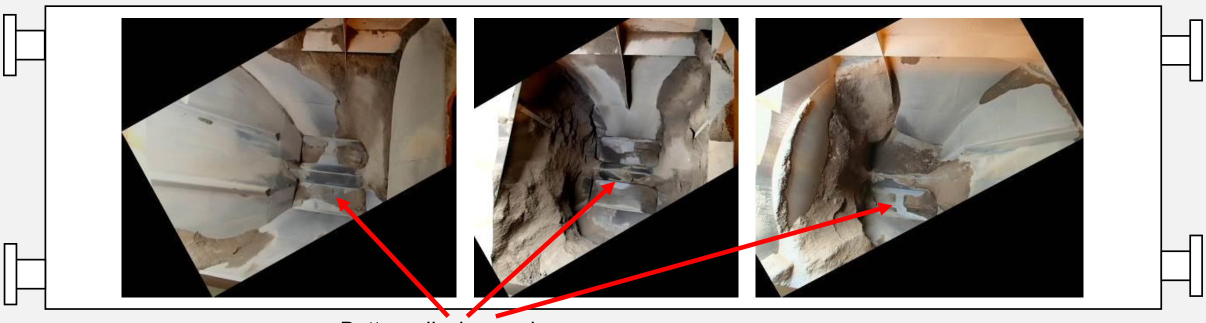
URGENT SAFETY ADVICE

1. INCIDENT DESCRIPTION			
LEAD INSPECTOR		**CONTACT TEL. NO.**	
INCIDENT REPORT NO	714	**DATE OF INCIDENT**	2 April 2014
INCIDENT NAME	Angerstein Junction		
TYPE OF INCIDENT	Flange climb derailment leading blockage of two running lines		
INCIDENT DESCRIPTION	On 2 April 2014, at about 12:16 hrs, the leading bogie of the 9th vehicle in a train of hopper wagons derailed shortly after leaving sidings at Angerstein Wharf while travelling on the freight only branch linking these sidings to Angerstein Junction on the North Kent line. The wagon continued onto the down North Kent Line and, after an automatic brake application caused when the brake pipe broke between the 9th and 10th wagons, stopped in a position where it was foul of the up North Kent line. Fortunately, there was no train on this part of the up line when the derailment occurred.		

2. URGENT SAFETY ADVICE	
USA DATE:	28 July 2014
TITLE:	Derailment risk to hopper wagons
SYSTEM / EQUIPMENT:	Hopper wagons with uneven residual load
SAFETY ISSUE DESCRIPTION:	Hopper wagons, in a nominally empty condition, are running over infrastructure with a residual load distributed in a way that makes them susceptible to derailment on track twists that the infrastructure maintenance standards allow to be present for a limited period of time, while trains are running.
CIRCUMSTANCES:	Some construction products (e.g. finely crushed stone, sometimes known as 'dust') can adhere to the sides or ends of hopper wagons resulting in a load offset from the middle of the wagon to the extent that this can cause a derailment on track that has twist less than that required to immediately close the line. In order to mitigate the risk of derailment, measures are needed to prevent nominally empty wagons entering traffic with a significant laterally offset residual load. The train that derailed had transported aggregate products from Bardon Hill Quarry to Angerstein Wharf, where it had been unloaded. The train left Angerstein Wharf with about 13 tonnes of finely crushed stone adhering to the sides of the 9th wagon, with the centre of gravity offset laterally from the centre of the wagon. RAIB analysis of recently obtained wheelchex data indicates that this crushed stone was present in the wagon before the aggregate was loaded at the quarry, and remained there after the aggregate was discharged at Angerstein Wharf. An initial analysis of the wheelchex data indicates that this residual load was offset sufficiently to have caused a significant lateral asymmetry between wheel loads at the time of the derailment. In the case of the leading axle of the derailed bogie these loads were probably in the order of 5.9 tonnes on the left hand wheel and 2.8 tonnes on the right hand wheel (as compared to the designed tare load of 2.8 tonnes on each wheel). The derailment occurred at a location where there was a track twist that was within the limits permitted for the operation of trains, but which requires maintenance action within 7 days of being detected. The RAIB considers that, after allowing for the track twist at the derailment site, the wheel unloading on the leading right hand wheel would have been sufficient to put it at a significant risk of a flange climb derailment on the left hand curve at which the derailment occurred. The wheelchex data also indicated that other nominally empty wagons in this train had significantly unbalanced loads on previous journeys. Inspection of wagons leaving an unloading facility on a separate occasion after the accident, showed that fine crushed stone can adhere to the sides of the hopper wagons and that it can require significant vibration to release it so that it can be discharged (see photographs below).

SUPPORTING PHOTOGRAPHS

Crushed stone adhering to the sides of the three hoppers in a wagon after unloading on 20 June 2014 at Angerstein wharf.



Bottom discharge doors

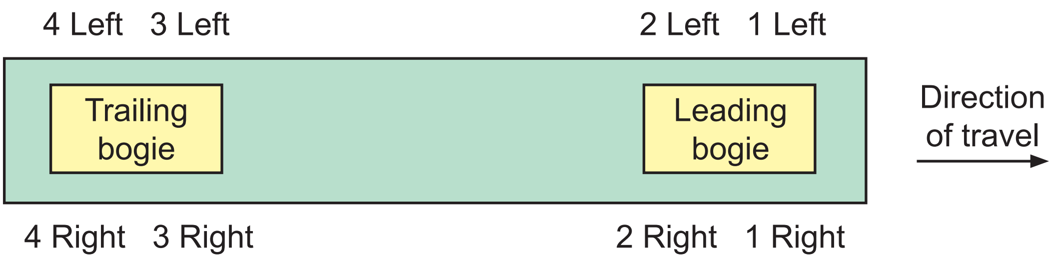
URGENT SAFETY ADVICE

CONSEQUENCES	Potential derailment of a wagon, with the risk of collision, injury or loss of life.
SAFETY ADVICE:	The RAIB is carrying out an investigation into the circumstances of the derailment that will include a detailed assessment of how the interaction between the track and the hopper wagon at Angerstein Junction led to derailment, and the standards associated with wagon loading and unloading. The investigation will also include a review of the condition of the track, and its inspection and maintenance. In the interim, this USA is being issued by the RAIB to alert operators and owners of hopper wagons to the circumstances of the derailment and its likely cause. On the basis of this derailment, the RAIB is concerned about the issue of unbalanced loading in hopper wagons that have not fully discharged. It advises operators of such wagons, in conjunction with terminal operators and wagon owners, to re-assess the associated risk of derailment, and to implement suitable mitigation measures. These may include measures to prevent the excessive build-up of undischarged materials in hoppers and checks that hopper wagons are not at risk due to unbalanced residual loads.

USA SIGN-OFF*			
INSPECTOR NAME:		**DCI NAME:**	
INSPECTOR SIGNATURE:		**DCI SIGNATURE:**	
DATE:	28 July 2014	**DATE**	28 July 2014

Appendix E - Calculation of lateral imbalance and diagonal wheel unloading

RAIB calculations show that the wheel load distribution of wagon 546 was likely to be as shown below at the time of derailment. This is based on WheelChex data from Thurmaston, recorded prior to loading the wagon at Bardon Hill quarry, and taking account of the subsequent records of quantities loaded and unloaded.



Axle (in direction of travel)	**Wheel load**	
	Left	**Right**
1 (Lead bogie 1st)	5.94 tonnes	2.87 tonnes
2 (Lead Bogie 2nd)	5.40 tonnes	3.95 tonnes
3 (Trailing Bogie 1st)	4.96 tonnes	2.87 tonnes
4 Trailing Bogie 2nd)	5.07 tonnes	3.19 tonnes

The lateral imbalance (per wheel) of the load on each bogie is derived using the following formulae (where Wx represents the load on wheel x):

Lateral Imbalance = ((W1L+W2L)-(W1R+W2R))/4 (for lead bogie)

Lateral Imbalance = ((W3L+W4L)-(W3R+W4R))/4 (for trailing bogie)

The diagonal wheel unloading (per wheel) for each bogie is similarly derived using the following formulae (where Wx represents the load on wheel x):

Diagonal wheel unloading = ((W1L+W2R)-(W1R+W2L))/4 (for lead bogie)

Diagonal wheel unloading = ((W3L+W4R)-(W3R+W4L))/4 (for trailing bogie)

These give the following results:

Bogie	**Lateral Imbalance**	**Diagonal wheel unloading**
Leading	1.13 tonnes	0.40 tonnes
Trailing	0.99 tonnes	0.05 tonnes

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