Rail Accident Investigation Branch

Rail Accident Report

Freight train derailment at Willesden High Level Junction, north-west London
6 May 2019

Report 07/2020
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This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC
- the Railways and Transport Safety Act 2003
- 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.

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 RAIB has described a factor as being linked to cause and the term is unqualified, this means that RAIB has satisfied itself that the evidence supports both the presence of the factor and its direct relevance to the causation of the accident or incident that is being investigated. However, where RAIB is less confident about the existence of a factor, or its role in the causation of the accident or incident, RAIB will qualify its findings by use of words such as 'probable' or 'possible', as appropriate. Where there is more than one potential explanation 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 or incident but are associated with the underlying management arrangements or organisational issues (such as working culture). Where necessary, words such as '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 accident or incident 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 RAIB, expressed with the sole purpose of improving railway safety.

Any information about casualties is based on figures provided to RAIB from various sources. Considerations of personal privacy may mean that not all of the actual effects of the event are recorded in the report. RAIB recognises that sudden unexpected events can have both short- and long-term consequences for the physical and/or mental health of people who were involved, both directly and indirectly, in what happened.

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 Willesden High Level Junction, north-west London, 6 May 2019

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Summary

At around 21:30 hrs on 6 May 2019 a single wagon in a freight train derailed on a curve approaching Willesden High Level Junction in north-west London. The wagon re-railed as it passed over the junction. Although no-one was injured, a derailment like this has the potential to foul lines that are open to passenger traffic or strike structures.

The track was supported by an earth embankment that Network Rail had been monitoring since October 2016, and which was showing signs of progressive seasonal movement. The empty two-axle wagon derailed where the track cross-level had been changing. Derailment occurred because the wagon encountered a significant track twist and had an uneven wheel load distribution. This combination resulted in there being insufficient load at the leading left-hand wheel to prevent the wheel flange climbing over the railhead. A check rail would have prevented the derailment. Network Rail had completed a risk assessment that had concluded this safeguard was not necessary on the small-radius curve.

The track twist had developed rapidly. This was because of the poor condition of the earth embankment and the loss of ballast support from under the sleepers. The measures that Network Rail had in place for inspection, maintenance and mitigation were not effective in detecting this risk and protecting the safe running of trains.

The wagon had a diagonal wheel load imbalance. This arose because the suspension adjustment arrangement was susceptible to introducing an imbalance of this type and routine maintenance had not detected that it was present.

Within Network Rail, separate teams are responsible for track maintenance and earthwork management. RAIB has identified the lack of sharing of information between these teams as a possible underlying factor.

RAIB has made four recommendations:

- Three are directed to Network Rail and concern:
  - the use, and limitations, of information from its track geometry measurement trains for understanding the condition of the track and problems with the track bed and/or supporting earthwork structures, and how this may affect the safe running of trains
  - measures to mitigate the risks arising from known defects in supporting earthwork structures.
- One is directed at DB Cargo, the owner and maintainer of the derailed wagon, relating to the maintenance of this and similar two-axle wagons.

RAIB has additionally identified learning points concerned with indications of poor track bed condition, the importance of good liaison between track maintenance and earthwork management teams and the management of wagon diagonal wheel load imbalance.

Introduction

Definitions

1 Metric units are used in this report, except when it is normal railway practice to give speeds and locations in imperial units. Where appropriate the equivalent metric value is also given.

2 All mileages in the report are taken from a datum at Mitre Bridge Junction. Left and right orientations relate to the direction of travel of the train.

3 The report contains abbreviations. These are explained in Appendix A.

The accident

Summary of the accident

4 At around 21:30 hrs on 6 May 2019, a single wagon, within freight train 6L36,[1] derailed on elevated curved track approaching Willesden High Level Junction in north-west London (figure 1). Train 6L36 was the scheduled 19:45 hrs service from Hoo Junction Up Yard, in Kent. It was carrying material from an engineering worksite, near Lewisham, to Network Rail's recycling facility and marshalling yard at Whitemoor, in Cambridgeshire.

5 The 21-wagon train had been routed from the down West London line to the up High Level line at Mitre Bridge Junction and was stopped at NL1048 signal, on the approach to Willesden High Level Junction (figure 2). The 20th wagon on the train derailed to the left around 30 seconds after the train started to move again. The train was travelling at 7.8 mph (12.6 km/h). The wagon re-railed as it crossed over the switch and crossing layout at Willesden High Level Junction. No other wagons derailed. The driver was unaware of the derailment. However, signallers observed an axle counter[2] failure at the junction after the train had passed and brought it to a stand at Hampstead Heath to check that the train had not divided. The driver was given permission to continue once this had been confirmed.

6 The derailment was not identified until around 14:00 hrs the following afternoon, when signalling technicians, attending to related lineside equipment faults, reported track damage and severed cables (figure 3).

7 No-one was injured and the damage to the wagon was mainly limited to the wheelsets. However, a derailment of this nature had the potential to foul adjacent lines, on which frequent passenger services were running, or to strike structures.

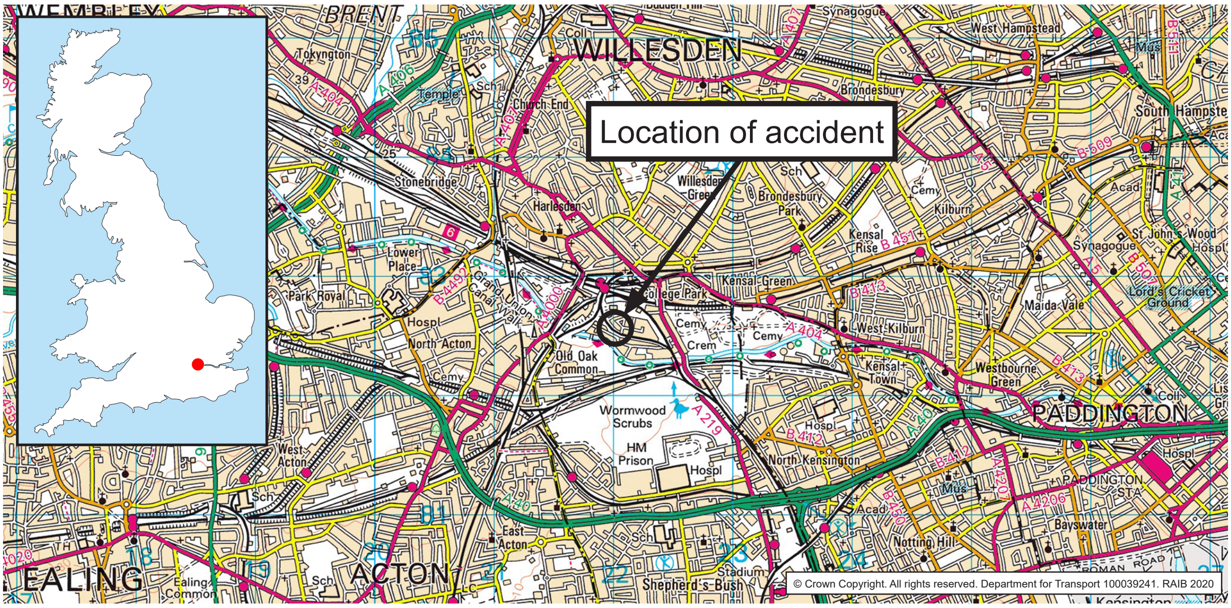

Figure 1: Extract from Ordnance Survey map showing location of the derailment

[1] An alphanumeric code, known as the 'train reporting number', is allocated to every train operating on Network Rail infrastructure.

[2] A track-mounted device that accurately counts passing axles. It is used by the signalling system to detect the absence and presence of trains.

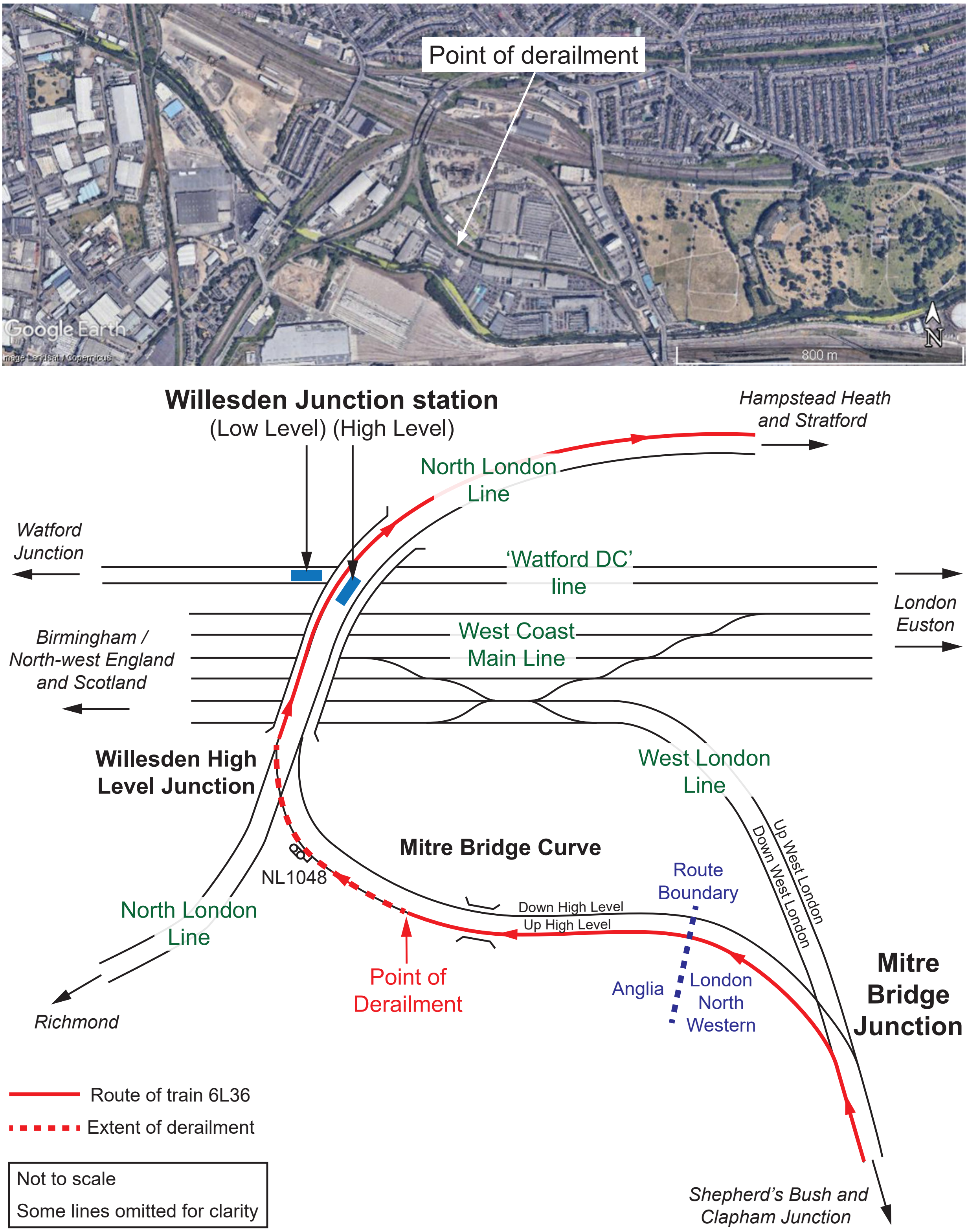

Figure 2: Layout of the railway near Willesden High Level Junction showing the route of train 6L36

Figure 3: Reported track damage (photographs courtesy of Network Rail)

Context

Location

8 The derailment occurred on Mitre Bridge Curve at around 0 miles 27 chains, 0.3 km south of Willesden Junction (High Level) station in north-west London. Here the railway runs on an earth embankment through an area of mixed industrial and warehouse development. It comprises two lines: the up High Level and the down High Level. Trains from the south join Mitre Bridge Curve from the West London Line at Mitre Bridge Junction (0 miles 0 chains) and leave to follow the North London Line at Willesden High Level Junction (0 miles 43 chains).

9 Trains approach Willesden High Level Junction on a right-hand curve. The derailment location was on the early part of the curve, just after the wagon had crossed a metal underbridge. The radius at that point is nominally 250 metres[3] and there is no check rail[4] on either line. A lubricated check rail is provided on the immediate approach to Willesden High Level Junction where the radius is tighter.

10 The following permanent speed restrictions apply to both lines:

- 20 mph (32 km/h), between Mitre Bridge Junction and 0 miles 36 chains (this includes the derailment location)
- 15 mph (24 km/h), between 0 miles 36 chains and Willesden High Level Junction.

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[3] As measured by Network Rail's track geometry measurement trains.

[4] A rail or other special section provided alongside a running rail to give guidance to flanged wheels by restricting lateral movement of the wheels.

11 Train movements in the area are controlled by multiple aspect lineside signals operated from Upminster signalling control centre. The lines are electrified with an overhead AC traction power supply. Neither the signalling nor the traction power system played a part in the derailment.

Organisations involved

12 Network Rail owns and manages the railway infrastructure involved. The derailment occurred on a section of line that was wholly within Network Rail's Anglia Route,[5] but close to the boundary with Network Rail's London North Western Route (figure 2).

13 GB Railfreight operated train 6L36 and owned the locomotive that was hauling it.

14 DB Cargo owned and maintained the wagon that derailed, as well as others in the train.

15 Network Rail, GB Railfreight and DB Cargo freely co-operated with the investigation.

Railway infrastructure

Track

16 The track on the up High Level line comprises jointed flat-bottom rail supported on sleepers and stone ballast. At the derailment location, the sleepers are timber and the rail fasteners comprise screwed baseplates, rubber pads and spring clips. Network Rail's asset database records that the rails and sleepers date from 2008. It was unable to supply RAIB with information on the last track renewal or the design of the layout relating to it. Figure 4 shows the up High Level line looking towards the point of derailment and Willesden High Level Junction.

17 The track maintenance engineer for Tottenham (Tottenham TME) is responsible for the sections of Mitre Bridge Curve within the Anglia Route (paragraph 12). A team based in Camden, reporting to the Tottenham TME via the local track section manager (Camden TSM), inspects and maintains the track.

18 Network Rail requires the routine inspection of its track to be carried out in accordance with company standard NR/L2/TRK/001 'Inspection and maintenance of permanent way'. The frequencies for inspection depend on the type of track and the track category (which is determined by the line speed and the annual loading from trains). The track on the up High Level line was classed as track category 3. As a result, NR/L2/TRK/001 requires:

- a basic visual inspection by patrollers every week
- a section manager's visual inspection every 13 weeks
- a track maintenance engineer's visual inspection every two years
- routine track geometry measurement, at a nominal interval of 16 weeks (and a maximum of 36 weeks). Network Rail's track geometry measurement trains are normally used.

Because of the low line speed, supplementary track maintenance engineer's and section manager's inspections by cab riding were not mandated. However, they were routinely carried out.

[5] Since the derailment, Network Rail has announced changes to the organisation of the routes on its infrastructure.

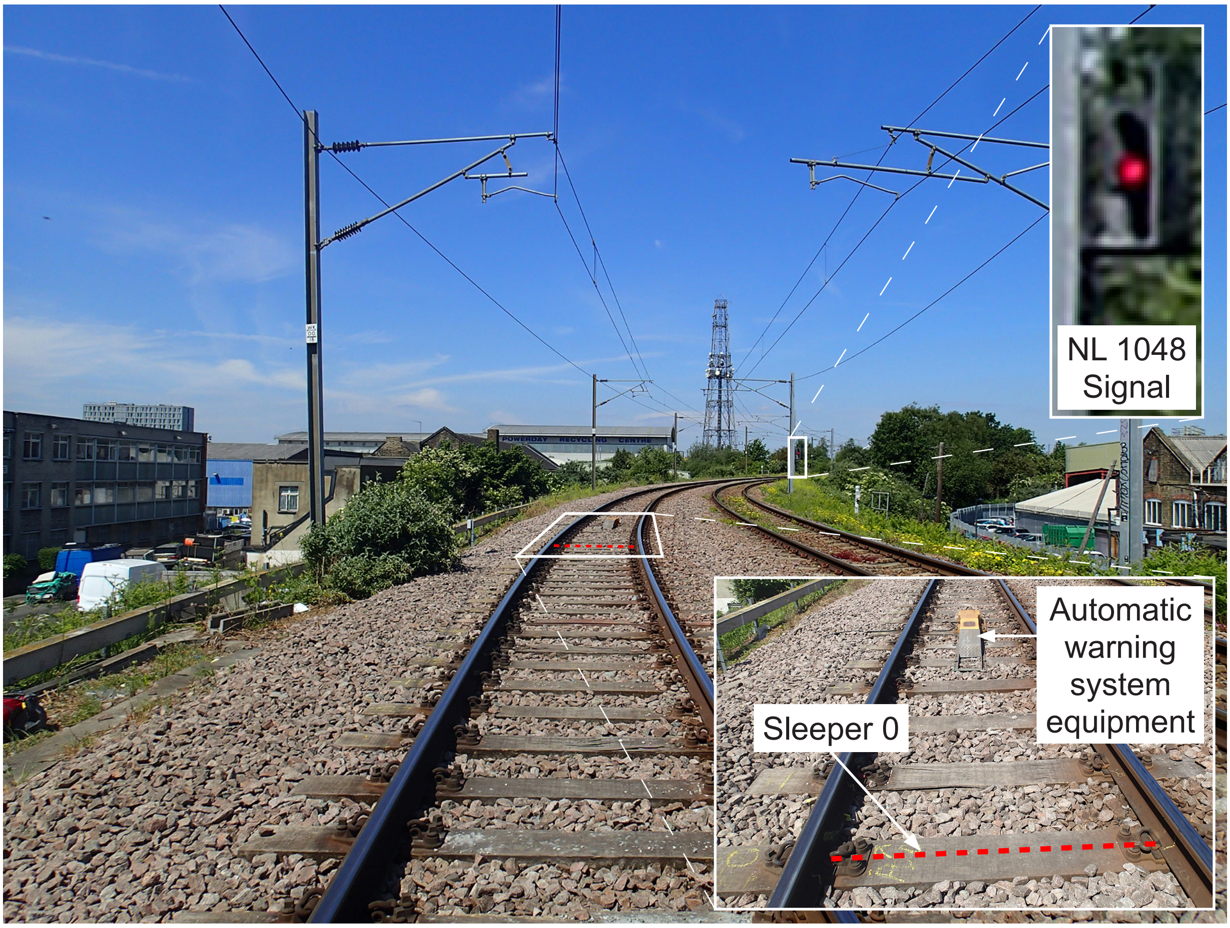

Figure 4: Up High Level line looking in the direction of travel of train 6L36, towards the point of derailment and Willesden High Level Junction. Sleeper 0 marks the designated point of derailment.

Earthwork

19 The earth embankment on Mitre Bridge Curve was built to elevate the railway above the nearby West Coast Main Line (figure 2). It is of typical Victorian construction: a core of London clay, probably loosely packed; and an upper layer of locomotive ash, used to provide a surface on which to lay the ballast and track.

20 The earthworks management process is defined in Network Rail standard NR/L2/CIV/086 'Management of earthworks manual'. On the Anglia Route, the route asset manager for buildings and civils (Anglia RAM(B&C))[6] was accountable for the overall process and approval of significant expenditure. The day-to-day management of the assets was the responsibility of the senior asset engineer for geotechnics (Anglia SAE(G)), who reported to the Anglia RAM(B&C). The Anglia SAE(G) was responsible for:

- identification of the earthwork assets on the route and management of the asset register
- examination of the asset condition, on a cyclical basis and following the report of a failure or incident (Network Rail has contracted an outside party to undertake this work)

[6] Asset management on the Anglia Route has recently been re-organised. The Anglia SAE(G) now reports to the route asset manager for off-track.

- undertaking evaluations, which are carried out when there is a need to appraise the stability of an earthwork and determine the necessary actions, such as additional examination tasks, further investigation and emergency works
- determining and prioritising the necessary intervention measures when the risk of failure can no longer be controlled by the examination process, such as earthwork maintenance, refurbishment and renewal
- determining the mitigation measures ahead of implementation of the intervention measures.

The Anglia SAE(G) was supported by the asset engineer for geotechnics (Anglia AE(G)). He also used external consultant engineers and specialist contractors.

21 The section of the embankment on Mitre Bridge Curve where the derailment occurred was an identified earthwork that was subject to cyclical examination. The reports from examinations in 2014 identified only an 'average risk' to the track. However, in early 2016[7] the Camden track maintenance team notified the earthwork management team of issues that were of sufficient concern for an evaluation to be started.

22 The Anglia SAE(G) decided to monitor the embankment movement using inclinometer[8] measurement devices. Holes for two inclinometers (BH02[9] and BH03) were bored in the slope adjacent to the up High Level line (up-side slope), see figure 5. A hole for a third inclinometer (BH01) was bored in the slope adjacent to the down High Level line (down-side slope). The monitoring of the embankment was ongoing at the time of the derailment. A pattern of progressive seasonal movement had been identified and the Anglia SAE(G) was overseeing the development of options for works designed to stabilise this.

Train involved

23 Train 6L36 comprised a class 66 locomotive and 21 two-axle low-sided open box wagons: a mixture of MHA (18 wagons), MFA (2 wagons) and MPA (1 wagon) types. The first 16 wagons were loaded with waste material. The remaining five wagons were empty. This included the derailed wagon, the 20th in the train, wagon number MPA 394228 (figure 6).

24 The MPA and MHA wagons are of similar construction; only the brake equipment differs. These wagons are converted (re-bodied) British Rail HAA-type coal hopper wagons with the original steel underframe and the running gear retained.

25 The wagon running gear is made up of two wheelsets, with a wheelbase of 5.562 metres, four axle box and horn guide[10] assemblies and four suspension units. Each suspension unit comprises a laminated leaf spring, each end of which is connected to an auxiliary spring unit by a pin and link arrangement (figure 9).

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[7] From the actions subsequently taken (paragraph 58), this was probably around May 2016.

[8] Inclinometers for monitoring ground movement typically comprise a length of plastic tube that is grouted within a borehole. Inside the tube are four equally-spaced longitudinal grooves. The shape of the tube is periodically measured using a probe, with wheels designed to follow the grooves. Ground movement is determined by comparing the initial shape of the tube with that measured at a particular moment in time.

[9] The designation given by the contractor who installed the inclinometers and reported on the measurements.

[10] The vertical guide placed either side of an axle box to restrain it in the lateral and longitudinal directions but permit vertical movement of the axle.

Figure 5: The inclinometer locations on the up-side slope of Mitre Bridge Curve embankment

26 British Rail built large numbers of HAA-type wagons for its merry-go-round (MGR) train operation that historically supplied coal to power stations. The programme to convert the wagons started in the late 1990s when coal traffic started to decline. The last conversion was in 2006. Wagon MPA 394228 was converted in 1998 by RFS, in Doncaster. DB Cargo refers to its converted HAA wagons as MGR-derivative wagons.

27 DB Cargo owns all the MGR-derivative wagons operating on Network Rail infrastructure and is the entity in charge of maintenance. It currently has 246 MPA and 680 MHA wagons in its fleet. It maintains them in accordance with DB Cargo's engineering standard DBS/ES/0081 'Maintenance plan – MGR & derivative wagons'.[11] This defines tasks supporting a component-based maintenance regime, which aims to ensure that components maintain compliance with relevant safety and performance standards. The repair and heavy maintenance of underframe, suspension and wheelset components is undertaken as part of a periodic vehicle inspection and brake test (VIBT). Staff at DB Cargo's maintenance locations carry out the work. MPA-type wagons are due a VIBT every two years.

28 The last two VIBT reports for wagon MPA 394228 were dated October 2018 and September 2016; the work was carried out at Toton North Yard on both occasions. DB Cargo audits each of its maintenance locations on a three-year cycle. The last audit of Toton North Yard was carried out on 28 March 2019. No non-compliances were reported that concerned staff competence, or maintenance tasks relating to the suspension and underframe of MGR-derivative wagons.

[11] Additional requirements are defined in DB Cargo technical bulletin DBS/TB/0421 'Supplement to DBS/ES/0081'. This supplement includes amendments to DBS/ES/0081 that are relevant to MPA type wagons. Where reference is made to DBS/ES/0081 this includes DBS/TB/0421.

Figure 6: Wagon MPA 394228

External circumstances

29 The nearby weather station at Northolt recorded an air temperature of 9.8ºC at the time of the derailment and a wind of 8 km/h from the west-north-west direction. Network Rail provided RAIB with rainfall data for the local area; it contained no record of precipitation for the preceding 24 hours. Dry ground conditions were assumed when selecting the wheel-rail interface friction parameters for the baseline simulation in the vehicle dynamics study (paragraph 72).

The sequence of events

Events preceding the accident

30 The wagons that were to form train 6L36 were loaded with spoil in a worksite near Lewisham on Sunday 5 May 2019. They were then stabled in Hoo Junction Up Yard, near Gravesend.

31 Train 6L36 departed from Hoo Junction Up Yard at 19:51 hrs on 6 May. It was then routed through south London and onto the down West London line at Latchmere Junction, after which it passed through Shepherd's Bush station. At 21:22 hrs, it was routed on to the up High Level line at Mitre Bridge Junction (figure 2).

32 Signal NL1048 on the approach to Willesden High Level Junction was displaying a red aspect. The driver brought the train to a stand at 21:24:00 hrs, with the leading wheelset of wagon MPA 394228 around 68 metres before the point of derailment (paragraph 37).

Events during the accident

33 Signal NL1048 cleared to show a green aspect and, at 21:29:15 hrs, the train started to move. Wagon MPA 394228 derailed 32 seconds later. It was travelling at 7.8 mph (12.6 km/h). Witness marks on the track were consistent with it later re-railing as it passed over switches and crossings at Willesden High Level Junction. The driver was unaware of the derailment and the train continued its journey.

34 The signaller at Upminster signalling control centre became aware of an axle counter failure at the junction shortly after train 6L36 had passed. He was concerned that train 6L36 had divided and brought the train to a stand at Hampstead Heath. He asked the driver of a passing train to check that train 6L36 was complete and allowed the train to continue once this had been established.

35 The train departed from Hampstead Heath at 21:47 hrs and arrived at Whitemoor Yard at 00:12 hrs on 7 May.

Events following the accident

36 Signalling technicians went to Willesden High Level Junction after signallers reported problems with resetting the axle counter, and that other signalling equipment had failed. However, it was only during a follow-up visit in daylight hours on 7 May that technicians found severed cables and other damage indicating that a derailment had occurred. They reported this at 13:56 hrs and requested that the track maintenance team attend.

37 The Camden TSM arrived at around 15:30 hrs and was joined by the Tottenham TME later in the evening. They could find no track geometry faults that required the line to be blocked. After watching several trains pass (and knowing that the line had been open to traffic during the day) they decided to allow trains to continue to run. The Tottenham TME had inspected the marks on the track and confirmed the location of the point of derailment (close to 0 miles 27 chains). He asked the assistant track maintenance engineer (Tottenham ATME) to complete a derailment survey the next morning. A Network Rail mobile operations manager had, in the meantime, examined train 6L36 at Whitemoor Yard and identified the derailed wagon from damage to its wheels.

38 The Tottenham ATME was on site at around 09:45 hrs on 8 May and met up with the Camden TSM who showed him the identified point of derailment. The Tottenham ATME followed the guidance in Network Rail company standard NR/L3/TRK/3405 'Derailment site record book'. He measured the difference in level between the two rails (cross-level) at the point of derailment, which he designated sleeper 0, and at each of the 20 sleepers on the approach and at each of the 10 sleepers beyond. He also installed void meters under the left-hand rail to measure the track movement that he had observed from the up side of the railway when trains passed. He observed only negligible track movement from the down side and decided not to install void meters under the right-hand rail. No maintenance work was done to alter the track geometry between the passage of train 6L36 and the Tottenham ATME's derailment survey.

39 From the cross-level and void measurements, the Tottenham ATME calculated that the maximum track twist[12] was 1 in 120, measured over the standard three-metre base that Network Rail uses for track maintenance purposes[13] (three-metre track twist). The twist that had formed on the up High Level line was recognised as a fault requiring action in 36 hours, and would have reduced wheel load at the leading left-hand wheel. The on-site track maintenance team carried out a manual repair by lifting and packing the track. Network Rail reported that missing and broken rail fastener components had been replaced the previous night. Network Rail notified RAIB about the derailment on 8 May.

[12] Track twist is change in the relative height of the two rails, along the track, measured over a specific distance. It presents a general derailment hazard to railway vehicles (paragraph 44).

[13] See NR/L2/TRK/001.

Background information

Post-derailment examination of the track

40 RAIB visited the derailment site on 23 May 2019 and inspected the track. It identified marks on the outside edge and face of the left-hand rail, and on the sleeper ends and rail fasteners. These were consistent with the flanges of the two left-hand wheels of wagon MPA 394228 having climbed onto the railhead before dropping into and running derailed in the track bed alongside the railway (known as 'the cess'). Because of the evidence of wheel flanges running on the outside edge of the railhead on the approach to sleeper 0, RAIB has concluded that the wheels had started to climb before reaching the designated point of derailment. The inside face (gauge face) of the left-hand rail was smooth and bright on the approach to sleeper 0, and RAIB could find no marks evidencing where the wheel flanges had started to climb and then cross the railhead (paragraph 78). The marks on the outside face of the rail at sleeper 0 matched marks on photographs taken on the evening of 7 May 2019 (paragraph 37). Further along was evidence of where the right-hand wheels had run between the rails. Figure 7 shows some of the marks that were identified.

41 RAIB's inspection confirmed that marks and damage at Willesden High Level Junction were consistent with wagon MPA 394228 re-railing on the switch and crossing trackwork there.

42 RAIB re-visited the site on 5 July to witness Network Rail's survey of the track. This included the measurement of the track cross-level and gauge (using a track measurement trolley), rail profiles and rail side wear. A further visit was made on 6 September to measure the position of the rails using total station survey equipment. This was required because lateral track geometry information was missing in the recording of the last track geometry measurement train run before the derailment (paragraph 55).[14]

Vehicle derailment risk on small radius curves with twisted track

43 Witness marks showed that the mechanism of derailment was a flange of a left-hand wheel of wagon MPA 394228 climbing the railhead (a mechanism known as 'flange climb'). There is a risk of derailment by flange climb when a wheel flange contacts the gauge face of the rail and the ratio of the lateral force of the wheel flange on the rail (Y) to the vertical wheel load (Q), known as the Y/Q derailment quotient, exceeds a critical limit value. Because of this, the lower the wheel load, or higher the lateral force, the greater the risk of derailment.

[14] Network Rail had arranged for a stone blower to carry out track geometry maintenance work on the up High Level line before this visit. The total station survey was carried out after confirming that the lateral geometry had not been significantly altered.

Figure 7: Marks showing evidence of derailed wheel flange running on the left-hand railhead, rail fasteners and sleeper ends (all photographs 23 May 2019, except as labelled)

44 Track twist presents a general derailment hazard for railway vehicles because it results in cross-level differences between wheelsets that can induce significant torques within the suspension system and vehicle structure. The torques are reacted at each wheelset by the wheel load increasing at one wheel and reducing (unloading) at the other. The track twist that affects a two-axle wagon is that which acts over the wagon wheelbase, which for wagon MPA 394228 is 5.562 metres (paragraph 25).[15] Horizontal track curvature is also a general hazard. When a two-axle wagon like MPA 394228 negotiates a curve, the flange of the leading outside wheel tends to be displaced towards the outside rail. On smaller radius curves the wheel flange can be forced into contact with the gauge face, risking a sustained high lateral force.

45 There is recognition of these hazards in Network Rail's track maintenance and design standards. For instance:

- NR/L2/TRK/001 defines detailed requirements for identifying and repairing track twist faults; for certain such faults, more rapid repair is needed on curves with a radius of less than 400 m
- NR/L2/TRK/2102 'Design and construction of track', defines when the radius of a curve is such that a check rail provision is required, or is to be considered.

46 On two-axle wagons, diagonal wheel load imbalance has a similar effect to track twist. DB Cargo's standard for the maintenance of MGR-derivative wagons, DBS/ES/0081, includes specific requirements for managing this risk (paragraph 65).

Management of the track geometry at Mitre Bridge Curve

47 In early 2016, a supervisor from the Camden track maintenance team was called to site by a track maintenance gang who were carrying out lifting work to repair a geometry fault close to the derailment location.[16] The vertical alignment of the track (top) looked to be poor and he observed that a nearby overhead line equipment mast was leaning. Concerned that the embankment was failing, he reported the signs to the earthwork management team.[17]

48 The track maintenance team made no change to the standard inspection regime and did not implement any special monitoring of the track. However, records show that, around this time, a work order was raised for a delivery of ballast that was needed 'due to bank slip and back fill' and because of general concerns with track top between 0 miles 25 chains and 0 miles 27 chains.

49 The last track maintenance engineer's visual inspection of Mitre Bridge Curve before the derailment was on 7 June 2018. Network Rail had approved the Camden TSM as competent to undertake this inspection and he reported the track as being in generally 'good condition'. The Camden TSM completed his own section manager's visual inspection around a month later, on 11 July 2018. The report he took with him that detailed the status of maintenance actions that were planned (known as the 'walkout report') listed no track faults near 0 miles 27 chains. He noted that the ballast ordered in 2016 had yet to be delivered and recorded a delayed work order completion date of 27 December 2018.

[15] A track twist measured over 5.562 metres is unlikely to be the same as the three-metre track twist that Network Rail uses in its track maintenance processes, NR/L2/TRK001.

[16] Track geometry measurement train runs in late 2016 suggested this work repaired the fault.

[17] It was this notification that caused the Anglia SAE(G) to start his evaluation of the embankment (paragraph 21).

50 On 12 September 2018 a track geometry measurement train run reported that track top faults had reoccurred on the up High Level line close to 0 miles 27 chains. The Camden track team again arranged lifting work to repair them. The same measurement train run reported track lateral alignment faults in the area that were of a level such that NR/L2/TRK001 required maintenance action to be taken (actionable faults). Data from earlier measurement runs indicated that these lateral alignment faults had developed from a single actionable fault that was identified on 7 December 2016, but which had not been repaired.

51 This earlier lateral alignment fault had not been identified on any of the intervening measurement runs, of which there were at least ten. RAIB has concluded that this was probably because, on these runs, the track geometry measurement train had been held at signal NL1048 and was moving too slowly to generate the reference it needed to be able to measure lateral track geometry. Network Rail engineers refer to this characteristic as ‘low-speed cut out’. It is a feature of the instrumentation system on Network Rail’s track geometry measurement trains that also affects vertical track geometry measurement. Low-speed cut out does not affect either track cross-level measurement or track twist, which is derived from it. None of these track geometry measurement train runs identified an actionable fault concerned with track twist.

52 Figure 8 shows lateral track geometry recordings made on Network Rail track geometry measurement train runs, the faults identified on 7 December 2016 and 12 September 2018, and examples of data loss due to low-speed cut out.

53 The last cab ride that the Tottenham TME did was on 26 September 2018. He reported the track to be ‘in a fair condition’. Network Rail could find no record of the section manager’s visual inspection that was due around the same time.

54 A supervisor from the Camden team completed the next section manager’s visual inspection on 12 December 2018. The walkout report he took listed the lateral alignment faults close to 0 miles 27 chains; they had not been repaired. Between 0 miles 9 chains and 0 miles 38 chains, he recorded observing ‘lack of ballast throughout length’; the ballast ordered in 2016 had yet to be delivered. The same supervisor carried out the last section manager’s visual inspection before the derailment on 14 March 2019. He again commented on the lack of ballast; his walkout report continued to list the unrepaired lateral alignment faults and the outstanding ballast delivery. This time the work order for ballast delivery was put back to December 2020. Several track geometry measurement trains had run in the meantime. However, low-speed cut out effects meant that none had recorded track top or track lateral alignment close to 0 miles 27 chains.

55 The last track geometry measurement run before the derailment was on 3 April 2019. It identified no actionable track twist faults and, again due to low-speed cut out effects, recorded neither track top nor lateral alignment in the derailment vicinity. The Camden TSM completed a cab ride through the site three days later. He reported that there was a need for ballast on the shoulder of the up High Level line between 0 miles 25 chains and 0 miles 27 chains.

56 The last track inspection was the basic visual inspection on 30 April 2019, by the patroller who normally carried out this weekly inspection. He found no ‘actionable defects’ at the derailment location. He considered the up High Level line to be one of the better sections of track that he inspected. No basic visual inspection report had highlighted a concern around 0 miles 27 chains in the previous six months.

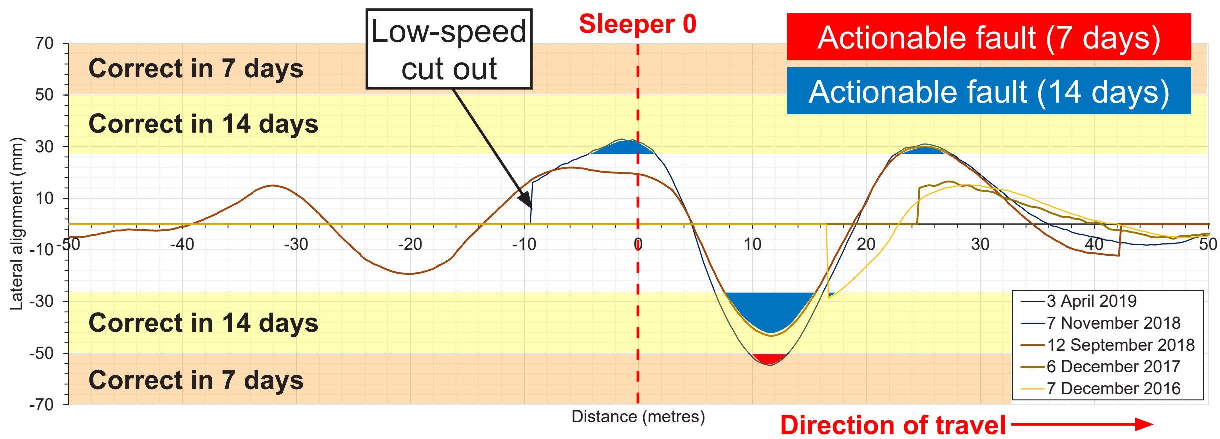


Figure 8: Lateral track alignment recorded on various track geometry measurement train runs prior to the derailment. Locations where low-speed cut out resulted in data loss are highlighted. On 3 April 2019 no lateral track geometry measurement data was recorded in the vicinity of the designated point of derailment, identified as 'Sleeper 0'.

Management of the embankment at Mitre Bridge Curve

57 Network Rail sub-divides its earth embankments into five-chain (100 metre) lengths for management purposes. At Mitre Bridge Curve, the examination contractor (paragraph 20) was required to inspect both embankment slopes of the length that includes derailment location, on a five-yearly cycle.[18] The inspection of the up-side slope on 25 March 2014 was the last cyclical examination before the Camden track maintenance team raised concerns about the embankment in 2016 (paragraph 47). The examination report assigned an earthwork hazard category of B[19] and concluded that the risk to the track due to soil-related failure mechanisms was 'average' (paragraph 21). Network Rail identified no actionable issues when it evaluated the previous examination, carried out on 24 November 2008.

58 The low risks identified by the examination process did not prevent the Anglia SAE(G) being concerned about the issues that the Camden track maintenance team reported. The Anglia AE(G) visited the site on 23 May 2016 to gather initial information, and the examination contractor carried out a special examination on 10 June 2016 after the up-side slope had been de-vegetated. The Anglia AE(G) noted several failure signs including exposed sleeper ends and that the cess and left-hand rail on the up High Level line had dropped. The examination contractor additionally observed the leaning overhead line mast, 'stilted' cable troughing and found an historical slump. The subsequent report assigned a slightly increased earthwork hazard category of C. However, it also concluded that the risk to track was 'average'.

[18] Network Rail allows a tolerance period of six months.
[19] Examiners use Network Rail's standard algorithm to determine the earthwork hazard category, a value between A and E. Earthworks with an earthwork hazard category are considered statistically more likely to fail.

59 The Camden track maintenance team's report also prompted the earthwork management team to review archive information. They found the details of a freight train derailment on 12 November 2003 that had occurred on a track twist in the same vicinity. The regional earthworks and drainage engineer (the Network Rail engineer responsible for earthwork management at the time) had visited the site three days later and carried out an inspection in accordance with the procedures that were then current. He concluded that the embankment was in a good condition and that there was a very low risk of failure. He further commented that, although the embankment was likely to have settled during the (preceding) summer, he did not consider this settlement would have been 'extreme or differential' or the cause of the derailment. He added that, if properly maintained, the track 'should cope with these seasonal variations'.

60 The Anglia SAE(G) decided to monitor the embankment movement and added it to a list of similar earthwork assets that he was monitoring on the Anglia route. The boreholes for the three inclinometers (paragraph 22) were added in October 2016, and the first readings made on 16 October 2016.

61 The up-side slope of the Mitre Bridge Curve embankment was found to be moving more than most of the other earthwork assets that were being monitored on the Anglia Route. The Anglia SAE(G) decided that intervention work was required and, in October 2018, commissioned Network Rail's framework contractor and engineering consultant to develop and implement a renewal scheme. Specialists working for the engineering consultant visited the site on 15 March 2019. They identified several signs that the embankment was failing: the leaning overhead line mast, a lack of ballast around sleeper ends, the lowered cess and bulging on the embankment slope. They also made observations relating to the track geometry, specifically a dip on the cess (left-hand) rail of the up High Level line (close to where the derailment later occurred). They detailed their findings on a site map, dated 23 March 2019. The same map was included in the desktop study report that the engineering consultant issued on 1 May 2019. By the time of the derailment, several design options had been developed but a decision had yet to be made on the scheme to be implemented.

Examination of wagon MPA 394228

62 RAIB examined wagon MPA 394228 at Whitemoor Yard and recorded the key dimensions and condition of the suspension, wheelsets, wheel profiles and underframe; a total station survey was used to measure the suspension geometry. An automatic level survey found no evidence of significant wagon distortion or twist in the wagon's underframe. The damage on the wheel treads and flanges was consistent with both wheelsets having run derailed.

63 Closed-circuit television images from Shepherd's Bush (paragraph 31), and data from the wheel impact load detector site at Wymondley, which the wagon passed over shortly after the derailment, both suggested the wagon was carrying negligible or no payload. At Whitemoor yard, the wagon was found to be empty.

64 RAIB arranged for the individual wheel loads to be measured using a calibrated portable weighbridge. In the first set of measurements, the static wheel loads were measured in a condition simulating level track (negligible difference in cross-level between the two wheelsets). The loads were measured immediately after a shunt move, which was intended to release friction forces locked-up within the laminated leaf springs. The measurements identified a diagonal static wheel load imbalance of around 0.6 tonnes[20] that favoured unloading of the leading left-hand wheel. This was compatible with the wheel load distribution measured at the Wymondley wheel impact load detector site (imbalance of around 0.7 tonnes). In the second set of measurements, all four wheel loads were measured while the rear left-hand wheel was progressively jacked up to simulate the effect of the track twist that wagon MPA 394228 encountered. The characteristic that was measured was used in the development of the computer models for the vehicle dynamics study (paragraph 71).

Management of diagonal wheel load imbalance

65 DB Cargo engineering standard DBS/ES/0081 recognises two means of introducing diagonal wheel load imbalance on MGR-derivative wagons: distortion of the wagon underframe structure (underframe twist) and variation in the preload in each suspension unit.

66 The last two VIBT reports for wagon MPA 394228 (paragraph 28) recorded nothing to suggest maintainers had identified any concern with underframe twist or the need to fit special metal packing pieces (cone packings[21]) to compensate for it. No cone packings were fitted to wagon MPA 394228, and RAIB's automatic level survey of the underframe did not identify a reason for them to be there (paragraph 62).

67 Figure 9 shows the arrangement of the main components comprising each suspension unit:

a. laminated leaf spring, which is supported by the axlebox

b. pair of auxiliary spring units: each abuts the underside face of one of the underframe scroll iron brackets. Flexibility is provided by a pair of internal rubber elements that are sandwiched between three plates: upper, mid and lower

c. pair of eyebolts: the shank of each eyebolt passes through a central hole in the auxiliary spring unit

d. pair of pinch nuts: each pinch nut is fitted on the threaded portion of one of the eye bolts, and abuts the underside of the lower plate of one of the auxiliary springs

e. pair of links, which connect the laminated leaf spring to the eyebolts

f. pair of upper pins, which secure each eye of the laminated leaf spring to the upper end of one of the links

g. pair of lower pins, which secure the eye of each eyebolt to the opposite end of each of the links.

[20] The mean wheel load was 3.6 tonnes.

[21] Cone packings fit between the axle box and the suspension unit (figure 9).

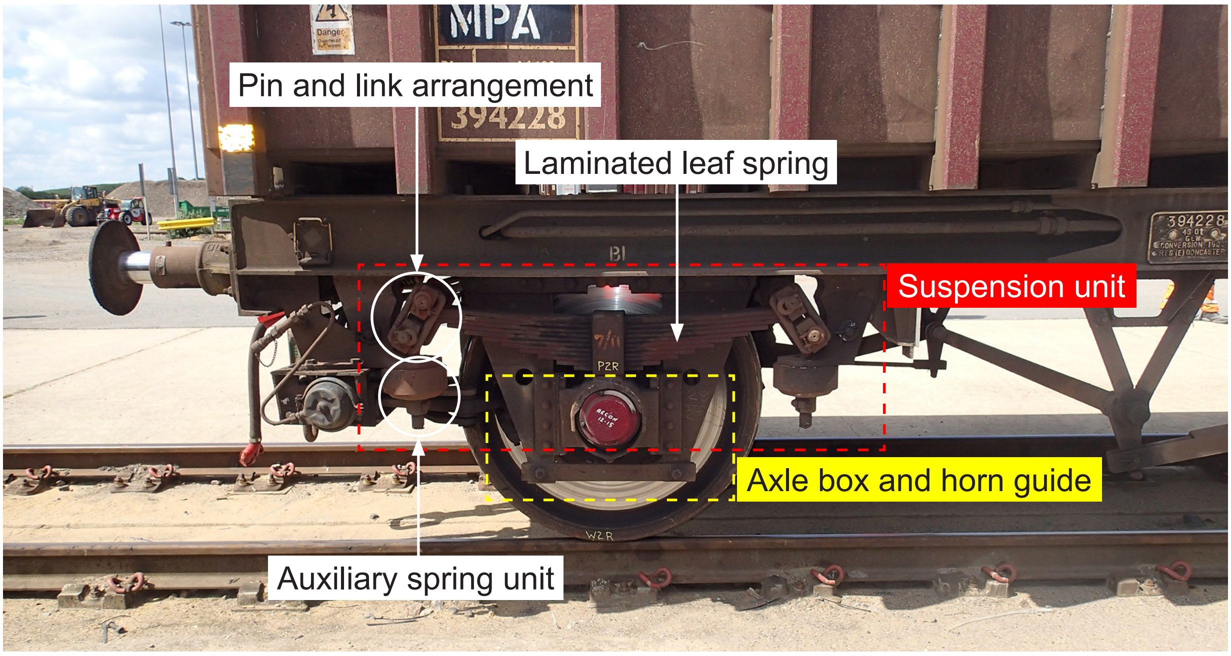
68 Preload is introduced and increased within each suspension unit by tightening the pinch nuts. This compresses the springs and draws the upper pins lower, increasing the distance between the underside of the solebar and the centre of the upper pin (dimension 'h' on figure 9). By increasing the preload within an individual suspension unit the wheel load at that wheel increases, as does the wheel load at the diagonally-opposite wheel. The wheel loads at the other diagonal pair of wheels reduce correspondingly.

69 To manage the risk of diagonal wheel load imbalance, DBS/ES/0081 requires that maintainers measure the dimension 'h' at each of the eight upper pins on the wagon, and determine the maximum difference. If the maximum difference is within ±2 mm, the degree of diagonal wheel imbalance is deemed to be satisfactory. This check is required at each VIBT.

70 RAIB found nothing in the last two VIBT reports to indicate that maintainers found any problems with the suspension on wagon MPA 394228 or its setting. Nothing was recorded to indicate concern with the measurement of the 'h' dimension or the adjustment of the pinch nuts.

Vehicle dynamics study

71 Several factors can affect the Y and Q forces acting at the wheel-rail contact point (paragraph 43). RAIB commissioned a vehicle dynamics study, using computer simulation, to investigate their significance in the derailment. The computer model of the wagon MPA 394228 was developed from a model that DB Cargo had commissioned. This had been constructed using a combination of data sources: historical design information, archive information from early HAA-type wagon models, wagon examination and survey data, and wheel profile measurements. The results from the wheel load measurements and jacking tests (paragraph 64) were used to check the behaviour of the wagon model on twisted track and make suspension parameter refinements. The computer representation of the track focused on the conditions on the approach to the point of derailment. It was created from multiple information sources including: the track geometry measurement train run of 3 April 2019 (paragraph 55), the cross-level and void measurements made by the Tottenham ATME on 8 May 2019 (paragraph 38) and the track geometry survey and rail profile measurements made during the post-derailment track examination (paragraph 42).



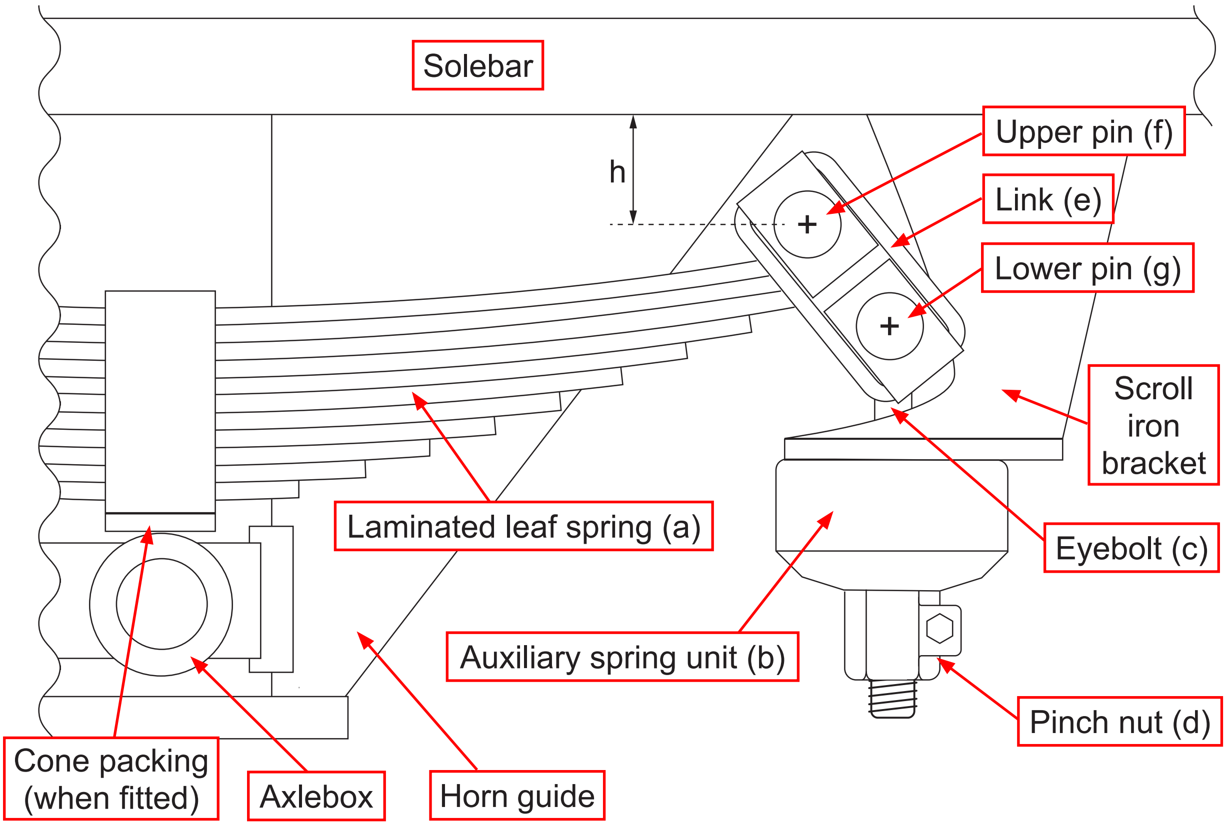


Figure 9: Suspension unit arrangement

72 The study focused on the derailment indicators (primarily the amount of wheel climb and the Y/Q derailment quotient) at the leading left-hand wheel. This was the wheel that was almost certainly the first to climb on to the railhead.[22] A set of baseline simulation conditions was first established and analysed. The study then investigated the sensitivity of a variety of parameters including:

- the level of friction at the wheel-rail interface
- train speed
- wheel and rail profile variation
- the degree of track twist
- reduced track lateral alignment
- variation in horizontal curve radius
- variation in track gauge
- the degree of diagonal wheel load imbalance
- wagon suspension condition: horn guide gaps, and friction and unintended additional (parasitic) stiffness effects in the laminated leaf spring and pin and link arrangement (figure 9).

73 A derailment criterion of 10 mm wheel climb was adopted. On climbing to this height, the contact angle between the wheel flange and the rail has reached a maximum and is gradually reducing. A wheel is unsafe in this state.[23] The simulations showed that track twist and diagonal wheel load imbalance were the key factors influencing the leading left wheel to climb. However, they also showed that a track twist greater than that measured by the Tottenham ATME was necessary. For the diagonal wheel load imbalance used in the baseline wagon model (0.6 tonnes as measured at Whitemoor yard (paragraph 64)) the simulations predicted wheel climb of 10 mm when the track twist was 1 in 110 over the wagon wheelbase (paragraph 44).

74 Although a characteristic of the track layout on Mitre Bridge Curve, the relatively small radius of the curve (nominally 250 metres) was a derailment pre-requisite. For a like-for-like track twist, the simulations predicted that the wheel climb would nearly halve if the curve radius were to increase to 300 metres.

75 Several of the parameters considered were found to be have insignificant effect on the flange climb derailment risk. These included speed, wheel and rail profiles, track gauge and, notably, lateral track alignment.

[22] The derailment occurred on a right-hand curve of relatively small radius. Experience of the running behaviour of conventional two-axle wagons on curved track is that the leading outer wheel (in this case the left) is the most prone to derailment by flange climbing.

[23] Classic derailment theory states that as the contact angle between the wheel flange and the rail reduces so does the level of Y/Q (paragraph 43) needed to initiate flange climb. Therefore, it becomes theoretically easier for the flange to climb the additional amount needed to clear the railhead.

76 Some of the other parameters were found to result in a noticeable increase in derailment risk. These included certain extreme combinations of friction at the wheel tread and wheel flange contact points, adverse horn guide gap conditions and suspension unit parasitic stiffness effects. It was not possible to define the precise values associated with these particular parameters, and reasoned estimates were used in the baseline simulations. If the actual values of these parameters were to significantly differ, the track twist needed to promote a derailment condition could have been less.

Analysis

Identification of the immediate cause

77 **There was insufficient wheel load at the leading left-hand wheel of wagon MPA 394228 to prevent the wheel flanges climbing over the outer rail of the curve on Mitre Bridge Curve embankment.**

78 The witness marks on the track, and the damage found on the wheels of wagon MPA 394228, were consistent with the left-hand wheels of the wagon climbing onto the outer rail and dropping off, and all wheels then running derailed over ballast, sleepers and rail fasteners (paragraph 40).

79 The vehicle dynamics study showed that track twist and diagonal wheel load imbalance were the key influences that led to the derailment (paragraph 73). Their effects combined to reduce the wheel load at the leading left-hand wheel. It is this that allowed the wheel to climb onto the outer rail. The limited load on the wheel probably explains why there was no clear mark on the gauge face of the outer rail, where the first wheel flange climbed on to the railhead (paragraph 40).

80 The vehicle dynamics study predicted that wagon MPA 394228 was at risk of derailment on a track twist of 1 in 110 over the wagon wheel base (paragraph 73). However, since a number of parameters used by the wagon model could not be precisely defined, it is possible that the track twist required to cause a derailment may have been less than predicted (paragraph 76).

Identification of causal factors

81 The derailment occurred due to a combination of the following factors:

a. There was no check rail on the curve where wagon MPA 394228 derailed (paragraph 82).

b. A significant track twist was able to rapidly develop on the up High Level line without measures being introduced to protect the safe running of trains. This was because:

   i. the track bed poorly supported the sleepers on the up High Level line and allowed the level of the left and right rails to drop by different amounts over a short period of time, thereby creating a track twist (paragraph 87)

   ii. there were no measures in place to reduce the risk of a significant track twist developing rapidly (paragraph 104).

c. Wagon MPA 394228 was operating with a diagonal wheel load imbalance that significantly reduced its ability to resist derailment on twisted track (paragraph 125).

Each of these factors is now considered in turn.

Check rail provision

82 There was no check rail on the curve where wagon MPA 394228 derailed.

83 Measurements from Network Rail's track geometry measurement train indicate that the radius of the curve on the Up High Level line is nominally 250 metres in the vicinity of 0 miles 27 chains. Check rail provision on passenger lines with a track radius of less than 200 metres has long been a requirement of Network Rail standard NR/L2/TRK/2102 'Design and construction of track', and of earlier documents. NR/L2/TRK/2102 was revised in December 2015 (compliance date of 1 May 2016). The revision included the new requirement to consider the provision of check rails on curves with radii in the range 201 to 300 metres. The consequences of a derailment, and the frequency of trains at the location being considered, were listed as issues to be taken into account.

84 The Tottenham TME reported that a Network Rail risk assessment procedure, entitled 'How to determine higher or unusual risk of derailment on track assets' (dated 1 April 2016), was used to decide if there was a need for a check rail on the up High Level line. The procedure requires locations to be assessed against a table of criteria, each of which has a risk score allocated. An overall risk score is established by summing the scores of the criteria identified to be relevant. If the overall risk score is 10 or more, the location is to be added to a risk register that is maintained by the track maintenance engineer. The procedure includes another table that lists suitable derailment risk mitigation measures. Check rail provision is identified as a measure for curves 'tighter than 300 metre radius' and that are 'not continuously checked'.[24]

85 RAIB was told that using the procedure to risk assess the up High Level line would yield a score of 9. As a result of this, and the relatively low track category of the line (it was classed as track category 4 in 2016), the Tottenham TME concluded that the table of mitigation measures did not need to be considered and a check rail was not necessary.

86 Network Rail could find no record of the risk assessment undertaken. RAIB has concluded that, given the characteristics of the location, a score of 9 is reasonable assuming an assessment similar to that shown at figure 10. However, this conclusion is based on the assumption that there was no concern regarding the need to include 'additional factors', such as the nature of previous problems and repeat faults at the site.[25] It is probable that, at the time the risk assessment was done, the Tottenham TME was unaware of the progressive seasonal movement of the earth embankment (paragraph 100) and the derailment that had occurred on 12 November 2003 (paragraph 59).

[24] Does not already have a check rail.

[25] It also assumes there was no concern regarding the low-speed cut out effects from track geometry measurement trains and how this may have affected the consideration of 'no dynamic geometry recording'. While low-speed cut out did not affect the track twist that is highlighted as a risk in the table, it would have reduced the information available to the track maintenance team.

	Criteria	Description	Risk Score
Accelerated failure	Curve between 600 and 300 metre radius	Track curvature increases the lateral forces resisted by the track system, these forces increase as the radius decreases.	2
	Curve tighter than 300 metre radius	The forces transferred to the track system significantly increase when the radius is 300m or tighter. *Note: these should be available on the DU curve register.*	4
	Wooden sleeper/bearer construction	Especially on curves if sleepers or bearers are of wooden construction, gauge widening can be subject to accelerated deterioration, therefore note this as a risk elevating factor.	2
	Curve not continuously checked	On curves the lateral dynamic forces from passing wheel sets increases significantly as the curve becomes tighter. The presence of a continuous check to protect the outside/steering rail will slow gauge widening and sidewear. Where a continuous check is not present note this as a risk elevating factor for curves tighter than 600m radius. *Note: if the check rail is not continuous for the entirety of the curve, this may result in high forces being applied to the steering rail where the check rail ends.*	2
	Environmental	Where rail is permanently wet, or subject to corrosive environment (e.g. level crossings or coastal routes or wet sleepers on DC routes)	2
	Mixed use	Where passenger and freight traffic use a track asset, this can sometimes lead to unusual wear patterns and therefore accelerated failure.	1
Faults less evident	No dynamic geometry recording	Dynamic geometry measurement will give a clear indication of the presence of potential geometry derailment risk such as twist and gauge widening. Where no scheduled dynamic geometry recording is undertaken this can be taken as a risk elevating factor as potential faults are less evident. Void meters should be used to obtain additional information. *Note: In S&C the assessed curve can only be noted as being dynamically recorded for track geometry if the recording vehicle uses that specific route for recording.*	3
	Inspected in darkness/artificial light	Potentially faults that could lead to a derailment are less evident to normal inspection regimes in artificial light leading to an increased risk of derailment. Note this as a risk elevating factor.	2
	Fastenings or fixings obscured by ballast, detritus, oil, RRAP, L'Xings	If fastenings or fixings are obscured, potentially faults that could lead to derailment may be less evident to normal inspection. Note this as a risk elevating factor.	3
Additional Factors (Engineering knowledge and judgement)		This includes: • Previous problem sites or repeat fault locations where it is inherent in the design • Obsolete components • Non-standard / exceptional design i.e. deviations from NR/L2/TRK/2049 and 2102 *Note: This is a subjective measure and should be noted if the infrastructure geometry is novel, under trial or subject to unusually rapid wear or corrosion due to its operating context*	Variable nominally 3

Overall risk score = 9

Figure 10: Example consideration of Network Rail's derailment risk assessment criteria for the Up High Level line at 0 miles 27 chains. Table taken from procedure: 'How to determine higher or unusual risk of derailment on track assets'.

Track twist formation – track bed support

87 The track bed poorly supported the sleepers on the up High Level line and allowed the level of the left and right rails to drop by different amounts over a short period of time, thereby creating a track twist.

88 Ballasted track, like that laid on the embankment at Mitre Bridge Curve, is reliant on the condition of the track bed to maintain the vertical level of the rails and avoid unintended cross-level differences leading to the formation of significant track twists.

89 RAIB analysed the recordings from track geometry measurement train runs on the up High Level line dating back to November 2016. They showed that the level of the left-hand rail had been dropping and that an adverse cross-level[26] feature had gradually formed close to 0 miles 27 chains. The shape of the feature remained similar, but the magnitude increased. By the last pre-derailment measurement train run on 3 April 2019 the left-hand rail was nearly 50 mm lower than the right-hand rail.

90 However, the feature that the Tottenham ATME measured 35 days later (paragraph 38) was significantly different in terms of both magnitude and shape (figure 11), and therefore twist. This rapid track geometry deterioration is evidence of the poor condition of the track bed. The recurrence of top faults at the location is further evidence (paragraph 50).

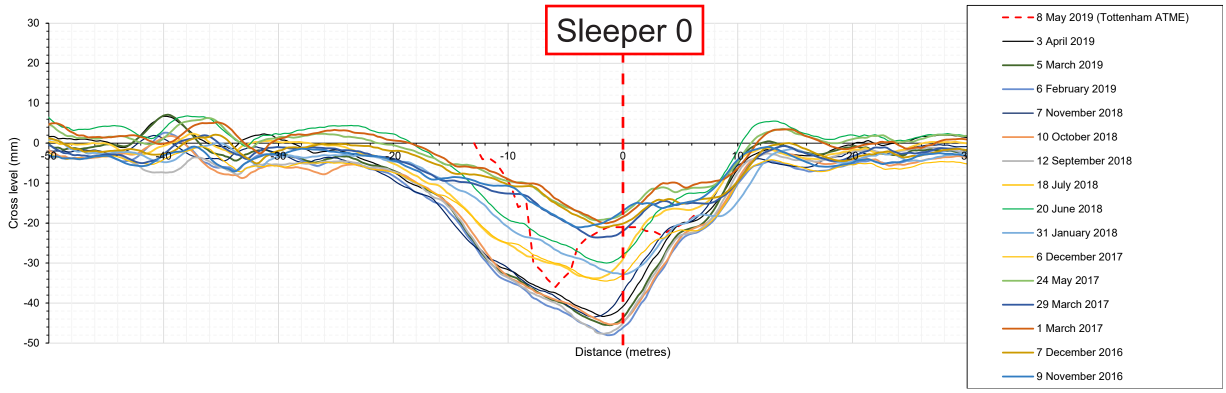


Figure 11: Track geometry measurements showing the gradual formation of the cross-level feature close to 0 miles 27 chains on the up High Level line and how this compared with the feature that the Tottenham ATME measured after the derailment.

91 The vehicle dynamics study predicted that train 6L36 must have encountered a cross-level feature that was probably significantly more challenging, in terms of track twist, than that measured by the Tottenham ATME (paragraph 73). The lack of void meter measurements for the right-hand rail (paragraph 38) may partly explain this. However, so could settlement of a poorly supporting track bed during the 36 hours of train operation after the derailment, and before the Tottenham ATME made his measurements.

[26] A cross-level feature on a curve where the outer rail is lower than the inner rail.

92 This track twist arose due to:

a. the loss of ballast support from under the sleepers of the up High Level line (paragraph 93); which was due to

b. a known failure of the up-side slope of Mitre Bridge Curve embankment resulting in progressive seasonal movement (paragraph 97)

Each of these factors is now considered in turn.

Ballast support

93 The loss of ballast support from under the sleepers of the up High Level line.

94 Prior to the derailment, several site examinations and inspections identified signs of a lack of ballast that suggested a loss of track support. These included:

- section manager's visual inspections on 12 December 2018 and 14 March 2019, which both reported a lack of ballast on the up High Level line between 0 miles 9 chains and 0 miles 38 chains (paragraph 54)
- the cab ride by the Camden TSM on 6 April 2019, which reported the need for ballast between 0 miles 25 chains and 0 miles 27 chains (paragraph 55)
- the site visit by the Anglia AE(G) on 23 May 2016, which identified exposed sleeper ends and a reduced cess height (paragraph 58)
- the specialists who visited the location on 15 March 2019, and specifically commented on the lack of ballast around sleeper ends and the lowered cess in their report (paragraph 61 and figure 12).

Figure 12: The condition of the up-side cess and ballast around 0 miles 27 chains on the up High Level lines as photographed during the specialists' site visit of 15 March 2019 (photograph courtesy SNC-Lavalin)

95 These signs were consistent with ballast becoming mobile and able to escape from under the sleepers because of movements in the underlying embankment (paragraph 97). Work orders that had been raised to deliver new ballast to the site had been rescheduled (paragraph 54)[27] and, in the years before the derailment, no mechanised track maintenance work, such as tamping or stone blowing, had been arranged which would have helped reinstate support to the track.

96 There were visible signs of distress on some of the timber sleepers close to the derailment location, suggesting they were likely to be more flexible and thus allow greater differences in cross-level on poor supporting ballast. RAIB compared the location of these sleepers, and the track-mounted automatic warning system equipment for signal NL 1048 (which is likely to have reduced sleeper flexibility), with the cross-level profiles measured by the Tottenham ATME, and those from the last pre-derailment track geometry measurement train run (figure 13). It noted a degree of correlation between the location of the distressed sleepers and the magnitude of the cross-level change. Therefore, it is possible that the condition of the sleepers contributed to a track twist being able to develop more rapidly.

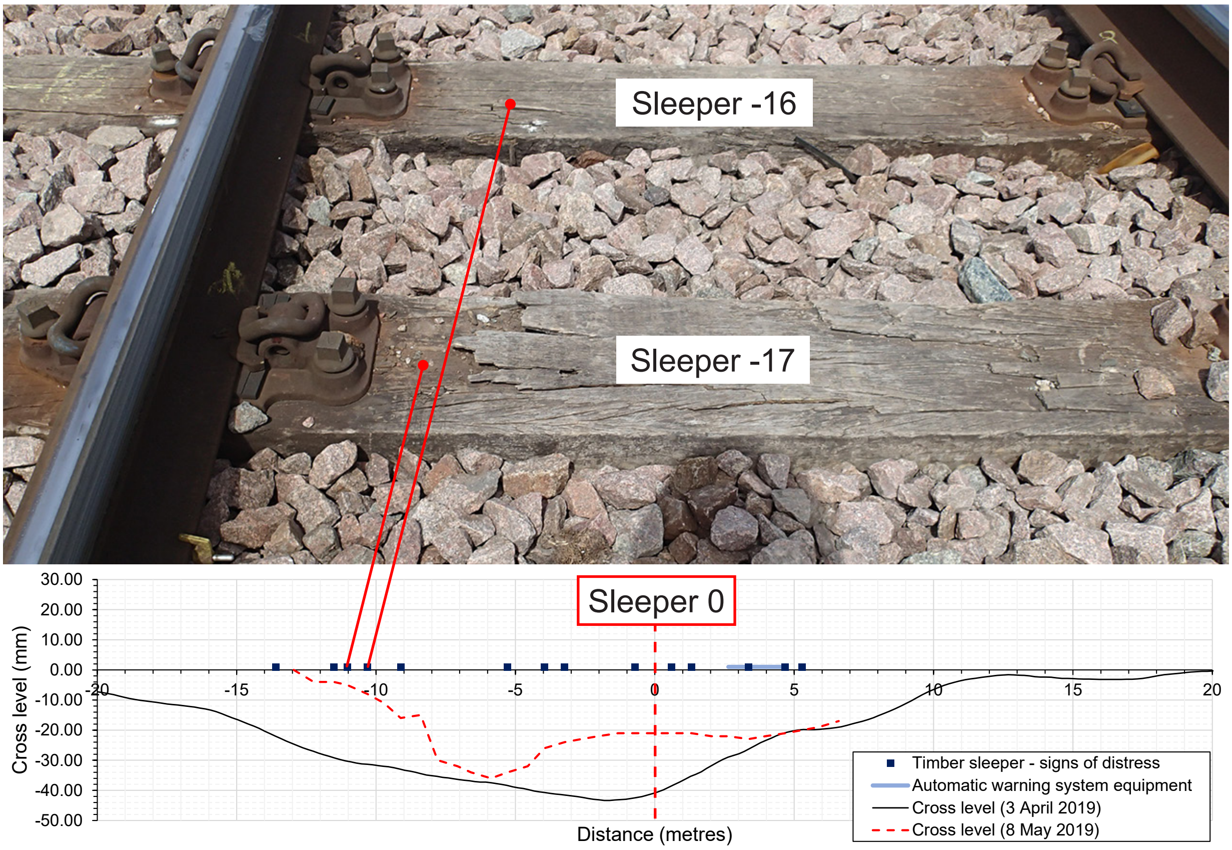


Figure 13: Location of distressed sleepers and automatic warning system equipment close to 0 miles 27 chains compared to cross-level profiles measured on 3 April 2019 and 8 May 2019

[27] In addition to the work order raised in 2016 (paragraph 48), a need to deliver ballast in 25 kg bags is mentioned in the section manager visual inspection reports of 12 December 2018 and 14 March 2019. This was to replenish the reported lack of ballast between 0 miles 9 chains and 0 miles 38 chains. While RAIB found evidence of fresh ballast on the up-side cess when it visited on 23 May 2019, the same cannot be seen in photographs in the Tottenham ATME's derailment survey report (paragraph 38).

Earthwork failure

97 A known failure of the up-side slope of Mitre Bridge Curve embankment resulting in progressive seasonal movement.

98 Embankments of London clay and locomotive ash are common on the Anglia Route (paragraph 19) and most were constructed with steeper slopes (therefore, more prone to failure) than would be adopted with modern design procedures. Network Rail uses five-year control periods to plan infrastructure investment and other priorities. The Anglia SAE(G) had identified 30 earthwork assets that required renewal work during the control period starting 1 April 2019 (Control Period 6). Of these, 23 were embankment slopes. They included both slopes of the five-chain length of Mitre Bridge Curve embankment around the derailment location (paragraph 57).

99 Figure 14 shows a cross-section of the embankment, the position of the inclinometers and the main soil types identified from the holes bored to install these instruments (paragraph 22 and 60). The inclinometer measurements indicate lateral ground movements[28] at depths down to about 2.5 metres occurring broadly as illustrated on figure 14. Based on these, and other movement features on the embankment slope (paragraph 102), RAIB has concluded that, while their exact form cannot be established, the ground movements were occurring broadly as illustrated. It is not possible to determine the exact extent to which the area of movement extended beneath the ballast. However, what is certain is that the upper part of the slip material was moving away from the up High Level line, thus removing support to the ballast, resulting in loss of the ballast shoulder which was, as a consequence, the means by which the ballast had been able to migrate and escape from under the sleepers (paragraph 95).

100 The inclinometer readings confirm that slip material was showing signs of progressive seasonal movement (figure 15). The inclinometer near the embankment crest (BH02) recorded minimal movement over much of the autumn and winter, but typically 25 mm during late spring, summer and early autumn each year. The complex nature of the ground movement is demonstrated by the inclinometer at the mid-slope position (BH03). This recorded progressive seasonal movement in 2017 and 2018, but not in 2019 (before and after the derailment). The derailment occurred around the time of the seasonal increase in movement at inclinometer BH02, after a period when negligible lateral embankment movement was measured. Little movement was measured on the down-side slope (inclinometer BH01).

101 RAIB found no evidence that mining, land fill or animal burrowing was a cause of track bed subsidence. There were no signs of construction or other engineering work on, or close to, the embankment slope.

[28] Inclinometers record only horizontal movement and quoted values are those measured perpendicular to, and away from, the track, in the lateral direction (as depicted by the arrows on figure 15).

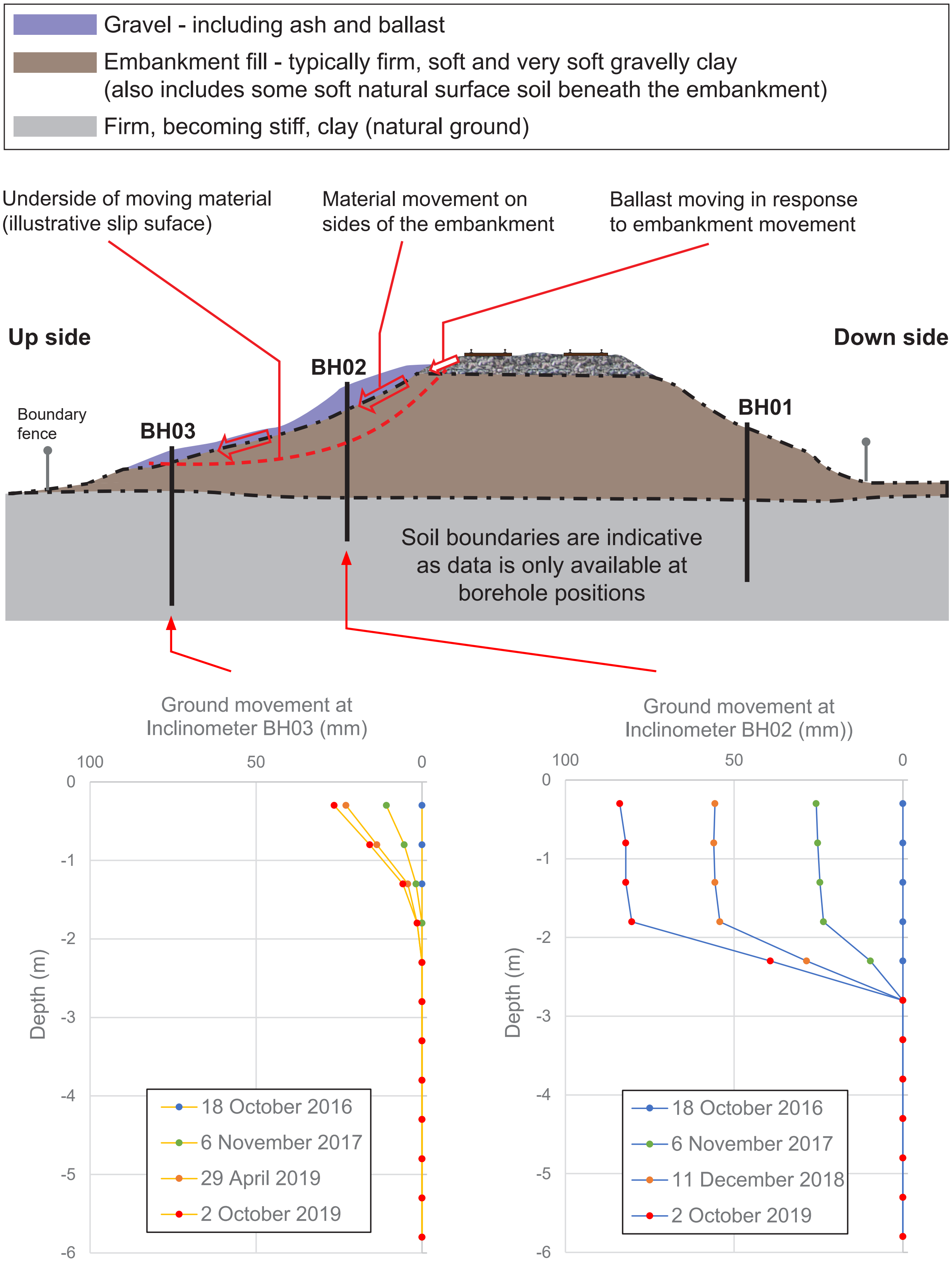


Figure 14: Cross-section of Mitre Bridge Curve embankment showing illustrative slip surface and simplified ground movement. Graphs show how the lateral movement measured at inclinometers BH02 and BH03 varied with borehole depth.

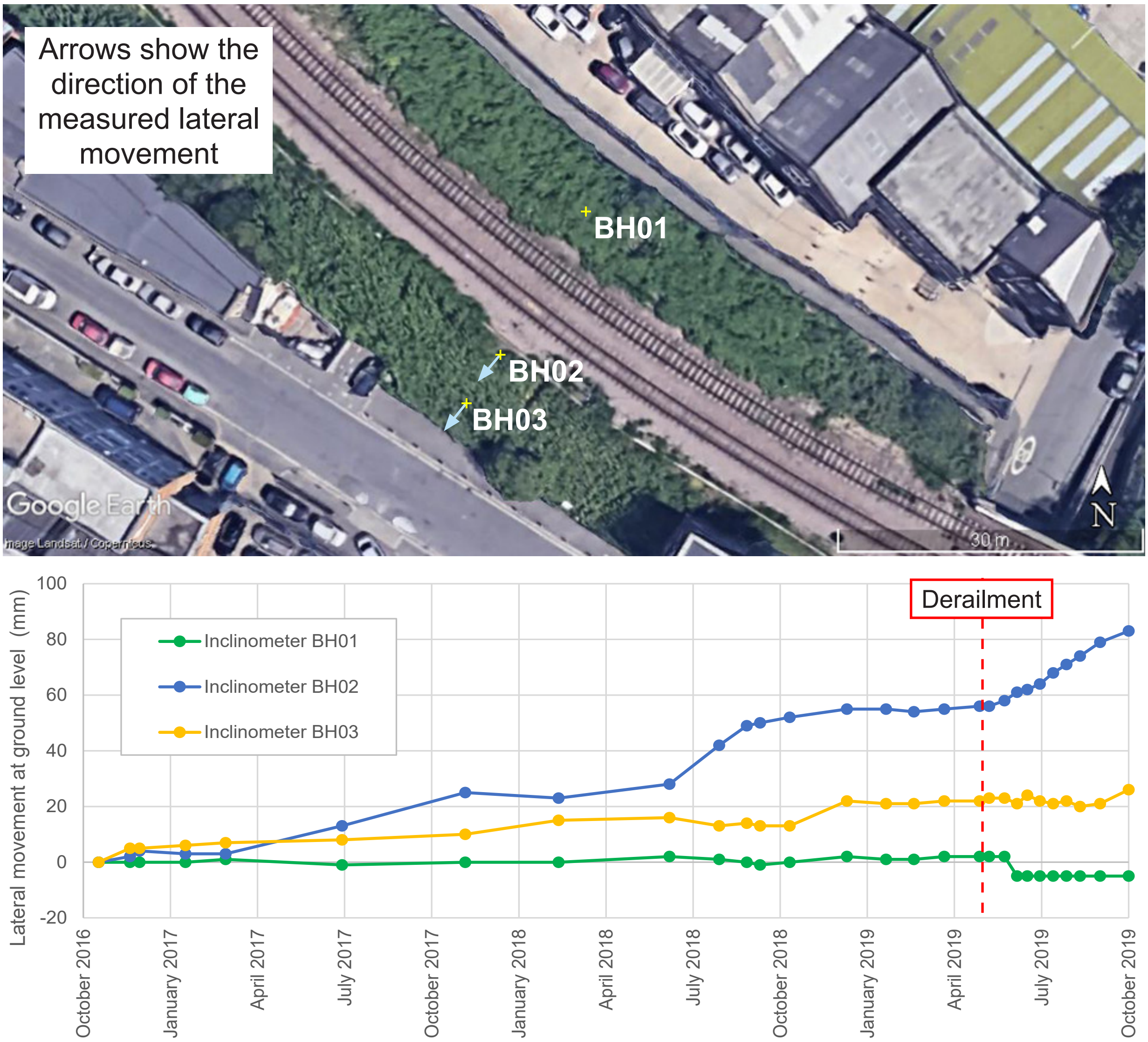


Figure 15: Lateral embankment movements measured at ground level by the inclinometers installed in the down-side slope (BH01) and the up-side slope (BH02 and BH03). Aerial image shows the location of the inclinometers.

102 The details of the failure mechanisms leading to the poor track bed support and ballast loss are likely to be complex and have not been investigated by RAIB. However, the following may aid understanding:

- The slump/bulge on the up-side slope of the embankment that was observed during at least two inspections (paragraphs 58 and 61), and a flat area identified on the slope from a light detection and ranging (LiDAR) survey (figure 16), were all indicative of a failure deep within the embankment.
- A layer of very soft (low strength) clay was identified near the underside of the moving material (that is, near the slip surface), in the hole bored for inclinometer BH02, indicating that zones of weakness were probably influencing the ground movement.

- The Anglia SAE(G) observed that the LiDAR survey data suggested that the back scar of the failure aligned with the cable troughing. Since it did not extend under the track, this suggested that the earthwork failure did not directly result in the formation of the cross-level feature in the track. Rather, it provided the means by which the ballast migrated from under the sleepers (paragraph 95). The reduced ballast shoulder restraint resulting from this process could also explain the lateral movement of the track that allowed alignment faults to form on the up High Level line (paragraph 153).
- The timing of effects at track level compared to the timing of movements within the underlying embankment was possibly influenced by the behaviour of the locomotive ash beneath the ballast. Although placed many years ago, movements would occur within this material if, as was probably the case, the underlying embankment crest settled unevenly. The timing of the ash movements could have been affected by the extent to which ash particles were bound together by moisture. Research for London Underground[29] has highlighted that movement of locomotive ash due to passing trains is likely to be more significant during summer months when there is a soil moisture deficit.

103 The Anglia SAE(G) considered that he had a sufficient understanding of the failure mechanism of the embankment to develop renewal works to stabilise it. Given the relatively minor scale of the work needed, there had been plans to carry out the renewal work before the start of Control Period 6 if there had been underspend in the preceding period.

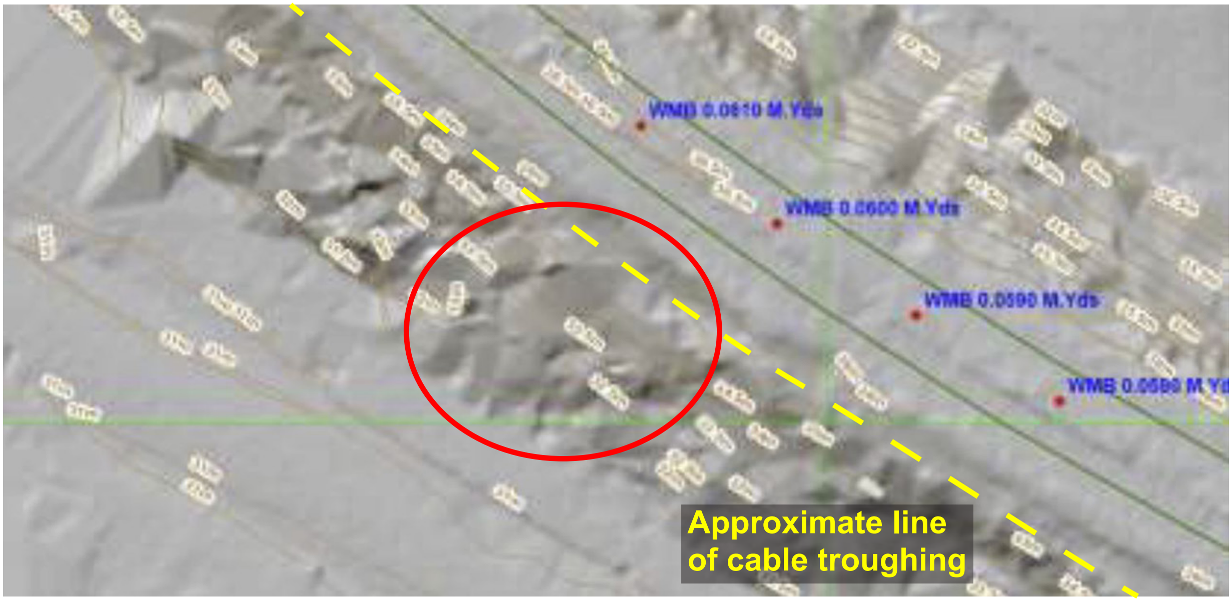


Figure 16: LiDAR survey of the embankment on Mitre Bridge Curve highlighting the flattened area on the up-side slope close to 0 miles 27 chains (image courtesy Network Rail)

[29] McGinnity et al (1998), 'A systematic and cost-effective approach to inspecting, prioritising and upgrading London Underground's earth structures', Proceedings of Seminar 'Value of Geotechnical in Construction', Institution of Civil Engineers.

Track twist formation – detection and mitigation

104 **There were no measures in place to reduce the risk of a significant track twist developing rapidly.**

105 The process arrangements that Network Rail used to maintain and manage track and earthwork assets did not identify the possibility of a significant track twist rapidly developing on the up High Level line. As a result, measures that could have avoided the derailment were not put in place.

106 This causal factor arose due to a combination of the following:

a. the teams responsible for earthwork management and for track maintenance did not identify the risk of a significant track twist developing from the information provided by Network Rail's routine track geometry inspection arrangements (paragraph 107)

b. the teams responsible for earthwork management and for track maintenance did not require that additional arrangements were put in place to monitor the movement of the track before they had been assured that the progressive seasonal movement of the embankment had ceased (paragraph 113)

c. Network Rail's routine visual and other track inspection processes did not identify the risk of a significant track twist developing (paragraph 121).

Each of these factors is now considered in turn.

Routine track geometry measurement

107 **The teams responsible for earthwork management and for track maintenance did not identify the risk of a significant track twist developing from the information provided by Network Rail's routine track geometry inspection arrangements.**

108 Network Rail company standard NR/L2/TRK001 required the track geometry of the up High Level line to be measured at a nominal interval of 16 weeks, just over three times a year. In practice, Network Rail's track geometry measurement trains ran over the line more regularly. There were seven recording runs in 2017 and six in 2018. In 2019, there had been three runs before the derailment. The last was on 3 April 2019. There was no interval between consecutive recording runs that exceeded the maximum allowed 36 weeks (paragraph 18).

109 All the track geometry measurement train runs recorded a three-metre track twist at the derailment location, around 0 miles 27 chains (paragraph 51). NR/L2/TRK/001 requires maintenance action when the track twist exceeds 1 in 200. These are known as actionable faults (paragraph 50). Any that are identified are listed in the so-called 'L2 fault' report that is produced after a measurement train run. 'L1 faults' are classed as geometry faults requiring correction during planned track maintenance; the limits defining the range for a L1 track twist fault are 1 in 200 to 1 in 250. None of the measurement train runs identified any L2 twist faults around 0 miles 27 chains; and, although several runs in 2017 and 2018 had reported L1 twist faults, none had been reported on the first three runs in 2019. As a result, the Camden track maintenance team had not been alerted to a need to carry out any track twist repair work prior to train 6L36 passing.

110 All the measurement train runs recorded the cross-level at the derailment location. Figure 17 compares the development of the maximum cross-level (paragraph 89) with the embankment movement recorded at inclinometer BH02 (figure 15). It shows that the main changes in cross-level occurred at a similar time to the progressive seasonal movement of the embankment, in late spring, summer and early autumn. This was an indication of the condition of the track bed, and that it was possible that the cross-level was about to significantly alter, and to abruptly produce a significant track twist.

111 Network Rail's track inspection and maintenance processes rely on information from individual track geometry measurement train runs, and there was evidence that the earthwork management team had a basic understanding of Network Rail's linear asset decision support tool which enabled it to use this information when assessing embankment repairs. However, the team did not use the tool to understand trends associated with track movement. Rather these were left to track specialists within the wider route asset management team to analyse and no discussion was had with the local track maintenance team. In summary, and in common with findings from other RAIB investigations (paragraphs 161 to 173), neither the earthwork management nor the track maintenance team were routinely using information from multiple track geometry measurement train runs to identify trends that might have helped them to understand and anticipate the effect of earthwork failure or track bed condition on the safe running of trains. RAIB found no evidence the teams had access to analysis tools that would easily facilitate this.

112 The loss of track top and lateral alignment information due to low-speed cut out effects (paragraphs 51 and 54) reduced the opportunity for those that routinely review data from track geometry measurement train runs to understand if other geometry parameters provided insight into the condition of the track bed.[30]

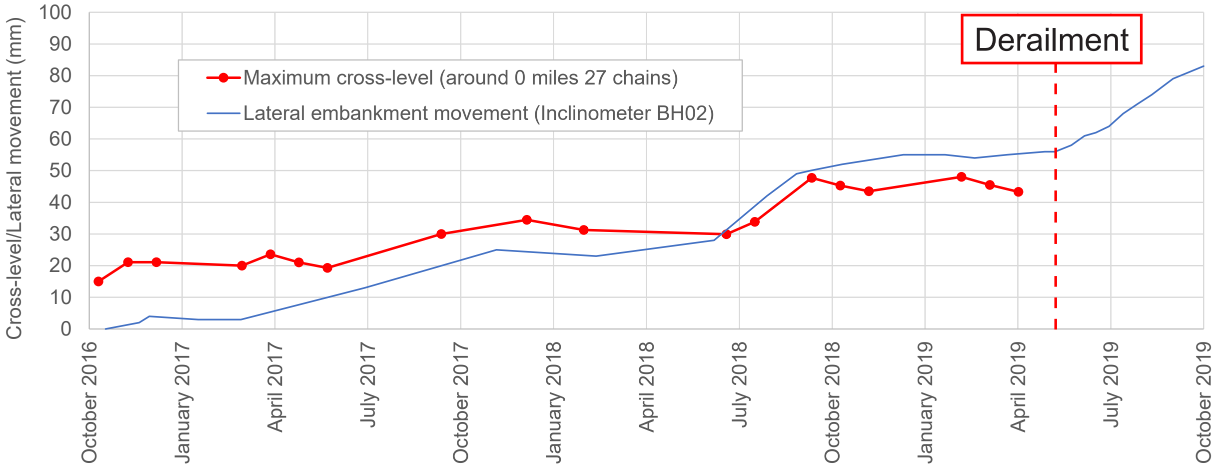


Figure 17: Development of the maximum cross-level around 0 miles 27 chains compared to the lateral embankment movement measured at ground level at inclinometer BH02

[30] Network Rail recently revised company standard NR/L3/TRK/038 'Track geometry: management of recording and of intervention and immediate action limits' to require that a log of missing and invalid data is sent to the track maintenance engineer. RAIB has concluded that given the compliance date, 1 September 2018, this change would not necessarily have affected the reporting of information from the early track geometry measurement train runs that were available to understand the track bed condition.

Supplementary track monitoring

113 **The teams responsible for earthwork management and for track maintenance did not require that additional arrangements were put in place to monitor the movement of the track before they had been assured that the progressive seasonal movement of the embankment had ceased.**

114 Continuous or frequent monitoring of the track geometry condition close to where the embankment movement was detected would have helped identify the significant track twist that formed rapidly. Established technologies exist to do this, including the remote monitoring of sleeper-mounted tilt sensors. These or other suitable track condition monitoring systems could have been used to provide timely alerts to the track maintenance or infrastructure fault control teams of the need to act to protect the safe running of trains. No-one in the earthwork management or track maintenance teams decided that this was required. The Anglia SAE(G) reported that no sleeper-mounted tilt sensors have been installed by the earthwork management team on the Anglia Route, and that he was only aware of their occasional use on Network Rail's infrastructure. While he was aware that Network Rail was starting to use remote track condition monitoring, it was at an early stage of development.

115 Network Rail company standard NR/L2/CIV/086 refers to the need for short-term mitigation measures to manage the safety risks associated with a failing earthwork before intervention measures can be implemented. This was the stage that Network Rail had reached in its management of Mitre Bridge Curve embankment. The Anglia SAE(G) was aware of the progressive seasonal movement of the embankment from the inclinometer monitoring (paragraph 100) but had concluded that the movement was gradual. He did not expect it to result in a rapid track geometry change and believed that Network Rail's standard track inspection and maintenance arrangements were adequate to identify and repair any developing faults before they would affect the safe running of trains.

116 NR/L2/CIV/086 lists earthwork monitoring and operational restrictions as possible mitigation measures.[31] Monitoring measures are described in a section entitled 'Earthwork monitoring strategy selection and implementation'. However, these are focused on geotechnical solutions, such as the inclinometer monitoring that had already been arranged. There is no mention of methods that involve the measurement of the track geometry. Operational restriction measures are described in a section entitled 'Earthworks operational restriction selection and implementation'. They include the use of track geometry monitoring. However, the selection process suggests that this type of mitigation measure is unlikely to have been considered unless it had been identified that 'full operational use of the track is not possible or safety of the line could potentially be compromised further'. Even if it were to be considered, the aforementioned section explains that 'selection of track monitoring shall be a function of the magnitude and rate of track movements monitored/predicted against those defined in NR/L2/TRK/001/mod11'. RAIB found no evidence that anyone had identified the need to restrict train operation at Mitre Bridge Curve. The Anglia SAE(G)'s conclusions regarding the severity of the embankment movement suggest that he considered the risks could be managed by existing arrangements and, therefore, did not consider the need for further monitoring. Network Rail's track geometry inspection and measuring arrangements did not provide information that might have led to an alternative view (paragraph 107).

117 Members of the Tottenham TME's team were aware of the embankment movement but did not, of their own accord, identify the need for additional monitoring or inspection (paragraph 47). The earthwork management team knew that the track maintenance team was aware of the issues at the location because they had originally alerted them. The Anglia SAE(G) further explained that the embankment at Mitre Bridge Curve was on the list of priority earthwork assets on Anglia Route for Control Period 6 (paragraph 98) and he understood that this list was available to the Tottenham TME. However, the Tottenham TME was unaware of the inclinometer monitoring that had been arranged and the progressive seasonal movement that had been identified. There was other information that was not shared, such as the observations from the specialist's site visit on 15 March 2019, which included features that were relevant to the condition of the track (paragraph 61). Network Rail explained that since the specialist concerned would not have been expert in aspects of track geometry these observations would have been treated with caution.

118 RAIB found a lack of structured liaison arrangements between the earthwork management and track maintenance teams. It was reported that it was rare that the earthwork management team needed to notify a track maintenance team of a problem or requirement, and that it was more usual for others to alert them.

119 Network Rail company standard NR/L2/CIV/086 refers to the need for earthwork managers to include recommendations for 'liaison with other asset owners' as part of the earthwork evaluation process (paragraph 20). However, no additional detail or guidance is given.

[31] Temporary restraints to prevent earthwork material falling on the track are also listed. These are not relevant to the failure of Mitre Bridge Curve embankment.

120 With regard to track maintenance responsibility, Network Rail company standard NR/L2/TRK/001 specifically mentions the effect of (embankment) settlement on ‘rapid and unpredictable geometry deterioration’. It identifies the use of additional monitoring as a means of limiting this. However, no additional guidance is given, such as the need for, or benefit of, liaison with the relevant earthwork manager. Given the information available to him, the Tottenham TME did not recognise the need for additional monitoring.

Other routine track inspection arrangements

121 **Network Rail’s routine visual and other track inspection processes did not identify the risk of a significant track twist developing.**

122 Network Rail company standard NR/L2/TRK/001 specifies various track inspection tasks in addition to track geometry measurement. For the up High Level line it required a weekly basic visual inspection by a patroller; a 13-weekly section manager’s visual inspection by the Camden TSM (or delegated person); and a two-yearly track maintenance engineer’s visual inspection by the Tottenham TME (or delegated person) (paragraph 18). RAIB found no evidence that these inspection tasks were not being routinely carried out. Cab riding, although not mandated, was also being done.

123 In the months prior to the derailment, none of the inspection tasks reported any direct concern regarding development of the cross-level feature or track twist around 0 miles 27 chains. Further, although several inspection reports mentioned the lack of ballast in the area (paragraph 94), none identified this as a sign of possible rapid track geometry deterioration.

124 In general, these inspections are visual in nature and only minimal measurements are taken. The inspection staff did not have major concerns regarding the overall condition of the up High Level line, and the Tottenham TME had not forwarded any problem statements to the route track asset management team regarding the need for track renewal or other investment work.

Wagon wheel load imbalance

125 **Wagon MPA 394228 was operating with a diagonal wheel load imbalance that significantly reduced its ability to resist derailment on twisted track.**

126 When HAA-type hopper wagons were converted to open box wagons, torsional stiffness testing was carried out to demonstrate compliance with the track twist derailment resistance requirement in British Railways Board group standard GM/TT0087 ‘Resistance of railway vehicles to derailment and roll-over’. The tests measured the reduction in wheel load (wheel unloading) as one of the wheels was progressively lifted to simulate a track twist of 1 in 150 over the wagon wheelbase. Derailment resistance was deemed unacceptable if the so-called ‘delta Q/Q’ ratio (the difference between the nominal wheel load (on level track) and the actual wheel load (on twisted track), divided by the nominal wheel load) exceeded 60%. This requirement and criterion continue to be used in the acceptance of rail vehicles operating on the national network.[32]

[32] Current requirements are defined in BS EN 14363.

127 The test reports[33] recorded delta Q/Q ratio values very close to 60%. It highlights that a MGR-derivative wagon's underlying resistance to derailment on twisted track is only just compliant with this standard vehicle acceptance criterion. Therefore, the wheel load reduction from only a slight diagonal wheel load imbalance is likely to significantly increase the derailment risk. HAA-type wagons have a similar derailment resistance performance since they have the same underframe and running gear (paragraph 24). RAIB found evidence of derailments involving HAA-type wagons, where diagonal wheel load imbalance was a factor (see paragraphs 154 and 155).

128 The diagonal wheel load imbalance that was measured on wagon MPA 394228 at Whitemoor yard (around 0.6 tonnes) was consistent with the Wymondley recordings (paragraph 64). The distribution of the imbalance meant that it contributed to unloading the leading left-hand wheel, which was almost certainly the first to derail (paragraph 72). Vehicle dynamics study calculations predicted that, for like-for-like track twist conditions, wheel climb at the leading left-hand wheel would have reduced by around 6 mm if this imbalance was removed, making a derailment much less likely.

129 Network Rail has wheel impact load detectors at strategic locations across the national network. RAIB analysed data from several of these for occasions when two-axle wagons had passed over. It found evidence of other lightly-loaded wagons operating with significant diagonal wheel load imbalance. Some wagons had an imbalance of greater than 1.2 tonnes; it is probable that a large proportion of these were MGR-derivative wagons. Therefore, the diagonal wheel load imbalance that was measured on wagon MPA 394228 is unlikely to be unusual.

130 This causal factor arose because:

a. the arrangement for adjusting the suspension on MGR-derivative wagons is susceptible to introducing a diagonal wheel load imbalance, if not correctly set (paragraph 131)

b. a significant diagonal wheel load imbalance was not detected during routine wagon maintenance (paragraph 137).

Each of these factors is now considered in turn.

Wheel load imbalance – suspension design

131 **The arrangement for adjusting the suspension on MGR-derivative wagons is susceptible to introducing a diagonal wheel load imbalance, if not correctly set.**

132 When British Rail operated HAA-type wagons in coal traffic, the maintenance regime comprised regular planned preventative maintenance (limited to tasks such as hopper door checks) and a routine visit to one of its engineering works for general repair.

[33] A MGR-derivative wagon of the MAA type was tested.

133 General repair included work to rebuild the wagon suspension, after which the wheel loads were measured on a weighbridge (at the works) and the split nuts on the eyebolts were tightened or loosened to adjust suspension unit preload (paragraph 68). Maintenance documents from this period described a process that involved simulating a track twist, by raising one of the wheels, and adjusting the suspension unit preload to ensure individual wheel loads were above a defined minimum.

134 Given the similarity of the above wheel load measurement process and the track twist derailment test (paragraph 126), RAIB has concluded:

- there was a historical recognition that diagonal wheel load imbalance had a significant effect on the derailment risk of HAA-type wagons
- that a key function of the split nut and eyebolt arrangement was to minimise this risk, by providing a means of adjusting wheel load imbalance during wagon maintenance and repair.

135 Significant preload can be introduced in the suspension unit by tightening the split nuts. DB Cargo engineering standard DBS/ES/0081 includes guidance that a half-turn is sufficient to change the wheel load by between 0.40 and 0.80 tonnes.[34]

136 RAIB measured the extent to which each of the split nuts were tightened on wagon MPA 394228 when it examined the wagon at Whitemoor yard (paragraph 62). On the leading right and trailing left diagonal pair of suspension units, the split nuts were tightened around 3 mm (approximately one half-turn) more, on average, than on the opposite diagonal. This amount of difference is consistent with, and would explain, the diagonal wheel load imbalance that was measured, in terms of distribution and order of magnitude.

Wheel load imbalance – detection and mitigation

137 A significant diagonal wheel load imbalance was not detected during routine wagon maintenance.

138 DB Cargo maintained the MGR-derivative wagons on train 6L36 using tasks carried out at periodic VIBTs. It explained that a VIBT-based regime had been in place since coal traffic started to decline and HAA-type wagons were withdrawn and converted. At first, the period between VIBTs was one year. However, because of reduced utilisation, the period was extended to two years for certain types of MGR-derivative wagon. This included MPA-type wagons.

139 The introduction of a VIBT-based regime accompanied the withdrawal of planned preventative maintenance and general repair. However, it was realised that wheel loads were not being regularly measured because the wagons were no longer being maintained at locations with weighbridges. To address this, a new ‘simplified wheel weighing process’ was introduced. This was based on the use of a portable calibrated wheel jacking device.

[34] DB Cargo explained that this information was taken from historical British Rail documents.

140 The simplified wheel weighing process is described in DB Cargo engineering standard DBS/ES/0081. It includes a check of whether the difference between individual wheel loads is greater than 0.20 tonnes, and to re-adjust the split nut and eyebolt arrangement accordingly. It is carried out as part of a VIBT if:[35]

- the suspension has been fully dismantled, at either wheelset; or
- it is found that the suspension units are set unevenly.

141 DBS/ES/0081 requires maintainers to assess suspension unit setting evenness by comparing the measured dimension 'h' values (figure 9) on a wagon. If the maximum difference is within ±2 mm wheel weighing is not required (paragraph 69). DB Cargo stated that this dimensional check is carried out at every VIBT.

142 Maintainers were only required to record limited measurements during a VIBT, such as brake pressure and application timing. They were not required to record the values they measured for dimension 'h' and none were.

143 RAIB calculated the 'h' dimension values from survey measurements made on wagon MPA 394228 at Whitemoor yard (paragraph 62) and DB Cargo measured them at a new location, before and after a shunting move. While there were significant differences between the three sets of data, the maximum difference within each set exceeded the ±2 mm criterion in every case. In the light of this, and the split nut positions observed at Whitemoor yard (paragraph 136), RAIB has concluded that it is probable that the 'h' dimensions on wagon MPA 394228 were non-compliant at the time of the last VIBT. However, it has also concluded that, because no defects or repair work relating to suspension settings were recorded in either of the last two reports (paragraph 70), the maintenance staff did not identify this.

144 The variation between the three sets of measurement data brings into question the reliability of using 'h' dimension difference as an indicator of diagonal wheel load imbalance. There is no guidance in DBS/ES/0081 on ensuring measurement accuracy, and DB Cargo does not provide its maintenance staff with a special measurement tool or gauge, or a calculation aid to evaluate the findings. Furthermore, the dimension will be affected by any unevenness of the track at the measurement location. While DBS/ES/0081 requires that the track is 'reasonably level' when measuring underframe twist (paragraph 65), there is no equivalent requirement in the task that describes the need to measure 'h' dimension difference.

145 Markings on the laminated leaf springs indicated that they were exchanged in 2011 as part of routine maintenance. DB Cargo advised that this work would not have involved full suspension dismantling or the need to adjust the split nuts. Therefore, wheel weighing was not required by the maintenance procedure at that time.

146 The condition of the split nuts and eye bolt threads on wagon MPA 394228 (figure 18) suggests that they had not been adjusted in recent years (possibly decades) and that the diagonal wheel load imbalance had existed for some time.

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[35] DBS/ES/0081 states it may also be needed as part of a derailment investigation.

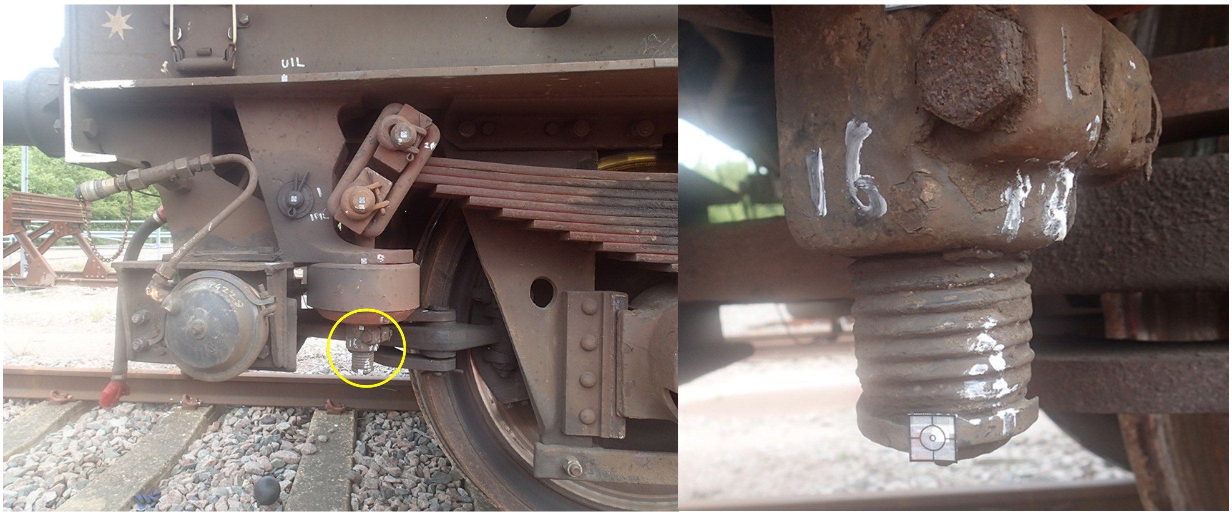

Figure 18: Typical split nut and eyebolt condition on wagon MPA 394228

Identification of possible underlying factor

147 **The low level of information sharing between the track maintenance and earthwork management teams meant there was no common understanding that the condition of Mitre Bridge Curve embankment presented a risk to the safe running of trains. This is a possible underlying factor.**

148 RAIB found that liaison between the track maintenance and earthwork management teams did not lead to a recognition that the condition of the embankment and track bed meant that:

- there was a risk of a rapid change in track geometry that could result in the development of a track twist that was harmful to the safe running of trains (paragraph 87)
- the track inspection and earthwork management mitigation arrangements that were in place would not be able to detect this in a timely manner (paragraph 104).

149 RAIB found evidence of informal liaison arrangements between the two parties. Communication normally took the form of email correspondence on an as-and-when basis, and there was no reference made to formalised procedures or tools. It also found cases where information generated to assist one party in their asset management/maintenance responsibilities, was not highlighted to, or fully considered by, the other even though it might have assisted in their decision making. Examples included:

- findings from inclinometer measurements that the Tottenham TME was unaware of (paragraph 117)
- information (and insight) from the track geometry measurement train runs that might have assisted the Anglia SAE(G)'s understanding of the effect of the progressive seasonal movement of the embankment on the track (paragraph 111).

150 Network Rail standards for track maintenance and for earthwork management both mention arrangements that are relevant to mitigating risks associated with the derailment. However, neither emphasises the value and importance of liaison between the two parties in coordinating their work activities (paragraphs 119 and 120).

Observations

151 **Network Rail did not repair a series of lateral track alignment faults that were detected on the up High Level line close to where the derailment occurred.**

152 Track geometry measurement trains recorded evidence of lateral track alignment faults that had been developing on the up High Level line before the derailment. On 7 November 2018, three discrete L2 faults were reported. One was greater than 50 mm in amplitude; it required inspection in 72 hours and repair within seven days. The other two were between 27 and 50 mm; they required repair within 14 days (figure 8). The faults were still present when train 6L36 passed on 6 May 2019, 180 days after they had been identified. Similar lateral alignment faults had been reported on earlier measurement train runs (paragraph 50). Low-speed cut out effects meant that the lateral track alignment was not recorded every time a measurement train ran (paragraph 51). This led to the faults not being included in the reports from the first three runs in 2019 (paragraphs 54 and 112).

153 Vehicle dynamics study calculations indicate that these lateral track alignment faults were not a factor in this derailment (paragraph 75) and RAIB has not investigated the reasons why these faults developed. However, it notes that it is possible that the lack of ballast shoulder in the vicinity of the derailment may have played a role in that it would have reduced lateral track restraint. RAIB is aware of other cases when such faults have acted in combination with track twist to promote derailment. This was, for example, a factor in the derailment at Santon, near Scunthorpe, on 25 January 2008 (see paragraph 154).

Previous occurrences of a similar character

154 RAIB has investigated a number of freight train derailments that have resulted from flange climb on twisted track and small radius curves. Those with similar characteristics include:

- Cricklewood Curve, 31 January 2006 (RAIB report 02/2007). The eighth and ninth wagon of an aggregate train, comprising 18 bogie hopper wagons, derailed and overturned on an excessive track twist associated with the rapid development of a cross-level feature on an embankment. The cross-level feature had formed at a site where embankment repair work was being carried out for Network Rail.
- King Edward Bridge, 10 May 2007 (RAIB report 02/2008). The 21st wagon of an empty MGR coal train derailed on a track twist that existed within a crossover. The wagon was of the HAA type. It had an underframe that was twisted and cone packings that were incorrectly fitted. The cone packing arrangement increased the effect of the underframe twist.
- Santon, 25 January 2008 (RAIB report 10/2009). The tenth wagon of a coal train, comprising 18 loaded bogie hopper wagons, derailed on a track twist on a plain line curve. The investigation found that a nearby track lateral alignment fault had combined with the twist to increase the derailment risk.
- Barrow upon Soar, 27 December 2012 (RAIB report 22/2013). The 11th and 12th wagons on an aggregate train derailed because the embankment supporting the track failed. The train, comprising 20 loaded bogie hopper wagons, divided and the last seven overturned. Support was lost from under one of the rails as the train passed over. This resulted in a rapid cross-level change.
- Angerstein Junction, 2 April 2014 (RAIB report 11/2015). The eighth and ninth wagons on an aggregate train, comprising 20 bogie hopper wagons, derailed on a combination of track twists. The train was departing from an aggregate terminal. The investigation found evidence of diagonal wheel load imbalance due to bogie frame distortion on the first wagon to derail.

155 RAIB found several British Rail reports of historical derailments involving HAA-type wagons. One involved the derailment of a single empty wagon on a MGR coal train that was leaving Drax power station, in North Yorkshire, on 18 October 1994. The report concluded that the derailment was due to an ‘excessive track twist’ of 1 in 82, measured over the wagon wheelbase. It recorded evidence of a ‘slight’ wagon twist. Investigators found marks on the outer face of the rail to show where wheels had dropped off the railhead, but they were unable to find where the wheel flanges had crossed over the railhead. The pattern of marks that RAIB found on the up High Level line was similar (paragraph 40).

156 RSSB[36] provided freight derailment information from its safety management intelligence system covering the period March 2017 to June 2020. This recorded around 25 incidents involving MGR-derivative wagons. Nearly all these derailments occurred in yards, depots and sidings. While the detailed derailment cause is not identified in every case, it is evident that factors such as track quality, load condition and operating issues were thought to be relevant. ‘Chassis twist’ is mentioned in one incident, which suggests a concern involving diagonal wheel load imbalance. Three derailments can be identified as having occurred on a Network Rail running line. One of these is the incident at Willesden High Level Junction on 6 May 2019. Operational anomalies in engineering work sites are cited in relation to the other two.

[36] A not-for-profit company owned and funded by major stakeholders in the railway industry, which provides support and facilitation for a wide range of cross-industry initiatives. The company is registered as ‘Rail Safety and Standards Board’ but trades as ‘RSSB’.

Summary of conclusions

Immediate cause

157 There was insufficient wheel load at the leading left-hand wheel of wagon MPA 394228 to prevent the wheel flanges climbing over the outer rail of the curve on Mitre Bridge Curve embankment (paragraph 77).

Causal factors

158 The causal factors were:

a. There was no check rail on the curve where wagon MPA 394228 derailed (paragraph 82, no recommendation).

b. The track bed poorly supported the sleepers on the up High Level line and allowed the level of the left and right rails to drop by different amounts over a short period of time, thereby creating a track twist (paragraph 87). This causal factor arose due to:

   i. The loss of ballast support from under the sleepers of the up High Level line (paragraph 93, no recommendation)

   which was due to:

   ii. A known failure of the up-side slope of the Mitre Bridge Curve embankment resulting in progressive seasonal movement (paragraph 97, no recommendation).

c. There were no measures in place to reduce the risk of a significant track twist developing rapidly (paragraph 104). This causal factor arose due to a combination of the following:

   i. The teams responsible for earthwork management and for track maintenance did not identify the risk of a significant track twist developing from the information provided by Network Rail's routine track geometry inspection arrangements (paragraph 107, **Recommendations 1 and 2**).

   ii. The teams responsible for earthwork management and for track maintenance did not require that additional arrangements were put in place to monitor the movement of the track before they had been assured that the progressive seasonal movement of the embankment had ceased (paragraph 113, **Recommendation 3 and Learning point 2**).

   iii. Network Rail's routine visual and other track inspection processes did not identify the risk of a significant track twist developing (paragraph 121, **Learning point 1**).

d. Wagon MPA 394228 was operating with a diagonal wheel load imbalance that significantly reduced its ability to resist derailment on twisted track (paragraph 125). This causal factor arose due to a combination of the following:

   i. The arrangement for adjusting the suspension on MGR-derivative wagons is susceptible to introducing a diagonal wheel load imbalance, if not correctly set (paragraph 131, no recommendation).

   ii. A significant diagonal wheel load imbalance was not detected during routine wagon maintenance (paragraph 137, **Recommendation 4 and Learning point 3**).

Underlying factor

159 The low level of information sharing between the track maintenance and earthwork management teams meant there was no common understanding that the condition of Mitre Bridge Curve embankment presented a risk to the safe running of trains. This is a possible underlying factor (paragraph 147, **Learning point 2**).

Additional observations

160 Although not linked to the accident on 6 May 2019, RAIB observes that:

a. Network Rail did not repair a series of lateral track alignment faults that were detected on the up High Level line close to where the derailment occurred (paragraph 151, **Recommendation 2**).

Previous RAIB recommendations relevant to this investigation

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

Network Rail's management of existing earthworks, RAIB report 25/2008, Recommendations 2 and 5

162 The relevant elements of these recommendations read as follows:

Recommendation 2

Network Rail should review the best practice found in the following areas during this investigation and include within their procedures so that it is universally applied:

…

- *communication systems between maintenance staff and territory earthworks teams*

Recommendation 5

Network Rail should develop and implement a communications procedure between Territory Earthworks and Drainage teams and local maintenance staff to provide relevant information and allow more effective management of the earthworks risk and Safety of the Line.

163 Network Rail referred to communication and reporting processes within company standard NR/L3/TRK/1010, 'Management of responses to extreme weather conditions at structures, earthworks and other key locations', when it advised the Office of Rail and Road (ORR) of the action taken. In December 2009, ORR reported that it accepted Network Rail's response and that it would not be carrying out confirmatory inspection work.

Derailment at Barrow upon Soar, 27 December 2012, RAIB report 22/2013, Recommendation 3

164 This recommendation reads as follows:

Recommendation 3

Network Rail should amend its company standards so that when an earthwork evaluation is carried out on an embankment, the evaluation should consider how the geometry of the track on top of the embankment has changed over time, using data recorded by Network Rail's track geometry recording trains. If the evaluation has been triggered by a change in track quality, flooding or the ponding of water, and includes an assessment of the embankment's susceptibility to flooding or water action, the levels of recent rainfall onto the top of the embankment should be considered as part of the assessment.

165 In December 2014, ORR reported that Network Rail had advised that:

- it was revising NR/L2/CIV/086 to mandate a review of track performance data during earthwork evaluations (the standard was re-published as issue 4)
- the local asset management team was already using its linear asset decision support tool to review track performance data

- there were further aspirations to incorporate track performance data within a new asset management system that was being implemented.

On reviewing the information Network Rail supplied, ORR reported that it considered the recommendation to be implemented.

166 The currently-adopted version of NR/L2/CIV/086 is issue 9. The requirements for what is to be carried out during evaluations are included in a section entitled 'Earthwork examinations'. Although these include consideration of changes to track geometry, there is no reference regarding the need, or desirability, for analysing information from track geometry measurement train records to understand the significance of changes over time.

167 RAIB has made other recommendations regarding the analysis of information from track geometry measurement trains and how it could benefit track maintenance and structure asset management. These include:

- Derailment at Santon, 25 January 2008 (RAIB report 10/2009), Recommendation 4
- Derailment at Stewarton, 27 January 2009 (RAIB report 02/2010), Recommendation 10

Derailment at Angerstein Junction, 2 April 2014, RAIB report 11/2015, Recommendations 2 and 5

168 These recommendations read as follows:

Recommendation 2

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.*

Recommendation 5

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.

169 ORR updated RAIB on the implementation of recommendation 5 in June 2019. It reported that, as a result of its collaboration with the cross-industry freight derailment working group,[37] Network Rail had confirmed that reports from its wheel impact load detection equipment were being supplied to freight operating companies, including information on wheel load asymmetry. It further reported that these reports were being used to understand and manage the causes of asymmetry. While this had mainly led to changes to the way wagons are loaded, for certain types of wagons, changes relating to maintenance had also been identified. On reviewing the information supplied, ORR reported that it considered recommendation 5 to be implemented.

170 ORR updated RAIB on the implementation of recommendation 2 in December 2019. It reported that RSSB, working with the cross-industry freight derailment working group, had reviewed the risks associated with asymmetric wheel loads. Rather than specifying limits for diagonal wheel load imbalance and bogie twist in Railway Group standard GM/RT 2141,[38] relevant guidance was to be included in document GM/GN 2688 'Guidance on Designing Rail Freight Wagons for use on the GB Mainline Railway'. On reviewing the information supplied, ORR reported that it considered recommendation 2 to be implemented. GM/GN 2688 has yet to be updated.

171 DB Cargo confirmed that Network Rail was supplying reports of measurements made by its wheel impact load detector equipment, such as that at the site at Wymondley (paragraph 63). Although the focus has been the front-to-back and side-to-side imbalance due to offset payload effects, it has advised that the reports now being provided aid an understanding of the wheel load imbalance on unladen wagons. RAIB found no evidence that the data had so far informed the maintenance regime used to control diagonal wheel load imbalance on MGR-derivative wagons. However, DB Cargo has explained that it is currently working with other freight operating companies, RSSB and Network Rail on several related initiatives. They include determining how to use wheel load impact data to highlight concerns with unladen wagons and fitting special tags to help identify wagons that are deemed to be at risk.

Train collision with washed-out aggregate at Corby, 13 June 2019, RAIB report 04/2020, Recommendation 3

172 This recommendation reads as follows:

Recommendation 3

Network Rail should review, and amend as necessary, its processes for the management of earthworks, so that its staff responsible for earthworks are trained and have clear guidance on when and how to trigger appropriate monitoring and/ or other short-term mitigations. This is particularly relevant when mitigations using geotechnical instrumentation are not viable options and actions that involve other functions within Network Rail or external organisations are needed instead.

173 This recommendation is too recent for progress on its implementation to be reported.

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[37] The cross-industry freight derailment working group has recently changed its name, and is now known as the cross-industry freight derailment prevention group. The group includes representatives from Network Rail, freight operating companies, Rail Delivery Group, RSSB and rail consultancy organisations.

[38] The national technical rule relating to railway vehicle derailment resistance.

Actions reported that address factors which otherwise would have resulted in a RAIB recommendation

174 Network Rail has advised that the preparations to carry out intervention work on Mitre Bridge Curve embankment are progressing (paragraph 22). The current plan is to complete the renewal of the up-side and down-side slopes during the early part of Control Period 6 (1 April 2019 to 31 March 2024).

175 Network Rail repaired the track twist that formed on the up High Level line on 8 May 2019 (paragraph 39). In September 2019, it arranged for a stone blower to carry out mechanised track maintenance work to further correct the vertical track geometry and help consolidate the track bed (footnote 14).

Other reported actions

176 Following the derailment, the Anglia SAE(G) requested frequent recording of the movements measured by the inclinometers installed on Mitre Bridge Curve embankment and started to routinely share this information with the Tottenham TME. Track maintenance staff reported that the route asset management team has sought to make more data available on the earthworks that are being monitored on the Anglia Route. The data is being posted on an information system that track maintenance teams have access to. Network Rail has also reported that, within its ongoing research programme, it is examining the use of data from its track geometry measurement trains as a means to identify embankment issues.

177 DB Cargo has advised that it is reviewing the procedures in engineering standard DBS/ES/0081 that are concerned with the control of diagonal wheel load imbalance. It is also evaluating the use of a portable weighbridge as an alternative to the calibrated wheel jacking device.

Recommendations and learning points

Recommendations

178 The following recommendations are made:[39]

1 *The intent of this recommendation is to make best use of routinely collected track geometry information for the purpose of understanding the condition of track bed and earthwork assets and how this may affect the safe running of trains.*

Taking into account findings from its ongoing research programmes, Network Rail should investigate whether recent advances in computing techniques allow data recorded by its track geometry measurement trains to be analysed in a way that enables the identification of track movement trends that are indicative of underlying problems with the track bed and/or supporting earthworks. If reasonably practicable, it should develop and implement analysis tools and processes and make these available to engineers responsible for the management of such infrastructure assets (paragraph 158c.i).

2 *The intent of this recommendation is that the significance of incomplete measurements made by track geometry measurement trains is made visible and managed accordingly.*

Network Rail should review the arrangements it uses to alert its track maintenance teams to missing data from its track geometry measurement trains, including the reports required by NR/L2/TRK/038 and other information that is made available, and the actions they then take. It should make enhancements to its processes, instructions and guidance to address deficiencies that could impact on the safe running of trains (paragraphs 158c.i and 160a).

[39] 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 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 intent of this recommendation is to ensure the timely identification of unsafe changes in track geometry arising from known defects in supporting earthwork structures.*

Network Rail should review and update, as necessary, its processes and guidance for the management of earthwork structures such that when ongoing movement is identified in a supporting earth embankment adequate monitoring of the track is established. The frequency of the monitoring and associated alert arrangements need to be such as to allow timely action to be taken in the case of a rapid deterioration of the track geometry, in order to prevent any impact on the safe running of trains. It should also review and enhance the arrangements for the department responsible for management of earthwork structures and the department responsible for track maintenance to inform the other of the potential susceptibility and, therefore, the need for enhanced monitoring (paragraph 158c.ii).

This recommendation should be considered and implemented in conjunction with Recommendation 3 in RAIB report 04/2020, 'Train collision with washed-out aggregate, Corby, 13 June 2019'.

4 *The intent of this recommendation is to ensure that MGR-derivative wagons do not travel on the national network with unsafe diagonal wheel load imbalance*.

DB Cargo should review the effectiveness of the maintenance processes and arrangements it uses to control the diagonal wheel load imbalance of MGR-derivative wagons. It should identify and implement any necessary changes to maintain any imbalance within prescribed safe limits. Implementation of this recommendation should consider whether:

- the means of determining and adjusting the diagonal wheel load imbalance are suitable for achieving the level of control required
- wheel load measurement is necessary as part of the VIBT maintenance cycle, or at another suitable maintenance interval.

DB Cargo should share the outcome of this review with other entities in charge of maintenance via an appropriate forum, such as the Freight Technical Committee, or other suitable means of communication (paragraph 158d.ii).

Learning points

179 RAIB has identified the following learning points:[40]

1 It is important that teams responsible for routine track maintenance understand that a lack of ballast around sleeper ends and a reduced ballast shoulder could be a sign of poor track bed support, and that action may be necessary to avoid rapid development of track faults which could affect the safe running of trains (paragraph 158c.iii).

2 It is important that teams responsible for track maintenance and structure asset management maintain good contact, and openly share information, in the event that a defective supporting structure is identified that may affect the safe running of trains (paragraphs 158c.ii and 159).

3 It is important that entities in charge of maintenance have processes in place to monitor and manage the risk of diagonal wheel load imbalance on wagons that are known to have marginal resistance to derailment on twisted track (paragraph 158d.ii).

[40] 'Learning points' are intended to disseminate safety learning that is not covered by a recommendation. They are included in a report when RAIB wishes to reinforce the importance of compliance with existing safety arrangements (where RAIB has not identified management issues that justify a recommendation) and the consequences of failing to do so. They also record good practice and actions already taken by industry bodies that may have a wider application.

Appendices

Appendix A - Glossary of abbreviations and acronyms

AE(G)	Asset engineer (geotechnical)
ATME	Assistant track maintenance engineer
LiDAR	Light detection and ranging
MGR	Merry-go-round
ORR	Office of Rail and Road
RAM(B&C)	Route asset manager (buildings and civils)
SAE(G)	Senior asset engineer (geotechnical)
TME	Track maintenance engineer
TSM	Track section manager
VIBT	Vehicle inspection and brake test

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