

Understanding the forces and energy in the electrification system during dewirements



Copyright

© RAIL SAFETY AND STANDARDS BOARD LTD. 2015 ALL RIGHTS RESERVED

This publication may be reproduced free of charge for research, private study or for internal circulation within an organisation. This is subject to it being reproduced and referenced accurately and not being used in a misleading context. The material must be acknowledged as the copyright of Rail Safety and Standards Board and the title of the publication specified accordingly. For any other use of the material please apply to RSSB's Head of Research and Development for permission. Any additional queries can be directed to enquirydesk@rssb.co.uk. This publication can be accessed by authorised audiences, via the SPARK website: www.sparkrail.org.

Written by: Steven Conway, Current Collection Solutions Ltd

Published: October 2015

Understanding the forces and energy in the electrification system during de-wirements

Executive summary

Industry stakeholders have expressed the need for an improved understanding of the forces and energy in electrification systems during de-wirements, reviewing both sides of the vehicle/infrastructure interface.

The way in which components fail during a de-wirement can limit or exacerbate the damage to rolling stock and infrastructure, and also have safety implications. Ceramic insulators tended to be the known location of failure during a de-wirement, however with increasing numbers being replaced by a much stronger polymeric or composite insulator, the frangibility point has moved elsewhere within the system.

The research comprised of an in-depth review of all incident reports provided by Network Rail dating from 2005. Unfortunately after 2011 only two reports had sufficient detail to carry out any meaningful analysis.

The analysis identified 7 trends:

- 1 Fracture pantograph horns
- 2 Pantograph pulled backwards with upper and lower arms close to horizontal
- 3 Pantograph pulled off the vehicle roof
- 4 Pantograph with knuckle uppermost
- 5 Pantograph chain failure
- 6 Failure of Arthur Flury Neutral section
- 7 14 of the 34 incidents analysed occurred within 1km of a station, underbridge or crossing

The analysis also identified there were three incidents of concern, any of which could have caused serious injury to staff or the public.

The purpose of this research is to ascertain the forces that may be generated during such incidents to allow failure modes to be optimised. Although the original concept was to mathematically simulate such forces, during the process of the analysis it became evident a simpler and less expensive method, which is almost guaranteed to produce meaningful results, would be to calculate the forces required to:

- Fracture the four foot insulators that allow the pantograph to be pulled off the vehicle
- Distort the mast, which supports the cantilever assembly

The knowledge obtained by calculating the above could be used to limit the damage to the rolling stock and infrastructure by designing frangible joints on the pantograph at the knuckle, and possibly between the base frame and the lower arm.

The following recommendations are made:

- 1 Calculate the forces require to:
 - a Fracture four ceramic pantograph foot insulators
 - b Distort the OLE mast
- 2 Consider using the forces calculated to design a frangible link(s) in the pantograph articulation.
- 3 To limit the risk to staff or the public consider the secondary retention of any detached items that occur as a result of the above (2).

Table of Contents

Executive summary.....	i
Introduction	1
Method.....	2
Results of analysis	2
Figure 9 - Incidents of concern.....	8
Figure 12 - Discussion	11
· Recommendations.....	13
Appendix A: Reports analysis	15

Understanding the forces and energy in the electrification system during dewirements

Introduction

Industry stakeholders have expressed the need for an improved understanding of the forces and energy in electrification systems during dewirements, reviewing both sides of the vehicle/infrastructure interface.

There have been significant dewirement incidents over the past 15 years resulting in risk to passengers, damage to infrastructure and rolling stock and considerable delays and costs to the GB rail network.

On 5 January 2012, one such dewirement incident occurred at Littleport, Cambridgeshire. Due to several causal factors, an impact broke several ceramic pantograph insulators on which the pantograph assembly was mounted, allowing it to fall from the roof, breaking two body-side windows and resulting in three minor injuries to passengers inside the train, in addition to extensive damage to overhead line equipment. The subsequent RAIB (Rail Accident Investigation Branch) accident report issued a learning point that '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.' However, the report also stated that 'polymeric and composite insulators are more likely to distort and absorb energy during an impact than ceramic insulators'.

The way in which components fail during a dewirement can limit or exacerbate the damage to rolling stock and infrastructure, and also have safety implications. Ceramic insulators tended to be the known location of failure (frangible) during a dewirement, however with increasing numbers being replaced by a much stronger polymeric or composite insulator, the frangibility joint has moved elsewhere within the system. This has led stakeholders to express concerns that the use of these insulators had the potential to indirectly cause further damage to overhead line equipment (OLE), with potential to lead to train derailments if damage leads to debris on the line. The problem that this research sets out to address is that with the increasing use of polymeric and composite insulators on both OLE and the insulators supporting the pantograph base, there is insufficient understanding of the transfer of forces and energy through the system components to enable the failure modes to be optimised.

Method

The research comprised of an in-depth review of all incident reports provided by Network Rail dating from 2005. Unfortunately after 2011 only two reports had sufficient detail in to carry out any meaningful analysis, the Littleport on the 05/01/2012 and the Birmingham New Street on the 25/07/2012. Prior to 2012, fifty two reports had sufficient detail in to allow analysis to be carried out. Of these, thirty four were analysed in detail (Appendix A), the remainder were reports of specific OLE component failures, which did not involve the pantograph, and hence were not relevant to this research. The remaining reports were analysed looking for any trends that may have occurred.

Results of analysis

The analysis, shown in Appendix A, identified 7 trends in the failure modes:

- Trend 1)** Fractured pantograph horns
- Trend 2)** Pantograph pulled backwards with upper and lower arms close to the horizontal
- Trend 3)** Pantograph pulled off the roof of the vehicle
- Trend 4)** Pantograph with knuckle uppermost
- Trend 5)** Pantograph chain failure
- Trend 6)** Failure of Arthur Flury Neutral Section
- Trend 7)** 14 of the 34 incidents analysed occurred within 1km of a station, underbridge or crossing

These are also colour coded in Appendix A.

The trends of the fractured pantograph horn (Trend 1) and Arthur Flury Neutral Section (Trend 6) failures were specific component design issues, which are commented on further in the 'Discussion' section of this report.

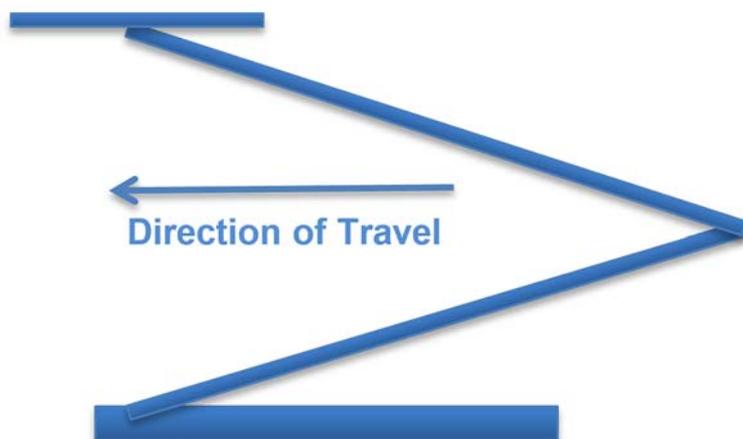
Although in 'Trend 2' the 'pantograph pulled backwards with upper and lower arms close to the horizontal' results in the pantograph being severely damaged it also minimizes any further damage to the OLE. Figure 1 shows the outcome of a typical incident where the pantograph ended up in this position.

Figure 1 - 'Trend 2' pantograph pulled backwards with upper and lower arms close to the horizontal.



All pantographs in 'Trend 2' were operating in the KT direction as in Figure 2.

Figure 2 - Pantograph operating in the knuckle trailing (KT) position



During a typical incident the pantograph would, 'snag' the contact wire and be pulled over as in Figure 3.

Figure 3 - Outcome of incident pantograph pulled backwards with upper and lower arms close to the horizontal (Trend 2).



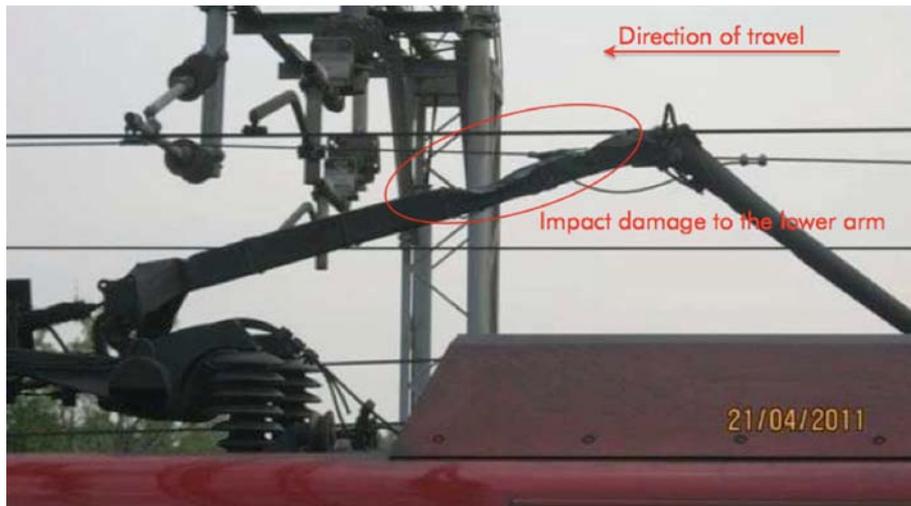
The pantograph being pulled off the roof of the vehicle, as in 'Trend 3', can only occur when ceramic foot insulators are fitted. An example of this incident can be seen in Figure 4.

Figure 4 - Example of a pantograph pulled off the roof (Trend 3).



In 'Trend 4' the 'Pantograph with knuckle uppermost' the pantograph is in the most 'dangerous' position, as it will result in further damage to the OLE. An example of such an incident can be seen in Figure 5.

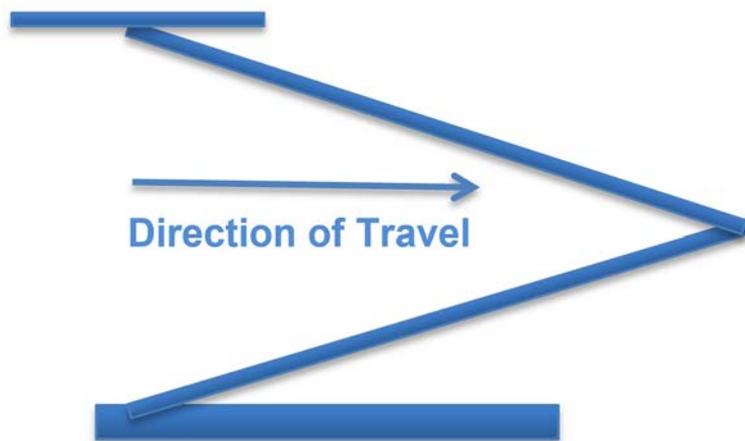
Figure 5 - Example of a 'pantograph with knuckle uppermost'.



The impact damage to the lower arm should be noted, where it has struck OLE components.

All pantographs in 'Trend 4' were operating in the KL direction as in Figure 6.

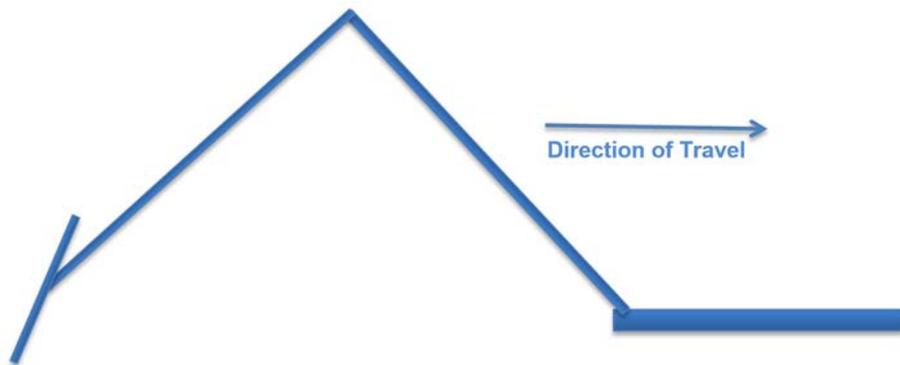
Figure 6 - Pantograph operating in the knuckle leading (KL) position.



During a typical incident the pantograph would either:

- 1 'Snag' the contact wire and pull the pantograph over as in Figure 7 with knuckle uppermost

Figure 7 - Pantograph pulled after over after 'snagging the contact wire' with knuckle uppermost.



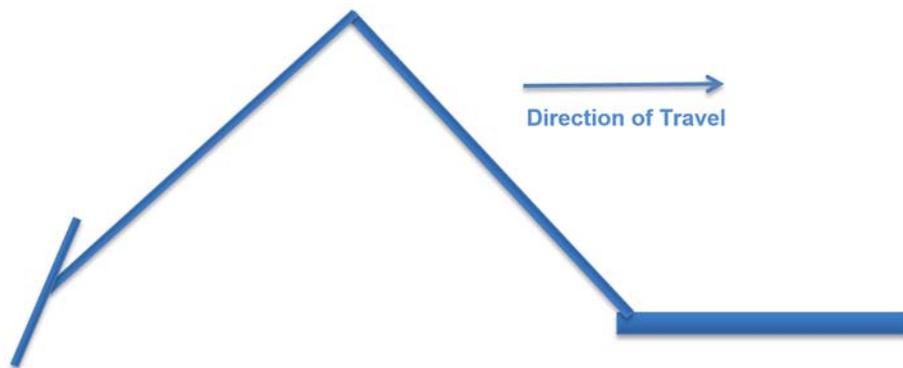
- 2 The outer chains would fail, which transfer the upward force from the lower arm to the upper arm, the upper arm then would fall as in Figure 8 due to the force applied by the air raising cylinder.

Figure 8 - Outer chains would fail and upper arm would drop.



The lower arm would raise because of the upward force still present from the air raising cylinder or springs resulting in the knuckle being uppermost.

Figure 9 - Lower arm raised, due to upward force still present, resulting in the pantograph being 'knuckle uppermost'.



'Trend 5' 'pantograph chain failure' all occurred on low speed vehicles (<100mph), confirming the findings of T1038 the 'Statistical distribution of pantograph characteristics', which demonstrated that the lower the speed of the vehicle the less well maintained the pantograph.

'Trend 7, demonstrated that 14 of the 34 incidents analysed occurred within 1km of a station, underbridge or crossing.

Incidents of concern

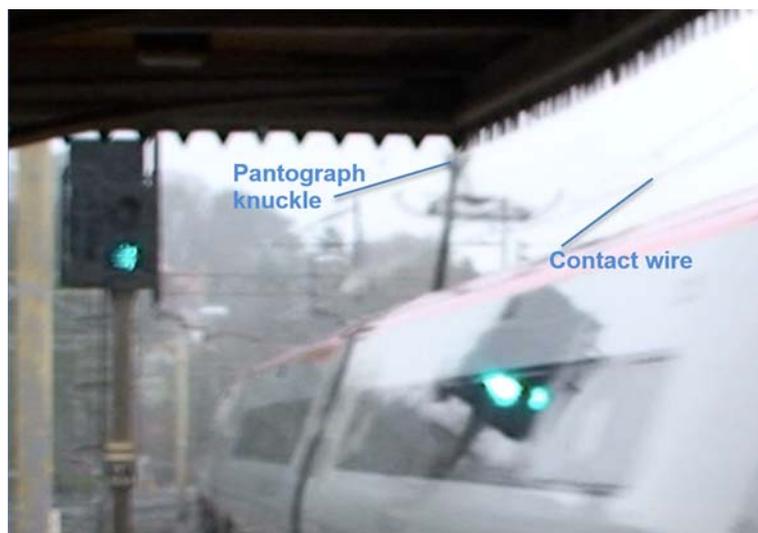
There were three incidents of concern, any of which could have caused serious injury to passengers:

- 1 Incident 9, Alexandra Palace
- 2 Incident 28, Berkhamstead
- 3 Incident 33, Littleport

The Alexandra Palace and Littleport incidents had the pantograph ripped of the roof, which ended up in the cess or hanging from the OLE as in Figure 4; all pantographs in these incidents were fitted with ceramic foot insulators.

The Berkhamstead incident occurred with polymeric foot insulators fitted to the pantograph and in a location where these type of insulators were also fitted to the infrastructure. The pantograph with knuckle uppermost, as Figure 10, had been previously damaged and the vehicle was travelling at 110mph; it should be noted that the knuckle was above the contact wire.

Figure 10 - Screen shot taken from a video of a 390 travelling at 110mph with knuckle uppermost.



This resulted in the pantograph striking the infrastructure and causing further damage as in Figures 11 and 12.

Figure 11 - Screen shot taken from a video of a 390 travelling at 110mph just after it struck a portal structure and the 'debris' recovered from site



Figure 12 - Distorted mast after being struck by the pantograph on 390 053



Discussion

Of the 'Trends' identified three were in the 'Primary cause of incident', these being:

- 1 Two pantograph horn failures between 11/10/2005 and 09/11/2006
- 2 Four pantograph chain failures between 15/04/2007 and 10/08/2007
- 3 Two Arthur Flury Neutral Section failures between 19/04/2008 and 04/01/2009

The 'pantograph horn failures' were addressed by changing the horn design and maintenance philosophy; as a result there have been no known failures since the above dates.

It is known that there has been at least one chain failure since the above dates, which has resulted in a major incident (Hendon, January 2014), but this particular report was not made available for analysis. Some TOCs have taken proactive steps to improve the condition of low speed pantographs whilst others have not.

It is not known whether there have been any additional failures of the Arthur Flury Neutral Section.

The most concerning and serious of the trends is 'Trend 3' 'Pantograph pulled of the vehicle roof and 'Trend 5' 'Pantograph with knuckle uppermost'. Both of these trends could have resulted in injury to passengers or staff by 'flying' OLE or pantograph debris. Also of concern was the distorted mast (Incident 28, Berkhamstead).

'Trend 7' '14 of the 34 incidents analysed occurred within 1km of a station, underbridge or crossing' is also of concern as it is possible that debris from the incidents could endanger staff or the public.

The purpose of this research is to ascertain the forces that may be generated during such incidents to allow failure modes to be optimised. Although the original concept was to mathematically simulate such forces, during the process of the analysis it became evident a simpler and less expensive method, which is almost guaranteed to produce meaningful results, would be to calculate the forces required to:

- Fracture the four foot insulators that allow the pantograph to be pulled off the vehicle
- Distort the mast, which supports the cantilever assembly

This may not ascertain the ultimate forces involved but it will provide a much better understanding of the forces. It also provides answers to two possible failure scenarios:

The RAIB made the comment in the report into the Littleport incident of the 05/01/2012 that 'The way in which components fail during a dewirement can limit or exacerbate the damage to rolling stock and infrastructure, and also have safety implications.' The knowledge obtained by calculating the above could be used to limit the damage to the rolling stock and infrastructure by designing frangible joints on the pantograph at the knuckle and possibly between the base frame and the lower arm. The forces generated during normal service operation are understood and well known; the force required to fracture the frangible links would have to have a safety factor of many times the forces experienced in normal operation yet below that required to either fracture the foot insulators or distort a mast.

Recommendations

The following recommendations are made:

- 1 Calculate the forces require to:
 - Fracture four ceramic pantograph foot insulators
 - Distort the OLE mast
- 2 Consider using the forces calculated to design a frangible link(s) in the pantograph articulation.
- 3 To limit the risk to staff or the public consider the secondary retention any detached items that occur as a result of the above (2).

Appendix A: Reports analysis

- Trend 1) Fractured pantograph horns
- Trend 2) Pantograph pulled backwards with upper and lower arms close to the horizontal
- Trend 3) Pantograph pulled off the roof of the vehicle
- Trend 4) Pantograph with knuckle uppermost
- Trend 5) Pantograph chain failure
- Trend 6) Failure of Arthur Flury Neutral Section
- Trend 7) 14 of the 34 incidents analysed occurred within 1km of a station, underbridge or crossing

No	Location of incident	Date of incident	Vehicle involved	Speed of vehicle	Weather conditions	Severity of failure	Insulator construction on vehicle and did it fail		KL or KT	Insulator construction on infrastructure and did it fail		Primary cause of incident	Approx. vicinity to station, underbridge	Position of Pantograph after incident
1	Claypole	11/10/2005	91132	125mph	N/A	N/A	Ceramic	N/A		Ceramic	N/A	Fractured horn	N/A	N/A
2	Madeley	26/03/2006	390024	N/A	N/A	5 spans	Polymeric	N/A	N/A	Ceramic	Yes	Flashover caused by wildlife	N/A	N/A
3	Attleborough	27/03/2006	390695 390698	N/A	Wind gusts of 20mph	N/A	Polymeric	No	KT	Polymeric	No	U bolt failure	N/A	Head, apex frame and control rod in ccess

No	Location of incident	Date of incident	Vehicle involved	Speed of vehicle	Weather conditions	Severity of failure	Insulator construction on vehicle and did it fail		KL or KT	Insulator construction on infrastructure and did it fail		Primary cause of incident	Approx. vicinity to station, underbridge	Position of Pantograph after incident
4	Grahame Park	21/04/2006	N/A	N/A	N/A	N/A	Ceramic	No	N/A	Ceramic	Yes	Failure of cross span ceramic insulator	N/A	N/A
5	Shenfield and Witham	30/08/2006	360 103 360 104	N/A	N/A	N/A	Ceramic	N/A	KL	Ceramic	N/A	N/A	N/A	N/A
6	Stowmarket	09/11/2006	90 013	N/A	N/A	N/A	Ceramic	No	KT	N/A	N/A	Fractured horn	N/A	Pulled Backwards with upper and lower arms close to the horizontal
7	Hanslope	07/12/2006	390 046	125mph	Wind gusts of 50 to 55mph	N/A	Polymeric	No	KT	Ceramic	N/A	Wind	0km	N/A
8	Rugby	15/01/2007	350 115	N/A	N/A	Minor	Ceramic	No	KT	Ceramic	N/A	In-conclusive	0km	Pantograph articulation hanging over the side of the vehicle

No	Location of incident	Date of incident	Vehicle involved	Speed of vehicle	Weather conditions	Severity of failure	Insulator construction on vehicle and did it fail		KL or KT	Insulator construction on infrastructure and did it fail		Primary cause of incident	Approx. vicinity to station, underbridge	Position of Pantograph after incident
9	Alexandra Palace	07/02/2007	313 057	40mph	calm - 6°C	Both panto's ripped off roof	Ceramic	Yes	N/A	Ceramic	yes	Slippage of cross wire span clamp	1km	Trackside
			313060					Yes						N/A
10	Monmore Green	**/03/2007	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Failure of in-line polymer rod	N/A	N/A
11	Thackley	15/04/2007	333 004	N/A	N/A	N/A	Ceramic	No	KL	N/A	N/A	pantograph chain failure	N/A	Knuckle uppermost
12	Ingatstone	19/04/2007	90 014	80mph	N/A	Minor	Ceramic	No	KL	Polmeric	No	pantograph chain failure	0km	Knuckle uppermost
13	Ilford Yard	23/05/2007	360 105	5mph	N/A	Minor	Ceramic	No	N/A	Ceramic	No	Fourth bar lug failure	N/A	Knuckle uppermost

No	Location of incident	Date of incident	Vehicle involved	Speed of vehicle	Weather conditions	Severity of failure	Insulator construction on vehicle and did it fail		KL or KT	Insulator construction on infrastructure and did it fail		Primary cause of incident	Approx. vicinity to station, underbridge	Position of Pantograph after incident
14	Hornsey	25/06/2007	313 063	N/A	N/A	Minor	Ceramic	No	KT	Ceramic	N/A	Pantograph running into unknown OLE component	1km	Pulled Backwards with upper and lower arms close to the horizontal
			313 025				Ceramic	No	N/A					Pantograph undamaged
15	Ben Rhydding	10/07/2007	333 015	N/A	Damp	Minor	Ceramic	No	KL	Ceramic	No	Pantograph chain failure	0km	Knuckle uppermost
16	Upton Park	10/08/2007	357 023	N/A	N/A	N/A	Ceramic	No	N/A	Ceramic	Yes	Pantograph chain failure	200 mtrs.	Pantograph undamaged
			357 034						KL					Knuckle uppermost

No	Location of incident	Date of incident	Vehicle involved	Speed of vehicle	Weather conditions	Severity of failure	Insulator construction on vehicle and did it fail		KL or KT	Insulator construction on infrastructure and did it fail		Primary cause of incident	Approx. vicinity to station, underbridge	Position of Pantograph after incident
17	Farringdon	17/08/2007	319 066	Slow	N/A	Severe	Ceramic	No	N/A	Ceramic	N/A	Driver failed to lower the pantograph whilst heading for an unwired road	50 mtrs.	Apex frame and head in cross contacts
			319 427				Ceramic	No	N/A					N/A
18	Armitage	20/09/2007	390 013	N/A	N/A	N/A	Polymeric	no	KT	Polymeric and ceramic	yes	Failure of Arthur Flury Neutral Section	N/A	Pulled Backwards with upper and lower arms close to the horizontal
19	Hutton-Bonville	18/11/2007	91 121	N/A	Wet and cold	Minor	Ceramic	No	KT	Ceramic	No	Fractured Neutral section	N/A	Pantograph housed (ADD operated)

No	Location of incident	Date of incident	Vehicle involved	Speed of vehicle	Weather conditions	Severity of failure	Insulator construction on vehicle and did it fail		KL or KT	Insulator construction on infrastructure and did it fail		Primary cause of incident	Approx. vicinity to station, underbridge	Position of Pantograph after incident
20	Shilbottle	15/12/2007	92 030	N/A	N/A	N/A	Ceramic	No	KL	Ceramic	yes	Pantograph failed due to running into an unknown OLE component	N/A	Knuckle uppermost
21	Quintins Hill	05/03/2008	92037	63mph	N/A	800 metres	Ceramic	No	KT	Ceramic	N/A	In-conclusive	1km	Pulled Backwards with upper and lower arms close to the horizontal
22	Armitage	19/04/2008	390 ***	N/A	N/A	N/A	N/A	N/A	KT	N/A	N/A	Failure of Arthur Flury Neutral Section	N/A	Pulled Backwards with upper and lower arms close to the horizontal
23	Kenton	11/07/2008	390 ***	125mph	Benign	5 spans	polymeric	N/A	KT	Ceramic	N/A	Catenary wire failure	N/A	N/A

No	Location of incident	Date of incident	Vehicle involved	Speed of vehicle	Weather conditions	Severity of failure	Insulator construction on vehicle and did it fail		KL or KT	Insulator construction on infrastructure and did it fail		Primary cause of incident	Approx. vicinity to station, underbridge	Position of Pantograph after incident
24	Watford Jct	04/01/2009	390 ***	N/A	cold - 5°C	N/A	N/A	N/A	N/A	N/A	N/A	Failure of stainless steel wire rope	1km	N/A
25	Wembley	04/01/2009	390 025	N/A	N/A	N/A	polymeric	N/A	N/A	N/A	N/A	Failure of Arthur Flury Neutral Section	2km	N/A
26	Hitchen	04/02/2009	365 513	40mph	N/A	N/A	Ceramic	No	KT	Ceramic	N/A	Loose jumper cable clamp	1km	Pulled backwards with upper and lower arms close to the horizontal
			365 539						KT					
27	Royson	04/02/2009	365 502	N/A	N/A	N/A	Ceramic	No	KT	Ceramic	N/A	Loose jumper cable clamp	500 mtrs	Pulled backwards with upper and lower arms close to the horizontal
			365 528				Ceramic	No	KT					

No	Location of incident	Date of incident	Vehicle involved	Speed of vehicle	Weather conditions	Severity of failure	Insulator construction on vehicle and did it fail		KL or KT	Insulator construction on infrastructure and did it fail		Primary cause of incident	Approx. vicinity to station, underbridge	Position of Pantograph after incident
28	Berkhamst'd	16/02/2010	390 053	110 mph	N/A	Major - structure distorted	polymeric	No	KL	polymeric	Yes	Failed insulator end casting	0km	Knuckle uppermost
29	Holme	30/08/2010	365 507	100mph	dry - wind 3mph - 12°C	N/A	Ceramic	No	N/A	Ceramic	N/A	In-conclusive	N/A	N/A
			365 537					No	KL					
30	Tollerton	14/02/2011	91 118	100mph	N/A	N/A	Ceramic	No	N/A	N/A	N/A	Fractured horn	10km	Pantograph head on wire but severely damaged
31	Northchurch	21/04/2011	390 007	N/A	N/A	N/A	polymeric	no	KL	N/A	N/A	pantograph chain failure	N/A	Knuckle uppermost
32	N/A	N/A	379 004	N/A	N/A	Minor	ceramic	no	KL	N/A	N/A	Pantograph chain anchor bolt failure	N/A	Flipped over with pantograph head perp'dicular to the contact wire

No	Location of incident	Date of incident	Vehicle involved	Speed of vehicle	Weather conditions	Severity of failure	Insulator construction on vehicle and did it fail		KL or KT	Insulator construction on infrastructure and did it fail		Primary cause of incident	Approx. vicinity to station, underbridge	Position of Pantograph after incident
33	Littleport	05/01/2012		80mph	High winds 50mph	Pantograph ripped off	Ceramic	Yes	KT	Ceramic	Yes	Movement of OLE structure	3.2km	Detached in the cess
34	Birmingham New Street	25/07/2012	323 219	10mph	N/A	Minor	Ceramic	no	KT	N/A	N/A	Failure of Arthur Flury section insulator	0km	Pantograph undamaged
			323 208				Ceramic	no	KT					Pulled backwards with upper and lower arms close to the horizontal

RSSB
Floor 4, The Helicon
1 South Place
London
EC2M 2RB

enquirydesk@rssb.co.uk

<http://www.rssb.co.uk>