Rail Accident Investigation Branch

Rail Accident Report

Runaway of an engineering train from Highgate 13 August 2010

Department for Transport

Report 09/2011
June 2011

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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Runaway of an engineering train from Highgate 13 August 2010

Contents

Summary

Shortly before 07:00 hrs on Friday 13th August 2010, an engineering train ran away along part of the Northern Line of London Underground.

The train consisted of a self-propelled diesel-powered unit designed for re-profiling worn rails. It had been working between Highgate and Archway stations on the southbound line during the night of 12/13 August. At the end of grinding operations that night, the crew of the unit found that they were unable to restart its engine to travel away from the site of work.

An assisting train, consisting of a six-car train of the 1995 stock used for passenger services on the Northern line, was sent to the rescue of the grinding unit. The assisting train was coupled to the grinding unit by means of an emergency coupling device, and the braking system of the grinding unit was de-activated to allow it to be towed. The combined trains then set out to run to East Finchley station. At about 06:42 hrs, after passing through Highgate station, the coupling device fractured and the grinding unit began to run back down the gradient towards central London. The crew of the grinding unit, who had no means of re-applying the brake, jumped off the unit as it passed through Highgate station. It then ran unattended for about four miles, passing through a further six stations, and came to rest near Warren Street station about sixteen minutes later. LUL control room staff took action to clear trains away from the path of the runaway unit.

No-one was hurt. There was some damage to the grinding unit, and points at Mornington Crescent station were damaged when the unit ran through them.

The emergency coupling broke because it was not strong enough for the duties it was intended to perform, and had been inadequately designed and procured. The RAIB has made seven recommendations to London Underground Ltd, covering the processes for introducing new engineering equipment, review of existing equipment, investigation of incidents, training of staff, the operation of unbraked vehicles, and the quality assurance processes used by LUL and its associated companies.

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Preface

1 The sole purpose of a Rail Accident Investigation Branch (RAIB) investigation is to prevent future accidents and incidents and improve railway safety.

2 The RAIB does not establish blame, liability or carry out prosecutions.

Key Definitions

3 All dimensions are given in metric units. Speeds are given in imperial units with the equivalent metric value.

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

The incident

Summary of the incident

5 On 13 August 2010, a defective rail grinding unit (RGU) was being pulled by an empty passenger train on London Underground's Northern Line. The trains were moving northwards up the incline towards East Finchley when, at 06:42 hrs, just after the trains had passed through Highgate station, the emergency coupler linking the RGU and the assisting train broke (figure 1).

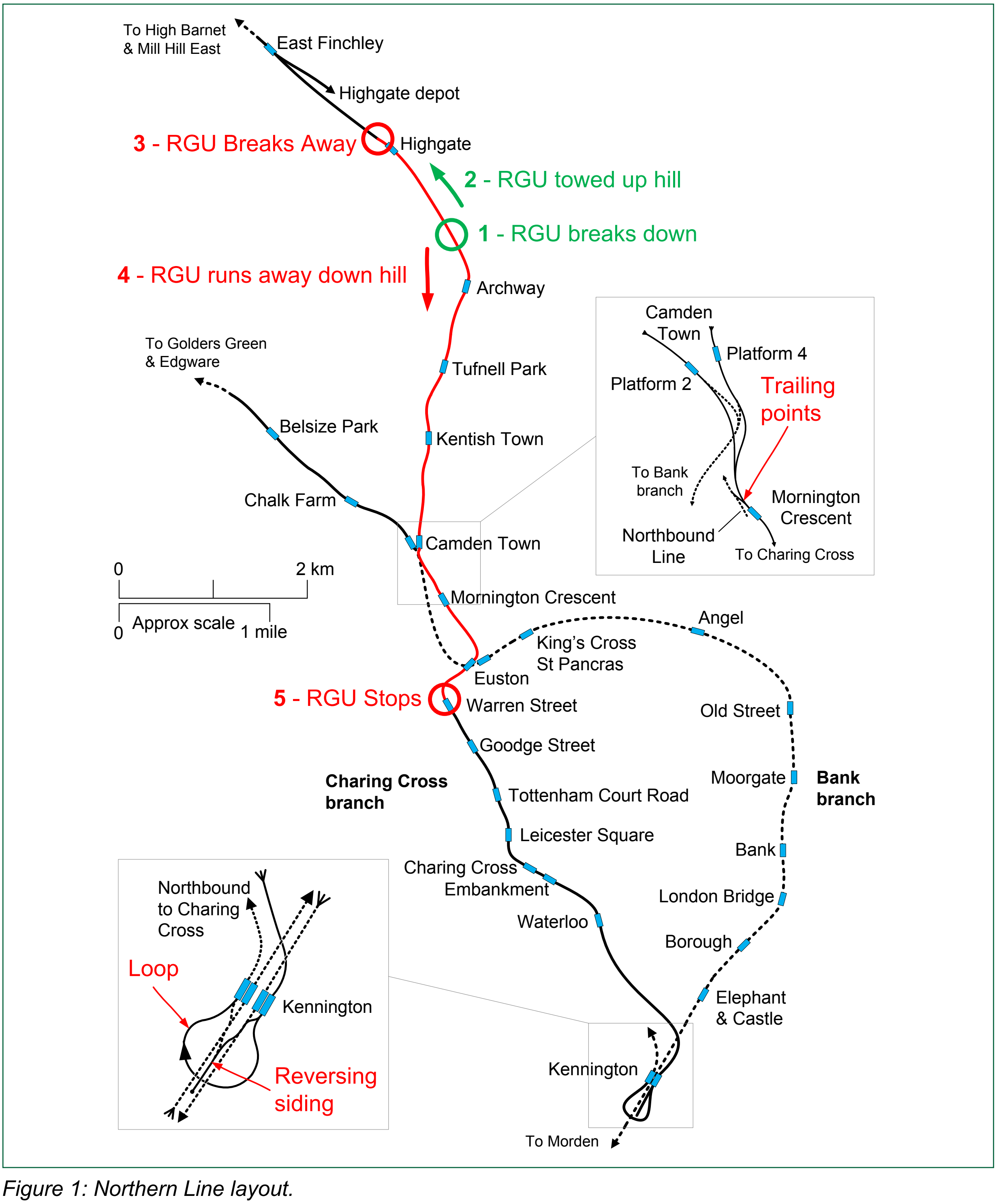


Figure 1: Northern Line layout.

6 The RGU then ran downhill through Highgate station and towards central London. Although the RGU's two-man crew were on the RGU, they were unable to stop it because its brakes had been disabled. They jumped off the RGU as it passed through Highgate station. The RGU ran downhill through Archway to Kentish Town and then continued on relatively level track until it was stopped by the rising gradient on the approach to Warren Street station. The runaway lasted 16 minutes and the RGU travelled about 6.9 km (4.3 miles).

7 Before the coupling broke, passenger carrying services had started to run from both Archway and Edgware towards central London. Some of these trains were directly in front of the runaway RGU so London Underground control room staff directed them away from the path of the runaway.

8 There were no casualties, but the RGU and the assisting passenger train incurred some damage.

Organisations involved

9 London Underground Limited (LUL) owns the Northern Line infrastructure and operates the passenger trains. LUL staff operate the control room which manages all rail traffic operations during *traffic hours* and some aspects of the railway during *engineering hours*. The relationships between LUL and the other organisations mentioned in this report are shown on the organogram in figure 7.

10 Infraco JNP was the part of LUL which undertook infrastructure maintenance and renewal on the Jubilee, Northern and Piccadilly Lines until 31 December 2002.

11 Tube Lines was formed by a consortium of private companies to maintain, renew and upgrade the Jubilee, Northern and Piccadilly Lines for a period of 30 years. This period began on 31 December 2002 when Infraco JNP staff and assets were transferred to Tube Lines. In June 2010, Tube Lines became a wholly owned subsidiary of Transport for London (TfL).

12 TransPlant was a discrete trading unit within Infraco JNP and subsequently a discrete trading unit within Tube Lines. It has supplied engineering plant and engineering trains to Infraco JNP, Tube Lines and some other organisations working on LUL assets.

13 The Emergency Response Unit (ERU) is part of Tube Lines. It provides resources for track and train emergencies throughout the LUL network.

14 Schweerbau Gmbh & Co Kg owns and operates engineering trains, including the RGU involved in the Highgate incident. It had hired the RGU and its crew to TransPlant.

15 Powerhouse Design & Engineering Ltd design and fabricate steelwork, including the emergency coupler used with the RGU when working on LUL infrastructure.

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

Location

17 The incident took place in the tunnels normally used by southbound trains on the High Barnet and Charing Cross branches of the Northern Line (figures 1 and 2). The southbound High Barnet branch enters tunnel at East Finchley and then falls at typically 1 in 60[1] to Highgate station and then onwards through Archway for around 3.5 km to Kentish Town. The line then follows a series of small rises and falls interspersed with short sections of level track for a distance of about 1.5 km through Camden Town to a junction where trains are routed to either the Bank (City) branch or the Charing Cross branch.

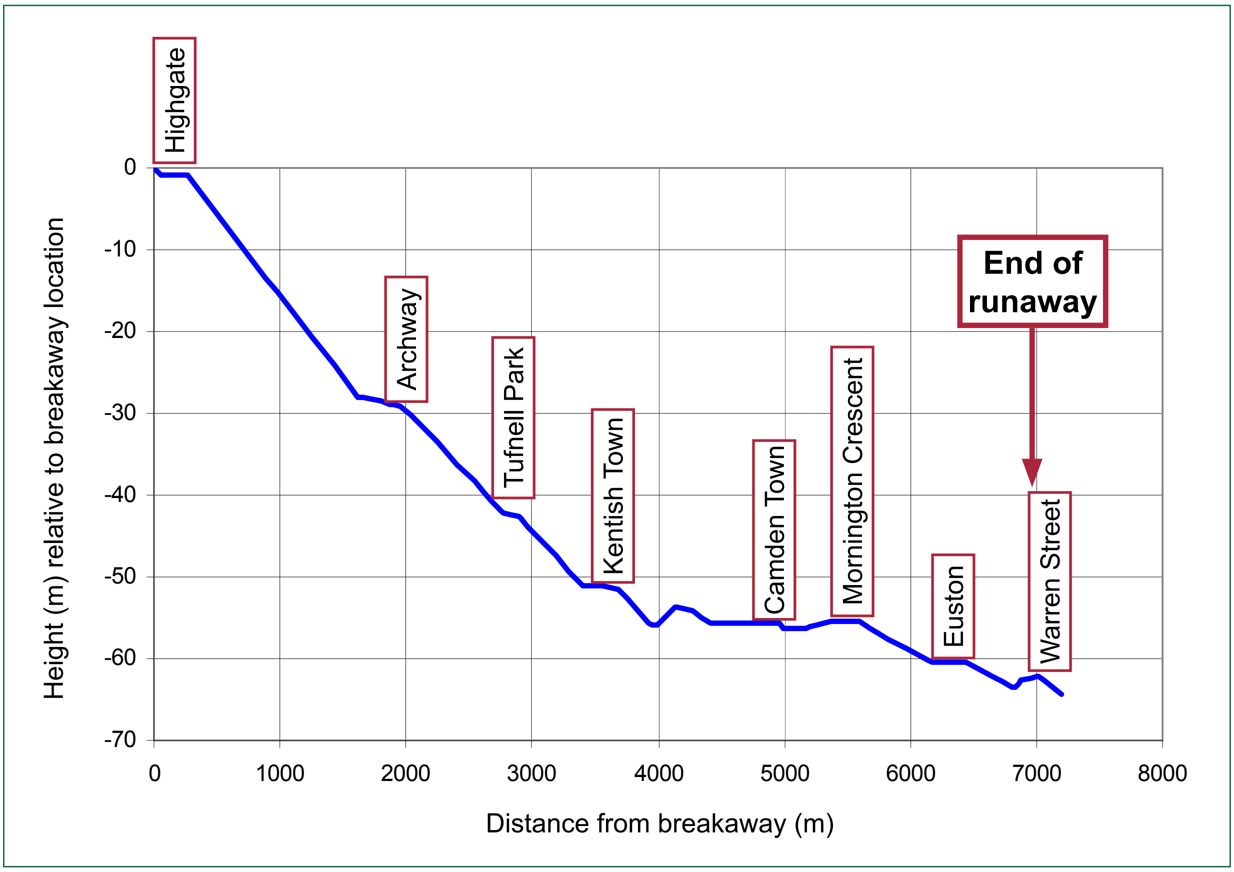


Figure 2: Northern Line vertical alignment.

18 Beyond this junction, it is about 2 km to Warren Street station on the Charing Cross branch. The first 0.5 km, including Mornington Crescent station, is approximately level. The line then falls and passes through Euston station before rising into Warren Street station. Beyond Warren Street station, the line falls almost continuously through Charing Cross and Waterloo stations before climbing into Kennington station. After passing through Kennington station, trains from Charing Cross can be routed to Morden, into a reversing siding or around a loop which takes them back onto the northbound Charing Cross branch.

19 Electric traction power for passenger and some engineering trains is supplied through a third and fourth rail *conductor rail* system.

[1] 1 metre change in level over a distance of 60 metres.

20 Except for lines within depots, the Northern Line is fully *track circuited* with *points* and signalling operated from a control room near Euston. Train movements are normally controlled using lineside colour light signals supplemented by *trainstops*. Control room staff give instructions by radio to train operators if trains are required to make unusual movements for which no signals are provided.

21 The maximum speed generally permitted for southbound trains between East Finchley and Archway is 40 mph (64 km/h) and from Archway to Warren Street is 35 mph (56 km/h). There is a local speed restriction of 20 mph (32 km/h) through the junction between Camden Town and Mornington Crescent, and a 30 mph (48 km/h) restriction on the curve approaching Euston station.

External circumstances

22 The incident occurred entirely within tunnel and was unaffected by weather.

Trains involved

23 The RGU is a self-propelled three-car diesel powered on-track grinding machine weighing about 37 tonnes (figure 3). It is equipped with grindstones which are used to maintain the shape of the railhead to give trains a safe and reasonably smooth ride. The train was built in 2001 and moves between various European railway and tramway systems. It was first used on LUL infrastructure in 2002. The RGU can be used in tunnels provided special ventilation arrangements are made to control exhaust emissions. The emergency coupler used with the RGU is described in paragraph 121. The defect which necessitated towing the RGU, and the absence of effective brakes during this activity are discussed in paragraph 68.

Figure 3: Rail grinding unit showing vehicle end which collided with passenger train.

24 All passenger trains on the Northern Line are 1995 tube stock (figure 4). They are electrically powered and obtain power from the conductor rails except when supplied by short lengths of cable for movements in depots and, occasionally, at other locations when conductor rail power is unavailable.

25 Battery locomotives are used to power most of the engineering trains needed for maintenance and renewal activities on the railway. Battery locomotives can draw power from conductor rails, when they are energised, or from on-board batteries (figure 5). As they are electrically powered, they are particularly suitable for engineering trains which operate in tunnels.

26 Diesel locomotives manufactured by Schoma (generally described as Schoma locomotives, figure 6) are used to power some trains above ground; their exhaust emissions normally preclude operation in tunnels.

Figure 4: Passenger train (1995 tube stock) (image courtesy of LUL).

Figure 5: Two battery locomotives (image courtesy of Tube Lines).

Figure 6: Side and end views of Schoma locomotives (side view image courtesy of Tube Lines).

Staff involved

27 The Plant Approvals Engineer was a TransPlant employee with responsibilities including obtaining the Tube Lines and LUL approvals needed for the RGU to work on LUL infrastructure. This, and other key roles, are shown on the organogram in figure 7.

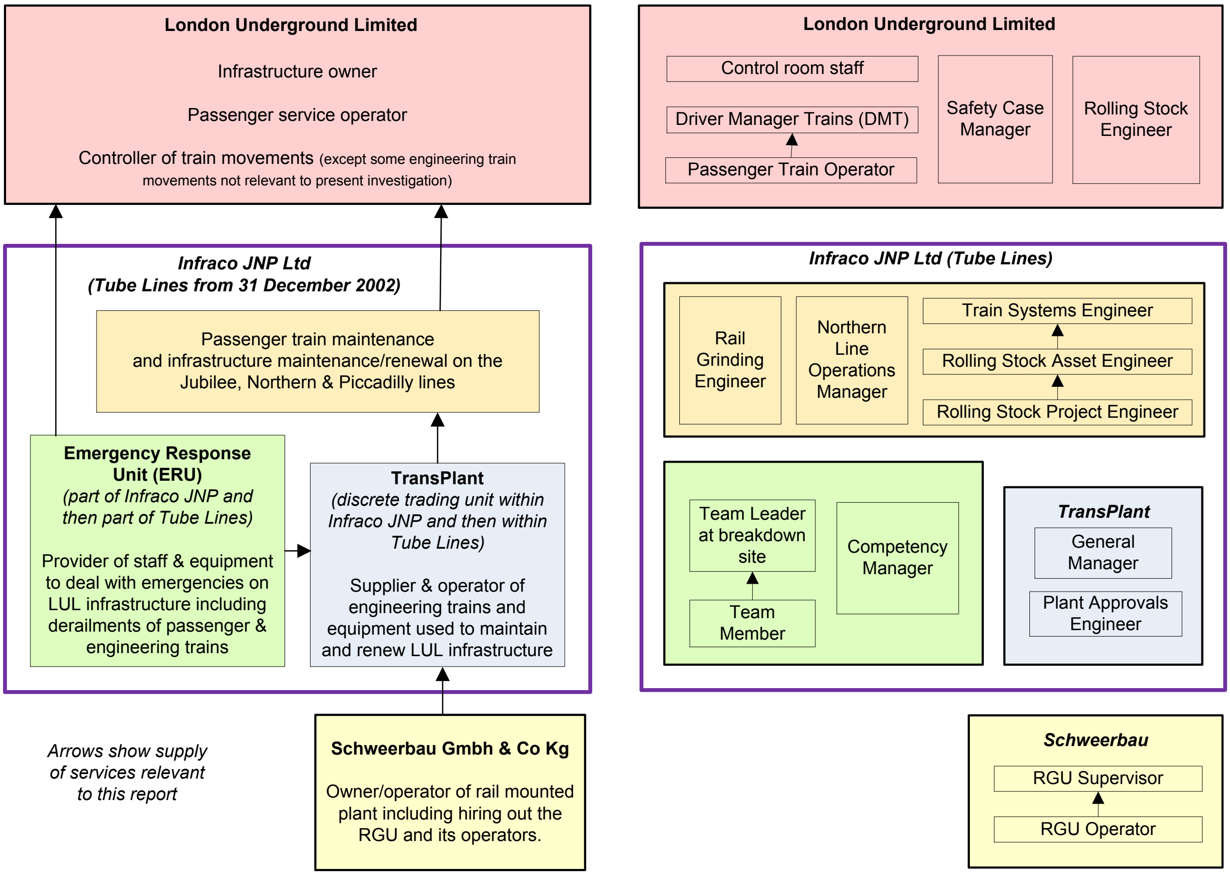


Figure 7: Company organogram (left) and staff organogram (right).

28 Rolling Stock Asset Engineer 1 was the Infraco JNP employee responsible for initial rolling stock approval of the RGU in 2002. This individual was subsequently promoted and his replacement, Rolling Stock Asset Engineer 2, was responsible for renewing this approval on behalf of Tube Lines in 2004 and 2008.

29 The Rolling Stock Project Engineer was an Infraco JNP employee working for Rolling Stock Asset Engineer 1. He was assigned particular responsibilities relating to assessing the rolling stock issues associated with introducing the RGU onto LUL infrastructure in 2002.

30 The Train Systems Engineer was a Tube Lines employee with duties including responsibility for rolling stock assets. Rolling Stock Asset Engineer 1 had been promoted to Train Systems Engineer before he was involved with investigating a problem encountered during recovery of the RGU shortly before the runaway in 2010.

31 Rolling Stock Engineer 1 was employed by LUL and endorsed approval of the RGU in 2002 and 2004. His successor, Rolling Stock Engineer 2, endorsed approval of the RGU in 2008. The post held by these individuals is formally known as “The Rolling Stock Engineer”.

32 The Rail Grinding Engineer was managing the rail grinding programme on behalf of Tube Lines; he did not normally accompany the RGU and was not present when the runaway occurred.

33 The RGU Supervisor and the RGU Operator were operating the RGU on the night of the incident. Both were employed by Schweerbau.

34 Tube Lines’ Northern Line Operations Manager was responsible for managing infrastructure work on the Northern Line. He did not normally accompany the RGU but was doing so on the night of the incident as part of an investigation into an event unrelated to the runaway.

35 The ERU Competency Manager was involved in assessing tests carried out on the RGU before the Highgate incident.

36 An ERU team leader, and an ERU team member, assisted recovery operations at the location where the RGU broke down.

37 The Service Manager was employed by LUL and was located at the Northern Line control room. He was responsible for managing services on LUL’s Northern Line at the time of the incident.

38 The Duty Manager Trains (DMT) became responsible for on-site management of recovery operations after the assisting train was deployed to site. He was an LUL employee.

39 The Train Operator was driving the passenger train which assisted the RGU and was employed by LUL.

Events preceding the incident

40 The RGU first worked on the LUL infrastructure in 2002 and returned for part of every year until the Highgate incident. It had returned to LUL from Stockholm in July 2010, and broke down on 17 July 2010 near West Hampstead station on the Jubilee Line. An attempt to push the RGU with a passenger train using the emergency coupling was stopped because staff were concerned by the amount of deflection of the emergency coupling. A passenger train then recovered the RGU by pulling it about 5 km (3 miles) to Neasden depot using the emergency coupler. Detailed records of this journey are not available so RAIB cannot determine whether it included any sudden brake applications. The absence of sudden brake applications is a possible reason why the emergency coupler did not break during this recovery (paragraph 109).

41 Testing after the July 2010 incident (paragraphs 164 to 172) resulted in a decision to provide a modified emergency coupler. Until this was available, Tube Lines permitted use of the RGU and the existing emergency coupler provided that the RGU was only recovered by being pulled. This decision was agreed with LUL's Rolling Stock Engineer 2.

42 The RGU had successfully completed the rail grinding work planned for the night of 12/13 August 2010 when, at about 03:30 hrs its engine failed with the RGU standing in the southbound tunnel about 500 metres north of Archway station (the breakdown site). The RGU crew found that they were unable to repair the defect without causing excessive delays to passenger services which normally start in this area at about 05:30 hrs. Control room staff therefore sent an empty passenger train from East Finchley station to recover the RGU. This train was intended to pull the RGU back to East Finchley station, and then into Highgate depot.

43 The assisting train reached the RGU at 05:44 hrs. Staff from the RGU and the assisting train coupled the trains together using the emergency coupler in accordance with instructions carried on the RGU (paragraph 80). The RGU crew then used hand tools to fix the RGU's brakes in the off (released) position. This meant that the RGU was now an unbraked vehicle at the rear of the assisting train.

44 Control room staff then gave authority for the assisting train to start pulling the RGU towards East Finchley (ie contrary to the normal direction of train movements in the southbound tunnel). This movement commenced at 06:34 hrs.

Events during the incident

45 At 06:42 hrs the RGU had been towed about 1.5 km northwards, and was about 140 m past Highgate station, travelling uphill at 10.6 mph (17 km/h), when the emergency brake was applied automatically on the assisting train (paragraphs 110 to 112).

46 As the assisting train slowed down, the emergency coupler broke. The unbraked RGU then collided with the rear of the assisting train and began to roll back down the incline towards Highgate station and central London.

47 The RGU crew were aware that they could not stop it (paragraph 70), and jumped onto Highgate station platform as the RGU passed through the station at about 11 mph (18 km/h).

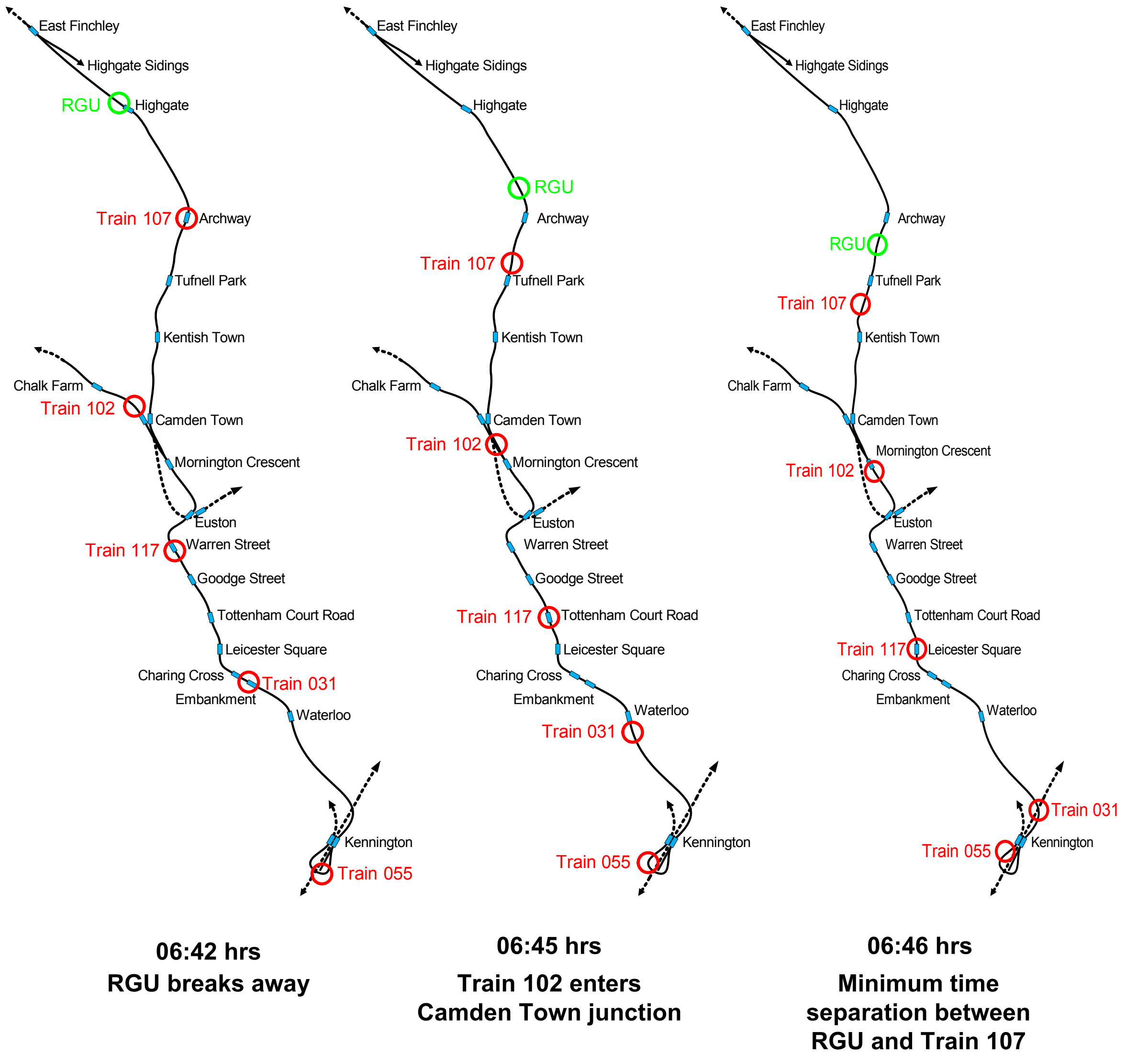
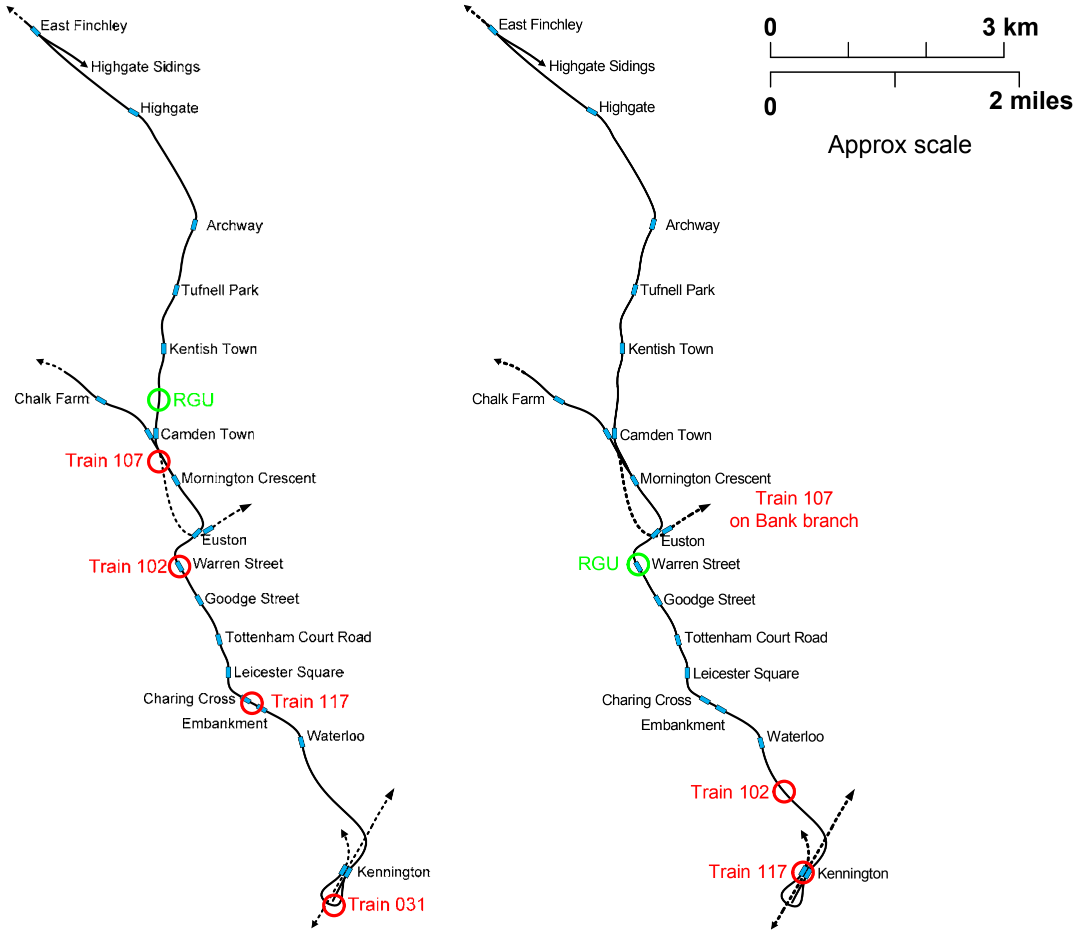


Figure 8: Train positions during the runaway.

48 At 06:43 hrs, the Northern Line Operations Manager and the DMT used their radios to tell control room staff that the RGU was running away. At this time the following passenger trains were in the southbound Northern Line tunnels between Archway and Kennington (figure 8):

- Train 107 standing at Archway station.
- Two trains on the Charing Cross branch: one near Warren Street station and the other near Embankment station.
- Train 102 at Camden Town station about to move onto the Charing Cross branch.
- Four trains on the Bank branch: near Euston, Old Street, Bank and Borough stations.

49 Control room staff immediately informed the operator of train 107 (at Archway) that there was an emergency and that he should start his train immediately.



06:49 hrs

Train 107 clears Camden Town junction, minimum distance between RGU and Train 107

06:58:00

RGU Stops

Figure 8: Train positions during the runaway (continued).

50 The service manager then reviewed the situation. He had no means of knowing how far the RGU would roll. He concluded that routing the RGU onto the Charing Cross branch gave the best opportunity to avoid a collision with a passenger train. It also provided two opportunities for trying to derail the RGU and the certainty that the RGU could be stopped at Kennington. The opportunities to derail the RGU were provided by *trailing* points which could be set against the RGU's route at Mornington Crescent and at Charing Cross. Routing the RGU into a reversing siding at Kennington provided the opportunity to stop the RGU by sending it towards a set of *buffer stops* (figure 1).

51 The service manager knew that there were staff on the RGU when it started to run away. When he was deciding what to do, he did not know that they had jumped off at Highgate. He appreciated the possible consequences for anyone on the RGU if it was derailed or ran into buffer stops. He decided that a collision between the RGU and a passenger train was likely to have worse consequences.

52 At 06:46 hrs the service manager directed a service operator to stop further trains entering the Charing Cross branch. This was about one minute after train 102 had left Camden Town (figure 8).

53 Train 107 reached Tufnell Park station at 06:46 hrs. At this time control room staff contacted the operator and instructed him to drive quickly and omit station stops. The operator complied with these instructions and left the station without opening the train doors.

54 The RGU gained speed as it ran down the incline from Highgate and was gaining on train 107 until this train was approaching Kentish Town station. At this point, the trains were about 46 seconds apart. The RGU reached its maximum speed during the runaway, about 35 mph (56 km/h), at about this time.

55 The RGU began to lose speed as it ran onto the generally level track beyond Kentish Town station. At about this time, Train 107 slowed to observe the speed restriction at Camden Town junction. The minimum spacing between the RGU and Train 107, about 650 metres, occurred as the rear of Train 107 passed clear of Camden Town junction at about 06:49 hrs.

56 Control room staff used the points at Camden Town junction to divert Train 107 onto the Bank branch from its planned route to the Charing Cross branch. The control system then automatically reset these points to direct the RGU onto the Charing Cross branch. Although the RGU and Train 107 were about 60 seconds apart, the available window for resetting the points was only about 45 seconds. This was because safety systems lock the points if any part of a train is on, or near, them. This is a safeguard against derailments caused by points moving beneath trains.

57 When the junction was reset to the Charing Cross branch, the nearest train in front of the RGU (Train 102) was at Warren Street station, around 2.4 km ahead of it. This distance gradually increased during the remainder of the runaway because the RGU was running relatively slowly and control room staff had instructed all southbound trains on the Charing Cross branch, including Train 102, to omit station stops.

58 The RGU was travelling at about 12 mph (19 km/h) as it passed over Camden Town junction and onto the Charing Cross branch at 06:50 hrs. It did not exceed this speed during the remainder of the runaway. Control room staff attempted to derail the RGU by setting trailing points at Mornington Crescent against the runaway. The RGU did not derail but it did slow down and damage the points as it passed over them.

59 The RGU reached Warren Street station at 06:58 hrs and rolled back a short distance, to stop with its south end cab about 60 metres from the north end of this station. If the RGU had not been slowed at Mornington Crescent points, it is possible that it would have run through Warren Street station and onto the predominantly downhill gradient to Waterloo.

Consequences of the incident

60 There were no casualties.

61 The emergency coupler was broken. The RGU suffered significant damage to the drawbar linking two of its cars. The *clevis* fixing on the RGU used to connect the emergency coupler was also damaged. The assisting train suffered damage to its coupling and minor bodywork damage.

62 The points at Mornington Crescent were damaged. The Charing Cross branch remained out of service until 17:58 hrs on the day of the incident.

The Investigation

Sources of evidence

63 The following sources of evidence were used:

- witness statements;
- the on train data recorder (OTDR) from the assisting passenger train;
- station CCTV recordings;
- records held on Trackernet – a system which records the times at which trains pass selected points on the railway;
- voice recordings of radio and telephone messages;
- emergency coupler design and testing records;
- post incident examination and testing;
- RGU approval, inspection and maintenance records;
- LUL and Infraco JNP/Tube Lines standards;
- site photographs and measurements;
- staff training and competency records;
- records of similar occurrences; and
- a review of previous RAIB investigations that had relevance to this incident.

Key facts and analysis

Identification of the immediate cause[2]

64 **The runaway occurred because there were no operational brakes on vehicles which became detached when an emergency coupler broke.**

65 The RGU became detached from the assisting train when the coupler broke. Its brakes had been isolated to allow it to be towed, and there was no other method of stopping it. It immediately began to run back down the 1 in 60 gradient on the southbound Northern Line towards Highgate station.

66 There were no measures in place to prevent a runaway on a rising gradient if for any reason the RGU became detached from the assisting train.

Identification of causal[3] and contributory factors[4]

RGU braking system inoperative and no other precaution against a runaway

67 **The RGU brakes had been fixed in the released position and could not be applied whilst the vehicle was in motion. No other precautions had been provided to prevent a runaway if the emergency coupler failed.**

68 The RGU brakes were held on by springs and released by application of air pressure to brake cylinders. Air pressure was normally provided by a compressor powered by the RGU's main engine but this was unavailable when the main engine would not run above idling speed. This defect, and the RGU's reliability, are discussed in appendix E.

69 The RGU had an auxiliary compressor which could be driven by the main engine in idling mode. However, this was only possible after a drive belt was connected between the auxiliary compressor and engine. The RGU crew attempted to fit this belt. They found the task difficult because, in the tunnel, there was not enough space to fully open an access door in the side of the RGU. They stopped trying to fit the drive belt when it became apparent that an assisting train would provide a quicker means of recovery, and thus a smaller delay to the passenger service.

70 The RGU had been designed to operate on its own, and there was no means of connecting the braking system of the RGU to any assisting train on LUL. As no air pressure was available to operate the RGU brakes, the brakes were released by inserting a special tool into some brake cylinders, and by unscrewing a bolt on the remaining brake cylinders. This was done from beneath the RGU. Once released by this means, there was no method of applying any brakes from the RGU cabs.

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

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

[4] Any condition, event or behaviour that affected or sustained the occurrence, or exacerbated the outcome. Eliminating one or more of these factors would not have prevented the occurrence but their presence made it more likely, or changed the outcome.

71 Witness evidence shows that some senior staff in LUL, Tube Lines and the ERU understood that unbraked vehicles require special precautions. This was illustrated during recovery of the RGU in July 2010 (paragraph 40). On this occasion, the ERU was leading operations on site, and an LUL line general manager was involved in planning some technical aspects of the recovery operation. As a result of these inputs, the emergency coupler was supplemented by a secondary coupling formed by chains attached between the assisting train and RGU. In addition, an empty train was secured as a barrier between the recovery operation and lines open to public traffic. Similar senior staff were not involved in the technical aspects of work at the Highgate breakdown site, mainly because the recovery was expected to have a smaller impact on the day's train service.

72 The only written instructions relating to recovery of the RGU were contained in the emergency towing procedure carried in the RGU cab. This procedure recognised that the RGU was an unbraked vehicle at the end of a train but did not include any mitigation against a runaway if the emergency coupler broke (paragraph 79).

73 The DMT became responsible for leading site activities when traction power was switched on around the RGU to allow the passenger train to reach the RGU. The DMT had taken up his post 11 months before the incident after completing a two year graduate training scheme. He had only received training on the LUL rules for passenger trains; these did not cover movement of unbraked stock because passenger train operating staff are not permitted to move unbraked stock.

74 The DMT's main role at the breakdown site was to ensure effective communication between the various people involved. He appreciated that the RGU was unbraked, but understood from the Northern Line Operations Manager that the RGU could not be moved without releasing its brakes.

75 Witness evidence shows that the Northern Line Operations Manager had checked that the coupling arrangements were in accordance with the emergency towing procedure before telling the DMT that the train was ready to move. There is conflicting evidence about whether the ERU staff on site also told the DMT that the train was ready to move. Recordings of radio messages show that, at 06:28 hrs, the DMT informed control room staff that the train was ready and, at 06:29 hrs, control room staff gave the train operator formal authority to commence the movement.

76 When LUL's Northern Line control room staff authorised the tow to commence, they did not apply any special procedures relating to runaway risk because:

- there was no special procedure in place to cover this situation (paragraph 79); and
- staff at the breakdown site had not asked control room staff to provide any special precautions and, based on previous experience working with the ERU and the Northern Line Operations Manager, the control room staff felt confident that site staff would manage the recovery safely. Witness evidence is that the control room staff were unaware that the RGU was unbraked but, even if they had known this, their confidence in the site staff meant that they would still have authorised the tow.

77 Section 1 of LUL's Rule Book 4 requires that the rostered duty officer (a senior member of LUL staff) should be consulted before "deviating" from the rule book requirements for dealing with defective trains. The same rule requires the rostered duty officer to undertake a real time risk assessment before authorising a deviation. These officers can, if necessary, obtain advice from rostered specialist staff. Some aspects of recovering the RGU were covered by instructions carried on the RGU (paragraphs 80 and 84). Remaining activities were being undertaken by staff directly involved in the incident, based on their experience and judgement.

78 LUL has stated that, in this context, "deviating" is intended to cover 'controlled situations where the contravention of rules will be authorised by the Rostered Duty Officer. It is not intended for use in situations where there are no applicable rules.' The staff involved with recovery of the RGU were following the instructions carried on the RGU (paragraph 80) and did not consult the rostered duty officer.

Design and documentation of the recovery procedure

79 **The design and documentation for the recovery procedure were inadequate. The procedure relied entirely on the emergency coupler to prevent a runaway. This was a causal factor.**

80 The emergency towing procedure carried in the RGU cab described how to deploy the emergency coupler and how to release the RGU brakes. It then stated that the RGU "is ready for towing". There is no reference to mitigation against a runaway due to a failure of the emergency coupler.

81 The emergency towing procedure had been written by Schweerbau staff based on their observation of the acceptance testing at Lillie Bridge Depot in 2002 (paragraph 156). It was submitted to TransPlant by Schweerbau, but there is no evidence of any formal checking by TransPlant. There was no formal consideration of the risks associated with the unbraked RGU running away if the emergency coupler broke.

82 Witness evidence is that chains were not used as a secondary coupling during acceptance testing at Lillie Bridge in 2002 because the RGU engine was running, allowing the RGU brakes to operate normally. Witnesses report that, when designing emergency couplers, the Plant Approvals Engineer had expected the ERU to attend any recovery and to use chains as a secondary coupler. There is no evidence of anyone considering how chains would be used if the ERU was not present. Emergency coupling chains are normally brought to incidents by the ERU. The RGU, in common with most London Underground rolling stock, does not carry them.

83 The use of chains is mentioned in the RGU emergency tow procedures which had been prepared by Schweerbau for use on some other European rail networks. It has not been possible to determine why Schweerbau only included chains in some of these emergency tow procedures.

84 LUL's standard TE-IS-0202-A2 'Plant Approval' requires that an operational safety plan & instructions (OSP&I) is produced for all items of plant operating on LUL infrastructure. This document defines the roles and responsibilities of staff operating the plant. It is not distributed to LUL railway operating staff as they do not operate plant. An OSP&I was written for the RGU by the Plant Approvals Engineer and a copy was in the RGU cab at the breakdown site.

85 The OSP&I for the RGU was not subject to a formal checking process within TransPlant or Infraco JNP (or, latterly, Tube Lines). However, email evidence shows that, like all OSP&I documents prepared until 2007, the revision of this document used to support initial approval of the RGU had been reviewed by LUL, and that changes were made as a result of this review. An email dated 29 October 2002 from the LUL Safety Case Manager shows that the OSP&I had been reviewed and was considered to be satisfactory. This revision of the OSP&I, and all subsequent revisions issued before the Highgate incident, noted (at paragraph 7.4.9) that the RGU brakes could not be operated from an assisting train during recovery operations. None of these revisions state that no emergency brake was available on the RGU.

86 The OSP&I for the RGU was revised on several occasions but the section relating to emergency procedures was unchanged between the first use of the RGU in 2002 and the Highgate runaway. The OSP&I states that the RGU carries emergency recovery equipment and procedures to enable recovery of the RGU if it becomes unserviceable. Details of these procedures are not given except to say that the "machine supervisor and operator are responsible for carrying out the emergency recovery procedures using the emergency recovery equipment provided on the machine and if/as necessary assisting the emergency response unit".

87 Neither the emergency towing procedure, nor the OSP&I, stated the type(s) of train which could be used to recover the RGU. The limitations on the types of train that could be used in practice are discussed in paragraphs 136 to 138. Neither document provides any information about the coupling settings to be selected on the assisting train.

88 The assisting train operator's training only covered passenger trains and, when he coupled his train to the RGU using the procedures that he had been taught, he found that air escaped from the braking system at the end of the passenger train adjacent to the RGU. He needed to stop the air escape in order to move the trains but had received no guidance about how to do this. He stopped the air escaping using a method which also had the effect of requiring him to drive the train in *restricted mode* (paragraph 110). A properly designed recovery process would have recognised that the emergency coupler could allow air to escape from the brake system. The process would then have provided explicit instructions on how to deal with this and provided the train operator with information about the correct position for other controls used during coupling operations.

89 The OSP&I and the emergency towing procedure both refer to a 5 mph (8 km/h) speed limit during recovery operations on LUL infrastructure. The OSP&I reference is in a section listing equipment carried on the RGU but is not mentioned in the section headed "emergency procedures". The emergency towing procedure reference is in a general introduction but not in the section describing how emergency towing is carried out on LUL infrastructure. Poor presentation of this speed limit may have contributed to staff being unaware of the limit when deciding to tow the RGU at speeds of up to 10 mph (16 km/h) (paragraph 111).

90 The OSP&I allocated responsibility for fixing the emergency coupler to the RGU supervisor and the RGU operator (paragraph 86). They undertook these roles at the breakdown site. Other tasks were allocated on site by mutual agreement between the staff involved. The emergency tow procedure gave no information on this topic. In most instances, there was no documentation allocating responsibilities to appropriate individuals.

91 The only other statement in the OSP&I concerning staff responsibilities said that emergency procedures should be carried out under the direction and supervision of the *site person in charge* (SPC). SPC is a LUL safety-related qualification for a person in charge of engineering operations on the track and not normally responsible for the operation of trains. Readers of the OSP&I are likely to assume that this qualification is being referred to, although a holder of it would not necessarily be competent to supervise a recovery operation. In many circumstances, including those at Highgate, there is no requirement for the holder of a SPC qualification to accompany the RGU.

92 The Rolling Stock Project Engineer's team was not involved in the preparation or approval of the emergency towing procedure or the OSP&I.

93 The LUL Railway Safety Case current when the RGU was first approved, required an operational safety plan (OSP) to be provided when a new piece of rolling stock or on-track plant was introduced onto LUL infrastructure[5]. The safety case states that "the Operational Support Manager (Train Services) accepts operational safety plans once they are assured...all operating staff's responsibilities have been identified, assigned and training has been provided".

94 The LUL standard covering first approval of the RGU was Ta251, 'Introducing New or Modified Rolling Stock to LUL', dated April 2002. This describes the purpose of the OSP as "to formally review the risks imported and to show how these are eliminated or mitigated...the paramount objective is to identify the actions to be taken to guarantee safety on the railway [and to identify] personnel responsible for carrying out these actions". Ta 251 required that "method statements which provide greater detail on how a vehicle is to be used must be written and referenced within the operational safety plan when necessary".

95 The Case for Safety Paper prepared in 2002 by Infraco JNP staff as part of the RGU approval process (paragraph 136) stated that a "safe system of operation and working [for the RGU on LUL infrastructure] will be set out in a generic operational safety plan (OSP)". This paper also stated that "recovery arrangements [will be] detailed in OSP and implemented in conjunction with London Underground".

96 LUL's Operational Support Manager (Train Services) approved introduction of the RGU in a letter dated 6 November 2002. This referenced the OSP&I which had been reviewed by LUL staff (paragraph 85) and an OSP relating to diesel emissions from the RGU. Neither of these documents detailed any LUL activities associated with recovery of the RGU.

[5] LUL Railway Safety Case version 3.10, 12 July 2002, paragraph 13.3.7.

97 Recovery of the RGU using a passenger train required the passenger train operator to select appropriate settings during coupling and to comply with a maximum speed limit. LUL's Railway Safety Case, Ta251 and the Case for Safety Paper required these (and possibly other) requirements for LUL operational staff to be documented in an OSP and/or method statement. There was no OSP or method statement covering these activities. Neither the OSP&I, nor any other documentation, dealt with the associated training activities as required by LUL's Railway Safety Case (paragraph 176).

98 Witness and email evidence shows that some people involved in the RGU approval process were using the term OSP when they meant OSP&I. It is uncertain whether this confusion misled anyone involved with approving the RGU.

99 LUL Standard Ta251 required technical details about rolling stock to be supplied to the ERU by the project manager responsible for introducing new rolling stock to LUL infrastructure. The Plant Approvals Engineer was acting as the project manager for the introduction of the RGU. The required details included information about emergency couplings and brake operation/isolation. The ERU had no record of receiving these details.

100 In the absence of instructions concerning appropriate actions, the Northern Line Operations Manager and the RGU crew decided that the RGU crew should travel on the RGU during the tow to report any problems. There is no evidence that the risks associated with this action were assessed when this decision was made.

Role of the ERU

101 ERU staff at the breakdown site did not query the recovery procedure when they saw that the RGU was being recovered as an unbraked vehicle. This is a possible causal factor.

102 The ERU provided specialist training and regular practical exercises for ERU staff. Formal training was targeted at specific activities such as how to use particular tools. There was no formal training in how to plan recovery operations taking account of issues such as the control of risks associated with an unbraked vehicle. It was expected that ERU staff would learn these planning skills through experience and through the regular practical exercises provided for them. Although not formally documented, witness evidence indicates that control of risks associated with unbraked vehicles was mentioned in some training courses.

103 ERU staff had received no training specifically relating to the RGU, and they had no technical details about the RGU (paragraphs 99 and 176).

104 The role of the ERU site team at the breakdown site was not defined. They had been mobilised by the Northern Line control room, shortly after the RGU broke down, to provide an additional resource if required. The ERU team's manager (based at Acton) specifically asked the team to check that the RGU grindstones were secured; the team did this. The site team leader followed his normal practice during recoveries: he watched the coupling from the rear cab of the assisting train and instructed the other ERU team member to travel in the front cab of the assisting train. Witness evidence shows that the ERU site team were not asked to provide any other assistance; and that they did not undertake any other activities.

105 ERU staff at the breakdown site appreciated that the RGU was being recovered as an unbraked vehicle on the end of a train. One of them asked whether the RGU could be towed with some brakes left on, a precaution used to prevent runaways when dealing with some LUL passenger stock. He was told by a member of the RGU crew that this would not be permitted because it would have led to overheating and the associated risk of fire.

106 If the ERU site team had been in charge of the recovery, witness evidence indicates that they would probably have consulted a senior manager before moving any train. Although not formally trained in planning recovery operations, witness evidence shows that some (possibly all) of these senior managers appreciated hazards associated with unbraked vehicles and the need for appropriate mitigation against a coupling failure. These staff appreciated that chains had sometimes been used to provide this mitigation. The ERU staff at the breakdown site had not attended the July 2010 recovery, so they had not seen chains used as a secondary coupling during this event (paragraph 71).

107 There was no further intervention from the ERU after they had been told that the RGU could not be towed with the brakes applied (paragraph 105). This led the DMT to believe that the ERU had endorsed the movement of the RGU as an unbraked vehicle at the rear of a train (paragraph 75).

108 The presence of the ERU at the breakdown site was one of the factors leading control room staff to be confident that the staff at the breakdown site would be able to manage recovery of the RGU safely.

Emergency brake application

109 **The emergency coupler was broken by loads caused by an emergency brake application. Although a causal factor, emergency brake applications are occasionally required and the coupler design should have allowed for them.**

110 The assisting train was being driven in restricted mode because of the settings selected when coupling to the RGU (paragraph 88). This mode is intended to limit train speeds to nominally 10 mph (16 km/h). An audible warning is given when the train approaches 10.6 mph (17 km/h) and the emergency brake is applied automatically if this speed is exceeded. Restricted mode is routinely used in depots and sidings to ensure compliance with the 10 mph limit which generally applies at these locations.

111 The RGU was being towed on the basis of a 10 mph (16 km/h) speed limit. None of the staff involved in deciding the towing speed realised that a 5 mph (8 km/h) limit was given in the emergency towing procedure (paragraph 89). The Northern Line Operations Manager relied on his own judgement to tell the assisting train operator that the recovery should be done slowly. The Operations Manager was aware that the train would be driven in restricted mode and, wrongly, believed that this limited the train speed to 5 mph[6]. The DMT understood that the Northern Line Operations Manager had given a 10 mph limit. The train operator understood that speeds should be limited to 10 mph. The difference between recovering the RGU at 5 mph and 10 mph should not have caused the coupler to fail (paragraph 130).

[6] Recovery speeds on LUL infrastructure depend on circumstances including the type of defect and the location of the recovery.

112 OTDR data from the assisting train shows an automatic application of the emergency brake 17 seconds before the train operator made a separate brake application. The train operator's brake application was in response to a message from staff at the rear of his train saying that the RGU had just broken away. This suggests that the automatic brake application triggered the coupling failure.

113 The passenger train operator had never pulled an engineering train before. There was no formalised procedure for towing engineering trains with passenger trains and the passenger train operator had not received any guidance about how to do this. Because restricted mode had been selected, the train operator could only select one 'power on' setting, a 'neutral' setting and brake settings. He could not select a power setting precisely suited to the desired speed.

114 The OTDR data shows that, after starting the tow, the train operator engaged, and then disengaged, power 60 times in the 8 minutes 10 seconds before the coupling broke. In this time, he received seven audible warnings that he was approaching the 10.6 mph (17 km/h) limit at which the emergency brake would apply. On each occasion he disengaged power and then reapplied it. On the final occasion, the train responded to the reapplication of power and exceeded the 10.6 mph (17 km/h) limit without a further audible warning.

115 The audible warning sounds when the train exceeds approximately 8 mph (13 km/h), and continues to sound until cancelled by the train operator. Even if the audible warning is cancelled, a visual reminder is shown on an in-cab display until the speed drops below approximately 7.5 mph (12 km/h). If the audible warning is cancelled, it will not sound again until the speed has dropped below 7.5 mph (12 km/h) and then exceeded 8 mph (13 km/h). Based on speeds recorded by the OTDR, it is probable[7] that, after the final audible warning, and despite power being briefly disengaged, the train speed did not drop below 7.5 mph (12 km/h) so the operator had no audible warning that the train was again accelerating towards 10.6 mph (17 km/h). Although the train operator is likely to have understood how to deal with the audible warning when operating a normal (braked) passenger train, he had no guidance and/or training on the different technique needed when towing an unbraked engineering train.

116 It is probable that the train speed reached the emergency brake trigger speed of 10.6 mph (17 km/h) because the train operator lacked guidance on how to tow engineering trains.

[7] Precise speeds cannot be determined at all stages of the incident as the OTDR does not record speed continuously, it only records speed when certain events occur.

Emergency Coupler

117 **The emergency coupler broke due to overstressing of a tow bar hinge assembly. This was a causal factor.**

118 The emergency coupler linked the *wedgelock* coupling on the passenger train to the clevis connector on the RGU (figure 9).

Figure 9: Emergency coupler.

119 The wedgelock coupling is the standard coupling for London Underground passenger trains. When coupled to another passenger train, the faces of these couplers are fixed rigidly to each other using hooked tongues inserted into sockets (figure 10). Two horizontal hinges (ie hinges allowing horizontal rotation) are needed to allow vehicles to negotiate horizontal curves and two vertical hinges are needed for vertical curves (figure 11). Each wedgelock/car body connection provides one horizontal hinge and one vertical hinge. The nominal centre of a wedgelock coupler is 395 mm above the *running rail*.

120 Each end of the RGU was fitted with a clevis connector (figure 3). The centre of the connector at the incident end of the RGU (B cab end) was 540 mm above running rail level. The corresponding dimension at the opposite (A cab) end of the RGU was 720 mm. The B end coupler was therefore 145 mm higher than a 1995 tube stock coupler and the A end was 325 mm higher.

Figure 10: Wedgelock coupler.

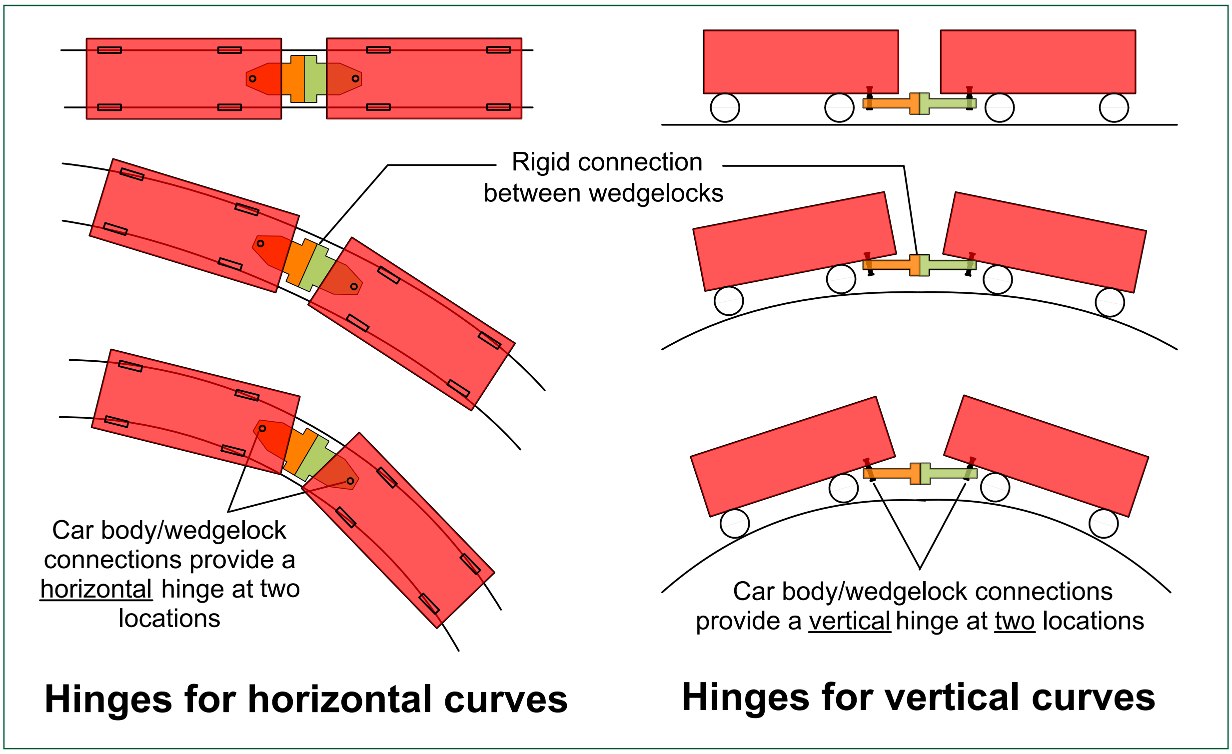


Figure 11: Coupling hinges needed to negotiate curves, illustrated with wedgelock couplers attached to simplified vehicles.

121 The emergency coupler comprised an adaptor box and a tow bar with hinged connectors at each end (figure 12). In use, the adaptor box was rigidly connected to the wedgelock coupler on the assisting train. A hinged connector linked the adaptor box to the tow bar. Horizontal rotation was permitted at the pin linking the connector to the adaptor box; vertical rotation was permitted by the pin linking the connector to the tow bar. The second hinged connector linked the tow bar to the clevis pin on the RGU. The pin linking the connector and tow bar allowed vertical rotation; the connection to the clevis pin allowed horizontal rotation.

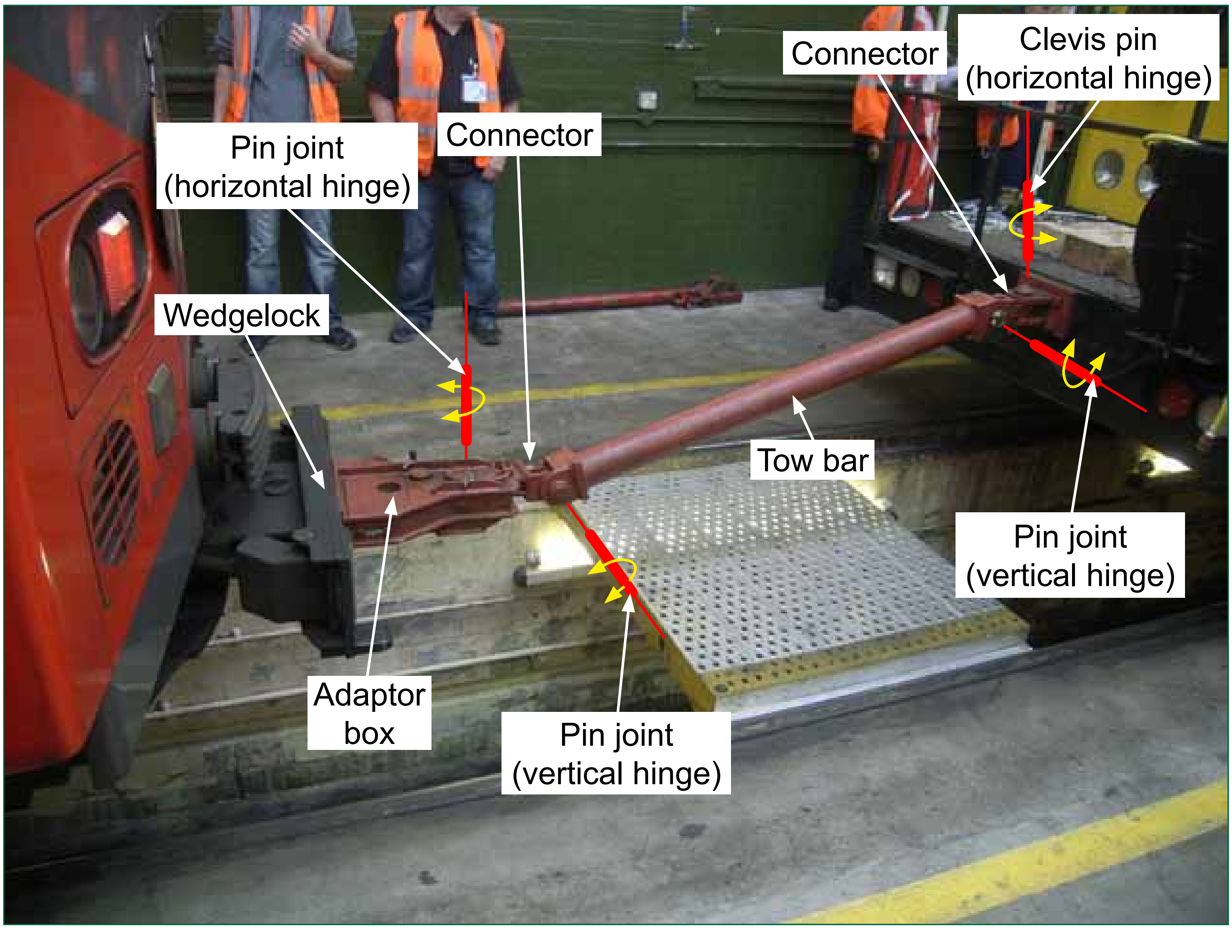


Figure 12: Emergency coupler components.

122 The RAIB undertook tests after the Highgate incident and has reviewed both witness statements and tests undertaken by Tube Lines after the July 2010 incident. The coupling probably performed broadly as described below during the Highgate incident.

123 When the train began to slow in response to the emergency brake application, the unbraked RGU pushed against the coupling, causing compressive loads in the coupling system. These loads caused the coupler to break at the lower hinge.

124 There were three phases in the breakage process – downward coupling deflection (phase 1); lateral coupling deflection causing a break at the lower end of the tow bar (phase 2); and collisions between the passenger train and the RGU resulting in the tow bar being released from the RGU clevis (phase 3). Phases 1 and 2 may have occurred at the same time.

125 The excessive downward deflection of the coupling in phase 1 was due to the presence of three hinges allowing vertical rotation at the top of the tow bar, the lower end of the tow bar and the wedgelock/car body fixing (figure 13). The nature, but not the maximum extent, of this deflection is illustrated by the still images extracted from a video made by Tube Lines during testing after the July 2010 incident (figure 14). This type of deflection was also described by witnesses to the attempted push recovery during the July 2010 incident and was seen during tests by the RAIB after the Highgate incident. The extent of this movement is evidenced by marks on the metal plate which extends over the pin at the lower end of the tow bar (figure 13).

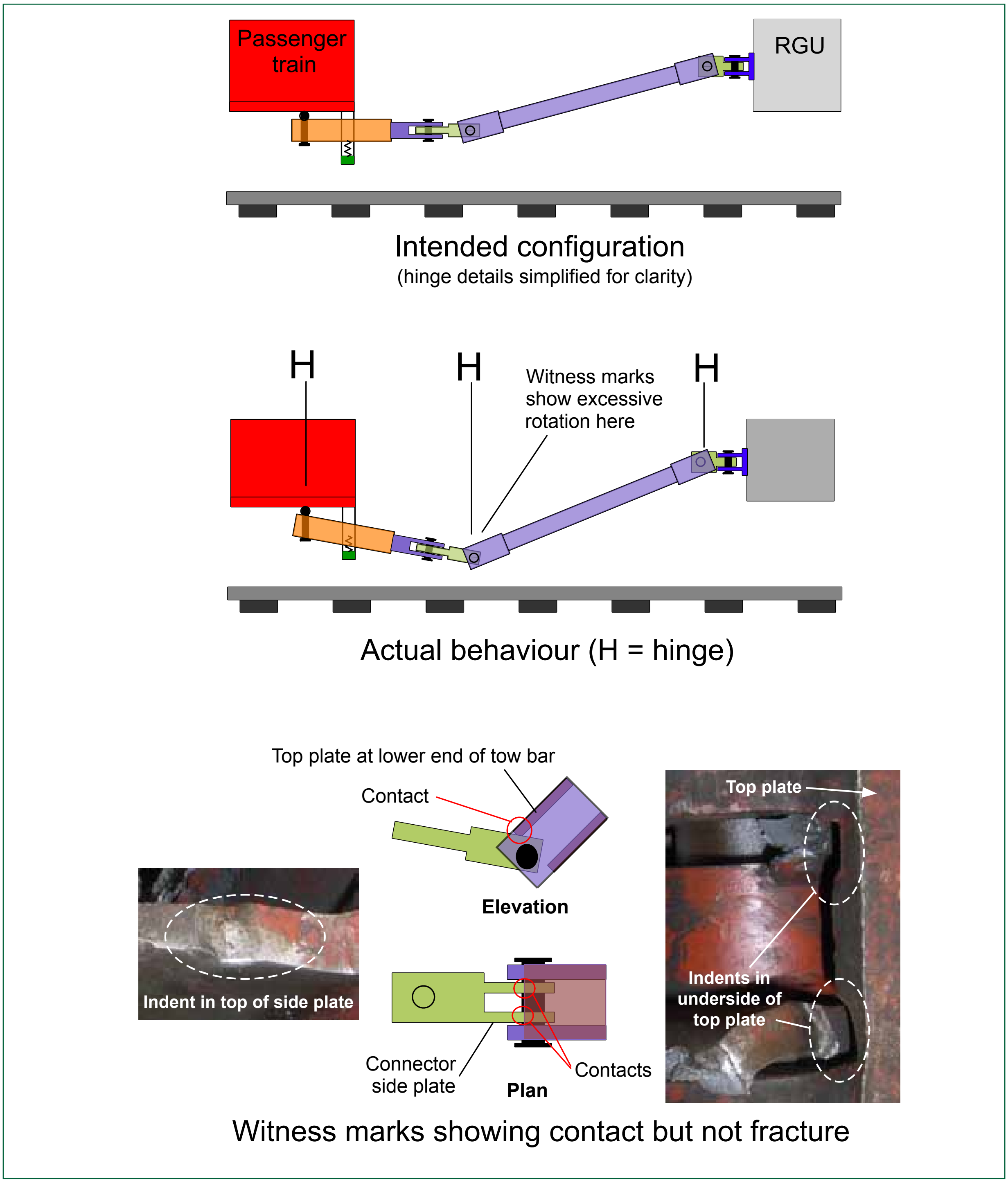


Figure 13: Vertical coupling deflection (phase 1 of breakage).

Figure 14: Vertical coupling deflection observed during July 2010 testing (images from video provided by Tube Lines).

126 The RAIB has calculated that the maximum vertical deflection was probably just sufficient for the lower end of the tow bar to have touched the *negative rail* (centre rail) as reported by staff who observed the attempted push recovery during the July 2010 incident. There were no marks indicating that the coupler struck the negative rail at Highgate. Contact may have occurred without leaving marks, as the area of tow bar likely to touch the rail had been wrapped with an insulating mat intended to prevent an electrical hazard if the coupler touched the negative rail (paragraph 167). Alternatively, the lateral deflection of phase 2 may have meant that the relevant part of the tow bar was not directly above the negative rail.

127 The excessive lateral deflection of the coupling in phase 2 is again due to the presence of three hinges. These allow lateral rotation at the clevis pin, at the adaptor box/tow bar connection and at the wedgelock/car body fixing (figure 15). This movement was observed during the push recovery in July 2010 and in the RAIB testing (figure 16). It is also evidenced by the way in which the two plates at the lower end of the tow bar fractured during the Highgate incident (figure 15).

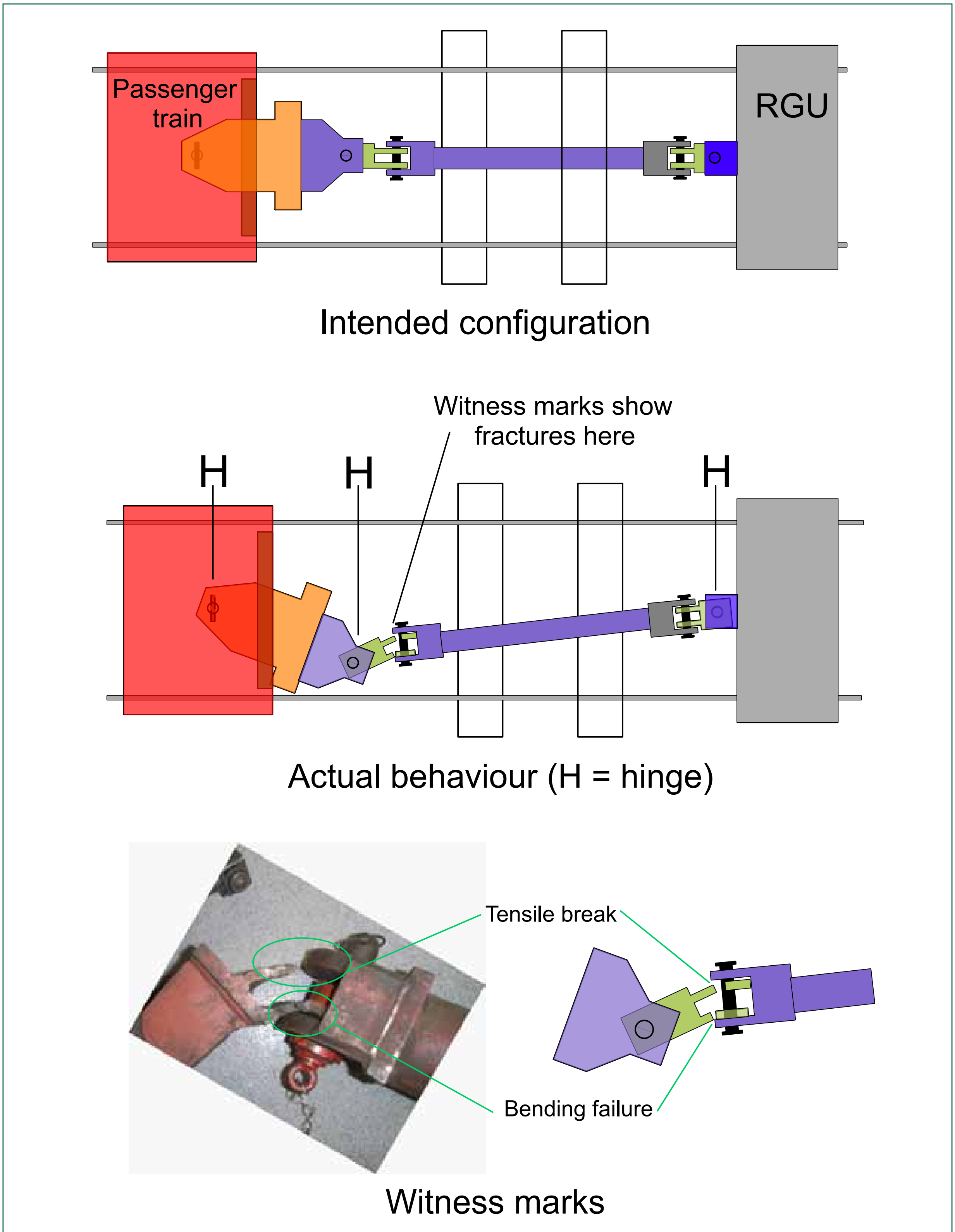


Figure 15: Lateral coupling deflection (phase 2 of breakage).

Figure 16: Lateral coupling deflection observed during post-incident RAIB testing.

128 The RAIB inspected the fracture faces shortly after the incident and concluded that the fracture was caused by a sudden overload event. There were no indications of fatigue failure and no significant manufacturing defects could be seen. RAIB has calculated that, during the emergency brake application, the coupling was subject to a compressive load of about 5.7 tonnes; significantly more than the 3.5 tonnes at which the coupler would be expected to fail in the deflected phase 2 configuration.

129 Phase 3 included the rapid upward movement of the tow bar and a collision between the RGU and the assisting train. The upward movement was observed by staff at Highgate; the collision is evidenced by the marks on the trains shown on figure 17. The upper RGU clevis plate deformed during the collision and allowed the tow bar to fall onto the track (figure 17). RAIB has not attempted to model phase 3 in detail.

130 The maximum loadings to be accommodated by emergency couplers due to an emergency brake application depend on the mass of the unbraked vehicle and the rate of deceleration. The deceleration achieved by the assisting train was not significantly affected by train speed. It is therefore possible that the emergency coupler would have failed following an emergency brake application even if recovery had been undertaken at a maximum speed of 5 mph (8 km/h) (as given in the recovery instructions, paragraph 89), rather than the actual maximum speed of 10.6 mph (17 km/h).

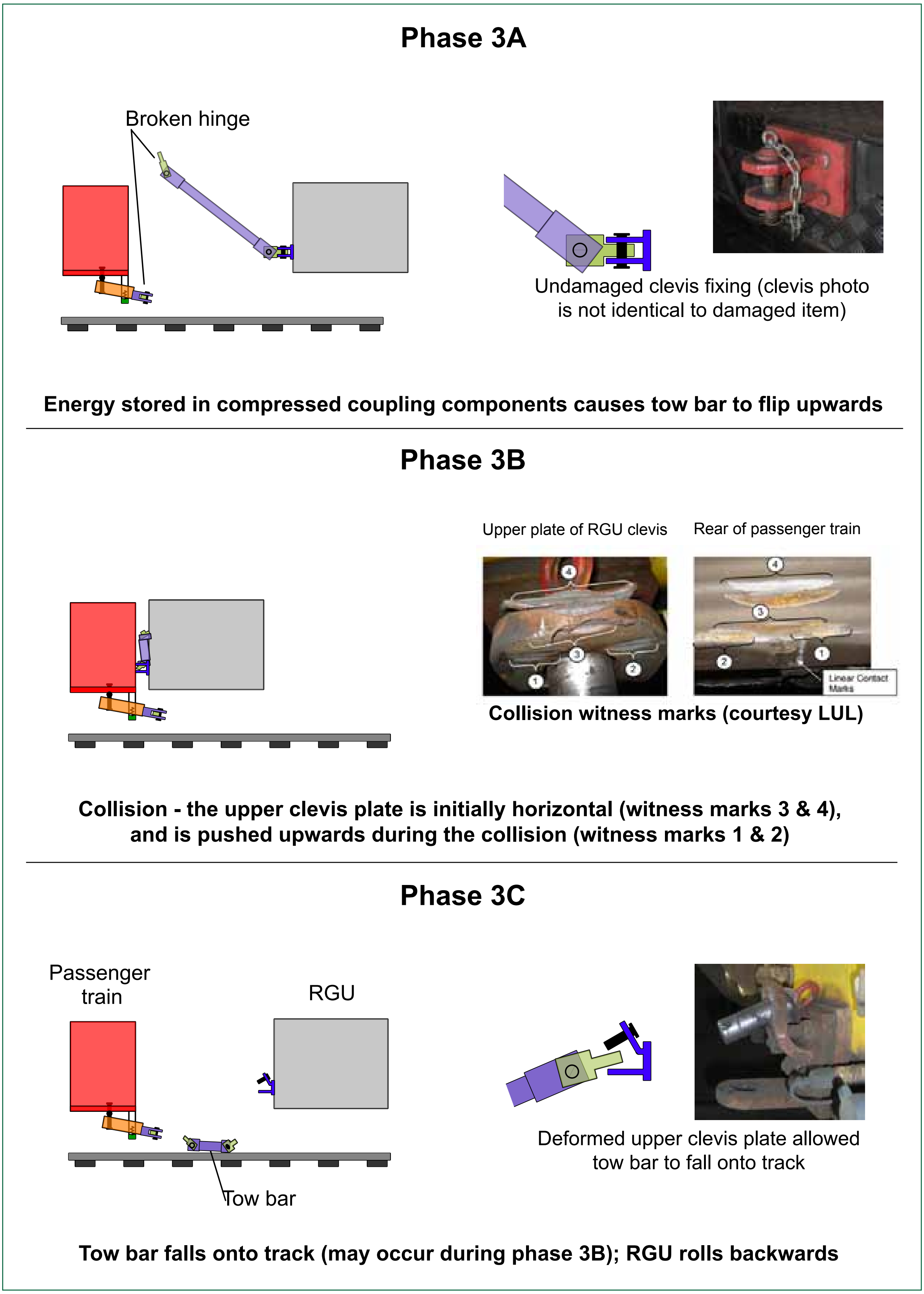


Figure 17: Upward tow bar movement (phase 3 of breakage).

131 After the incident, significant deformation was found in the drawbar linking two of the RGU cars (figure 18). The drawbar damage may have been caused during the incident. It is not likely that the damage existed before the incident because it would probably have been detected during the daily inspection of the RGU. Even if the damage existed before the coupling broke, it would not have played any part in the emergency coupler failure.

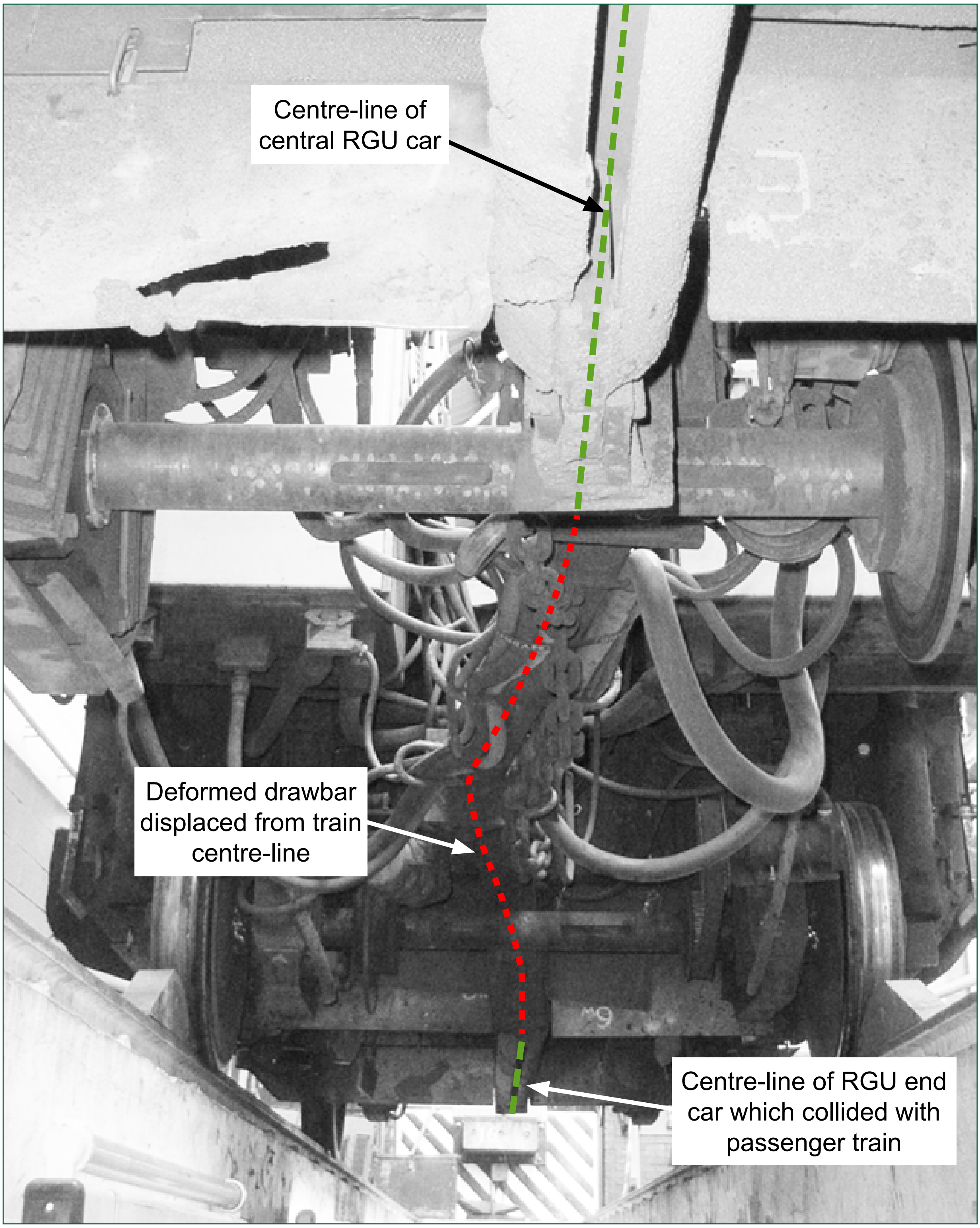


Figure 18: Deformed drawbar on RGU.

Design and approval of the emergency coupler

132 **Inadequacies in the specification, design, checking and approval of the emergency coupler meant that it was unable to withstand the forces generated in service. These inadequacies were a causal factor.**

133 Both Infraco JNP rolling stock specialists and plant specialists at TransPlant were involved in the processes to approve the use of the RGU before it first worked on LUL infrastructure in late 2002. The work included developing the operating instructions and the special equipment needed to operate on LUL infrastructure. Rolling stock elements of this work were then reviewed by rolling stock engineers, and other staff, within LUL. Approval certificates were signed by staff from all three organisations when they believed this work was satisfactorily completed.

134 The processes for introducing the RGU onto LUL infrastructure included the design and supply of two identical emergency couplers suitable for use with the trains likely to recover the RGU on the London Underground. The Plant Approvals Engineer was responsible for the procurement of these couplers.

135 There was no specification describing the intended function of the emergency coupler. Witness evidence shows that Infraco JNP staff initially expected that battery locomotives would be used for RGU recovery. It is not clear when the possibility of using passenger rolling stock was identified. It was probably after April 2002, and certainly by August 2002 when an email from Rolling Stock Asset Engineer 1 referred to compatibility between the emergency coupler and passenger trains.

136 LUL standard Ta251 dated September 2000 (Introducing New or Modified Rolling Stock to LUL) mandated preparation of a safety plan as part of the RGU approval process. A document of this type, entitled "Case for Safety Paper", was prepared. The latest available version (version 8) is dated 12 November 2002 and states that "following detailed discussions with London Underground...passenger rolling stock may have to be used [for emergency recovery]". This version also contains a risk assessment prepared with input from Rolling Stock Asset Engineer 1 and the Rolling Stock Project Engineer, including a description of RGU recovery which only refers to use of a battery locomotive. The first version of this paper was dated 14 May 2002. It is probable that the risk assessment was prepared before the possible use of passenger rolling stock was appreciated.

137 The Plant Approvals Engineer procured the emergency couplers in September 2002. Each coupler required an adaptor box to connect with the assisting train (paragraph 121). The Plant Approvals Engineer anticipated that the assisting train would generally consist of passenger rolling stock. In order to avoid potential delays with the approval of a new adaptor box, he developed an outline design using an existing approved adaptor box. This existing box would only couple to passenger trains and the two Schoma locomotives equipped with wedgelock couplings. He and other staff within TransPlant, including the general manager, were aware that the existing adaptor box was incompatible with battery locomotives (paragraph 145).

138 There is no evidence of a formal change control process for the decision to preclude use of battery locomotives. There is no evidence that Infraco JNP rolling stock engineers were aware of this decision. The Plant Approvals Engineer was aware of the discussions with LUL (paragraph 136) and proposed use of a "tube stock emergency coupling adapter"; Rolling Stock Asset Engineer 1 agreed to this proposal on 30 August 2002 without realising that it precluded use of a battery locomotive. Tube Lines staff remained unaware of the incompatibility with battery locomotives until after the Highgate incident (appendix E, paragraph E.3).

139 The emergency coupler design included two hinges allowing vertical rotation, one at each end of the tow bar, to allow for the differences in coupler height and to allow for vertical curvature (paragraphs 119 and 120). The Plant Approvals Engineer had limited knowledge of passenger rolling stock and was unaware that its wedgelock couplers can rotate downwards considerably further than the corresponding couplers on engineering locomotives (paragraphs 161 and 162). This wedgelock rotation, together with the two hinges intended to allow vertical rotation, provided the three hinges which allowed the excessive vertical deflection of the coupler (figure 13).

140 The Plant Approvals Engineer did not appreciate that the connection between the tow bar and adaptor box required a means of locking to prevent horizontal rotation when in use. This horizontal hinge, together with the intended hinge at the RGU clevis pin and the rotation provided at the wedgelock/car body fixing, provided the three hinges which allowed the excessive horizontal deflection of the coupler (figure 15).

141 TransPlant's Railway Safety Case applicable when the RGU was introduced in 2002 states that, as a "means of controlling risks arising from a lack of knowledge, skills or experience", "each operational and management position in TransPlant has a job description giving...responsibilities competence and qualification requirements". It also states that "to ensure we are using competent staff [we]... match people to competencies required"[8]. There was no job description for the Plant Approvals Engineer in 2002. The only job description for this role is a draft document prepared in about 2009. This contains "key accountabilities" which include "provide guidance for projects initiated by TransPlant including the design and manufacture of any specialist equipment". The scope of input to design work is not defined. The draft job description lists "essential/desirable experience/ qualifications"; these do not include a competency in the design of equipment or trains.

142 The Plant Approvals Engineer's outline design was not checked within the TransPlant organisation. The Plant Approvals Engineer expected the technical aspects of the design to be reviewed by Infraco JNP rolling stock specialists. An email shows that he obtained agreement to use a "tube stock emergency adapter" from Infraco JNP's Rolling Stock Asset Engineer 1 before ordering the emergency coupler. In the same email, Rolling Stock Asset Engineer 1 instructed that compatibility between the emergency coupler and passenger trains should be reviewed with the Northern Line passenger train maintenance organisation (Alstom). Although this email was addressed to the Plant Approvals Engineer, he took no action on this matter because it was a rolling stock issue and the email was copied to the Rolling Stock Project Engineer. Rolling stock engineers did not act on this instruction (paragraph 147).

[8] TransPlant Railway Safety Case version 3.06, 4 February 2002, section 21.2.

143 Infraco JNP's rolling stock input to the RGU approval was led by Rolling Stock Asset Engineer 1. In April 2002 he prepared a list of rolling stock issues to be closed out before the RGU could be approved. This included a requirement to consider "rescue and recoverability". Rolling Stock Asset Engineer 1 tasked the Rolling Stock Project Engineer with resolving the rolling stock issues, including rescue and recoverability. The Rolling Stock Project Engineer was to be assisted in this task by members of his own team and by other specialists.

144 There were no specific Infraco JNP or LUL standards covering couplers. Successful design of these couplers relied on the professional skill and judgement of the designers. A LUL standard was subsequently prepared for other types of couplers but, at the time of publishing this report, there is still no LUL standard for emergency couplers.

145 The Rolling Stock Project Engineer summarised his work in a memo dated 22 October 2002 and addressed to Rolling Stock Asset Engineer 1. This stated "A tow bar is carried at either end of the vehicle to facilitate emergency rescue of the vehicle. This has been tried at Lillie Bridge depot using a Schoma locomotive. In operation, a battery loco will be held on permanent standby at the nearest possible location." Investigations by RAIB have shown that this would not have been practicable – all battery locomotives in service during, and since, 2002 have lacked the hooked tongue necessary to couple with the emergency coupler's adaptor box (figure 19).

146 The 22 October 2002 memo neither endorsed, nor precluded, rescue of the RGU using passenger rolling stock.

147 It is unlikely that the Rolling Stock Project Engineer's team were involved in the design or checking of the emergency coupling design. There is no evidence of their active involvement in this work although they received emails relating to the process. There is conflicting evidence about whether a rolling stock engineer attended the tests on the emergency coupler at Lillie Bridge. Witness evidence shows that the rolling stock engineers, including Rolling Stock Asset Engineer 1, were relying on TransPlant (particularly the Plant Approvals Engineer) to provide the necessary input.

148 LUL standard Ta251 required LUL's Rolling Stock Engineer to satisfy himself that the RGU met appropriate standards before it entered service. Ta251 does not define the extent of checks which should be carried out on work undertaken by TransPlant and Infraco JNP staff. Witness evidence suggests that, in 2002, LUL should have reviewed all design principles, including the outline design of the emergency coupler. There is evidence of LUL reviewing some aspects of the RGU before it was introduced (paragraph 85). There is no evidence to show whether the emergency coupler was reviewed.

149 Approval of the rolling stock elements of equipment such as the RGU is formally recorded by the issue of a certificate of technical conformance (CTC) for rolling stock signed by the Infraco JNP/Tube Lines rolling stock asset engineer and by LUL's rolling stock engineer. Approval of plant elements of the RGU should be indicated by a plant approval certificate signed by the plant approvals engineer.

a) Passenger train and adaptor box - Hooked tongue permits mechanical connection

b) Schoma locomotive and adaptor box - Hooked tongue permits mechanical connection

c) Battery locomotive and adaptor box - Mechanical connection impossible because neither tongue has a hook

Figure 19: Coupler compatibility.

150 The RGU's first CTC for rolling stock was signed by Rolling Stock Asset Engineer 1 on 4 November 2002 and by Rolling Stock Engineer 1 on 5 November 2002. It expired on 4 October 2003 and was intended to allow trials of the RGU on appropriate parts of the LUL infrastructure. This certificate included the Rolling Stock Project Engineer's memo of 22 October 2002 referring to use of battery locomotives for recovery of the RGU.

151 It is likely that the RGU did not work on LUL between October 2003 and September 2004. The second CTC for Rolling Stock was drafted by the Plant Approvals Engineer. It was signed by Rolling Stock Asset Engineer 2 and by Rolling Stock Engineer 1 on 2 September 2004. It expired on 31 September 2007 and was intended to allow widespread use of the RGU on LUL infrastructure. An email from the Plant Approvals Engineer to Rolling Stock Asset Engineer 2 stated that there had been no technical changes relevant to the emergency coupler since the original approval. The absence of technical changes meant that there was no requirement for a technical reappraisal of the coupler and none was undertaken.

152 The Rolling Stock Project Engineer's memo of 22 October 2002 was not referenced on the updated certificate. This meant that there was now no mention of the types of train which could, or could not, recover the RGU. This information was not (and had never been) contained in any other operating instructions or comparable documentation. Although not part of a written procedure, witness evidence indicates that, in the absence of contrary instructions, staff involved with recovery would use any type of available rolling stock which appeared suitable. Rolling stock engineers did not undertake a technical review of the decision to remove this memo.

153 Two further CTCs for rolling stock covering the RGU were signed by Rolling Stock Asset Engineer 2 and Rolling Stock Engineer 2 in 2008. These permitted continued use of the RGU until 31 May 2011. There were no technical changes on these CTCs relevant to emergency recovery and so there was no technical reappraisal of this issue when the updated certificates were issued. All CTCs for rolling stock had been accompanied by a corresponding plant acceptance certificate signed by the Plant Approvals Engineer.

154 Overall, there was no effective process for ensuring that all rolling stock issues had been properly considered, and fully closed out before rolling stock asset engineers signed the CTC for rolling stock. LUL did not carry out an adequate technical review of Infraco JNP's work. The requirement for the emergency coupler to be compatible with passenger rolling stock, and the decision to preclude use of battery locomotives, were added without adequate change control.

Emergency coupler acceptance testing

155 **Acceptance testing of the emergency coupler did not reveal the defective design philosophy because this testing was carried out using a Schoma locomotive whose coupling differed from that on a passenger train. Inadequate acceptance testing was a causal factor.**

156 The Plant Approvals Engineer arranged for acceptance testing of the emergency coupler to take place at Lillie Bridge depot in 2002, as part of the approval process for the RGU. The RGU was coupled to a Schoma locomotive using the emergency coupling and then pulled and pushed over both plain track and points.

157 If testing is to be used as a means of demonstrating that equipment is safe to use, good engineering practice requires a test plan which identifies the test aims, the method of testing, the information to be collected and acceptance criteria. The test plan, and the test results, should be kept for future reference[9].

158 The acceptance testing at Lillie Bridge was intended to demonstrate that the emergency coupler was acceptably safe. Although an email shows that the Plant Approvals Engineer asked Rolling Stock Engineer 1 for test requirements, there is no evidence of a test plan or that acceptance criteria were established. There was no LUL or Infraco JNP standard explicitly stating that these were required. Ta251 required staff approving rolling stock to satisfy themselves that the rolling stock met appropriate standards, but did not say how this was to be done.

159 Acceptance tests were carried out using a Schoma locomotive equipped with a wedgelock coupler because passenger rolling stock was not readily available. The Plant Approvals Engineer did not appreciate that the wedgelock on a passenger train would behave differently from a Schoma's wedgelock (paragraph 161). It is unclear whether any rolling stock engineers witnessed the emergency coupler tests – there is no documentary evidence and witnesses' recollections differ. Rolling stock engineers were aware that a Schoma locomotive had been used for the tests (paragraph 145).

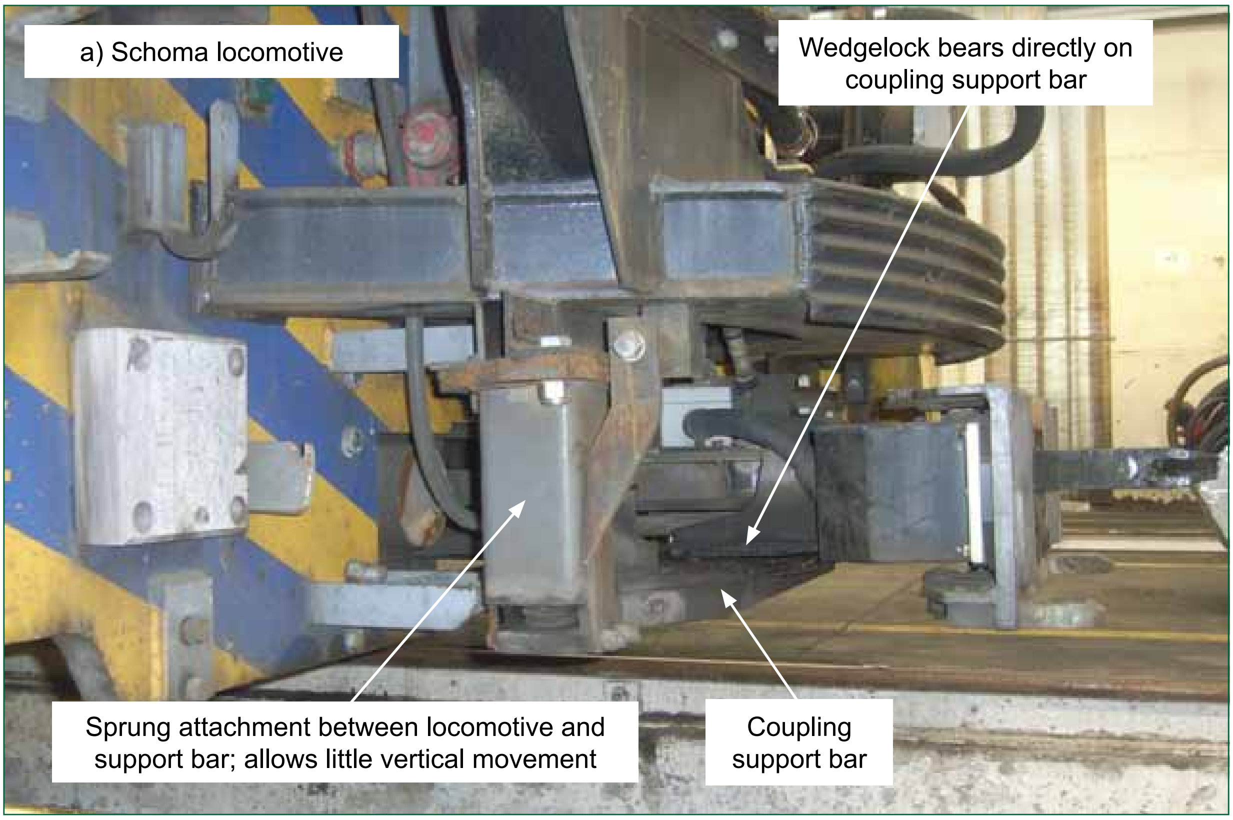
160 No formal record of the acceptance testing was made and it is not known whether an emergency brake application was included – the emergency brake application is harder than a service brake application (1.3 m/s^2 compared to 1.1 m/s^2). After these tests, Infraco JNP staff were content for the emergency coupler to be put into service.

161 The excessive downward movement of the emergency coupler when used with passenger rolling stock (paragraphs 125 and 167) did not occur during the acceptance testing. This is because the wedgelock on the Schoma was prevented from significant downward rotation by direct contact with a horizontal bar immediately beneath the coupler. The bar is relatively stiff and is supported on springs attached to the locomotive body (figure 20). The springs allow only the relatively small downward coupler movement needed when negotiating vertical curves (paragraph 119).

162 On a passenger train, spring loaded feet are attached to the wedgelock. These bear on a horizontal sector bar which is less stiff than the corresponding horizontal bar on the Schoma locomotive. The spring loaded feet and the horizontal sector bar are intended to carry the weight of the wedgelock when the coupling is not being used (figure 20). They provided less resistance to downward coupling movement than the corresponding arrangement on a Schoma locomotive.

163 It is uncertain why the excessive horizontal deflection of the emergency coupler (phase 2, figure 15) was not observed during the acceptance testing. It is possible that friction between the diesel locomotive's wedgelock coupler and the supporting bar was sufficient to prevent horizontal rotation of the wedgelock. The possible absence of an emergency brake application during the tests may also have been a factor.

[9] This approach is needed to achieve the levels of assurance given in Engineering Safety Management (the Yellow Book) published by the Rail Safety Standards Board and applicable throughout the UK railway industry.



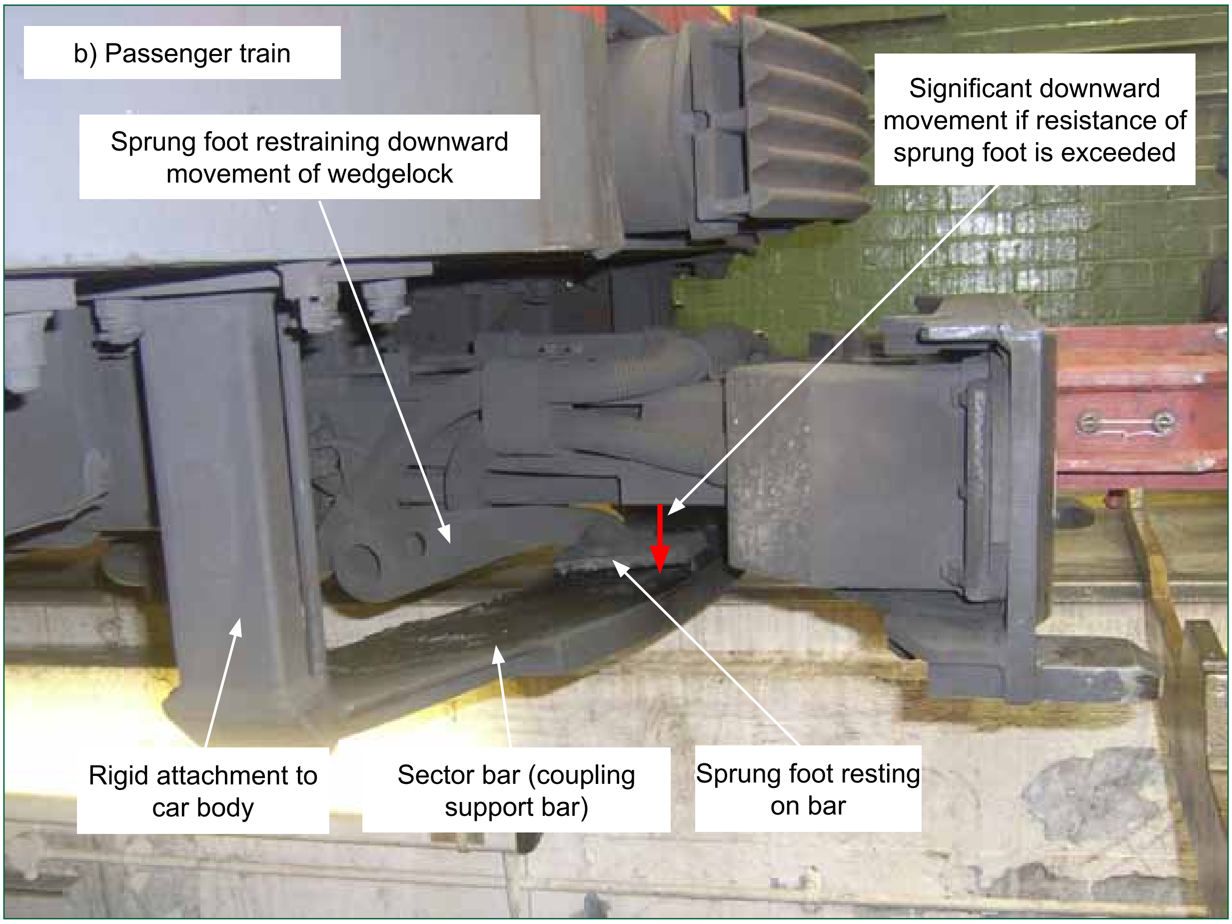


Figure 20: Wedgelock vertical rotation.

Inadequate investigation of the July 2010 incident

164 **The investigation into the July 2010 incident (paragraph 40) was insufficient to detect the extent to which the emergency coupler was behaving unacceptably. The inadequate nature of this investigation is a probable causal factor.**

165 The RGU required recovery on 17 July 2010 following a mechanical breakdown on the Jubilee Line at West Hampstead. This was the first time the London Underground emergency coupler had been used since the acceptance testing at Lillie Bridge depot in 2002 (paragraph 158). During this recovery operation, an attempt to push the RGU with a Jubilee Line train, using the emergency coupler, was abandoned when staff at the scene observed downward and lateral deflections they considered to be excessive. These staff reported that the coupler touched the negative rail during this operation. The RGU was then pulled by a Jubilee Line train to Neasden Depot using the emergency coupler supplemented by chains (paragraph 71), and withdrawn from service while the incident was investigated.

166 Staff at West Hampstead recognised the electrical risks associated with the coupler touching the negative rail and the subsequent investigation concentrated on this issue. Although large deflections were observed at West Hampstead, there was no evidence during this incident that the coupler had insufficient strength and coupler strength was not included in the remit for the subsequent investigation. This investigation was conducted in accordance with LUL standard 1-558, Formal Investigation of Incidents, dated April 2008. This standard did not specify the process to be used for any testing needed as part of the investigation.

167 The investigation included two sets of testing. The first set was at Neasden Depot on 22 July 2010 when the emergency coupler was tested using a Jubilee Line train to push and pull the RGU on a line within the depot. There was significant vertical deflection of the coupling. Staff present at these tests recognised that pushing the RGU caused an unacceptable risk of contact between the tow bar and the negative rail. They also identified a small risk of contact when the RGU was being pulled (eg when applying brakes) and it was decided that insulation should be wrapped around part of the tow bar as a precaution against the electrical hazard.

168 The ERU competency manager was among those watching the first test. He had 18 years practical experience of recovery work, and reported that the test did not represent realistic conditions – witness evidence indicates that he considered the short towing distance, the low speeds, and the amount of braking, were unrepresentative of conditions likely to be found during a real recovery operation on the main line. He asked for a realistic test to be undertaken on the main line. The Northern Line Operations Manager endorsed this request and suggested a suitable time for this to be done during engineering hours.

169 A second set of tests was arranged by the Rail Grinding Engineer and took place on 28 July, again within Neasden Depot. There was no test plan (paragraph 157) and no formalised process for deciding that depot testing was sufficient despite the comments made after the first set of tests. The focus of attention on 28 July was on the performance of the insulation material which had been wrapped around the tow bar. No experienced professional engineers attended the tests; the Rail Grinding Engineer was present but he had very little experience of rolling stock and plant engineering. The RGU was pushed and pulled with only gentle brake applications. There was no attempt to undertake an emergency brake application although this was probably the situation most likely to cause contact between the tow bar and the negative rail. Even without an emergency brake application, significant vertical coupling deflection occurred (figure 14).

170 There is no evidence that the lateral deflection seen at West Hampstead was reproduced during any of the subsequent testing, possibly because the RGU was not subject to a realistic recovery scenario. The lateral deflection is mentioned in the ERU's report on the West Hampstead incident, but there is no evidence that this was distributed to staff involved in the post-incident assessment of the coupling.

171 The Train Systems Engineer was the most senior rolling stock engineer involved in approving reintroduction of the RGU. The extent of testing was not formally reported but an email sent by the Rail Grinding Engineer to the Train Systems Engineer said that the test was "a success" but notes that the coupler touched the negative rail when the RGU was pushed. The Train Systems Engineer then sent an email to Tube Lines staff involved with approving reintroduction of the RGU. This email said that the test was "only a partial success...we cannot totally rule out pushing as part of a rescue...there remains a real risk of contact with the negative rail albeit intermittently...[it is therefore] imperative that the insulation material is in good order and robustly applied". The email also said that the Train Systems Engineer would accept use of the existing emergency coupler "provided ERU accept the method as a legitimate rescue technique" and provided "a more secure [coupling] that does not present the risk of conductor rail contact is developed". There is no evidence that compressive loads due to emergency braking, and the associated coupling deflection, were explicitly considered when the test results were being reported and assessed.

172 Approval to reintroduce the RGU onto LUL infrastructure was then given in an undated "Initial Technical Report and Case for Resuming Operations"; this limited use of the existing emergency coupler to towing movements. The report stated that "the ERU are content with this arrangement for towing". The ERU had not been content with the first set of tests and sought more realistic testing which did not happen (paragraphs 168 and 169). The ERU's representative at the second set of tests understood that the purpose of the test was to establish whether the insulated wrapping was an effective means of dealing with the risk of contact with the negative rail. He was not briefed about the need for realistic testing (paragraph 168). After observing a push test, he said that he would not endorse this method of recovery. He did not observe the tow testing because he had been assisting the train operator and was inside the passenger train. Coupling performance during this test was described to him and he concluded that the emergency coupler could be used to recover the grinder by towing at walking pace.

173 If an emergency brake application had been included in the tow testing on 28 July, it is likely that the coupler would have deflected excessively and/or touched the negative rail and/or broken. It is likely that any of these conditions would have resulted in the RGU remaining out of service until the defective coupler was replaced.

174 An email from the Plant Approvals Engineer to senior LUL staff, sent on the afternoon of 11 August 2010, described the breakdown of the RGU at West Hampstead and the reasons why the emergency coupler deflected towards the negative rail when the RGU was pushed by an assisting train (paragraph 165). He then outlined the work that would be necessary to redesign the coupler, revise the recovery arrangements and improve the training of staff in the recovery of the RGU. At the time he sent this message, the Plant Approvals Engineer was aware that the RGU had re-entered service. He did not advise that the RGU's emergency coupler should be withdrawn from service until the identified issues had been resolved, because he was aware of the temporary instruction that had been issued to only recover the RGU by towing - the method which had been used to move the defective RGU from West Hampstead to Neasden (paragraph 165). Documentary evidence shows that LUL were considering the Plant Approval Engineer's email, but had not implemented any actions, when the runaway at Highgate occurred on the morning of 13 August.

175 Inadequate investigation was undertaken before the RGU resumed working after the July 2010 incident. There was no effective process for establishing test requirements and no effective process for ensuring that all tests had been satisfactorily completed before the Train Systems Engineer approved reintroduction of the emergency coupler.

Briefing, training and practice in emergency recovery procedure

176 **There had been minimal briefing, no training, and no practising, of the emergency recovery procedure. This was a contributory factor as it might have revealed the design flaws and/or the lack of mitigation against a runaway due to failure of the emergency coupler.**

177 The emergency coupler for the RGU had been tested at Lillie Bridge depot in 2002 and had then not been used again until it was required during the July 2010 incident.

178 Although the RGU crew were aware of the instructions relating to use of the emergency coupler (paragraph 80), this topic was not covered in their formal training or assessment. None of the LUL or Tube Lines staff likely to be involved with RGU recovery had been briefed or trained in how to do this. Requirements for briefing, training and practical experience of the emergency recovery procedure had not been identified when this procedure was developed (paragraphs 93 to 98). The absence of instructions meant that staff used their judgement to decide some technical issues and to decide the allocation of some tasks (paragraphs 88, 90 and 111).

179 It is possible that training and practical experience in using the emergency procedure might have led to recognition that the RGU would be recovered as an unbraked vehicle without mitigation against the risk of a runaway. Practical training might also have revealed the inadequacies in published instructions (paragraphs 79 to 100) and the impossibility of using the emergency coupler with a battery locomotive (paragraph 137).

180 Although not a factor in the Highgate incident, the lack of practice increased the risk that staff would make a mistake during recovery operations.

Identification of underlying factors[10]

181 The RAIB identified three underlying factors. These are:

- inadequate specification of technical requirements despite processes intended to provide appropriate specifications;
- inadequate input from mechanical (rolling stock) engineers and other appropriately skilled staff despite processes intended to provide appropriate expertise; and
- lack of clear responsibility for planning and implementation of emergency recovery procedures.

Inadequate specification of technical requirements

182 **Inadequate specification of technical requirements is apparent in both design and testing of the emergency coupler.**

183 The technical requirements for the emergency recovery procedure, and for the emergency coupler design, would have been identified if an appropriate specification had been produced (paragraphs 79 and 132).

184 An appropriate specification for acceptance testing of the emergency coupler would have included testing with coupling systems representative of those found on all the types of train which might have been used to recover the RGU. An appropriate test specification would have included the most onerous potential operating conditions, including an emergency brake application. Implementing these tests would have revealed the excessive coupler deflection (paragraph 155).

Inadequate input from mechanical (rolling stock) engineers and other appropriately competent staff

185 **Inadequate input from mechanical (rolling stock) engineers and other appropriately competent staff is apparent in both design and testing of the emergency coupler.**

186 Deficiencies in the emergency recovery system would have been identified if sufficient staff, with appropriate competencies, had been involved in the design of the recovery system (paragraph 79). Defects in the design of the emergency coupler would have been avoided if the design and approval process had included appropriate input from mechanical (rolling stock) engineers (paragraph 132).

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

187 Shortcomings in the emergency coupler acceptance testing programme would have been avoided if there had been adequate technical input from appropriate mechanical (rolling stock) engineers. Appropriate acceptance testing of the emergency coupler would have revealed the excessive coupler deflection (paragraph 155). If appropriate professional engineering input had been provided for the testing undertaken after the July 2010 incident, these tests would have covered the full range of potential operating conditions, including an emergency brake application. It is probable that this would have revealed the unacceptable coupling behaviour (paragraph 164).

Responsibility for planning and implementing emergency recovery

188 **Responsibility for planning and implementing emergency recoveries on LUL infrastructure is unclear. It is uncertain whether better defined responsibilities would have avoided the Highgate incident.**

189 Responsibility for planning and implementing recovery of broken down trains is unclear. The processes intended to control risks associated with recovery appear targeted at relatively complex recoveries where collision damage and/or derailments require the specialist skills of the ERU. The processes assume a significant input from the ERU in both the design and the implementation of recovery procedures. In practice, the ERU are not involved in designing equipment used to recover broken down trains. In many instances, such trains are recovered by coupling them to another train in an operation undertaken by the train operators with no ERU involvement.

190 LUL standard Ta251 required provision of an emergency coupler. The wording implies that the ERU would not be involved in the design or validation of this coupler.

191 Ta251 also stated that “the ERU expect to be called only to deal with any event or incident causing the rolling stock to become immobile that cannot be corrected by the crew, train technician or other trained personnel...(eg...engine failure)”. This does not clearly state whether or not the ERU would attend if other staff can “correct” rolling stock by recovering it with other trains using a standard procedure. In practice, the ERU do not always attend engineering or passenger trains in these circumstances.

192 LUL’s Rule Book 4 (section 4) includes a procedure for one passenger train to push another stalled passenger train using only the train operators and instructions from the control room. LUL Rule Book 18 (section 8.2) provides three categories of defects on mechanised engineer’s trains: defects which can be rectified by the vehicle operator, defects which require the vehicle to be hauled from the running line and defects requiring attention from the ERU. These rules show that the ERU would not necessarily attend a recovery operation.

193 The ERU had no involvement in the design of the RGU emergency coupling. The ERU competency manager attended the approval test at Lillie Bridge depot in 2002. The ERU understood that the RGU crew had the skills needed to recover the vehicle following an engine defect. There is conflicting evidence about whether the ERU gave an opinion on the method of recovery used in such instances. An email sent after the tests said only that the ERU could recover the RGU following a derailment.

194 When recovery work was in progress at the breakdown site, the presence of the ERU at the breakdown site reassured both the DMT and control room staff that operations were being undertaken correctly (paragraphs 107 and 108). In fact, the ERU were taking little part in the recovery operation (paragraph 104).

195 Responsibility for technical management of the breakdown site was unclear (paragraph 90). There is no LUL or Infraco JNP/Tube Lines standard defining how this responsibility should be allocated.

196 It is uncertain whether a clear definition of responsibilities for recovery operations would have prevented the Highgate incident.

Other occurrences of a similar character

197 Uncontrolled runaway of vehicles on London Underground infrastructure is very rare. RAIB has found no evidence of uncontrolled engineering train runaways affecting lines open for passenger service in the last 20 years. An accident at Chorleywood in 1990 and a collision at St Johns Wood, both restricted to areas closed to passenger traffic, are described below.

198 A wagon ran away on the Metropolitan Line at Chorleywood on 16 May 1990 and killed four people working on the track. The wagon had been left on an incline without being properly secured. The Health & Safety Executive (HSE) investigation into the accident[11] concluded that, in addition to omissions by individuals, the accident was due to “the failure of LUL to ensure adequate training, to allocate and document individual tasks and responsibilities, to prepare and monitor safe working practices and to provide equipment to ensure the safety of their employees and others”.

199 HSE recommended that “LUL should undertake measures to ensure that all engineering tasks where hazards can arise are identified and that a written safe system of work is prepared and issued”. The recovery of the RGU was an engineering task. The Highgate runaway would have been avoided if the hazards associated with RGU recovery had been identified, and dealt with, as recommended by the Chorleywood report.

200 A powered trolley towing two trailers collided with stationary trolleys near St Johns Wood on 25 October 2007 (RAIB Report 24/2008). No casualties and only minor damage resulted from this incident. The vehicles had been provided by TransPlant. The collision occurred because some of the trailer brakes did not operate correctly. Underlying factors reported by RAIB included that the “design, testing acceptance and approvals process did not detect that the design of the braking system was deficient and the absence of adequate maintenance documentation”.

[11] A report of the inquiry into the accident that occurred on 16 May 1990 at Chorleywood on the Metropolitan Line of London Underground, HSE, 1992, available from www.railwaysarchive.co.uk.

201 The lack of expertise applied to the approval process for equipment supplied by TransPlant is a common factor in both the Highgate and St Johns Wood events. Shortcomings in preparation of documentation are also apparent in both events – at Highgate, the recovery instructions were inadequate (paragraph 132); at St Johns Wood, gradient related braking requirements were omitted from Tube Lines' specification for the trolley, and there was no comprehensive set of maintenance documents.

202 RAIB recommendations following the St Johns Wood incident included asking LUL to review and, where necessary, implement improvements to its process for acceptance and approval of on-track plant (recommendation 11: see appendix D). Version A4 of LUL standard 1-538, Assurance, was issued in June 2009 and includes processes covering these matters. There was no requirement to apply this standard to equipment already in use.

203 TransPlant introduced a new *tamper* in 2007 to assist with track maintenance. This required an emergency coupler to allow recovery by a passenger train if it broke down. The Plant Approvals Engineer procured a coupler intended for use with passenger trains using a procurement method similar to that used for the RGU. This coupler included the same design deficiencies which caused the Highgate incident.

204 The instructions for use would have resulted in the tamper being recovered as an unbraked vehicle at the end of a train. They did not mention mitigation against a runaway and required a member of staff to travel on the unbraked tamper. In practice there was very little likelihood of the passenger train/tamper coupling being used. A different coupler was provided for use with battery locomotives, and a locomotive of this type has always accompanied the tamper to ensure proper operation of signalling systems.

205 After the July 2010 incident and subsequent testing (paragraph 164), Tube Lines began procuring an improved emergency coupler using a similar process to that adopted for the original coupler in 2002. The Plant Approvals Engineer had provided a revised outline design to Powerhouse before the Highgate incident occurred. This design dealt with the excessive vertical deflection seen during the July 2010 testing. It did not address the excessive lateral deflection which had been seen during the July 2010 recovery and which caused the coupling failure at Highgate. Tube Lines had just started a process to review the improved coupler design when the Highgate incident occurred.

Observations[12]

Staff performance during the runaway

206 None of the control room staff, or train operators, dealing with the consequences of the runaway RGU had any experience, training or guidance on how to handle this type of situation. Their performance, and particularly that of the service manager, deserves commendation.

[12] 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.

Detail design arrangements

207 Infraco JNP commissioned the detail design of the tow bar from an organisation which was not operating the procedures appropriate for the design of a safety critical component of this type.

208 The Plant Approvals Engineer commissioned the design and manufacture of the emergency coupler from Powerhouse. This company was a regular supplier to TransPlant. It had been designing and manufacturing small items of equipment used for maintaining the London Underground since 1992.

209 The Plant Approvals Engineer provided Powerhouse with sketches showing the coupling outline design and instructed it to undertake detail design of both the tow bar and its connections. Powerhouse had insufficient information to establish whether the outline design was satisfactory and this did not form part of its remit.

210 In view of the safety-critical nature of the emergency coupler, the design should have been undertaken by suitably qualified staff and checked by a different person. This is normal engineering practice and was probably a contractual requirement. The actual contractual requirement cannot be established because the relevant paperwork is not available. However, similar contemporary commissions from Infraco JNP to Powerhouse required Powerhouse to operate a quality assurance process including appropriate checking procedures.

211 Although drawings prepared by Powerhouse in 2002 show that the tow bar was to be used in an inclined position, the calculations that were done by Powerhouse as part of the design process did not take the inclination into account. They calculated that the tow bar would carry a *proof load* of about 36.5 tonnes in compression. RAIB has calculated that, ignoring the excessive deflections illustrated in figures 13 and 15, the coupling compressive proof load was about 17.6 tonnes with the tow bar inclined to connect with the RGU clevis in use at the Highgate incident, and only about 7 tonnes with the tow bar connected to the higher clevis at the opposite end of the RGU.

212 Powerhouse had no system for routine checking of calculations, and the tow bar calculations were not checked. The error in Powerhouse's calculations played no part in the tow bar failure, but is indicative of an organisation lacking the processes needed for safety critical design of a tow bar.

213 Infraco JNP's Contractual Safety Case applicable during procurement of the emergency coupler stated that "[JNP] processes are designed to control our contribution to LUL's system risk...including any risk that may be imported through our suppliers...We achieve this by...selecting and briefing capable suppliers" (Safety Case version 3, paragraph 11.1). The need for surveillance of suppliers and, if necessary, quality checks was also acknowledged (paragraph 11.11).

214 Before procuring the emergency couplers in 2002, Infraco JNP had neither audited the quality of Powerhouse's work, nor established the services which Powerhouse were competent to deliver. Powerhouse continued to supply Infraco JNP, and subsequently Tube Lines, until at least August 2010 when Tube Lines started procuring a new emergency coupler from Powerhouse (paragraph 205). Despite this on-going relationship, neither Infraco JNP, nor Tube Lines, had audited the quality of Powerhouse's work, or formally established Powerhouse's competencies, when RAIB made enquiries in October 2010.

Conclusions

Immediate cause

215 The immediate cause of the incident was the absence of operational brakes on a vehicle which became detached when an emergency coupler broke (**paragraph 64**).

Causal and contributory factors

216 The causal factors were:

a the RGU braking system was inoperative, and there was no alternative mitigation against a runaway, when being recovered (**paragraph 67, Recommendation 5**);

b the design and documentation for the recovery procedure were inadequate (**paragraph 79, Recommendations 1, 2 and 5**);

c the emergency coupler was broken by loads caused by an emergency brake application (**paragraph 109, Recommendation 4**);

d the emergency coupler broke due to overstressing of a tow bar (**paragraph 117, Recommendations 1 and 2**);

e inadequacies in the specification, design, checking and approval process for the emergency coupler meant that it fractured due to an unexpected deflection (**paragraph 132, Recommendations 1 and 2**); and

f acceptance testing of the emergency coupler was undertaken using an inappropriate locomotive so did not reveal the defective coupling performance (**paragraph 155, Recommendations 1 and 2**).

217 A contributory factor was the inadequate investigation of the July 2010 incident which did not detect the unacceptable emergency coupler behaviour (**paragraph 164, Recommendation 3**).

218 A possible causal factor was that the ERU staff at the breakdown site did not query the recovery procedure when they learnt that the RGU had to be recovered as an unbraked vehicle (**paragraph 101, Recommendation 4**).

219 A contributory factor was the minimal briefing about the emergency recovery procedure; and, the absence of any training, or practicing, of this procedure. These shortcomings meant that there was little opportunity to discover the defective coupling and lack of mitigation against a runaway (**paragraph 176, Recommendations 4**).

Underlying factors

220 The underlying factors were:

a inadequate specification of technical requirements (**paragraph 182, Recommendations 1, 2 and 5**);

b inadequate input from mechanical (rolling stock) engineers and other appropriately skilled staff (**paragraph 185, Recommendations 1 and 2**); and

c unclear responsibility for planning and implementation of emergency recovery procedures (**paragraph 188; Recommendation 4**).

Additional observations

221 Although not linked to the incident on 13 August 2010, the RAIB observes that Infraco JNP commissioned the detail design of the tow bar from an organisation which was not operating the procedures appropriate for the design of a safety critical component of this type (**paragraph 207, Recommendations 6 and 7**).

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

222 LUL and Tube Lines report that they are developing processes intended to address many of the issues identified in RAIB's recommendations. Whilst these processes are being developed, LUL has introduced temporary rules relating to movement of unbraked stock. These movements must now be authorised by a senior member of staff who will make appropriate checks before giving authority. The only exceptions relate to some clearly defined situations where adequate braking is provided by adjacent vehicles.

223 Before the Highgate incident, Tube Lines had begun to implement a process to formally check all existing OSP&Is. The RGU's OSP&I had not yet been checked as part of this process when the incident occurred. The requirement for LUL to approve OSP&Is has been reintroduced following the Highgate incident.

224 LUL reports that managers have discussed the incident with relevant control room staff and that issues arising from these discussions, together with issues identified by the formal LUL/Tube Lines internal investigation of the incident, will be included in a planned training day for controllers. These issues include the resumption of normal southbound train services between Archway and Camden Town at about 07:12 hrs, before the line had been examined. This was an error – the line should have been examined to check for possible damage by the runaway RGU.

225 Tube Lines reports that the RGU re-entered service on LUL infrastructure in April 2011 with new arrangements including:

- The RGU machine has undergone a full overhaul.
- The access hatches to the equipment areas have been modified to enable them to be opened in tube tunnel sections.
- Recovery will only be by TransPlant locomotives. Recovery will be at 5 mph (8 km/h) and these locos have controls designed for continuous low speed operation.
- A purpose built tow-bar has been designed and tested to couple the RGU to an assisting locomotive. The specification of requirements was prepared by a reputable supplier with extensive rolling stock experience.
- Testing of the tow-bar was done by the intended recovery vehicle, ie a battery locomotive and has included over speed emergency brake tests from 10 mph (16 km/h). The tow bar has passed these tests to the criteria expected.
- The testing was done to a pre-determined written test plan and results recorded that have been verified by rolling stock engineers.
- During a recovery the RGU brakes will not be isolated. Air will be supplied from the assisting locomotive to hold the RGU's spring applied brakes 'off'; these brakes will therefore apply automatically if there is a failure of the coupler.
- The coupling between the RGU and battery locomotive will be undertaken by competent licensed TransPlant staff.
- Designated competent TransPlant Managers will oversee the coupling and recovery process on site.

- Roles and responsibilities have been clarified in operating guidelines and emergency arrangements have been detailed in the OSP&I for the RGU. The ERU, Tube Lines staff and LU rolling stock engineers have been involved in the development, testing and sign off of the revised arrangements.

226 Tube Lines have published a new procedure, “Approval of Plant, Tools and Equipment”, with requirements including full application of the assurance process.

Recommendations

227 When Metronet responsibilities were transferred to LUL in May 2008, LUL became directly responsible for maintaining all Underground lines except those covered by Tube Lines (the Jubilee, Northern and Piccadilly Lines). Recommendations 1 to 5 are addressed to LUL in its role as infrastructure owner/operator and in its role as maintainer of some lines. Recommendations 6 and 7 relate only to its role as infrastructure owner/operator. The following recommendations are made:[13]

1 *This recommendation is intended to provide sufficient and appropriate inputs to the <u>future</u> introduction of new and modified engineering trains and rail mounted plant.*

LUL should, with assistance from Tube Lines, review and, where necessary, amend processes and practices so that adequate design, checking, approval and testing is provided for new and modified engineering trains and rail mounted plant. The processes and practices should include specifying and allocating sufficient staff with appropriate qualifications, defining the individual responsibilities and providing effective coordination between them (paragraphs 216b, 216d, 216e, 216f, 220a and 220b).

2 *This recommendation is intended to identify and remedy any <u>existing</u> approvals where the extent of specialist inputs may have been insufficient to provide reasonable assurance of compliance with the standards applicable at the time of approval.*

In respect of engineering trains and rail mounted plant supplied by (or through) TransPlant: LUL should, with assistance from Tube Lines, review all existing approvals to determine whether the inputs to the approval process were sufficient to give reasonable assurance that adequate safety standards are met by safety critical equipment, operating procedures and documentation. If inputs were insufficient to give this assurance, LUL, with assistance from Tube Lines, should introduce a time-bound process to implement the measures needed to comply with appropriate safety standards (paragraphs 216b, 216d, 216e, 216f, 220a and 220b).

continued

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[13] 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 167 to 171) can be found on RAIB's website www.raib.gov.uk.

3 *This recommendation is intended to provide sufficient experienced staff involvement to the investigation of allegedly defective equipment so that lessons are learnt from equipment malfunctions before these result in an accident.*

LUL should, with assistance from Tube Lines, review and, where necessary, amend the processes and practices used to investigate allegedly defective equipment. This review should cover the specification and implementation of adequate testing and the assessment of both defects and test results (paragraph 217).

4 *This recommendation is intended to clarify the responsibilities of, and provide adequate instructions and training for, people involved in the recovery of engineering trains and rail mounted plant. The training process should include a means for identifying and resolving any problems, or improvements, identified during the training.*

LUL should, with assistance from Tube Lines, review and clarify the responsibilities of all staff who may be involved in the recovery of engineering trains and rail mounted plant. Where necessary, processes should be implemented to provide these staff with appropriate instructions, training and practice. This training process should include appropriate actions to be taken if problems, or possible improvements, are identified during training (paragraphs 216c, 218, 219 and 220c).

5 *This recommendation is intended to minimise the risks associated with the operation of unbraked vehicles at the end of trains.*

LUL should, with assistance from Tube Lines, provide guidance and instructions to ensure a safe system of work to recover vehicles with defective or ineffective braking (paragraphs 216a, 216b and 220a).

6 *The intention of this recommendation is to identify any shortcomings in the quality assurance processes applied to organisations supplying TransPlant with plant and equipment including design services.*

LUL should audit Tube Lines’ supplier quality assurance system, as applied to TransPlant’s suppliers, with particular emphasis on ensuring that responsibilities for design, checking and approval are clearly defined and then allocated only to people and organisations which have been verified as having the necessary competencies. LUL should close out this audit after ensuring that Tube Lines have undertaken any necessary corrective actions (paragraph 221).

continued

7 *The intention of this recommendation is to identify any shortcomings in the quality assurance processes applied within LUL in relation to the supply of safety critical design services by Tube Lines and organisations working for Tube Lines.*

LUL should review the level of assurance provided by LUL's audit regime for the design elements of safety critical services provided to LUL, by Tube Lines and its suppliers. If the existing audit regime does not provide an adequate level of assurance, LUL should introduce a time-bound process to implement the measures needed to achieve an adequate level of assurance (paragraph 221).

Appendices

Appendix A - Glossary of abbreviations and acronyms

CTC	Certificate of Technical Conformance
DMT	Duty Manager Trains
ERU	Emergency Response Unit
HSE	Health & Safety Executive
LUL	London Underground Limited
JNP	Jubilee, Northern, Piccadilly (lines on the London Underground)
OSP&I	Operational Safety Plan & Instructions
OSP	Operational Safety Plan
OTDR	On Train Data Recorder
RGU	Rail Grinding Unit
SPC	Site Person in Charge
TfL	Transport for London

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.

Buffer stops	A device used to stop the progress of rail vehicles at the end of sidings and other dead-end lines.*
Clevis coupler	A removable pin passing through two parallel plates attached to a vehicle. A loop from another vehicle can be placed between the parallel plates and secured by passing the pin through the loop (figure 3).
Conductor rail	An additional rail used to convey and enable collection of electrical traction current at track level.*
Engineering hours	The time between the end of traffic hours and the start of the next traffic hours.
Negative rail	A conductor rail positioned midway between the running rails.
Points	A section of track with moveable rails that can direct a train from one track to another.
Proof load	The maximum load which can be applied and then removed without causing permanent deformation.
Restricted mode	A train operating condition which imposes additional restrictions to those which apply in normal service.
Running rail	A rail that supports and guides the flanged steel rail wheels of a rail vehicle.*
Trailing (points)	Points where lines converge in the direction of travel.
Tamper	A rail vehicle which aligns track and simultaneously compacts the ballast (stones) which support the track.
Track circuited	Provided with electrical or electronic devices used to determine whether there is a train within a defined section of track.
Traffic hours	The time during which traction current is normally supplied to conductor rails for routine operation of passenger trains.
Trainstop	A device that ensures compliance with a signal displaying a stop aspect by automatically applying the brakes should the driver attempt to pass the relevant signal.*
Wedgelock	The standard automatic coupling used by London Underground; described in paragraph 119.

Appendix C - Key LUL standards

TE-IS-0202-A2 (November 2000)	Plant Approval
Ta251 (April 2002)	Introducing New or Modified Rolling Stock to LUL
1-558 version 7 (April 2008)	Formal Investigation of Incidents
1-538-A4 (June 2009)	Assurance

Appendix D - Previous Recommendation

The following previous RAIB recommendation is relevant to this incident

Minor collision between an engineering unit and two manual trolleys near St. John's Wood, 25 October 2007 (report 24/2008)

Recommendation 11

London Underground Ltd should review the suitability of its process for the acceptance and approvals of trolleys, trailers and other items of on-track plant. Any necessary improvements identified should be implemented.

LUL reported in January 2009 that it would review its arrangements (as contained in its category one standard 1-172 Plant Tools and Equipment- Performance and Design) and if considered necessary make relevant changes to the standard.

Appendix E - RGU Reliability

E.1 The RGU broke down and it was impractical for the RGU crew to repair the defect. This was a foreseeable event so adequate procedures should have been available to deal with it.

E.2 The RGU was constructed for use on a variety of railway networks throughout Europe. It first entered service in 2001 and first operated on LUL infrastructure in 2002. It had operated 940 shifts before the Highgate incident shift on 13 August 2010. Around 60% of these shifts were on LUL infrastructure. The remainder were in various European countries and included work on the Docklands Light Railway in London, and on the Nexus system in Tyne & Wear.

E.3 During these 940 shifts, the RGU was unable to leave the railway under its own power on three occasions. These were due to a frozen air system in Stockholm during February 2002; a defective alternator in Newcastle during April 2006; and, a defective starter motor on LUL's Jubilee Line at West Hampstead on 17 July 2010 (paragraph 165). There were other mechanical breakdowns which affected planned work but which were repaired by the RGU crew. These included an instance on LUL infrastructure at Victoria in May 2008 when battery locomotives were sent to site as a precautionary measure. They were not required so their incompatibility with the emergency coupler was not discovered (paragraph 138).

E.4 On 13 August 2010, a hydraulic pressure sensor developed a defect and this prevented the RGU's main engine providing the power needed to propel the RGU and to operate the braking system. On this occasion, the RGU crew were unable to repair the engine without undue delay to passenger services.

E.5 Tube Lines assessed the RGU's reliability following the July 2010 incident and concluded that the reliability was acceptable. This view was endorsed by the LUL/Tube Lines inquiry panel set up after the Highgate incident. Occasional breakdowns are inevitable with any type of train so a safe method of recovery should always be available.

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