Rail Accident Investigation Branch

Rail Accident Report

Accident involving a pantograph and the overhead line near Littleport, Cambridgeshire 5 January 2012

Report 06/2013 v2
November 2013

This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC;
- the Railways and Transport Safety Act 2003; and
- the Railways (Accident Investigation and Reporting) Regulations 2005.

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Change control	Date	Paragraph no(s).	Description of change
v2	05/11/13	Summary (first para), 10, 33,	Minor factual amendments
		A1-A16 (pages 53-57)	Addition of new addendum paragraphs

Accident involving a pantograph and the overhead line near Littleport, Cambridgeshire 5 January 2012

Contents

Summary

At 07:19 hrs on Thursday 5 January 2012, the pantograph assembly fell from the roof of a passenger train, breaking two windows on its way to the ground. The train, the 06:51 hrs service from Kings Lynn to London King's Cross, was travelling at approximately 80 mph (129 km/h), about 2 miles (3.2 km) south of Littleport, in Cambridgeshire, when the accident happened. The train stopped 1.75 miles (2.8 km) after the accident location.

One passenger received treatment for minor cuts at the site, and two others suffered minor shock but did not require medical treatment. There was extensive damage to the overhead line equipment and minor damage to the train body.

The investigation identified that the pantograph head had lost contact with, and risen above, the overhead line, resulting in the pantograph arm hitting a cantilever overhead line support structure. This impact broke the electrical insulators on which the pantograph assembly was mounted, allowing it to fall from the roof.

The pantograph head lost contact because the overhead line was deflected from its intended position due to a combination of long term movements of the overhead line support mast foundations and the force of the wind at the time of the accident.

The RAIB concluded that maintenance of the overhead line had not been carried out in accordance with Network Rail standards, meaning that the overhead line had not been adjusted to allow for long term foundation movements.

The RAIB has made two recommendations to Network Rail. They are concerned with:

- ensuring that the risk associated with the authorisation of non-compliances with maintenance standards are assessed and mitigated; and
- providing overhead line maintenance personnel with information that allows them to effectively manage overhead line alignment.

The RAIB has also identified a learning point for the railway industry concerning the possible use of polymeric or composite insulators to support pantographs.

Introduction

Preface

1 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.

2 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.

Key definitions

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

4 In this report, left and right are referenced to the direction that the train involved in the accident was travelling (from Kings Lynn towards London). This is the reverse of the convention used by Network Rail when describing overhead line alignment, where left and right is normally referenced to a view point facing away from London.

5 All mileage is measured from the zero datum at London Liverpool Street station.

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

The accident

Summary of the accident

7 At 07:19 hrs on Thursday 5 January 2012, two windows of train 1T53, the 06:51 hrs service from Kings Lynn to London King's Cross, were broken when the train's *pantograph* fell from the roof. The train was travelling at approximately 80 mph (129 km/h) and was about 2 miles (3.2 km) south of Littleport, in Cambridgeshire, when the accident happened (figure 1).

8 The train was formed of a single four-car class 365 *electric multiple unit*, operated by First Capital Connect.

9 The train's pantograph had become dewired (ie it had lost contact with the overhead line, and moved above the *contact wire*) and then hit an overhead line *cantilever structure*. This caused the pantograph assembly to become detached from the roof of the train, and to fall down onto the side of the line. As it fell, it hit two of the train windows, causing one of them to be pushed into the passenger compartment.

10 The train stopped near to the signal at Queen Adelaide crossing, where the driver reported the accident to the signaller.

11 Two passengers suffered minor shock, but did not require medical treatment. A third passenger received treatment from ambulance staff for minor cuts but did not go to hospital.

12 There was damage to the overhead line, over a distance of approximately 150 metres, which meant that train services were suspended for the rest of that day.

13 Two of the train's windows were broken. There was superficial damage to the roof and side, and extensive damage to the pantograph assembly.

Context

Location

14 The accident occurred at 74 miles 02 *chains*, on the *up line* of the route between Kings Lynn and Cambridge, 2 miles (3.2 km) south of Littleport. This line is used by trains heading towards Cambridge and London.

15 The line at the accident location is double track, consisting of an up line and a *down line*. This is a stretch of straight track, with no *points* or level crossings in the immediate vicinity. The maximum permitted speed for electric multiple units is 80 mph (129 km/h).

16 *Overhead line equipment,* of a design known as Mk3b, is installed along the line to supply electricity, at 25 kV AC, to trains. The overhead line is supported by cantilever structures, mounted on separate masts. The electrification on the route is controlled from the electrical control room at Romford.

17 The signalling at this location is controlled from the signal box at Littleport (at 75 miles 79 chains).

18 At this location, the railway track passes across an area of exposed, flat countryside on an embankment that is approximately two metres above the surrounding land (figure 2).

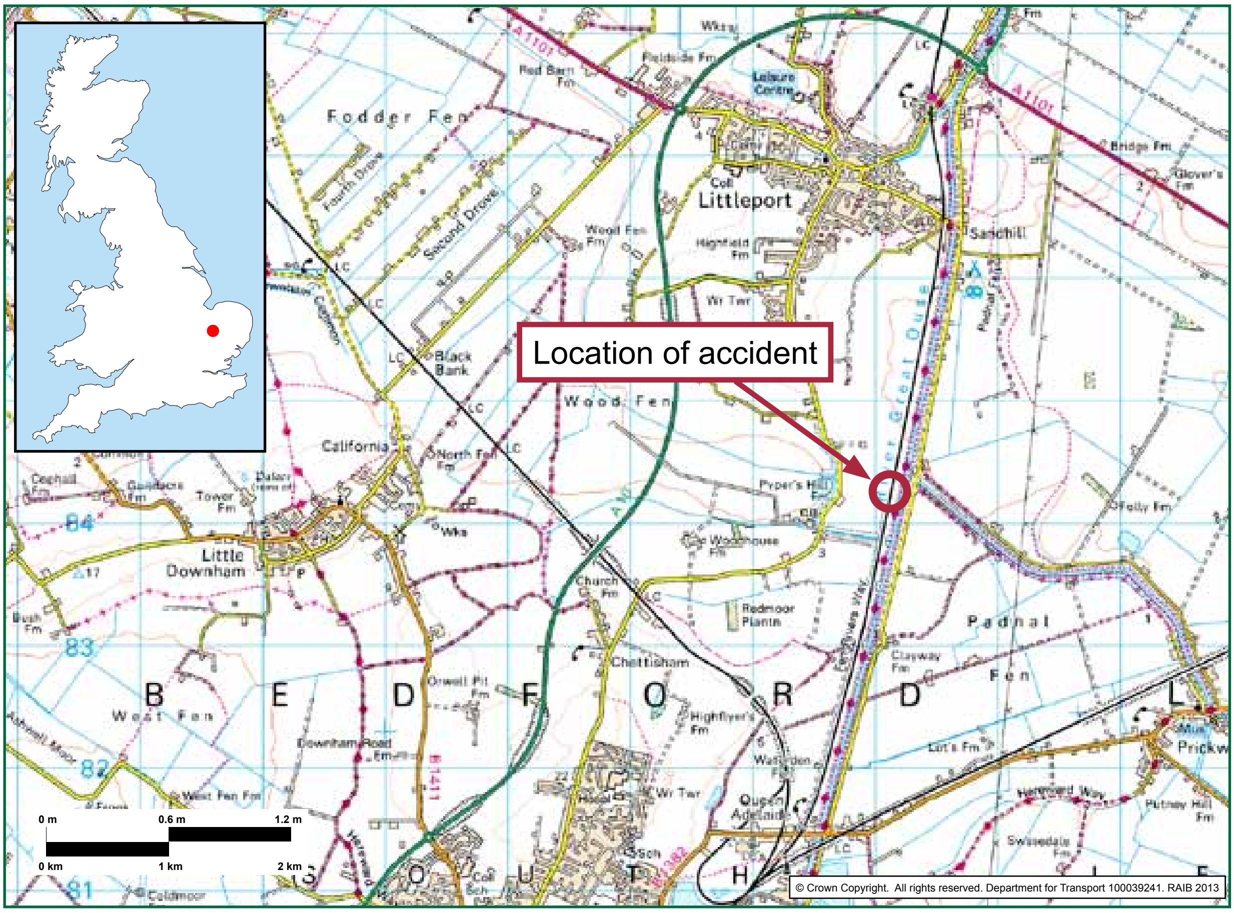


Figure 1: Extract from Ordnance Survey map showing location of accident

Figure 2: General view of accident location (Courtesy of First Capital Connect)

Organisations involved

19 Network Rail owns, operates and maintains the railway infrastructure, including the overhead line equipment. The accident location is within Network Rail's West Anglia route, and the overhead line equipment is maintained by Tottenham Maintenance Delivery Unit (MDU).

20 First Capital Connect Limited operates and maintains the train involved in the accident, and was the employer of the train driver.

21 Eversholt Rail (365) Limited leased the train to First Capital Connect Limited, and Eversholt Rail (UK) Limited acted as asset manager on its behalf.

22 Network Rail, First Capital Connect Limited and Eversholt Rail (UK) Limited freely co-operated with the RAIB's investigation.

Train involved

23 The train involved in the accident was a four-car Class 365 (Networker Express) electric multiple unit. The train was built by ABB Limited at York in 1995.

24 The train was fitted with a Brecknell Willis high-speed pantograph. Similar pantographs are fitted to most of the overhead powered electric multiple units that have entered service in the UK since the late 1980s.

25 The train was not fitted with *forward facing closed circuit television* (FFCCTV), so there was no video evidence of the overhead line and of the weather conditions at the time of the accident.

External circumstances

26 Weather data, provided to Network Rail by a contractor, shows that it was windy at the time of the accident, with the wind speed averaging around 30 mph, gusting to over 50 mph. The wind was blowing directly across the railway from the west. These records also indicate that it was not raining at the time of the accident, but that there were scattered showers in the area throughout the morning.

Events preceding the accident

27 The train departed from Kings Lynn at approximately 06:51 hrs. After calling at Watlington and Downham Market, the train stopped at Littleport, leaving there at approximately 07:16 hrs. Nothing unusual had occurred to the train up to this point.

28 The train then accelerated, reaching the maximum permitted speed of 80 mph (129 km/h) by the time it reached the accident location.

Events during the accident

29 As the train approached the accident location, the contact point between the contact wire and the pantograph moved towards the left side of the pantograph head (facing the direction of travel) and reached a position where it slipped off the left end of the pantograph head. This allowed the pantograph head to move upwards past the contact wire (figure 3), as evidenced by witness marks on the left-hand horn (the curved side of the pantograph head).

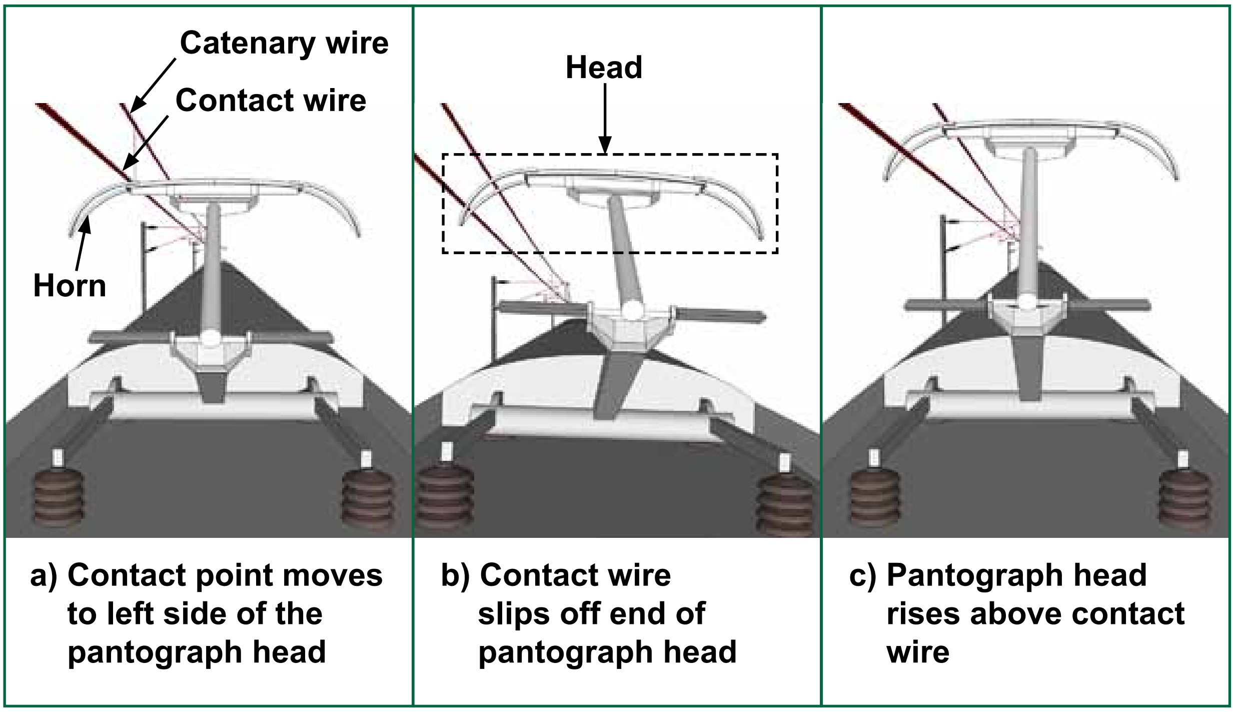


Figure 3: Illustration of process of dewirement

30 The pantograph head was now between the contact wire and the *catenary wire*. The pantograph then passed to the right of the next overhead line cantilever structure but hit the subsequent one (details, including supporting evidence, are given in paragraphs 66 to 70).

31 The impact with the cantilever structure caused the pantograph to separate from the train roof. Witness marks on the train show that the pantograph then fell from the roof towards the left side of the train, landing in the up *cess* approximately 100 metres after striking the cantilever structure (figure 4 and figure 5).

32 As it fell, the pantograph hit two of the train's side windows. This caused both windows to shatter and one of the window panes fell into the passenger compartment (figure 6 and figure 7).

Events following the accident

33 The train lost power, but the driver allowed it to coast towards Queen Adelaide crossing, about 1.75 miles (2.8 km) from the accident location, where it was stopped by a passenger operating an emergency door release handle[1]. The driver contacted the signaller after the train had stopped.

34 The passengers were evacuated from the train and walked along the track to the crossing. This had been completed by 08:50 hrs.

35 The repairs to the overhead line were hindered by the high winds at the site, but were completed by 21:00 hrs the same day.

36 The train was recovered to Hornsey depot by another electric multiple unit at 22:50 hrs, after the power had been restored.

[1] The method used to stop the train is dealt with in Addendum 1, which takes account of additional information provided by a passenger after first publication of the RAIB report into this accident.

Figure 4: Support structure hit by the pantograph, at mast C118/32 (courtesy of Network Rail)

Figure 5: Remains of the pantograph in the cess (courtesy of Network Rail)

Figure 6: External damage to the train (courtesy of First Capital Connect)

Figure 7: Window after falling into passenger area (courtesy of First Capital Connect)

The investigation

Sources of evidence

37 The following sources of evidence were used:

- weather data (from Network Rail's weather records, and from www.wunderground.com);
- Network Rail's procedures for responding to high winds;
- *MENTOR coach* data on overhead line alignment and quality;
- *measurement train* data on track alignment and quality;
- Network Rail standards for overhead line installation and maintenance;
- maintenance records for the overhead line;
- maintenance records for the train and pantograph;
- information from the on-train data recorder (OTDR);
- manufacturer's data on the pantograph and its components;
- manufacturer's testing of pantograph components;
- Railway Group Standards for train window construction and impact resistance;
- survey of dewirement incidents at other Train Operating Companies (TOCs); and
- witnesses.

38 *RSSB* provided technical assistance to the RAIB investigation, by modelling the dynamic responses of the train to high winds. This modelling was based on earlier work carried out as part of RSSB research projects[2] T689 'Determining pantograph sway limits from combined vehicle dynamic and aerodynamic effects – 2008/9' and T942 'Pantograph sway acceptance requirements and methodology - 2011'. These projects used both computer simulation[3] and wind tunnel testing to predict train behaviour in wind conditions. RSSB also provided information relating to pantograph play from BR Research Report TM VDY 045 'Dewirement Dynamics – Final Report – 1990'.

[2] http://www.rssb.co.uk/research.

[3] This used industry standard 'VAMPIRE' software for modelling the class 365 unit and its dynamic behaviour.

Key facts and analysis

Background information

Pantograph

39 The pantograph is the mechanical system mounted on the roof of a train, which is used to transmit electrical current from the overhead line to the train (figure 8). It consists of a hinged arm supporting a head assembly, into which are mounted contact strips that slide along the overhead line as the train moves. The arm is supported on the pantograph frame, which is mounted in the *pantograph well* on the train roof using four ceramic post *insulators*.

40 When in use, a mechanism pushes the head assembly upwards against the contact wire, and the entire pantograph assembly, including the arm, head and frame, is live at the supply voltage (in this case 25 kV AC). The assembly is kept electrically separate from the train by the ceramic post insulators.

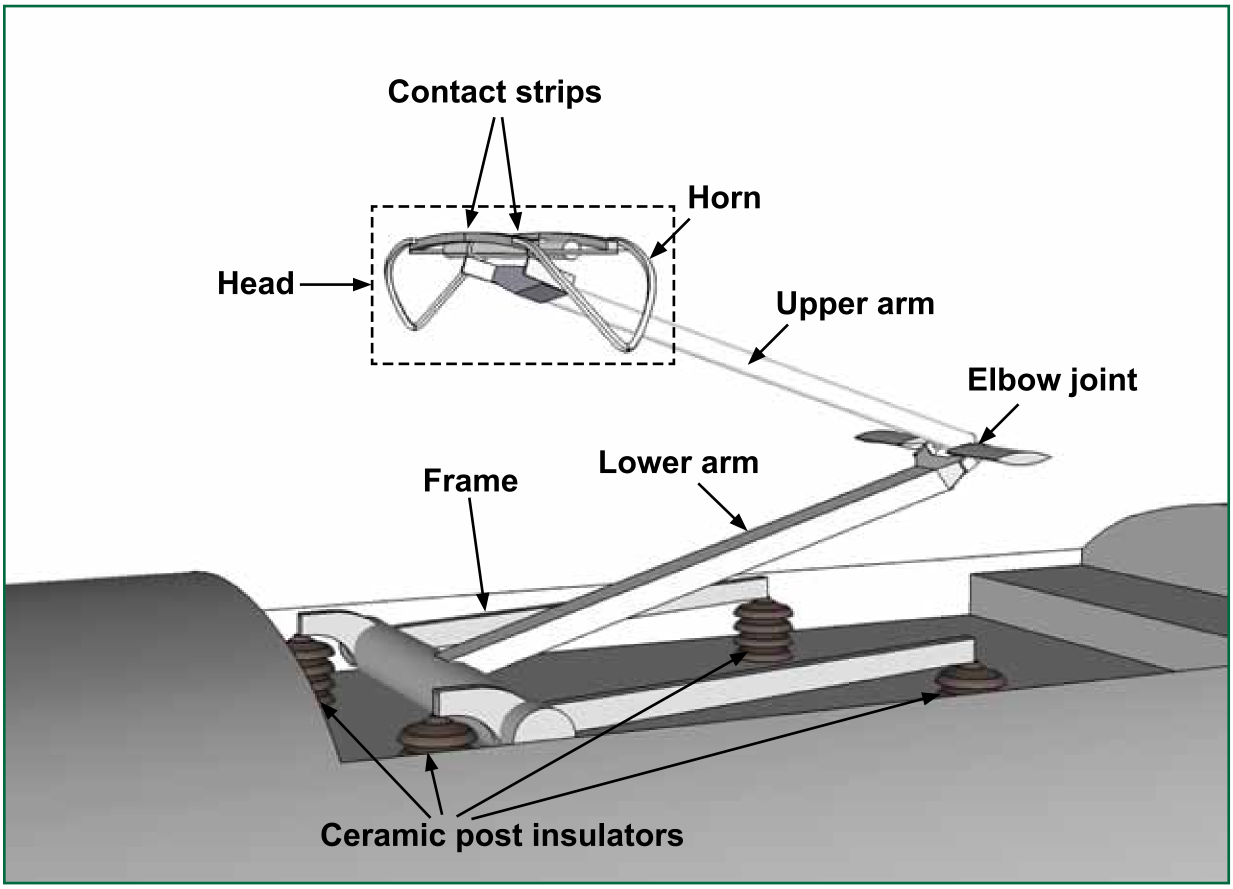


Figure 8: Illustration of train pantograph

41 If a significant impact occurs to the pantograph, it is designed to collapse by breaking internal chains which provide constraint in the elbow and base joints. This allows the pantograph arm to collapse so that it lies flat along the roof of the train. The pantograph lower arm is also designed to buckle in a controlled fashion, in order to absorb some of the energy during an impact.

42 The pantograph is fitted with an *automatic dropping device* (ADD), which incorporates an air pipe which passes along the arm and into the carbon contact strips. This is designed to allow the pantograph to lower in a controlled fashion if the pipe is ruptured. This could be caused by the pantograph head becoming detached, damage to the carbon strips, or impact damage to the arm.

43 The ADD is also activated by an overheight valve if the pantograph arm reaches its maximum permitted height (approximately 3.125 metres above the train roof).

44 When the ADD is activated there is a delay of approximately one second, as the air is exhausted from the pipe, before the pantograph lowers. The pantograph lowers at a controlled rate, taking between five and eight seconds to move from fully raised to fully lowered.

45 There is some play in the position of the pantograph head, due to inherent flexibility in the arm and at its joints. This means that, when raised, the pantograph head can deviate slightly from the central position relative to the train roof. Maintenance of the pantograph is designed to ensure that excessive play is identified and corrected. British/European standard BS EN 50206-1:2010 'Railway applications-Rolling stock-Pantographs-Characteristics and tests-Pantographs for main line vehicles' specifies that this play should not exceed 30 mm to either side of the centre position (at the pantograph head) on application of a sideways force of 300 N. This limiting value of play in the pantograph mechanism was applicable at the time of the accident.

46 Maintenance records show that the pantograph had been maintained in accordance with the manufacturer's specifications. Maintenance included a full test of the pantograph mechanism seven weeks before the accident, and an inspection, including functional testing of some components, three weeks before the accident. The test and inspection procedures require adjustments to be made to the mechanism, if they are needed to ensure that the pantograph remains within specification, but they do not require these adjustments to be recorded. Because of the damage sustained by the pantograph, it was not possible to determine its condition immediately prior to the accident.

Overhead line

47 The overhead line consists of a contact wire that is suspended from a catenary wire. The train pantograph is raised to touch the contact wire, allowing current to flow between the electrical supply substation, the overhead line and the train as it travels along the track. The current returns to the substation through the train wheels to the running rails, and then via lineside cabling, completing the circuit back to the supply. Figure 9 shows a typical overhead line mounted on lineside masts.

48 The catenary wire is held above the railway using cantilever structures mounted on masts, portals or other supporting structures. The catenary wire mechanically supports the weight of the contact wire, which is suspended from it by *dropper wires*. The contact wire is supported so that it remains relatively level above the track, to avoid disruption to the pantograph contact as trains move along the line. The catenary and contact wires are held in tension by weights at the end of each *wire run*. The *registration arm*s are used to provide sideways restraint to the contact wire at the support positions.

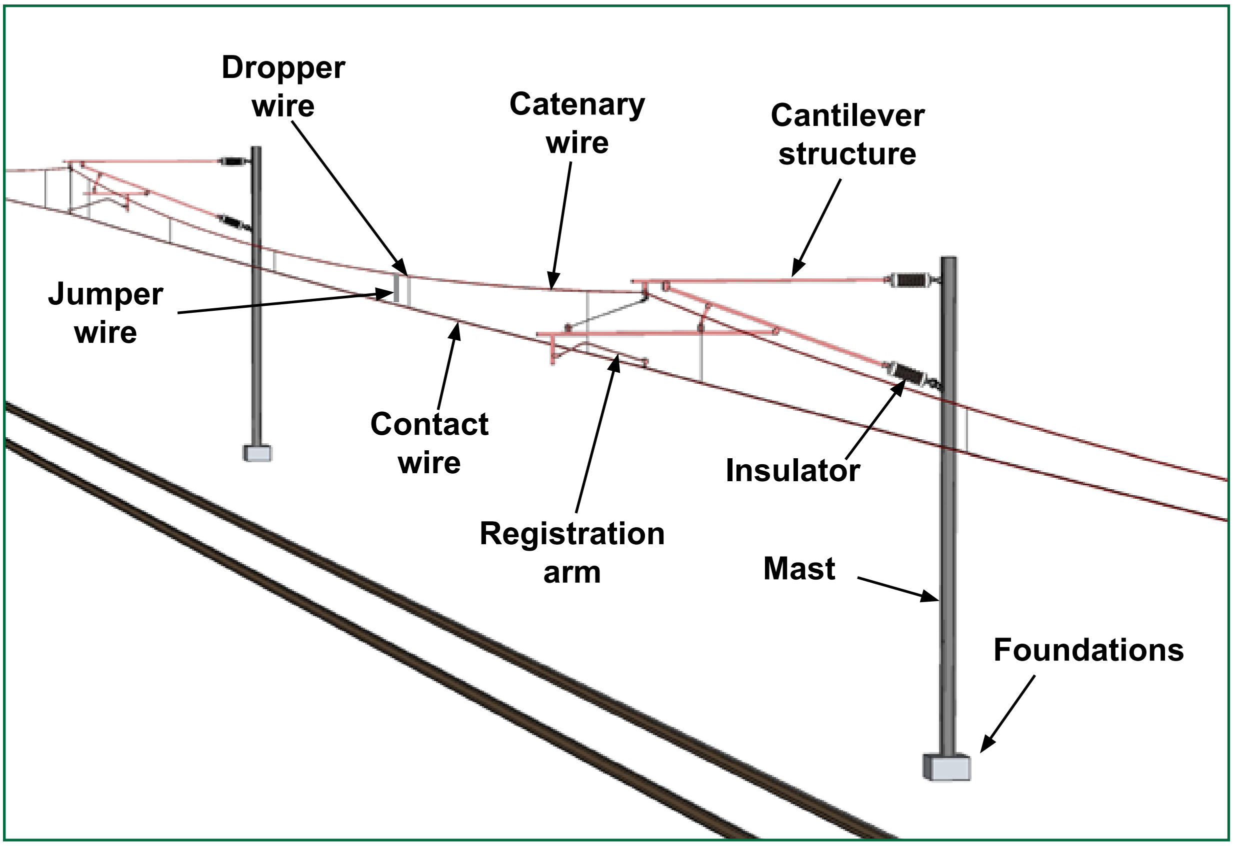


Figure 9: Illustration of overhead line detail

49 The catenary wire, the contact wire and the cantilever structure are electrically live. *Jumper wires* provide additional electrical connections between the catenary and contact wires. Electrical insulators are used to insulate the live components from the rest of the supporting structure.

50 The contact wire is aligned so that its position moves from side to side, relative to the track centre line, along the length of the line. This is known as *stagger*, and is intended to ensure that the contact position on the pantograph head moves from side to side as the train moves along the line, to spread the wear on the pantograph contact strips. Figure 10 shows the designed stagger of the overhead line at the accident location.

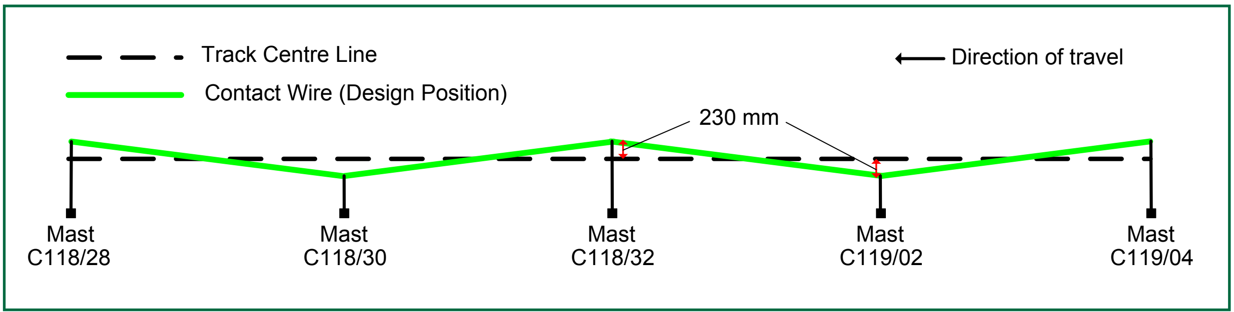


Figure 10: Overhead line designed stagger at accident location

51 At the accident location, the overhead line was supported on cantilever structures that were mounted on separate lineside masts, as shown in figure 9. The registration arms were mounted on alternating sides of the track centre line, to ensure that the contact wire stagger was maintained along the straight length of track.

Wind conditions

52 Figure 11 shows wind speed data recorded at weather stations close to Littleport, around the time of the accident, while figure 12 shows the locations of those weather stations relative to the accident site. The wind speed information is summarised in table 1.

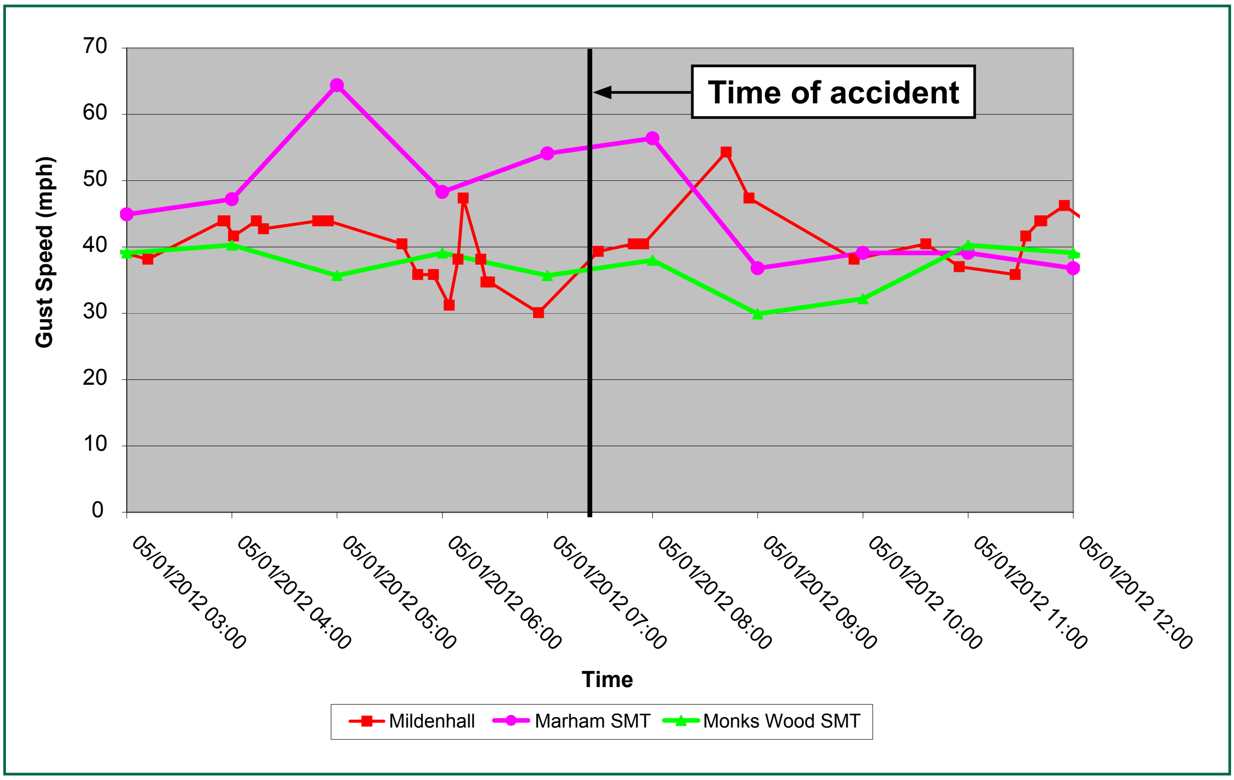


Figure 11: Wind gust speeds at weather stations

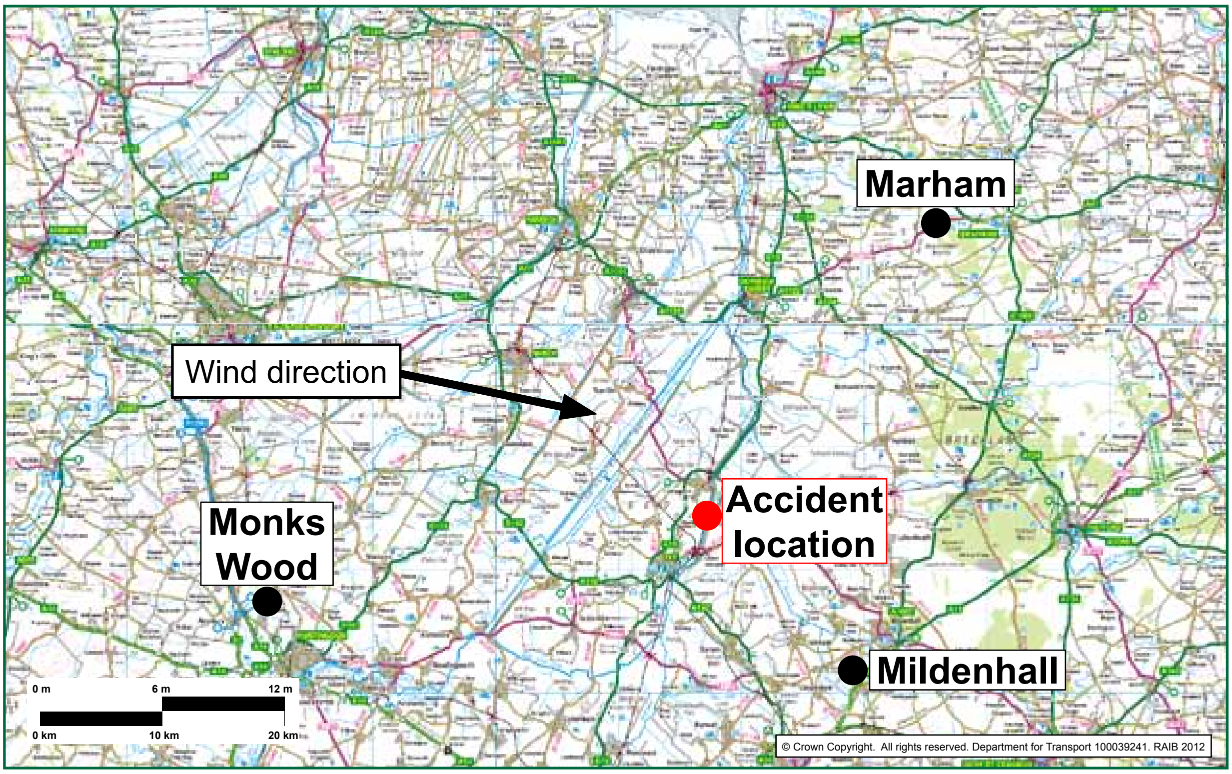


Figure 12: Locations of weather stations

Weather station	Location relative to accident	Max gust speed recorded between 07:00 hrs - 08:00 hrs*	Max gust speed recorded between 03:00 hrs - 12:00 hrs*
Mildenhall	16 km ESE	40 mph (18 m/s)	54 mph (24 m/s)
Marham	31 km NNE	56 mph (25 m/s)	64 mph (29 m/s)
Monks Wood	35 km W	38 mph (17 m/s)	40 mph (18 m/s)

Accident occurred at 07:19 hrs

Table 1: Summary of the wind gusts recorded at local weather stations

53 The maximum recorded wind gust speeds (highest gust within a 1 hour period) at nearby weather stations were between 38 mph and 56 mph (17 m/s and 25 m/s) at about the time of the accident. However, a gust speed of 64 mph (29 m/s) had been recorded at Marham between two and three hours before the accident.

54 The Marham weather station is nearer to the coast than Littleport. However, it is unlikely that this is relevant to assessing the accident wind speed because the wind was not blowing from the sea.

55 A wind gust had to be longer than three seconds for it to be recorded in the weather station data. Gust durations of less than three seconds have not been considered by the RAIB. This is because typical wind speed data (the Durst curve) given in American Society of Civil Engineers standard ASCE/SEI 7-10 (Minimum design loads for buildings and other structures) shows that the one second gust speed is typically less than 5% higher. Additionally, gusts significantly shorter than three seconds will have a more limited effect on the OLE, because they are not sustained for sufficient time for the inertia of the overhead line to be fully overcome.

56 Based on the data summarised in table 1, it is likely that a weather station at the accident location would have recorded a maximum gust speed between 38 mph and 56 mph (17 m/s and 25 m/s). Because a peak gust speed of 64 mph (29 m/s) had been recorded at Marham between two and three hours prior to the accident, the RAIB also considers it feasible that there was a gust of this magnitude.

57 Network Rail standard NR/GN/ELP/27039 'Wind loading on overhead line equipment and structures' provides a method for estimating wind speeds at the height of the overhead line by combining weather station data with allowances for the position of the track and the surrounding environment. For a track positioned on a two metre high embankment, on flat terrain, such as at the accident site, the wind speed at the OLE is considered to be 9% higher than that which would be recorded by a weather station[4].

58 Taking this factor into account, the RAIB has considered 'likely maximum' wind gusts at the overhead line of between 42 mph and 61 mph (19 m/s and 27 m/s), and a 'feasible' gust of 70 mph (31 m/s).

[4] Localised increases in wind speeds where the railway is located on embankments are explained in more detail in the RAIB report on the detachment of containers from freight wagons that occurred on 1 March 2008 near Cheddington and Hardendale (RAIB report 12/2009).

Network Rail's weather management processes

59 Network Rail defines the actions required during extreme weather conditions in standard NR/L3/OCS/043/7.1 'National Control Instructions and Approved Code of Practice - Section 7.1 Weather Management'.

60 These instructions require speed restrictions to be imposed if high wind conditions are forecast. The wind conditions and actions required are shown in table 2.

Weather Alert Category (provided in weather forecast)	Forecast Wind Speed (corresponding to weather station data – Table 1)	Action Required
Wind 1	Forecast of gusts up to 59 mph	No action
Wind 2	Forecast of gusts from 60 mph to 69 mph (Not sustained)	Be aware of the possibility of 'Wind 3' being reached
Wind 3	Forecast of frequent* gusts from 60 to 69 mph (sustained over 4 hours)	50 mph speed restriction for all trains in the affected Weather Forecast Area
Wind 3	Forecast gusts 70 mph or over	50 mph speed restriction for all trains in the affected Weather Forecast Area
Wind 3	Gusts 90 mph or over	All services suspended in the affected Weather Forecast Area

*** Frequent is defined as winds/gusts reaching the determined speed at least once every 10 minutes.**

Table 2: Network Rail wind management actions (simplified from NR/L3/OCS/043/7.1)

61 The forecast for Network Rail's Anglia route (which encompasses the West Anglia route) for the early hours of 5 January 2012 was for peak gusts of 50 to 60 mph. The weather alert category in the forecast was 'Wind 1'. This forecast meant that, according to its company standards, Network Rail did not need to implement any operational restrictions on this line on that day. The measured wind speeds at nearby weather stations at the time of the accident were also less than those that, if forecast, would have triggered operational restrictions.

Identification of the immediate cause[5]

62 **The immediate cause of the accident was that the pantograph became detached from the train roof, impacting the train windows as it fell to the ground.**

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

Identification of causal factors[6]

63 The accident occurred due to a combination of the following causal and underlying factors:

- the pantograph assembly detached from the roof because of an impact with a cantilever structure, the fracturing of the insulators connecting the pantograph to the train, and the subsequent entanglement of the pantograph in the overhead line (paragraphs 64 and 76);
- the pantograph hit the cantilever structure because it became dewired (paragraph 91);
- the dewirement was caused by the overhead line being deflected from its intended position due to a combination of mast foundation movement and wind (paragraphs 91 and 120);
- the overhead line alignment had not been maintained (paragraphs 127 and 131);
- maintenance limits for the overhead line were inconsistent and not clearly understood (paragraph 140); and
- the train window entered the passenger compartment because of an impact from the pantograph assembly (paragraph 82).

64 **The pantograph insulators broke so that the pantograph became detached from the train.**

65 The RAIB examined the damage to both the pantograph and the overhead line equipment. This, in conjunction with photographic evidence of where the damaged components came to rest, allowed the RAIB to develop a likely sequence of events that led to the dewirement and detachment of the pantograph (figures 13, 14 and 15).

Likely sequence of events

66 The pantograph became dewired to the right of the contact wire (figure 14a), between electrification mast numbers C119/04 and C119/02.

67 The pantograph head moved into the gap between the contact wire and the catenary wire, and broke a dropper wire as the train moved towards electrification mast C119/02 (figure 14b).

68 At mast C119/02, the overhead line was supported from the left, while the pantograph arm was positioned to the right of the contact wire. The pantograph head passed this mast without hitting any of the cantilever structure (figure 14c).

69 The pantograph head, still between the contact and catenary wires, hit the first dropper wire after mast C119/02 (figure 14d). Adjacent to this dropper wire was a jumper wire, which had a much bigger cross section (it was designed to make a good electrical connection between the catenary and contact wires, rather than to provide mechanical support). It is likely that the pantograph head became detached from the arm as a result of hitting the jumper wire. The next five dropper wires, up to mast C118/32, remained intact as the pantograph arm passed to the right of them.

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

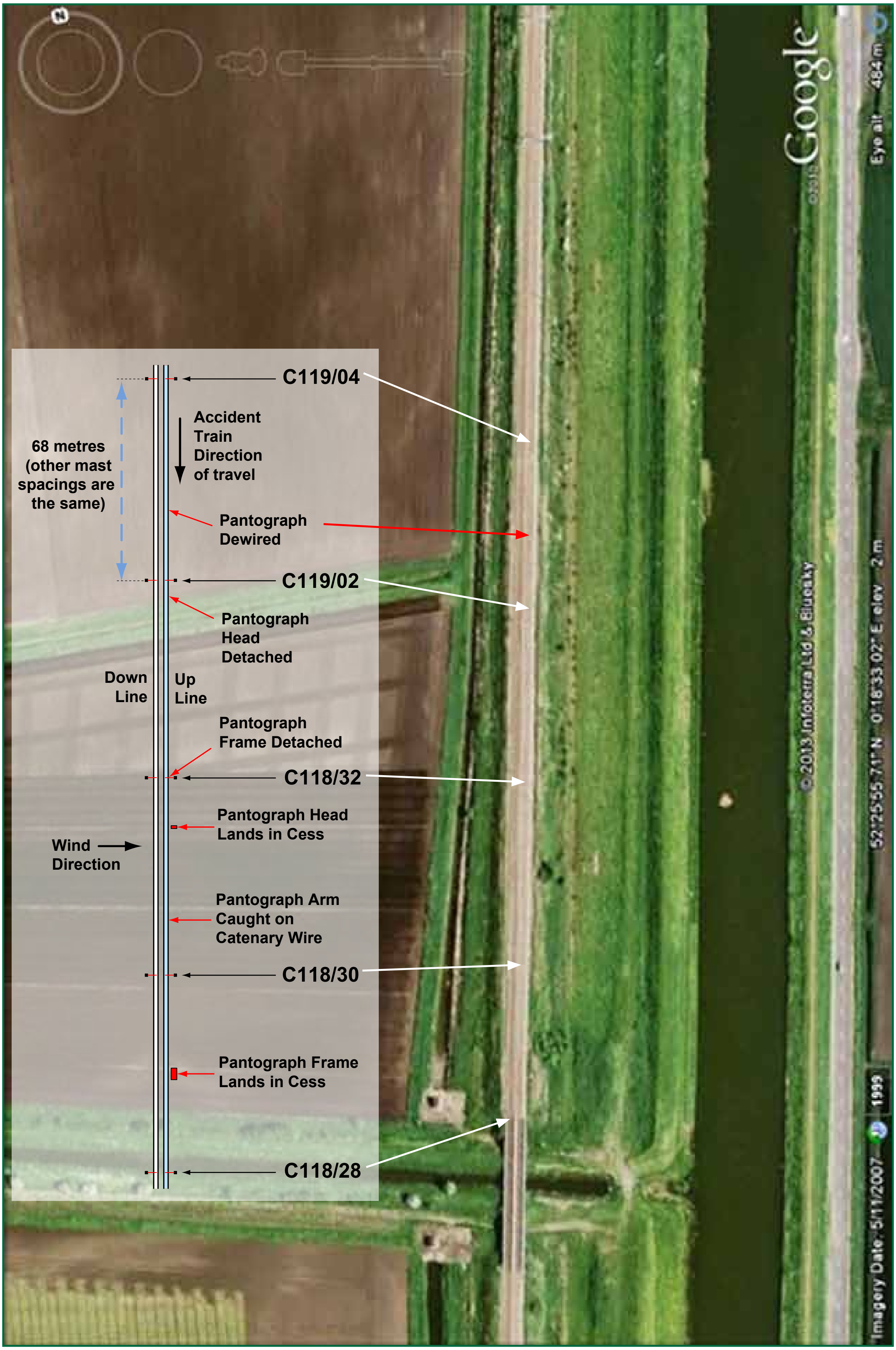


Figure 13: Overview of the accident location

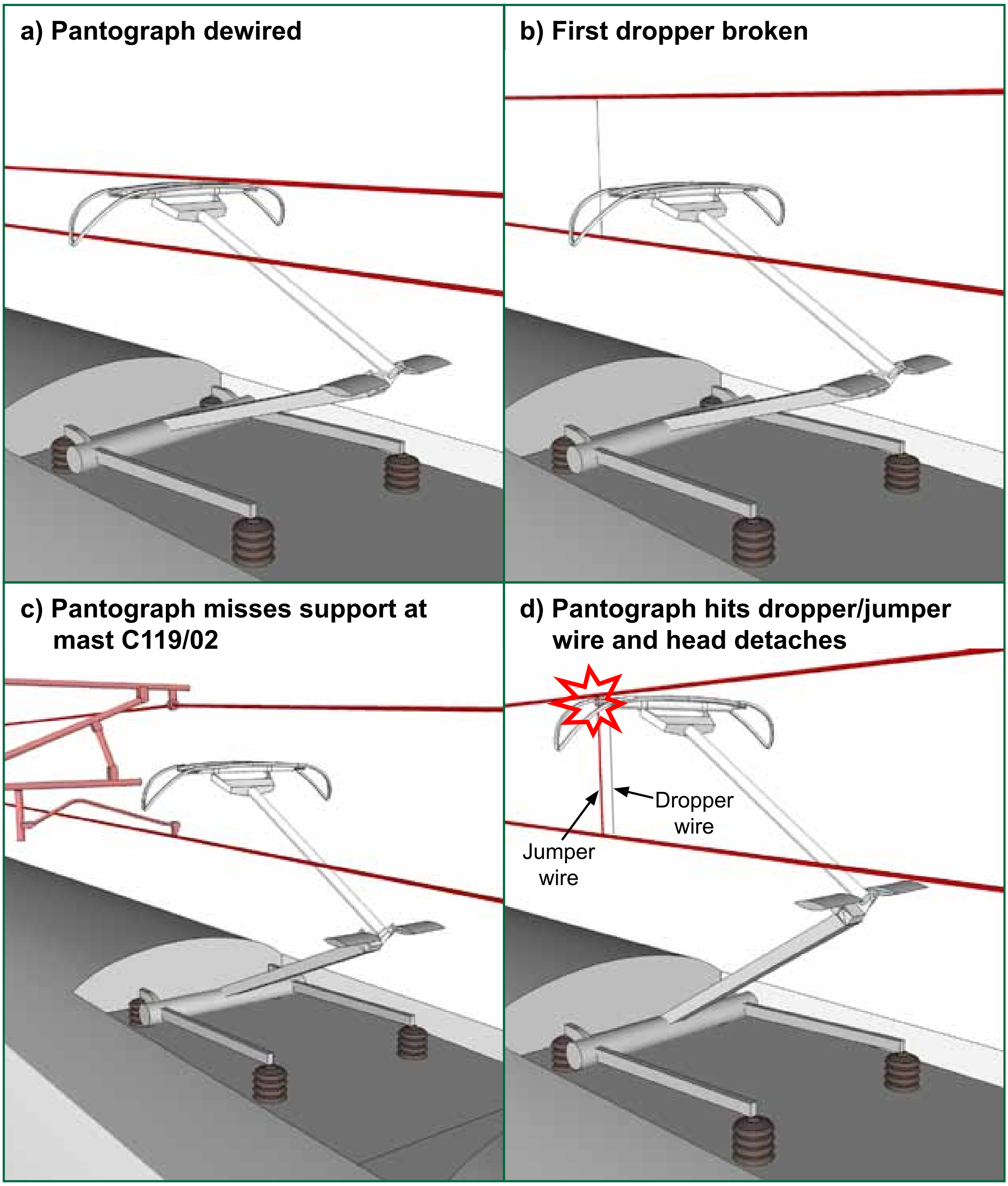


Figure 14: Illustration of pantograph failure sequence

70 At mast C118/32, the overhead line was supported from the right side, meaning that the cantilever structure was hit by the pantograph arm, which was still positioned to the right of the contact wire (figure 15a).

71 On detachment of the pantograph head (paragraph 69), the ADD would have been activated. However, the RAIB estimates that lowering of the pantograph would have taken at least 4 seconds from the height of the catenary wire, which is the highest point at which the head could have detached (paragraph 44). As the train was travelling at 80 mph (129 km/h), it would have taken less than 2 seconds to reach mast C118/32 after the head became detached. As a result the pantograph would not have had time to lower sufficiently to avoid hitting the overhead line supports at mast C118/32. In addition, the pantograph overheight system would not have been activated because the pantograph head was constrained by the catenary wire above, preventing the arm from reaching full height until after the ADD had been activated.

72 As a result of the impact at mast C118/32, the pantograph arm buckled, the constraint chains in the pantograph joints broke, and the pantograph started to collapse, all as designed. In addition, the four ceramic post insulators on which the pantograph frame was mounted broke, meaning that the pantograph assembly was no longer secure on the train roof. However, the pantograph assembly remained in position in the pantograph well (paragraph 39).

73 The ceramic post insulators are secured to the train using a metal collar that is bolted to the train roof. All four of the insulators broke just above the collar. Because there was no deformation of the metal collars, it is likely that the insulators suffered a sudden impact loading, leading to the failure.

74 Data sheets for the insulators showed that each is designed to withstand a static sideways loading of approximately 10 kN. Test data from the pantograph manufacturer showed that the insulators broke on application of a static sideways loading of approximately 14 kN.

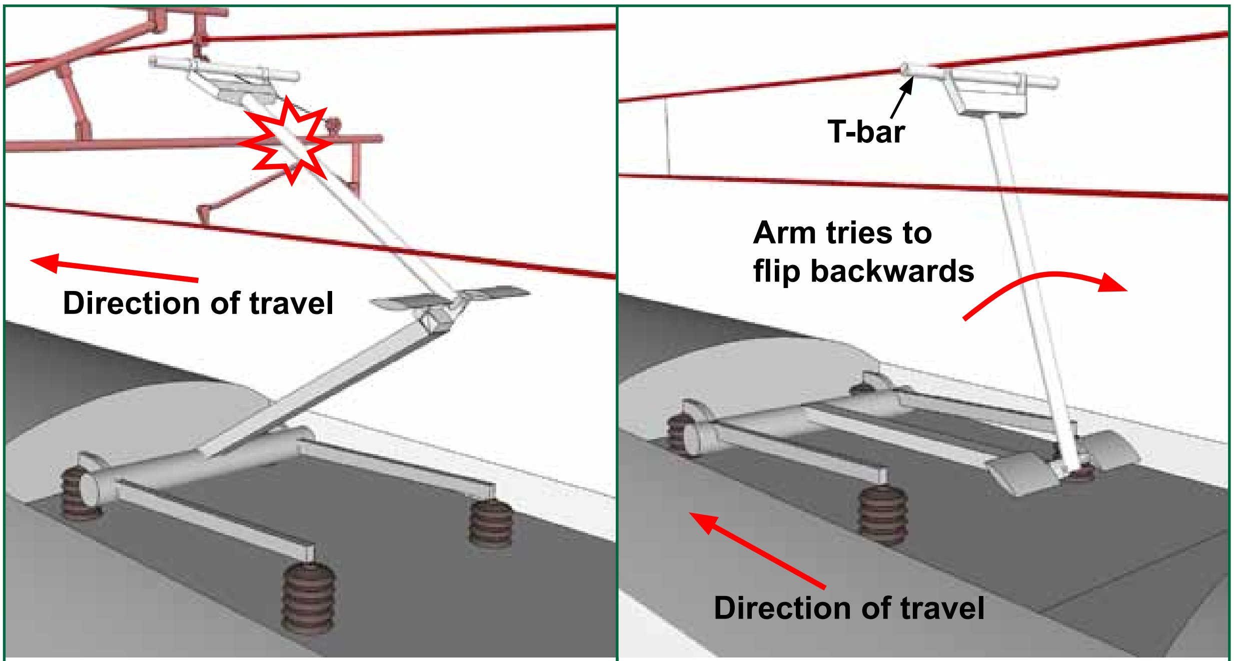
75 The pantograph assembly, which weighs around 225 kg, was travelling at 80 mph (129 km/h) when it hit the cantilever structure at mast C118/32. This would have resulted in a sudden large impact loading. RAIB calculations have shown that an impact load in excess of that required to break each of the insulators was likely to have resulted from the collision between the pantograph and the cantilever structure. The pantograph manufacturer also considered that it was possible that such an impact loading would cause the insulators to break.

76 **External forces from the wind, train movement and contact with the overhead line pushed the pantograph assembly off the roof of the train.**

77 Although the pantograph arm hit the cantilever structure at mast C118/32 and became detached from the train roof, it initially remained within the pantograph well (paragraph 72).

78 When the pantograph arm collapsed, aerodynamic forces from the forward movement of the train, as well as friction forces as the upper arm was dragged along the underside of the catenary wire, would have acted to try and flip the upper arm backwards. However, because the pantograph T-bar was below the catenary wire, and there was insufficient space between the roof of the train and the catenary wire, the upper arm was unable to flip backwards (figure 15b).

79 Because it was constrained vertically, the T-bar was pushed along the underside of the catenary wire as the train continued to move at 80 mph (129 km/h). This resulted in the T-bar breaking a number of dropper wires after mast C118/32. The catenary wire was also damaged by the T-bar dragging along it.



a) Pantograph impact at mast C118/32

b) Pantograph collapse constrained by catenary wire

Figure 15: Illustration of pantograph failure sequence (continued)

80 As the T-bar dragged along the catenary wire, it was still attempting to flip over backwards. It is likely that the forces involved in this resulted in the upper arm bending sideways.

81 The RAIB has not established the exact sequence of events which then dislodged the pantograph from the well and pushed it off the roof towards the left-hand side of the train. It is probable that this was a consequence of interaction between some, or all, of the following:

- forces associated with the interaction of the T-bar with the overhead line, that resulted in bending of the pantograph upper arm;
- a sideways force to the left on the whole pantograph assembly resulting from the high winds blowing across the path of the train;
- a backwards force on the whole pantograph assembly resulting from the relative air movement as the train moved forwards at 80 mph (129 km/h); and
- forces associated with the lateral sway of the train.

82 The window was forced into the train by impacts from the pantograph assembly.

83 The pantograph was mounted towards the rear of the second coach of the train. Scrape marks on the train roof show it was displaced onto the roof of the third coach, before falling down the left side. As the pantograph fell, it impacted the left side of the third coach several times. This caused scrape marks to the coach bodywork, showing that the pantograph was moving backwards relative to the moving train. There were signs of impact on the frames and panes of the sixth and seventh windows (out of nine) on the left side of the third coach. These impacts resulted in the pane of the sixth window falling onto the adjacent table inside the coach (figure 7).

84 Railway Group Standard GM/RT2100 Issue 4 'Requirements for Rail Vehicle Structures' defines impact tests for windows in modern trains and was current at the time of the accident. This standard was not in place when the class 365 units were manufactured, but standard GM/TT0122 'Structural Requirements for Windscreens and Windows on Railway Vehicles' was applicable at that time.

85 The tests in GM/RT2100 are used to determine the performance of the window in resisting penetration by missiles from outside, and in containment of people and objects within the train. Both of these tests include firing a spherical object at the centre of a window pane from a position outside the train. Table 3 shows the requirements of these tests, including the kinetic energy applied to the window panes from the outside. At the time the train was manufactured, the requirement for missile penetration in GM/TT0122 was identical to that in GM/RT2100 for the type of glass that was fitted to the train at the time of the accident, but there was no requirement for passenger containment.

86 The window strength requirements in GM/RT2100 are only directly applicable to impacts that occur perpendicular to the centre of a pane. They do not apply to impacts to the window frame, or to glazing bars between panes, as occurred at Littleport.

Test	**Projectile Weight**	**Projectile Speed**	**Kinetic Energy Applied**	**Relevant Standards**
Missile penetration	0.25 kg	100 km/h	96 Joules	GM/RT2100 (current) GM/TT0122 (superseded)
Passenger Containment	5 kg	34 km/h	223 Joules	GM/RT2100 (current)

Table 3: Window impact tests

87 The weight of the pantograph assembly was approximately 225 kg, including the insulators. For a moving mass of 225 kg to have the same kinetic energy as that applied in the missile penetration test, it would have to be moving at 3.3 km/h perpendicular to the centre of the window. Similarly for a kinetic energy equivalent to that applied in the passenger containment test, the assembly would have to be moving at 5.1 km/h.

88 This suggests that if a spherical object of the same mass as the pantograph assembly had hit the centre of the window, moving in a perpendicular direction, at a speed of up to 3.3 km/h (or 5.1 km/h for the latest rolling stock), the window should have remained in situ and relatively intact. It is not possible to determine the exact nature of the impact of the pantograph, or the kinetic energy available during it, because the pantograph has a much more irregular profile than a sphere, and it would have been falling, and possibly rotating, past the window. In addition, the train was travelling forwards at 80 mph (129 km/h), and possibly swaying, as the pantograph fell.

89 However, it is very probable that the impact from the pantograph included a perpendicular component exceeding the resistance required to satisfy the missile penetration and passenger containment standards. There was no evidence of a pre-existing defect in the window. It is certain that the impact also included substantial components parallel to the window in the downward and backward directions.

90 Examination of the window frames showed impacts to the lower frame of the main window pane, and to the glazing bar between the main pane and the opening pane (figure 7). The distortion of these frame components would have weakened the window support, and thus facilitated the window being pushed into the passenger compartment. On this type of train, the windows were mounted from the inside. On most modern designs of train the windows are mounted from the outside, and inherently have a greater push-in resistance.

91 The pantograph became dewired allowing the pantograph head to move above the contact wire, and the pantograph arm to hit a cantilever structure.

92 The train's pantograph became dewired between masts C119/04 and C119/02 (the location at which the first dropper wires were broken). This was as a result of the wire moving off the left-hand end of the pantograph head, as indicated by wire marks on the left-hand horn.

93 The position of the overhead line relative to the pantograph head was affected by a combination of the following:

- the static offset of the overhead line above the track (paragraph 94);
- the overhead line moving from its static position due to the wind (paragraph 96);
- sideways play in the pantograph mechanism (paragraph 99); and
- the pantograph moving laterally as the train swayed, due to its movement along the track and the wind conditions (paragraph 100).

Analysis with the worst case combination of probable values

94 Extrapolation of site measurements taken by Network Rail between 2007 and 2011 (paragraph 126) indicates that movement of mast foundations had caused the contact wire to be offset by approximately 230 mm from the track centre at the mid-span between masts C119/04 and C119/02.

95 The design drawings for the overhead line showed that the mid-span position of the overhead line was intended to be directly above the track centre line (figure 16).

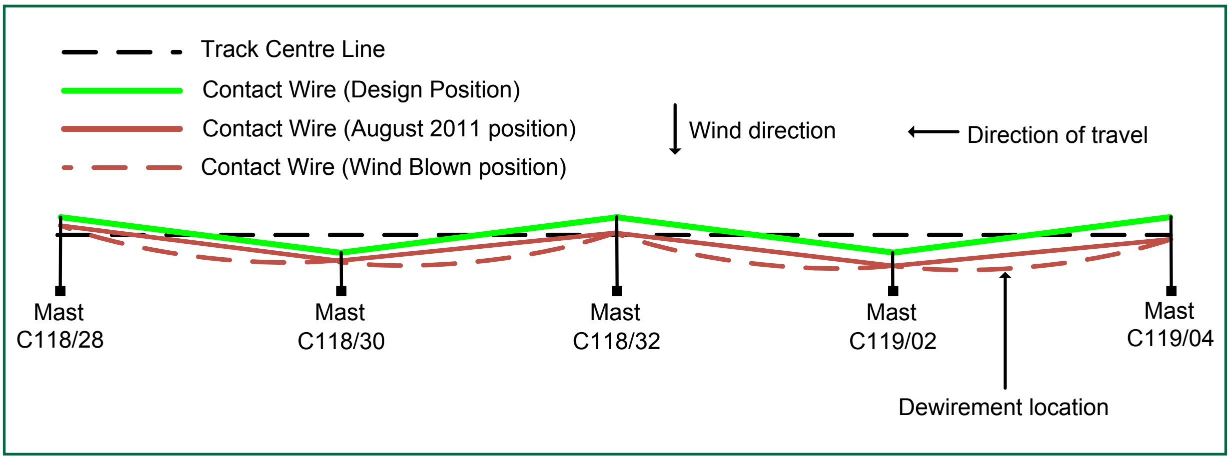


Figure 16: Overhead line alignment at accident location (plan view not to scale)

96 Network Rail standard NR/L2/ELP/27214 'Maintenance of Mk3b overhead line equipment' provides tables giving the expected *wind deviation* of the overhead line in response to side winds, assuming the wire supports remain stationary (figure 17). This deviation incorporates both *blow-off* at the mid-span position and an additional component called '*stagger effect*' (required because the maximum deviation does not occur at the mid-span position if the overhead line is not parallel with the track - figure 18).

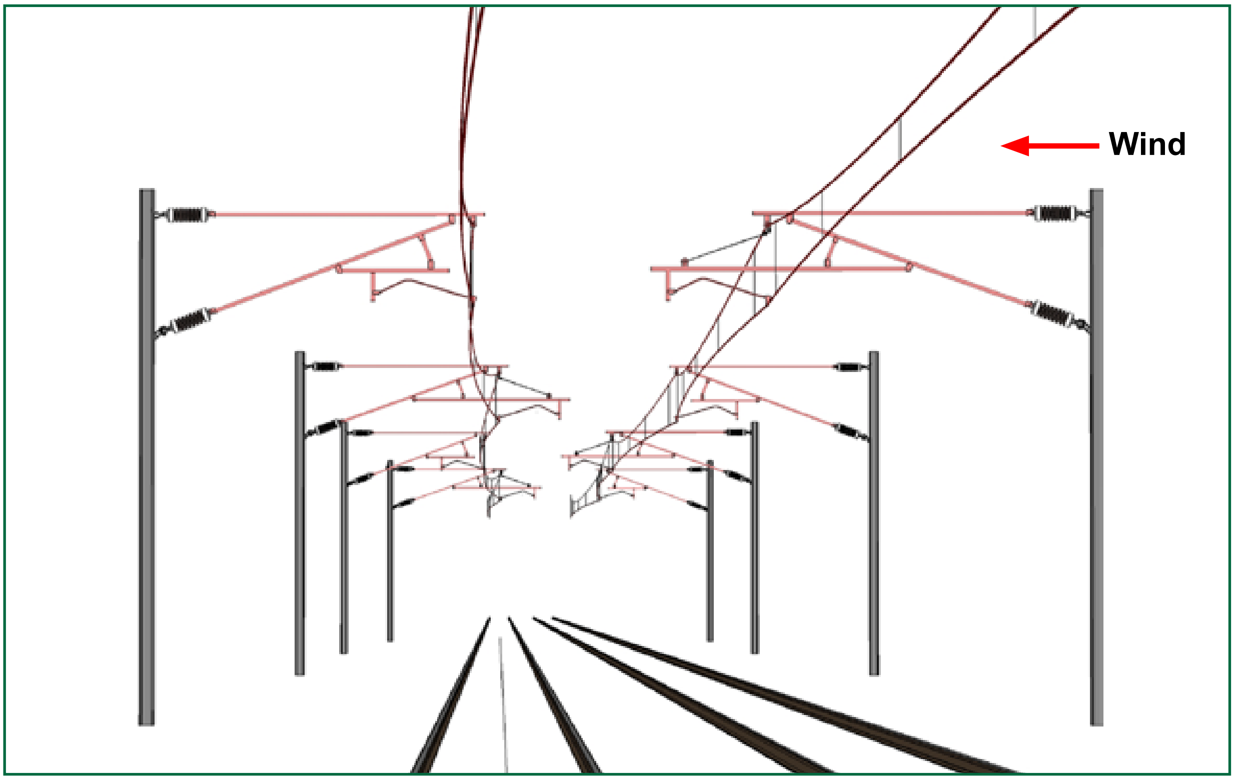


Figure 17: Illustration of overhead line in side wind conditions

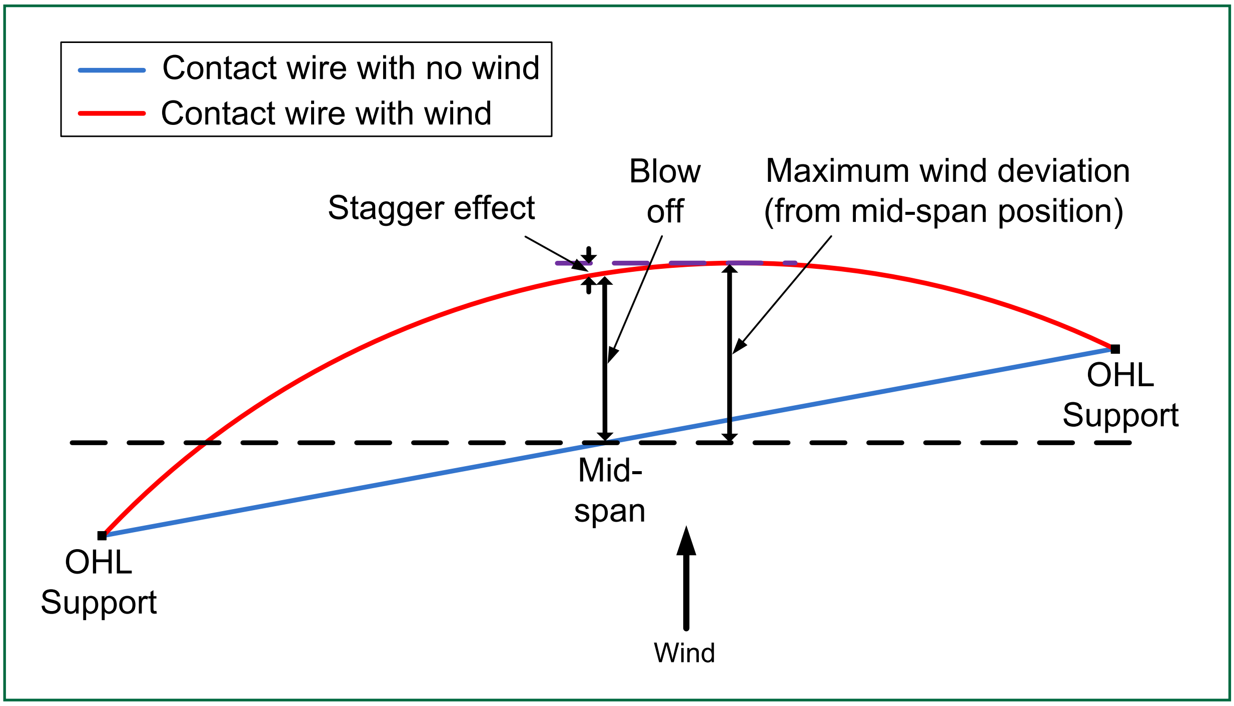


Figure 18: Illustration of wind deviation terminology

97 The tables indicate that for the lower and upper end of the likely wind speed range at the contact wire (42 mph and 61 mph (19 m/s and 27 m/s) – paragraph 58), the wire deviation would be 174 mm and 266 mm respectively.

98 The masts supporting the overhead line deflect due to wind loading on the wires and wind acting directly on the masts. Network Rail standard NR/GN/ELP/27039 'Wind loading on overhead line equipment and structures' provides a methodology for calculating the wind loading on the wires and on the masts. The RAIB has used this methodology to calculate the wind loading on the masts, and has calculated that the resulting mast movements would cause the span between masts C119/04 and C119/02 to move 9 mm at the lower end of the likely gust speed range (41 mph), and 19 mm at the upper end (61 mph). Network Rail standard NR/SP/ELP/27215 'Instruction for design of overhead line structures' requires that the resulting mast deflection does not cause more than 50 mm of contact wire lateral movement at the *design wind speed* at the contact wire (56 mph (25 m/s) at the accident location).

99 Any sideways play in the pantograph mechanism could result in the pantograph head moving from its centre position, in either direction, due to both the wind and the movement of the train. RAIB and RSSB analysis of data from BR Research Report TM VDY 045 (paragraph 38) indicated that the dynamic play was likely to reach 15 mm at the lower end of the likely gust speed range (41 mph), and 22 mm at the upper end (61 mph), which was compliant with the requirements of BS EN 50206-1:2010 (paragraph 45).

100 Track movements due to ground movement, or maintenance (such as track relaying or tamping) can also contribute to changes in the position of the overhead line relative to the track centre line. However, there is no evidence of significant recent movements relative to the mast foundations. It should be noted that all monitoring of the contact wire position was carried out relative to the track and thus takes account of any track movements (paragraphs 94 and 126).

101 Research projects, undertaken by RSSB before the accident, modelled the dynamic response of class 365 electric multiple units (paragraph 38). After the accident, RSSB used these models to evaluate pantograph movement due to train sway, taking account of the wind conditions, the track geometry and the train speed applicable at the accident location.

102 The post-accident modelling considered two scenarios with winds gusting to 37 mph and 55 mph (16 m/s and 25 m/s), similar to the likely wind range at the accident location (paragraph 56). The modelling showed that the train swayed about a mean position on the down-wind side of the track centre line (figure 19).

103 The RAIB has used the RSSB modelling data to assess the approximate mean sway and the approximate amount of oscillation at the pantograph head for a lightly loaded train with a pantograph height of 4.96 metres (the accident situation) in the likely range of wind speeds. A mean sway of 72 mm, with an oscillation of 37 mm each side, was obtained for the lower end of the range (42 mph gust at contact wire height). Corresponding values of 111 mm and 39 mm were obtained for the upper end of the range (61 mph gust at contact wire height).

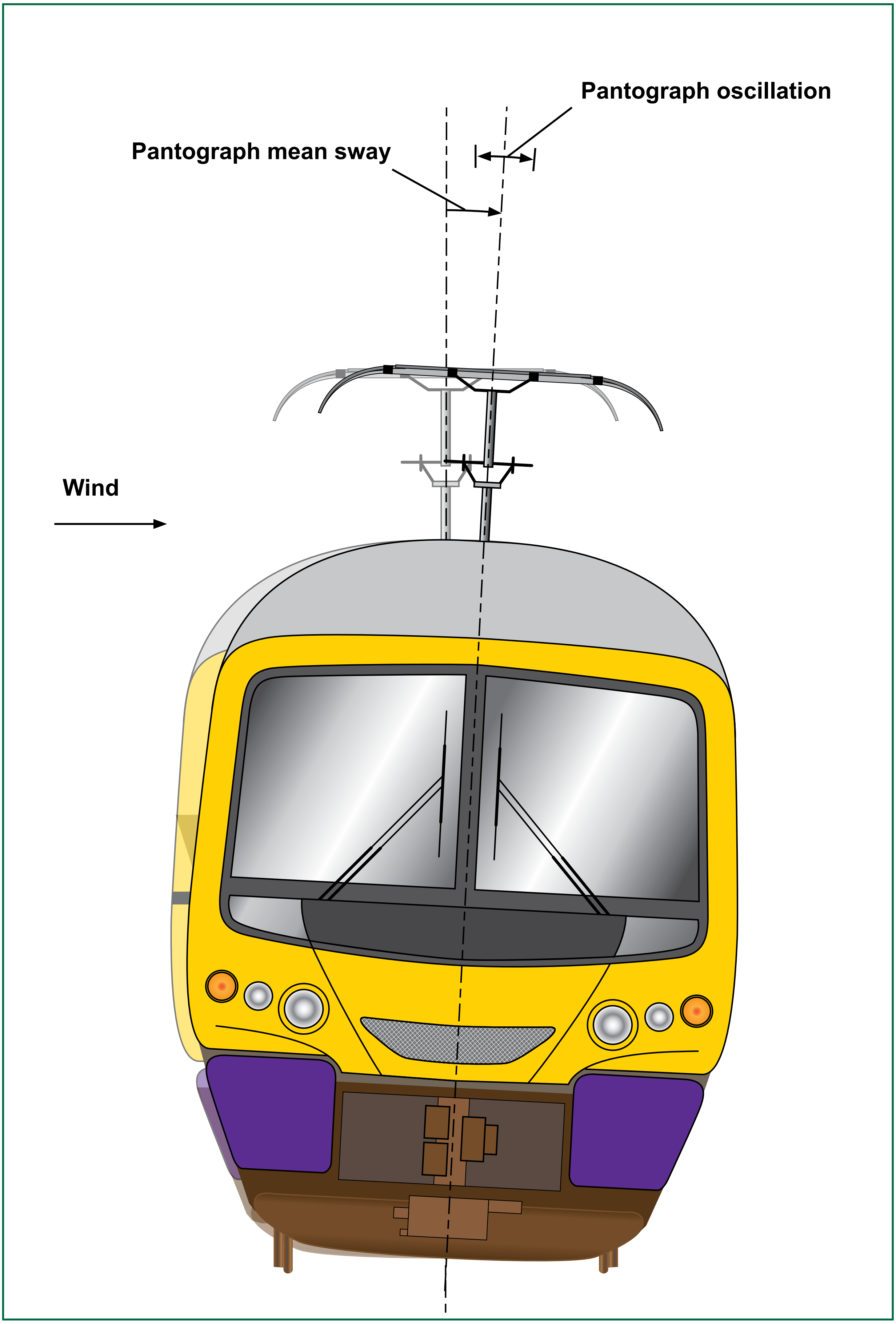


Figure 19: Illustration of train sway

104 The calculated sway values lie within limits given by Railway Group Standard GM/RT2149 ‘Requirements for defining and maintaining the size of railway vehicles’. This standard allows a maximum pantograph deviation from track centre of 190 mm at 4.3 metres contact wire height and a wind speed of 35 m/s (78 mph). This corresponds to a maximum pantograph deviation of approximately 220 mm at the contact wire height of 4.96 metres (recorded by the *new measurement train* at the accident site in November 2011). This maximum value allows for the effects of the *canted track* provided at some curves.

105 Table 4 and figure 20 summarise the characteristics which affect the contact position of the overhead line on the pantograph at the wind speeds of interest. Positive values indicate movements in the direction tending to cause dewirement. Oscillating values (eg pantograph play) are shown in the configuration most likely to cause dewirement.

Condition	**Lower end of likely range during the accident**	**Upper end of likely range during the accident**	**Feasible gust (paragraph 112)**
Gust speed at contact wire	42 mph (19 m/s)	61 mph (27 m/s)	70 mph (31 m/s)
Gust speed at weather station	38 mph (17 m/s)	56 mph (25 m/s)	64 mph (28 m/s)
Static wire offset	230 mm	230 mm	230 mm
Wind deviation of contact wire	174 mm	266 mm	333 mm
Mast deflection	9 mm	19 mm	25 mm
Pantograph play	15 mm	22 mm	25 mm
Pantograph mean sway	-72 mm	-111 mm	-131 mm
Pantograph oscillation	37 mm	39 mm	40 mm
Distance of contact wire from pantograph centre line	393 mm	465 mm	522 mm

Table 4: Summary of the most adverse possible wire/pantograph movements

106 This shows that, if the most adverse effects occur simultaneously, the contact wire could deviate up to 465 mm from the centre of the pantograph during the maximum likely gust speed at the time of the accident. However a higher deviation would be possible in the presence of the feasible gusts (paragraph 112).

107 The pantograph head is curved downwards towards the ends, to allow the contact wire to run on and off the pantograph as the train passes the ends of wire runs and locations where adjacent lines converge and cross. It also has an upwards force applied to it to keep it in contact with the overhead line (paragraph 40). Because of this the pantograph will push up past the contact wire, and dewirement will occur, if the wire moves too far from the centre line of the pantograph head.

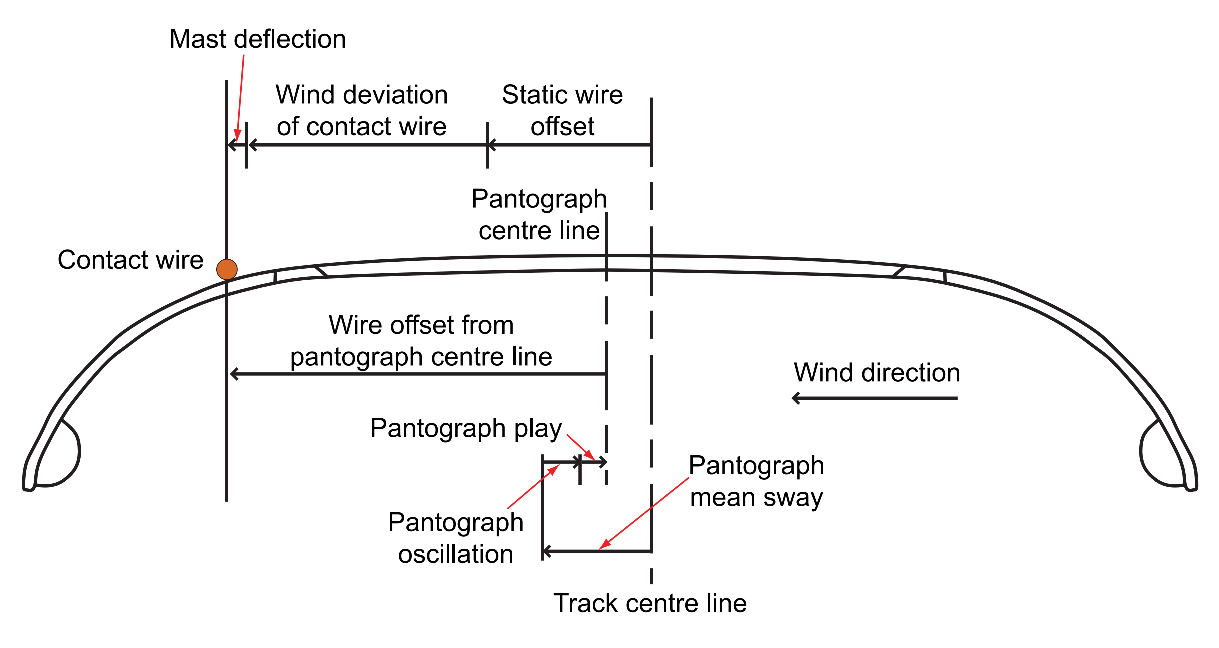


Figure 20: Pantograph head profile showing the factors affecting the contact wire position

108 RSSB research project T689 (paragraph 38) has shown that the risk of dewirement depends on variables, including the lateral restraint in the overhead line (which is lowest near to the mid-span position), the tension in the overhead line, the up force applied by the pantograph head, the speed of the train and the time that the wire remains in the vicinity of the limit on the pantograph head. RSSB research project T689 has used a mathematical model to predict the 'safe working limit', which is the distance between the pantograph centre line and the contact wire position at which dewirement is feasible but, depending on the precise circumstances, not certain.

109 For defined conditions (pantograph uplift force 160 N, wire lateral stiffness 596 N/m, wire vertical stiffness 1057 N/m), the RSSB research project predicts a safe working limit of 511 mm for a lightly loaded class 365 train operating on straight track under Mk3b overhead line equipment with a span of 75 metres at a contact wire height of 5.3 metres. Although the train and type of overhead line equipment match those at the accident site, adjustments are needed to allow for the span length of 68 metres, and the wire height of 4.96 metres, at the accident location. Applying these adjustments, the safe working limit is approximately 525 mm from the pantograph centre line, assuming that the overhead line lateral and vertical stiffnesses are as stated in the RSSB research project.

110 The values of the defined conditions assumed by the model are in line with the design specifications for the overhead line, but the actual values during the accident are not known, and could vary because of factors such as friction in the overhead line tensioning equipment. As a result, the safe working limit must be considered as approximate. The pantograph uplift force assumed by the model represents the highest transient up force that could reasonably be expected during movement of the train, and is higher than the static up force when the train is stationary (nominally 90 N).

111 The predicted wire displacement from the pantograph centre line (465 mm at the highest likely gust speed) is less than the estimated safe working limit (525 mm). This apparent inconsistency is likely to be due to inaccuracies in the calculated wire displacement, as discussed in paragraphs 112 to 119, and/or the assumptions implicit in the safe working limit (paragraph 109).

Areas of uncertainty

112 It is possible that the wind gust speed during the accident was greater than the speeds recorded at the weather stations at about the same time. Increasing the gust speed at the wire to 70 mph (31 m/s), a feasible speed consistent with observations during the preceding two hours (paragraph 56) affects the variables described in paragraphs 94 to 111, and gives a predicted wire position up to 522 mm from the pantograph centre line (table 4). This is very close to the 525 mm safe working limit assessed from the RSSB research project (paragraph 109).

113 Given the relative magnitudes of the possible uncertainties, the RAIB believes that it is highly likely that wind speeds higher than those recorded at the weather stations are at least a partial explanation for the dewirement.

114 Figure 21 gives a qualitative illustration of how the dewirement risk relates to contact wire position on the pantograph head. This shows that a dewirement starts to become feasible when the contact wire moves past the safe working limit. As the wire moves further across the pantograph head, the likelihood of dewirement increases, until it becomes almost certain as the contact wire moves towards the end of the horn. Factors affecting the likelihood of dewirement include the time that the contact wire remains beyond the safe working limit, the tension in the contact wire, and the up force on the pantograph.

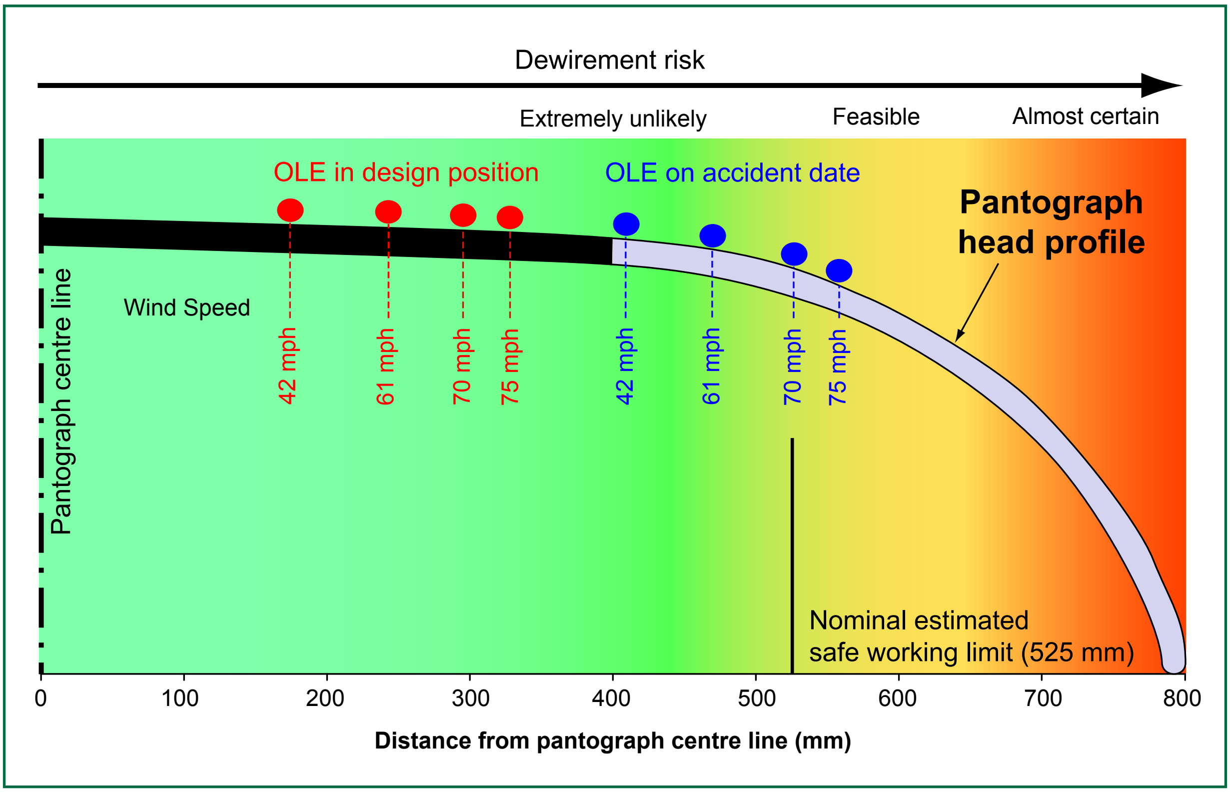


Figure 21: Illustration of dewirement risk in high winds (worst case conditions)

115 Figure 21 also shows the worst case positions of the contact wire in different wind conditions, indicating that a dewirement was feasible in gusts of 70 mph, with the likelihood increasing for higher wind speeds. Figure 21 also shows that dewirement would have been extremely unlikely to have occurred if the overhead line had been maintained in the design position.

116 The contact wire deviations due to wind, shown in table 4, are the maximum values which occur at only one position on the 68 metres long wire span. However, a significant length of wire is close to this value. As a result, if the wind speed is increased, even by a small amount, a significant length of wire moves beyond the original deviation (figure 22). For example, if the wind speed is increased by 1 mph, more than 15% (10 metres) of the span moves to a position beyond the original maximum deviation. Similarly, if the wind speed increases by 5 mph, more than 34% (23 metres) of the span moves to a position beyond the original maximum deviation. This shows that a small change in the wind speed can have a large effect on the length of the overhead line that exceeds a defined wind deviation, and thus a large effect on the probability of a dewirement occurring. The lengths of span affected by changes in the wind speed do not change significantly for wind speeds in the range 42 mph to 70 mph (19 m/s to 31 m/s).

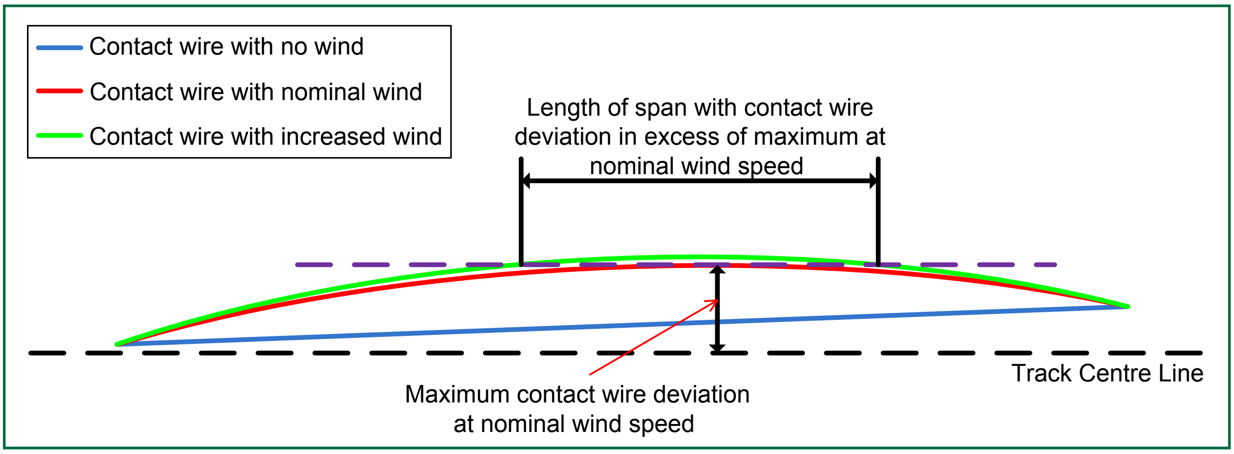


Figure 22: Effect of increased wind speed

117 A similar effect can be seen if the distance between the contact wire and the pantograph centre line changes for other reasons. For example, a 10 mm increase in this dimension results in approximately 21% (14 metres) of the span moving beyond the original contact position, when the wind speed is 61 mph (27 m/s), and 18% (12 metres) of the span when the wind speed is 70 mph (31 m/s).

118 The static offset of the contact wire is estimated by the RAIB to have an uncertainty of ±15 mm, based on an assessment of the data plotted in figure 26. Wind deviation and mast deflection have been calculated using Network Rail standards[7] and engineering design practices, which have been validated by extensive operational experience. The RAIB has not established the accuracy of these procedures, or whether they tend to under or over estimate wire movements. However, it is unlikely that the calculation procedures have introduced a large error into the predicted wire movements.

[7] NR/L2/ELP/27214 'Maintenance of Mk3b overhead line equipment' and NR/GN/ELP/27039 'Wind loading on overhead line equipment and structures'.

119 If the play in the pantograph exceeded the allowed values (paragraph 45) then it is possible that this could increase the risk of dewirement. In addition, if the train suspension did not perform as modelled by RSSB, it is possible that additional lateral movement of the pantograph increased the dewirement risk. These effects are unlikely to have been significant, because train maintenance records showed no evidence of problems with either the train suspension or the pantograph.

120 **Movement of the OLE mast foundations rotated the overhead line away from the centre line of the track.**

121 The accident occurred at a location where the railway embankment is crossing fenland, an area in which weak natural soils often result in embankment and foundation movements. This is the probable explanation for mast rotation at the accident location, which has pulled the overhead line away from the track, towards the cess, and vertically upwards (figure 23). Movements of this type are additional to short term mast deflection caused by wind loading (paragraph 98).

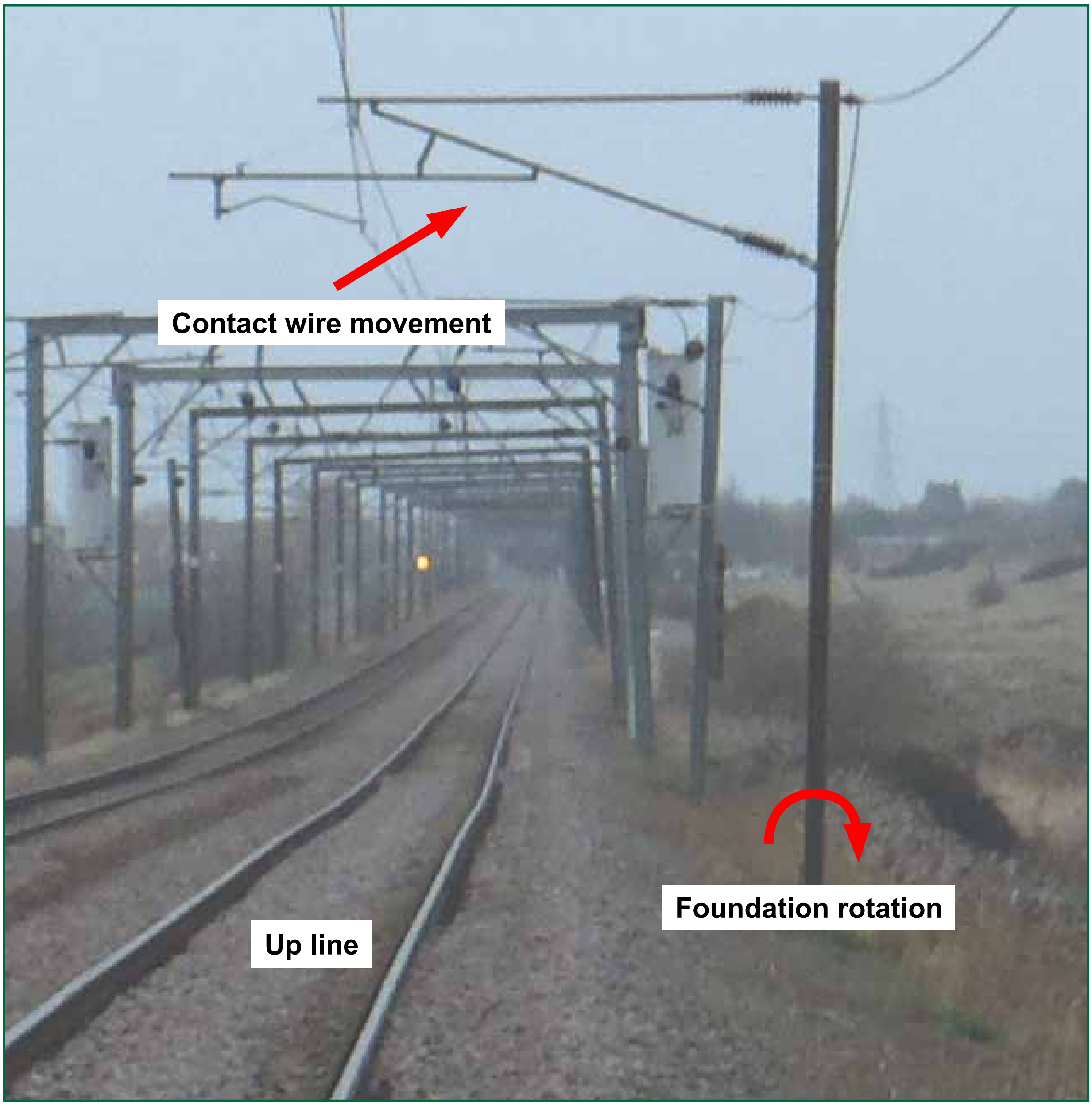


Figure 23: Masts at the accident location, showing results of foundation movement (courtesy of First Capital Connect)

122 Portals, where the two masts on either side of the line are connected together by an overhead structure, are more resilient to this type of movement. Figure 24 shows an example of portal structures. The overhead line up to 200 metres before the accident was supported on portal structures. After this point, separate masts were used.

Figure 24: Portal structures immediately before mast C119/04 (courtesy of First Capital Connect)

123 The horizontal alignment of the OLE contact wire on the up line in the vicinity of the accident is shown in figure 25. This data was collected by the 'MENTOR' overhead line measurement coach in November 2011, and adjusted by the RAIB to take account of known inaccuracies in the method of measurement[8]. These inaccuracies included calibration differences that led to inconsistencies between successive recordings, and the absence of compensation for dynamic movement (sway) of the coach during recordings. The position of the contact wire is seen to alternate from one side of the track centre line to the other, whilst supported by portal structures. However, where the OLE is supported by separate masts, the alignment of the contact wire is seen to be predominantly left of the track centre line.

[8] The MENTOR coach collects a variety of data relating to the overhead line equipment. At the time of the accident, this data contained inaccuracies which made it unsuitable for informing the routine maintenance of horizontal alignment of the contact wire. These inaccuracies were being addressed by a refit of the MENTOR coach in January 2013 (paragraph 172). The MENTOR coach, as configured prior to January 2013, did provide warnings to maintenance teams if its data suggested a possible alignment problem, but Network Rail standards did not permit maintenance teams to rely on this data.

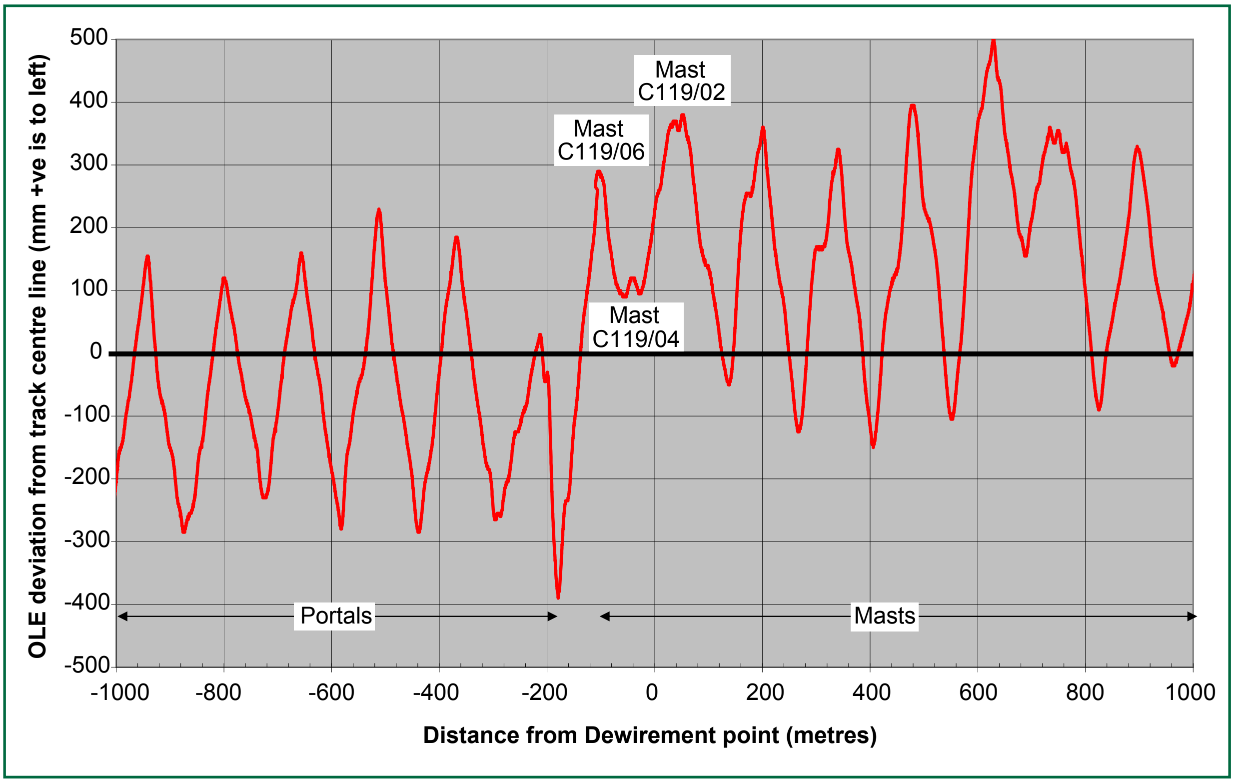


Figure 25: Overhead alignment recorded by MENTOR coach

124 Network Rail had recognised that the mast foundations were moving in the area around the accident location and had implemented its process for monitoring moving structures (Network Rail standard NR/L/ELP/27237 'Overhead line work instructions'). Moving structures are also referred to as slipping structures by Network Rail. At the time of the accident, Network Rail was undertaking annual slipping structure inspections on masts C119/04 and C119/02.

125 Table 5 shows the positions of the contact wire at masts C119/04 and C119/02, as recorded at the last slipping structures inspection before the accident in August 2011, and how this compares to the design position. Masts C119/04 and C119/02 were both measured as leaning by 3.1 degrees away from the vertical position. The initial installation specification had required the masts to be vertical. RAIB calculations show that 3.1 degrees of mast rotation about the foundations, away from the track, corresponds to the contact wire moving approximately 310 mm to the left and approximately 170 mm upwards. This shows that the movement of the contact wire from the design position can largely be accounted for by the rotation of the masts. Any historical wire position adjustments, or non-verticality in the initial installation of the masts could contribute to the variation between the calculated and measured deviations.

	Horizontal position of contact wire, relative to track centre			Height of contact wire from rail level		
	Design	August 2011	Difference	Design	August 2011	Difference
Mast C119/04 (before dewirement)	230 mm right	58 mm left	288 mm left	4700 mm	4921 mm	221 mm
Mid-span (dewirement) interpolated from mast data	0 mm	224 mm left	224 mm left	4700 mm	4896 mm	196 mm
Mast C119/02 (after dewirement)	230 mm left	390 mm left	160 mm left	4700 mm	4870 mm	170 mm

Table 5: Summary of mast movements from design/installation position to August 2011 position

126 The slipping structure monitoring had been undertaken annually since 2007. The RAIB has extrapolated this data to estimate that the contact wire at mid-span was likely to have been 230 mm (±15 mm) left of track centre at the time of the accident (figure 26). It is probable that this movement consists of both a long term trend and seasonal fluctuations.

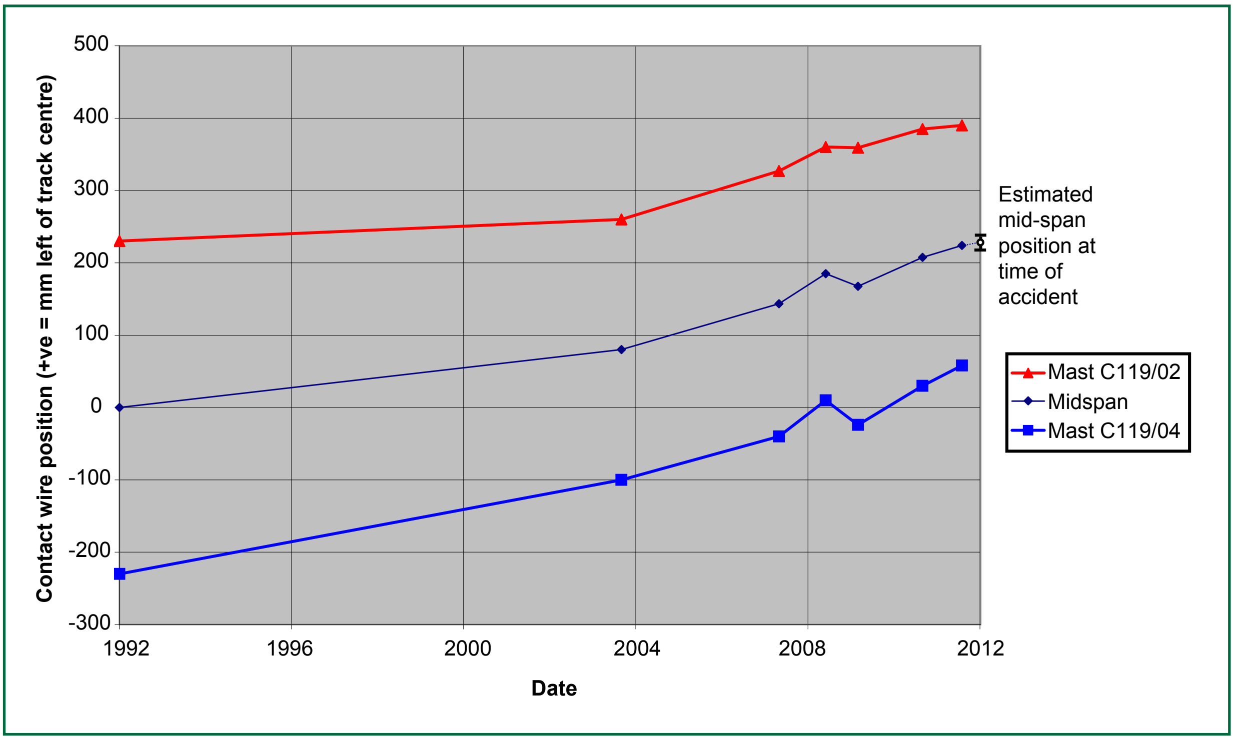


Figure 26: Movements of OLE at masts C119/02 and C119/04, and at mid-span

127 The slipping structure monitoring process did not include an assessment of wire position relative to its design position.

128 The maintenance procedure for slipping structures (paragraph 124) is documented in Network Rail standard NR/L3/ELP/27237 'Overhead line work instructions'. This standard does not specify what actions are required after the slipping structures data has been collected. However, the Tottenham MDU checked the measurements for signs of significant mast movements since the slipping structure monitoring had started (since 2007 in the case of masts C119/04 and C119/02).

129 This meant that the process had identified contact wire movements of 98 mm and 63 mm to the left at masts C119/04 and C119/02 between 2007 and 2011, which were less than the 100 mm informal limit being applied by maintenance staff (paragraph 153). However, because the process being used did not look at the absolute position of the masts when slipping structure monitoring started, it did not identify the fact that the contact wire positions at masts C119/04 and C119/02 were already 190 mm and 97 mm respectively left of their design positions in 2007, and so were 288 mm and 160 mm respectively away from their design positions in 2011 (table 5). Network Rail was unable to identify a standard or process that specified the corrective action required in response to the slipping structure measurements, such as those at masts C119/04 and C119/02.

130 The slipping structures process only considered the positions of the overhead line at the masts, and did not consider the positions of the contact wire at the mid-spans adjacent to those masts. That meant that no check was made on the expected deviations of the contact wire at mid-span resulting from a combination of the mast foundation movement and high winds. Had this been done, taking account of movements since 2007, it is likely that the increased risk of dewirement would have been identified.

131 Routine inspection and maintenance was deferred beyond specified limits without implementing mitigation against risks associated with support structure movement.

132 The stretch of overhead line in the vicinity of the accident should have been subject to a six-yearly routine inspection and maintenance, as required by Network Rail standard NR/L2/ELP/21087 'Specification for maintenance frequency and defect prioritisation of 25kV overhead line equipment'. This includes measurement of the lateral position of the contact wire, and analysis of its expected deviation during high winds.

133 The last inspection was carried out in September 2003, and the lateral position of the overhead line was found to be, or adjusted to be, within the informal maintenance limits described in paragraph 152. Analysis of the wind deviation was not carried out, as this required technical resource that was not available in Tottenham MDU.

134 The next inspection was required to be carried out by May 2010, allowing for the additional 8 months tolerance permitted by NR/L2/ELP/21087. This mandatory inspection and maintenance activity had not been carried out by the time of the accident in January 2012.

135 In August 2009, a routine review of maintenance requirements identified that a number of lines covered by Tottenham MDU had been wrongly categorised and as a result, the time interval between scheduled overhead line inspections had to be reduced to be compliant with NR/L2/ELP/21087. Recategorisation meant that 146 wire runs within this area were overdue their inspections. In addition, other wire runs became due for inspection earlier than had been planned.

136 Tottenham MDU raised a Temporary Non-Compliance (TNC) certificate in September 2009 to permit continued deferment of inspection and maintenance of the 146 wire runs that were then overdue their inspection. The TNC indicated that these runs would be compliant by August 2011. This TNC did not cover the wire run involved in the accident, as this did not exceed its 8 month tolerance until May 2010. The TNC was authorised by Network Rail's professional head of electrical power.

137 A Temporary Non-Compliance (TNC) authorises a defined part of Network Rail not to comply with all or part of a standard (eg a maintenance schedule) for a pre-determined period of time. The TNC requires an action plan to achieve full compliance to be defined and monitored, as well as implementation of interim measures to identify and control the risks that might arise until compliance is achieved.

138 The TNC raised in September 2009 acknowledged that the risks posed by the delays to inspections could not be judged accurately, and as a result they were considered to be high. The recorded mitigation measures included identification of visible defects during regular line patrols, prioritising repair of existing known defects and highlighting power trips on non-compliant wire runs to identify possible defects. These mitigation measures were unlikely to recognise overhead line movements associated with gradual mast rotation.

139 Staff at Tottenham MDU stated that they did not recognise that the September 2009 TNC did not cover the additional wire runs that subsequently became due for inspection earlier than planned (paragraph 135), and were unable to be maintained within the timescales required by NR/L2/ELP/21087 due to the backlog of work. No further TNCs were raised to cover wire runs that became non-compliant after September 2009, until a TNC was raised in March 2012, two months after the accident. This means that the wire run involved in the accident was non-compliant with the maintenance standard from May 2010 onwards, and there was no TNC in place to authorise this.

Identification of underlying factors[9]

140 **The overhead line alignment specifications and maintenance limits in Network Rail standards were inconsistent and not clearly understood by maintenance staff at Tottenham MDU.**

141 Network Rail has two standards dealing with overhead line alignment, both of which require assessment of the effects of wind. These standards are described in paragraphs 142 to 151. Maintenance personnel in Tottenham MDU were not applying these standards, but were applying informal maintenance criteria, described in paragraphs 152 to 155, to maintain the overhead line alignment.

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

NR/L2/ELP/27214 'Maintenance of Mk3b overhead line equipment'

142 Network Rail standard NR/L2/ELP/27214 details the maintenance tolerances for the Mark 3b design overhead line equipment installed at the accident location. This standard specifies that the maximum allowable distance which the contact wire may be from the centre line of the track at any point in the span, at the design wind speed, is 400 mm (reduced by 40 mm per metre rise in contact wire height above 4.7 metres).

143 At the accident location, where the contact wire height was 4.96 metres, this gives a maximum permissible wire deviation of 390 mm.

144 The contact wire positions at the masts on either side of the dewirement location were both recorded to be within the 390 mm limit of this standard in August 2011 (table 5).

145 At the location where the dewirement occurred, the design wind speed was 56 mph (25 m/s), and the span length was 68 metres. Using the wire position data collected in August 2011 (table 5), the combined effect of static offset and wind effects on the contact wire gives a maximum wire deviation of 455 mm from track centre, which is 65 mm beyond the limit specified in this standard.

146 Although the title of this standard refers to maintenance, it was not used by maintenance personnel or referred to in the maintenance procedures. As a result, no checks of compliance against this standard were undertaken as part of maintenance prior to the accident.

147 If the overhead line had been maintained to this standard, the contact wire would likely have been at least 65 mm nearer to the track centre line, and it is unlikely that the dewirement would have occurred. However, use of this standard would require technical expertise to calculate the maximum expected wind deviation, using the design wind speed for each span.

NR/L2/ELP/21087 'Specification of maintenance frequency and defect prioritisation of 25kV overhead line equipment'

148 Network Rail standard NR/L2/ELP/21087 defines the thresholds for alignment at which maintenance is required. These maintenance action limits are based on the 'assessed' position of the overhead line (table 6). Although it is not stated in the standard, Network Rail has explained to the RAIB that the 'assessed' position of the overhead line is relative to the centre of the pantograph of a passing train. However, maintenance personnel measure the position of the overhead line relative to the track centre line. The difference between these two reference points is the lateral movement of the pantograph, relative to the track centre line, as a result of pantograph sway, and play in the pantograph mechanism (figure 20). Network Rail has been unable to identify a standard, or instruction to its staff, that defines the meaning of the 'assessed' position of the contact wire.

Contact wire position	No Action Required	Maintain within 2 Years	Maintain within 28 Days
At Mast	< 450 mm	450 mm to 550 mm	> 550 mm
At Mid-span	< 560 mm	560 mm to 650 mm	> 650 mm

Table 6: Maintenance action thresholds for the 'assessed' (pantograph centred) position of the overhead line (from NR/L2/ELP/21087)

149 Before maintenance personnel can compare their track centred measurements with a pantograph centred threshold, there needs to be some analysis of the measurements to take account of the differing reference points and the wind effects. Network Rail intended this analysis to be undertaken by technical personnel within the MDUs, although there were no formal procedures in place to define the analysis required.

150 Tottenham MDU had no technical personnel to undertake this analysis. Furthermore, they did not appreciate that the maintenance action limits could not be used directly with their track centred measurements.

151 Because there was no formally documented method for carrying out the required analysis, the maintenance action limits could not be applied consistently. As a result, the RAIB has been unable to determine if the overhead line was within the maintenance action limits in August 2011.

Informal maintenance criteria

152 The maintenance team in Tottenham MDU had developed an informal local process for managing overhead line alignment that did not require input from the missing technical resource. This process recognised that the wire had to be maintained relative to its design position.

153 At the routine inspection, intended to be six yearly at the accident location (paragraph 132), the maintenance personnel measured the position of the overhead line at each registration point and at each mid-span position. This was recorded on a sheet which also showed the design position for each point. If the measured position deviated more than approximately 100 mm from the design position, then the overhead line position would be adjusted to bring it back towards the design position.

154 Network Rail standard NR/L2/ELP/27214 required the overhead line mid-span position to be within 159 mm of its designed position at the accident location. The informal maintenance criteria would have achieved compliance with this standard.

155 If the overhead line had been maintained to this informal process, then it is unlikely that the accident would have occurred.

Observation[10]

156 Because ceramic insulators are very brittle, they are susceptible to breaking on application of a sudden sideways impact load. Insulators can be manufactured from less brittle materials, such as those used in polymeric or composite insulators. These are widely used by Network Rail on overhead line support structures, but have not been widely adopted on pantographs (apart from on the class 390 'Pendolino' fleet).

157 At present, equipment specifiers have concerns regarding the compatibility of polymeric and composite insulators with fire and smoke regulations, and hence they are not being widely adopted for mounting pantographs.

[10] An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the accident but does deserve scrutiny.

158 Polymeric and composite insulators are more likely to distort and absorb energy during an impact than ceramic insulators, and so are less likely to result in detachment of the pantograph. This is illustrated by testing undertaken recently by Brecknell Willis in January 2013 which demonstrated that a polymeric insulator will distort, but not detach, on application of an impact with an energy of 550 Joules. The equivalent ceramic insulator was demonstrated to break on application of impacts with energies between 200 Joules and 400 Joules.

Previous occurrences of a similar character

159 In order to understand how often similar detachments of a pantograph occur, the RAIB prepared a questionnaire seeking information from seven train operating companies that operate trains with pantographs, about their experiences of dewirement. The information requested included how many dewirements involved the detachment of a pantograph, and how many of those resulted in the pantograph falling from the roof of the train.

160 The responses included data about both main line and commuter services, covering 98 dewirement incidents during the period from January 2007 to January 2012, excluding the accident at Littleport. The response data provides a representative sample, but is not a complete record of all dewirements over that period.

161 The survey showed that in 94 of the 98 dewirements the pantograph frame remained attached to the train roof. In some of these instances the pantograph arm collapsed and/or the pantograph head detached, as they are designed to do.

162 There were four instances where the entire pantograph frame became detached from the roof. In three of these, the pantograph assembly remained on the roof. One occurred at Lolham, Lincolnshire, on 1 April 2008, another at Queen Adelaide crossing, between Littleport and Ely, on 23 September 2011, and a third at Penkridge, Staffordshire, on 6 December 2011. In the second of these cases, parts of the arm ended up hanging down between two coaches, but did not cause damage to the windows.

163 There were two instances where parts of the pantograph arm became detached from the frame during a dewirement. Only one of these fell from the train, but it caused no damage to the train side or windows.

164 There was only one report of a complete pantograph assembly falling from the roof of a train. This occurred at Cambridge Heath, on the approach to London Liverpool Street station, on 14 August 2011. On this occasion, the overhead line became entangled in the pantograph base frame, ripping it from its mountings as the train moved forward. No damage to the train sides was reported during this incident. The pantograph arm did not strike the OLE structures, and so did not collapse.

165 Staff involved with operation of pantograph equipped trains and overhead line equipment have provided anecdotal evidence that the loss of a complete pantograph assembly from the roof of a train is very rare. No individual could remember more than one incident during their career. This was consistent with the evidence provided by the questionnaire responses.

166 Since this survey, Network Rail has provided details of a further two incidents where entire pantograph assemblies became detached from trains. One occurred on 13 February 2013 at Radlett, Hertfordshire, and a second occurred on 1 March 2013 at Hanslope, Buckinghamshire. In the second of these, two pantograph assemblies fell from a single train that was formed from two electric multiple units. Network Rail also provided details of a third incident, which occurred on 18 March 2013, also at Hanslope, where a pantograph arm impacted, and became embedded in, an overhead line support structure. In this incident, the pantograph frame, which was mounted on polymeric insulators, remained attached to the class 390 'Pendolino' train.

167 During such incidents there is the potential for large, heavy and fast moving debris to present a risk to railway staff, to passengers on stations and on trains, and to the public on land near the railway.

168 Other than the accident at Littleport, the RAIB has not carried out any investigations into accidents or incidents involving the loss of a complete pantograph assembly.

Summary of conclusions

Immediate cause

169 The immediate cause of the accident was that the pantograph became detached from the train roof, impacting the train windows as it fell to the ground (**paragraph 62**).

Causal factors

170 The causal factors were:

a. movement of the OLE mast foundations rotated the overhead line away from the centre line of the track (**paragraph 120, Recommendation 2**);

b. routine inspection and maintenance was deferred beyond specified limits without implementing mitigation against risks associated with support structure movement (**paragraph 131, Recommendation 1**);

c. the slipping structure monitoring process did not include an assessment of wire position relative to its design position (**paragraph 127, Recommendation 2**);

d. the pantograph became dewired allowing the pantograph head to move above the contact wire, and the pantograph arm to hit a cantilever structure (**paragraph 91, Recommendation 1**);

e. the pantograph insulators broke so that the pantograph became detached from the train (**paragraph 64 and paragraphs 156 to 158, Learning point 1**);

f. external forces from the wind, train movement and contact with the overhead line pushed the pantograph assembly off the roof of the train (**paragraph 76**); and

g. the window was forced into the train by impacts from the pantograph assembly (**paragraph 82**).

Underlying factors

171 The underlying factors were:

a. the overhead line alignment specifications and maintenance limits in Network Rail standards were inconsistent and not clearly understood by maintenance staff at Tottenham MDU (**paragraph 140, Recommendation 2**).

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

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

172 Network Rail's Tottenham MDU has developed a plan aimed to address the backlog of 6-yearly maintenance checks of the overhead line equipment. Network Rail has reported that the backlog of wire runs in this area, that were outside their maintenance period tolerances, had been reduced to eleven by the end of April 2012. All of these were covered by a new TNC, and were planned to be maintained by February 2014.

173 Network Rail's Tottenham MDU had already identified the lack of monitoring of mid-span positions in October 2011, during mast replacement work at Black Horse Drove, north of Littleport. It has increased its technical resource to allow assessment of mid-span positions to be carried out during routine inspection and maintenance activities. This additional resource also allows assessment of the contact wire position at OLE supports to be undertaken with reference to the maintenance criteria in Network Rail standard NR/L2/ELP/21087 (paragraph 148). MENTOR data relating to overhead line position is also being reviewed to inform the need for mast adjustment.

174 Network Rail's Letter of Instruction NR/BS/LI/115, Issue 2 (18 March 2011) allows contact wire horizontal and vertical position data collected by the new measurement train to be used in place of manual measurements, to inform overhead line maintenance. In addition, Network Rail reports that the MENTOR coach was undergoing a refit in January 2013 that would improve the accuracy of its data to a standard that was at least equivalent to the new measurement train. This refit includes installation of compensation for dynamic movements (sway) of the coach during recordings. Network Rail reports it is exploring the potential for more automatic analysis of train collected data, in conjunction with mast position and design wind speed information, to monitor potential mid-span deviations due to the wind.

175 Network Rail's Tottenham MDU has modified its slipping structures inspection process to incorporate an assessment of the effect of mast movements on mid-span position of the overhead line, as well as any movements relative to the design position. It is also undertaking a review of existing data for slipping structures to identify any other locations where the wire is outside the specified limits.

176 Before the accident, Network Rail's Tottenham MDU had started to install wind speed and air temperature monitoring equipment at key locations on the line to Kings Lynn. These stations automatically alert staff at Tottenham MDU when extreme conditions are recorded, allowing localised speed restrictions to be applied in order to reduce the dewirement risk. Eleven such installations have been installed in the Tottenham MDU area, all of which are located between Ely and Kings Lynn.

Learning point[11]

177 The RAIB has identified a key learning point for the railway industry:

1. Consideration should be given to using polymeric or composite insulators to support train pantographs, as they have the potential to mitigate the risks arising from pantographs hitting structures (paragraph 170e).

[11] 'Learning points' are intended to disseminate safety learning that is not covered by a recommendation. They are included in a report when the RAIB wishes to reinforce the importance of compliance with existing safety arrangements (where the 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.

Recommendations

178 The following recommendations are made[12]:

1 *The intention of this recommendation is to ensure that the risks associated with the authorisation of Temporary Non-Compliance certificates are properly assessed, and that appropriate mitigation is implemented.*

Network Rail should review the manner in which Temporary Non-Compliance certificates (TNCs) are being used in relation to overhead line equipment, and take corrective action if they are being issued without risks being adequately assessed and mitigated (paragraphs 170b and 170d).

2 *The intent of this recommendation is to provide maintenance personnel who are required to check alignment of the overhead line equipment with information that is in a format that can be easily used, and is appropriate for their level of competence.*

Network Rail should review the standards and procedures for the management of overhead line alignment in order to provide maintenance staff with a simple means of relating measurements that are recorded at site to required alignment criteria. The review should include, at least, consideration of:

- providing maintenance staff with information allowing them to determine the acceptable range of contact wire positions at every support; and
- removing the need for maintenance staff to make their own assessment of pantograph movements when determining if adjustments to the overhead line are required (paragraphs 170a, 170c and 171).

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

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail Regulation 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.raib.gov.uk.

Appendices

Appendix A - Glossary of abbreviations and acronyms

ADD	Automatic dropping device
FFCCTV	Forward facing closed circuit television
MENTOR	Mobile electrical network testing, observation and recording
MDU	Maintenance delivery unit
OLE	Overhead line equipment
OTDR	On-train data recorder
PCA	Passenger Communication Apparatus
PEA	Passenger Emergency Alarm
TNC	Temporary non-compliance

Appendix B - Glossary of terms

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

Automatic dropping device	A protection device fitted to a pantograph which lowers it if it rises above a set maximum height limit or if the contact strip becomes damaged.
Blow-off	The lateral displacement of the mid-span of the overhead line due to the effect of the wind.
Canted track	Track on which one rail is raised higher than the other.*
Cantilever structure	A structure to support the overhead line that is mounted on a mast, or other support, so that it is supported at one end and hangs out over the track (figure 9).
Catenary wire	The uppermost wire in an overhead line electrification system.*
Cess	The area along the side of the railway track.
Chain	An imperial unit of length measurement that is equivalent to 22 yards (approximately 20 metres).
Contact wire	The wire with which the pantograph makes contact in order to collect current.
Design wind speed	The maximum wind speed in which the overhead line is designed to operate normally. This is specified to take into account the range of expected wind speeds at the location, as well as topographical details, ground surface roughness and embankment height.
Down line	A track on which the normal passage of trains is in the down direction, ie away from London, the capital, the original railway company's headquarters or towards the highest mileage.*
Dropper wires	The vertical wire link between the contact wire and the catenary wires in an overhead line electrification system which maintains the contact wire at the correct height.*
Electric multiple unit	A train consisting of one or more vehicles (semi-permanently coupled together) with a driving cab at both ends and whose motive power is electricity supplied externally from overhead line equipment or conductor rails.*
Forward facing closed circuit television	A camera system facing forward from the cab, recording the driver's view of the railway.
Insulator	A porcelain or polymer device used to isolate the live parts of an OLE system from its supports.*

Jumper wire	A flexible connection provided to distribute electrical current between the catenary wire and the contact wire.*
Measurement train	A train equipped with sensors to measure and record many physical characteristics of the track and overhead line electrification. The 'new measurement train' is an example of this.
MENTOR coach	A modified railway coach fitted with a pantograph and measuring and recording equipment. It was introduced in 1973, and is used to monitor and record the physical characteristics of overhead line electrification, including the position of the contact wire.
New measurement train	A converted high speed train, introduced in 2003 to measure and record many physical characteristics of the track and overhead line electrification.
Overhead line equipment (OLE)	An assembly of metal conductor wires, insulating devices and support structures used to bring a traction supply current to suitably equipped trains.*
Pantograph	A device fitted to the roof a train which contacts the contact wire of the OLE, allowing the vehicle to draw current.*
Pantograph well	A lowered section of the roof of a train, in which the pantograph assembly is mounted.
Points	A section of track with moveable rails that can direct a train from one track to another.
Registration arm	An OLE component which attaches at one end to the supporting structure and at the other end to the contact wire. It maintains the contact wire in the correct lateral position.
RSSB	Industry organisation formerly known as the Rail Safety and Standards Board.
Stagger	An intentional variation in the lateral position of the contact wire with respect to the centre line of the track. It ensures that the contact wire sweeps across the width of pantograph heads and wears them evenly.
Stagger effect	An additional distance that quantifies the difference between blow-off (of the overhead line mid-span position) and the point where there is the largest wind deviation of the overhead line span from track centre. This difference is because the point of maximum wind deviation does not occur at the mid-span position where the span is not parallel with the track.
Up line	A track on which the normal direction of trains is in the up direction, ie towards London, the capital, the original railway company's headquarters or lowest mileage.*

Wind deviation	The maximum distance the overhead line is displaced from its static position due to the wind. This consists of both blow-off and stagger effect.
Wire run	A discrete length of overhead line that is held in tension by weights, and extends over a number of spans (typically 10 to 15 spans near the accident location).

Appendix C - Key standards current at the time

ASCE/SEI 7-10 'Minimum design loads for buildings and other structures'	American Society of Civil Engineers - 2010
BS EN 50206-1:2010 'Railway applications. Rolling stock. Pantographs. Characteristics and tests. Pantographs for main line vehicles'	British Standards Institution – September 2010
GM/RT2100 'Requirements for Rail Vehicle Structures' Issue 4	RSSB – December 2010
GM/RT2149 'Requirements for defining and maintaining the size of railway vehicles' Issue 3	Railway Safety – February 2003
GM/TT0122 'Structural Requirements For Windscreens and Windows on Railway Vehicles' Issue 1	British Railways Board – June 1993
NR/GN/ELP/27039 'Wind loading on overhead line equipment and structures' Issue 2	Network Rail – February 2006
NR/L2/ELP/21087 'Specification of maintenance frequency and defect prioritisation of 25kV overhead line equipment' Issue 5	Network Rail – 5 March 2011
NR/L2/ELP/27214 'Maintenance of Mk3B overhead line equipment' Issue 3	Network Rail – 26 August 2008
NR/L3/ELP/27237 'Overhead line work instructions' Issue 6	Network Rail – 5 March 2011
NR/L3/OCS/043/7.1 'National Control Instructions and Approved Code of Practice - Section 7.1 Weather Management' Issue 4	Network Rail – 4 December 2010
NR/SP/ELP/27215 'Instruction for Design of Overhead Line Structures' Issue 1	Network Rail – December 2004

Addendum

A1 After the report into this accident was first published, a passenger on the train contacted the RAIB and stated that passengers were unable to operate the Passenger Emergency Alarm[13] (PEA) handles to alert the driver following the accident (paragraph A3), and had therefore stopped the train by operating the emergency door release[14]. This addendum deals with issues identified following further investigation.

Events after the accident

A2 Following the dewirement, the train lost power, and the driver allowed the train to coast towards the signal at Queen Adelaide crossing, because he could see from the cab that the overhead line in front of the train was not moving, and he concluded that the train had not become tangled with it. The driver recognised that Queen Adelaide crossing was the next location at which the passengers could be more easily evacuated, and was intending to stop there. The driver was not aware that windows had been broken on the train.

A3 After the windows were broken by the falling pantograph, some passengers on the train attempted to operate a PEA handle. A PEA handle is located at each of the passenger doorways in the train. When this is pulled, the passenger and driver can talk to each other, and the driver can then stop the train if necessary. The brakes are automatically applied five seconds after the handle is pulled, if the driver does not operate an override button.

A4 The PEA handles were coloured red, mounted in the ceiling of each doorway passage (figure A1), and needed to be pulled downwards to operate them. Instructions for operation of the handle were printed on the inside face of the external door next to the handle. Each handle was covered by an opaque, perforated, soft plastic cover on which is printed instructions for its removal (figure A2). The cover had a perforated hole into which a finger could be inserted to tear off the cover. This then revealed the handle.

A5 Adjacent to the PEA handles, also mounted in each doorway ceiling, was the emergency door release handle, which was coloured green (figure A1). This was the same type of handle, but it was covered by a transparent, hard plastic cover, which had to be punched to break it. The instructions for this handle were mounted on the inside face of the adjacent external door. Operation of the emergency door release handle immediately applies the train brakes and releases the adjacent door mechanism, although the door is not mechanically unlocked until the train comes almost to a stop.

[13] The PEA equipment is also referred to as Passenger Communications Apparatus (PCA) in the railway rule book.

[14] Neither the OTDR printout of the train's speed and braking, nor the driver's report of the accident, had given any indication that the brake operation had not been initiated by the driver, or that an emergency door release handle had been operated.

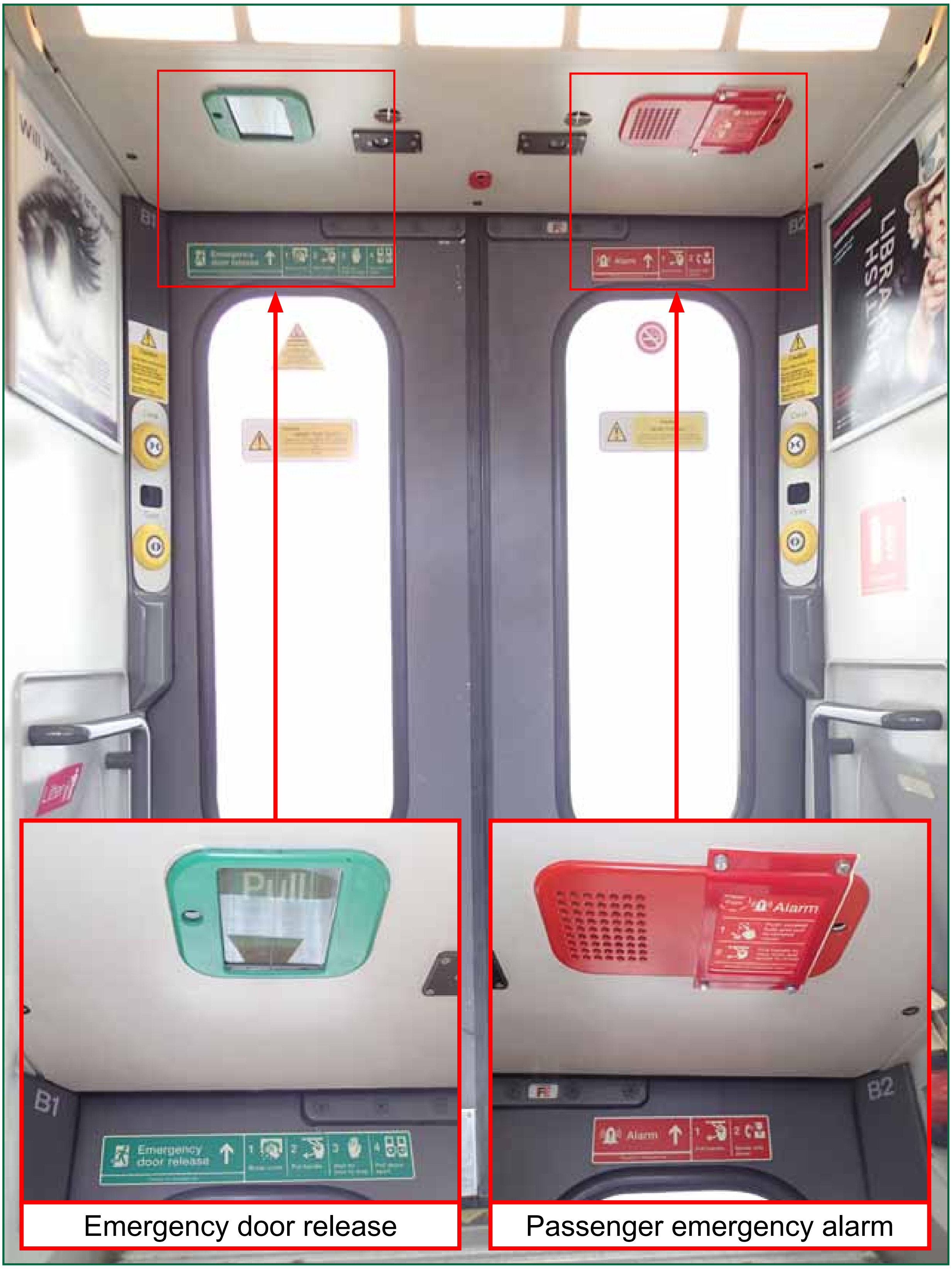


Figure A1: PEA and emergency door release handles

A6 After the windows were broken by the falling pantograph, at least two passengers attempted to operate the nearest PEA handle, while the driver allowed the train to continue coasting. However, they were unable to remove the plastic cover to gain access to the handle. After several attempts they gave up, and a passenger decided to break the cover to the emergency door release handle, and to operate this instead. Because the train's speed did not appear to be reducing, the passengers believed that the driver was not intending to stop. They were unaware that he was attempting to reach a convenient access point and was intending to stop at Queen Adelaide crossing.

A7 Operation of the emergency door release handle immediately applied the train brakes, and the train came to a stop close to the signal on the approach to Queen Adelaide crossing, close to the point at which the driver had intended to stop the train. The driver then reported the accident and the passengers were subsequently evacuated from the train (paragraph 34).

Examination of the PEA covers

A8 The RAIB carried out an inspection of the covers fitted to the PEA handles on a randomly selected class 365 electric multiple unit. Testing showed that the downwards force required to remove the opaque plastic covers varied significantly, requiring a force equivalent to up to 11 kg to tear the perforations. Newly fitted covers required significantly less force to remove them.

A9 It was necessary to fully insert a finger into the perforated hole on the cover to be able to tear it off by a downwards hooking action (paragraph A4). Because the cover was opaque, it was not possible to see what was behind it, and so it is likely that some passengers would be reluctant to insert their finger fully. As a result, the RAIB considered that some passengers may try to remove the cover by pulling it with their finger tips holding the edge of the perforated hole, or by trying to grip on the downwards facing surface. The RAIB found that this gave insufficient grip to enable removal of some of the covers.

A10 The covers were in the ceiling surface, about 1.9 metres above floor level, meaning that their visibility and removal could be affected by the height of the passenger. Shorter passengers would have difficulty reaching the covers, while taller ones would have difficulty in reading the instructions printed on it. Neither the wording nor the pictogram on the cover (figure A2) made it clear that it was necessary to fully insert a finger into the hole in order to grip and tear off the cover. In addition, the instructions on the door did not indicate that it was necessary for a cover to be removed in order to operate the PEA.

A11 First Capital Connect stated that the covers had been fitted to the class 365 fleet between 2009 and 2010, in an attempt to reduce the numbers of non-emergency PEA operations. Similar covers had been fitted to other types of rolling stock operated by First Capital Connect, but these trains had wall mounted PEA handles, and the covers had a 'ring-pull' type handle to assist removal. First Capital Connect believed that this design was inappropriate for use on the class 365 PEA handles, because the ring pulls would hang down from the ceiling in a position which could encourage passengers to pull them.

Figure A2: PEA handle cover, showing instructions for removal

A12 First Capital Connect carried out a risk assessment for fitment of the covers, and this noted that Railway Group Standards did not prohibit covers on PEA handles. The risk assessment also noted that the covers were easily removed, and so concluded that they did not hinder the ability of passengers to operate the PEA handles. However, First Capital Connect has been unable to identify if any trials or assessments were carried out to determine the ease with which the covers could be removed by passengers.

A13 The RAIB has looked at other types of train that have the same type of ceiling mounted PEA handles (class 165 and class 465). These are operated by other train operating companies, and none of these were seen to be fitted with any type of cover over the PEA handles.

Actions taken

A14 In November 2012, Eversholt Rail (UK) Limited, in conjunction with First Capital Connect, completed a feasibility study into possible modifications to the class 365 door system. This study had been commissioned as part of their response to the RAIB's investigation into a passenger's hand becoming trapped in a train door as it departed from London King's Cross station in October 2011 (RAIB report 09/2012).

A15 This study recommended that the PEA handle covers should be removed to reduce the response time in an emergency situation. Eversholt Rail (UK) Limited and First Capital Connect implemented a programme to remove the covers from the PEA handles on the Class 365 fleet as trains passed through heavy overhaul, but were concerned that removal would result in a rise in false passenger activations of the PEA. By August 2013 the PEA handle covers had been removed on two trains. After undertaking the testing described in paragraphs A8 to A10, the RAIB expressed concern to First Capital Connect about the difficulties some passengers could experience due to the PEA handle covers. In response, First Capital Connect reported that the programme had been accelerated, and that all the PEA handle covers on the class 365 units were removed by the end of September 2013.

A16 The removal of the PEA handle covers addresses the difficulties experienced by the passengers during the accident at Littleport. For this reason, the RAIB is not making any further recommendations in relation to the investigation described in this addendum.

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