Rail Accident Investigation Branch

Rail Accident Report

Collision with debris from bridge GE19 near London Liverpool Street 28 May 2008

Department for Transport

Report 22/2009
August 2009

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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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 Left and right are defined from the point of view of a train approaching bridge GE19 when travelling in the down direction (ie away from London).

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

- abbreviations are explained in appendix A; and
- technical terms (shown in *italics* the first time they appear in the report) are explained in appendix B.

Summary of the report

Key facts about the accident

5 At approximately 19:17 hrs on Wednesday 28 May 2008, train 1K12, travelling from London Liverpool Street to Southend Victoria collided with concrete debris lying on the track beneath the newly constructed bridge LTN1/19 (known as GE19) near Liverpool Street station. This debris had fallen from the bridge following the failure of supports at one end of the bridge deck. This caused a sudden jolt which shook the deck.

6 Train 1K12 came to a halt, partly beneath bridge GE19. Damage to the train was minor and there were no injuries. However, concern over the stability of the bridge resulted in the signaller stopping all other trains in the vicinity by reverting signals to danger. This inadvertently caused two other trains to be halted beneath bridge GE19. An emergency isolation then prevented the trapped trains from moving clear from the structure.

7 Train crews, assisted by the emergency services, supervised the evacuation of nine trains. Approximately 700 passengers were required to walk along the track to Bethnal Green station and 350 passengers to Liverpool Street station.

8 Both Network Rail and the emergency services overlooked a train requiring evacuation near Bethnal Green station until after the site was declared clear.

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

Immediate cause, causal and contributory factors

9 The immediate cause of the accident was concrete planks falling from the partly-completed deck of bridge GE19 onto the track below, triggered by a sudden movement of the bridge deck. Train 1K12 then hit the debris.

10 Causal factors were:

a. the inadequate planning and lack of design input to the deck repositioning activity, which resulted in the need to ensure the continued stability of the temporary supports at the east *abutment* being overlooked;

b. the unauthorised modification of the temporary support by introducing an additional sliding surface, which made the east abutment supports vulnerable to instability due to horizontal force or movement;

c. the installation of lubricated PTFE-faced *slipper pads* on a gradient, which introduced a sustained horizontal force into the east abutment temporary supports sufficient to destabilise them; and

d. the decision to substitute the positive tie between individual pre-cast concrete permanent formwork planks (*Omnia* planks) with cement mortar, which made it more likely that individual planks, if subjected to a large jolt, would fall onto the track.

11 Contributory factors were:

a. the lack of accurate or sufficient detail in the steelwork method statement or work plan, which allowed the site team to work outside of the approved documents;

b. the hazard identification process not identifying some low probability high impact hazards (eg failure of the *temporary works*), which were consequently omitted from the steelwork risk assessment for the post-*launch* phase;

c. the Balfour Beatty-Carillion joint venture's decision to delegate responsibility for temporary works checks to Fairfield Mabey, which meant that they lost visibility of how the structure was performing, or of measures being taken to correct the horizontal movement;

d. the downhill movement of the bridge deck resulting from slippage of the parking restraints;

e. the lack of a plan to manage thermal movement, which resulted in further displacement of the deck, probably during the transfer of horizontal restraint;

f. the lack of relevant experience within the site team which led to the decision to incorporate an additional slip surface on an inclined plane;

g. the exposure of the permanent bearings at the east abutment to thermal movement without releasing the *transit cleats*, thereby weakening the transit cleat bolts;

h. the absence of post-work checks, which allowed the unstable condition of the east abutment temporary supports and lack of a secondary means of support to go undetected;

i. a lack of ownership of the risks presented by the unsecured deck section to the operational railway during *jack down*; and

j. the modification of the deck layout, which allowed sections of the deck greater freedom to move, and off-set the permanent formwork planks against the *shear studs* thereby reducing their effectiveness in preventing the unsecured planks from falling from the deck.

Severity of consequences

12 Damage to the track and train was minor and there were no injuries. However, Liverpool Street station remained closed to all traffic for approximately 14 hours until 09:30 hrs on Thursday 29 May 2008 while remedial works to stabilise the bridge deck were completed.

Recommendations

13 Recommendations can be found in Paragraph 333. They relate to the following areas:

- Four recommendations have been made to Network Rail. These cover the areas of
  - guidance on criteria to consider before approving construction work;
  - operational procedures; and
  - amendments to the National Emergency plan;
- One recommendation has been made to London Underground Limited, Rail for London, the Heritage Rail Association, the Light Rail Engineering Group and Northern Ireland Railways to provide guidance to their railway or sector;
- One recommendation has been made to the Health and Safety Executive (HSE) to promulgate issues identified in this report; and
- One recommendation has been made to the train operating company, National Express East Anglia, to cover the area of appointing a site representative during a major railway incident.

The Accident

Summary of the accident

14 At 19:17 hrs on Wednesday 28 May 2008, train 1K12, the 19:15 hrs London Liverpool Street to Southend Victoria service, struck debris on the track. The debris had fallen from a new rail bridge under construction, spanning the mainline railway close to Liverpool Street station. The train suffered minor damage and there were no injuries.

15 Bridge GE19 forms part of the ongoing East London line extension project (paragraph 28), and had been installed across the railway during the bank holiday weekend of 3 - 5 May 2008. At the time of the accident, the bridge deck was in a part-finished state, and remained raised on *temporary supports* at its eastern end. These supports failed at 19:16 hrs, causing the deck to drop and a shock wave to pass through the structure which dislodged part of the incomplete deck. Five pre-cast concrete *permanent formwork* planks fell from the bridge together with a large volume of water which had collected on the deck following a period of wet weather. Three of the planks fell onto the track, and the remainder onto ballast between the tracks (Figure 5).

16 Concern over the immediate safety of the structure led to the signaller stopping all trains between Liverpool Street and Bethnal Green stations at 19:20 hrs, and an *emergency isolation* being taken at 19:34 hrs. A total of nine trains became stranded and over 1000 passengers were evacuated on foot along the track to the nearest station (Figure 2).

Figure 2: Photograph taken by an evacuating passenger at about 19:45 hrs looking back towards Liverpool Street. Bridge GE19 is in the background (Photograph: WENN)

The parties involved

17 Network Rail (East Anglia) owns and maintains the railway between Liverpool Street and Bethnal Green stations which is spanned by bridge GE19. The design and construction of bridge GE19 was an undertaking independent of Network Rail, and at the time of the incident the bridge was not part of the railway infrastructure. However, Network Rail has a responsibility to take into account of and manage the risks arising from activities carried out by other persons which may impact on the safe operation of its railway.

18 Transport for London (TfL) is the client for the East London line extension project which includes the installation of bridge GE19.

19 London Rail, a subsidiary of TfL, is responsible for overseeing the construction of the East London line project on TfL's behalf.

20 A Balfour Beatty-Carillion joint venture (BB-CJV) was the *principal contractor*, awarded the contract for the design and construction of the East London Line project. This included the design, fabrication and installation of bridge GE19.

21 Carillion Engineering Services (CES), a division of Carillion plc were temporary-works designers for BB-CJV.

22 Fairfield Mabey Ltd was the steelwork *sub-contractor* to BB-CJV.

23 MJ Hughes Limited (MJ Hughes) was the steelwork erection sub-contractor to Fairfield Mabey.

24 Benaim Group (Benaim) were the designers of bridge GE19, working under contract to BB-CJV. Benaim have since become part of the Scott Wilson Group.

25 Scott Wilson Group plc (Scott Wilson) undertook the *Category III design check* of the design of the new bridge GE19, and were the main design consultant for other aspects of the East London line project.

26 National Express East Anglia (NXEA) is the train operating company for all passenger train services from London Liverpool Street.

27 All the above parties freely co-operated with the investigation.

Location

28 The East London Railway will connect Highbury and Islington to New Cross, Crystal Palace and West Croydon and form part of the London Overground network. When the line opens to Dalston in 2010, Rail for London (trading as London Overground) will be the infrastructure manager. Network Rail will operate the signals and provide traction power control under Rail for London direction. London Overground Rail Operations Ltd (LOROL) will provide train services, which will be extended to Highbury and Islington in 2011

29 Bridge GE19 will carry the double track East London Railway across Network Rail's infrastructure, and is set on a gradient rising from east to west. The existing railway is located between high walls at this location, and access to the track is prohibited when trains are running. To reduce the impact of the new structure on the existing railway, both abutments of the new bridge were positioned off Network Rail's property.

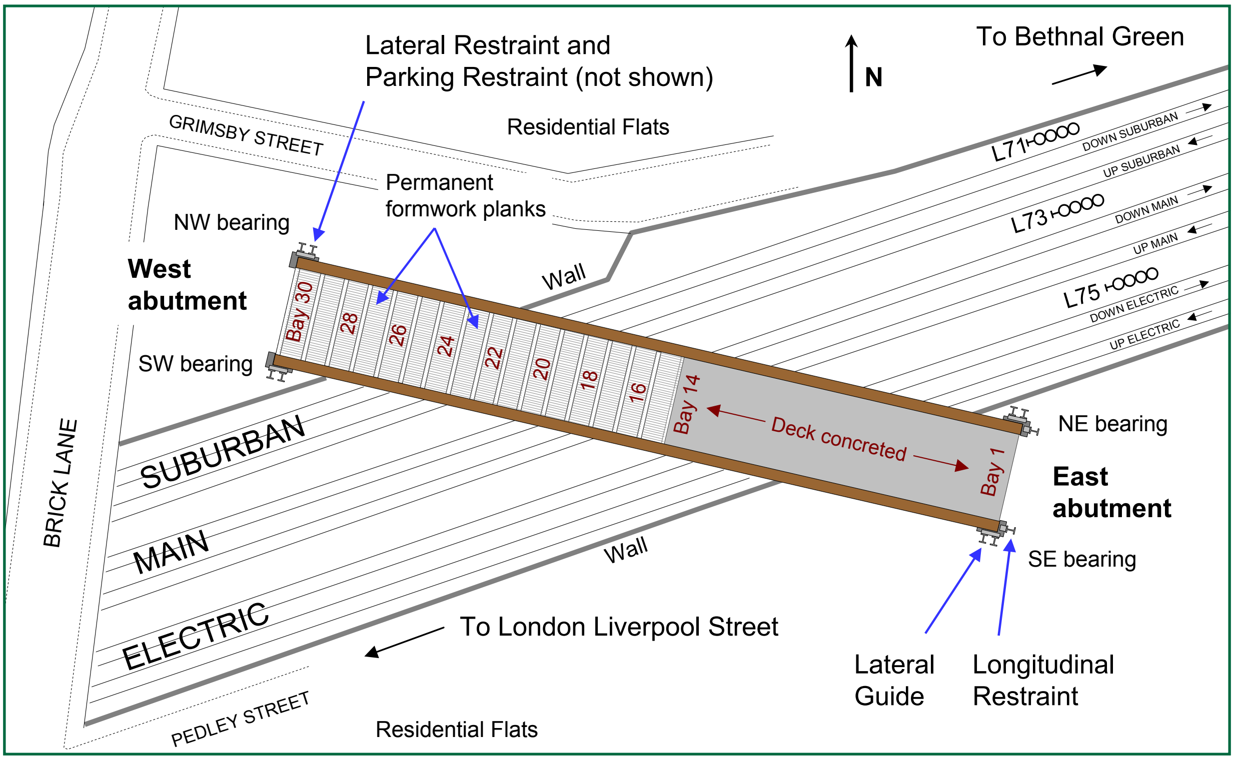


Figure 3: Schematic diagram of bridge in position, showing main construction features at time of partial collapse

30 Bridge GE19 is located 1.1 km (0.68 miles) from London Liverpool Street station to the east of Brick Lane, EC2. The bridge spans over six railway lines which are arranged in three pairs: suburban; main and electric (Figure 3). All lines are electrified by the 25 kV AC overhead system.

External circumstances

31 The incident occurred during daylight on a midweek evening. The weather was dry and clear and had no direct effect on the accident. However, rain during the previous two days contributed to water collecting on the bridge deck (paragraph 174).

Train/rail equipment

32 Train 1K12 was formed of two four-car Class 321 electrical multiple units. The leading vehicle sustained minor damage when it struck debris from the bridge. Other trains affected by the incident were undamaged.

33 The track was undamaged, but the 25kV overhead *catenary* was slightly damaged by falling debris.

Events preceding the accident

34 Bridge GE19 is a new structure, replacing a redundant bridge at the same location. The new bridge deck was successfully *launched* into position by being jacked across the railway during the bank holiday weekend 3 - 5 May 2008. The deck had been assembled on a construction site to the east of the railway and was moved using horizontal jacks in a westerly direction. During this operation, the railway was under *possession* and the catenary system was isolated.

35 To ensure the correct weight distribution for the launch, the western section of the deck needed to be as light as possible. Deck bays 15 to 30, to be located above the main and suburban lines, were fitted with pre-cast concrete planks in preparation for later concreting, but this section of deck was otherwise incomplete. The eastern section of the deck needed to be heavier to provide a counterbalance, and the main concrete deck slab was constructed over bays 1 to 14 (Figure 3).

36 At the end of the launch possession on 5 May, the structure was in the correct horizontal position, but remained supported on launching equipment and elevated above its final level. The process of removing the launching equipment, which included a substantial amount of temporary steelwork, took two weeks. The lowering of the deck into its final position, referred to as 'jack down', commenced on 23 May and was nearing completion at the end of the working day on 28 May. The deck remained supported on a small number of *temporary packing plates* at its eastern end until immediately prior to the accident.

37 At 19:15 hrs on 28 May, train 1K12 left Liverpool Street station and was routed onto the down main line. The train accelerated up to 15 mph (24 km/h) to leave the station, before the driver shut off power to allow his train to coast. Once clear of the station area, he was initially unable to accelerate due to loss of traction current provided via the overhead catenary system. The train gradually slowed to 10 mph (16 km/h).

38 At 19:16 hrs, Network Rail's electrical control room responsible for the Liverpool Street area recorded a short-circuiting of the overhead catenary supplying the down main line in the vicinity of bridge GE19. The overhead catenary was re-energised and the fault logged (fault number 90223).

39 At the same time, two Metropolitan Police officers who were in the vicinity, heard "an almighty bang" followed by aftershock noises and ran towards the bridge. They observed a large volume of rust-coloured water pouring from a gap in the bridge's deck onto the catenary system and informed their control room of the incident by radio.

40 The Metropolitan police's emergency control room also received an emergency call from a member of the public who stated that a large chunk of metal had just fallen onto the railway causing an obstruction. The Metropolitan Police controller correctly identified this as a railway incident, which triggered a pre-planned response which included informing the British Transport Police (BTP) and giving safety advice to officers on the scene.

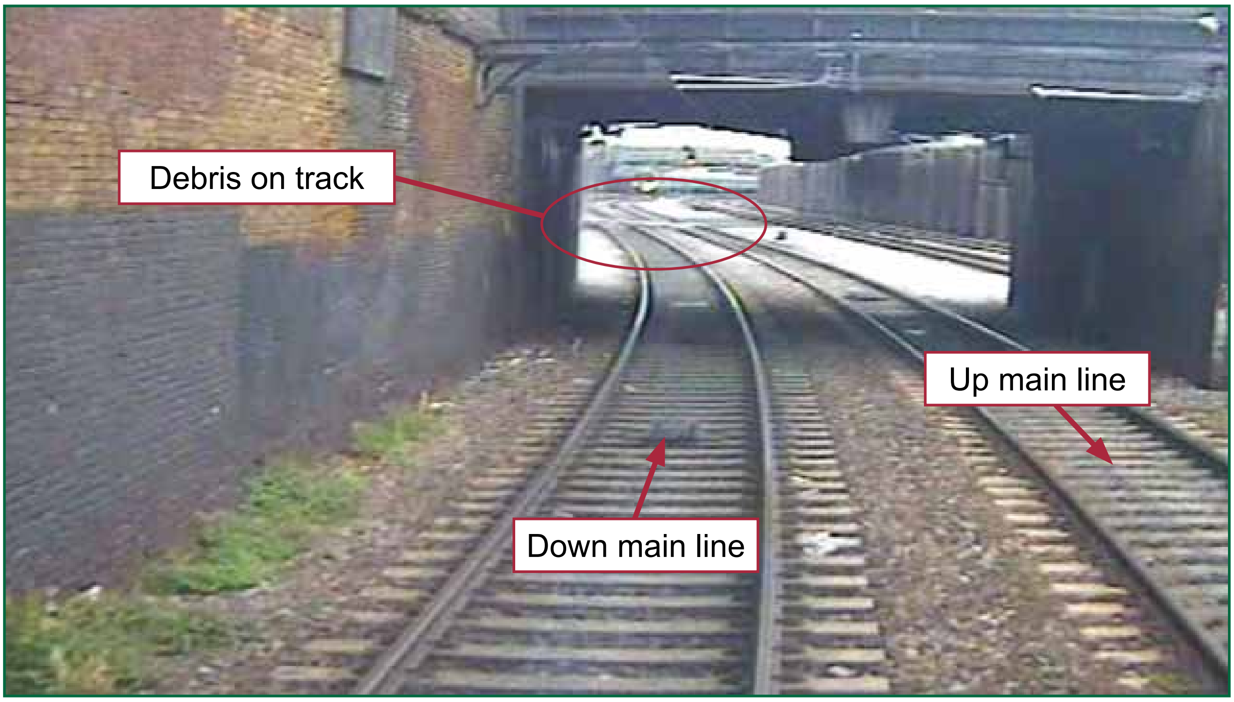


Figure 4: Image from CCTV equipment fitted to train 1K12, six seconds before collision with debris

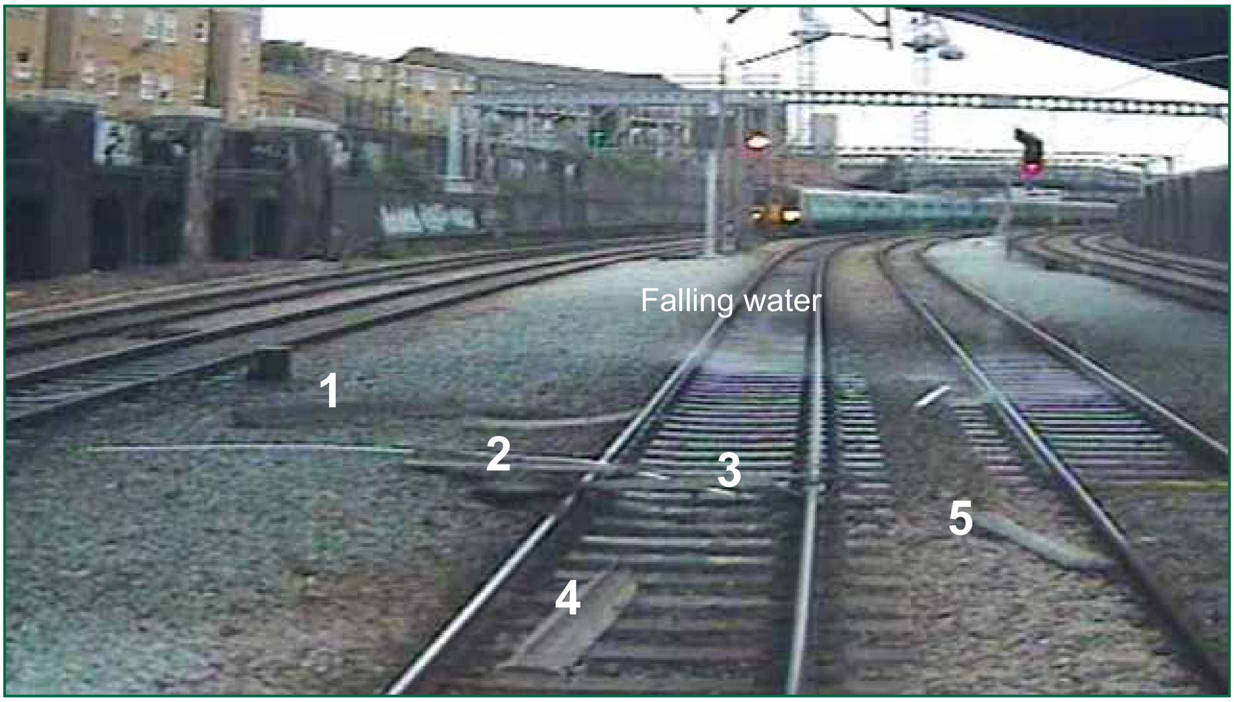


Figure 5: Image from CCTV equipment on train 1K12 showing debris on track immediately before the collision. The position of the five pre-cast concrete permanent formwork planks is indicated

Events during the accident

41 Once the power supply was restored, train 1K12 accelerated to 30 mph. The driver's first sighting of debris on the track occurred six seconds before impact, his visibility being restricted by a left hand bend and the abutment of the existing Brick Lane bridge (Figure 4). The driver was also aware of a cascade of water falling from the structure.

42 The driver made an emergency brake application four seconds later, but was unable to avoid running through the debris (Figure 5). The driver then briefly lost forward vision due to falling water hitting his windscreen, and his cab was struck by an object hanging from the overhead catenary. This was later found to be a strip of wet hessian originating from the deck.

43 One plank was dragged forwards under the leading bogie for a distance of approximately 50 metres (Figure 6). The train came to a halt close to a signal, after travelling 77 metres (84 yards) with the emergency brake applied. This was within normal parameters after activation of the emergency brake.

Figure 6: Damaged permanent formwork plank after being dragged forwards under train 1K12

44 At 19:17:49 hrs, the driver of train 1K12 contacted the Liverpool Street signalling centre using the train's cab-secure radio. Network Rail's communications protocol requires the phrase "this is an emergency call" to be used at the beginning of an emergency message, but the driver did not use these words. He informed the signaller that part of the new bridge had fallen down and that his train had hit concrete and girders. He gave his position by correctly stating that he had stopped at signal number L73. The signaller informed the driver that he would stop trains on the adjacent line to allow him to inspect his train for damage, and briefly interrupted the call while he took this action.

45 When the call resumed, the driver informed the signaller that residents of a block of flats close to the railway were leaning from their windows and shouting to him "bridge is broken". The driver informed the signaller that his train was partly under the bridge (Figure 7). At 19:21 hrs, with the scale of the incident becoming more apparent, the signaller took the decision to stop trains on all lines and informed the driver of 1K12 that no more would be run until he had inspected the track and bridge and reported back. During the radio call, two trains passed train 1K12 on the suburban lines. Neither sustained damage.

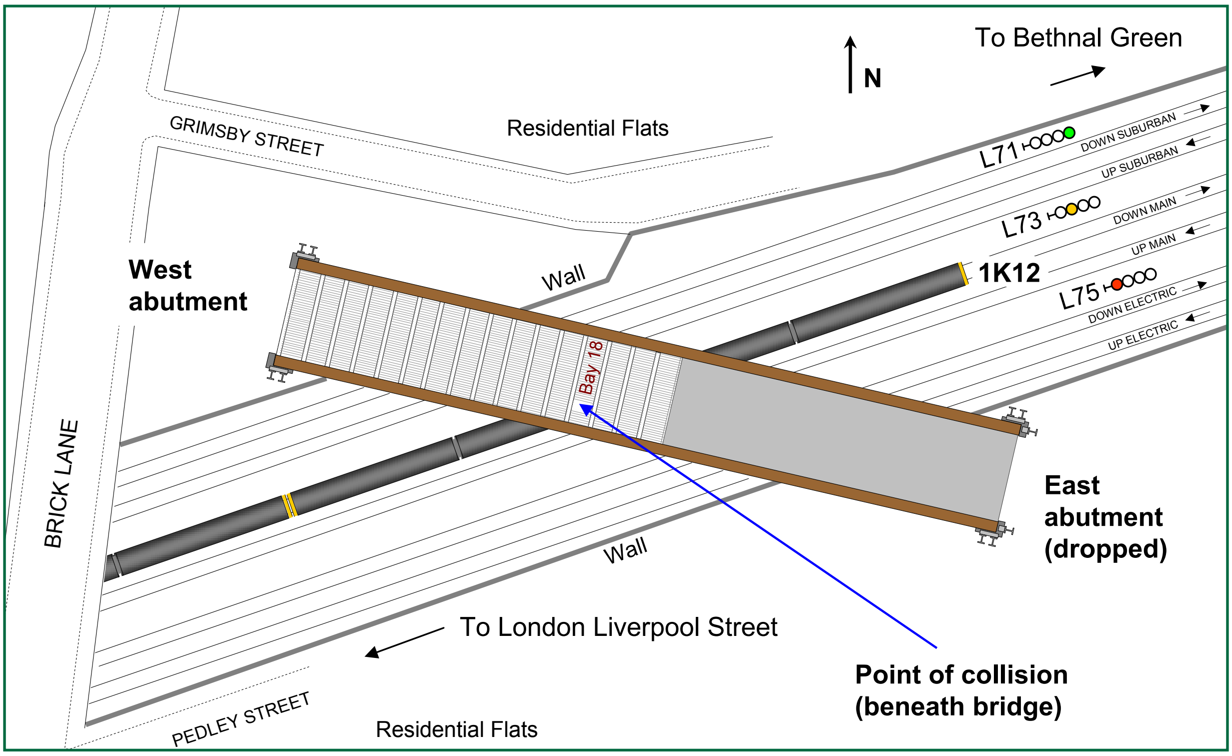


Figure 7: Situation at 19:18 hrs with train 1K12 stopped partly beneath bridge GE19

46 The driver of train 1K12 used the train's public address system to inform passengers to move towards the rear of the train and clear of the bridge.

47 At 19:18 hrs, the Metropolitan police control room notified BTP of the incident. Shortly afterwards, the Metropolitan police officers on the scene gained access to the west abutment construction site and were able to get a closer look at the bridge. They observed that the scaffolding around the opposite abutment showed signs of considerable impact damage and was buckled. They reported that water appeared to have forced the structure out of place.

48 Two trains had departed Liverpool Street at 19:18 hrs: train 1A50 for Harwich via the down electric line; and train 2T06 for Chingford via the down suburban line. Both trains were travelling towards bridge GE19 when the signaller took action to stop all trains, and drew to a halt alongside train 1K12 at signals L75 and L71 respectively (Figure 8).

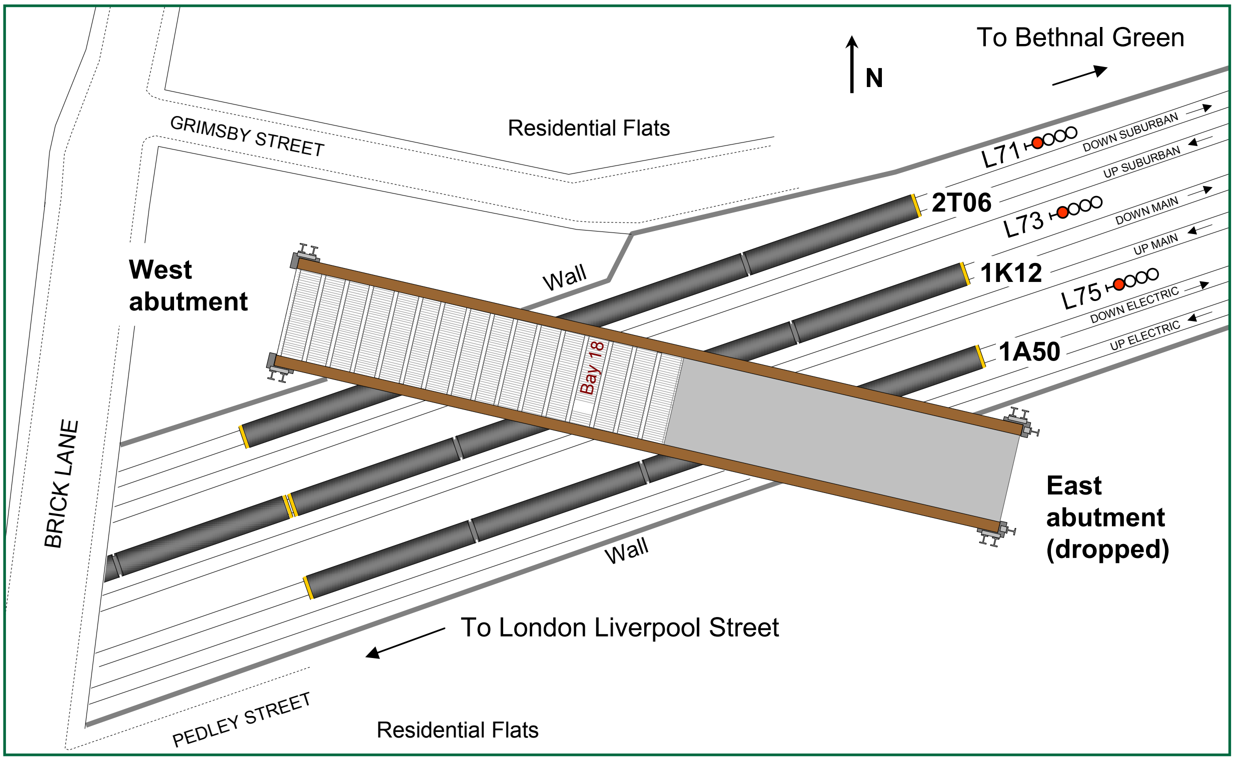


Figure 8: Situation at 19:22 hrs with three trains now stationary beneath the bridge

49 Seven other trains were affected by signals reverting to danger at 19:21 hrs (Figure 9).

50 At 19:22 hrs, the Metropolitan police contacted Network Rail's Route Control, based at Liverpool Street, to inform them of the reported incident. The route controller who responded was aware of the interruption to the power supply, but not the subsequent accident. The route controller had no means of contacting the site, or a nominated person, to discover more about the nature of the accident.

51 At 19:23 hrs, the shift signalling manager contacted Route Control, stating that a driver had reported hitting the new bridge and requested the attendance of a mobile operations manager (MOM) from Stratford.

52 At 19:25 hrs, a BB-CJV site security guard contacted his office and reported hearing three loud bangs.

53 At 19:26 hrs, the driver of train 1A50 contacted the signaller and informed him he was stationary at signal L75. He asked if he could move his train forwards and clear of the bridge. The signaller, having instructed the driver of 1K12 to go onto the track to examine his train, was not prepared to allow any further train movements until the driver of 1K12 contacted him back. The driver of 1A50 was instructed that he could move his train when signal L75 changed to a *proceed aspect*. The driver was asked what he could see and reported that there was water rushing off the bridge and that it appeared to be much lower on the east side.

54 At 19:28 hrs, the driver of train 1K12 contacted the signaller to inform him that there were now police and fire brigade personnel at the scene, and that the police wanted all three trains evacuated. The signaller was not aware that the emergency services had been called, but authorised the driver to evacuate his train and undertook to communicate with the other drivers involved.

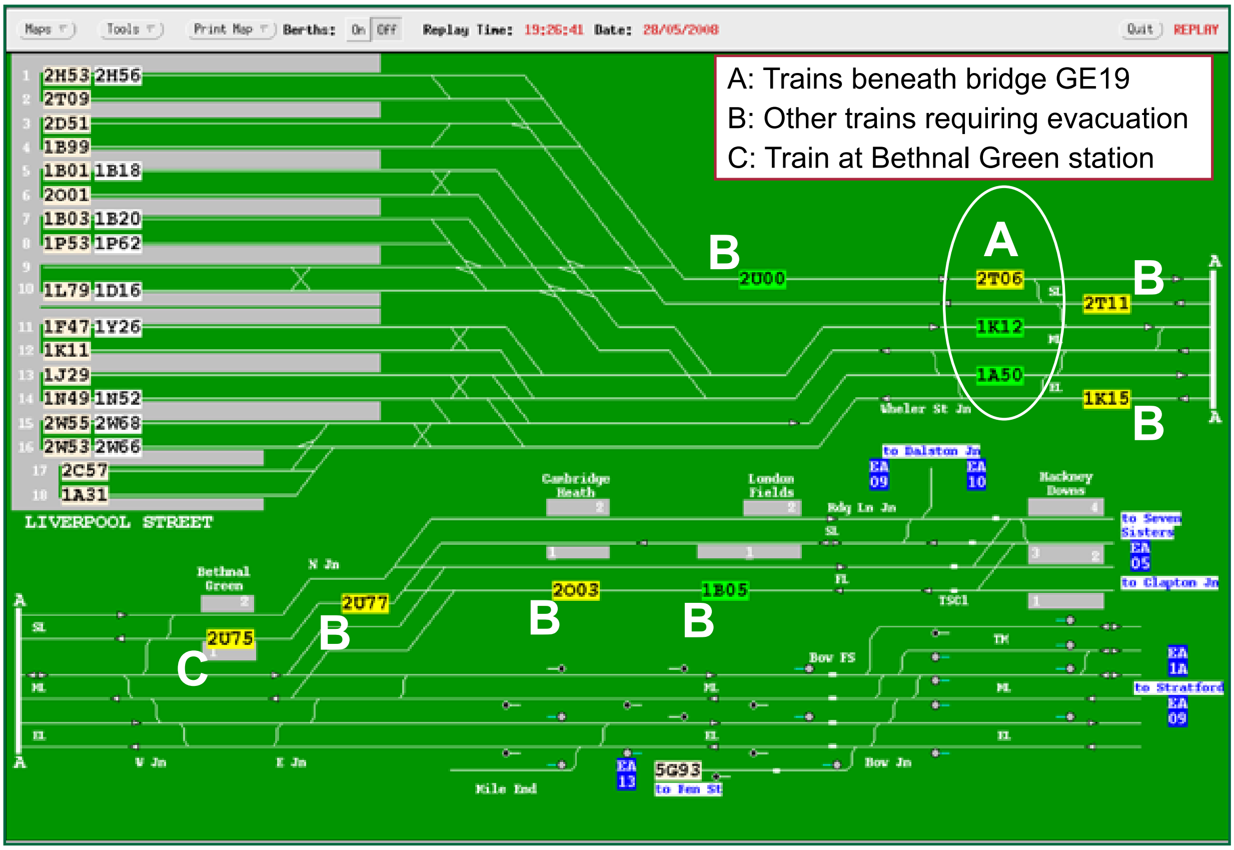


Figure 9: Image of signalling data at 19:26 hrs showing location of stationary trains following accident.

55 At the scene, the emergency services were unable to access the track or determine whether the bridge presented a continuing risk to the trains beneath it. However, they were aware that there were passengers in the carriages immediately beneath the structure and shouted instructions to commence the evacuation of passengers to the drivers involved.

56 At 19:30 hrs, the driver of 1A50 contacted the signaller and relayed a request from the London fire brigade for an emergency isolation of the overhead catenary. The signaller relayed this request directly to Network Rail's electrical control room at Romford, rather than via Route Control for expediency.

57 At 19:34 hrs, the signaller was granted an emergency isolation of the 25 kV AC traction supply by Romford electrical control room. The isolation had to be taken rapidly and, as a consequence, covered a large area including all lines from Liverpool Street to Hackney Downs and Bow Junction (near Stratford), and the North London Line between Dalston and Stratford. This affected a further eleven trains, of which nine were halted between stations.

58 At 19:35 hrs, evacuation (detraining) of the trains beneath the bridge commenced under the control of the train crew. The Metropolitan police officers were instructed by their control room to stay clear of the track until the BTP arrived.

59 At 19:40 hrs, BTP officers arrived at the scene and took command of the incident. They were able to access the track from Grimsby Street via a ladder put in place by the London Fire Brigade. Prior to their arrival they reported difficulty in contacting Network Rail's Route Control as the telephone was constantly engaged.

60 At 19:40 hrs, Network Rail advised London Rail project staff of a problem with GE19 and that all services into and out of London Liverpool Street station had been suspended. London Rail in turn notified BB-CJV.

61 At 19:50 hrs, the Network Rail MOM arrived and accessed the track via the London Fire Brigade's ladder. He was appointed to act as the Rail Incident Officer (RIO) by Route Control, to provide an interface between Network Rail and other organisations on site.

62 The RIO's role and responsibilities are defined in Network Rail standard NR/L2/OCS/250 'National Emergency Plan', as the lead rail industry person, co-ordinating all rail activities on site. The RIO's duties include establishing regular, structured rail industry site meetings to ensure effective liaison and co-ordination. At incidents where the emergency services implement a three-tier incident command structure (ie *gold/silver/bronze*), the silver tier is represented by the lead person from each organisation on site. The RIO acts as the *silver* representative for Network Rail and is normally assisted by a Train Operator's Liaison Manager (TOLO) appointed by the train operating company when passengers are involved.

63 In this instance, a TOLO was not appointed and BTP officers supervised the detraining of passengers from trains in the vicinity of the bridge with assistance from railway staff. Passengers were required to walk either east towards Bethnal Green station, 700 metres (0.45 miles) away, or back to Liverpool Street, so as to avoid having to pass under the bridge. The emergency services were not able to evacuate passengers via the adjacent, but now disused, Shoreditch Station as there was no safe access.

Consequences of the accident

64 The emergency isolation and subsequent remedial works meant that Liverpool Street main line station remained closed until 09:30 hrs on the following morning.

65 BTP estimate that approximately 700 people were evacuated to Bethnal Green station and a further 350 people were evacuated back to Liverpool Street station. In addition, an unknown number were evacuated via London Fields station from trains trapped in that area.

66 There were no injuries caused by the accident. However, one person twisted an ankle during the evacuation and required assistance. Another, with an existing hip problem, required a stretcher and was carried to Bethnal Green station by firemen.

67 Unit 321 333, forming the front portion of train 1K12 experienced damage to the fibreglass front valence, a rail guard adjacent to the leading wheels and impact marks to the leading left-hand wheel-set. The unit was examined at Seven Kings depot on 29 May, and released back into traffic later the same day.

68 The overhead line equipment for the down main line was slightly damaged by debris falling from the bridge. A repair was effected overnight in time for the reopening of Liverpool Street station.

Events following the accident

69 At 20:00 hrs, a senior BB-CJV manager, who had been notified of the accident, returned to site and immediately contacted the Fairfield Mabey site manager to inform him of a problem with the bridge. The Fairfield Mabey site manager returned to site with the site supervisor at 20:30 hrs.

70 At 20:05 hrs, the driver of train 2U77, standing to the north of Bethnal Green station, made first contact with the signaller. He was instructed to lower his pantograph. There was no recorded contact with the drivers of the two trains behind him.

71 From 20:10 hrs, London Rail's Chief Operating Officer co-ordinated activities within the organisation at a senior level. London Underground and London Bus control centres had already been advised of the incident from other sources. They were able to adapt their services to accommodate passengers who were unable to travel via Liverpool Street.

72 London Underground ran additional services to Stratford (Central line) and Tottenham Hale (Victoria line) to accommodate displaced passengers during this period. It was considered necessary to re-schedule planned engineering works on the Victoria line, which had been due to close at 22:00 hrs, to accommodate passengers travelling home from an international football match at Wembley.

73 At 20:16 hrs, the senior BTP officer at the scene declared the event to be a *critical incident*. This required BTP control to put in place procedures including notifying the BTP on-call Senior officer, liaising with other emergency services and monitoring the response more closely.

74 The Network Rail Route Control log records that a message was received from BTP control at 20:46 hrs, confirming that all trains stranded on the country (i.e. Bethnal Green) side of the bridge had been detrained successfully. However, a BTP log entry at the same time suggests that this information originated from Network Rail.

75 At 21:08 hrs, the shift signalling manager informed Route Control that train 2U77 near Bethnal Green had been overlooked and still required detraining. Train 2U77 was standing at signal L100 signal on the up suburban line. Once the train was reached, passengers were evacuated on foot to the station. All passengers were confirmed clear of the line at 21:36 hrs.

76 At 21:10 hrs, BTP convened a meeting with silver command representatives (silver meeting) from the emergency services and Network Rail. A senior representative from BB-CJV and the local authority, Tower Hamlets also attended. BB-CJV informed the meeting that the bridge had moved, possibly by 75 mm, but that there was no risk of it collapsing onto the railway. The RIO undertook to contact the train operating company to arrange for drivers to remove the stranded trains, and to arrange lighting for the site.

77 At 21:25 hrs, Network Rail reduced the size of the emergency isolation to allow the recovery of trains remote from the bridge site, and allow services to resume on the North London line (Passenger services in this area, despite drawing their traction supply from the 3rd rail DC system, had been halted by a freight train trapped across a junction by the AC isolation).

78 At 22:15 hrs, a further silver meeting was held. The meeting was informed that the RIO had been replaced following a shift change. The newly-arrived RIO did not attend the meeting as he was fully engaged on the track, and a senior Network Rail operations manager attended on his behalf. The operations manager continued to support the RIO by providing liaison between the site, the train operating company, and Route Control.

79 The meeting was informed that the structure had come to rest in a stable condition and there was no risk of progressive failure, following a joint inspection by BB-CJV and Fairfield Mabey. Network Rail stated that trains could be run once the damaged overhead catenary was repaired. An estimated time of two hours was given to complete the recovery operation.

80 At 22:38 hrs with the rescue complete, the emergency services stood down. The railway was handed back to Network Rail for the recovery phase. However, Network Rail staff did not inform London Rail or BB-CJV that they had assumed control, or implement a revised command structure for the site. The newly-arrived RIO's focus was on making arrangements to move the large number of stranded trains and restoring the railway. He did not have any contact with London Rail or BB-CJV staff, although Network Rail did have project staff and other engineers on site to oversee remedial work to the bridge and liaise with London Rail and BB-CJV.

81 London Rail's focus was on the recovery from the construction incident. In the absence of a command structure, management of the two recovery operations evolved separately, although there was informal communication between the groups.

82 BB-CJV commenced works to secure the deck following an initial inspection by the RAIB. These works involved removing or repositioning loose planks, installing plywood sheets over holes and other gaps in the deck, and placing additional steel bars to lace the permanent formwork planks together (Figure 10).

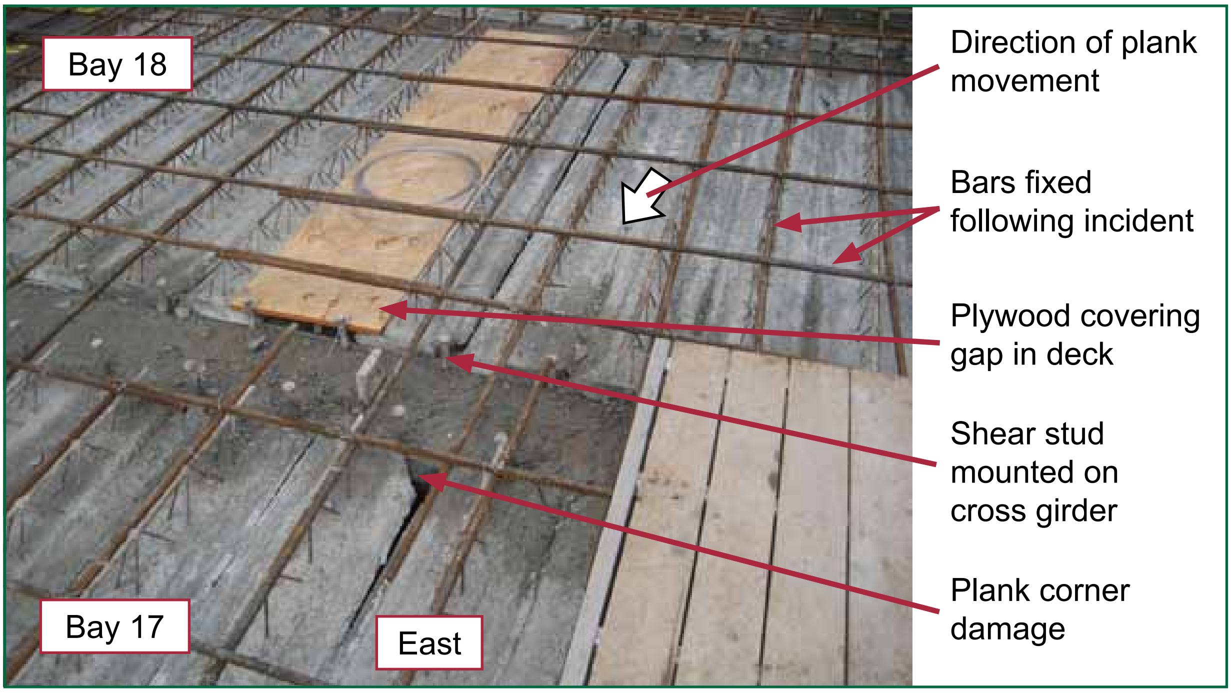


Figure 10: Photograph showing damage to deck (photograph TfL)

83 At 02:22 hrs, Network Rail electrification staff fitted earthing straps to the catenary to allow safe access to inspect cables damaged by the falling debris. This inspection was necessary before train 1K12 could be moved and required staff to gain access to the train's roof by ladder. There was no demarcation to protect railway staff working beneath the bridge from the work taking place overhead.

84 Following this inspection, Network Rail operations staff sought to have the traction power to the overhead catenary switched back on as soon as possible in order to start moving the trapped trains. A member of the electrification staff held the isolation permit and was answerable to the RIO.

85 The BB-CJV manager in charge of the deck stabilisation works had prior experience of working in an operational railway environment and above overhead electrification equipment. He was informed in advance that the isolation was due to be given up in order to move the trains, and considered it safe for work on the deck to continue as the main gaps had been covered by this time. Staff working on the deck were briefed accordingly, but this information did not reach Fairfield Mabey personnel working on the bearings.

86 At 03:36 hrs, the isolation was given up, and the catenary re-energised.

87 Shortly afterwards, a Network Rail civil engineer commenced an inspection of the ongoing deck remedial works, unaware that the isolation had been given up. He requested additional steel bars to lace the permanent formwork together in both directions (ie laterally and longitudinally).

88 When the civil engineer asked to see the isolation certificate, it was not available. When he discovered that it was no longer in force, he instructed BB-CJV to immediately clear all personnel from the deck as he considered the risk to personnel handling long lengths of steel bar and wire working above exposed high voltage cables to be unacceptable. At this time, the track was still visible through gaps in the deck (Figure 11). BB-CJV estimated that they had less than one hour of work remaining to complete the remedial works.

89 At approximately 04:00 hrs, senior representatives of BB-CJV, Scott Wilson, Benaim and Fairfield Mabey completed and signed a statement confirming that the works to secure the steelwork were complete, although work to secure and seal the deck was ongoing. The condition statement was handed to the Network Rail civil engineer, but he did not accept it until an explanation was given to explain the deck movement and how further movement would be prevented.

90 The deck works remained suspended until a second isolation was obtained at 06:29 hrs. Network Rail required written confirmation from London Rail that the bridge was safe to allow trains to pass under before the second isolation was given up. This occurred at 08:55 hrs, allowing trains to be moved into position for Liverpool Street station to reopen at 09:30 hrs. Normal services were reinstated by 13:00 hrs on 29 May.

91 Network Rail subsequently prohibited non-emergency work on the deck until an initial investigation into the failure was completed.

Effect of the loss of temporary support on the bridge structure

92 A loss of support at the north-east and south-east bearings resulted in the east end of the deck dropping by 200 mm an this caused a shockwave to pass through the structure. The deck came to rest supported on the *base plate* of both permanent bearings.

93 The displaced temporary support components were found on the ground up to nine metres in front of the abutment, and comprised *temporary taper plates*, temporary packing plates and *bearing top plates*. A 500 tonne capacity jack weighing 325 kg, previously positioned in front of the north-east bearing, was found at the foot of the railway boundary wall, having been thrown a distance of approximately four metres parallel to the *longitudinal* axis of the bridge. A steel packing plate, previously part of the temporary support, was found on top of the railway boundary wall.

94 The passage of the shock wave through the structure resulted in the displacement of 228 permanent formwork planks, this being more than half of the total number. Bays 16-24, towards the mid-span of the structure, were most affected. Many of the displaced planks had moved longitudinally downhill (i.e. to the east), and laterally to the south. In some cases, planks had moved by over 100 mm.

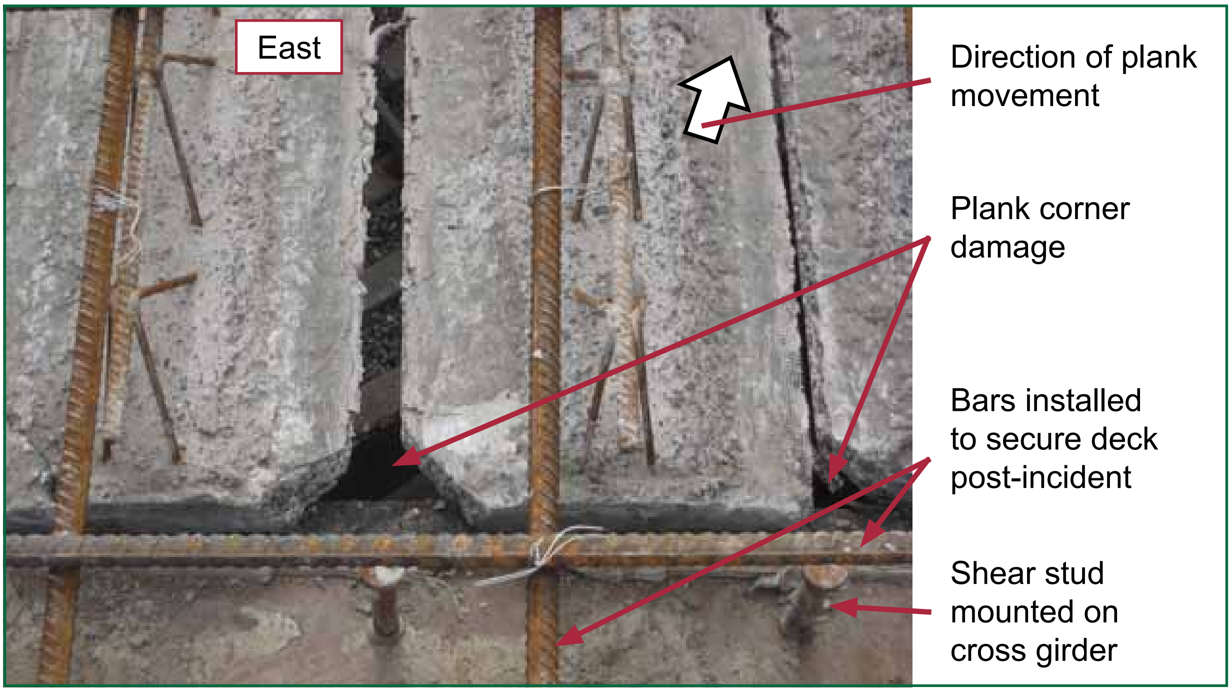


Figure 11: Photograph of damage to permanent formwork planks. The track is visible through the gap (Photograph TfL)

95 Five planks were missing from bay 18, together with a similar number of uPVC strips used to span gaps between groups of planks. One plank in bay 21 was considered too dangerous to leave in position and was removed by BB-CJV staff. Elsewhere, the deck was fractured allowing rain water, which had previously been observed collecting in bay 15 at depths of up to 50 mm, to escape.

96 A damage survey identified that 75 planks needed replacement, having either diagonal cracks or knocked-off corners (Figures 10 and 11).

97 Subsequent inspection of the bolted connections confirmed that the structure experienced significant differential movement due to twisting during the collapse. Analysis by the designer, Benaim, confirmed that the primary steelwork was undamaged, but recommended that the bearings be replaced and the bolts in several joints be renewed. These works were undertaken during a series of overnight railway possessions.

The Investigation

98 In agreement with the Health and Safety Executive (HSE), the RAIB has limited its investigation into the failure of the end support of the bridge and loss of materials from the deck to the extent necessary to understand its effect on the operation of the railway. The investigatory and regulatory authority for the construction of the bridge is the HSE.

The investigation process

99 The investigation focused on the following aspects:

a. adequacy of temporary support arrangements;
b. approval processes adopted by BB-CJV, London Rail and Network Rail;
c. information provided to site personnel;
d. action taken following the discovery of unplanned horizontal movement;
e. planning of the jack down operation;
f. actions of site personnel during the jack down operation;
g. actions of the signaller and train drivers;
h. emergency arrangements for the site;
i. the response of the emergency services; and
j. actions of Network Rail and project staff during the recovery phase.

Sources of evidence

100 Evidence has included:

a. examination of the site;
b. witness statements;
c. project documentation and incident reports provided by London Rail, BB-CJV and Fairfield Mabey;
d. project documentation provided by Network Rail;
e. CCTV evidence from train 1K12; and
f. Control room voice recordings.

Key Information

Project background

101 Bridge GE19 was designed to replace a redundant structure which spanned the railway at approximately the same location, giving access to the former Bishopsgate goods yard. This structure was unsuitable for reuse as part of the East London line due to its condition and height over the existing railway.

102 Bridge GE19 spans the railway at an oblique angle (Figure 3). The bridge is located on a part of the East London line where the railway transitions between sub-surface and elevated sections, and is set on a 1 in 30 (3.3%) gradient for this reason, rising from east to west.

103 Due to the bridge's size and location, the method of erection had an influence on the design and needed to be determined at an early stage. The availability of land to the east of the existing railway, and the requirement to minimise the impact on train services, led to a decision to pre-fabricate the structure beside the railway and then launch it into position in a single operation by physically sliding across the railway. The design of the bridge was developed on this basis.

104 Benaim produced design drawings, information on the loading during launching and a design risk assessment. This document used an alpha-numeric classification with risk severity ratings ranging from 1 'catastrophic' to 4 'negligible'.

105 The construction sites for each abutment were separated from the railway by high masonry walls, these being a legacy from the original structure. While this provided protection for the railway, the walls created a physical and visual barrier between the sites and meant that the only access between the two abutments at the time of the incident was by road.

Protection of Network Rail's assets

Network Rail

106 Network Rail required that the operational railway be protected from risks arising from the construction works occurring on either side, and above their infrastructure.

107 Once the design and outline methodology for the construction of the bridge was agreed, an 'Asset Protection Agreement' was prepared to cover both the demolition of the existing structure and construction of the new bridge. Network Rail Infrastructure Ltd. signed the agreement with London Underground Limited on 9 March 2007, as the project came under the auspices of London Underground Ltd at that time.

108 The Asset Protection Agreement made reference to standards to be adopted and the roles and responsibilities of each party. It also encompassed the submission of *method statements* to Network Rail for approval, the appointment of a project manager and supporting resources, including safety inspections over the duration of the period of construction to ensure the safety of the network.

109 Network Rail appointed a project manager on 14 May 2007, supported by a senior project engineer and a project engineer. Network Rail directly managed the demolition of the existing structure, which took place in December 2007, on behalf of London Rail.

110 Network Rail's role reverted to asset protection for the construction of bridge GE19, as this part of the project was led by London Rail. The project engineer was given delegated authority to approve documents on behalf of Network Rail, and was required to approve works to be undertaken within 15 metres of the railway. He also had powers to instruct the contractor directly where a safety issue was concerned.

111 The Network Rail senior project engineer and project engineer jointly reviewed the need to undertake their own risk assessment for the erection of the bridge. They deemed this unnecessary on the basis that it was not a Network Rail project and there was no perceived risk to the operational railway during the launch, as this was to be undertaken during a possession.

112 Network Rail did not consider it necessary to have full-time site supervision, except for during the launch itself, on the basis that Balfour Beatty, Carillion and Fairfield Mabey were experienced railway contractors. The safety inspections described in the asset protection agreement were to be undertaken by the project engineer during his site visits.

London Rail

113 London Rail adopted the Network Rail standards RT/E/P/02009 'Engineering Management for Projects', and NR/SP/CIV/003 'Technical approval of design and construction and maintenance of civil engineering infrastructure' to comply with the Asset Protection Agreement.

114 RT/E/P/02009 defined the roles and responsibilities of staff responsible for the management and engineering issues. This included the role of the Designated Project Engineer (DPE), defined as a person appointed to take overall responsibility for the co-ordination of technical and engineering aspects of a specific project. The DPE role was fulfilled by a senior member of London Rail's engineering staff, and he was permitted to delegate responsibilities defined by the standard to his team, but was required to remain accountable for their execution.

115 NR/SP/CIV/003 defined procedures to control the risk to Network Rail's infrastructure, railway operations, and railway passengers arising from the design, construction and maintenance of a structure over Network Rail infrastructure. Specifically, this included approval of the design, the means to verify that construction was in accordance with the design and arrangements to ensure that construction methods would not adversely affect the structural integrity of the structure or the safety of adjacent infrastructure. It also covered the arrangements for the issue of a 'Certificate of fitness to be taken into use' known as a 'Form E' certificate.

116 The DPE was responsible for determining the competence of the persons responsible for monitoring the construction work and had delegated this task to London Rail's construction team comprising a site engineer and an inspector. NR/SP/CIV/003 states 'verification that construction work is compliant with the design shall be carried out by consideration of method statements, provision of certification to confirm materials compliance with the design, and monitoring of fabrication and construction work against the design and accepted method statement'. This formed the basis of the team's work.

Description of the new bridge

117 Bridge GE19 spans 84 metres and is 10.4 metres wide between the main *Warren truss* girders. The deck is supported on four permanent bearings (i.e. a bearing at each corner), which are in turn supported on cast concrete columns, 3 m long and 1.7 m wide. Each abutment comprises a pair of columns (Figure 14).

118 The purpose of the bearings is to support the deck, while allowing movement to occur to accommodate changes in the temperature of the steelwork (i.e. thermal movement). The two bearings at the west abutment are designed to control the position of the deck and do not permit longitudinal movement. Conversely, the two bearings at the east abutment do allow longitudinal movement (Figure 12), and incorporate an ultra-low friction polytetrafluoroethylene (PTFE) surface for this purpose (Figure 13). Prior to the collapse, the upper and lower sections of each bearing were connected with temporary *transit cleats* (shown in red in Figure 20), designed to keep the bearing together until in its final position. The transit cleats were fixed to the bearing with four 12 mm diameter bolts, but as the top bearing plate was smaller than the *bearing base plate*, a 25 mm gap behind the upper part of the transit cleat was packed with washers. This allowed the bolts to be tightened.

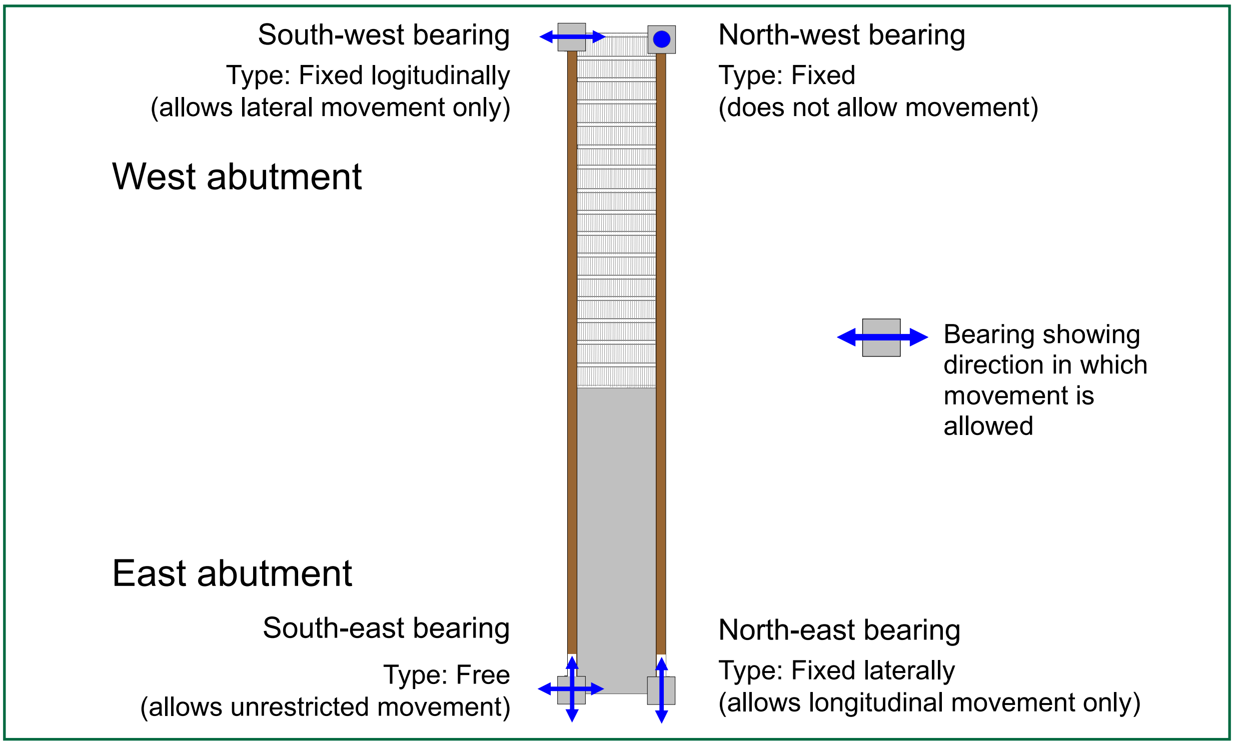


Figure 12: Bearing, showing direction in which movement is permitted

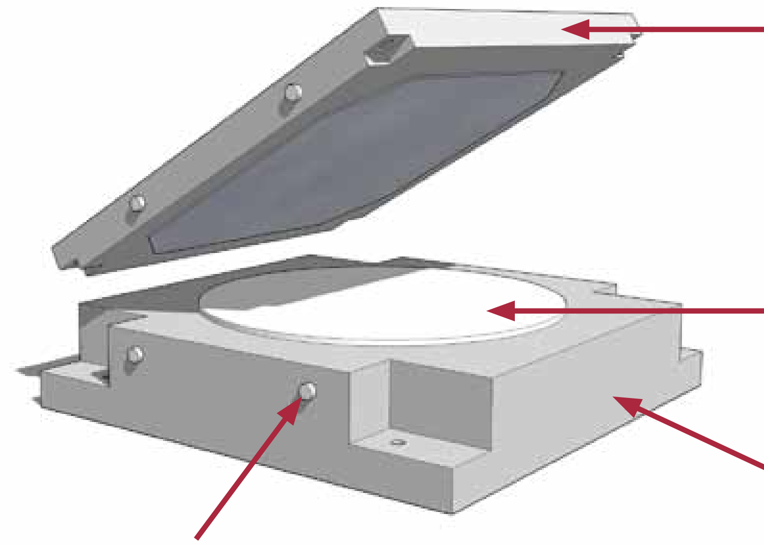


Figure 13: Schematic diagram showing top and base plates of a free permanent bearing

119 The deck is positioned on a 3.3% gradient, giving a height difference of 2.78 metres between the east and west abutments. As the bearings were to be set horizontally, wedge-shaped 'taper plates' were provided above each bearing to accommodate the gradient of the deck.

120 The main girders are connected by steel cross girders forming 30 deck bays, numbered from bay 1 at the eastern end. The steelwork frame supports the concrete deck which was designed to be constructed in two sections; a lower layer of pre-cast concrete permanent formwork planks spanning between the cross girders, and an upper layer of cast-in-situ concrete (Figure 14). Shear studs welded to the top of the cross girders were provided to connect the steel and concrete elements together to maximise the structural strength of the completed deck.

121 Each permanent formwork plank weighs 110 kg and is 0.3 metres wide by 2.41 metres long. The length of the planks is sufficient to span between the cross girders, giving a bearing length (overlap) of 55 mm at each end. Each plank is reinforced with three longitudinal steel reinforcing bars, which are located towards the centre leaving the outer 78 mm unreinforced, and a protruding lattice to connect into the cast-in-situ concrete (Figure 15). Each deck bay required 34 planks, numbered from 1 to 34, with plank 1 being closest to the south side of the bridge.

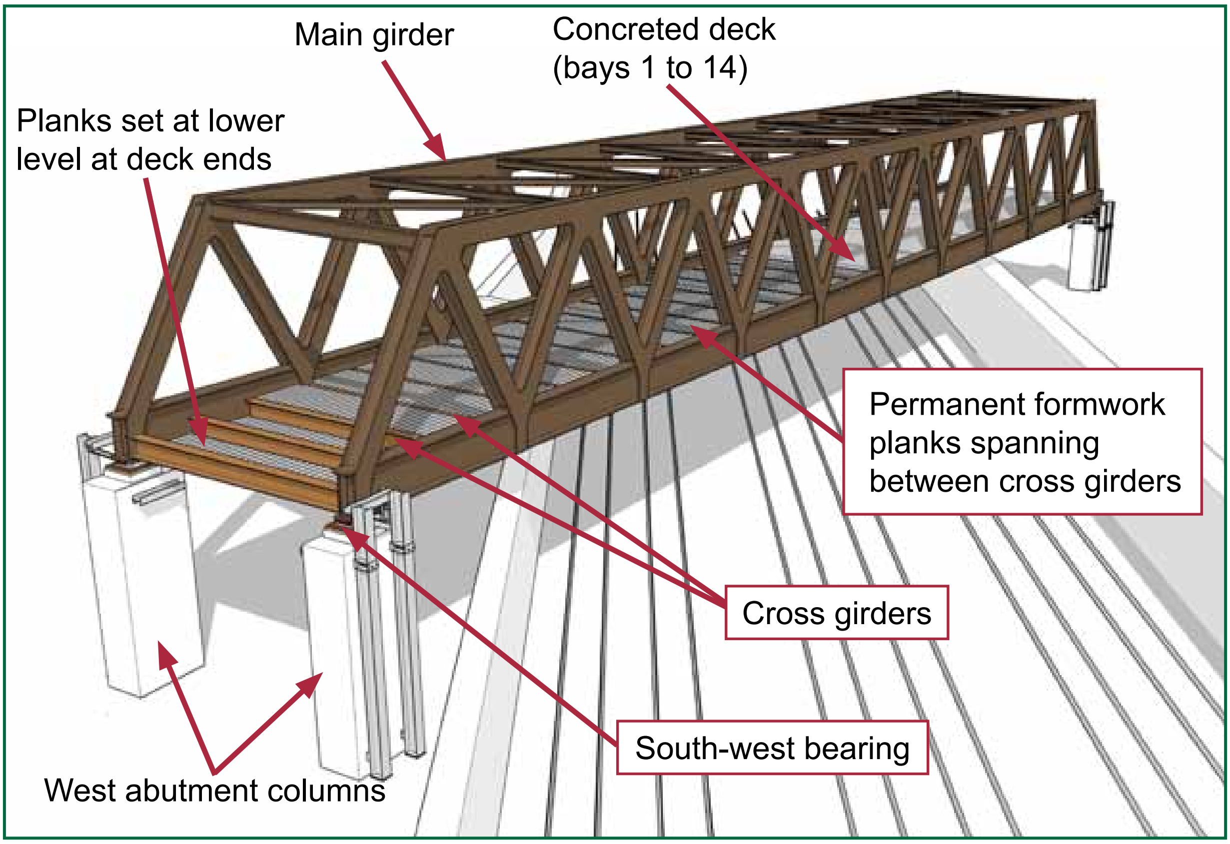


Figure 14: Schematic diagram showing main deck components

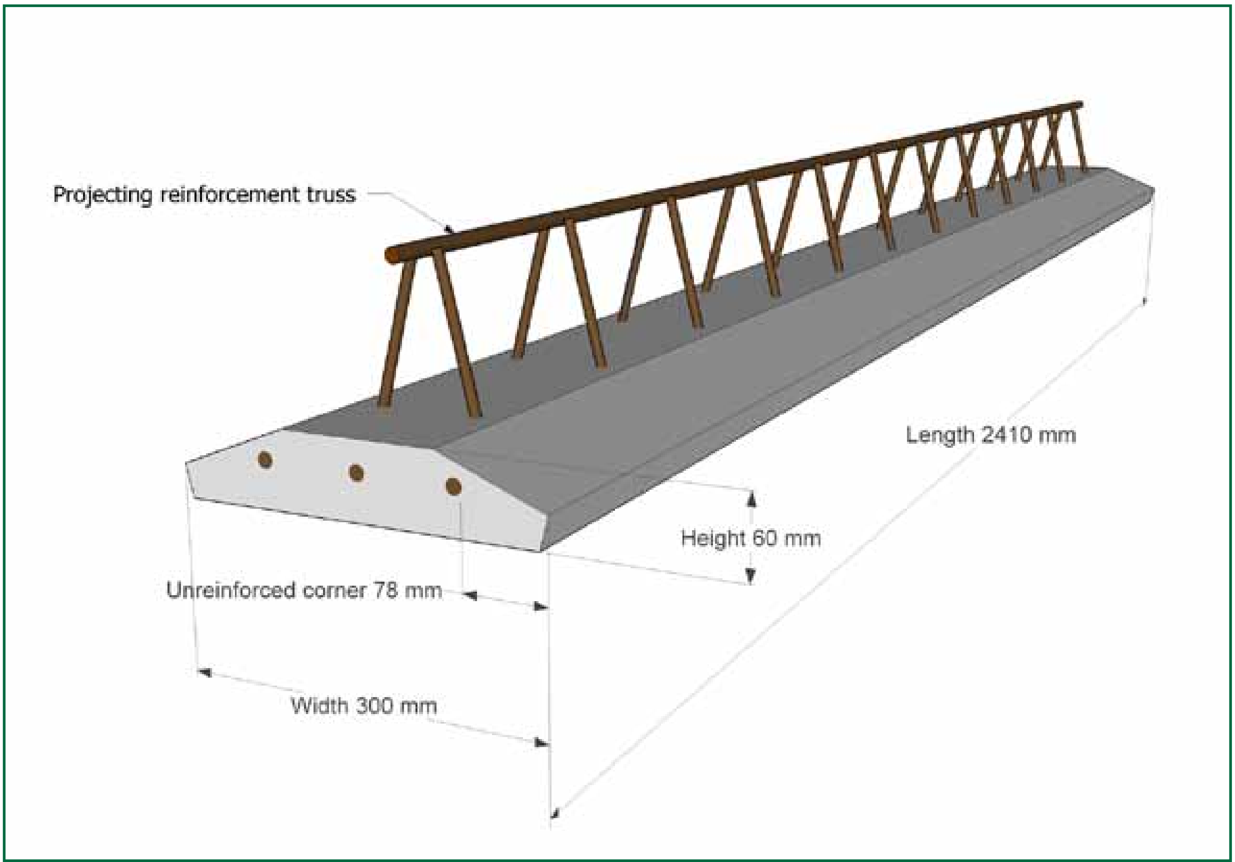


Figure 15: Schematic diagram of a permanent formwork plank installed on bridge GE19.

122 The deck was designed to be launched into position without the need for an intermediate support in order to minimise the disruption to the operational railway. This was achieved by fitting a temporary steel '*launching nose*' to the leading (ie western) end of the structure, and by paying careful attention to the weight distribution to avoid the risk of overbalancing. The deck was required to be launched in a partly-completed state, with the western end (bays 15 to 30) having the permanent formwork planks in position for later concreting. Conversely, the eastern end of the deck needed to be heavier to act as a counterweight and the design specified that bays 1 to 14 were to have the cast-in-situ concrete placed in advance of the launch.

123 The total weight of the deck during launching was approximately 1300 tonnes, with the heavier eastern end weighing 800 tonnes. Up to 300 tonnes of counterweight, placed on the eastern end of the deck, was used during the launch to balance the structure, but this was removed at the end of this activity. However, the eastern end of the deck continued to carry the additional weight of steel reinforcement, required to complete the western section of the deck, during the jack down phase.

Construction of the new bridge

Deck steelwork

124 In January 2007, BB-CJV awarded a contract for the fabrication and erection of the steelwork to Fairfield Mabey Ltd. The scope of Fairfield Mabey's contract included the design of the temporary works associated with the erection of the steelwork. Fairfield Mabey's contract also included three smaller bridges on other sections of the East London Line project.

125 Fairfield Mabey appointed a senior site manager to manage the project in July 2007.

Temporary works design

126 In February 2007, Fairfield Mabey commissioned an independent structural engineer to undertake the role of 'temporary-works designer'. His first task was to develop preliminary ideas for temporary works needed to support Fairfield Mabey's general concept for the launching of the bridge.

127 The temporary-works designer's remit was initially to design items required for the launch, including *lateral restraints* to be attached to the east and west abutments. This was later expanded to incorporate other elements, including support trestles, *longitudinal restraints* and the jack down arrangements. However, the senior site manager elected to adopt a jack down arrangement similar to one he had used on a previous project in preference to that proposed by the temporary-works designer, who subsequently believed that he had been relieved of responsibility for this element of the design.

128 Elements of the temporary works which are relevant to this investigation are described below:

a. Lateral restraints: required to steer the deck during the launch, and designed to attach to steel frames clamped onto the outer face of each concrete column by tensioned high-strength steel bars (Figure 18 and Appendix D). The 40 mm diameter tensioned bars passed through 75 mm ducts cast into the concrete columns, and were therefore loose-fitting until tensioned. The design specified a 25 mm grout layer at the steel/concrete interface to accommodate uneven surfaces and provide tolerance.

b. Parking restraints: required to act as *gravity restraints* to secure the deck at the end of the launch and prevent it moving downhill. These were designed to connect the lateral restraints to the bridge deck at the west abutment, and therefore depended on the clamping force generated by the tensioned bars to resist movement. The clamping force for each tensioned bar was specified at 924 *kilonewtons* (kN) (equivalent to 94 tonnes), with four bars securing each lateral restraint (Figure 18).

c. Longitudinal jackdown restraint (longitudinal restraint): required to prevent the deck moving downhill during the jack down phase as the parking restraints were unsuitable for this purpose. This restraint was to be provided by steel columns attached to the rear of the east abutment, but they could not be erected until part of the *rocker box* had been removed due to the relatively narrow width of the concrete columns (Figure 19 and Appendix D).

129 During a review of the design, the senior site manager identified that the grout layer specified between the lateral restraints and concrete columns would be difficult to execute. He corresponded with the temporary-works designer by email and proposed the use of an alternative arrangement involving a thin nylon pack and steel shims at this interface. The temporary-works designer responded with a request for more information on the proposed grade of nylon to be used. The matter was subsequently raised during a technical meeting held in October 2007 attended by various Fairfield Mabey staff, including the senior site manager, temporary-works designer and checker. The outcome of this meeting is unclear, but the proposed change of material was not formally progressed via Fairfield Mabey's drawing change procedure, and as a consequence, the temporary-works design was not amended.

130 The temporary-works designer was not required to make provision for horizontal adjustment of the deck following the launch. The senior site manager was confident that the deck could be positioned to the required accuracy during the launch, based on his previous experience. Fairfield Mabey has confirmed that, of the six bridges launched by the company on a gradient between 2003 and 2007, none required horizontal repositioning after the launch, or during or after lowering. All members of the site team had been involved in the erection of one or more of these structures.

Temporary works design check

131 The complexity of the proposed temporary works meant that an independent design check (Category III check) was required in accordance with NR/SP/CIV/003. A Category III check requires a person, independent of the designer, to undertake separate calculations in order to verify the proposed design.

132 Fairfield Mabey appointed a second structural engineer to perform the role of temporary-works checker in September 2007. The checker's work included calculating the loading on the parking restraint independently and he was satisfied that the proposed arrangement was sufficiently robust.

133 The checker identified that the design of the packing required for the temporary supports for the jack down phase was missing from the drawings and calculations he was reviewing. For expediency, he undertook the necessary design work based on details provided by Fairfield Mabey's senior site manager. The scheme involved the substitution of the launching equipment with temporary supports, comprising steel packing, to allow the incremental lowering of the deck onto its permanent bearings.

134 Drawings numbered TW976019-211 (drawing 211) for the east abutment and TW976019-212 (drawing 212) for the west abutment, were produced by Fairfield Mabey to indicate these arrangements, and incorporated design work from both the temporary-works designer and the checker. The drawings (included as Appendix D) also give a procedure for the jack down operation, and this indicates that the longitudinal restraints should be installed prior to the permanent bearings.

135 Fairfield Mabey presented the temporary-works designer with drawings 211 and 212 to sign as the designer. He had not seen the drawings before and as they incorporated some elements which were not his work, he declined to sign them until he had the opportunity to complete a review and arrange for minor changes to be made. Once he was satisfied, he signed the drawings as the designer, and this allowed the checker to sign the check certificate confirming that the temporary works design was complete. The check certificate lists the standards and codes used for the design, and these included BS 5975:1996 'Code of practice for falsework' and BS 5400: 2000 'Design of steel bridges'.

136 CES were contracted to provide BB-CJV with design and checking for temporary works on the project. This involved a review of the temporary-works design to ensure the coordination and integration of work by various designers involved in the launching and lowering of the bridge deck, each the subject of an individual check certificate. At the conclusion of this process, CES issued an 'Integration Check Certificate' for the complete set of designs.

Steelwork method statement

137 Fairfield Mabey's senior site manager developed the steelwork method statement between July and November 2007, and issued the first revision on 22 November 2007. This was a single document, numbered EMS-976-019-01-A, covering the site assembly, erection of the temporary works, launch, jack down, and the final handover to BB-CJV. Although the early stages of the work were comprehensively documented, the level of detail reduced for the later stages.

138 Section 4.8 of the document was entitled 'Jack down and structure hand over'. This section comprised a series of one sentence instructions largely replicating the sequence indicated on drawing 211. Under the heading 'Lowering Structure', the document included the single statement: 'Lower structure at all 4 corners simultaneously, repacking and resetting jacks as necessary'.

139 The steelwork method statement incorporated a site specific risk assessment as an appendix. This was primarily concerned with health and safety risks to staff and the launch, and contained only one direct reference to the jack down phase. This identified that the truss (i.e. the deck) could become unstable and categorised this as capable of causing a fatality (category 4 under Fairfield Mabey's rating system). The risk mitigation required the retention of positive restraints to control both transverse and longitudinal movement until the truss was fixed to its permanent bearings and this was to be provided by retaining the lateral restraints and longitudinal restraints. This action was judged sufficient to ensure that the steelwork remained on the abutments, and was assessed as reducing the likelihood of such an event occurring from 'likely' to 'remote', thereby reducing the risk rating from 'high' to 'low'.

140 BB-CJV reviewed Fairfield Mabey's method statement, and when they were satisfied with its content, included it as an appendix into their own document (numbered ELLP-SS006-MES-05-01364 Rev A01), for the construction and launch of the bridge. The document included descriptions of both BB-CJV and Fairfield Mabey's risk assessment processes which differed. Fairfield Mabey used a two-stage process (i.e. severity multiplied by likelihood) with a severity rating of 1 representing 'minor injury'. BB-CJV used a three-stage process (ie frequency multiplied by severity multiplied by probability) with a severity rating of 1 representing 'up to 1 minor injury'.

141 London Rail received revision A01 of the method statement on 27 November 2007. After completing their review, which involved several members of the DPE's team, they responded with comments on 07 January 2008. London Rail's procedure for reviewing method statements required the originator of a comment to categorise it 'A', 'B' or 'C'. Category 'A' comments needed to be addressed, whereas category B comments needed to be considered but could allow a method statement to be accepted with comments. Category 'C' dealt with more minor issues.

142 A method statement review meeting was held on 14 January, attended by London Rail, BB-CJV and Fairfield Mabey at which London Rail's comments were discussed. Of the 30 comments received, the following are pertinent to this investigation:

Ref.	Cat	London Rail comment	BB-CJV/Fairfield Mabey response to London Rail comment
2	B	Although it is appreciated that this method statement only covers FM [Fairfield Mabey] works, it would be beneficial to include references to other method statements that are specifically noted within this method statement, such as deck works.	Noted. Suitable references made in revised method statement.
16	B	A drawing of this staging at each abutment would be useful. The drawings supplied only give details at some stages. This section is not clear in a number of areas: What is the relevance of the longitudinal restraint shown on drawing 211 and when is it installed? How are the permanent bearings installed? How are 4 corners simultaneously lowered?	Discussed at meeting 14/01 and agreed. Method statement updated as necessary.
26	A	Are there going to be additional MS [method statements] to cover items in this section – it is suggested that the installation of bearings on this structure be covered in a separate method statement to address the complex nature of the works on this structure?	As discussed at the meeting on 14/01, the detailed installation of the bearing will be described in a work plan, approved by all parties.

Table 1: selected comments on method statement A01 and responses

143 Both BB-CJV and Fairfield Mabey revised their sections of the method statement. BB-CJV, who had the main role for checking method statements, reviewed the document before it was resubmitted to London Rail as revision A02 on 16 January 2008. This document included a schedule of responses to London Rail's comments (refer to Table 1), but there was no other formal record of the method statement review meeting.

144 Revision A02 of the method statement contained some new information in response to London Rail's comments, but the section concerning the lowering of 4 corners of the structure simultaneously (comment 16) was unchanged. Despite this, the revised method statement was accepted by London Rail on 29 January 2008.

145 Network Rail undertook their own review and accepted the method statement on 21 April 2008.

146 A work plan, as referenced in the response to comment 26 above, is defined in BB-CJV procedures as being a document used to provide task specific instructions and information on activities covered by a method statement. Under the project's procedures, BB-CJV were not required to submit work plans to London Rail, although they were to be accepted by Network Rail for work in the vicinity of the operational railway.

147 BB-CJV convened a risk review meeting on 14 February 2008 attended by Network Rail, London Rail and Fairfield Mabey. During the meeting, Network Rail's project engineer queried how the structure would be aligned at the end of the launch. Fairfield Mabey were confident that the deck could be positioned within the 15 mm required tolerance and stated that any repositioning necessary would be undertaken by horizontal jacking (plan jacking) using the lateral restraints prior to completion of the launching phase.

148 At the same meeting, BB-CJV sought clarification on when the 'Form E' should be issued, its purpose being to certify that construction work had been carried out in accordance with the accepted design, and to describe any departures from the accepted design. NR/SP/CIV/003 states that a Form E certificate should be completed and signed:

a. 'before any significant part of a scheme (except the track) is taken into use'; and

b. 'before any temporary works whose failure or presence could reasonably affect the safety of the railway or of any persons other than those under the control of the construction organisation are taken into use or otherwise used by the construction organisation.'

However, as bridge GE19 was to be completed in stages and was not due to be brought into use for some time, the meeting agreed that the Form E should be issued only once the structure was in its final position (i.e. after jack down) to avoid issuing multiple versions of the certificate.

Steelwork assembly

149 The steelwork, weighing 812 tonnes, was fabricated by Fairfield Mabey and brought to site in sections for final assembly. This took place on an area of site to the east of the railway between January and March 2008.

150 Fairfield Mabey's site team comprised a full-time site manager supported by the visiting senior site manager. Other staff were provided by MJ Hughes Ltd, whose contract included the provision of supervision, labour and equipment. MJ Hughes was a long-term supplier of steelwork erection resources to Fairfield Mabey, and members of the team had worked together on previous projects. All senior members of the joint team had experience in the erection of steel bridges by launching.

151 Prior to works commencing on site, MJ Hughes' staff were inducted by BB-CJV on general site issues, and by Fairfield Mabey on specific issues. Copies of all the method statements, drawings and risk assessments were issued to the site supervisor, who gave daily briefing to his staff based on this information. Staff signed an attendance sheet each day to confirm that the briefing had been received.

152 Once the steelwork assembly was complete, responsibility for the structure passed to BB-CJV for the construction of the concrete deck. It had been transferred back to Fairfield Mabey for the launch and jack down, and was due to be finally handed over to BB-CJV once in its final position.

Deck concrete

153 The non-steelwork elements of the deck were constructed by BB-CJV following completion of the steelwork by Fairfield Mabey. A section engineer led the BB-CJV site team.

154 BB-CJV prepared a method statement for the installation of the permanent formwork and for placing cast-in-situ concrete to deck bays 1 to 14 (numbered ELLP-000-MES-05-01616 revision A01). As this phase of the work was to be undertaken entirely within the construction site area prior to the launch, the document was focused on construction activities rather than the interface with the operational railway, except for the requirement for a hoarding to protect the deck edge. It did not address the stability of the permanent formwork during the launching or jack down phases. A revised version of the method statement was proposed to cover the completion of the deck, including placing concrete above the operational railway, but this had not been finalised at the time of the incident.

Provision of positive ties between permanent formwork planks

155 During the planning of this activity, the BB-CJV team reviewed a risk assessment prepared in August 2007 by the designer, Benaim. This identified a hazard caused by dropping the permanent formwork during construction and defined this as 'major', being capable of causing a 'fatality, multiple severe injury or occupational illness' (category 2 under Benaim's risk rating system), albeit that the likelihood was judged remote.

156 The proposed mitigation was to provide a reasonable bearing surface for the permanent formwork planks, and to partially fix reinforcement over the permanent formwork to provide a positive tie between all units. The risk assessment indicated that this mitigation made the residual risk 'acceptable', and Benaim included an allowance for the additional weight of the proposed ties in their calculations for the launch.

157 The Construction Industry Research and Information Association (CIRIA) publish guidance on construction issues. CIRIA publication C543, 'Bridge detailing guide', identifies the need to consider the risk of accidental dislodgement and recommends that each permanent formwork element 'be adequately secured to the main girders, or to adjacent elements which have themselves been well secured.'

158 The BB-CJV section engineer was unaware that Benaim had allowed for the additional weight of the proposed ties, and the addition of ties conflicted with his desire to minimise the weight of the western half of the deck in order to balance the structure during the launching operation.

Furthermore, the ends of the permanent formwork planks were seated on double-sided adhesive strips stuck to the upper edges of each cross-girder, and thick cement mortar was applied between the planks making the deck watertight and precluding any movement of the planks. On this basis, the BB-CJV team took the decision that the planks were adequately secured and that a positive tie between each was therefore unnecessary. The possibility of the deck receiving a jolt sufficiently large to break the mortar was not considered during hazard identification.

159 Fairfield Mabey were not provided with a copy of the design risk assessment. Neither were they involved in discussions regarding the securing of the permanent formwork planks or the decision to dispense with this control measure.

160 The deck concrete method statement was submitted to London Rail, who responded with comments, which predominantly related to construction site issues, on 13 February 2008. Revision A02 was submitted and addressed London Rail's comments, and London Rail accept the revised method statement on 18 March 2008.

Modification of the deck layout

161 The width of the deck was not designed as a multiple of the width of a standard permanent formwork plank. This meant that a gap would result at each side of the deck if the permanent formwork planks were installed in accordance with the design, unless extra-wide planks were ordered from the manufacturer. The design aligned the permanent formwork planks with shear studs welded to the top flange of each cross girder (Figure 16), although this was not apparent unless several drawings were compared.

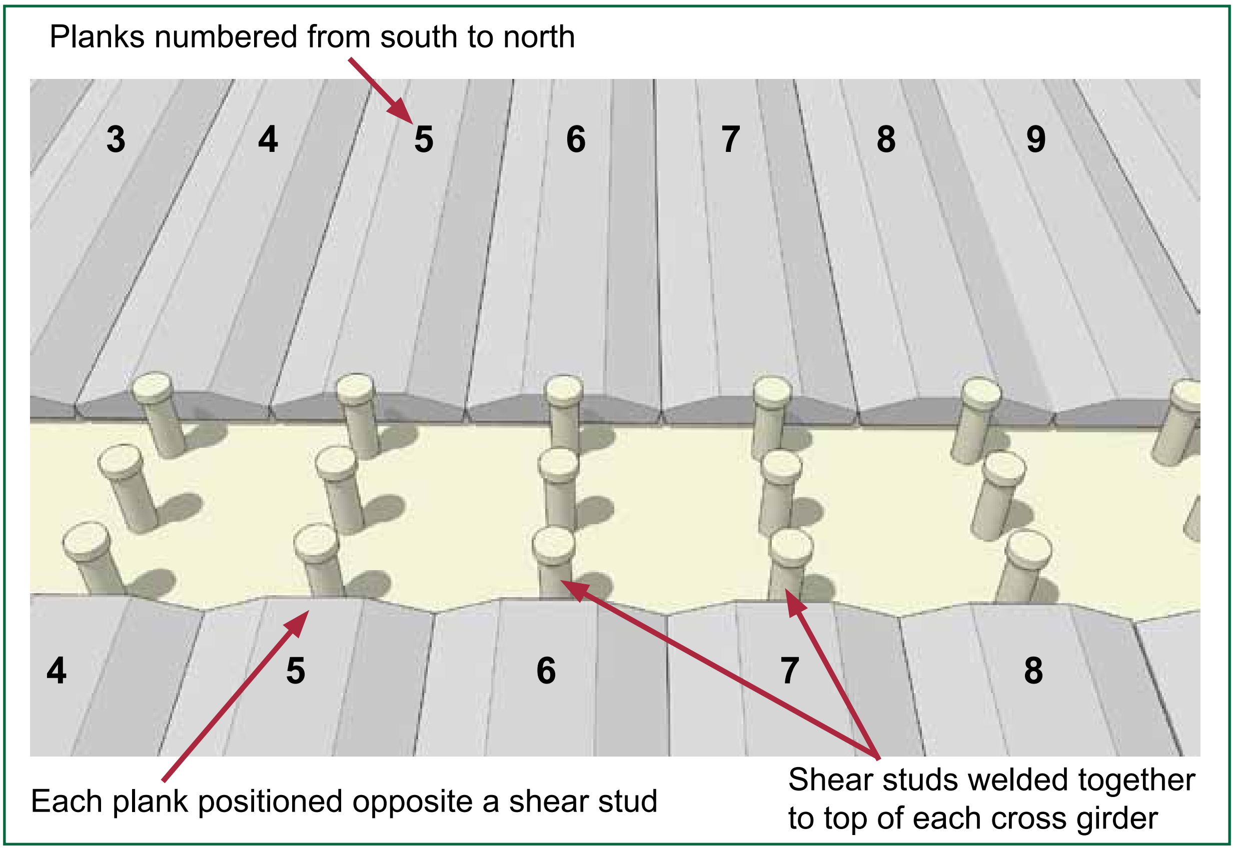


Figure 16: Schematic diagram showing a typical deck bay, and the as-designed relationship between shear studs and permanent formwork planks

162 The BB-CJV team decided to modify the deck layout to distribute the gap across the width of the deck, such that planks were arranged in groups of four or eight, with smaller gaps of up to 50 mm between each group. A uPVC strip was to be provided to span these gaps and these were specified accordingly. Once in position, the gaps between planks, cross-beams and uPVC strips were sealed with hessian strips impregnated with cement grout in order to stabilise the deck and prevent leakage of wet concrete.

163 BB-CJV's decision to amend the deck layout was taken without reference to Benaim or London Rail. This modification affected the relationship between the planks and the shear studs, particularly towards the outer edges of the deck where the off-set was greatest. Planks 2 to 9, located as a group towards the southern edge of each deck bay were most affected, with each plank being off-set by 84 mm from its original position (Figure 17). This was sufficient to place the unreinforced edge of the plank in closest proximity to the adjacent shear stud, the centre of the stud being 66 mm from the edge of the plank (paragraph 121).

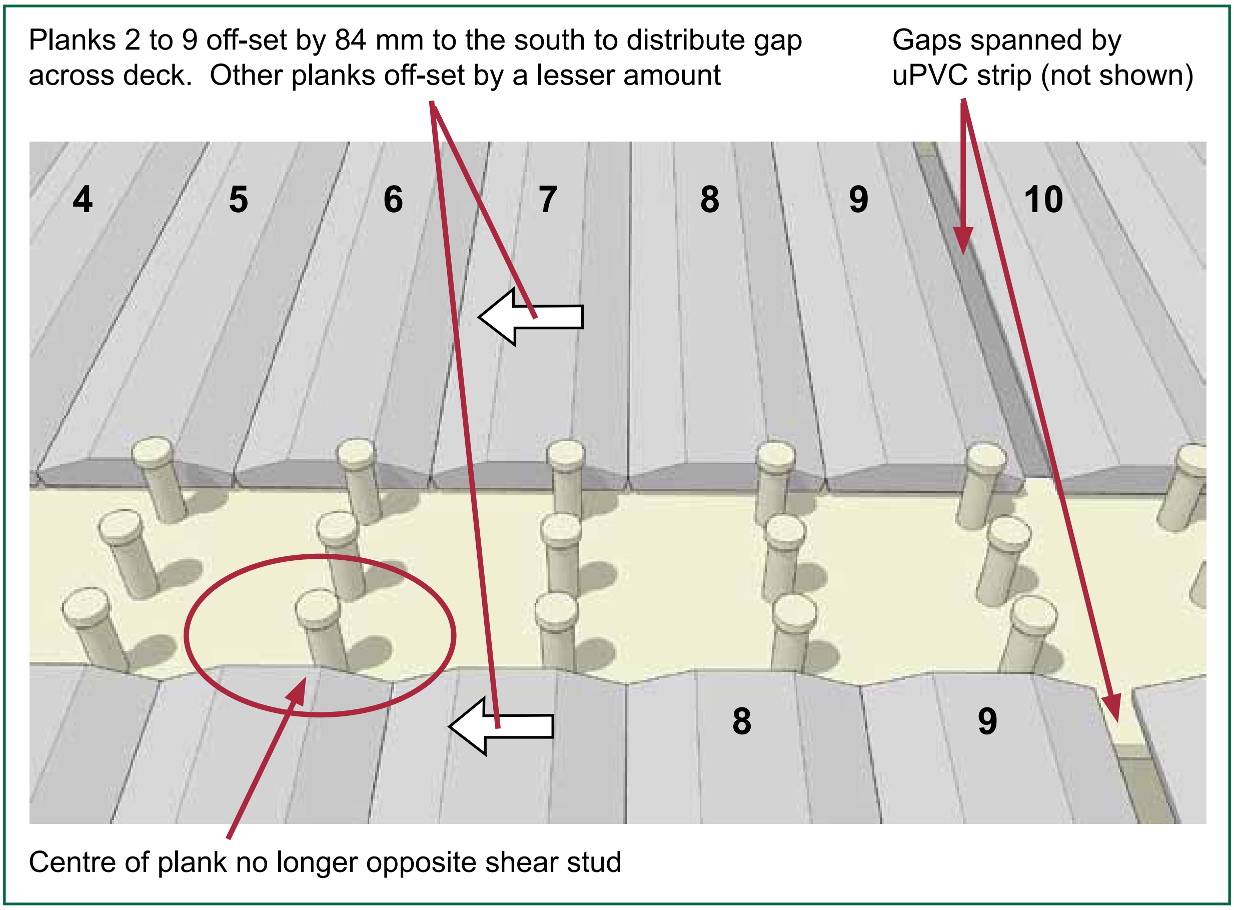


Figure 17: Schematic diagram showing a typical deck bay, and the modified relationship between shear studs and permanent formwork planks.

Preparation for launching

164 Prior to launching, cast-in-situ concrete was placed in bays 1 to 14 at the eastern part of the deck in accordance with the permanent works design. The un-concreted western section of the deck comprised 544 individual permanent formwork planks, with 34 planks per deck bay.

165 Following a joint inspection by BB-CJV and Fairfield Mabey staff on 25 April 2008 at which a list of outstanding works was agreed, responsibility for the deck transferred back to Fairfield Mabey for the launch and jack down phases.

166 The lateral restraints were erected at the west abutment in April 2008, but with shot-blasted steel shims in place of the grout layer (paragraph 129). The surface of the concrete columns, to which the steelwork was attached, was very smooth and traces of an oily residue (mould oil) arising from the construction process were present. Once erection was complete, Fairfield Mabey issued a 'Permit to Load' for the temporary works at both abutments which stated that the structural steelwork had been 'constructed and located in accordance with the approved Form C (check certificate) and designer's drawings.' Both BB-CJV's section engineer and Fairfield Mabey's senior site manager signed the permit on 2 May 2008.

167 BB-CJV's procedures for the management of temporary works on the project required a weekly inspection by a competent person, and for a record of the inspections to be maintained. This requirement applied from when an element of temporary works received a 'Permit to Load' and continued until a 'Permit to Dismantle' was issued. BB-CJV had previously appointed Fairfield Mabey's senior site manager as a temporary works supervisor, and this required him to undertake checks on the temporary works supporting bridge GE19.

Erection of the new structure

Launching of the deck

168 For the duration of the launch, Network Rail provided continuous site supervision. The level of supervision reverted to weekly visits by the project engineer once the launch was completed. There was also a reorganisation within BB-CJV following the launch and a new section engineer was appointed with responsibility for GE19.

169 At the completion of the launch, the deck was confirmed as being within 1 mm of its correct position in plan, and was secured against further horizontal movement by the parking restraints fitted adjacent to the west abutment (paragraph 128b). The deck remained supported on rocker boxes and PTFE-faced elastomeric-rubber slipper pads used for the launch (Appendix D), and was positioned 650 mm above its final level at the east end and 450 mm at the west end.

Post-launch activity

170 During the following two weeks, the launching nose (paragraph 122) was removed, and preparations were made to substitute the rocker boxes at each bearing location with the permanent bearings, temporary packing plates and wedge-shaped temporary taper plates to accommodate the gradient of the deck. Temporary taper plates were required because the permanent taper plates were difficult to man-handle, but could not be welded onto the structure in advance as the main girders were required to have a smooth underside (*soffit*) for launching. These arrangements were in accordance with drawings 211 and 212 (Appendix D).

171 Fairfield Mabey's site manager issued a work plan for the jack down activity (document ELLP-000-WAP-05-02605), on 12 May 2008. The document repeated the relevant section of the method statement, but included the requirement for jacks to be fitted with mechanical *locking collars*. Both BB-CJV and Network Rail approved the work plan on the following day. Although the document included the items required by BB-CJV's work plan procedure, the section describing the method of working was copied directly from the method statement and included no new information. In particular, the misleading phrase 'lower structure at all 4 corners simultaneously' was retained, although Fairfield Mabey actually intended to lower one end of the deck at a time incrementally by manually controlled jacks.

172 This activity coincided with a period of hot weather. On 13 May, the steelwork temperature was recorded at 39ºC. Weather records for that day show that it was clear with a maximum air temperature of 21ºC.

173 Fairfield Mabey held discussions with BB-CJV on how to accommodate thermal movement, as the length of the bridge was varying by 20 mm between day and night. Options included the possibility of working out of hours when temperatures were lower, and dispensation was obtained from the local authority under Section 61 of the Control of Pollution Act for late working on 15 May. In the event, works had not progressed sufficiently for restraint to be transferred from the west to the east abutment by this stage.

174 During wet weather, rain water falling on the sealed deck ran down the gradient until impeded by the completed section of deck which acted as a dam. As a consequence, a pool of water collected in bay 15, directly above the up and down main lines and catenary (Figure 3).

175 On 16 May, Fairfield Mabey's senior site manager examined the connections between the lateral restraint supporting the parking restraint and the concrete abutment columns and observed rust marking on the concrete (Figure 18). The deck remained supported on PTFE-faced slipper pads at this time, and the marks indicated to him that the parking restraint had slipped by 10-15 mm allowing the deck to move down the slope towards the east abutment. He was satisfied that further movement was unlikely after the tensioned bars came into contact with the side of the ducts (paragraph 128a). However, he was aware that the deck might need repositioning as a consequence, and mentally assessed this to be a low risk activity and within the experience of the site team. The matter was not reported to BB-CJV or Network Rail, and was not referred to the temporary-works designer.

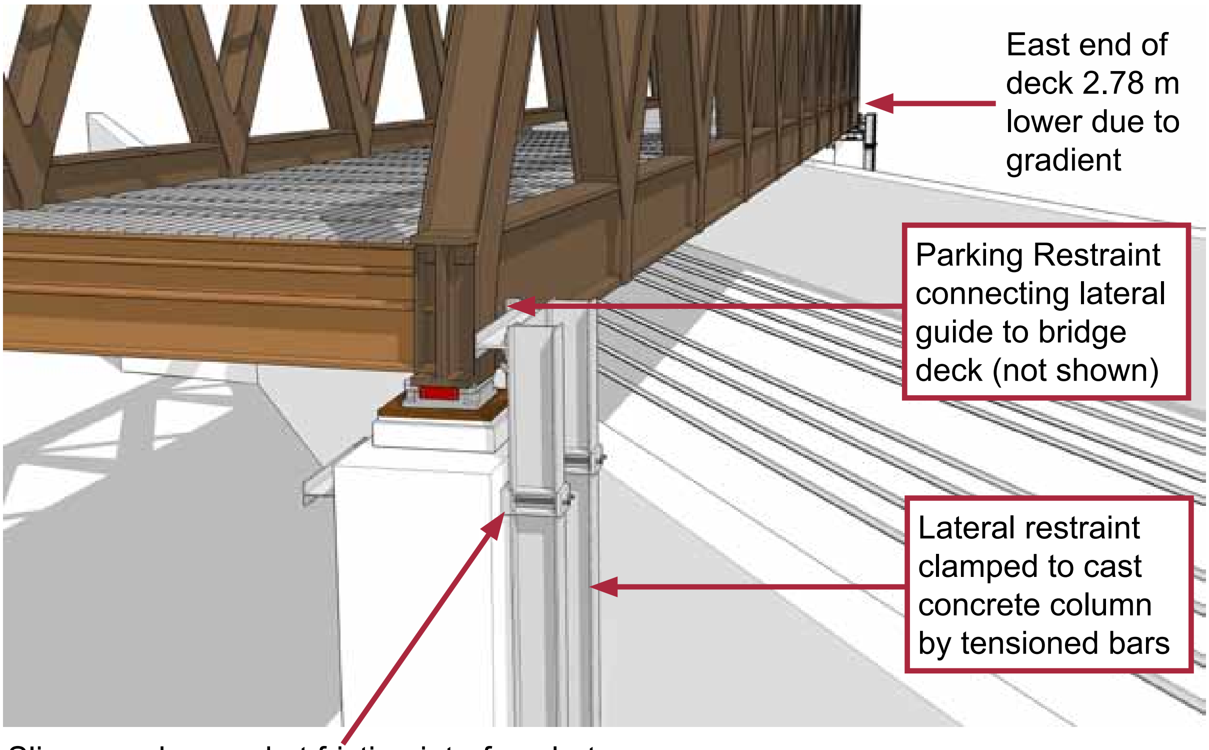


Figure 18: Schematic diagram showing location of parking restraint at the west abutment, acting as a temporary fixed bearing.

176 Preparations for jack down at the east abutment commenced on 20 May. The temporary supports and permanent bearings were installed later the same day.

177 The removal of the rear section of each rocker box created the space necessary to allow the erection of longitudinal restraints (paragraph 128c) on 21 May (Figure 19). However, the site manager's diary indicates that the deck remained restrained at the west abutment until restraint was transferred on 27 May.

178 A 'design temperature' of 13ºC was specified on the steelwork drawings, and this included the proviso that if the east abutment bearings were to be permanently fixed into position when the steelwork was at a different temperature, the base plate was to be off-set by a pre-determined amount to compensate. This was not addressed in the method statement.

Jack down of the deck

179 Jack down of the east end of the deck commenced by lowering it from 650 mm to 450 mm on 22 May and to 250 mm on the following day where it remained until 28 May (Figure 20). The deck was lowered one end at a time using a pair of manually controlled hydraulic jacks. The lateral restraints were retained to reduce the risk of unintended deck movement and steel wedges were placed between the bearing top plate and base plate to prevent rotation of the bearing.

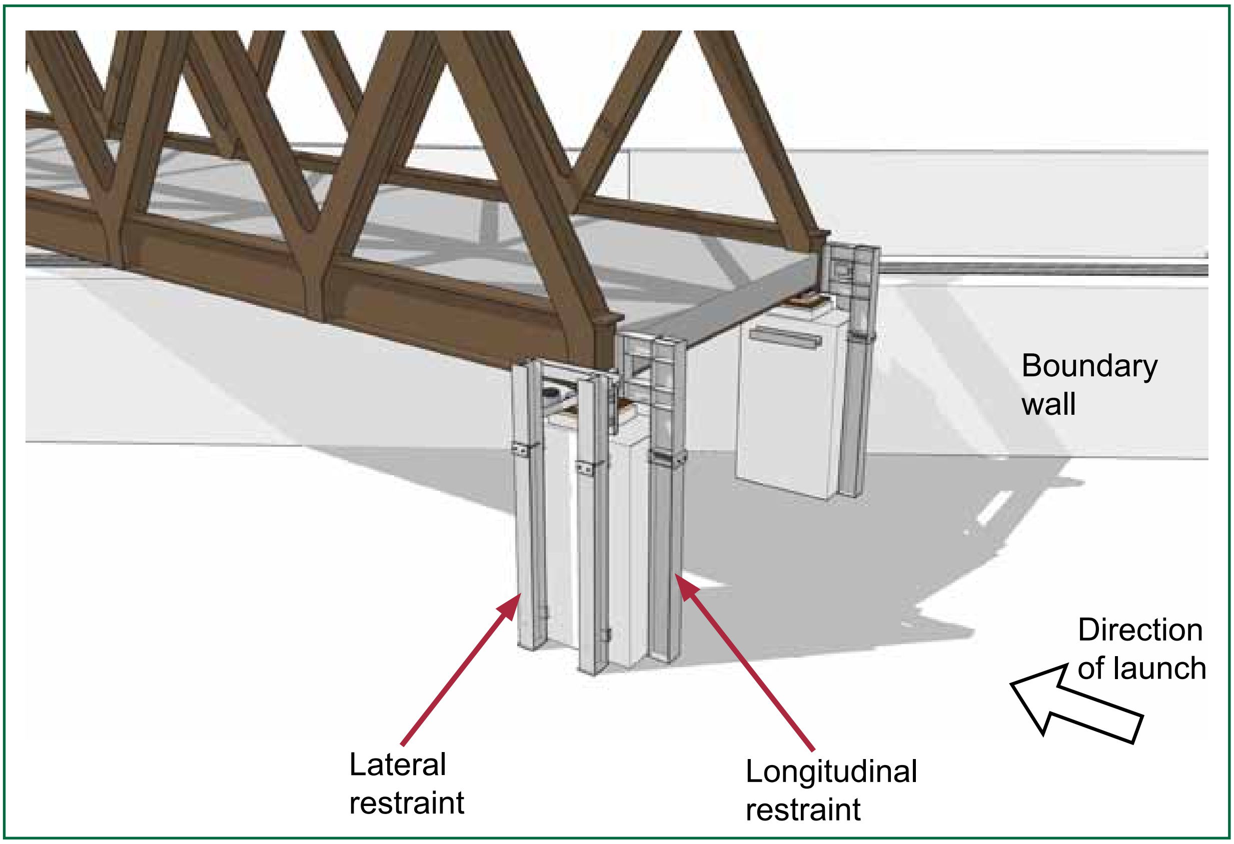


Figure 19: Schematic diagram showing temporary works at the east abutment following erection of the longitudinal restraints.

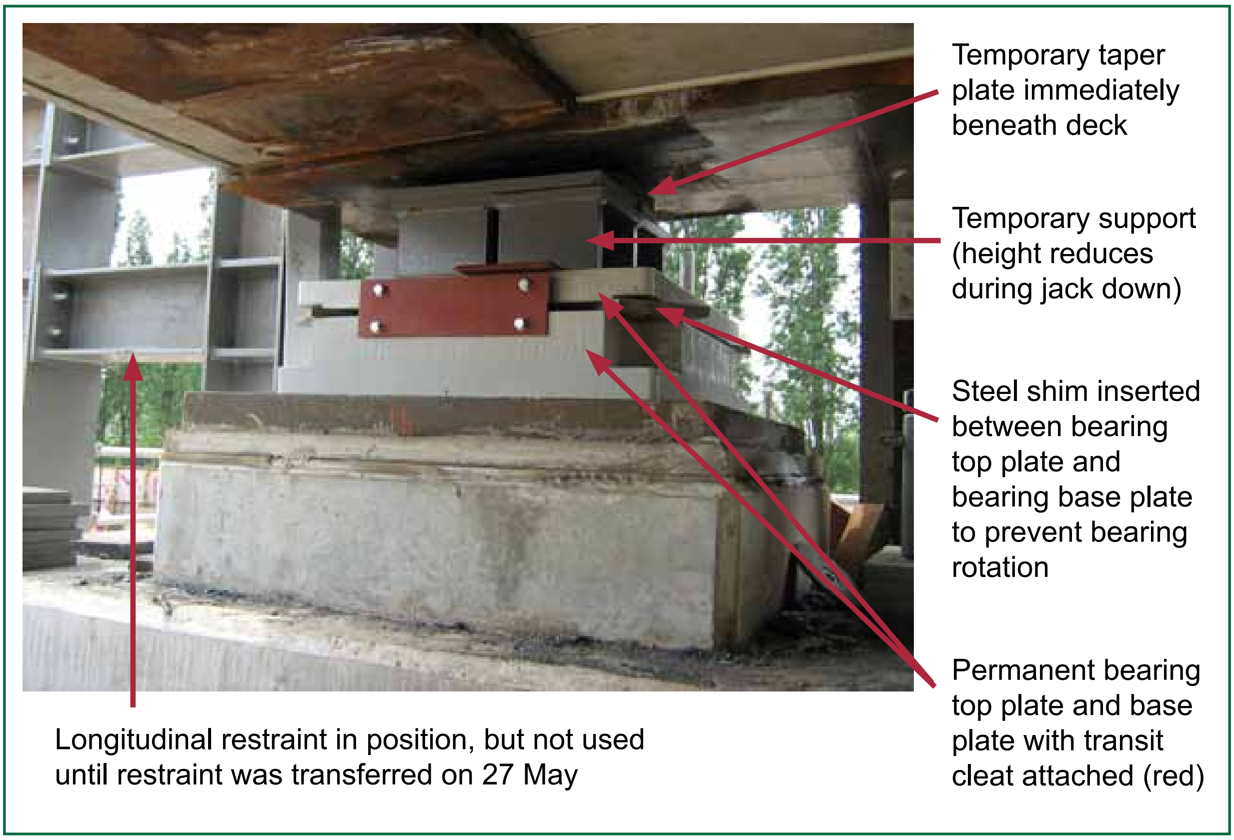


Figure 20: Photograph of south-east bearing during jack down (photo TfL).

180 Jack down at the west end of the deck was dependent on the release of the parking restraints. The transfer of restraint to the east abutment was achieved on Tuesday 27 May by placing temporary packing plates between the longitudinal restraints and the east end of the deck. Jack down of the west end of the deck then commenced, with the intention of completing this activity by Thursday 29 May when welders were due to weld keep-plates around the bottom bearing plate on top of the abutment plate, fixing the bearings into their final position.

181 On Wednesday 28 May, an experienced steelwork erector became available from another Fairfield Mabey site and he was used to augment the site team. Although he had not worked on bridge GE19 previously, he was assigned to supervise the work at the east abutment and lead a team of three, relying on the site briefing to inform him of the proposed activities for that day, which included the repositioning. He had undertaken a similar activity on a different structure two weeks earlier. During the day, the east end of the deck was lowered until it was 120 mm above its final position. The west end of the deck was lowered into its final position, and the temporary taper plates at this end replaced with larger permanent versions bolted to the bearings.

Repositioning of the deck

182 Prior to the arrival of the welders on 29 May, the Fairfield Mabey site team needed to address the downhill movement of the deck (paragraph 175). As the deck was to be fixed at the north-west bearing, the site manager took measurements at this location to determine the degree of repositioning required. These measurements, taken on 28 May, indicated that the deck needed to be moved 38 mm longitudinally (ie to the west) and 15 mm laterally. The alternative of seeking a concession to leave the deck in its displaced position was not considered.

183 The Fairfield Mabey senior site manager and site manager had discussed the matter previously as the senior site manager was not due to be on site that day. As the repositioning activity was perceived to be routine, no written documentation was produced to describe the activity.

184 The daily briefing sheet used by the site supervisor to brief the site team on 28 May was identical to that used on the previous day and related to the ongoing jack down operation. It made no reference to the planned repositioning.

185 The site manager gave an additional briefing to cover the repositioning activity, which involved raising the deck and placing PTFE-faced slipper pads, recovered from the launch operation, between the taper plate and underside of the bridge at each bearing location. This would allow the deck to be jacked horizontally into its correct position using small hydraulic jacks placed between the east end of the deck and the longitudinal restraints.

186 The slipper pads were installed beneath each corner of the deck in accordance with the site manager's instructions, above the temporary taper plates and on the same 3.3% gradient as the deck at all four corners of the bridge. The slipper pads had been in the same position during the launch, but on that occasion they were supported on rocker beams which were fixed in position, whereas on this occasion they were supported on the permanent bearings. The PTFE surfaces were lubricated with an industrial hand cleaner to reduce the jacking force required.

187 Horizontal jacking to reposition the deck commenced at approximately 16:00 hrs. During the jacking operation, the site manager and site supervisor were located at the north-west bearing where the measurements had been taken. He communicated with his staff, including those operating the jacks at the east abutment, by hand-held radio. There was no access across the deck during the jacking operation.

188 The transit cleats fitted to each bearing (Figure 20) had been retained to keep the bearings together until the deck was in its final position. An experienced site manager from a different site arrived on site during the repositioning operation, and observed that a transit cleat bolt attached to the south-east bearing had failed. He did not consider this event to be particularly unusual and believed that the site team were aware of it.

189 By 17:30 hrs on 28 May, the deck was restored to its correct position, and the site team disconnected the jacking equipment and placed steel packs between the deck and the longitudinal restraint to prevent further horizontal movement. The deck was left supported on PTFE-faced slipper pads at all four corners, and on 120 mm of temporary packing plates at the east abutment. The lateral restraints and longitudinal restraint remained in position in accordance with Fairfield Mabey's risk assessment (paragraph 139).

190 Vertical jacks used during jack down were left in a raised position at the west abutment, but they did not have mechanical locking collars screwed down to prevent movement, despite this being identified in the work plan (paragraph 171). The vertical jacks at the east abutment were left in a lowered position with a gap of approximately 350 mm between the top of the jack and the underside of the deck.

191 The site manager neither inspected the east abutment supports following the completion of the repositioning activity nor instructed the removal of the PTFE-faced slipper pads to secure the deck as he did not recognise the hazard of leaving them in place. After packing equipment away, all Fairfield Mabey staff and sub-contractors left site by 18:30 hrs, 46 minutes before the incident.

Analysis

Summary of the collapse mechanism

192 Between 5 May and 28 May, the newly installed deck had unexpectedly moved 38 mm downhill. This was probably due to a combination events including slippage of the parking restraints (paragraph 175), and thermal movement of the deck (paragraph 173). The deck was pushed back into its correct position by inserting a PTFE-faced slipper pad immediately below each corner of the deck and using small hydraulic jacks.

193 When the additional PTFE was introduced, no-one recognised the risk of instability created at the east end of the deck, because the permanent bearings were designed to allow longitudinal movement (paragraph 118) and this meant that there were now sliding surfaces at two levels within each temporary support. The PTFE-faced slipper pads had been installed on the same gradient as the deck and this caused a horizontal load to be imposed on the temporary supports which the transit cleats were not designed for. The transit cleats subsequently failed and the temporary supports were forced out, causing the eastern end of the deck to drop 200 mm (Figure 21).

194 The resulting shock wave displaced pre-cast concrete formwork planks laid on the deck, and five planks fell onto the track because they were not tied together. A more detailed explanation of these events is given below.

Identification of the immediate cause[1]

195 The immediate cause of the accident was train 1K12 colliding with concrete debris on the track which had fallen from bridge GE19.

Identification of causal[2] and contributory[3] factors

Adequacy of the steelwork method statement and work plan for jack down

196 Fairfield Mabey had issued a single method statement to cover all aspects of their work on site (paragraph 137). While the sections of the document dealing with the stages up to and including the launch were relatively comprehensive, the post-launch phase was covered in less detail. Section 4.8 of the document, dealing with the jack down phase, was made up of single sentence instructions which confirmed the sequence of working shown on drawing 211, but did not provide any additional guidance to assist the site team.

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

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

[3] 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.

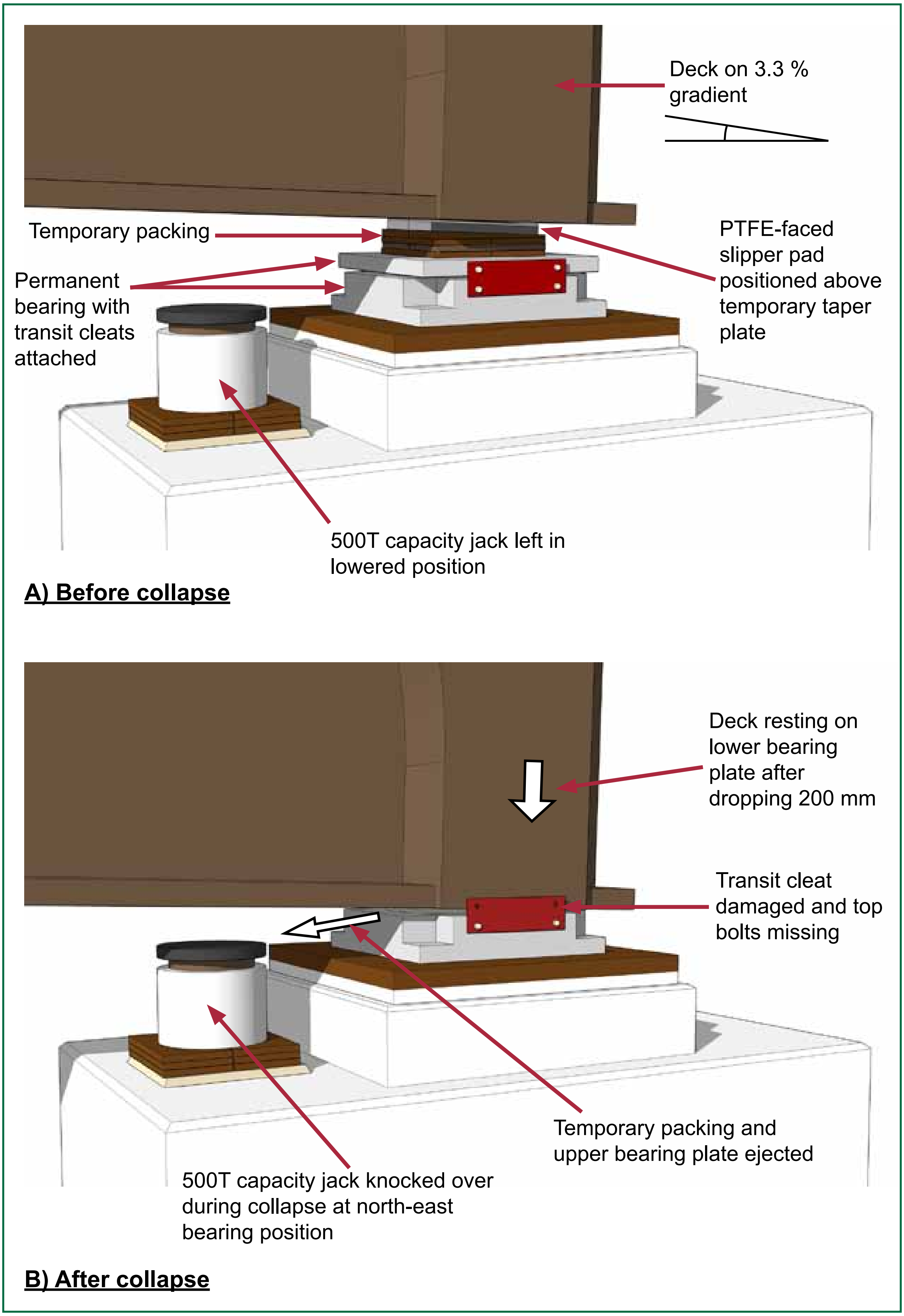


Figure 21: Schematic diagrams of south-east bearing and temporary support before and after collapse

197 Fairfield Maybey has stated that they adopted this approach to take the competency of their staff into account, and avoid producing voluminous documents that are of little use to the end user. However, although the operations involved in transferring fixity were listed in sequence, the method statement contained no reference to the control of thermal movement during this phase, or repositioning of the deck should it subsequently become necessary to do so.

198 The method statement was complemented by the work plan (paragraph 171), the purpose of which was to provide the task specific instructions and information on the activities covered by the method statement (paragraph 146). Although this document contained some additional information, the technical content relating to the jack down operation was copied directly from the method statement.

199 Both documents contained the instruction "lower structure at all 4 corners simultaneously"; an arrangement that was not described on drawings 211 and 212, and would have required additional staff and equipment, together with a higher degree of pre-planning. The work plan was issued for approval less than 10 days before jack down commenced, and there is therefore no reason why it should have still contained erroneous information when the intention was to jack the structure down incrementally, one end at a time.

200 Although this method of working was relatively conventional, it was not the one described in the approved documents. The site supervisor and steel erectors therefore relied on information contained on the temporary works drawings and their experience.

201 Fairfield Mabey's use of a single method statement resulted in a decreasing level of detail for the latter stages of the project, possibly because this was not available when the document was first written six months earlier. The work plan provided a missed opportunity to remedy this, despite the need for further information being highlighted during London Rail's review as a Category A comment (Table 1). The resulting lack of accurate or sufficient detail for the jack down phase required the site team to work outside of the approved method statement and was a contributory factor in the resulting incident.

202 Fairfield Mabey's risk assessment considered the overall stability of the deck during jack down, but did not cover other low frequency high consequence risks as unforeseen horizontal or vertical movement or jack failure. The hazard identification process not identifying some low probability high consequence hazards affecting the post-launch phase was also a contributory factor.

Movement of the bridge deck prior to 28 May

Temporary works inspections

203 BB-CJV appointed Fairfield Mabey's senior site manager as a temporary works supervisor with delegated responsibility for inspecting all temporary works associated with the erection of bridge GE19 on a weekly basis (paragraph 167).

204 The delegation of this responsibility meant that BB-CJV did not maintain an awareness of how the temporary works were performing. The lack of a report from Fairfield Mabey concerning the movement meant that BB-CJV remained ignorant of the problem and of ensuing events. This was a contributory factor in the failure of the temporary supports.

Slippage of the parking restraints

205 The lateral restraints, to which the parking restraints were connected, were erected with shot-blasted steel shims in place of the specified grout layer at the interface between the lateral restraint steelwork and concrete columns (paragraph 166). Although this change was made for practical reasons and had been the subject of correspondence with the temporary-works designer (paragraph 129), this arrangement was not in accordance with the approved temporary-works design.

206 Expert advice received by the RAIB is that substituting the grout layer with shot-blasted steel shims will have significantly reduced the coefficient of friction at this interface. The effect of the shot-blasting, coupled with the oily residue present on the concrete surface will have reduced the frictional resistance, and the potential bonding of the grout would be lost.

207 Fairfield Mabey first became aware of deck movement on 16 May when the senior site manager observed slippage and rust staining at the connection between the lateral restraints, to which the parking restraints were attached, and the concrete columns at the west abutment (paragraph 175 and Figure 18). As the parking restraints on each side of the bridge were physically independent of each other, both needed to move to allow the deck to move.

208 The parking restraints were required to resist an estimated horizontal (down-hill) force of 430 kN (equivalent to 44 tonnes) due to the weight of the deck on the gradient (paragraph 128b). The combined clamping force of the eight tensioned bars connecting the lateral restraints to the concrete columns resisted this, having a design value of 924 kN/bar x 8 bars = 7392 kN (equivalent to 754 tonnes).

209 British Standard BS 5975:1996, which is listed on the temporary works check certificate as a standard used in the design, contains no values for grouted surfaces, but BS EN 12812:2004 'Falsework, performance requirements and general design' gives a coefficient of friction of 0.5 for this combination of materials. If steel is substituted for grout, the coefficient of friction is 0.3 according to BS EN 12812:2004, but only 0.1 according to BS 5975:1996.

210 BS EN 12812:2004 is a CEN Standard, developed by the European Committee for Standardisation. It is a *limit state design* standard, and requires a *load factor* to be applied to loads and materials. Using BS EN 12812, the ultimate disturbing force is 580.5 kN, whilst the design value of the resistance against sliding is 1535.3 kN. The standard does not require a *Factor of Safety*, so the requirement of Cl.9.2.2.4 that the value of resistance is greater than the ultimate disturbing force is satisfied.

211 BS 5975:1996 is a *permissible stress design* standard, and gives the coefficient of friction between steel and concrete of 0.1, but as a lower bound value for general guidance. This standard recommends that a factor of safety of not less than 2.0 is to be applied in cases where lateral restraint is to be provided by friction to ensure that any variations in conditions can be tolerated by the design without failure, and requires the designer to exercise judgment in individual cases. Using BS 5975 Cl. 6.4.4.6 the force causing sliding is 430kN. The force resisting sliding is 739.2kN. As the resistance is greater than the force causing sliding, the body should not slide. However, the Factor of Safety against sliding is 739.2 / 430, i.e. 1.719. This is lower than the recommended value of 2.0.

212 The precise failure mechanism is unknown, but it is evident that either the disturbing force was greater than anticipated, or the ability of the parking restraints to resist movement was lower than anticipated. In the absence of any evidence that the lateral restraints, to which the parking restraints were attached, were otherwise incorrectly installed or maintained (paragraph 166), the most probable explanation is that the actual coefficient of friction at the steel to concrete interface was insufficient to prevent movement, due to the substitution of the grout layer specified in the design for shot-blasted sheet shims, and compounded by the smoothness of the concrete surface and presence of an oily residue.

213 The amount of movement possible following slippage of the parking restraint was limited by the diameter of the ducts cast into the concrete columns (paragraph 175), and therefore catastrophic failure as a result of this movement was always unlikely. However, the slippage of the parking restraints was responsible for a proportion of the deck movement, leading to the later decision to correct its position by horizontal jacking and subsequent failure of the temporary supports. The slippage of the parking restraints was therefore a contributory factor.

Transfer of restraint

214 The 38 mm movement recorded at the west abutment on 28 May cannot be explained by slippage of the parking restraints alone. The tensioned bars would have come into contact with the side of the ducts, cast into the concrete column, after approximately 16 mm of movement occurred. For the parking restraints to move further, the tensioned bars themselves would have had to fail, and this did not happen.

215 The most probable explanation for the remaining movement is due to the inadequate control of the effects of thermal movement during the transfer of restraint from the parking restraint at the west abutment to the longitudinal restraint at the east abutment (paragraph 180). An 84 metre long steel structure will expand by approximately 1 mm for each 1 degree rise in the temperature of the steelwork, and being painted dark brown, would have absorbed more heat and been particularly susceptible to the effects of sunlight.

216 The clear weather on 13 May resulted in the steelwork temperature rising to 39ºC despite the air temperature not exceeding 21ºC. This is the only time the steelwork temperature was recorded, and this would have caused the deck's length to increase by approximately 26 mm, based on the difference between the 39ºC recorded temperature and the 13ºC design temperature (paragraph 178).

217 The transfer of restraint from west abutment to east abutment and then back again could have been achieved without affecting the position of the structure if both transfers had occurred when the steelwork was at the same temperature. However, if the steelwork temperature was higher during the first transfer, any subsequent cooling would lead to the deck contracting and the bearings at the west abutment moving out of alignment. Conversely, the effect would reduce as the steelwork temperature increased.

218 Although it is difficult to predict steelwork temperatures, weather records for 27 May when the first transfer occurred show that the maximum air temperature was 18ºC with clear periods (ie sunshine), whereas on 28 May when the 38 mm dimension was measured, the maximum air temperature was 17ºC and overcast. The steelwork will have reached a higher temperature on 27 May and it is probable that the overall movement can be attributed to a combination of parking restraint slippage and a relatively high steelwork temperature when restraint was transferred to the east abutment, which had reduced by the time the 38 mm dimension was measured.

219 A lack of guidance in the method statement on how to manage the effects of thermal expansion resulted in further deck movement occurring, probably during the transfer of horizontal restraint. This was a contributory factor.

Deck repositioning

Planning of the repositioning activity

220 The repositioning was planned without reference to the temporary-works designer or checker. This made it less likely that the site manager would be aware of all the hazards associated with this activity, particularly as these were compounded by the absence of fixed taper plates (paragraph 170) due to it being a launched structure. The temporary supports were not designed to accommodate horizontal movement (paragraph 130), and the act of introducing a PTFE layer will have made the existing Category III check certificate invalid.

221 The absence of any written documentation for the repositioning activity meant that the supervisor put in charge of the east end of the structure, who had no previous experience of working on this bridge, was dependent on the verbal briefing given by the site manager (paragraph 181) and the collective experience of the site team. Although each had previous experience of launching bridges, the need to horizontally reposition a launched bridge on a gradient was an unusual event in their experience and this was a contibutory factor (paragraph 130).

222 The planning and co-ordination of the horizontal repositioning activity was deficient and did not identify or mitigate risks associated with this activity, some of which were foreseeable. This overlooked the need to ensure the continued stability of the temporary supports at the east abutment, was a causal factor in the subsequent collapse.

Installation of an additional PTFE surface within the east abutment temporary supports

223 During the afternoon of 28 May, Fairfield Mabey staff, working to the site manager's verbal instructions, jacked up the bridge deck and placed lubricated PTFE-faced slipper pads above the taper plates at all four corners of the bridge (paragraph 186). At the west abutment, the permanent taper plates had already been attached to the bearings, meaning that the slipper pads had to go in this position, but at the east abutment, they could have been placed either above or below the temporary taper plates.

224 Both the east abutment bearings were designed to permit longitudinal movement once the transit cleats were released (paragraph 118). The introduction of additional sliding surfaces above the temporary taper plates therefore had the potential to destabilise the temporary supports if the transit cleats failed, but the need to ensure that this did not happen was not recognised and their capacity was not assessed.

225 Alternatively, the bearings' ability to permit longitudinal movement could have been utilised to avoid the need for slipper pads at the east abutment. Removing the transit cleat bolts would have allowed movement to take place between each bearing's top and base plate. The bearings had a total travel in excess of 38 mm, and although they would have subsequently required resetting, use of this facility would have maintained the stability of the temporary supports.

226 The unauthorised modification of the temporary supports by introducing an additional sliding surface was therefore unnecessary, and made the stability of the temporary supports dependent on the capacity of the transit cleat bolts to resist movement. This action was intrinsically unsafe, and a causal factor in the subsequent failure of the supports.

Failure of the transit cleat bolts

227 The transit cleats were installed by the bearing manufacturer, and were intended to keep the top plate and base plate together during transportation and installation. They were not designed to resist horizontal movement after installation. This was to prevent damage to the permanent structure if they were inadvertently left in place.

228 On 20 May, the rocker boxes at the east abutment were replaced with permanent bearings and temporary supports (paragraph 176). Although the longitudinal restraints were installed on the following day, horizontal restraint continued to be provided by the parking restraints at the west abutment until 27 May (paragraph 180). The site manager's diary records that temporary bearings were installed at the east abutment, but this actually refers to the permanent bearings and temporary packing plates rather than the provision of a sliding surface to accommodate thermal movement. In the absence of such a sliding surface, the permanent bearings were required to accommodate all thermal movement during this period, despite still having transit cleats attached. The steelwork temperatures during this period are unknown, but the resulting thermal movement will have exposed the transit cleats to very large horizontal forces relative to their load carrying capacity.

229 The bolts connecting the transit cleats to the bearing top plates incorporated a 25 mm gap packed with washers (paragraph 118). The RAIB have calculated that the strength of this connection was limited by the bolt's ability to resist bending stresses due to the connection being packed with washers, and that failure would have occurred once the horizontal force exceeded 12 kN (equivalent to 1.2 tonnes) at each bearing, or the relative movement between the upper and lower bearing plates exceeded 3 mm. Furthermore, due to the small movements involved, any failure would have been difficult to identify.

230 Fairfield Mabey's method statement, work plan and drawing 211 each list a sequence of work in which the installation of the longitudinal restraints at the east abutment precede the installation of the permanent bearings. In the absence of any reference to the transfer of restraint, it could be assumed that this should occur before the installation of the permanent bearings, as the temporary supports have no provision to accommodate movement without removing the transit cleats. Therefore, by installing the permanent bearings seven days before transferring restraint, the construction work could be deemed to have contravened the accepted design.

231 The site team varied the sequence to create additional working space for the installation of the permanent bearings. However, had the transfer of restraint occurred immediately after the permanent bearings were installed, the transit cleats fitted to the east abutment bearings would not have been required to accommodate thermal movement. In practice, the transit cleat bolts were subjected to unknown horizontal loading between 20 May and 27 May. This reduced their capacity to resist movement on 28 May and was a contributory factor in their subsequent failure.

232 When the deck was repositioned by being jacked horizontally on 28 May, it is not known whether the movement occurred entirely at the upper sliding surface between the slipper pad and deck as intended, or partly at the lower sliding surface within the permanent bearing following failure of the transit cleat connections. In either case, the horizontal jacking will have imposed a load on the transit cleat bolts, and at least one connection was observed to have failed by the time the horizontal jacking was complete (paragraph 188). The lack of damage to the thin transit bracket plates also demonstrates how little force was required for this connection to fail (Figure 23).

Post-work checks

233 The planning of the repositioning activity made no special provision for post-work checks to ensure the bridge was secure prior to the end of the shift. Specifically, the PTFE-faced slipper pads were left unsecured on a gradient in all four corners of the deck, and the vertical jacks at the east abutment were left in a lowered position.

234 The need to remove the PTFE-faced slipper pads at the east abutment, secure the packing horizontally, or to provide a secondary means of support in the event of the primary support failing, was not recognised (paragraph 191).

235 The lack of a post-work check at the east abutment, by either the site manager or site supervisor which might have identified that the temporary supports were unstable was a contributory factor. This situation was compounded by the lack of a secondary means of support which could have been provided by raised, locked jacks at the east abutment.

Identification of the failure mechanism

Examination of the scene following the failure

236 Analysis of the collapse mechanism suggests that the north-east support failed first. This distorted the deck, causing a momentary increase of the load on the south-eastern support which failed almost immediately afterwards.

237 This hypothesis is supported by the location of the components from the north-east support, which were found in front of the abutment and in line with the bridge deck, with the trajectory of the ejected components being controlled by the bearing's directional guide, provided to resist lateral movement. Components from the south-east support were distributed over a wider arc.

238 The ejected temporary taper plates, steel packing plates and bearing top plates were found up to nine metres from the abutment, suggesting that they were ejected at speeds estimated at 9 metres per second (20 mph). It also confirms that the railway boundary wall played an important function in preventing the vertical jack from the north-east bearing landing on or close to the track (paragraph 93). This object weighed 325 kg and would have created a substantial obstacle if hit by a train.

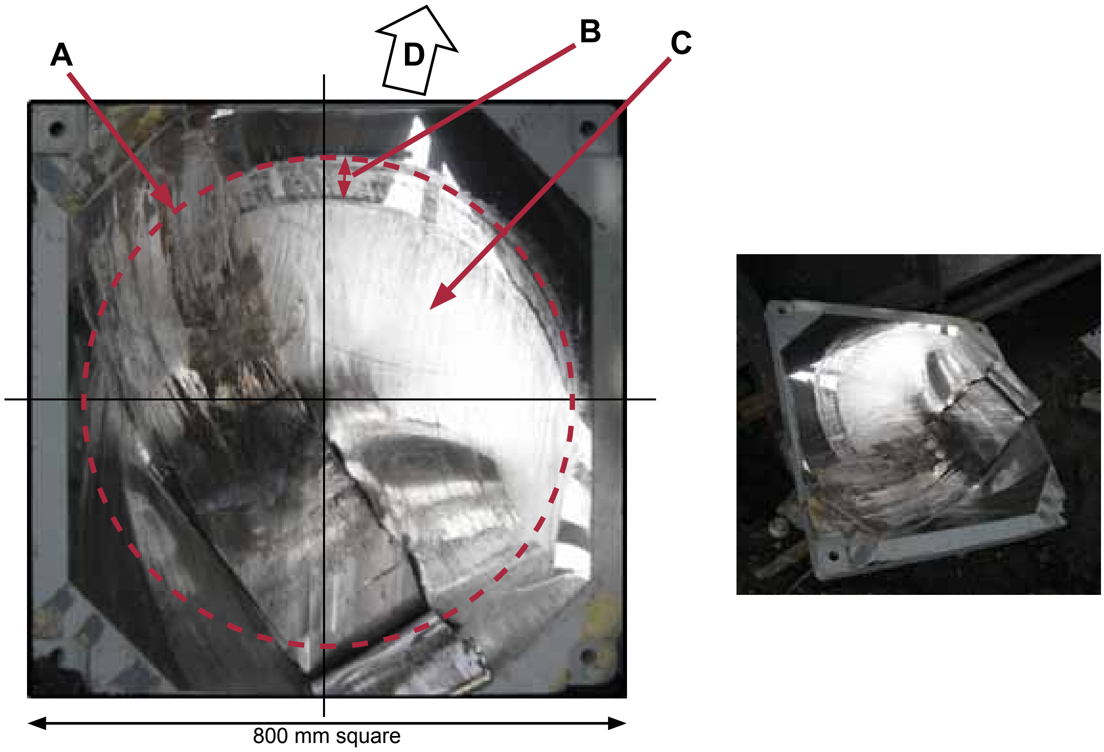
239 Figure 22 shows the south-east bearing four hours after the collapse, and this can be compared with the photograph shown in Figure 20. The transit cleat (painted red) remains connected to the base plate of the bearing by a single bolt.

Figure 22: South-east bearing following collapse showing a failed transit cleat.

240 Figure 23 shows the opposite transit cleat, still attached to the base plate of the bearing after the collapse. The cleat shows evidence of distortion caused by bolt rotation, indicating that the bolts failed rather than the cleat itself.

Figure 23: Failed transit cleat on south-east bearing (photograph BB-CJV)

241 Figure 24 shows the stainless steel underside of the south-eastern bearing top plate following ejection, with one corner partly embedded in the ground. The imprint of the PTFE disc attached to the bearing base plate can be seen in the grease markings in its centralised position (ie prior to the failure of the transit cleat connections). Significantly, all subsequent movement has occurred in the same direction suggesting that the bearings were installed while the deck steelwork was thermally extended (paragraph 218).



A = Imprint of 650 mm diameter PTFE disc in centralised position (dashed line)
B = Marks indicating zone of backwards and forwards movement (up to 53 mm)
C = Marks indicating zone of one-directional movement
D = Direction of ejection

Figure 24: re-orientated photograph of the underside of the south-east bearing top plate, showing major dimensions and (inset) as-found.

242 The movement occurred in two phases, and a clear boundary is evident between a zone of backwards and forwards movement ‘B’, evidenced by multiple disc imprints and probably due to thermal movement, and a zone of one-directional movement during the ejection, ‘C’. Part of the stainless steel plate is torn giving a further indication of the high forces involved.

Stability of the temporary supports at the east abutment

243 The east end of the deck weighed an estimated 794 tonnes at the time of collapse. This figure does not include the additional weight of steel reinforcement which was stacked on the eastern end of the deck in preparation for the completion of the western section after jack down, and which had provided part of the counterweight during launch (paragraph 123).

244 The effect of placing the slipper pads above the temporary taper plates was that they were positioned on the same 3.3% gradient (1.9º angle) as the deck, and hence at an angle to the permanent bearings set horizontally. This increased the force needed to move the deck, as the repositioning operation was required to push the deck uphill, rather than just horizontally.

245 It also had the effect of converting a proportion of the 397 tonne vertical load acting on each east abutment bearing into a horizontal force, acting to destabilise the temporary support. The ability of the temporary support to resist this horizontal force and remain stable depended on the combined friction restraint from both top and bottom PTFE surfaces, and the mechanical resistance provided by the transit cleat bolts. The forces on one east end bearing are shown in Figure 25.

Behaviour of PTFE

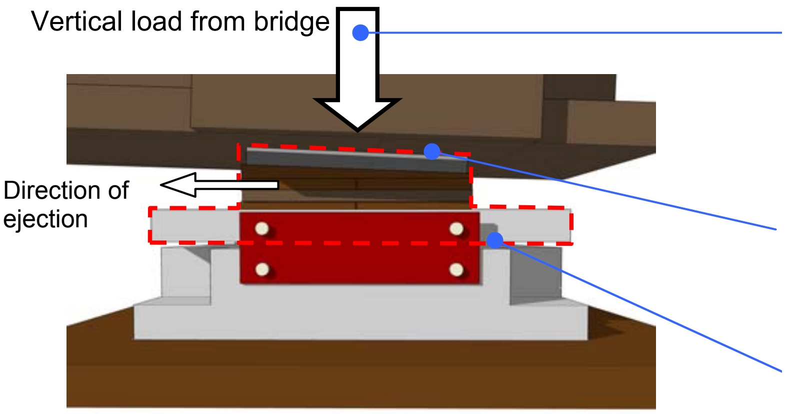
246 The behaviour of PTFE is complex. Unlike many other materials, the coefficient of friction (μ) reduces as the load increases (ie the heavier the object being supported, the lower the coefficient of friction and the easier it is to move).

247 During 2007, Fairfield Mabey undertook a series of tests to improve their understanding of the behaviour of PTFE during horizontal jacking. Tests of lubricated PTFE on paint suggested that the *static* and *dynamic coefficients of friction* could be as low as 0.02 and 0.01 respectively for the high loads present before the incident.

248 The tests also demonstrated that the friction between lubricated PTFE and painted steelwork gradually reduced under a sustained horizontal load (ie the coefficient of friction would change from a static to a dynamic state possibly due to the shear load on the lubricant). In practice, this means that a heavy object, supported on lubricated PTFE, can be moved by applying a horizontal force up to 50% lower than would normally be necessary, if the force is sustained for a 30-60 minute period.

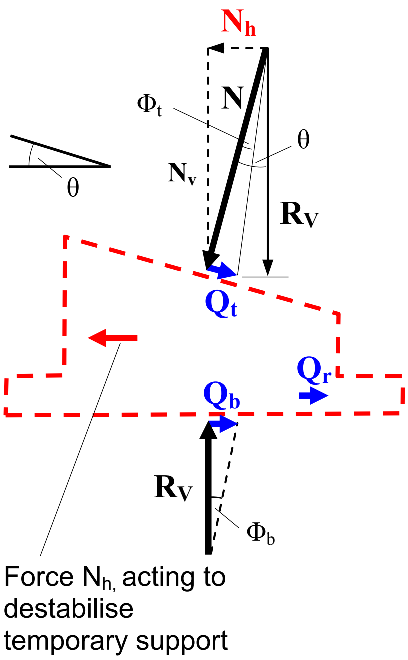
Failure of the temporary supports

249 Following the completion of work on 28 May, the deck remained supported on slipper pads at each corner (paragraph 189). The orientation of the slipper pads resulted in an out-of-balance force being exerted on to the temporary supports; the weight of the deck exerting a sustained horizontal force on the wedge. At the east abutment where there were two potential sliding surfaces, movement was resisted only by friction at the PTFE surfaces and any residual capacity in the transit cleat connections.



a) Schematic diagram showing ejected components within red dashed outline (see forces diagram below).

The load from the bridge deck acting on the top sliding surface (N) can be separated into vertical and horizontal components, N_V and N_h, where N_h is the horizontal component acting to destabilise the temporary support.



b) Simplified forces diagram with slope gradient exaggerated.

R_v	Primary vertical reaction from vertical load of bridge = 3900 kN
θ	Gradient of top of temporary support (3.3% is equivalent to an angle of 1.9º)
N	Load from bridge acting perpendicular to top sliding surface (R_v/Cos θ) = 3902 kN
N_h	Horizontal component of N, acting to destabilise temporary support (R_v Tan θ) = 130 kN
N_v	Vertical component of N
Q_t	Friction restraint from top sliding surface = 0.017 R_v = 66 kN (reducing to 33 kN)
Φ_t	Angle related to coefficient of friction of top sliding surface, where Tan Φ_t = coefficient of friction (μ_t)
Q_b	Friction restraint from bottom sliding surface = 0.026 R_v = 101 kN (reducing to 51 kN)
Φ_b	Angle related to coefficient of friction of bottom sliding surface, where Tan Φ_b = coefficient of friction (μ_b).
Q_r	Mechanical restraint provided by up to four top plate transit cleat bolts = 0 to 48 kN

<u>Summary of forces:</u> (for range of possible values, refer to Table 2)

Prior to failure: $N_h < Q_t + Q_b + Q_r$
At point of failure: $N_h = Q_t + Q_b + Q_r$

Figure 25: Diagrams showing distribution of forces on temporary support at an east abutment bearing

250 The coefficient of friction between the slipper pad and the underside of the deck was likely to have been lower than that between the bearing top and bearing base plates because of its smaller contact area (paragraph 246). From literature published by Du Pont, a PTFE manufacturer, the static coefficient of friction can be estimated at 0.017 for the top sliding surface which accords closely with Fairfield Mabey's findings (paragraph 247), and 0.026 for the bottom sliding surface within the permanent bearing. These values are likely to reduce by up to 50% over a period of hours (ie medium term) due to the combined effect of lubrication and a sustained horizontal force (paragraph 248).

251 The particular characteristic of lubricated PTFE, whereby it can start to move under a relatively low, but sustained horizontal force, may offer an explanation for the final failure mechanism. The delay between the end of the working day at 17:30 hrs and the collapse at 19:17 hrs can possibly be explained by the time required for the coefficient of friction to reduce sufficiently on both sliding surfaces to allow movement to commence. In addition, the elastomeric-rubber slipper pads will have deformed slightly under the horizontal jacking force into a shape similar to a parallelogram. In so doing they will have absorbed strain energy (like a spring or rubber band) which could be released unexpectedly at a later stage. This may have contributed to the horizontal force imposed. Once the wedge started to move, the characteristics of the PTFE will have changed from static to dynamic (paragraph 247) increasing the tendency to slide and gradually reducing the area supporting the load. This in turn will have reduced the coefficient of friction further until failure became inevitable as the wedge was squeezed out (Table 2). It is therefore most probable that failure was initiated as a result of creep (ie a slow steady movement), rather than a sudden break-out.

Summary of forces on temporary support at an east abutment bearing (from Figure 25)	**Short term**	**Medium term**
Friction restraint from top sliding surface (Q_t)	66 kN	33 kN
Friction restraint from bottom sliding surface (Q_b)	101 kN	51 kN
Mechanical restraint from transit cleats (Q_r) assuming that two top plate bolts have failed (paragraph 183)	24 kN	24 kN
Available resistance = (Q_t + Q_b + Q_r)	191 kN	108 kN
Disturbing force (N_h)	130 kN	130 kN
Effect on temporary support	Stable (as resistance > disturbing force)	Unstable (as resistance < disturbing force)

Table 2: Range of forces acting on the temporary support at an east abutment bearing

252 The failure of the temporary supports occurred as a result of a combination of events. The presence of an additional sliding surface above the temporary taper plates, and earlier weakening of the transit cleat bolts was compounded by the sustained horizontal load which was imposed on the lubricated PTFE surfaces by virtue of the angle of the upper sliding surface. The placing of PTFE-faced slipper pads on a gradient, without considering and mitigating the resulting horizontal force, was a causal factor.

253 There is currently a lack of published guidance relating to the safe use of PTFE in construction for the purpose of moving heavy loads.

254 A similar failure could not have occurred at the west abutment, despite the slipper pads being placed in a similar location, as the bearings were designed to resist longitudinal movement regardless of the condition of the transit cleat bolts.

Stability of the partly-completed deck

Adequacy of the deck concreting method statement

255 London Rail reviewed BB-CJV's method statement for the construction of the concrete deck prior to the launch (paragraph 160). Its scope was limited to construction activities while the deck was positioned away from the railway, and for this reason, the document was not submitted to Network Rail for acceptance.

256 London Rail were therefore the only party to review the method statements for both the steelwork erection and deck concreting other than BB-CJV. Although BB-CJV had the primary role in reviewing the method statements, London Rail did not identify that both documents overlooked the need to ensure the stability of the pre-cast concrete planks during the jack down phase above the open railway. This may have been due to the steelwork and concreting method statements being reviewed at different times.

257 The associated risk assessment did not identify the risk of permanent formwork planks dropping or reflect BB-CJV's decision not to install positive ties between planks (paragraph 158) as the deck reinforcement for the eastern section had been fixed prior to placing concrete. This would again be the case when concreting the remaining deck over the railway. During the jack down phase, the risk of planks moving was not considered or included in the risk assessment. The positive ties could have taken the form of steel bars or cables looped through the reinforcement protruding from the top of each permanent formwork plank, and could, if necessary, have been installed immediately following the launch to avoid problems with balancing the deck.

258 Fairfield Mabey were not provided with a copy of BB-CJV's deck concreting method statement or risk assessment, and while their own risk assessment considered the stability of the truss (paragraph 139), it had not specifically identified or considered other high consequence low frequency risks. Such a consideration should have included the risks associated with lowering or manoeuvring a partly-completed deck, loaded with unsecured components, into position above an operational railway including collapse of a temporary support.

259 The failure to identify the hazard imposed onto the operational railway by the unsecured permanent formwork during the jack down phase resulted in neither party undertaking an assessment of the risk or its consequences. This was a contributory factor.

Effect of the temporary support failure on the partially-completed deck

260 When the temporary supports failed, the deck was subjected to a shock wave which fractured the grout and grout-impregnated hessian securing the individual planks in many locations. Benaim have calculated that the deck may have deflected by as much as 120 mm during the collapse, causing more than 50% of the planks to move. Some planks moved laterally by more than 100 mm.

261 Many of the planks in bays 16 to 24 came to rest abutting the shear studs to their east (ie on the downhill side), this shock-induced longitudinal movement causing corner damage to planks where they came into contact with shear studs. The planks which fell from the deck from bay 18 had moved sufficiently to the south such that the gaps between individual planks aligned with the shear studs, and to the east to lose support at their opposite ends (Figures 10 and 26).

262 BB-CJV's decision not to install positive ties between individual permanent formwork planks made it possible for individual planks, once loose, to fall onto the track. The lack of a positive tie was a causal factor in the subsequent accident.

Deck layout

263 The layout of the permanent formwork planks was modified by the BB-CJV site team to avoid having a gap of approximately 100 mm between the edge of the planks and the steelwork at the sides of the deck. The modification was not referred to the designer or referred to in the deck concreting method statement.

264 The modified layout required planks to be placed in groups, with a series of 40 mm gaps distributed across the deck. These gaps were to be spanned with uPVC strips, designed for this purpose. The original design aligned the centre of each plank with a shear stud, but the modification caused some planks to be off-set against the shear studs. While the purpose of the shear studs was to ensure that there was a good connection between the deck concrete and the cross-girders, they provided a useful secondary function by limiting the longitudinal movement of the permanent formwork planks (Figure 26).

265 The offsetting of the planks, particularly planks 2-9 where the effect was most pronounced, meant that the shear studs were aligned with the unreinforced section of each plank in this area (paragraph 121). This increased the vulnerability of these planks to impact damage and risk of displacement once damaged. It also reduced the effectiveness of the shear studs in preventing loose planks from falling from the deck.

266 The risk of a permanent formwork plank becoming displaced was exacerbated by the introduction of gaps across the width of the deck, which reduced the lateral restraint available and allowed planks to move more easily. The modification of the deck layout was therefore a contributory factor in the deck being less able to withstand the imposed shock wave, resulting in the loss of five planks from the structure.

Identification of underlying factors[4]

Review of the steelwork method statement

267 BB-CJV, London Rail and Network Rail each reviewed the steelwork method statement, which incorporated all of Fairfield Mabey's intended site activity. The document focused on the assembly and launch, and gave relatively little detail on the post-launch activities despite this being the only time that work was to be undertaken with the structure spanning the operational railway.

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

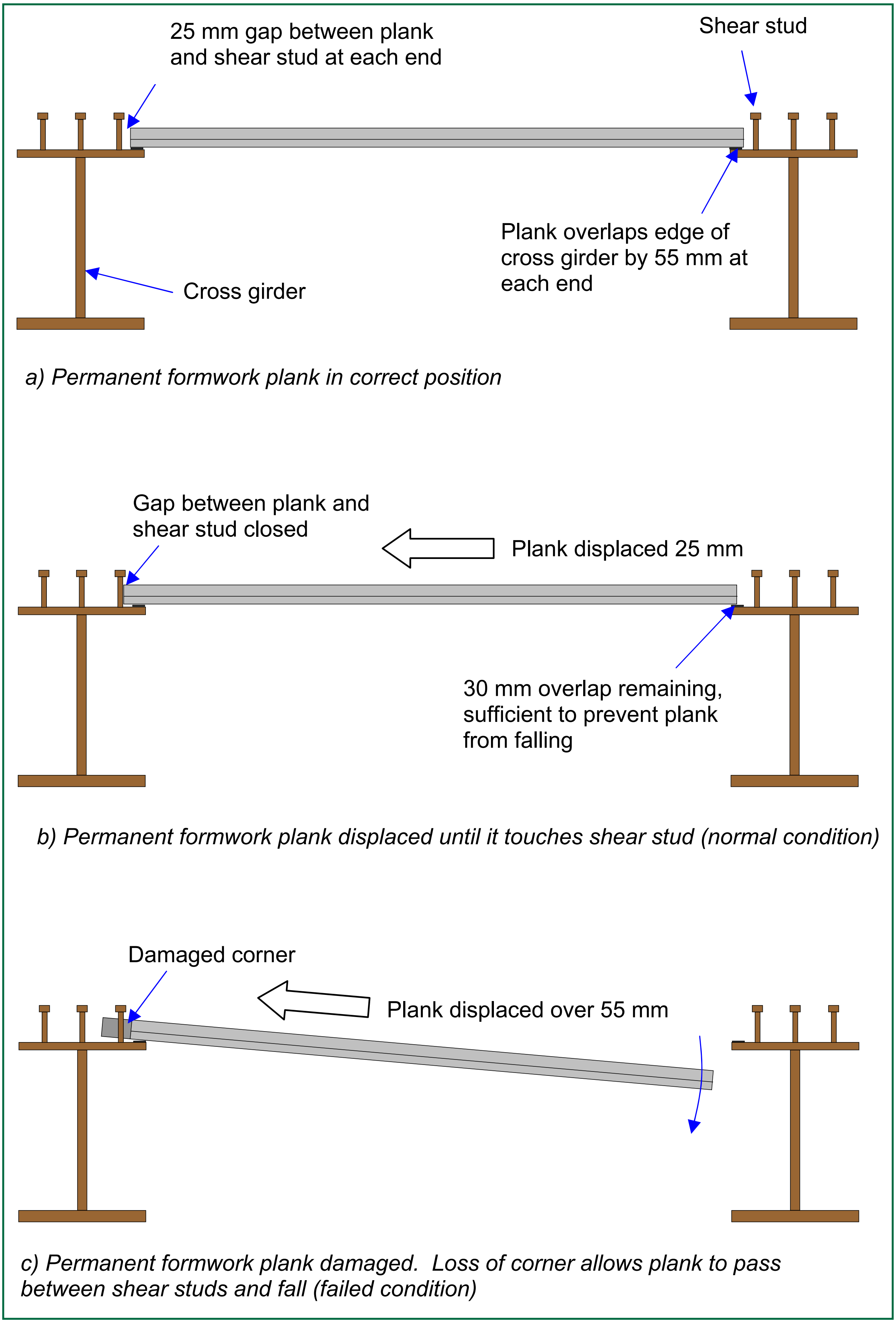


Figure 26: Schematic diagram showing effect of shear stud in restraining movement of a permanent formwork plank.

268 Bridges are routinely jacked up to allow their bearings to be maintained or replaced, and this may have led to a relatively relaxed view being taken by Network Rail. However, Bridge GE19 was significantly different to other schemes, by virtue of its relatively narrow abutment supports, the effects of the gradient and the fact that a substantial section of the deck was to remain in a partially-completed state while the bridge was manoeuvred into its final position.

269 London Rail queried several aspects pertinent to the jack down phase during their review of the method statement, and this included clarification of the intended method of working (Table 1). Fairfield Mabey subsequently revised the method statement to address some of the issues raised, but others were dealt with during the joint meeting on 14 January. This may have satisfied London Rail's requirements, but the inclusion of the comment "discussed at meeting on 14/01" on the question and answer sheet included with the revised document was not helpful to anyone who did not attend the meeting in the absence of any other record of the discussion.

270 Neither BB-CJV, London Rail or Network Rail all omitted to comment on the absence of information on the transfer of restraint between abutments or on controlling the effects of thermal movement during their reviews of Fairfield Mabey's documentation.

271 Despite London Rail's requests for a drawing showing the staging at each abutment to address omissions in the information, and clarification on how four corners were to be simultaneously lowered (Table 1), the updated method statement contained no further information in this respect. However, London Rail accepted the revised document without further comment.

272 London Rail's review of the initial method statement identified issues pertinent to the jack down operation which required further development. However, the process adopted by London Rail was not sufficiently rigorous to ensure that issues, once identified, were properly addressed. Although BB-CJV were responsible for approving Fairfield Mabey's method statement, the weakness in London Rail's review process allowed inaccurate and incomplete information to be used for construction, and was an underlying factor.

Control of risk imported onto Network Rail's infrastructure

273 Network Rail were satisfied that the risk posed by the construction of bridge GE19 was low, given that the launch was scheduled to take place during a possession and that the remaining activities were relatively routine.

274 Network Rail's project engineer attended weekly meetings with BB-CJV and Fairfield Mabey, and inspected the site after each meeting. However, he was not made aware of the unplanned deck movement when undertaking his inspections, or during meetings with Fairfield Mabey.

275 Neither BB-CJV nor London Rail's routine site inspections identified the deck movement, nor that the jack down method differed from the approved method statement. This meant that, despite the requirements imposed by NR/SP/CIV/003 (paragraph 115), they were unable to determine whether the construction methods adopted by Fairfield Mabey would adversely affect the structural integrity of the structure or the safety of adjacent infrastructure. Both parties assumed that Fairfield Mabey staff, as specialists, knew best.

276 The decision to delay the issue a 'Form E' certificate until the jack down was complete did not strictly comply with NR/SP/CIV/003, as the structure was supported by 'temporary works whose failure could affect the safety of the railway' (paragraph 148b) from immediately after the launch. However, the issue of a single certificate at that time would not have provided a means of certifying the stability of the temporary works on an ongoing basis, given the requirement to repeatedly modify these temporary works during the jack down operation. The existing Form E process was therefore unsuited to this purpose. In practice, work progressed in accordance with the accepted design until the working sequence was varied on 20 May (paragraph 231).

277 A lack of management control by Network Rail, London Rail or BB-CJV contributed to a collective lack of knowledge of the events which occurred during the post-launch phase. This meant that there was less focus on the bridge at a time when the risk to the railway had actually increased, and Fairfield Mabey were able to undertake a horizontal jacking activity for which they had not adequately prepared without being challenged. Although the accident occurred during a time when the site was non-operational, the collapse of the temporary supports occurred as a direct result of actions taken earlier in the day. The lack of adequate supervision and focus on the risks imposed on the operational railway during the post-launch phase was an underlying factor.

278 The difficulty in finding site supervision with the same level of expertise as any specialist contractor is also an underlying factor.

Severity of consequences

Repositioning of deck while on temporary supports

279 Repositioning the deck while it remained on temporary supports at the east abutment did not increase the likelihood that the support would fail. However, the decision to move the bridge before the jack down was complete increased the height of the fall by approximately 75 mm, and this made the resulting shock wave more severe. This, in turn, made it more likely that the permanent formwork would be displaced and increased the severity of the consequences.

Actions taken by the signaller

280 The signaller was informed of the accident by the driver of 1K12 at 19:17 hrs. He took action to stop all trains as soon as the severity of the event became clear, but this was too late to prevent two trains passing under the bridge on the suburban lines while he was still speaking to the driver. These trains were not affected.

281 The signaller did not have information available to indicate the position of the bridge or the signals to be controlled in order to stop other trains clear of the structure. His method of stopping trains inadvertently led to two other trains being brought to a halt beneath a potentially dangerous structure. Although this did not increase the number of passengers involved, a greater number of passengers were exposed to risk.

282 The signaller did not make any general calls to all drivers using the cab-secure radio system. This may have been due to the very high workload being experienced at this time and the fact that cab-secure radio cannot be used while a general call is being broadcast. However, this omission hampered information being provided to passengers on board the stranded trains.

Emergency Isolation

283 The signaller requested an emergency isolation at 19:30 hrs in response to a request from the London Fire Brigade to facilitate the detraining and evacuation of passengers. The signaller contacted the electrical control room directly without referring to Route Control due to the risk of imminent danger. This is permitted in emergency situations, and allowed the isolation to be obtained rapidly, but did not allow the impact on other train services to be considered. This increased the number of trains stopped between stations, including services on the North London line (paragraph 57).

284 However, due to the unknown condition of the structure at this time and the amount of water being discharged onto the live catenary, this is considered to have been an expedient course of action.

Network Rail's management of the accident scene

285 Network Rail responded to the accident by dispatching a MOM, together with operations and engineering staff. Some senior Network Rail managers also attended during the initial stages due to the high profile of the incident and its close proximity to central London.

286 On arrival, the MOM was appointed as the RIO. Network Rail standard NR/L2/OCS/250 states that a three-tier structure should be applied to the management of rail response to an incident, whatever the severity. The three tiers are defined as strategic (gold), tactical (silver) and operational (bronze), with the RIO performing the silver (tactical) role and a Rail Incident Commander (RIC), situated within Route Control, performing the gold (strategic) role. This arrangement mirrors that imposed by the emergency services who use the same three tiers.

287 The RIO was faced with an ongoing emergency involving large numbers of passengers on the track and a distressed bridge presenting unknown risks. Initially he had no resources, and had to deal with a site involving non-rail industry organisations and physically divided by high walls. This was therefore a particularly difficult site to manage.

288 Although initial communication between the different organisations represented on site was adequate during the rescue phase, this changed following the departure of the emergency services. During the recovery phase, Network Rail's staff were focused operational issues and did not assume effective control of the non-railway areas of the site as they assumed that this was the responsibility of others. The absence of a command structure with an identified person in charge meant that the railway operations and bridge repair activities were allowed to progress separately.

289 The involvement of non-rail industry organisations in the site recovery phase meant that the normal requirements of NR/L2/OCS/250 did not apply (paragraph 62). This procedure assumes that the rail industry has primary responsibility for site recovery and allocates responsibilities accordingly. As damage to the railway was very minor, the RIO did not consider the need to identify himself to London Rail as the person in charge, or make arrangements to hand over responsibility for the site to another person.

290 The situation would have been more serious, but for the continuing presence of a senior Network Rail operations manager (paragraph 78) who supported the RIO and maintained an informal communication channel. BB-CJV confirm that they were notified in advance of the intention to re-energise the catenary running beneath the bridge. However, other staff were not informed, including Fairfield Mabey personnel working on the bearings and the Network Rail civil engineer overseeing repairs to the deck (paragraph 88).

291 The lack of adequate coordination or a recognised command structure imposed by Network Rail meant that there was a lack of coordination where the parallel activities interfaced. As a consequence, staff were exposed to unnecessary risk: those on the track from falling debris and those on the bridge from the re-energised catenary. Furthermore, had BB-CJV and Network Rail engineering staff been given the opportunity to request a short extension of the original isolation beyond 03:31 hrs, work on the deck could have been completed without the need for a further isolation. This would have reduced the overall duration of the line closure (paragraph 90).

Evacuation of train 2U77

292 Train 2U77 stood at signal L100 to the north of Bethnal Green station until 21:08 hrs before Network Rail identified that there were passengers on the train requiring assistance (paragraph 75). While it is not clear whether it was Network Rail or BTP that declared all trains to be clear of passengers on the Bethnal Green side of the bridge at 20:46 hrs (paragraph 74), this information was inaccurate. Route Control did not verify this, despite train 2U77 being visible on screen (Figure 9). As a consequence, passengers on this train were trapped for an unnecessarily long period.

293 This situation was compounded by the lack of a general cab secure radio broadcast being made to all affected trains which would have improved the communication to passengers awaiting the attendance of the emergency services.

Response of others

Emergency Services

294 The first police officers on the scene arrived very quickly and were presented with a large structure spanning the railway which was under construction and exhibiting signs of damage. They were unable to identify what had happened or whether the structure presented a continuing risk to passengers on trains below. As a consequence, they considered the bridge to be at risk of collapse.

295 Their priority was therefore to get members of the public away from the area of risk. As it was not possible to move train 1K12 until the condition of the train, track and overhead catenary had been assessed, evacuation of the train was considered necessary. This commenced under the control of the train crew, but under the direction of the emergency services as soon as an emergency isolation had been obtained.

296 Emergency services personnel did not go onto the track until the safety of the line had been confirmed by Network Rail.

297 Following their arrival, BTP officers supervised the successful evacuation of over 1000 members of the public, with the assistance of the Metropolitan Police, London Fire Brigade and the London Ambulance Service. The evacuation of nine trains was completed by 21:36 hrs with passengers exiting via London Fields, Bethnal Green and Liverpool Street stations. CCTV evidence indicates that this took place calmly and safely.

National Express East Anglia

298 National Express East Anglia, as the train operating company for all services operating from London Liverpool Street, experienced severe disruption to services as a result of the complete route closure resulting from this accident. NXEA reinforced their control room operation, which is co-located within Network Rail's Route Control, by bringing in on-call staff and managers, and others who volunteered to assist.

299 A senior manager was appointed to liaise with Network Rail and BTP, and other staff were appointed to deal with the drivers involved and passengers affected. Due to the scale of the incident, NXEA were unable to mobilise sufficient staff to deal with all the passengers involved, so overall control of the evacuation was left with BTP. The lack of a clearly defined incident site also contributed to the decision not to appoint a TOLO, despite this being a requirement of both NR/L2/OCS/250, which states 'the RIO will have support from the train operator in the form of a Train Operators Liaison Officer (TOLO)' and the National Express Emergency (Incident Response) Plan which states 'NXEA Silver command must be provided by appointing a TOLO.' The matter was further complicated by NXEA having services affected on their three different routes (West Anglia, Mainline and Metro) simultaneously. A manager was instead appointed to cover TOLO duties from the control room.

300 NXEA's senior on-call manager liaised with his counterpart within Network Rail, but was provided with information he found to be contradictory and inconsistent due to initial uncertainty over the extent of the damage to the bridge. As a consequence, he was unable to determine how many trains were affected, the immediate risk to passengers on the trains, or when train services were likely to recommence.

301 Had NXEA had the resources to establish a TOLO or other site presence, the senior on-call manager would have had access to better intelligence from the ground. It is also probable that train 2U77 would have been identified as awaiting assistance at an earlier time (paragraph 75).

302 External communication was compromised by an inability to keep station passenger display systems up to date due to a number of different systems in use, making it necessary to switch many of them off. Furthermore, the NXEA website was not kept up to date due to a lack of staff available for this purpose. This affected customers wishing to obtain information on train services.

Other factors for consideration

303 National Express East Anglia have expressed concern over a lack of multi-agency emergency planning exercises for their staff. Network Rail normally arrange these exercises.

Management of the temporary works design

304 The temporary-works designer's remit evolved over several months to include the lateral restraints, parking restraints and longitudinal restraints. However, the temporary-works designer believed that he had been relieved of responsibility for the temporary supports following the decision by the senior site manager to use a solution based on experience gained from a previous project (paragraph 127). This led to confusion over who was responsible for this element of the design.

305 The temporary-works designer was later presented with drawings 211 and 212 to sign, but these incorporated details of the temporary supports which he had not designed (paragraph 135). Although he was able to check the drawings before signing, the fact that he was asked to sign drawings for which he was not wholly responsible is contrary to the principle of the independent checking process, or any recognised quality control procedure. Although the design was found to be adequate, the roles of the designer and checker became reversed for this element of the work.

306 The fragmented way in which the temporary works design was managed created an anomaly in the checking process and may have prevented any one party from maintaining an overview of the whole erection process. There was also a lack of construction method checks against the temporary works design in that the mitigation of the effects of thermal movement on the temporary supports was not considered. This approach may also have contributed to the lack of consideration of, or omission of information critical to, the safe erection of the bridge during the post-launch period.

Water trapped on the deck

307 The lack of drainage allowed a substantial volume of water to collect on the bridge deck. Although the additional weight of this water was negligible when compared with the overall weight of the deck, its sudden release onto the live overhead catenary system during the incident created a risk of *flash-over*. This risk was increased when a strip of wet fabric made direct contact between the catenary and the cab of train 1K12 (paragraph 42).

Adequacy of BB-CJV's site emergency procedure

308 The BB-CJV section of the steelwork method statement listed a telephone number with which to contact the signaller in the event of an emergency. However, Fairfield Mabey staff had not been briefed on the use of this number during their site induction, nor was it visibly displayed on site.

309 A caller would have been unable to easily describe the location of the site in railway terms (eg mileage), or list the relevant signal numbers to protect the site. While these arrangements were not tested as the accident occurred when the site was closed, it is not certain that they would have been adequate during working hours to arrange for trains to be stopped quickly.

Conclusions

Immediate cause

310 The immediate cause of the accident was concrete planks falling from the partly-completed deck of bridge GE19 onto the track below, triggered by a sudden movement of the bridge deck. Train 1K12 then hit the debris.

Causal factors

311 Causal factors were:

a. the inadequate planning, and lack of design input to the deck repositioning activity, which resulted in the need to ensure the continued stability of the temporary supports at the east abutment being overlooked (paragraph 222, **Recommendation 1a**);

b. the unauthorised modification of the temporary support by introducing an additional sliding surface, which made the east abutment supports vulnerable to instability due to horizontal force or movement (paragraph 226, **Recommendation 1b**);

c. the installation of lubricated PTFE-faced slipper pads on a gradient, which introduced a sustained horizontal load into the east abutment temporary supports sufficient to destabilise them (paragraph 252, **Recommendations 1c and 6**); and

d. the decision to substitute the positive tie between individual pre-cast concrete permanent formwork planks with cement mortar, which made it more likely that individual planks, if subjected to a large jolt, would fall onto the track (paragraph 262, **Recommendation 1d**).

Contributory factors

312 Contributory factors were:

a. the lack of accurate or sufficient detail in the steelwork method statement or work plan, which allowed the site team to work outside of the approved documents (paragraph 201, **Recommendation 1e**);

b. the hazard identification process not identifying some low probability high impact hazards (eg failure of the temporary works), which were consequently omitted from the steelwork risk assessment for the post-launch phase (paragraph 202, **Recommendation 1f**);

c. BB-CJV's decision to delegate responsibility for temporary works checks to Fairfield Mabey, which meant that they lost visibility of how the structure was performing, or of measures being taken to correct the horizontal movement (paragraph 204, **Recommendation 1g**);

d. the downhill movement of the bridge deck resulting from slippage of the parking restraints (paragraph 213);

e. the lack of a plan to manage thermal movement, which resulted in further displacement of the deck, probably during the transfer of horizontal restraint (paragraph 219, **Recommendation 1e**);

f. the lack of relevant experience within the site team which led to the decision to incorporate an additional slip surface on an inclined plane (paragraph 221);

g. the exposure of the permanent bearings at the east abutment to thermal movement without releasing the transit cleats, thereby weakening the transit cleat bolts (paragraph 231);

h. the absence of post-work checks, which allowed the unstable condition of the east abutment temporary supports and lack of secondary means of support to go undetected (paragraph 235, **Recommendation 1a**);

i. a lack of ownership of the risks presented by the unsecured deck section to the operational railway during jack down (paragraph 259); and

j. the modification of the deck layout, which allowed sections of the deck greater freedom to move, and off-set the permanent formwork planks against the shear studs thereby reducing their effectiveness in preventing the unsecured planks from falling from the deck (paragraph 266).

Underlying factors

313 The underlying factors were:

a. the method statement review processes adopted by London Rail, which was not rigorous enough to identify whether their review comments were adequately addressed (paragraph 272);

b. the lack of adequate supervision and focus on the risks imposed on the operational railway by all parties during the post-launch phase, which allowed Fairfield Mabey's site staff the freedom to attempt a horizontal jacking activity without an adequate understanding of the risks involved (paragraph 277); and

c. The difficulty in obtaining site supervision with the same level of expertise as any specialist contractor (paragraph 278).

Other factors affecting the consequences

314 The following factors affected the severity of the accident:

a. the decision to reposition the deck while it remained on temporary supports at the east abutment, which increased the height of the drop and made the resulting shock wave more severe (paragraph 279);

b. the signaller's selection of method to stop trains in an emergency, which inadvertently led to two other trains being brought to a halt beneath a potentially dangerous structure (paragraph 281);

c. an emergency isolation which needed to be taken rapidly, and as a consequence, affected a wide geographical area and halted a total of 20 trains (paragraph 283);

d. the lack of adequate site coordination which led to the premature re-energisation of the overhead catenary, which put staff working on the deck at risk and delayed the resumption of train services into Liverpool Street station (paragraph 291, **Recommendation 4b**); and

e. the rain water that was allowed to collect on the deck, which cascaded onto the track during the incident and created the risk of a flash-over when train 1K12 hit a wet object suspended from the live catenary (paragraph 307, **Recommendation 1h**).

Additional observations[5]

315 Network Rail's Route Control had no mechanism for contacting the site or a nominated person in order to identify the nature of the incident being reported to them (paragraph 50, **Recommendation 3a**).

316 The Form E process within NR/SP/CIV/003 did not provide an adequate mechanism for signing-off the structure as safe to operate trains under while it remained supported on temporary works which were being regularly modified (paragraph 276, **Recommendation 1i**).

317 There is a lack of published guidance available on the safe use of PTFE in construction. Although the small number of companies engaged in this work maintain individual lessons-learnt databases, there is an absence of common guidance, meaning that industry best practice is not automatically shared (Paragraph 253, **Recommendation 6b**).

318 Network Rail's National Emergency Plan does not adequately account for situations where the recovery operation is led by non-railway organisations (paragraph 289, **Recommendation 4a)**.

319 Train 2U77 was not identified as requiring evacuation until 21:12 hrs; 27 minutes after the site had been declared clear. By the time the emergency services arrived, passengers had been held on a stationary train, awaiting evacuation, for almost two hours (paragraph 292, **Recommendation 4c**).

320 There is a significant discrepancy between the coefficient of friction values recorded for steel against concrete in BS EN 12812:2004 and BS 5975:1996. Although BS 5975:2008 superseded BS 5975:1996 in December 2008, this discrepancy remains (paragraph 209).

321 The lack of a TOLO or other NXEA site representative increased the workload on Network Rail staff at the scene, particularly the RIO (paragraph 78). It also prevented NEXA's senior on-call manager from obtaining more accurate information from the scene. In view of the number of trains and passengers involved, this is considered to have been an omission (paragraph 301, **Recommendation 7**);

322 The risk assessment formats used by Benaim, BB-CJV and Fairfield Mabey were substantially different. The use of different classification systems made the comparison of risk ratings difficult (paragraphs 104 and 140, **Recommendation 1j)**.

[5] 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.

323 The management of the temporary-works design contract divided the work into small packages and this may have prevented an overview of the behaviour of the bridge during the jack down phase being obtained. It is probable that this contributed to the omission of information required by the site team (paragraph 306).

324 Had the collapse occurred during the working day, no person working on the bridge had immediate access to a Network Rail emergency number. This information was contained within the method statement, but this document was held in the site office which was a short distance from the bridge. Even with access to the emergency number, a caller would have lacked information required by the signaller to identify the site or the signal numbers necessary to stop trains in an appropriate place (Paragraphs 308 and 309, **Recommendation 3b**).

325 National Express East Anglia have expressed concern at the lack of live or multi-agency table top emergency exercises, coordinated by Network Rail, and involving their staff during 2008 or 2009 (Paragraph 303).

326 The launching of structures above transport infrastructure is set to become increasingly widespread due to the relatively low impact on railway or highway operations when compared with other construction techniques. However, a structural failure of the type identified in this report has the potential to affect the owner of any property on or over which work is being undertaken (**Recommendation 2)**.

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

327 Bridge GE19 has been completed in preparation for the commissioning of the East London Railway during 2009 and 2010. Remedial works included the replacement of all bearings, damaged permanent formwork planks and the bolts at connections identified as being over-stressed by Benaim.

328 Fairfield Mabey has produced a revised risk assessment and guidance for the safe use of PTFE on their sites.

329 London Rail has implemented a series of recommendations identified in its own report into this incident. This has included reviewing the extent to which it assures itself of the performance of contractors; a desktop exercise to refine its emergency plans; and a review of its escalation and on-call procedures. London Rail also recommended that BB-CJV should review their risk assessment process to ensure that it correctly captures low likelihood high impact risks; and ensure that all sub-contractors and designers within the project use the same risk assessment matrix.

330 London Rail, with the assistance of BB-CJV and Fairfield Mabey, has publicised the findings of their investigation to raise awareness of the temporary support failure mechanism within the engineering community. This has included presentations given to the Bridge Owners Federation, the Institution of Structural Engineers and the Institution of Mechanical Engineers.

331 The RAIB has written to the Highways Agency, copy to the HSE, drawing their attention to the issues raised in this report, so that they can learn any lessons relevant to their own infrastructure.

332 The RAIB has written to the British Standards Institution, drawing its attention to the discrepancy in coefficients of friction between BS EN12812:2004 and BS5975:1996 (Paragraph 320), so that they may review and, if necessary, reconcile the standards.

Recommendations

333 The following safety recommendations are made[6]:

Recommendations to address causal and contributory factors

1 Network Rail should review its Safety Management System, and procedures, to satisfy itself that the following points are covered before approving construction work, particularly by third-parties, on or over the operational railway:

a. The requirement for an approved design, method statement and risk assessment for any remedial activity involving load-bearing temporary works. This should include consideration of a range of failure modes, and inspection against known parameters after the structure or temporary works have been knowingly disturbed (paragraph 311a);

b. The means of safely adjusting the horizontal position of a structure should this become necessary (paragraph 311b);

c. The requirement to specifically consider the risks arising from the use of unrestrained low-friction surfaces, such as PTFE, which may be subjected to unpredicted lateral loads and disturbing forces during construction activity. This should include the reduction in the coefficient of friction which can occur when a sustained horizontal force is applied (paragraph 311c);

d. The means of securing permanent formwork and other construction materials, to protect against sudden or unplanned structural movement (paragraph 311d);

e. The need for method statements to contain accurate information on all construction stages, and to consider the effects of thermal movement where structures are supported on bearings (paragraphs 312a and 312e);

continued

[6] 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, recommendations 1, 2 , 3, 4, 5 and 7 are addressed to the Office of Rail Regulation (ORR), recommendation 2, where applicable, is also addressed to the Department for Regional Development in Northern Ireland, and recommendation 6 is addressed to the Health and Safety Executive (HSE), to enable each 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 web site at www.raib.gov.uk.

f. The need for contractor's risk assessments to include consideration of low probability high impact risks associated with temporary works (paragraph 312b);

g. The need for independence in the routine inspection of complex temporary works, which should not be delegated to the organisation responsible for providing them (paragraph 312c);

h. The means to prevent rain water collecting directly above 25 kV electrification equipment due to the risk of flash-over if the water is released in an uncontrolled manner (paragraph 314e);

i. The requirement for the intermediate certification of structures, including temporary works, for which the existing Form E process may be inadequate (paragraph 316); and

j. The benefit to all parties on major projects of adopting a common categorisation for risk assessments, to enable a coherent risk profile to be generated and to avoid the risk of confusion (paragraph 322).

2 London Underground Limited, Rail for London, the Heritage Rail Association, the Light Rail Engineering Group and Northern Ireland Railways should establish processes so that information is available to any potential suppliers of similar projects or assets regarding the issues raised within this report (paragraph 326).

3 Network Rail should establish procedures so that information is available to operations staff where construction activities could reasonably affect the safety of the railway. These should include, in particular:

a. the provision of emergency contact details for identified project representatives out-of-hours (paragraph 315); and

b. information on the location of each site, and the signal numbers necessary to protect the line (paragraph 324).

4 Network Rail should expand NR/L2/OCS/250, the National Emergency Plan to:

a. make provision for maintaining or extending the command structure in place following the exit of the emergency services from the site to ensure that post-incident activities are managed properly (paragraph 318);

b. reinforce arrangements for managing non-railway organisations during the incident recovery phase and prevent persons being exposed to risk due to a lack of site coordination (paragraph 314d); and

c. require route controllers to positively confirm what trains are involved in an incident, establish the location and ensure communication with all trains requiring assistance (paragraph 319).

continued

5 Network Rail should enhance the incident management training given to operations staff to reflect the requirements of Recommendation 4.

6 The Health and Safety Executive should:

a. draw the attention of the *Standing Committee on Structural Safety* (SCOSS) to the issues identified in this report regarding the safe use of PTFE in construction to ensure a wider promulgation amongst the civil engineering community (paragraph 311c); and

b. approach companies known to be involved in moving large loads using PTFE to check they have appropriate guidance and internal procedures to address the safe use of PTFE (paragraph 328).

Recommendations to address other matters observed during the investigation

7 National Express East Anglia should review their procedures relating to the appointment of a TOLO, or other site representative, in response to major railway incidents involving passengers (paragraph 321).

Appendices

Appendix A - Glossary of abbreviations and acronyms

BTP	British Transport Police
CEN	European Committee for Standardisation
CIRIA	Construction Industry Research and Information Association
DPE	Designated project engineer
HSE	Health and Safety Executive
kN	Kilonewton
NXEA	National Express East Anglia
ORR	Office of Rail Regulation
RIO	Rail Incident Officer
PTFE	Polytetrafluoroethylene
TOC	Train operating company
TOLO	Train Operator Liaison Officer
uPVC	Polyvinyl chloride

Appendix B - Glossary of terms

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

Abutment	Support for the end of the structure.
Bearing top plate	The upper part of the permanent bearing (refer to Figure 13)
Bearing base plate	The lower part of the permanent bearing (refer to Figure 13)
Cast-in-situ	Concrete poured into place.
Catenary	A description of the complete assembly of tensioned wires that make up the overhead line electrification (OLE) system. *
Category III design check	A check undertaken on a design by an organisation completely separate from the designer. This is the highest level of checking and can apply to temporary or permanent works.
Coefficient of friction	The ratio of the force required to cause a body to slide along a plane (in the direction of sliding) to the normal force pressing the body and surface together. *
Critical incident	A critical incident is any incident where the effectiveness of the police response is likely to have a significant impact on the confidence of the victim, their family and/or the community. A major incident is generally also a critical incident, but not all critical incidents are necessarily major incidents.
Dynamic coefficient of friction	The coefficient of friction which applies to an object moving over a surface.
Emergency isolation	An isolation of an electrification system imposed by the electrical control room (ECR) without prior planning, typically in response to an accident. Procedures such as the application of earths may also be omitted should the situation demand prompt action. *
Factor of safety	The fraction of structural capability over that required, used as a measure of the reliability of a particular design.
Flash-over	An uncontrolled electrical discharge. In the case of bridge GE19, the deck was bonded (ie earthed), but the cross beams were unpainted and could have acted as a bare conductor.
Gold / silver / bronze	Emergency command structure: gold (strategic), silver (tactical), and bronze (operational). The silver representative is the lead person from each organisation on site.
Gravity restraint	Physical restraint to prevent the structure moving downhill due to the effects of gravity.
Jack down	The process of lowering the structure into its permanent position.

Kilonewton (kN)	A measure of force. The newton (symbol: N) is the SI unit of force. A newton is the amount of force required to accelerate a mass of one kilogram at a rate of one meter per second squared. When acting vertically, 9.81 kN = 1 tonne.
Lateral	Direction across the width of the bridge
Lateral restraints	Temporary works provided in order to stop the bridge moving perpendicular to its centre line (refer to drawing 211, Appendix D)
Launch / launched	A construction technique involving the sliding of a structure into place. For bridge GE19, a temporary 'launching nose' and counterweights were required to prevent the structure overturning during this process.
Launching nose	A temporary structure attached to the leading end of the bridge (ie the west end) during the launch, to prevent the structure overturning during this process.
Limit state design	A design method used in structural engineering. A limit state is a set of performance criteria that must be met when a structure is subject to loads.
Load factor	A number by which a specified load is multiplied to determine the required design load.
Locking collar	Device fitted to a hydraulic jack to allow the jack to take load in the event of the loss of hydraulic pressure.
Longitudinal axis / direction	Direction across the length of the bridge
Longitudinal restraints	Temporary works provided in order to stop the bridge moving parallel to its centre line (refer to drawing 211, Appendix D)
Method statement	Any document used in some manner to describe the erection method during the course of a project from conception to completion.
Omnia plank	Trade name for pre-cast concrete planks manufactured by Hanson Concrete Products, and used to support the wet concrete during construction and remaining in place as part of the permanent works.
Parking restraint	Temporary steelwork fitted to the west abutment to stop the bridge sliding downhill after the launch.
Permanent formwork	Former used to support the wet concrete during construction and remaining in place as part of the permanent works.
Permissible stress design	A design philosophy which requires the designer to ensure that the stresses developed in a structure due to service loads do not exceed the elastic limit. This limit is usually determined by ensuring that stresses remain within the limits through the use of factors of safety.

Possession	A period of time during which one or more tracks are blocked to trains to permit work to be safely carried out on or near the line.*
Principal Contractor	A principal contractor has to be appointed for construction projects which last more than 30 days or involve 500 person days of construction work. The principal contractor's role is to plan, manage and co-ordinate health and safety while construction work is being undertaken. The principal contractor is normally the main or managing contractor for the work.
Proceed aspect	A signal aspect which authorises a driver to pass that signal (ie yellow or green). *
Rocker box	Temporary works steelwork to provide support to slide the bridge on during its launch (refer to drawing 211 Appendix D)
Standing Committee on Structural Safety	An independent body supported by the Institution of Civil Engineers, the Institution of Structural Engineers and the Health and Safety Executive to maintain a continuing review of building and civil engineering matters affecting the safety of structures.
Shear studs	Part of the permanent works design used to transfer shear loads into the structure.
Slipper pad	Elastomeric rubber bearing pad with PTFE sliding surface bonded to one side to facilitate moving a load into position.
Silver	The silver representative is the lead person from each organisation on site during a major incident, responsible for to determine the priorities in allocating resources and obtaining other resources as required. This includes planning and coordinating the overall response from site.
Soffit	Underside of a structure (ie main girder)
Static coefficient of friction	The coefficient of friction which applies between two surfaces when no movement is taking place.
Sub-Contractor	A contractor employed by the Principal Contractor to undertake construction works on the project.
Taper plate	A wedge shaped steel plate, machined to the 3.3% (1 in 30) the erection of the bridge as these were smaller and easier to handle.
Temporary support	A temporary support provided at each corner of the bridge following removal of the rocker box. From the top down, this comprised a temporary taper plate (to accommodate the 3.3% gradient), a variable height of steel packing plates and stools up to a maximum thickness of 640 mm, and the permanent bearing. Refer to drawing 211 (Appendix D).
Temporary packing plate	Steel plates used for the temporary support of the bridge. For GE19, each plate was 25 mm thick and 250 mm x 500 mm in plan.

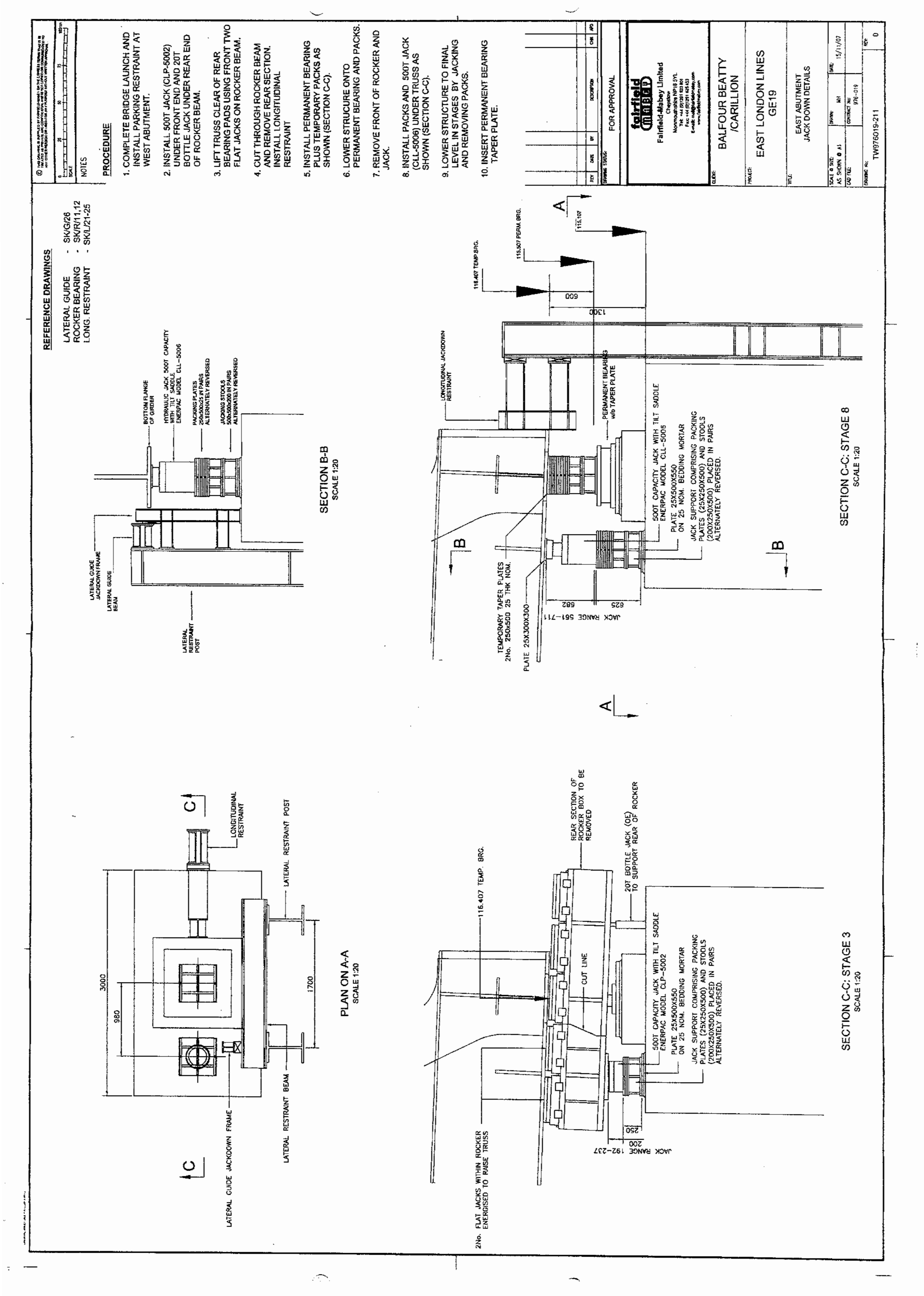
Temporary works	Temporary structures or staging works which are provided to enable construction works to be carried out but which are removed or which come out of use at or before the completion of the permanent works.
Transit cleats	Temporary steel plates bolted to the permanent bearings, designed to keep the bearing top plate aligned with the bearing base plate until in its permanent position.
Warren truss	A truss girder formed of equilateral triangles. The diagonal members carry both compression and tension forces.

Appendix C - Key standards current at the time

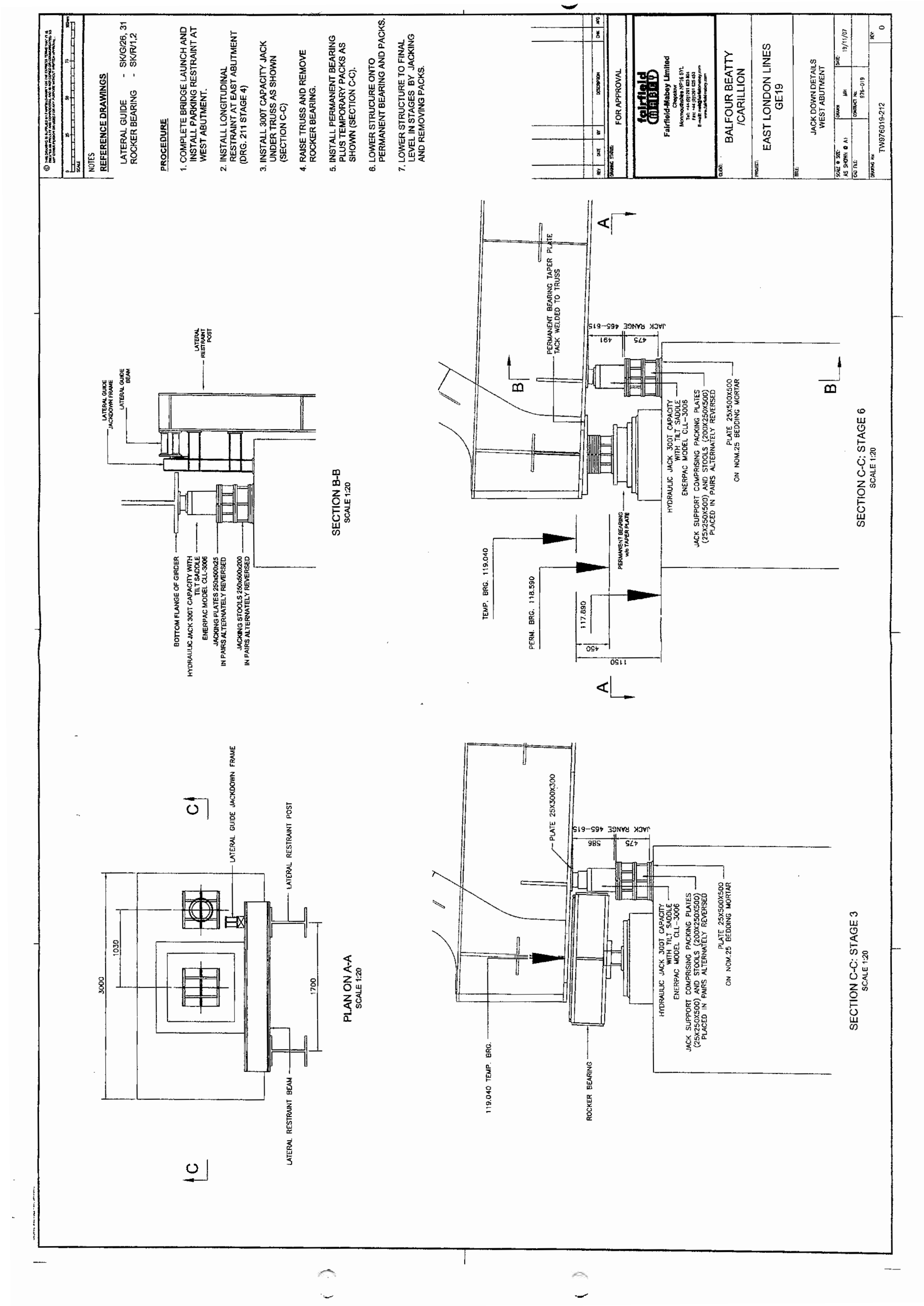
NR/L2/OCS/250	National Emergency Plan
RT/E/P/02009	Engineering Management for Projects
NR/SP/CIV/003	Technical approval of design and construction and maintenance of civil engineering infrastructure
BS EN 12812:2004	Falsework, performance requirements and general design
BS5975:1996	Code of practice for falsework
BS 5400	Steel, Concrete and Composite Bridges
BD37/01	Loads for highway bridges

Appendix D - Temporary Works Drawings 211 and 212

1 Drawing 211 shows the temporary works at the east abutment including the longitudinal restraint (Section C-C: Stage 8)



2 Drawing 212 shows the temporary works at the west abutment.



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