RAIB

Rail Accident Investigation Branch

Rail Accident Report

Derailment of a London Underground Central Line train near Mile End station 5 July 2007

Department for Transport

Report 03/2008
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This investigation was carried out in accordance with:

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

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Contents

Introduction

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.

3 Access was freely given by London Underground Ltd (LUL) and Metronet Rail to their staff, data and records in connection with the investigation.

4 Appendices at the rear of this report contain the following glossaries:

- abbreviations and acronyms are explained in Appendix A;
- technical terms (shown in italics the first time they appear in the report) are explained in Appendix B; and
- references to other documents are listed in Appendix C.

5 References to right and left are made looking forward in the direction of travel of the derailed train.

6 Where the report refers to the train operator, this means the train operator of the derailed train. Other train operators are specifically described where necessary.

Summary of the report

Key facts about the accident

7 At 09:01 hrs on 5 July 2007 westbound train 117 struck a roll of fire resistant material lying on the track between Mile End and Bethnal Green tube stations on the Central Line of the London Underground Network. In consequence three *bogies* were derailed. The *train operator* applied the *emergency brake* and the train stopped after approximately 148 m (468 ft).

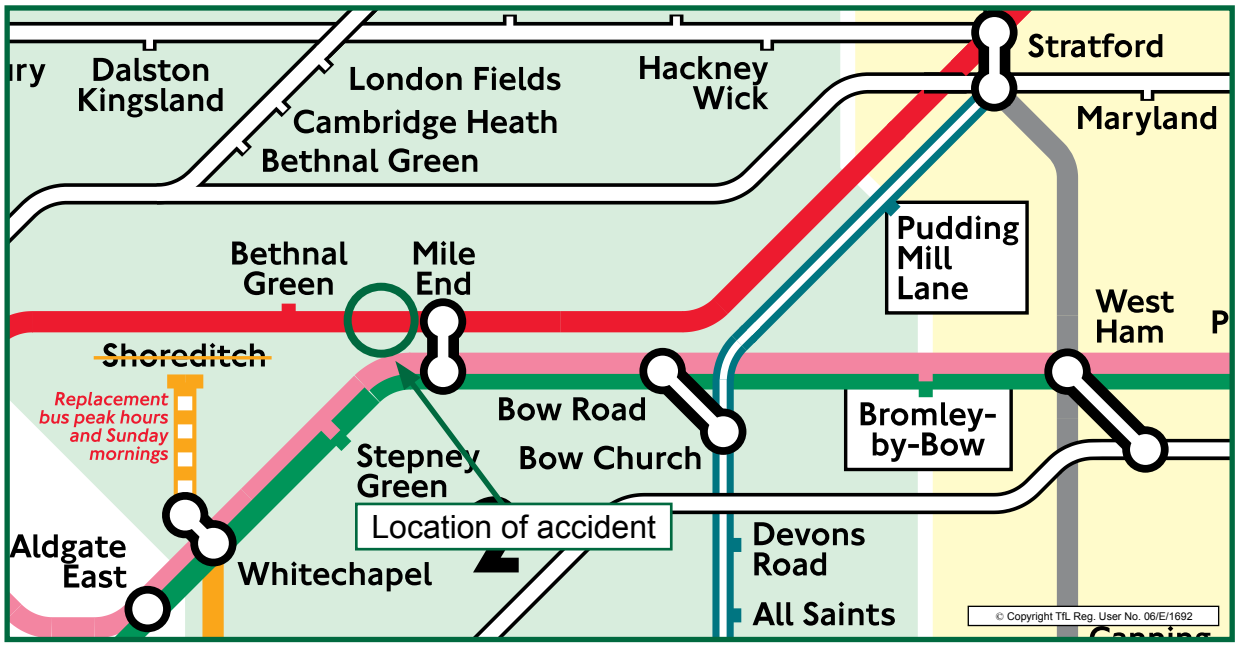


Figure 1: Extract from London Underground map showing the location of the accident

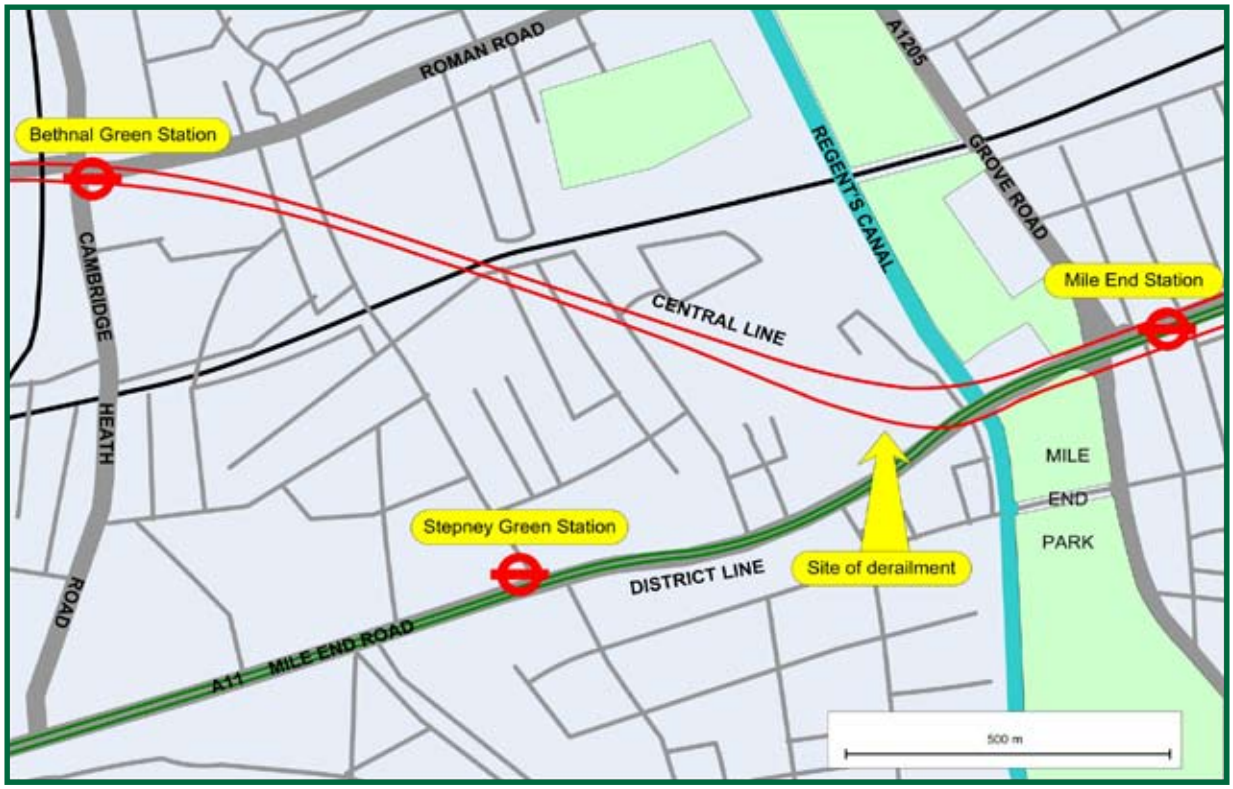


Figure 2: Route of the Central Line from Mile End towards Bethnal Green

Immediate cause, causal and contributory factors, underlying cause

Immediate cause

8 The immediate cause of the derailment was a roll of *fire-resistant blanket*, approximately 120 – 145 mm diameter and 1.8 m long, lying across one *running rail*.

Causal factors

9 The incomplete training and supporting documentation provided to Site Persons in Charge (SPCs) in relation to the storage of materials in *cross passages*.

10 The decision that full bags of *Tecroc* should be treated as a fire risk.

11 The lack of complete guidance on the use of fire-resistant blanket.

12 The lack of awareness about the possibility that cross passage wind could cause a roll of fire-resistant blanket to unroll and move its bulk longitudinally down the passage.

Contributory factors

13 Possibly, the late change in the work being undertaken.

14 The need to store materials in cross passages.

15 The presence of wind at high velocities in cross passages and running tunnels.

16 The staff awareness about managing fire risks in relation to other risks.

Underlying cause

17 The underlying cause was the lack of a comprehensive risk analysis being performed to support the use of fire-resistant blankets.

Severity of consequences

18 No serious or life threatening injuries or fatalities occurred. Twenty passengers received medical treatment. Five hundred and twenty people were evacuated along the running tunnels to Mile End station from the incident train.

19 The first two *cars* of the train sustained damage to their wheels, gearboxes and *shoegear*. Minor damage was sustained to the car bodies and underfloor equipment.

20 Infrastructure damage was sustained by the running rail *chairs*, *conductor rail* support *insulators*, one signal, tunnel wall cabling, track bonds and cables.

21 The positive conductor rail beneficially guided the wheels of the leading car of the train and kept it from hitting the tunnel wall.

Recommendations

22 Recommendations can be found in paragraph 145. They relate to the following areas:

- amendment to the content of SPC training to ensure that it contains adequate information on the storage of materials and the effect of wind in cross passages;
- a review of the coverage of risk assessments of stored materials to ensure that they include the operational railway;
- a review and amendment of instruction on the use of fire-resistant blankets;
- ensuring that appropriate staff know about the effects of wind in the *deep level tube* system.

The Accident

Summary of the accident

23 At 09:01 hrs on 5 July 2007 westbound train 117 struck a roll of fire-resistant blanket lying across a running rail in the tunnel between Mile End and Bethnal Green tube stations on the LUL Central Line. The first three bogies of the train, which was travelling at nearly 41 mph (65 km/h), were derailed. Both axles of the first bogie, one axle of the second bogie and both axles of the third bogie left the rails. The train operator applied the emergency brake causing the train to stop after travelling approximately 148 m (468 ft).

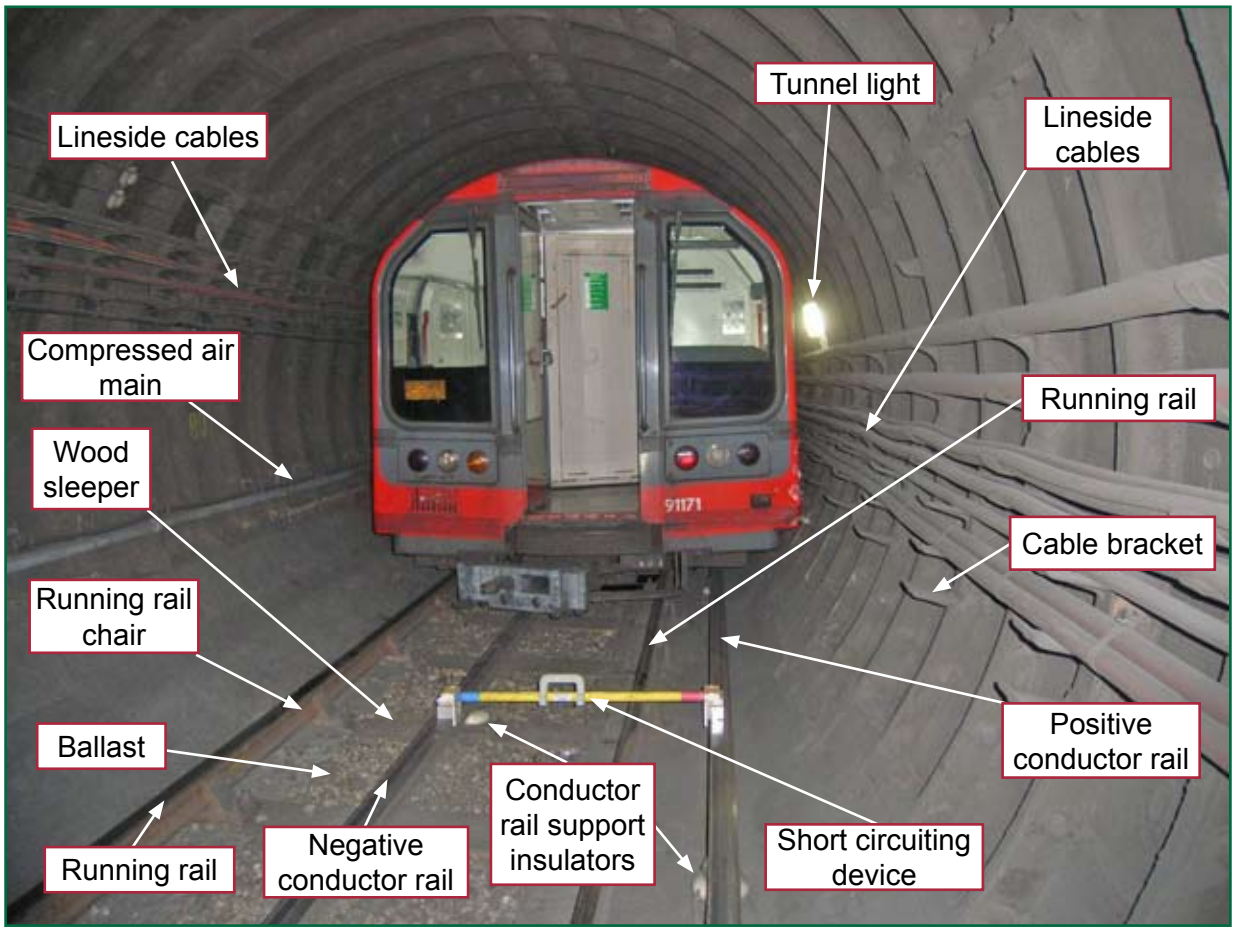


Figure 3: The derailed train viewed from the front

Figure 4: The remains of the fire-blanket after train 117 had passed over it

24 Immediately following the derailment the train caused a *short circuit* between the positive and negative conductor rails, causing the *traction current* to *discharge* and the *tunnel lights* to illuminate automatically. Apart from the *emergency lights* all other interior train lights went out.

25 The train did not come into contact with the tunnel wall, however one signal was destroyed, cables sustained insulation damage, and cable brackets and many cast iron rail chairs and conductor rail insulators were broken. Damage to the train was relatively minor with only a small number of glass shards entering the passenger compartments.

26 Evacuation commenced at 10:15 hrs and was completed at 11:30 hrs. Five hundred and twenty people were detrained from the rear of train 117 located approximately 371 m from the headwall at Mile End station. Other passengers were detrained from three other westbound trains; those from trains 145 and 110 were detrained in the platforms at Mile End and Bethnal Green, 369 passengers from train 15 were detrained along the tunnel between there and Stratford. Subsequently the curtailment of both eastbound and westbound services between Stratford and Liverpool Street required passengers to be detrained in a controlled manner at both stations.

27 Medical treatment was given to 20 people; none of the injuries were considered by the ambulance crews to be of a serious nature. Most of these injuries were received during evacuation along the tunnels due to the uneven walking surface and stress induced discomfort. Eight people received hospital attention, including one with an ankle injury sustained during the derailment.

Figure 5: The tunnel and rear of train 117

The parties involved

28 Transport for London defines the services, performance and facilities that LUL is required to deliver.

29 LUL is the organisation that provides the train services. It provides all the operational staff for the stations, trains, signal boxes and operations control rooms. It defines the technical and contractual standards that the *Infracos* are required to meet.

30 Metronet Rail BCV Ltd (Metronet) is one of three Infracos that have been contracted to undertake the maintenance, repair, renovation and renewal of the assets forming the London Underground system. These assets include the trains, stations, tunnels and track. The Central Line is covered by Metronet's contract. Since the accident Metronet has entered *PPP administration* but continues to fulfil its maintenance and renewal contract.

31 Balfour Beatty is one of several companies that were shareholders of Metronet. Balfour Beatty Rail Projects (BBRP) was the principal contractor for the track renewal project that was being undertaken on the eastbound Central Line between Mile End and Bethnal Green. It sourced staff to undertake the contract both from within its own organisations and from subcontractors and staff supply agencies (see paragraph 86).

Location

32 The accident occurred 350 m from the west end *headwall* of Mile End Central Line tube station. At this location the line curves to the right (400 m radius) on a downward gradient of 1 in 125.

33 Mile End station platforms are 6.8 m below pavement level. The site of the derailment is 8.5 m below platform level.

The line

34 The section of the Central Line through Stratford - Mile End - Bethnal Green - Liverpool Street was opened in December 1946. It provided an eastern link between the original section of the Central London Railway between Wood Lane and Liverpool Street and main line branches to Epping and Hainault.

35 The eastern link was built on the hump station principle whereby tunnels on the approach to a station were built with an upward gradient and those on the departure side are on a downward gradient. The latter significantly assists with the acceleration of the train after a station stop. This enabled train 117 to accelerate to almost 41 mph (65 km/h) in the relatively short distance from Mile End station to the site of the cross passage. The target speed used by the automatic train operation system on this section of line during the passage of train 117 was 40 mph (64 km/h).

The stations

36 Mile End is a *sub-surface station* built on the *cut and cover* principle that provides cross platform interchange with the LUL District Line. This station provided the means of access by the emergency services and the egress for passengers from train 117. Following the derailment it was closed for normal passenger use with no District Line trains stopping until normal start of traffic on 6 July 2007. Central Line services did not resume until normal start of traffic on 7 July 2007.

37 Bethnal Green station is a deep level tube station with separate tunnels for each platform. The station at Bethnal Green played no part in the incident, although it was used for access by the Emergency Response Unit for LUL during re-railing and recovery of the train.

The tunnel and track

38 The section between Mile End and Bethnal Green is constructed as deep level tube using single track circular bored tunnels with cast iron segment linings. Cables and air pipes run along the sides of the tunnel; they are hung from brackets bolted to the tunnel linings (see Figure 3). Tunnel lights are fitted every 40 m which become illuminated when traction current is discharged.

39 The track between Mile End station and the derailment site comprises *bullhead rail* held in cast iron chairs; the rail is retained by *Panlock keys*. The hardwood sleepers are set in concrete at their ends with granite *ballast* levelled to the tops of the sleepers (see Figure 3).

Figure 6: Track damaged by the derailment after the train had been removed

40 There are two conductor rails: the positive rail is located to one side of the running rails whilst the negative rail is centred between them. Both are higher than the running rails; the positive rail by 3 in (76 mm) and the negative rail by 1½ in (38 mm). They are energised at a (nominal) direct current potential of 600 volts between them.

41 The piston effect of the trains pushes large quantities of air through the tunnels and ventilates the stations and tunnels. Between Mile End and Bethnal Green stations there are a number of cross passages and one ventilation shaft. The ventilation shaft beyond the site of the derailment connects both the eastbound and westbound lines to the surface. A ventilation fan that draws air from the tunnels was operational at the time of the incident but played no part in the events leading to the derailment.

42 There are several cross passages between Mile End and Bethnal Green. They are used for a number of functions:

a) walkway between the eastbound and westbound lines, capable of use both for maintenance activities and emergency access and egress;

b) draught relief between the eastbound and westbound lines;

c) storage of maintenance materials; and

d) carrying cable routes and *air lines* between the eastbound and westbound lines.

The train

43 The line is operated by 1992 Tube Stock built by ABB Transportation Ltd. Each train is made up of 2-car units marshalled into 8-car trains. Units 91171 (leading), 93183, 93024 and 91121 formed the train involved in the derailment.

44 The 1992 Tube Stock is of *monocoque construction* from aluminium extrusions. Some items of train equipment have a limited memory function which enables a history of commands and equipment operations to be obtained. The train is not fitted with a separate train data recorder which could capture more comprehensive information on commands, traction, braking and door operation.

45 All passenger trains on the Central Line can run under Automatic Train Operation (ATO). Trains normally operate under ATO on weekdays and full manual control at weekends. In ATO mode the train operator controls the opening and closing of the doors and instructs the train to the start from the platform (by pushing two start buttons). The train then runs automatically to the next station. This was the mode in which the train was operating at the time of the derailment. The train operator is always able to operate the emergency brake.

Events immediately preceding the accident

46 Part of Metronet's contract (paragraph 30) involves track reconditioning on the Central Line. This work is undertaken at night when trains are not running, (a time called Engineering Hours). Groups of track workers then undertake a range of maintenance tasks within the tunnels, e.g. on the running rails, conductor rails, sleepers, rail fixings and ballast (see Figure 3).

47 As part of Metronet track reconditioning *contract C345* various engineering activities were planned entirely during engineering hours for both lines between Mile End and Bethnal Green. This included the removal of contaminated track ballast, levelling of ballast, removal of scrap materials and rubbish, renewal of sleepers, and the welding, grinding and replacement of rails.

48 Sleeper replacement includes the removal of life expired or damaged wood sleepers prior to fitting new concrete ones. To ensure that the track cannot move relative to the tunnel walls, the sleepers are set into concrete at their ends. The old concrete needs to be broken out before a replacement sleeper may be fitted; fast setting concrete (Tecroc) is then installed to retain the sleeper in place so that the line is usable by the first morning train.

49 During the earlier upgrading works on the Central Line during the 1990s the scale of activity caused severe problems for the transport of materials to and from work sites. Widespread use of the cross passages for storage was used to as a means to alleviate the restricted availability of engineering trains. LUL recognised the fire hazards arising from materials storage and required that each material be assessed. The authorisation to store and use these materials was constrained by clear limitations on the quantity and means of storage, and the manner of use, and on the need to maintain a walkway alongside stored material.

50 In 1996 particular difficulties were experienced on the Central Line with the storage of materials for upgrading and renewal works. The use of heavy duty polythene bags for short term storage was proposed as a means of overcoming the lack of nightly engineering trains. The bags were intended for the storage of non-combustible materials and as rubbish sacks. They were tested by LUL Technology Services and were found not to meet the required flammability performance (see paragraph 51).

51 In order to permit their use Waiver 822 was issued in July 1996 by the LUL Waiver Committee (Materials Fire Performance) against LUL Chief Engineer's Standard "Code of Practice – Fire Safety of Materials used in the Underground". It was specific to the Central Line and permitted up to 500 bags to be stored at any one time for up to 4 weeks. No quantified risk assessment was carried out, however the committee considered the content of the report from LUL Technology services and exercised their judgement in granting the waiver. There is no evidence that any consideration was made of effects on the operational railway other than for fire.

52 In July 1998 LUL was in direct control of all maintenance activities. Following the good testimonial service obtained under Waiver 822 LUL extended the use of the plastic bags to system wide use with mandatory covering with an authorised fire-resistant blanket which had to be adequately anchored down. The risk assessments undertaken at that time were less prescriptive regarding analysis and content than those currently used by LUL and the Infracos; they did not cover all operational hazards. Subsequently, following the start of the Public Private Partnership, the Infracos did not replace inherited risk assessments by new ones undertaken under the latest guidance. Instead, the controls on the bags and associated fire-resistant blankets have been kept under review since that time. Through procedures issued by Metronet, Tubelines and LUL the legacy use of the fire-resistant blanket has been maintained to ensure that any fire hazard from stored material is controlled *as low as reasonably practicable*.

53 The fire-resistant blanket is a consumable item and is kept in stock in the material stores system. It is supplied wrapped in heavy duty polythene. Each roll consists of a 75 mm diameter cardboard core onto which is wound a single 50 m length of fire-resistant blanket. When new the roll is 1.8 m long by 180 mm diameter and weighs 40 kg.

54 There is no specific guidance anywhere on the LUL system on exactly how fire-resistant blankets should be used nor do there appear to be any risk assessments that cover hazards that could be transferred on to the operational railway. In use, lengths are sometimes cut, with difficulty (see paragraph 122), from the roll and sometimes a length is simply unrolled. Fire-resistant blankets are also regularly used as a protection on station surfaces, such as between a station platform and a temporary plywood covering. For this reason many staff working underground prefer to use complete rolls of blanket, rather than cut lengths.

55 In June 2005 Metronet was granted a concession for the use of Tecroc BBLUL1515 fast setting concrete (LUL reference CR01637). This material had enhanced properties over the existing authorised and single sourced concrete. It is supplied in strong paper bags, which are flammable. A number of conditions were imposed on the use of the concrete; however, none of these related to the need to cover the material with fire-resistant blanket during storage. Procedures did address the storage of paper, e.g. empty paper bags, for which specific fire precautions were in place (within storage bins or beneath fire-resistant blankets).

56 Prior to 2005 the storage of materials within a station was covered by the Fire Precautions Act (FPA). Section 12 had direct application to stations that were more than 50 per cent covered or enclosed. The FPA was superseded by the Regulatory Reform (Fire Safety) Order 2005 [Reference 1] which appears to cover all parts of the tube and subsurface network[1]. The Metronet procedures, mandated by an LUL contract document [Reference 3], cover the storage of materials in cross passages, thereby implementing the requirements of the Order. A licence is required to be displayed at each location listing the stored materials (Figure 7).

Figure 7: The storage licence and storage bins located in the cross passage as seen facing the westbound tunnel

57 On the night of 3/4 July an engineering gang, controlled and managed by Balfour Beatty and based at the Ruislip depot of Metronet, worked on the eastbound line between Mile End and Bethnal Green. Prior to this they had worked on the section between Liverpool Street and Bethnal Green. On this night they assisted specialist contractors who were undertaking the removal of contaminated ballast. These contractors provided their own certificated operators to move hand pushed trolleys conveying materials along the track. The engineering gang also moved materials, including 20 bags of Tecroc fast setting cement, from Mile End platform to the cross passage.

[1] Legal debate is ongoing over the possible application of the requirements of the Regulatory Reform (Fire Safety) Order 2005 to parts of the system that were not included under the original Fire Precautions Act.

58 This was the first night that the engineering gang had access to the Mile End to Bethnal Green section; the condition of the infrastructure and what tools and materials had been left on site by the previous gang were unknown to this gang. The SPC observed that the previous gang had left a new roll of fire-resistant blanket lying on two steel storage bins (Figure 7) in the cross passage. At the end of work the SPC checked that the cross passage was in a safe condition and decided that the Tecroc bags should be covered with fire-resistant blanket. There was, however, nothing with which to cut the packaging material from around the roll; ordinary open bladed knives were prohibited by BBRP and no safety cutter was present in the storage bins. As a consequence the Tecroc was left uncovered. Prior to the following night's work the SPC organised the issue of a safety cutter from the project stores.

59 On the night of 4/5 July the engineering gang arrived at Mile End station for their second night on the eastbound line. Within their planned work schedule they intended to break out four existing wooden sleepers and to replace them by new ones of concrete. No gang was working on the eastbound line.

60 During the platform briefing by the *Protection Master*, it became apparent that three trolley operators were required. Because only one person present (the SPC) was certificated to carry out this duty, that night's planned activity had to be changed. The supervisor and SPC thus arranged alternative work, involving the digging of ballast, packing of rail chairs and an audit of tools and equipment.

61 Two operatives were allocated the job of inspecting the licence, the tools and equipment stored in the cross passage. This involved listing everything stored there, including items within two large storage bins (Figure 7), checking the condition of equipment and whether the items were within their safe usage date, and checking that everything was properly secured. During this time the roll of fire-resistant blanket was moved to the top of a low pile of sleepers so that the contents of the storage boxes could be inspected.

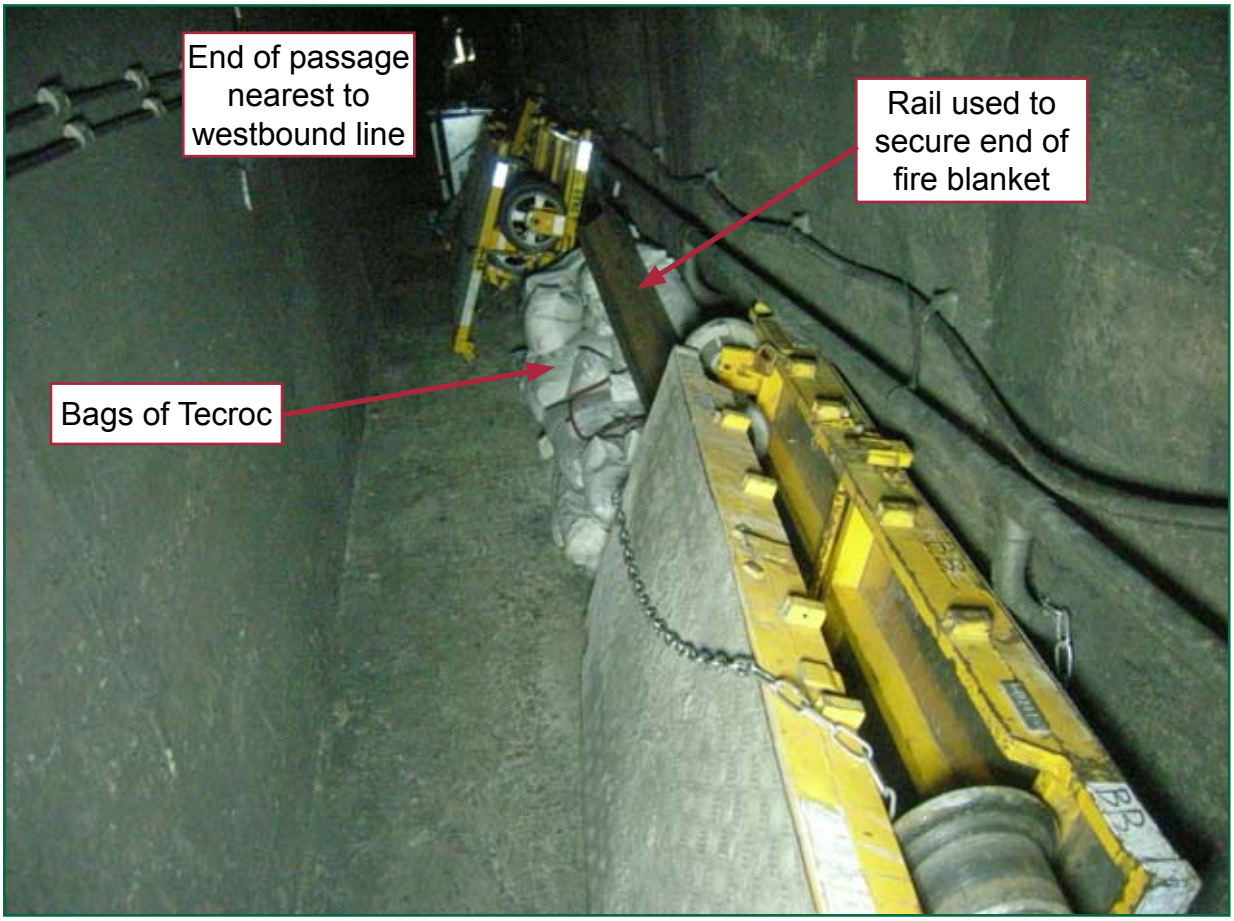


Figure 8: Equipment stored in the cross passage as found immediately following the derailment and viewed from end closest to the eastbound track

Figure 9: Equipment stored in the cross passage as found immediately following the derailment and viewed looking towards the westbound track

62 The SPC instructed two operatives to cover the Tecroc with the fire-resistant blanket. Due to the weight of the fire-resistant blanket (40 kg) they were both involved in moving it to where the Tecroc was stored. They then used the safety cutter (Figure 10) to remove the packaging which was placed on the eastbound line for removal at the end of work.

Figure 10: Safety cutter

Figure 11: Cross passage showing rail and Trecroc bags

63 The blanket was unrolled and the free end secured under a piece of flat bottom rail just over 900 mm in length and weighing in excess of 50 kg. Figure 11 shows how the rail and Tecroc were left at the end of the gang's shift. The fire-resistant blanket is a fire retardant woven fibre material and is difficult to cut with an ordinary knife; it is even more difficult to cut with the narrow vee-shaped blade of the safety cutter (Figure 10) which tends to clog as it is drawn through the material. The unrolled length of fire-resistant blanket was left attached to the roll. The orientation of the roll was such that it was free to roll across the floor of the cross passage; it was not being prevented from doing so by the unrolled length of fire-resistant blanket.

64 The two operatives, and later the SPC, inspected the cross passage and assessed that the Tecroc and roll of fire-resistant blanket were being left in a safe condition. The supervisor also looked into the cross passage and did not notice anything that looked out of place. All considered that the size and weight of the roll on the floor was adequate to withstand any movement caused by wind from the passing of trains.

65 None of the people working on the eastbound line ventured on to the westbound line; they all stayed within the boundary of the cross passage. There is no evidence that any other staff may have entered the passage.

66 On 5 May 2007, from the start of traffic to the time of the derailment, 74 westbound and 59 eastbound trains were timetabled to pass through the section between Mile End and Bethnal Green. Between 08:00 hrs and 09:00 hrs, 30 westbound and 27 eastbound trains passed the cross passage in this section.

67 Train 117 operated its service normally following its entry into traffic at 08:28 hrs from Hainault depot. The train operator was booked to commence his duties later at Leytonstone but arranged to operate the train from its entry into service from Hainault depot.

68 Train 117 was preceded by train 110, the 8:22:30 hrs service from Epping, which also operated normally throughout its journey. The train operators of train 110 and the two previous trains did not notice anything unusual (such as plastic bags or sheets) adjacent to the cross passage.

69 At approximately 09:00 hrs the train operator on westbound train 117 received the signal from the station assistant on the platform at Mile End that the train could leave. The Train operator checked the platform starting signal, closed the doors and upon obtaining the doors closed indication, pressed the start command buttons on the right-hand console (paragraph 45). The train then accelerated normally away from the platform on the downward gradient, the speed increasing rapidly towards the ATO target speed of 40 mph (64 km/h). After the train had travelled about 300 m the train operator saw what appeared to be a large white carrier bag fluttering on the right-hand side of the tunnel at track level. Because an encounter with a plastic bag is a common occurrence, the train operator did not consider this an unusual or hazardous situation.

70 The train continued to accelerate towards the cross passage. As the passage became nearer the train operator noticed that the white object appeared to be more of the size of a sheet rather than a bag. Again he did not consider that this could pose any hazard to the train. The train operator did not notice anything lying across the track.

Events during the accident

71 Immediately after the train operator noticed the sheet like material, the train struck a roll of fire-resistant blanket that was lying across the right-hand rail. The impact resulted in a loud bang and caused the car body to lift. The train operator reacted to this noise by pushing the control handle forward into the emergency brake position. The train then seemed to the train operator to move to the left and dropped downwards a short distance. This was followed by repeated clattering until the train came to a stand after travelling approximately 197 m, the rear cab then being situated 21 m past the entrance to the cross passage.

72 Both *wheelsets* (A and B axles) on the front bogie and one wheelset (D axle) of the second bogie of the leading car derailed, as did both wheelsets (A and B axles) on the leading bogie of the second car. All the subsequent wheelsets of the train ran over the roll but were not derailed. One car end window and one side window were broken but remained intact, with no objects, other than a few shard of glass, penetrating the passenger space. All the vehicles remained upright and no collision with the tunnel lining occurred. Damage was sustained by the car body ends and sides, by some underfloor equipment and by the wheels and gearboxes.

73 Immediately following the derailment the traction current was automatically discharged on overcurrent by a short circuit between the conductor rails via the bogie frames, wheelsets and motors. This triggered the tunnel lights to illuminate automatically. The tunnel lights remained illuminated throughout the incident until traction current was recharged for the commencement of service on 7 July.

74 The loss of traction current also caused the internal train lights to switch to emergency operation with one fluorescent tube illuminated above each doorway. These lights, powered by on-train batteries, remained illuminated in excess of two hours (the LUL requirement is 90 minutes minimum). Evacuation was completed before the train emergency lights were exhausted.

75 During the time that the train ran in a derailed condition it caused considerable damage to the infrastructure; one signal head, several cable brackets, a number of track bonds, one length of 22 kV cable and many rail chairs and conductor rail insulators were damaged beyond repair. One length of high voltage cable was damaged but repaired in situ. The positive conductor rail was bent and displaced to the left.

Consequences of the accident

76 Twenty people sustained injuries as a result of the derailment; however most of these were incurred during the evacuation from trains 117 and train 15. The most significant injury, which was not classified as serious, was caused to the ankle of a person on train 117 during the derailment. Other injuries were received during evacuation along the tunnels due to the uneven walking surface and stress induced discomfort. Eight people received hospital attention.

77 Three westbound trains became stalled due to loss of traction current; one at Bethnal Green station, one at Mile End station and one in the tunnel. Two westbound trains were instructed to remain at Stratford station, but with traction current remaining available.

78 District Line trains did not stop at Mile End until start of service on Friday 6 July due to the need to use the station for access by infrastructure repair and train recovery teams. Central Line services were withdrawn between Liverpool Street and Stratford until the start of service on Saturday 7 July.

Events following the accident

79 As soon as the train had stopped, the train operator contacted the *service controller* to report that the train had hit an object and had derailed. The train operator then made an announcement to passengers over the public address system, advising that the train had derailed.

80 A short time later the service controller contacted the train operator and reported that the emergency services had been contacted, as is normal practice on LUL, and that other trains in the area had been alerted. The service controller requested details of the derailment and whether any injuries had been sustained. The train operator then used the public address system to request that any passengers with injuries should make themselves known to him as he walked through the train, and that the emergency services had been notified. The majority of the passengers appeared calm and the train operator only encountered one passenger with an ankle injury, and several who had been shaken.

81 Near the rear of the train, the train operator encountered another member of LUL staff; an off duty train operator from the Piccadilly Line. He had been assisting passengers at the rear of the train. The Piccadilly Line train operator then went into the rear cab with an undertaking to advise the train operator via the cab-to-cab communication system if anyone approached the train along the tunnel from Mile End.

82 The train operator then made his way to the front cab and advised the service controller that there appeared to be only one injury. He also advised that the evacuation would need to be towards Mile End due to the train's location. The Piccadilly Line train operator then contacted the train operator in the front cab to report that the emergency services had arrived at the rear of the train. The train operator advised the service controller about this and then left the cab, walked a short distance forward along the track and applied the *short circuiting device* across the conductor rails. The Piccadilly Line train operator also applied a short circuiting device at the rear of the train.

83 The train operator then moved to the back of the train and was assisted by a British Transport Police (BTP) officer to deploy the detrainment ramp (this can be seen forming a ramp from the cab door in Figure 5). The train operator then tried to report this to the service controller from the rear cab but failed to get a response over the radio system; contact was eventually made from the front of the train.

84 At 10:01 hrs 369 passengers from stalled train 15 began to be slowly evacuated westward along the track towards Mile End station. At 10:19 hrs 520 passengers from train 117 also began to be evacuated in groups eastwards to Mile End station which the emergency services reported as becoming very congested. Passengers requiring medical attention were seen by paramedics who were using train 45, stalled in Mile End Central Line westbound platform, as an assessment and treatment centre. At 11:30 hrs it was confirmed that all passengers had been evacuated.

The Investigation

Sources of evidence

85 Sources of evidence included:

- the documentary and photographic record of the damage to the train and infrastructure;
- an inspection of the train following its re-railing and movement to Bethnal Green;
- an analysis of train and signalling data logs;
- air flow tests in the cross passage;
- a review of LUL and Metronet documentation;
- witness statements; and
- a multi-agency debrief with emergency services and LUL.

Factual Information

Track Reconditioning at Mile End

86 As part of Metronet contract C345, BBRP work planners allocated two work gangs to the eastbound line for track renewal between Mile End and Bethnal Green. One group was involved in the use and storage of materials in the cross passage nearest to Mile End station. Staff involved were employed by a number of organisations under subcontract to BBRP as follows:

Engineer in Charge	A1 Secured
Supervisor	BBRP
Site Person in Charge (SPC)	GM Rail
Operatives	VGC
Protection Master	SureTrack
Track Handback	Coyles.

87 The Engineer in Charge was accountable for the project as a whole, co-ordinating resources and activities and providing technical expertise.

88 The supervisor was accountable for the managerial oversight of the engineering activities being undertaken. At Mile End, the supervisor was responsible for two work gangs each consisting of seven people.

89 The SPC, who reported to the supervisor, was the immediate manager of the work group and ultimately responsible for safety. He was accountable for the programme of work, work progress, discipline, plant, materials, and general health & safety [Reference 2]. LUL procedures require that the SPC is certificated for Fire Safety, endorsed Fire Core and Fire Engineering, and to have a broad, but not detailed knowledge of the activities being undertaken.

90 The SPC delegated responsibility for protection to the Protection Master. The Protection Master undertook *Line Clear* procedures which provide protection for the work group from trains, live current rails and other operational hazards. Following LUL procedures the Protection Master was required to give a platform briefing to everyone in the group on the protection, the work site, and the work that has been authorised.

91 The SPC was responsible for ensuring that materials stored in the track environment, cross passages, ventilation shafts etc, are secured to prevent them moving during the passage of trains, and that the storage licence (Figure 7) was displayed and obeyed.

Conditions after the accident

92 During the evacuation of passengers following the incident BTP officers ensured that no evidence was disturbed. The squashed remains of the roll of fire-resistant blanket was lying at approximately 30° to the right-hand running rail and 6.6 m from the entrance to the cross passage. The roll was separated from an unrolled length that stretched from about 2.4 m away from the roll, back along the running tunnel and thence along the cross passage (Figures 5 and 9).

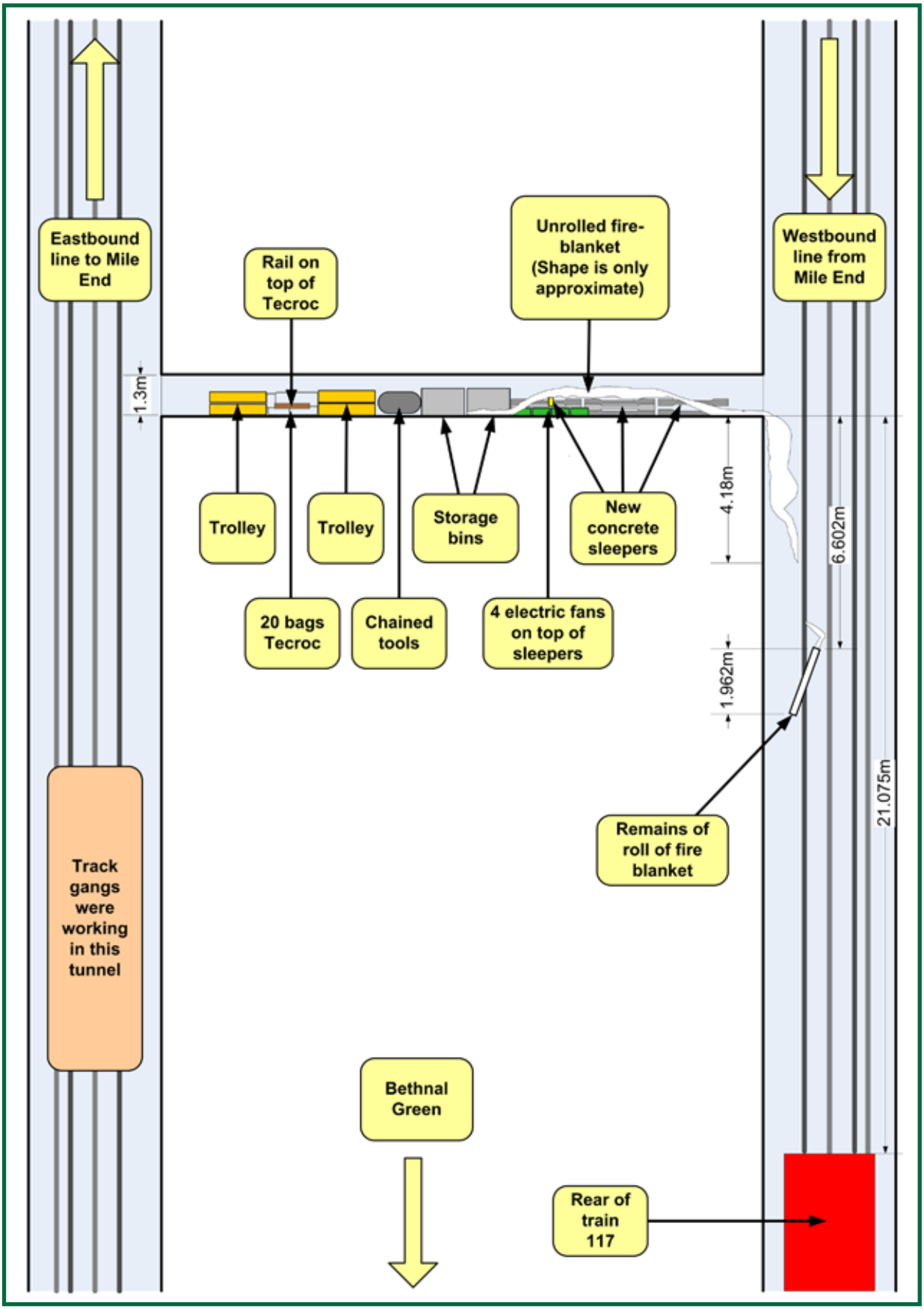


Figure 12: Diagram of cross passage and running tunnels

93 The unrolled length was snagged at various places, particularly behind the air pipe in the running tunnel immediately adjacent to the cross passage entrance and on the reinforcing bars protruding from the sides of some stored concrete sleepers. The further end was at the junction between the two storage boxes and lying on the top of the one closest to the westbound line.

94 Within the cross passage a length of rail slightly in excess of 3 ft (912 mm) long was found lying on top of bags of Tecroc.

95 Short fibres of material were found snagged on various clamps retaining electrical cables and conduit in place, these fittings being half way up the wall on both sides of the passage. Fibres were also found snagged on a cable bracket above the westbound line entrance to the cross passage.

96 Between the cross passage entrance and the roll of fire-resistant blanket there were a number of white marks on the rail head. These were approximately equally spaced (Figure 14).

97 Inspection of some of the train wheels showed signs of the white deposit (paragraph 116) around part of their periphery.

98 A vee-bladed safety knife was found tucked behind an electrical cable on the west side wall (Figure 10).

Cross passage wind tests

99 Following the incident Metronet contracted 4-Rail Services Ltd to monitor the wind velocities in the cross passage. Care was taken to ensure that materials and equipment in the cross passage were in similar positions to that at the time of the derailment. At the cross passage, the reducing speed of eastbound trains for the station stop at Mile End generated lower speed gusts than the constant high speed of trains travelling on the westbound line. The tests showed that the maximum gust velocity occurred following the passage of a train. The direction of the airflow was complex and depended upon the number and location of trains between the Mile End and Liverpool Street stations; however, the predominant direction was towards the westbound line. The maximum wind gusts of 60 mph (100 km/h) occurred at the end of the passage next to the westbound line. Gusts of 35 mph (58 km/h) occurred in the centre of the passage. Mean gust figures were approximately 35 mph (58 km/h) at the westbound end of the passage and 30 mph (50 km/h) at the centre.

Previous occurrences of a similar character

100 There is no evidence of incidents or near misses over the past five years that are of a similar nature to that at Mile End. Incidents involving objects hit by a train since the beginning of 2006 are shown in Table 1. Under the Railway (Accident Investigation and Reporting) Regulations 2005 none of the incidents required immediate notification to the RAIB.

Date	Location	Area	Description
20/3/2006	Tottenham Court Road to Oxford Circus (Westbound line)	Cross passage storage area	Train collided with a plastic water container which was believed to have been blown out of a cross passage.
2/10/2006	Mile End to Bethnal Green (Westbound line)	Cross passage storage area	Train collided with a plastic water butt which was believed to have been blown out of a cross passage.
2/11/2006	Mile End to Bethnal Green (Westbound line)	Cross passage storage area	Train collided with a metal object believed to be the top of a tool storage bin which had been stored on top of another bin. It is believed the movement was caused by wind and vibration from the passing of trains.
9/2/2007	Kennington to Waterloo		Trains collided with plywood sheets.
21/5/2007	Mile End to Bethnal Green (Westbound line)	Recess in tunnel	Train collided with metal tool storage bin which moved possibly due to air movement.
21/6/2007	St James's Park Station (Eastbound line)	Beneath platform	Length of pipe rolled on to track from its position under the eastbound platform. Possibly caused by poor storage.

Table 1: Incidents involving objects hit by a train during 2006 and 2007

Analysis

Identification of the immediate cause

101 Virtually at the same instant that the train operator noticed the sheet like material, the train struck a roll of fire-resistant blanket that was lying across the right-hand rail. The object was of such a size and rigidity that it caused the train to derail. The presence of the roll of fire-resistant blanket was thus the immediate cause of the accident.

Mechanism causing the fire-resistant blanket to move

102 There were small fibres of fire-resistant blanket that had been snagged on fittings and equipment in the cross passage. Due to the position of some of these (e.g. on a cable bracket in the cross passage above the entrance from the westbound line) it was not likely that the normal transport of a roll or cut piece of fire-resistant blanket would have left fibres in that position. The clean condition of the fibres towards the end of the passage closest to westbound line indicated that they had only recently been deposited there. Evidence relating to the unused roll of fire-resistant blanket indicates that it was taken into the cross passage from the eastbound track by the previous work group, still wrapped in the manufacturers' polythene covering.

103 The dimensions of the roll of fire-resistant blanket, approximately 2 ft (600 mm) longer that the width of the passage, and the obstructions caused by stored materials in the passage, meant that the roll could only have moved in two ways. It could either have moved longitudinally down the free side of the passage, or vertically. Vertical orientation would require it to have been carried by an unknown person, however there was no evidence to support this possibility.

104 After the derailment the unfurled length of fire-resistant blanket was lying unevenly over the stored materials in the passage with its free end pulled from under the length of rail that was still resting on top of the bags of Tecroc. The rail had not moved substantially from the position that it was left the previous night (Figure 11).

105 In the westbound running tunnel immediately adjacent to the exit of the cross passage, the unfurled fire-resistant blanket had been firmly caught between the air piping and its support brackets (Figure 5). A further length that was separated from the remains of the roll was lying alongside the track.

106 In the deep level tube system, the piston effect of trains moving through the tunnels is used to ventilate both the stations and tunnels. There is no evidence that any abnormal pattern of the train service caused higher velocity winds than normal.

107 The wind tests undertaken for Metronet (paragraph 99) allowed an estimation of the forces acting on the roll of fire-resistant blanket. Data from standard tables (see Figure 13) indicates that with a drag coefficient of 0.7, a force of approximately 64 kg could be generated by a wind speed of 60 mph (96 km/h) acting perpendicularly on a sail area of 1 m^2. (A conservative value for drag coefficient has been used for these calculations. This type of data has been derived by empirical means; typically 1.28 for a flat plate, 0.8 to 1.5 for billowing sails and 0.75 or greater for parachutes).

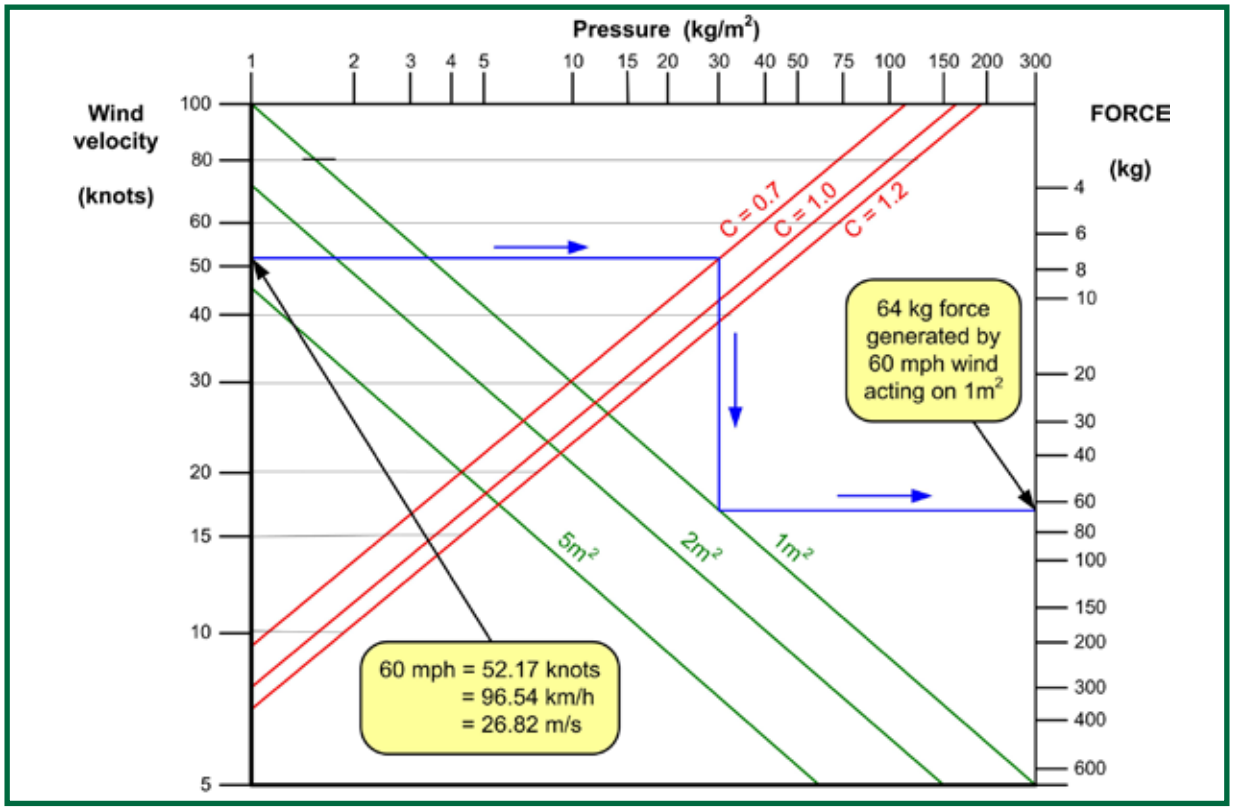


Figure 13: Wind speed and force diagram [Reference 5]

108 The movement of the roll across the floor of the passage would expose an additional 600 mm length of fire-resistant blanket. The 1.8 m width of the roll would permit 1.08 m^2 to be available as a sail (neglecting any sail from the fire-resistant blanket on top of the bags of Tecroc). With a coefficient of friction of 0.5 between the roll of fire-resistant blanket and the floor, the force of 64 kg would be more than twice the amount necessary to move the 40 kg roll longitudinally along the passage. (A conservative figure for the coefficient of friction has been used which has discounted the lubricating properties of tunnel dust on the floor of the cross passage. Typically woven materials moving across a rough concrete floor have coefficients of friction between 0.5 and 0.7).

109 The most likely scenario is that the roll was initially moved by wind acting on the unfurled length of fire-resistant blanket. This caused it to roll to the other side of the cross passage from its position close to the bags of Tecroc. It was not prevented from moving in this manner by its orientation (paragraph 63). Only a small force, relative to frictional forces, would have been required to do this. The increased length of blanket then continued to act as a sail. From time to time the direction of the prevailing wind changed causing the sail to billow in the opposite direction. When it became taught, it snatched at the roll causing it to rotate against the restraint of the passage wall. The increased length of sail was then available to generate more force. Eventually the prevailing wind and area of sail were sufficient to drag the roll towards the cross passage entrance next to the westbound line. It continued to unfurl as it moved along.

110 When the roll was near the entrance to the cross passage, the draught behind train 110 (paragraph 26) caused the sail to drag the roll out into the running tunnel. The roll was deposited across the right-hand running rail with the sail billowing beyond. It was the billowing of the sail that the operator of the following train 117 saw as he approached. There was no evidence of fibres on the preceding train that might indicate that the fire-resistant blanket was dragged from the passage by the train itself.

111 When train 117 hit the roll, the impact force likely caused the end of the material to be snatched out from under the rail on top of the Tecroc bags. It also likely caused the unfurled material to become forced behind the air piping.

Process of derailment

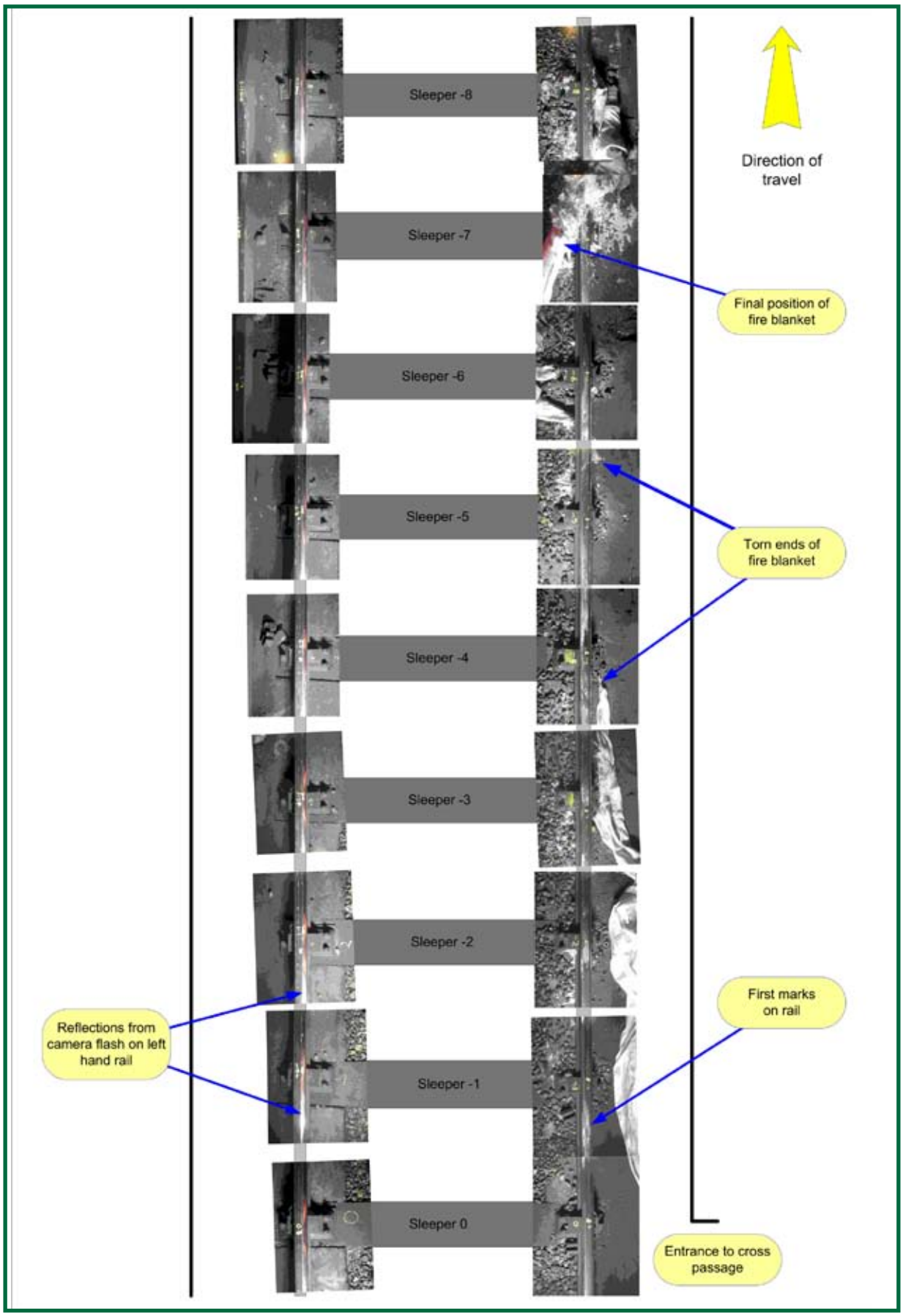


Figure 14: Composite photo diagram showing the rails between the initial point of impact and the final position of the roll of fire-resistant blanket

112 When the leading wheel set hit the roll of fire-resistant blanket located midway between sleepers -3 and -4 (Figure 14) it caused the leading right-hand wheel to lift (all sleepers have been numbered negative after the point of derailment). This in turn caused the flange of the left-hand wheel to lose contact with the running rail. The transverse vertical skew of the axle caused the wheelset to be deflected to the left. When the axle dropped after passing over the obstruction, the left wheel flange followed a path along the head of the rail, dropping to the outside of the rail after about 2 m (midway between sleepers -3 and -4 and smashing the cast iron rail chair on sleeper -4. The roll of fire-resistant blanket remained in its initial position whilst the wheel rolled over it but it was subsequently dragged forward by the current collector shoe on the right-hand side of the train until it was stopped by the next rail chair on sleeper -2.

113 The roll of fire-resistant blanket was subsequently run over by the second wheelset which also lifted and derailed to the left at sleeper -5 (Figure 14). The third wheelset was not found in a derailed condition. It is possible that this wheelset ran along the rail head and then dropped back into the correct position but the rail head marks do not allow any definite conclusion to be drawn from them. The fourth wheelset of the first car and the first wheelset of the second car derailed at sleepers -6 and -7. Wheelset two of the second car derailed at sleeper -9. The derailment marks on the rail head became much more complex after sleeper -7, however there are clear signs that between sleepers -7 and -10 three wheelsets ran with their flanges on the top of the left-hand rail; however they all dropped back to their correct, underailed, position. It is possible that wheelset three was one of these however there is no definite evidence for this.

114 As each wheel hit the roll of fire-resistant blanket, it was incrementally moved forward to reach its final position adjacent to sleeper -7. All subsequent bogies of the train ran over remains of the roll which was compacted and partially cut through by the flanges, the thickness remaining on the rail head varied between 30 and 40 mm. Beyond sleeper -8 the railhead was severely marked by parts of the bogies and the motor gear cases running on the rail head.

115 Further rail head marks show that one, or possibly two more wheel flanges ran along the top of the rail but also dropped back to their correct position. By sleeper -16 the rail head marks are so complex that further analysis has not been possible.

116 The white deposits on the rail and wheels (paragraph 97) were caused by the crushing of the fibre glass fire-resistant blanket.

117 During the onward motion of the train some of the weight of the cars was taken by the leading motor gear cases. These are located on alternate sides of the bogie for each of its two axles. The wheels on the other side of the axle bumped along the approximately level surface of the sleepers and concrete infill next to the rail chairs. The bogie frames displaced the conductor rail to the left which then assisted in constraining the trajectory of the train so that the leading gear cases on the leading ends of the first and second cars remained on the rail head. This prevented the car bodies from further displacement and collision with the tunnel wall (Figures 3 and 15).

Figure 15: Photograph showing how the conductor rail has helped to guide the bogie

Identification of causal and contributory factors

Causal factors

118 In order to determine the causal factors the following questions are considered:

a) Did the training or subsequent company briefings provide the SPC with sufficient knowledge about the storage of materials?

b) Why was it thought necessary to cover the bags of Tecroc with fireproofing material?

c) Why was it not recognised that the winds in cross passage could move the roll of fire-resistant blanket?

119 Evidence from a number of sources shows that the SPC at the site acted throughout in a conscientious manner by attempting to address all the risks that he understood could exist. This is evidenced by the neat stacking and securing of equipment. To minimise fire risk, the paper bags containing the Tecroc were covered with fire-resistant blanket with the free end held down with a heavy weight. The gang members also acted conscientiously in understanding what needed to be done before being instructed and fulfilling the SPC's requirements. The content of the training to act as an SPC, and the lack of generic risk assessments for the storage of materials in cross passages meant that the SPC was not fully equipped to manage the situation. The training addressed all the procedures necessary to carry out work in the tunnels; however, the course contained little subject matter on the storage of materials. Some of the trainers recognised this omission by advising their pupils about good practices including the use of fire-resistant blankets. This additional content was not supported by documentation, nor was it supported by adequate risk assessments. The risk assessments formed input to the method statements and supporting documentation reviewed by the SPC and protection master at a planning meeting. The incomplete training is thus a causal factor.

120 There was a general lack of clear guidance about where fire-resistant blankets needed to be used in LUL tunnels. Much of the information gleaned by SPCs has been by word of mouth through interaction with other gangs. There was a general understanding that anything flammable needed to be covered with fire-resistant blanket. This was not assisted by a general confusion over the controls and applicability of Waiver 822 (paragraphs 51 and 52). On occasions other gangs took this to extremes, covering wooden sleepers with a fire-resistant blanket if they were left in a cross passage. Here they would be remote from the most likely source of ignition; an arc from the collector shoes of the train. However, sleepers were not covered if left on the track or when installed into the track.

121 It was widely known that the paper bags that contained Tecroc were flammable when empty. Paper had been recognised as a fire hazard since the earliest days of the tube network, however the main focus on fire assessment and licensing of stored materials was introduced following the station fire at Kings Cross in 1987. Subsequently a developing number of controls required flammable materials including paper to be removed from the tunnels at the end of Engineering Hours, or kept in a flameproof storage box, or covered with a fire-resistant blanket. The instruction to do so was also applied when the bags of Tecroc were full although the Concession / Fire Waiver Request, (LUL Reference CR01637) recorded that Tecroc did not pose any fire risk. In practice the non-flammable contents would have suppressed any fire hazard from the paper bags. There was also a belief by some that the fire-resistant blanket was also used to control any dust given off from the bags. The decision that full bags of Tecroc should be treated as a fire risk is thus a causal factor.

122 The procedures for using fire-resistant blankets also did not recognise that lengths should be cut from the roll; furthermore, with the prohibition on the use of open bladed knives, the tool provided to cut the packaging was not well suited for use on a woven material. The systematic lack of appropriate instructions and methods for cutting fire-resistant blanket material was thus a causal factor.

123 Company information from Metronet, provided the SPCs and others in the gang with some knowledge about storage techniques. It came in several forms, including written notices, improvement notices, safety bulletins and verbal briefings. Instructions were issued on the need to secure any equipment that might be likely to move due to winds and on the need to secure or weigh down the ends of any fire-resistant blanket. The means of briefing out this information from the company to the workforce was not completely robust but it worked acceptably on many occasions. However, some information might not always reach everyone concerned. There was no formal record kept of those missing briefings or not receiving information. Storage boxes and trolleys were known to move due to their large face areas and were often secured by chains to the passage walls if other means were not available. Small equipment was either secured or stored in bins. Experience gained by the gang members was that items would often be found in a different position to where they had been left the previous night. Whilst they suspected that this was due to wind, they were occasionally unsure whether this might be due to the actions of someone else.

124 The effect of wind in cross passages and other parts of the deep tube network was well recognised by LUL, Metronet and all members of the workforce. A number of recent incidents when large unsecured items had been moved by wind became very well known through briefings, notices and word of mouth. Actions resulting from investigations into the movement of items due to the effects of wind were being implemented at the time of this incident. However none of these highlighted any issues with the use of fire-resistant blankets.

125 The possible effect of wind on the fire-resistant blanket used to cover the Tecroc bags was recognised by the SPC and the gang members. Two gang members used a heavy piece of rail to secure the free end. This weighed approximately 50 kg and needed two people to lift it into position. Because the only available means to cut the blanket was difficult to use, the roll was left uncut, this being a practice that was not prohibited. The remainder of the roll, weighing approximately 40 kg, was left on the floor. The belief that the roll would not move was reinforced by the knowledge that the wrapped roll had been stable since the previous night when it was stored on top of the storage boxes. What no-one recognised was that it could now roll across the passage and thus allow a sail to develop (paragraphs 108 and 109). Even if this had been recognised it is doubtful if anyone present would have considered that this could cause the roll to be moved longitudinally along the passage and on to the running line. The lack of awareness about the possible effect of wind on the roll of fire-resistant blanket was thus a causal factor.

Contributory factors

126 The late change to planned work for the night meant that the bags of Tecroc were not used. It was the practice of the gang to remove as much rubbish as possible after each night's work. It is thus possible that the empty paper bags would not have needed to be covered and the roll of fire-resistant blanket would thus not have been opened. The late change to the planned work was thus a possible contributory factor.

127 The ongoing need to store materials needed for maintenance and renewal work in cross passages had been undertaken in compliance with the instructions issued by Metronet (paragraph 122) and specifically with the 'Guidance for Material Storage Underground'. This was confirmed during the RAIB inspection immediately following the derailment. In an adjacent section (Mile End to Stratford), an HMRI field inspector undertaking track inspections some days before, noted that materials were stored in a neat and safe manner. Despite the effort taken to ensure that material was stored correctly their presence in the cross passage was a contributory factor.

128 As confirmed by measurement, there was nothing abnormal about the wind velocities or changes of direction that were present in the time leading up to the derailment. However the velocity of the winds experienced in the cross passage were sufficiently high to generate a force capable of moving the roll of fire-resistant blanket. The velocity of the wind was thus a contributory factor.

129 The need to take appropriate precautions against fire has been well recognised by the organisations and workers concerned with running and maintaining the deep level tube system. Robust procedures existed to ensure that fire and other work place risks were eliminated or controlled. All the gang members, Metronet and LUL placed great emphasis on mitigating the risk of fire and it was this that initiated the use of the fire-resistant blanket. The high level of staff awareness about managing fire hazards was a thus contributory factor.

Identification of underlying cause

130 The risk assessments focussed upon the immediate use of the blankets to suppress fire and did not consider the operational issues of their use, such as transport to site and cutting to length, nor on their possible impact with the passenger railway. The lack of a comprehensive risk analysis being performed to support the use of fire-resistant blankets when first introduced and subsequently, was thus an underlying cause.

Severity of consequences

131 Upon hitting the roll of fire-resistant blanket the train derailed to the left by five of the six leading wheelsets. For a considerable distance the train was supported by some of the motor *gear pans* which ran along the left-hand running rail. The train wheels were then guided by the conductor rail which prevented it from hitting the wall of the tunnel. Had the train hit the tunnel wall, damage to the two leading cars would have been substantially greater, with the likelihood of severe damage to the driver's cab and with broken windows and object incursions into the passenger space.

132 Two windows were broken however shards of glass were largely retained by the protective plastic film. Only a few small pieces of glass from the end window, and no objects from outside the train entered the passenger space.

133 Overall the train performed well given a derailment in a confined space from 40 mph (65 km/h). No crashworthiness issues were highlighted by the accident.

Response of others

134 The emergency services reacted in a timely manner with rapid response and evacuation being achieved. An inter-service review, attended by the RAIB, was conducted following the accident. This concluded that the performance by all the emergency services and local council services was acceptable, but that a number of procedural issues could have been improved. The most important concerned the difficulties of communication and inter-service liaison between the accident site, the platforms and the control vehicle parked on the road outside the station.

Other factors for consideration

135 Since the fire at Kings Cross Underground Station in 1987 and the application of Section 12 of the Fire Precautions Act to works undertaken in stations, LUL has issued very stringent standards to control fire risk. All staff contacted about the derailment demonstrated a high level of awareness about fire risk on the London Underground system. This awareness has had the occasional result of deflecting attention away from operational hazards imported on to the system, but to concentrate upon the measures needed to prevent or mitigate the effects of fire. The derailment at Mile End is evidence that a highly focussed and formal assessment on fire prevention (Waiver 822) led to fire risk being well managed; however, that approach failed to recognise the possible risks imported on to the operational railway purely by the material being present. The introduction of the Regulatory Reform (Fire Safety) Order 2005 with its emphasis on risk assessment should enable an holistic approach to be taken, with appropriate emphasis being given to conflicting measures for risk mitigation.

136 Evidence obtained shows that some differences exist in the policies and instructions normally applied by the subcontractors involved in work on the London Underground system, even though all the staff were undertaking work for Metronet as the prime contractor, and subject to Metronet instructions. This existed even between the constituent companies that owned Metronet. The staff of these companies grew to understand what was acceptable to their direct employer but found differences when working for a main contractor. The wide range of employers is demonstrated by the composition of the work gang involved in using the Mile End cross passage for storage. The investigation discovered that these differences, whilst of a minor nature, do affect the way that work is planned and undertaken. From time to time practices acceptable to one member of the gang may not be acceptable to another. An example would be for one organisation to cover stored wooden sleepers with fire-resistant blankets, despite uncovered sleepers on the operational railway being closer to a source of ignition. Other organisations would not plan to cover the stored sleepers. The differences in approach did not affect the decision to cover the bags of Tecroc with a fire-resistant blanket and thus did not contribute to the accident.

Conclusions

Immediate cause

137 The immediate cause of the accident was train 117 hitting a roll of fire-resistant blanket that was laying across the right-hand rail after it had been blown out of the cross passage situated between the eastbound and westbound lines west of Mile End station (paragraph 101).

Causal factors

138 Causal factors were

a. The incomplete training and supporting documentation provided to SPCs in relation to the storage of common materials in cross passages (paragraph 119, **Recommendation 1**).

b. The decision that full bags of Tecroc should be treated as a fire risk (paragraph 121, **Recommendations 2 and 3**).

c. The lack of guidance on the use of fire-resistant blankets and the lack of an effective means to cut it (paragraph 122, **Recommendations 4**).

d. The lack of awareness about the possibility that cross passage wind could cause a roll of fire-resistant blanket to unroll and move its bulk longitudinally down a cross passage (the sail effect) (paragraph 125, **Recommendation 5**).

Contributory factors

139 The following factors were considered to be contributory;

a. possibly, the late change in the work being undertaken (paragraph 126);

b. the need to store materials in the cross passages (paragraphs 127);

c. the presence of wind at high velocities in cross passages and running tunnels (paragraph 128); and

d. the staff awareness about managing fire risks in relation to other operational risks (paragraph 129).

Underlying cause

140 The underlying cause was the lack of a comprehensive risk analysis being performed to support the use of fire-resistant blankets when first introduced and subsequently (paragraph 130, **Recommendation 2 and 3**).

Other factors affecting the consequences

141 The following factors affected the severity of the accident:

a. The location and shape of the motor gear pans that enabled the bogies to slide along the rails, thus precluding further deflection towards the wall of the tunnel.

b. The guidance provided to the train by the positive conductor rail.

142 LUL have assessed the practicality of fitting *lifeguards*. For existing stock they would be difficult to fit within the mechanical design constraints for tube trains, and would interfere with the electrical performance of the ATO system. Although there is not sufficient evidence for the features listed in paragraph 141 to form a recommendation within this report, they could usefully be examined to determine if any benefit could be obtained for future infrastructure works or rolling stock designs.

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

143 Immediately following the accident a number of instructions and directives were issued and actions undertaken; the implementing organisation are shown below in parentheses:

a) LUL Engineering Regulatory Notice issued to Metronet (LUL).

b) LUL Emergency Directive served on Metronet (LUL).

c) Check of all items stored next to track or in tunnel crossways for conformity with the storage licences and to ensure that could not fall, slip, roll or be blown onto the track or railway equipment (Metronet Technical Conformance Regulatory Notice dated 5 July 2007).

d) Suspension of non-essential works to facilitate above checks (Metronet).

e) Safety Alert issued on 5 July 2007 reminding staff on the requirements for storage (Tubelines).

f) Notice and guidance issued on 5 July requiring special inspection to confirm safe storage (Tubelines).

g) Safety Alert issued on 6 July 2007 and re-issued on 10 July 2007 clarifying the requirements for storage (Metronet)

h) Track Group set up to look at storage, behaviour and the training of SPCs, links between Protection Masters and SPCs, the introduction of supplementary briefings and a licensing scheme (Tubelines).

i) Investigation to source non-flammable bags (Metronet and Tubelines).

144 Specific recommendations are included in the Formal Investigation report (Reference 6) issued jointly by Metronet and LUL. A summary is shown below:

a) LUL to review the change control standards to confirm that they properly consider wider system risk (LUL Group FIR Recommendation 1).

b) LUL to review the existing standards defining the rules for storage of materials and equipment where their storage may adversely affect the safe movement of trains, the movement of people or risk of fire (LUL Group FIR Recommendation 2).

c) LUL to review the training course for SPCs following the review of change control standards (paragraph a) (LUL Group FIR Recommendation 3).

d) LUL, Metronet and Tubelines to determine strategically the requirements for storage in the track environment and to develop proposals about how storage facilities should be enhanced (LUL Group FIR Recommendation 4).

e) LUL will review whether it is feasible and reasonably practical to fit lifeguards on the leading bogies of trains (LUL Group FIR Recommendation 5).

f) LUL, Metronet and Tubelines to enhance the investigation process to make it more effective at learning lessons and ensuring recommendations are effectively implemented (LUL Group FIR Recommendation 6).

Recommendations

145 The following safety recommendations are made[2]:

Recommendations to address causal and contributory factors

1 LUL should amend the requirements on the content of the SPC training to ensure that it contains adequate information on the storage of materials including the effect of wind in cross passages (paragraph 138a).

2 Metronet or its successor organisation(s) should ensure that risk assessments related to storage of materials in cross passages are reviewed to ensure that they fully address risks to the operational railway. Where risk assessments that have been mandated or inherited from LUL are found to be deficient then LUL should be made aware of the shortcoming (paragraphs 138b and 140).

3 LUL should address any advised deficiencies in risk assessments for stored materials which have been mandated or inherited by the Infracos from LUL, consistent with the current contractual responsibilities of LUL and the Infracos (paragraphs 138b and 140).

4 Metronet or its successor organisation(s) should review and if necessary, amend the instructions on the use of fire-resistant blankets (paragraph 137c).

5 Metronet or its successor organisation(s) should take steps to ensure that appropriate staff, including work planners and SPCs, are made aware of the wind effects that can occur in the deep level tube system (paragraph 138d).

[2] Duty holders, 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 ORR (HMRI) to enable them to carry out their 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 at www.raib.gov.uk

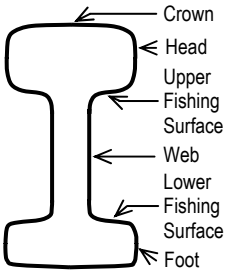
Appendices

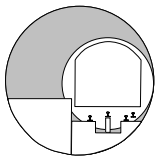
Glossary of abbreviations and acronyms — Appendix A

ATO	Automatic Train Operation
BBRP	Balfour Beatty Rail Projects
BTP	British Transport Police
Infraco	Infrastructure company. Three infracos have responsibility for the London Underground; Metronet BCV, Metronet SSL and Tubelines.
LUL	London Underground Ltd
RAIB	Rail Accident Investigation Branch
SPC	Site-Person-in-Charge

Glossary of terms — Appendix B

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

(tunnel) air lines	Pipes located on the side of tunnels that are used to carry compressed air to trackside equipment.
as low as reasonably practicable	A description of the residual risk that is acceptable, acknowledging that there will always be some small risk remaining irrespective of the funds expended to try to eliminate it.*
ballast	Crushed stone, nominally 48 mm in size and of a prescribed angularity, used to support Sleepers, Timbers or Bearers both vertically and laterally. The stone used is generally Granite, but Limestone has been employed.* (Sometimes known as shingle by the staff of the Infracos.)
bogie	A metal frame equipped with two wheelsets and able to rotate freely in plan, used in pairs under rail vehicles to improve ride quality and better distribute forces to the track.*
bullhead rail	The former standard rail section in Britain, not normally laid in as new. However, there are many installations where the reduced resistance to lateral bending (compared with a Flat Bottom Rail) of Bullhead Rails is a positive advantage, particularly in industrial layouts where radii are tight and speeds low. The rail has a rail head and rail foot that are similarly shaped.* 
contract C345	Contract placed by Metronet on BBRP entitled "Full Reconditioning" for replacement of wood sleepers by concrete, and bullhead rail by flatbottom between Bethnal Green and Mile End. The contract commenced on 10 July 2005 and has a planned completion date of 3 Aug 2008.
car	London Underground term for a railway coach suitable for carrying passengers.
chair	A cast or fabricated support for Bullhead Rail.*
conductor rail	An additional rail, generally of a unique section such as 150 Pounds Per Yard, used to convey and enable collection of electrical traction current at track level. Conductor rail systems carry voltages of the order of 600 - 1000 Volts, generally DC. The conductor rails are supported on conductor rail insulators.* The London Underground system uses two conductor rails, one at a nominal voltage of +450 direct current located outside the running rails, and the other, at a nominal voltage of -150 direct current centred between the running rails. Both are higher than the running rails.
cross passage	A passageway that connects two running tunnels. It is used for ventilation relief, staff and emergency access.

cut and cover	A method of building tunnels by excavating a hole from the surface and then installing a roof structure over it.
deep level tube	A part of the London Underground system that uses circular, or near circular, bored tunnels beneath the surface.
discharge (of traction current)	The automatic or manually commanded disconnection of the 600 volts traction supply to the conductor rails.
emergency brake	The brake command available to the train operator that will bring the train to rest in the shortest possible distance.
emergency (train) lights	Train lighting that remains illuminated after the traction supply becomes unavailable. The lights are supplied from train batteries.
fire-resistant blanket	A non flammable woven material that can protect flammable items from a source of ignition, such as an electrical arc. The material can also be used to smother a burning material.
Gear pans	The casing that encloses the gears linking the traction motor and the axle.
headwall	The flat wall where the tunnel enclosing a platform reduces to the narrower diameter running tunnel between Stations.* 
Insulators	The electronically insulating support that holds a conductor rail in place.
lifeguard	Heavy metal brackets fitted vertically immediately in front of the Leading End wheels of a Rail Vehicle, one over each Rail. Their purpose is to deflect small objects away from the path of the wheels.*
Line Clear	The safety procedure used to ensure that it is safe to work in tube tunnels in Engineering Hours.
monocoque construction	A construction technique that supports structural loads using the external skin of the vehicle, in contrast to using an internal framework that is then covered with a non load-bearing skin.
Panlock key	A commercial fastening device that keeps the rail firmly in its correct position in a rail chair.
PPP administration	A form of administration defined by Statutory Instrument 3141 entitled "The PPP Administration Order Rules 2007".
Protection Master	The person responsible for providing protection from operational risks when no passenger trains are moving during Engineering Hours.
running rail	A rail that supports and guides the flanged steel rail wheels of a rail vehicle. A rail that does not support a wheel is a non-running rail.*
Service Controller	The person in the control centre who is responsible for overseeing the operation of a line. (Formerly called the Line Controller).

short circuit	The unwanted condition when the two poles of an electrical supply are connected together.
short circuiting device	A piece of equipment used specifically for connecting the Conductor Rail and Traction Return Rail together to prevent the Conductor Rail becoming energised during a Possession.*
shoegear	The equipment used to collect traction current from the conductor rails. It comprises a cast iron shoe that is supported by links from an insulating beam.
Sub-surface	A Line or Track that is constructed below ground level. On London Underground Ltd (LUL) Routes the term is limited to Routes built using the Cut and Cover method, the other "below ground" Lines being Tube Lines or Deep (level) Tube Lines.*
Sub-surface station	A Station whose Platforms are enclosed or underground as defined in clause 3 of the Fire Precautions (Sub-surface Railway Stations) Regulations 1989.*
Tecroc	A proprietary brand of dry pre-mixed fast setting concrete.
traction current	The electrical power available to trains through the current rails.
train operator	The person who operates the train.
tunnel lights	Lights that are provided in the running tunnels throughout the deep tube system which illuminate whenever the traction current is discharged.
wheelset	Two rail wheels mounted on their joining axle.*

References

Appendix C

1	Statutory Instrument 2005 No. 1541. Regulatory Reform (Fire Safety) Order 2005 with associated document on fire safety risk assessment	
2	LUL Training Standard SPCC July 2001 Amendment 1/04	Issued by LUL
3	Contract QUENSH Conditions Manual.	Issued by LUL
4	London Underground Rule Books Set of 22 booklets detailing the rules by which the London Underground railway operates.	Issued by LUL
5	Mile End Station, Cross Passage Air Velocity. Report No: 4RS-AJB-070449-R174401	Issued by 4-Rail Services Ltd
6	Formal investigation into the Central Line Derailment on the West Bound road between Mile End and Bethnal Green stations on Thursday 05 July 2007. Ref: 170/17011895	Issued jointly by Metronet BCV and LUL

Train

1 Two broken windows:

- 1 saloon side window to leading end of third car;
- 1 saloon end window to leading end of second car).

2 Car body work damage (especially to driver's corner of leading car).

3 Detached inter-car barrier.

4 Damage to underfloor equipment:

- 5 bogie frames;
- leading shoe gear;
- gear boxes;
- brake equipment cases;
- air receivers;
- ATO pick-up coils.

Infrastructure

5 150 rail chairs and Panlock keys.

6 60 Conductor rail insulators.

7 Positive conductor rail bent.

8 1 Sleeper.

9 1 Signal head (A5450) and associated cables.

10 1 ATO spot loop cable.

11 1 Earth bond cable.

12 2 x 22kV power cables (1 repaired, 1 replaced).

13 Scuffing to various cables.

14 Various cable brackets.

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