Rail Accident Investigation Branch

Rail Accident Report

Partial collapse of a bridge onto open railway lines at Barrow upon Soar, Leicestershire 1 August 2016

Report 10/2017
June 2017

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

The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents or by mitigating their consequences. It is not the purpose of such an investigation to establish blame or liability. Accordingly, it is inappropriate that RAIB reports should be used to assign fault or blame, or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

The RAIB's findings are based on its own evaluation of the evidence that was available at the time of the investigation and are intended to explain what happened, and why, in a fair and unbiased manner.

Where the RAIB has described a factor as being linked to cause and the term is unqualified, this means that the RAIB has satisfied itself that the evidence supports both the presence of the factor and its direct relevance to the causation of the accident. However, where the RAIB is less confident about the existence of a factor, or its role in the causation of the accident, the RAIB will qualify its findings by use of the words 'probable' or 'possible', as appropriate. Where there is more than one potential explanation the RAIB may describe one factor as being 'more' or 'less' likely than the other.

In some cases factors are described as 'underlying'. Such factors are also relevant to the causation of the accident but are associated with the underlying management arrangements or organisational issues (such as working culture). Where necessary, the words 'probable' or 'possible' can also be used to qualify 'underlying factor'.

Use of the word 'probable' means that, although it is considered highly likely that the factor applied, some small element of uncertainty remains. Use of the word 'possible' means that, although there is some evidence that supports this factor, there remains a more significant degree of uncertainty.

An 'observation' is a safety issue discovered as part of the investigation that is not considered to be causal or underlying to the event being investigated, but does deserve scrutiny because of a perceived potential for safety learning.

The above terms are intended to assist readers' interpretation of the report, and to provide suitable explanations where uncertainty remains. The report should therefore be interpreted as the view of the RAIB, expressed with the sole purpose of improving railway safety.

The RAIB's investigation (including its scope, methods, conclusions and recommendations) is independent of any inquest or fatal accident inquiry, and all other investigations, including those carried out by the safety authority, police or railway industry.

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Partial collapse of a bridge onto open railway lines at Barrow upon Soar, Leicestershire 1 August 2016

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Summary

At around 23:50 hrs on 1 August 2016, a bridge carrying Grove Lane in Barrow upon Soar, Leicestershire, over the Midland Main Line, partially collapsed and a large volume of masonry fell onto the railway lines below. At the time of the collapse, core sampling work was being undertaken to investigate localised subsidence in the footpath on the south side of the bridge. The bridge was closed to the public when the collapse occurred, but the railway lines below were open to traffic.

When the coring had reached about 1.4 metres below ground, water appeared at the surface and shortly afterwards, the adjacent wall fell away from the side of the bridge, taking with it part of the footpath, a length of cast iron water main and the core sampling rig. Five workers were able to get clear as the collapse occurred and no-one was injured. Two of the four railway lines through the bridge were completely obstructed and there was debris on a third. There were no trains on the immediate approach to the bridge at the time of the collapse.

The RAIB investigation found that the incident occurred because the bridge wall, built around 1840, was not designed to resist overturning. It had also been weakened by a full-height vertical crack. The water main, which ran close to the vertical crack, probably had a slow leak which was causing on-going subsidence in the footpath. Prior to 1 August, however, there was no evidence that the wall was at risk of imminent collapse.

The coring work on the night of the incident disturbed the pressurised water main and it ruptured. The consequent release of water behind the wall quickly overloaded it and caused the wall to overturn about its base.

Underlying the incident was the lack of understanding of the risk posed to the structure and to the open railway from coring in proximity to the water main.

The RAIB has made two recommendations to Network Rail. The first relates to the competence of its staff and contractors, and the availability of information to enable them to manage the potential risk to its structures from breaches of water utilities. The second relates to the provision of appropriate engineering input to risk assessments for intrusive investigations and masonry repairs on bridges carrying water services. A further recommendation is made to Network Rail's contractor, Construction Marine Limited, about the improvement of processes relating to street works and the location of water services.

The report has identified a learning point to reinforce the requirement for bridge examiners to report evidence of underground services and any changes since the previous inspection to enable a possible connection to be drawn between a water main and observations of defects on the bridge.

Introduction

Key definitions

1 Metric units are used in this report, except when it is normal railway practice to give speeds and locations in imperial units. Where appropriate the equivalent metric value is also given.

2 The report contains abbreviations and technical terms (shown in *italics* the first time they appear in the report). These are explained in appendices A and B. Sources of evidence used in the investigation are listed in appendix C.

The incident

Summary of the incident

3 At around 23:50 hrs on 1 August 2016, the bridge over the Midland Main Line at Grove Lane in Barrow upon Soar partially collapsed (figure 1). The collapse mainly involved the bridge's south-east (known as the 'Sileby') *wing wall*.

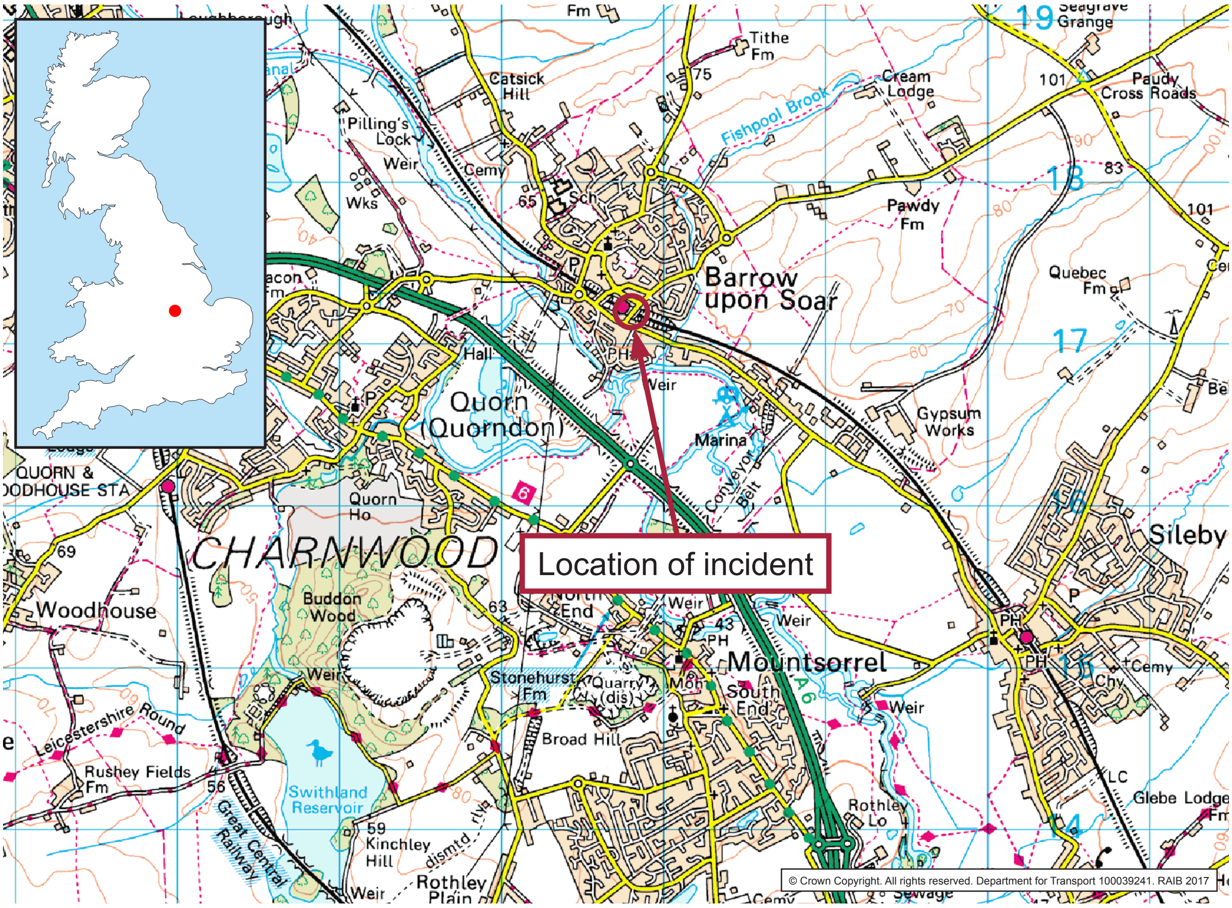

Figure 1: Extract from Ordnance Survey map showing location of incident

4 At the time of the collapse, a core sampling rig on the bridge was taking soil samples to investigate the cause of subsidence in the footpath adjacent to the Sileby wing wall (figure 2). The bridge was closed to the public but the railway lines below were open to traffic.

5 Shortly after the coring works commenced, water unexpectedly rose to the surface. A minute or so later, cracks appeared in the footpath, and the adjacent wall, footpath and the sampling rig fell from the bridge. Workers engaged in the coring work ran to safety and no-one was injured. Approximately 57 cubic metres of masonry rubble fell onto the railway below, completely obstructing two lines and fouling another (figures 3 and 4).

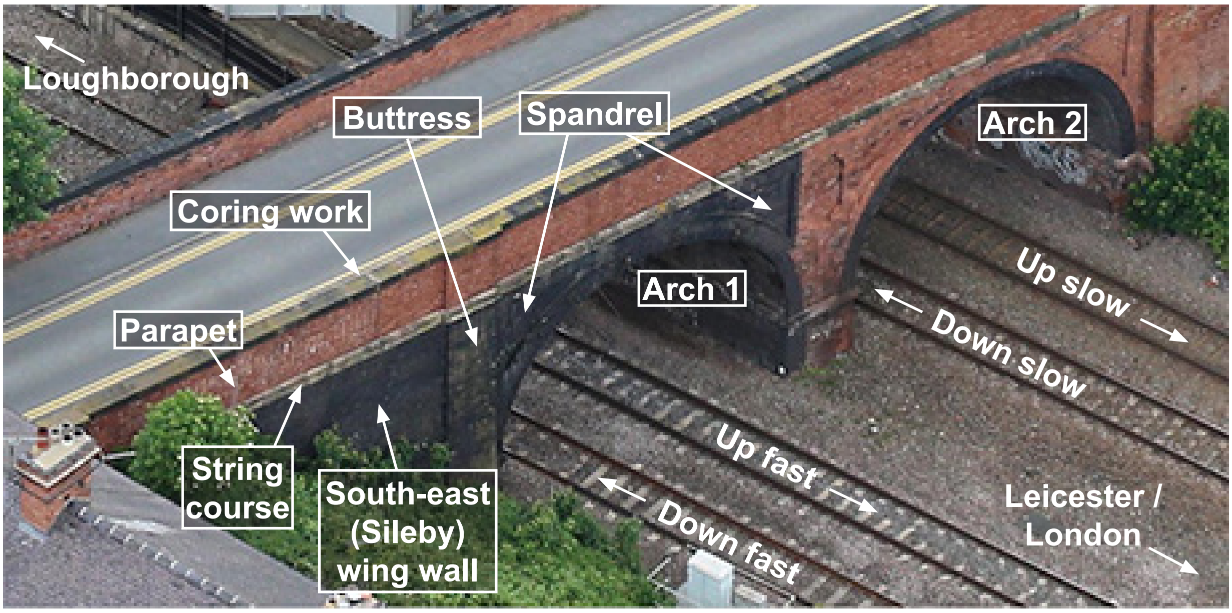

Figure 2: Location of incident and key features of Grove Lane bridge (image courtesy of Network Rail)

Figure 3: Masonry rubble post-incident (image courtesy of Network Rail)

Figure 4: Extent of collapse and rubble obstructing the up and down fast lines

6 There were no trains in the immediate vicinity at the time of the collapse. However, about six minutes earlier, a London St Pancras to Nottingham service travelling at approximately 92 mph (148 km/h) and, about two minutes earlier, an empty train, travelling at approximately 96 mph (154 km/h), passed under the bridge on the lines which became obstructed. Soon after the collapse a freight train approaching on the line fouled by debris, was halted by an emergency call from the signaller, when about 500 metres away (paragraph 34).

7 Rail services were suspended until Wednesday 3 August to allow the bridge to be made safe.

Context

Location

8 The bridge, designated by Network Rail as SPC5/57 'Grove Nook Lane', spans the four-track Midland Main Line at 108 miles 48 chains[1]. It carries the unclassified Grove Lane over a cutting and also provides pedestrian access to Barrow upon Soar station.

9 The two lines passing through the bridge arch adjacent to the Sileby wing wall (arch 1) are the *fast* lines with a maximum permitted speed of 110 mph (177 km/h) for *high speed trains* and 100 mph (160 km/h) for all others. The lines through the second arch (arch 2) are the *slow lines* with a maximum permitted speed of 65 mph (105 km/h) (figure 2).

[1] Measured from a zero datum point at London St Pancras station.

Organisations involved

10 The infrastructure, including Grove Lane bridge[2], is owned by Network Rail. It is managed by its London North Eastern and East Midlands (LNE&EM) Route Asset Management section in York and maintained by the Route Minor Works (Civils) section, also based in York.

11 Construction Marine Limited (CML) is a framework contractor to the LNE&EM route. CML was commissioned by the Minor Works (Civils) section to carry out investigation works at the bridge on the night of the incident and on a previous occasion in March 2015.

12 CML employed the gang, comprising a supervisor and two operatives, who attended the bridge on 1 August. They also employed a site manager who had carried out previous investigation works at the same place in 2015.

13 Central Alliance Limited was sub-contracted by CML to undertake core sampling (paragraph 53 to 57) as part of the investigation of the subsidence in the footpath. It employed two core sampling operators who were operating the core sampling rig when the incident occurred.

14 Leicestershire County Council is responsible for the condition and safety of the highway and footpath.

15 Severn Trent Water (STW) owns the underground water main which was laid across the bridge and was responsible for maintenance of the water main.

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

Staff involved

17 The Network Rail asset engineer worked in the asset management section and undertook the day-to-day management of the bridge. He had four years' experience looking after structural assets, including bridges. Part of his role was to review bridge examination reports and recommendations made and decide on any necessary follow up action. The asset engineer was familiar with Grove Lane bridge, having inspected it several times. He reported to the asset manager.

18 The Network Rail project manager in the Minor Works (Civils) section was responsible for managing the process for allocating maintenance work to Network Rail's four framework contractors. He had two and a half years' experience in his role. The project manager had no previous knowledge of Grove Lane bridge.

19 The CML site manager had worked at CML for five years and was responsible for the delivery and planning of works commissioned by Network Rail. He held an NVQ Level 4 qualification in site supervision, and railway competences, including 'safe system of work planner'. He was also qualified to work in the public highway. In March 2015, the site manager carried out a previous excavation of the footpath to investigate the subsidence.

20 The CML supervisor was in charge of the CML gang that went to site on 1 August and supervised the investigation works. He had worked at CML for nearly three years. The supervisor held railway competences including *controller of site safety*; he had no qualifications for undertaking work on a public highway (street works).

[2] The report has adopted the name in common usage, rather than the Network Rail name for the bridge.

21 The Central Alliance core sampling rig operator held an NVQ level 2 diploma in land drilling operations issued in July 2016. He was experienced in carrying out ground investigations by core sampling, mainly of railway *underline bridges*; this was his first experience of core sampling an *overline* bridge. He was assisted by an operator also employed by Central Alliance.

External circumstances

22 The core sampling work was being carried out on a warm night with light rain. The weather was not a factor in this incident.

23 Grove Lane had been closed by arrangement with Leicestershire County Council to permit the works to be carried out.

The sequence of events

Events preceding the incident

24 In March 2016, Network Rail's asset management section prepared a remit to undertake core sampling into the footpath in the vicinity of a vertical crack in the *parapet* and wing wall (paragraph 70) (figure 5). The purpose was to locate any voids which would explain why the footpath near the crack was suffering continuing subsidence (paragraph 84) (figure 6). The remit was sent to the Network Rail Minor Works (Civils) section and was allocated to CML by the Minor Works project manager with a completion timescale of 16 weeks.

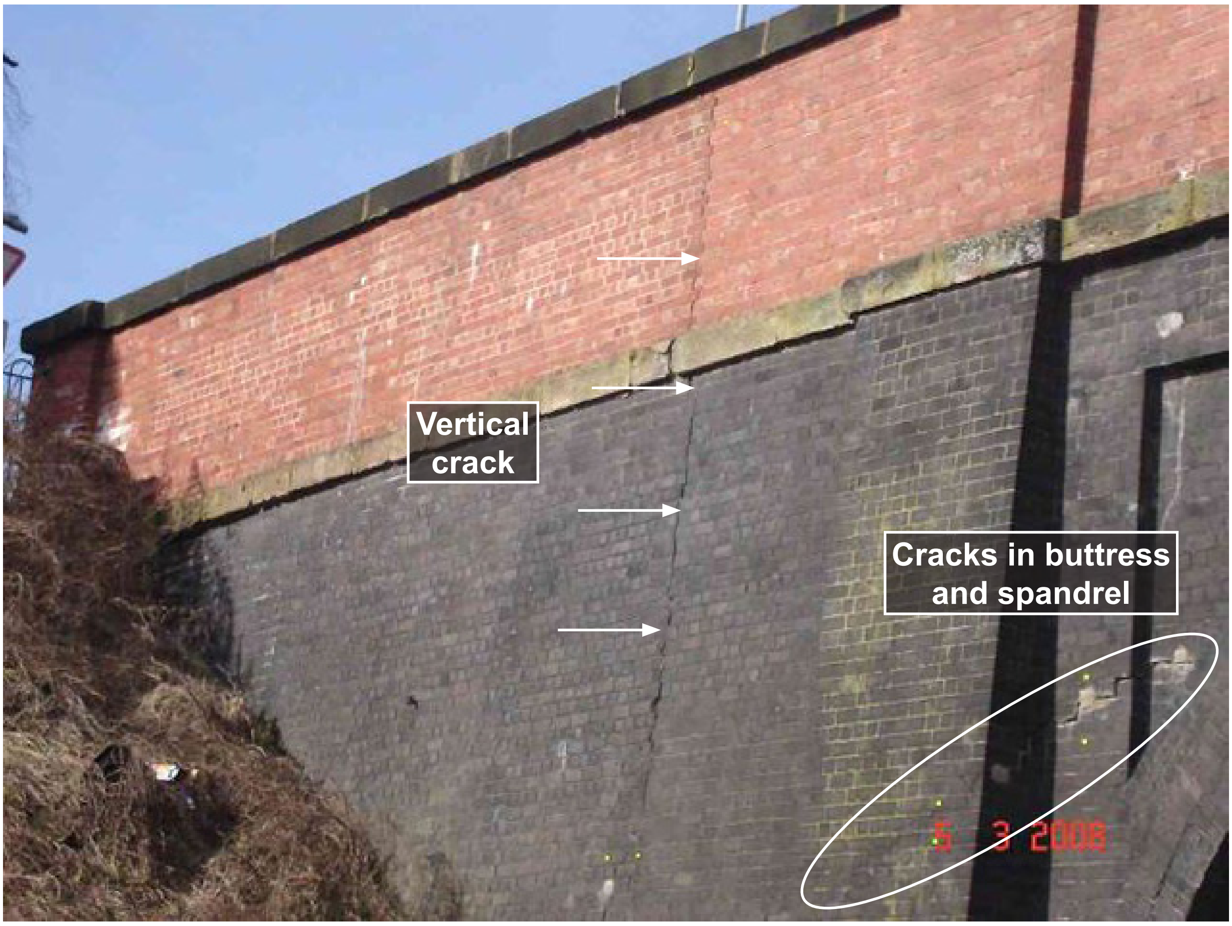

Figure 5: Vertical crack in Sileby wing wall and parapet (image courtesy of Network Rail)

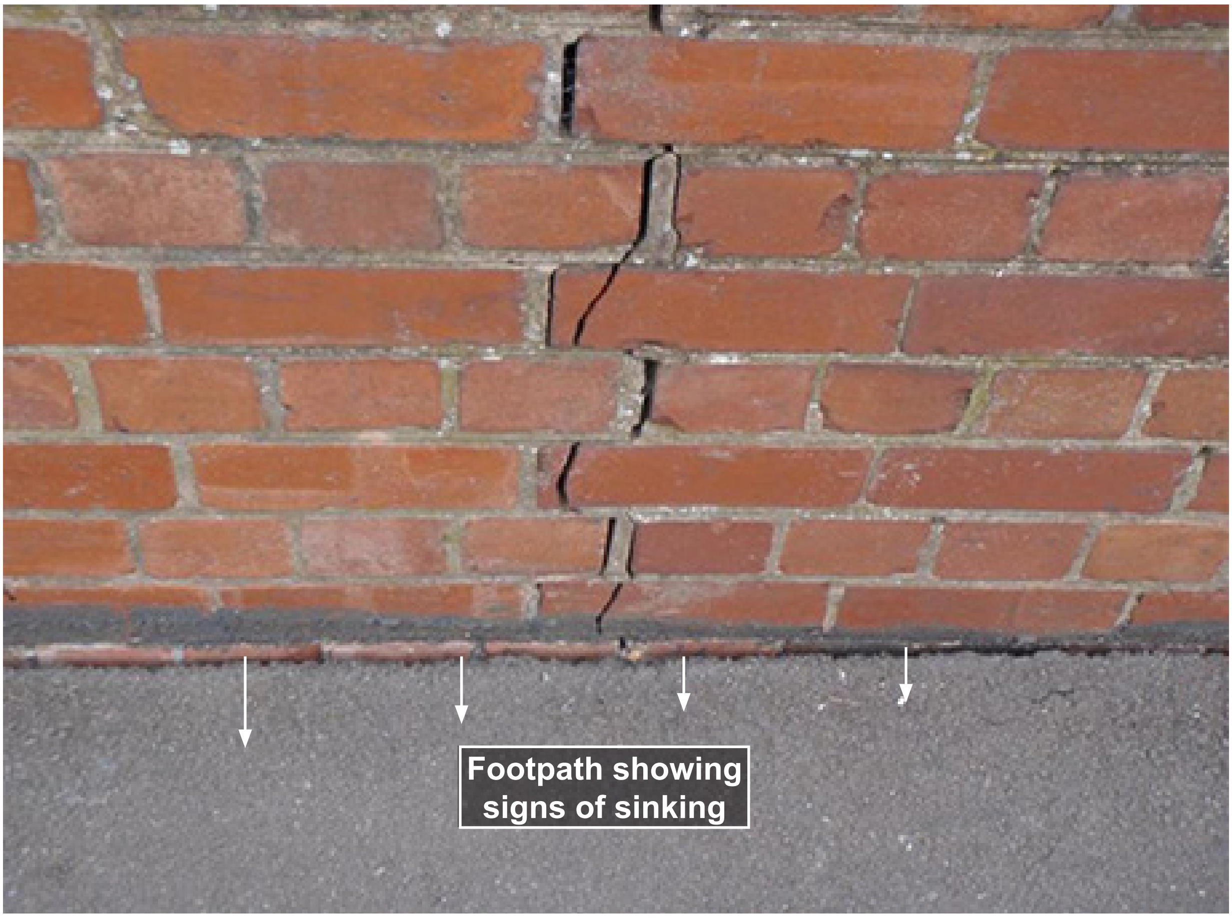

Figure 6a: September 2009 - first report of footpath sinking adjacent to the vertical crack (image courtesy of Network Rail)

Figure 6b: January 2012 - subsidence continuing, with dips evident at both the parapet and the kerb (image courtesy of Network Rail)

Figure 6c: June 2014 - the level of the footpath has been reinstated following the excavation in January 2012, but has continued to sink at the kerbside (image courtesy of Network Rail)

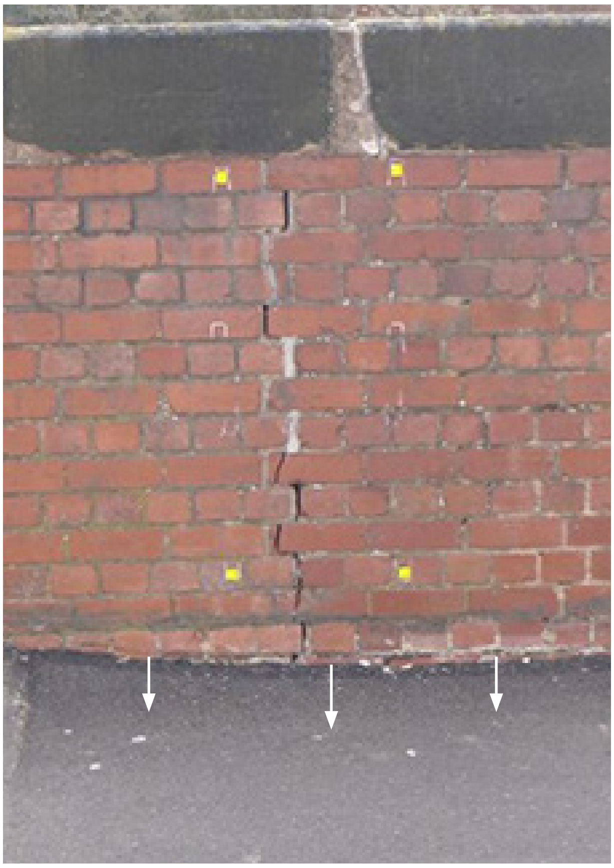

Figure 6d: March 2016 - the subsidence has recurred (image courtesy of Network Rail)

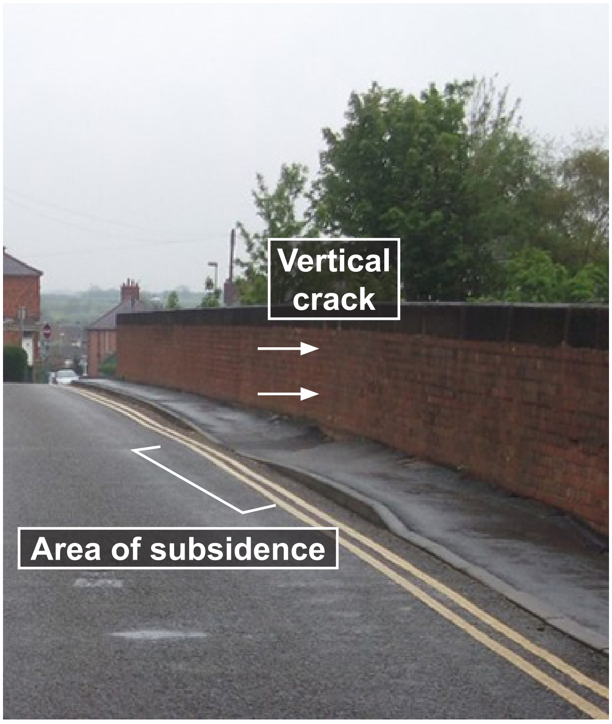

Figure 6e: May 2016 - area of subsidence in the footpath (image courtesy of Leicestershire County Council)

Figure 6f: May 2016 - close-up of area of subsidence (image courtesy of Leicestershire County Council)

25 CML subsequently contracted with Central Alliance to undertake the core sampling works. However, CML was to provide the supervision, labour and equipment for identifying any underground services, breaking out the footpath and its reinstatement on completion.

26 On 1 August 2016, the CML supervisor and two operatives, and the Central Alliance sampling rig operator and assistant, arrived at Grove Lane bridge around 22:00 hrs. The supervisor stated that, after locating the area of work, he carried out a survey to locate any underground services using a cable avoidance tool and signal generator set (sometimes known as a 'CAT and Genny' (paragraph 106)). He then issued a 'permit to dig' for the digging of a trial hole in the footpath. The trial hole measured 300 mm by 300 mm by 800 mm deep and was reportedly centred 500 mm from the inside face of the parapet (figure 7).

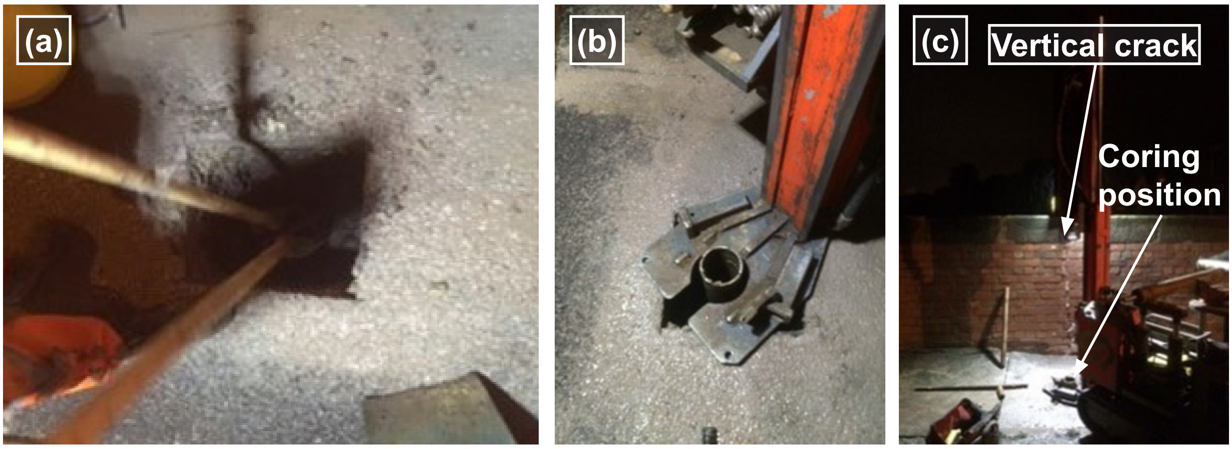

Figure 7: Photographs from the day of the incident showing; (a) 300 x 300 mm trial hole being dug; (b) coring machine set over trial hole; and (c) proximity of coring to vertical crack in parapet (images courtesy of CML)

27 The permit to dig stated that the trial hole was to be hand dug to identify a concrete plinth believed to be protecting the water main and that the coring was positioned to the side of it, to avoid striking the water main. The plinth was reportedly found at a depth of 800 mm.

28 Core sampling using a percussive method (paragraph 53) commenced from the bottom of the trial hole. The sampling rig operator and assistant inserted a 1 metre length sample barrel and casing into the trial hole and 'hammered' it until the leading end was 1 metre below ground level. A sample measuring around 200 mm was reportedly withdrawn from the core barrel and work progressed to sample the second metre below ground.

29 At some point during the second metre the core barrel and casing struck something hard and were unable to go further. The core rig operators applied two or three further blows of the drop hammer, as is their usual practice, before the obstruction cleared. Witnesses then saw water briefly rise in the core casing and overflow the top into the surrounding trial hole. It then stopped and the trial hole emptied of water. At this point, the core barrel and casing began to sink into the ground under their own weight.

30 The sampling rig assistant went to report what had happened to the supervisor who was in the CML van parked on the bridge a few metres away. Meanwhile the sampling rig operator attempted to put another extension rod on to the core barrel, fearing that he would lose the core barrel in the ground.

Events during the incident

31 About a minute after the discovery of water (witness accounts of the interval vary from 40 seconds to two minutes), and as the assistant and supervisor were walking back from the van towards the trial hole, the sampling rig operator noticed that the parapet wall was moving away. He shouted a warning before the wall fell, shortly followed by the footpath and sampling rig. Witnesses report that the footpath cracked beneath them. At either end of the failed area water was flowing from the broken water main.

32 The two sampling rig operators and the supervisor ran off the bridge to safety, alerting the two CML gang members in the van on the way. They quickly got out and ran clear of the area.

33 At 23:53 hrs the CML site supervisor made an emergency call to the signaller to report the incident and asked for all lines to be blocked to traffic. The signaller made an immediate emergency group call to all trains in the Barrow upon Soar area instructing them to stop.

34 Train 6M15, a GB Railfreight locomotive hauling one wagon, was travelling at a reported 60 mph (96 km/h) on the *down* slow line on the approach to Barrow upon Soar when the driver heard the signaller's emergency group call. He stopped his train within sight of the bridge, approximately 500 metres away.

Events following the incident

35 The supervisor secured the bridge to prevent access by members of the public pending the arrival of the emergency services and Network Rail response staff.

36 STW isolated the water main at 01:55 hrs. In the interim, water had flooded the track and washed down more soil from the damaged area of the bridge. STW estimated that around 310 cubic metres of water was lost. Once the flow had ceased the water was dispersed by the track drainage.

37 Calculations indicate that around 57 cubic metres of masonry and soil, weighing around 100 tonnes, fell on to the cutting face and the track.

38 On 2 August 2016 Network Rail commenced work to stabilise the structure and to remove the rubble obstructing the railway. The slow lines were reopened at line speed and the fast lines at a restricted speed of 20 mph (32 km/h), on 3 August. This speed restriction was subsequently eased as remedial work continued and was removed completely on 18 August. The bridge remained closed to road vehicles until 27 March 2017.

Key facts and analysis

Background infromation

Grove Lane bridge

39 The bridge carrying Grove Lane was originally built with a single arch during the construction of the Midland Counties Railway in about 1840. It was later extended to a two-arch structure around 1868 when the railway was widened to four tracks. The collapsed wing wall is believed to be part of the original construction. The original construction was in blue brick while the newer parts of the bridge are mostly in red brick (figure 2).

40 No original construction drawings of the bridge were found during the investigation. However, a drawing prepared at a later date for the bridge extension had some sparse 'as built' construction detail of the original bridge. This showed the Sileby wing wall to be wider at the bottom than at the top, and gradually tapering in thickness towards the side of the cutting. This drawing did not match the actual construction of the wall.

41 The maintenance history of the bridge is largely unknown as few records have been retained. However, there is evidence of extensive brickwork repairs, mostly to the northern elevation. The parapet of the Sileby elevation has also been largely rebuilt.

42 The carriageway over the bridge has a footpath on both sides and carries one-way vehicular traffic. The bridge was assessed by Leicestershire County Council in 1998 as capable of carrying a load of 40 tonnes. There is a 7.5 tonne weight restriction applying to Barrow upon Soar, although heavier (eg delivery) vehicles may use the bridge for local access purposes.

43 The bridge is subject to an examination regime by Network Rail to record and assess its condition, including the severity and extent of defects. Prior to its last detailed examination in 2005, it received detailed examinations every six years and an annual visual examination. These examinations were undertaken on Network Rail's behalf by a specialist contractor.

44 The interval between detailed examinations was subsequently extended to 12 years, after the introduction of a risk-based approach to bridge examinations. This took account of the actual condition of the bridge, using a structure condition scoring system defined in Network Rail company standard NR/CIV/006, 'Handbook for the examination of structures' (in several parts). The score given to Grove Lane bridge was 68 which put it in a condition grade 2 (1 = good, 5 = poor) with a 'medium' risk level.

45 However, in 2008, the bridge was made subject to six-monthly additional examinations to monitor a number of cracks in the structure for further movement.

The water main

46 The bridge carried a 4” (102 mm) internal diameter (120 mm external diameter) cast iron water main, reported by STW to be around 70 or 80 years old, with a service life of over 100 years. The water main had an inner cement-mortar lining, which was thicker at the bottom of the pipe, indicating that it had been applied in situ and had slumped before setting. STW had no record of when the lining was applied.

47 The water main ran under the footpath adjacent to the Sileby wing wall. It was fitted with a sluice valve, accessed via a manhole in the footpath, approximately 2.6 metres from the end of the Sileby parapet and around 7.5 metres from the area of subsidence (figure 8(a)). The water main (to the top of the pipe) was 1230 mm below ground level at the sluice valve (figure 9(a)).

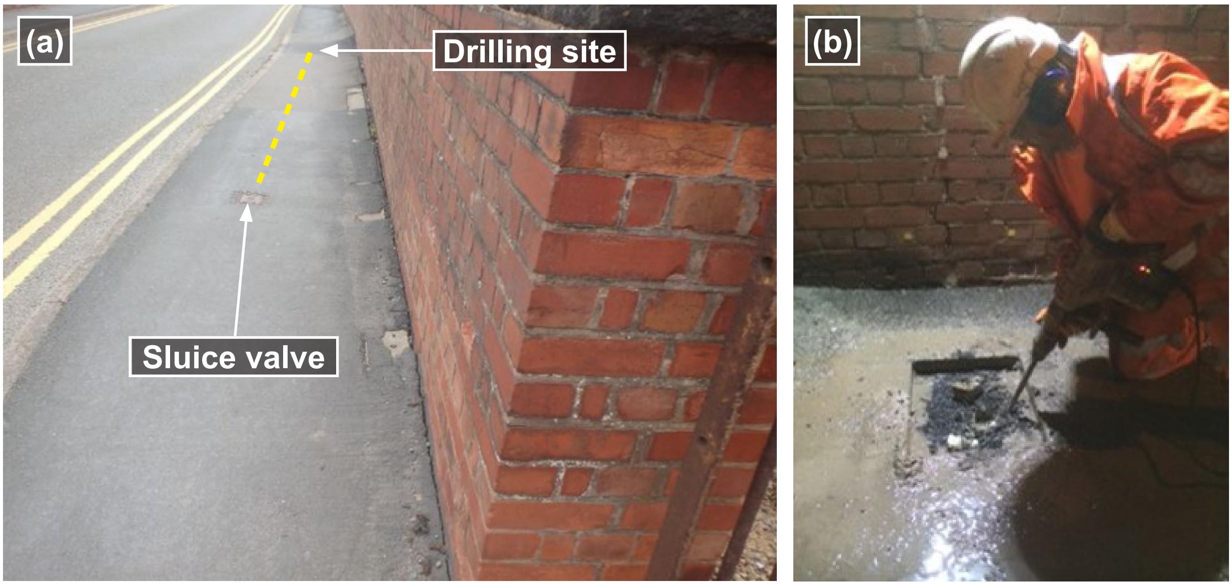

Figure 8: (a) trial hole site in relation to sluice valve (image courtesy of Network rail); and (b) trial hole on line of water main (image courtesy of CML)

Figure 9: (a) exposed sluice valve and depth of water main; and (b) alignment of water main in footpath (image courtesy of Network Rail)

48 The water main was considered by STW to be a high pressure main. It was rated for a pressure of at least 10 bar[3] and at the time of the incident the pressure in the main was reported by STW to be around 7 bar. The direction of water flow is shown in figure 9(b).

49 STW's records, held since 2010, indicate that there had been no bursts of the water main on Grove Lane bridge during that period. STW also had no records of any maintenance on the water main on the bridge. There had, however, been two bursts on Grove Lane, downstream of the bridge, in April and July 2015 and water leaks in 2010 and in 2016.

50 After the collapse, approximately 16.2 metres of water main was found to be missing. Of this, 15.9 metres of pipe in five sections was recovered from the rubble. One of the sections of recovered pipe had a modern coupling. STW was unable to provide any maintenance history of this repair. The coupling was not in the area of the footpath subsidence.

51 There are no other water services, such as surface water drains, carried through the bridge.

52 The pipework was forensically examined by a laboratory acting for STW, under the supervision of a forensic specialist acting for the RAIB.

Core sampling

53 Core sampling on the night of the incident was conducted using a percussive 'drop hammer' method. The sampling rig drops a weight on to sampling tubes to drive them into the ground. The tubes consist of a 101 mm external diameter sample barrel containing a plastic liner in which the sample is collected, and a 116 mm external diameter casing. The casing fits around the sample barrel and both are driven into the ground simultaneously by the drop hammer. The casing remains in the ground to hold the ground open when the sample barrel is withdrawn.

54 Casings are 1 metre long and are added progressively as the core sampling proceeds. However, the sample barrel is extended using 1 metre rods that are screwed on to the top of the barrel.

55 At the start of each 1 metre depth of sampling, a standard penetration test (SPT) is carried out to assess the ground strength. This test uses a smaller diameter rod marked off in 75 mm steps, and hammered into the ground to 450 mm. The number of blows for each 75 mm of penetration is recorded and the total number of blows for the final 300 mm of penetration is reported as the SPT value.

56 The core sampling rig, which was owned by Central Alliance, was crawler-mounted and weighed approximately 775 kg. It had been subject to statutory examination and test and its certification of compliance was in date. The machine was capable of both percussive sampling and sampling by means of a rotary drilling process.

57 Central Alliance's planned coring method for the work on the night of the incident followed its company voided structure methodology. This involved carrying out percussive sampling until a solid structure was encountered and then changing to a rotary sampling method to look for voids in the structure.

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[3] A bar is equivalent to 100 kPa or 14 psi.

Identification of the immediate cause

58 **The Sileby wing wall became overloaded, causing it to overturn and deposit debris on the open railway.**

59 The Sileby wing wall fell away from the bridge when the loading applied to it exceeded the capacity of the wall to withstand it.

60 Photographs and witness evidence show that the wing wall overturned close to the ground, taking part of the *buttress* and *spandrel* with it (figures 3 and 4).

Identification of causal factors

61 The incident occurred due to a combination of the following causal factors:

- the design of the wing wall made it susceptible to overturning (paragraph 62);
- the wing wall was weakened by a longstanding vertical crack and was leaning towards the track (paragraph 69);
- the water main probably had a slow leak which was causing subsidence of the footpath (paragraph 73); and
- the core sampling activity in proximity to the water main disturbed the pipe such that it ruptured and the increased loading from water pressure was sufficient to overturn the wing wall (paragraph 95).

Each of these factors is now considered in turn.

Design of the wing wall

62 **The design of the wing wall made it susceptible to overturning.**

63 After the collapse of the wing wall it was found that, when the cutting was excavated to build the original railway, the Victorian engineers did not cut out all of the ground where the bridge was to be built. They left part of the natural rock formation jutting out from the side of the cutting on the southern side (and probably on the northern side also) which was incorporated into the bridge wing wall construction. The southern end of the 1840 arch, and probably also the northern end, were therefore founded on the projecting natural rock formation. Any projecting formation on the northern side would have been removed when the bridge was extended for the widening of the railway (paragraph 39).

64 The strata exposed by the collapsed wing wall were analysed by Network Rail and found to be consistent with strata in the cutting face. The natural ground formation is largely Lias group[3] mudstone clay with a layer of limestone about 300 mm thick, at approximately 2.6 metres below ground level. Above the limestone there was a layer of mudstone overlaid by clay-rich made ground about 1.5 metres deep. After the collapse the natural formation remained self-supporting with a near vertical stable face (figure 4).

65 The investigation found that the Sileby wing wall was built as a free-standing wall, to 'face' the projecting formation. It was built as a stepped structure into the slope of the cutting and had little or no foundation (figure 10).

[4] The Lias group are rock strata comprising lime-rich mud (mudstone), marine limestone, clays and shale.

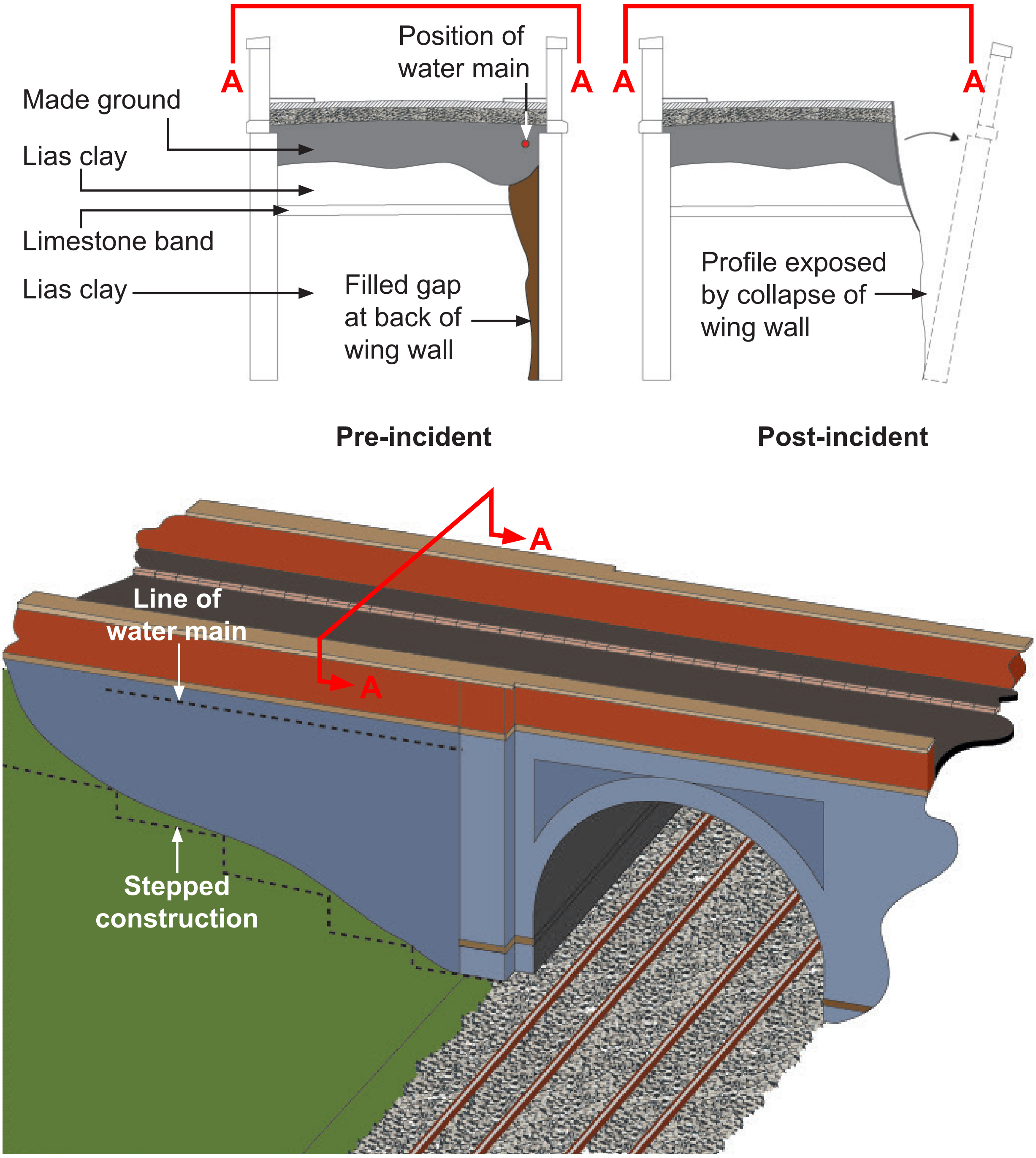

Figure 10: Schematic diagram showing section through bridge in area of collapse

66 The way that the wing wall was built meant that there was a gap between the wall and the natural formation. This gap would have been manually filled with a lesser consolidated material (known as 'fill') which was not compacted in place. This fill material, however, would have compacted over time leading to an increased lateral load on the back of the wing wall. It would also provide an area for the accumulation of any water getting into the structure, which would add to the lateral load on the wing wall.

67 The wing wall was built with a uniform thickness which was insufficient to carry the relatively large loads often found behind retaining walls of similar height. Network Rail reported that, after the incident, the wing wall was found to be 540 mm thick all the way up to the string course (figure 2). Brick walls intended to carry significant lateral loads are generally built thicker at the bottom than at the top to provide greater resistance to overturning.

68 The design of the wing wall was reported to be unlike any other on the Midland Main Line and not within the experience of Network Rail's asset engineers. As a consequence, they had not realised that the design of the structure gave it a latent susceptibility to overturning.

Condition of the wing wall

69 The wing wall was weakened by a long-standing full-height vertical crack and was leaning towards the track.

70 The Sileby wing wall had a vertical crack extending its full height and continuing through the parapet (figure 5). It is not known when the full-height vertical crack first appeared in the wing wall; Network Rail's earliest record of the crack dated from a 1998 assessment report of the bridge's load capacity. This report also recorded a number of other cracks in the bridge masonry on both elevations.

71 The exact cause of these cracks is difficult to determine. The RAIB considers that the pattern is symptomatic of loading on the back of the spandrel and wing walls from the fill material and water ingress, combined with dynamic loading from the passage of road vehicles. The loading also appeared to be generating an outward tilt of the wing wall. The last additional monitoring report before the collapse recorded that the wall in the vicinity of the full-height vertical crack was leaning by almost two degrees towards the track.

72 The monitoring of the cracks by Network Rail since 2008 had found little evidence of significant further movement. There had been some localised changes in the size of cracks which Network Rail attributed to seasonal movements, but there was no evidence that the wing wall was at risk of imminent collapse.

The water main

73 The water main probably had a slow leak which was causing the subsidence in the footpath.

74 Examination of the water pipes, carried out by RAIB's forensic specialist, found that a section of water main under the area of subsidence in the footpath had corroded through the full thickness of the pipe wall. This combined with other evidence summarised below indicates that the pipe was probably leaking (figure 11).

75 The RAIB's forensic specialist reported that the tapered sides to the corrosion indicated that it had started on the inside of the pipe, possibly because of a defect in the lining at this location, and progressed through the pipe.

76 At the site of the leak there was also evidence of pitting on the outside of the pipe from oxygenated wet corrosion, suggesting that water had collected under the pipe.

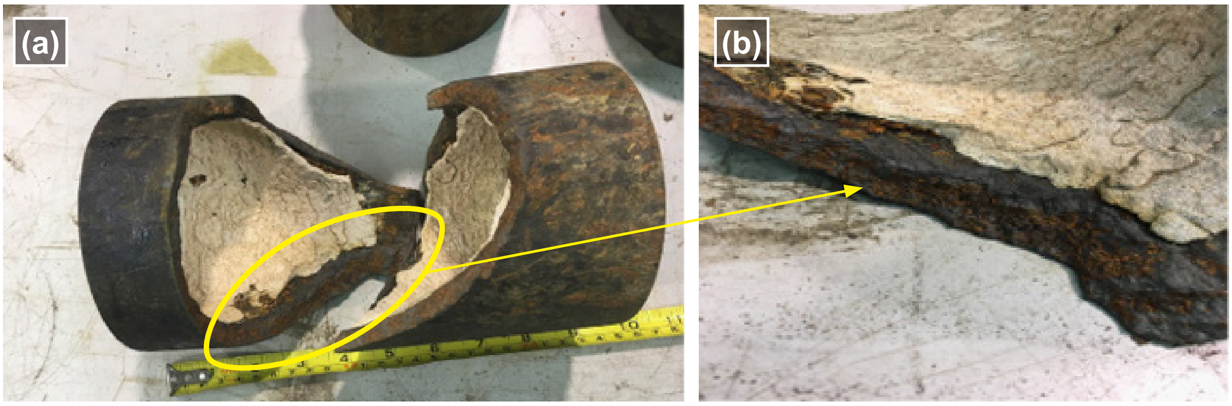

Figure 11: (a) fractured ends of the two mating lengths of water main and area of corrosion. Note that some of of the pipework is missing; and (b) close up of area of corrosion (images courtesy of SureScreen Scientifics)

77 The corrosion mechanism (known as graphitic corrosion[5]) is of a type that forms a labyrinth of small channels, through which water can pass and emerge as a slow leak. In the experience of the RAIB's forensic specialist, cast iron high pressure water pipes with corrosion of this type can survive without catastrophic failure for many years. This is because the remaining metal in the pipe retains some strength to hold the pipe together. The RAIB's forensic specialist estimated that the pipe had been leaking for approximately five years and possibly longer.

78 A separate report on the forensic examination of the pipes was prepared for STW by its own consultant. STW's consultant concluded that, while there was corrosion on both the inside and outside of the pipe and it was possible that the corrosion extended through the full thickness of the pipe wall, in their opinion there was no evidence of water leakage prior to the incident.

79 However, other evidence was consistent with a slow leak. Witness evidence from the coring activity is that the ground material in the vicinity of the water main was wet, similar to moulding clay and could be squeezed through the fingers. The SPT test (paragraph 55) in the area close to the water pipe was recorded as '1', indicating the soil had a very soft consistency. After the incident it was found that bridge fill material remaining behind the failed part of the spandrel (figures 2 and 4), and below the line of the water main, was also very soft, suggesting that some water may have been channelled to areas remote from the leak.

80 A leak on an underground water pipe is a well-known cause of localised subsidence. For example, the Association of British Insurers, in its guidance on subsidence, refers to leaks from drains as a cause of subsidence. Water from a leak would tend to soften and weaken the clay material in the bridge fill and reduce its ability to support the load above it. It would also tend to wash away fine particles, creating a void into which the footpath could subside.

[5] Graphitic Corrosion of a Gray Iron Water-Main Pipe Resulting in a Corroded-Through Hole. J.J. Snyder, Failures of Iron Castings, Failure Analysis and Prevention, Vol 11, ASM Handbook, ASM International, 1986, p 344–379.

81 It is not clear where the fill material was migrating to; normally there would be indications of *leachate* emerging through nearby brickwork and it might be expected to appear through the vertical crack, but there was little evidence of this. It is possible that the material was being washed into voided areas at the back of the wing wall and into any gaps created by movement of the wing wall. It is also possible that it was washed elsewhere as there was evidence of leachate appearing through cracks in the adjacent buttress, spandrel and around arch 1 (figure 2).

82 The footpath was sinking and there was relative movement between the kerb and the road and also between the footpath and the parapet, creating gaps through which water could ingress. The last additional examination of the bridge before the collapse, carried out in March 2016, recorded that the gap between the kerb and the road measured up to 30 mm wide by 500 mm long and varied from 100 to 200 mm deep (figure 12(a)). The gap between the footpath and parapet was typically between 5 mm and 50 mm wide with a maximum depth of 70 mm (figure 12(b)).

Figure 12: (a) March 2016 - void at kerbside; (b) May 2012 - gap opened up between footpath and parapet (images courtesy of Network Rail)

83 Water from a leaking pipe and from the ingress of surface water would probably have increased the moisture content of the Lias clay and clay-rich made ground (paragraph 64) and therefore the loading on the wing wall, although it is not possible to determine by how much and how far this loading might have extended.

Footpath subsidence

84 The first report of voiding in the footpath occurred in 2006. A void 1 metre long by 250 mm wide and 350 mm deep appeared where the footpath joined the parapet in the vicinity of the vertical crack in the Sileby wing wall/parapet. At that time, the voiding was attributed by Network Rail to localised failure of the sealant between the footpath and the parapet, permitting surface water to get in and wash away the fill.

85 In 2009, an examination report of the bridge by Network Rail's specialist contractor noted that the footpath was sinking slightly, close to the vertical crack (figure 6(a)).

86 By January 2012, and following a concern raised by a member of the public, it was found that the footpath had a dip of 100 mm adjacent to the vertical crack and a gap of up to 30 mm between the footpath and parapet (figure 6(b)). An excavation of the area of subsidence by a Network Rail contractor reportedly failed to find what was causing it and the area was made good. (Network Rail has no other records or photographs of the investigation.) The subsidence continued to occur (figure 6(c)) and in October 2014 a recommendation was made to Network Rail in an additional examination report that the subsidence be investigated again to discover the cause of the problem.

87 In March 2015 Network Rail commissioned CML to carry out an excavation in the area of subsidence and a hole was hand-dug down to the string course (figure 2). This work was undertaken by the site manager. He reported that the fill was wet but no voids were found within the depth excavated to explain the subsidence. The water main, which was below the string course, was not identified by a pre-work survey, it was not uncovered by the excavation and its presence was not reported on. The area was made good and a report submitted to Network Rail which suggested that subsidence of the wing wall may have been a possible cause. This was considered to be improbable by Network Rail who took no follow-up action on the report.

88 In July 2015 a further concern about the condition of the bridge and footpath was notified to Network Rail by a member of the public. Network Rail deployed a bridge examiner from its specialist contractor (paragraph 43) to investigate the concern. The bridge examiner reported that the lean on the wing wall was unchanged but recommended that the root cause of the voiding in the footpath be investigated. This led to the coring works a year later.

89 In the meantime, the RAIB understands that the issue came to the attention of Leicestershire County Council, who carried out a special visual inspection of the highway in May 2016. The Council sent photographs of the subsidence in the footpath to Network Rail so that it could assess if any action was needed (figures 6(e) and 6(f)).

90 Leicestershire County Council's Highways Engineer was aware from experience that settlement of this type could be caused by leakage from water pipes. Although the Council could have conducted its own investigation, it tended to leave this responsibility to the structure owner. The Council was aware from the applications for road closures that Network Rail was investigating and assumed the matter was in hand.

91 However, Network Rail's investigation strategy did not include eliminating the water main as a possible source of the subsidence. STW had no records of a request from Network Rail for assistance in ascertaining whether the water main was leaking (STW was not aware from its own leak detection processes of a slow leak at this location).

92 Network Rail's asset engineer did not investigate a leak as a possible cause of the subsidence because, during his several visits to the bridge, he had not observed signs of soil and water leaching through the structure, and through the vertical crack in particular, as might be expected (paragraph 81). However, he stated that he did not generally know whether there were buried services in a bridge. Network Rail's database containing details of structures does not include information relating to buried services.

93 The Network Rail standard for the examination of bridge structures NR/L3/CIV/006/2A 'Handbook for the examination of structures Part 2A: Bridges', issue 2, June 2010) includes a requirement for bridge examiners to record evidence of services below the road of overline bridges and any changes since the previous examination. Although there were repeated references in examination reports to subsidence in the footpath, the contractors who undertook bridge examinations on behalf of Network Rail did not record any observation of the presence of a water main in their reports. A buried water main in Grove Lane bridge is, however, listed in Network Rail's *National Hazard Directory* and there was an access chamber for a water main sluice valve in the footpath, approximately 7.5 metres from the area of subsidence (figure 8(a)).

94 Instead, Network Rail's investigation strategy was to look for man-made voids in the structure behind the wing wall into which fill may have been disappearing and causing the subsidence. This strategy was influenced by the drawing of the bridge extension (paragraph 40) which showed that voids were incorporated into the centre pier between the two arches. This was a technique used to reduce the static loading (deadweight) on the arches. After the incident it was reported that the centre pier was found to have been built with voids but these had been filled with soil. It is not known when this occurred but it is thought to be a long time ago. The likelihood of finding a void in a wing wall was low as there is no structural advantage in reducing the deadweight in a wing wall and, therefore, it is unlikely that voids would have been deliberately built in this part of the bridge. The asset manager confirmed that he had not come across voids in traditional bridge wing walls before.

Breach of the water main

95 The core sampling activity in proximity to the water main disturbed the pipe such that it ruptured and the increased loading from water pressure was sufficient to overturn the wing wall.

96 The forensic examination of the fractured water main was able to match the ends of the recovered pipework to reconstruct it as before the incident. One of the fractures had a jagged appearance and coincided both with the corrosion through the pipe and the area of sampling (figure 11). The forensic examination, on behalf of the RAIB, found evidence that this part of the pipe had fractured in a different manner from other fractures on the recovered water main, and showed evidence consistent with a high energy event, such as, being struck, directly or indirectly.

97 There were, however, no impact marks on the water pipe at this (or any other) site or any evidence of cast iron fragments in the recovered core sample. It is possible that the piece of pipe where an impact occurred had broken off and was not recovered. There was an irregular shaped piece, measuring up to 130 mm, missing from the recovered pipe where it had fractured in the vicinity of the coring works (figure 11). Alternatively, the core barrel or casing may have struck a hard cobble and indirectly come in contact with the pipe causing it to break.

98 The top of the water main was buried approximately 1230 mm below ground level at the sluice valve (figure 9(a)) and, because of the rising gradient of the highway, probably deeper than this, approximately 7.5 metres away, at the point of core sampling. Water mains are normally around 900 mm deep but it is not unusual for them to be deeper.

99 The sampling rig operators stated that the core barrel hit a hard object at about 1.5 metres below the surface, and they gave it two or three blows of the drop hammer to confirm that the barrel had hit 'refusal' ie, that it was unable to penetrate further. The sampling rig operators were expecting to hit brickwork so this did not cause them concern. The coring tubes then went through the object and continued to sink into soft ground under their own weight. The length of recovered sample in the core barrel broadly confirmed the witness evidence regarding the depth reached before the collapse.

100 After striking the hard object, water appeared under sufficient pressure to rise 2 metres up through the core casing and flow over into the trial hole. The water main is the only credible source of pressurised water. Artesian water on a bridge may be discounted and, after the incident, it was reported that ground investigations carried out on behalf of Network Rail found ground water at a depth of 10 metres below the level of the excavated cutting.

101 The absence of a plume of water, which might be expected if a water main is breached, was probably due to the water being released underground and having a restricted path to the surface. It is likely that the escaping water went back down the trial hole when it created a less restricted path underground.

102 Over the course of the following one or two minutes a large volume of water from the water main would have discharged behind the wing wall. The lateral pressure of water quickly loaded the wall beyond its capacity and, due to its low resistance to overturning, the wall opened up about the vertical crack and fell away from the structure.

103 The RAIB considers that the partial collapse of the bridge would not have occurred without the trigger of a burst water main. Other causes have been considered and discounted. There was, for example, no evidence of a collision between the sampling rig and the parapet, and the weight of the rig (775 kg) would have applied insufficient loading to destabilise the wall. The RAIB's assessment of the effect of vibration from percussive coring is that it would have been localised to the sampling tubes and insufficient to have significantly affected the wall.

Planning, supervision and competence

104 CML did not carry out the required pre-work survey to scope the core sampling works and identify services because a hole had been excavated in the same place the previous year and no services had been found (paragraph 87). The report of the excavation made by the Site Manager stated that it had been dug 1.5 metres wide, 1.5 metres long and 1.5 metres deep but witness evidence and photographs confirm that the hole was only dug down to the string course (figure 2) at approximately 1 metre below ground level. The supervisor was not made aware of this discrepancy, which may have influenced his belief that the water main was in a different position.

105 A pre-work scoping visit to identify services is important where mechanical plant is to be used because of the greater risk of damage. The underground services report obtained by CML prior to the work, which identified the location of the water main under the footpath, contained STW's condition that apparatus (including pipework) is located by hand digging before the use of mechanical plant and that every possible precaution should be taken to avoid damaging STW pipework.

106 CML's risk assessment for the work recognised the risk of bursting the water main and stipulated the use of a CAT and Genny to locate the pipe. A CAT scanner detects signals naturally radiating from metallic services. Its accuracy in locating services is improved if used with a Genny. This generates a distinctive signal that the CAT can detect more readily. The Genny can either be connected directly to a water pipe, eg at a sluice valve, for optimum accuracy in locating a pipe, or it can be used in a mode which radiates a signal into the ground to assist the CAT scanner to locate the water pipe.

107 On the night of the incident, the evidence of the sampling rig operators is that the trial hole was dug to 800 mm. The CML supervisor has stated that he CAT scanned the bottom of the trial hole. The CAT scanner would have had limited movement to operate effectively in the hole and it is possible that it would not detect the water main at this depth. The Health and Safety Executive's guidance, 'Avoiding danger from underground services'[6] states that the degree of confidence in the accuracy of a detection device varies with factors such as the training, skill, hearing and experience of the operator, the nature of the ground conditions, whether or not a signal generator is being used and the calibration and reliability of the detecting device.

108 In the event, the depth of the pipe and its alignment (figures 9(a) and 9(b)) were not identified and the CML supervisor permitted the core sampling to commence without the water main having been accurately located by hand digging (figures 8(a) and 8(b)). The supervisor has stated that he believed that the water main was protected by a concrete plinth because his previous experience was that all services were protected in this way. However, this is not generally the case. The piece of concrete material located by the trial hole was not part of any protection for the water main.

[6] HSG47 'Avoiding danger from underground services', 3rd edition, 2014 ISBN 978 0 7176 6584 6.

109 The CML supervisor did not hold the relevant street works competences[7], including the competence relating to location and avoidance of underground services, required for the work being undertaken. He was also not supervised on site by someone with the relevant training and competence.

Identification of underlying factors

Risk to the structure was not understood

110 Neither Network Rail nor CML understood the risk to the bridge structure and to the open railway from the coring works.

111 The safety risk from ruptured water mains is not normally regarded as significant. The guidance in HSG47 states that 'in general, work near underground water pipes is of low risk and most precautions are more concerned with reducing the cost of damage than with eliminating the risk'.

112 However, in this case the risk of damaging the bridge structure from coring in proximity to the high pressure water main, close to the vertical crack, could not reasonably have been assessed as low. Although Network Rail was unaware of the design of the wing wall (paragraphs 65 to 68), the RAIB considers that, with the level of knowledge before the incident, it was foreseeable that the rapid release of a high volume of water behind the cracked wing wall was likely to damage the wall.

113 An assessment of the risk involved would have required careful civil engineering evaluation in consultation with STW to minimise the likelihood of affecting the water main, but such an evaluation was not applied at any stage of the planning and execution of the investigation works.

114 The remit prepared by Network Rail's asset management section simply set out the objective to be achieved (ie to carry out coring works through the footpath in the vicinity of the vertical crack to find any voids in the structure). Although asset engineers have the most comprehensive knowledge of their structures, no guidance was provided to the framework contractor on the sensitivity of the structure and there was no consideration of the potential risks involved in delivering the work. The asset manager considered that a risk assessment of the proposed works should have been managed by Network Rail's Minor Works (Civils) section, which has access to all the bridge records and civil engineering competence within the section.

115 The Minor Works (Civils) project manager responsible for procuring the works was not a civil engineer and had no knowledge of the structure. Although the section has civil engineers who can be consulted on complex works, there appeared to be no reason to commission a special risk assessment for this work, which seemed to be routine in nature. The project engineer reported the impracticability of commissioning risk assessments for the high volume of work items handled on a daily basis.

[7] As required by the New Roads and Street Works Act 1991.

116 In this instance, Network Rail placed the responsibility for undertaking the risk assessment for the works, onto its contractor, CML. Network Rail provides its contractors with access to its database of information, including all bridge examination reports, and contractors are expected to reach an informed view about the condition of the structure and how it will be affected by the works. The contractor was responsible for deciding how best to achieve the remit objective, including the type of core sampling to be used, seeking further advice if necessary from the asset engineer or the minor works project manager.

117 When planning the safe system of work for the core sampling works, the CML site manager considered whether the work would present a risk to the railway such that it could only be done safely when trains were not operating. This would require a *possession* to temporarily close the railway to normal operations for safety reasons. The site manager concluded that the work could be done safely without the need for a possession. This was because the work site was on a road, not directly over the operational railway and, in his estimation, at least 15 to 20 metres from the nearest running line. He also did not consider that coring into the footpath could lead to the collapse of the wing wall.

118 The risk assessment carried out by CML's site manager for the coring works recognised the potential for damage to a buried pipe and the need for a search to be carried out beforehand using locating equipment, but it did not specifically refer to STW's requirements for water pipes to be located by hand digging prior to work commencing. The risk assessment also did not consider the risk to the bridge structure from a breached water main. CML did not ask Network Rail for advice or clarification on coring in proximity to a water main and did not consider any alternative ways of achieving the required outcome.

119 The CML risk assessment was not shared with Network Rail before the work was carried out. Risk assessments are normally uploaded with other paperwork to a shared database by the contractor after the work has been completed and so there was no opportunity for the assessment to be reviewed by Network Rail prior to the work being done. The level of communication between the parties was such that neither understood the real nature of the risk from the core sampling works.

Factors affecting the severity of consequences

120 A collision between a passenger train and the rubble on the track was avoided because the collapse happened during a gap in the passage of trains (paragraph 6). The consequences of a collision would have been very serious.

121 The prompt emergency call from the supervisor to the signaller also prevented the approach of a freight train and averted the danger of a collision.

122 The sampling rig operator detected the movement of the parapet and alerted his colleagues in time to get themselves clear of the immediate area before the footpath collapsed.

Summary of conclusions

Immediate cause

123 The Sileby wing wall became overloaded, causing it to overturn and deposit debris on the open railway (paragraph 58).

Causal factors

124 The causal factors were:

a) the design of the wing wall made it susceptible to overturning (paragraph 62, **Recommendation 2**);

b) the wing wall was weakened by a long-standing full-height vertical crack and was leaning towards the track (paragraph 69, **Recommendation 2**);

c) the water main probably had a slow leak which caused subsidence of the footpath (paragraph 73, **Recommendations 1b, 1c, 2a, 3 and learning point 1**); and

d) the core sampling activity in proximity to the water main disturbed the pipe such that it ruptured and the increased loading from water pressure was sufficient to overturn the wing wall (paragraph 95, **Recommendations 1a, 1b, 1d, 2 and 3**).

Underlying factor

125 Neither Network Rail nor CML understood the risk to the bridge structure and to the open railway from the coring works (paragraph 110, **Recommendations 1a, 1b, 1d and 3**).

Previous occurrences of a similar character

126 The RAIB has previously investigated two accidents relating to the LNE & EM Route's asset management and minor works sections at York and which have similarities with this incident.

Collapse of a retaining wall at Dryclough Junction

127 In February 2011 a passenger train was derailed at Dryclough Junction when it ran into stone rubble from a collapsed retaining wall (RAIB report 17/2011). The collapse of a retaining wall was probably due to a leaking surface water pipe causing cracks in the adjacent footpath. The cracks in the footpath were not recorded in any of the structural examination reports and their significance to the integrity of the wall was, therefore, not evaluated by the examining engineer. This is similar to the examination reports for the bridge at Grove Lane which did not include any record of the water main. However, the RAIB's recommendations in the Dryclough Junction report are not directly relevant to the Grove Lane bridge incident.

Movement of an embankment during repair works

128 On January 2006 a freight train derailed on the Cricklewood Curve because contractors repairing an embankment did not monitor its movement effectively (RAIB report 02/2007). The investigation found that there was a lack of clear understanding between Network Rail's civil engineering and minor works sections at York as to who was responsible for specifying the monitoring of the track while the repair was underway. It also found that the focus in the minor works section was on contract and programme management and project managers were not required to develop civil engineering competences.

129 The underlying cause in the derailment was that information on the condition of the embankment, risks inherent in carrying out construction works on it and the means of mitigating the risk to rail traffic were not clearly communicated to the contractor.

Recommendations and learning points

Recommendations

130 The following recommendations are made[8]:

1 *The intent of this recommendation is that Network Rail's asset management teams have sufficient competence and information to manage the potential risk to its structures from breaches of water and other relevant utilities (eg gas).*

Network Rail should:

a. identify in its structures database those structures that carry water (and other) utilities so that this information is readily available to its asset engineers, structures examination contractors, and minor works contractors (paragraphs 124c 124d and 125);

b. provide training and guidance to its asset engineers and structures examination contractors so that they are able to identify the presence of water (and other) utilities in structures, recognise defects caused by leaks, are aware of the consequences of a major utility failure, and decide on appropriate actions to be taken (paragraphs 124c and 125);

c. introduce a requirement in its procedures to notify the relevant utility company about any emerging problems which might affect the integrity of a structure, to enable early remedial action and prevention of further deterioration (paragraphs 124c); and

d. rebrief its asset engineers and structures examination contractors on the importance of recording evidence of underground utilities and any changes since the previous examination, as required by current Network Rail company standards (paragraph 124c).

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

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail and Road to enable it to carry out its duties under regulation 12(2) to:

(a) ensure that recommendations are duly considered and where appropriate acted upon; and

(b) report back to RAIB details of any implementation measures, or the reasons why no implementation measures are being taken.

Copies of both the regulations and the accompanying guidance notes (paragraphs 200 to 203) can be found on RAIB's website www.gov.uk/raib.

2 *The intent of this recommendation is that future intrusive investigations and repairs of bridge structures take into account the potential risks of significant structural damage or collapse arising from a breach of a buried utility.*

Network Rail should:

a. review how it procures intrusive works to its structures carrying water (and other) utilities, and verify that the process provides for sufficient input by suitably qualified engineers to assess the risk to the structure from the proposed works;

b. review its process for determining the appropriate level of competence for site supervision of the works; and

c. address any deficiencies found

(paragraphs 124a, 124b, 124d and 125).

3 *The intent of this recommendation is that CML examines the way it approaches 'street works' on Network Rail structures to ensure that the risk of damaging water services are fully understood and its operatives are properly trained and equipped to control those risks.*

CML should undertake a review of its management processes for the planning and execution of works on structures that carry water (and other) services. This should include the training, competence and supervision of operatives that may be required to locate pipework. CML should then implement a programme to deliver the identified improvements and to monitor its effectiveness (paragraphs 124d and 125).

Learning point

131 The RAIB has identified the following key learning point[9]:

1 Bridge examiners should record evidence of underground services, including water mains, and any changes since the previous examination, as required by Network Rail company standard NR/L3/CIV/006/2A, to alert bridge assessors and asset engineers to a possible connection between the water main and observations of defects on the bridge (paragraph 124c).

[9] 'Learning points' are intended to disseminate safety learning that is not covered by a recommendation. They are included in a report when the RAIB wishes to reinforce the importance of compliance with existing safety arrangements (where the RAIB has not identified management issues that justify a recommendation) and the consequences of failing to do so. They also record good practice and actions already taken by industry bodies that may have a wider application.

Appendices

Appendix A - Glossary of abbreviations and acronyms

CAT	Cable avoidance tool
COSS	Controller of site safety
LNE&EM	London North Eastern and East Midlands

Appendix B - Glossary of terms

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

Buttress	A thicker section built into a retaining wall or other masonry structure to increase its strength or to assist it in resisting earth pressures.*
Controller of site safety (COSS)	A person certified as competent and appointed to provide a safe system of work (SSoW) to enable activities to be carried out by a group of persons on Network Rail infrastructure in accordance with the requirements of the railway rule book.*
Down	In the direction away from London.
Fast	On a route with four or more tracks the pair used by express passenger trains will often be titled the up fast and down fast.
High speed train	In the context of a differential speed limit, a high speed train may be any of a defined range of locomotive and coaching stock formations, and multiple units. In this case, a class 43 locomotive with mark 3 coaches and driving van trailer, and classes 158, 170, 220, 221, 222.
Leachate	Liquid that passes through matter, picking up soluble or suspended solids with it.
National Hazard Directory	A database maintained by Network Rail which contains details of the health, safety and environmental hazards known to exist on Network Rail controller infrastructure.*
Overline bridge	A bridge which carries a carriageway over the railway.
Parapet (wall)	The low wall built along the edges of a bridge deck or arch to prevent pedestrians or vehicles straying over the edge and onto that which lies beneath.*
Possession	A period of time in which one or more lines are blocked to trains to permit work to be safely carried out on or near the line.*
Slow line	A track of lesser importance than a fast line but which runs alongside a fast line. A slow line may not be slower than the fast line.*
Spandrel (wall)	The approximately triangular wall which occupies the space above the arch or arches of an arch bridge.*
Up	In the direction towards London.
Underline bridge	A bridge which carries the railway over a carriageway.
Wing wall	A wall adjacent to bridge abutments which act as retaining walls.*

Appendix C - Investigation details

The RAIB used the following sources of evidence in this investigation:

- information provided by witnesses;
- site photographs and measurements;
- a report from a forensic specialist commissioned by the RAIB;
- records and drawings of bridge;
- bridge examination reports;
- Leicestershire County Council records;
- Leicestershire Records Office archive material;
- recordings of voice communications with signallers;
- reports commissioned by Network Rail from a civil engineering consultant; and
- a review of previous RAIB investigations that had relevance to this incident.

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