Rail Accident Investigation Branch

Rail Accident Report

Structural failure caused by scour at Lamington viaduct, South Lanarkshire 31 December 2015

Report 22/2016
November 2016

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.

Any enquiries about this publication should be sent to:

RAIB	Email: enquiries@raib.gov.uk
The Wharf	Telephone: 01332 253300
Stores Road	Fax: 01332 253301
Derby UK	Website: www.gov.uk/raib
DE21 4BA	

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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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Structural failure caused by scour at Lamington viaduct, South Lanarkshire
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Contents

Summary

At 08:40 hrs on Thursday 31 December 2015, subsidence of Lamington viaduct resulted in serious deformation of the track as the 05:57 hrs Crewe to Glasgow passenger service passed over at a speed of about 110 mph (177 km/h). The viaduct spans the River Clyde between Lockerbie and Carstairs. Subsequent investigation showed that the viaduct's central river pier had been partially undermined by scour following high river flow the previous day. The line was closed for over seven weeks until Monday 22 February 2016 while emergency stabilisation works were completed.

The driver of an earlier train had reported a track defect on the viaduct at 07:28 hrs on the same morning, and following trains crossed the viaduct at low speed while a Network Rail track maintenance team was deployed to the site. The team found no significant track defects and normal running was resumed with the 05:57 hrs service being the first train to pass on the down line. Immediately after this occurred at 08:40 hrs, large track movements were noticed by the team, who immediately imposed an emergency speed restriction before closing the line after finding that the central pier was damaged.

The viaduct spans a river bend which causes water to wash against the sides of the piers. It was also known to have shallow foundations. These were among the factors that resulted in it being identified as being at high risk of scour in 2005. A scheme to provide permanent scour protection to the piers and abutments was due to be constructed during 2015, but this project was deferred until mid-2016 because a necessary environmental approval had not been obtained.

To mitigate the risk of scour, the viaduct was included on a list of vulnerable bridges for which special precautions were required during flood conditions. These precautions included monitoring of river levels and closing the line if a pre-determined water level was exceeded. However, this process was no longer in use and there was no effective scour risk mitigation for over 100 of the most vulnerable structures across Scotland. This had occurred, in part, because organisational changes within Network Rail had led to the loss of knowledge and ownership of some structures issues.

Although unrelated to the incident, the RAIB found that defects in the central river pier had not been fully addressed by planned maintenance work. There was also no datum level marked on the structure which meant that survey information from different sources could not easily be compared to identify change.

The RAIB has made three recommendations to Network Rail covering the management of scour risk, the response to defect reports affecting structures over water, and the management of control centre procedures. The report also contains five learning points related to effective management of scour risk.

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 07:29 hrs on Thursday 31 December 2015, the driver of a southbound Virgin West Coast 'Pendolino' service from Glasgow Central to London Euston informed the signaller that he had just come over the viaduct at Lamington and he had felt a dip in the track while crossing the viaduct. This train was travelling on the *up* line.

4 The signaller then instructed train drivers to travel slowly over the viaduct, and some drivers were asked to examine the line while track maintenance staff travelled to site.

5 The track maintenance staff arrived on site at about 08:10 hrs and after examining both tracks while crossing the viaduct, informed the signaller that the line could reopen at normal line speed.

6 Within five minutes, a northbound train approached on the *down* line travelling at about 110 mph (177 km/h). The track maintenance staff watched it cross the viaduct and noticed unusual movement between the carriages. They then observed that the down line had distorted so that 'sweeping dips' were visible across the viaduct.

7 The track maintenance staff immediately re-imposed the speed restriction and started to look for the cause of the track movement. During this time, one train crossed the viaduct at low speed on the up line. Beneath the deck, they found a stone block missing from the central river pier and large fractures above the gap. At 08:52 hrs, the track maintenance team leader closed the line and reported serious structural problems. The line remained closed for over seven weeks until Monday 22 February 2016 while repairs were carried out.

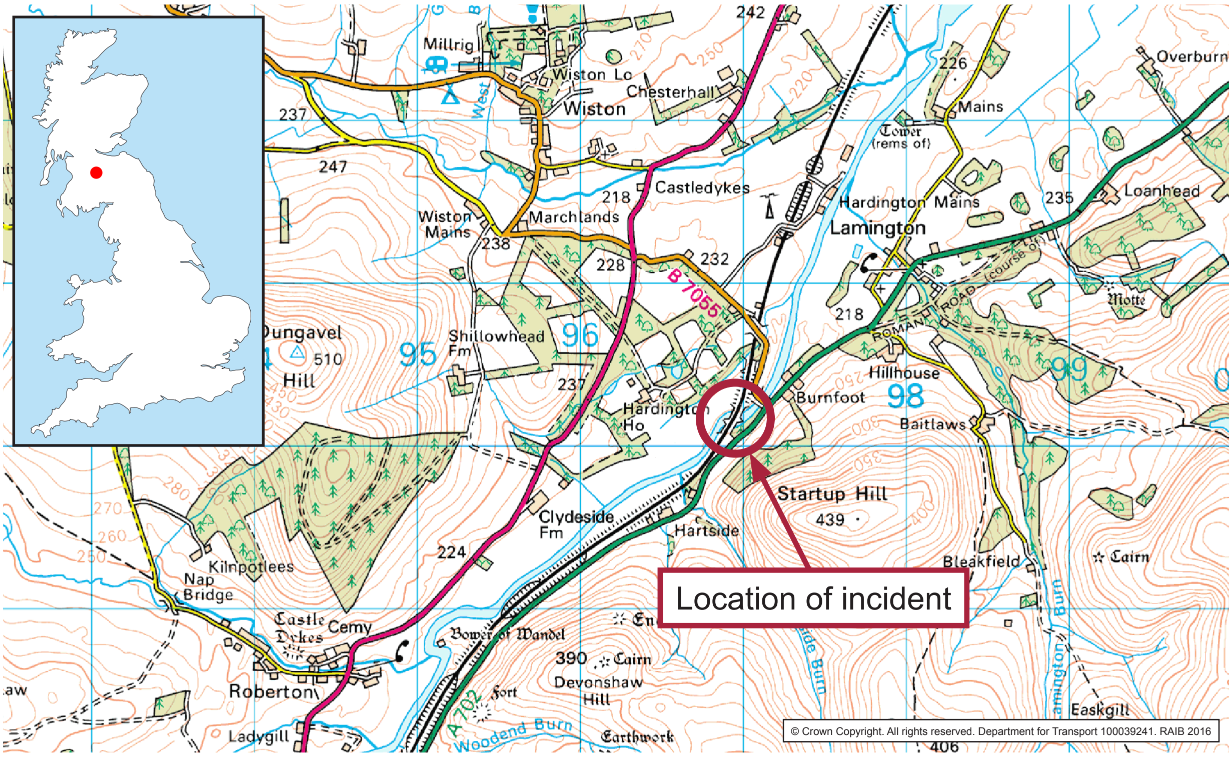

Figure 1: Extract from Ordnance Survey map showing location of incident

Figure 2: Aerial view of Lamington viaduct looking south-west towards Lockerbie and Carlisle on 4 January 2016 (photograph courtesy of Network Rail)

8 There was no damage to any train and no injuries. Subsequent examination of the viaduct showed that the central pier had moved and was significantly damaged. There was a large hole beneath part of the central pier caused by *scour* of the river bed.

Context

Location

9 Lamington viaduct is located south-west of the village of Lamington in the upper Clyde valley, and carries the West Coast Main Line over the River Clyde (figures 1 and 2). The viaduct is located on the route from Gretna to Glasgow Central (via Beattock) at 62 miles 1452 yards[1], between the stations at Lockerbie and Carstairs.

10 The West Coast Main Line forms the main rail link between London Euston and Glasgow Central. At Lamington, it carries a mix of long-distance passenger and freight traffic, and a high proportion of the overnight services in Scotland.

11 Approaching the viaduct from the south, the railway runs beside the River Clyde for approximately 300 metres on a low embankment. The railway curves left to cross the river, which flows beneath the viaduct from west to east. This part of the river is approximately 30 metres wide and up to 1.5 metres deep during normal flow conditions. The river at this location drains a catchment area of about 425 km^2, and following heavy rain, its depth can rapidly increase by over 2 metres.

Organisations involved

12 Network Rail was the owner and maintainer of the railway infrastructure at Lamington and the employer of the track maintenance and operations staff and the civil engineers responsible for maintenance of the viaduct structure and track.

13 Virgin Trains West Coast (VTWC) operated passenger services using Lamington viaduct, and was the employer of their train crew. It operated the train whose driver first reported the track defect.

14 First TransPennine Express[2] (FTPE) also operated passenger services using Lamington viaduct, and was the employer of their train crew. It operated the trains whose drivers examined the line at low speed after the defect was reported.

15 DB Schenker[3] (DBS) was the operator of some freight services using Lamington viaduct. It also employed the drivers of these trains.

16 Amey plc employed bridge examiners to undertake *visual examinations*, and *detailed examinations* on behalf of Network Rail in Scotland from 2009 onwards. Amey also undertook *underwater examinations* at Lamington viaduct from 2011.

17 Jeremy Benn Associates Ltd, trading as JBA Consulting, undertook scour assessments on behalf of Network Rail, including those at Lamington.

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[1] Track mileages on this route are measured from Carlisle station.

[2] First TransPennine Express was renamed 'TransPennine Express' on 1 April 2016.

[3] DB Schenker Rail (UK) Ltd was renamed DB Cargo (UK) Ltd on 1 March 2016.

Trains involved

18 Eight trains crossed the viaduct between the first report of a problem on 31 December 2015 and the line being closed. Due to the curvature of the track across the viaduct, the maximum line speed is 100 mph (161 km/h) except for two classes of train as noted below. The types of train which crossed the viaduct during the incident, and their maximum permissible speed at this location were:

- Class 390 'Pendolino' tilting electric trains, operated by VTWC, and permitted to travel at an *enhanced permissible speed* of 120 mph (193 km/h).
- Class 221 'Super Voyager' tilting *diesel-electric multiple unit* trains, also operated by VTWC and permitted to travel at an enhanced permissible speed of 110 mph (177 km/h).
- Class 350/4 *electric multiple unit* trains operated by FTPE, limited to 100 mph (161 km/h).
- A locomotive hauled intermodal (container) freight service travelling between Mossend (Glasgow) and Daventry, and operated by DB Schenker. This class of freight train can travel at up to 75 mph (121 km/h).

The structure involved

19 Lamington viaduct (structure number WCM1/30/332) is a four span concrete and masonry bridge. The viaduct is orientated in a south-west to north-east direction with the abutments and intermediate supports (piers) at a skew of about 30 degrees to the track. The viaduct crosses a river bend, so the water pushes against the sides of the piers as it flows east and then north towards Carstairs and Glasgow.

20 The *ashlar* masonry substructure (piers and abutments) was built of solid *coursed* sandstone in 1863 during replacement of a timber viaduct which had carried the line since its opening in 1848. Contemporary borehole records suggested that pier 2 was founded on rock. The substructure was widened by 13 metres in 1936 when unreinforced *in situ concrete* pier extensions were added to the downstream end of each pier, extending their length in the direction of river flow to approximately 28 metres. This work was part of a project to increase train speeds by providing a stronger superstructure (deck) on a new alignment to straighten a previously sharp curve, and was completed in 1938. The new deck alignment meant that only the west side of the viaduct, carrying part of the down line (northbound trains), was supported on the masonry substructure making the upstream end of each pier redundant (figure 3). In 1999, the life-expired deck was replaced again on a similar alignment. This permitted a further increase in train speeds as part of the *West Coast route modernisation project*.

21 The modern *reinforced concrete* deck provides approximately 4 metres clearance above normal water level. Three *continuous* longitudinal main beams support the concrete deck. Each beam is supported on a steel bearing at each abutment and pier position. This allows controlled horizontal movement to accommodate thermal expansion and contraction of the deck. Access walkways are fitted to the outer faces of the outer main beams (figure 4).

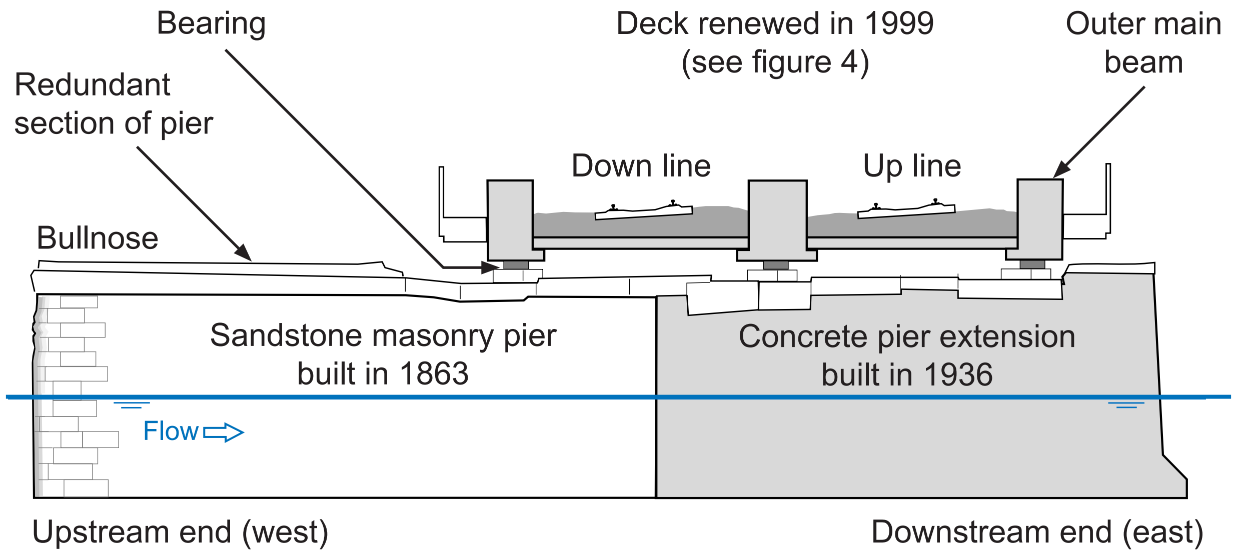

Figure 3: South face of pier 2 looking north, showing the position of current bridge deck in relation to the substructure. The up line is carried on the concrete pier extension (see also appendix D).

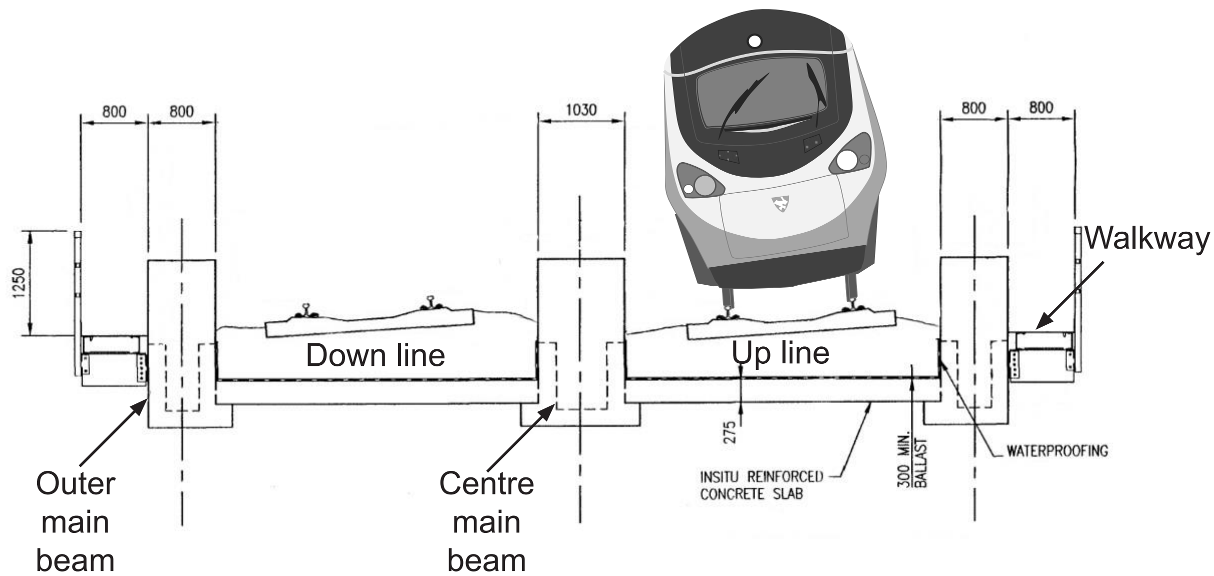

Figure 4: Cross-section through viaduct deck looking north, showing main beams and walkways

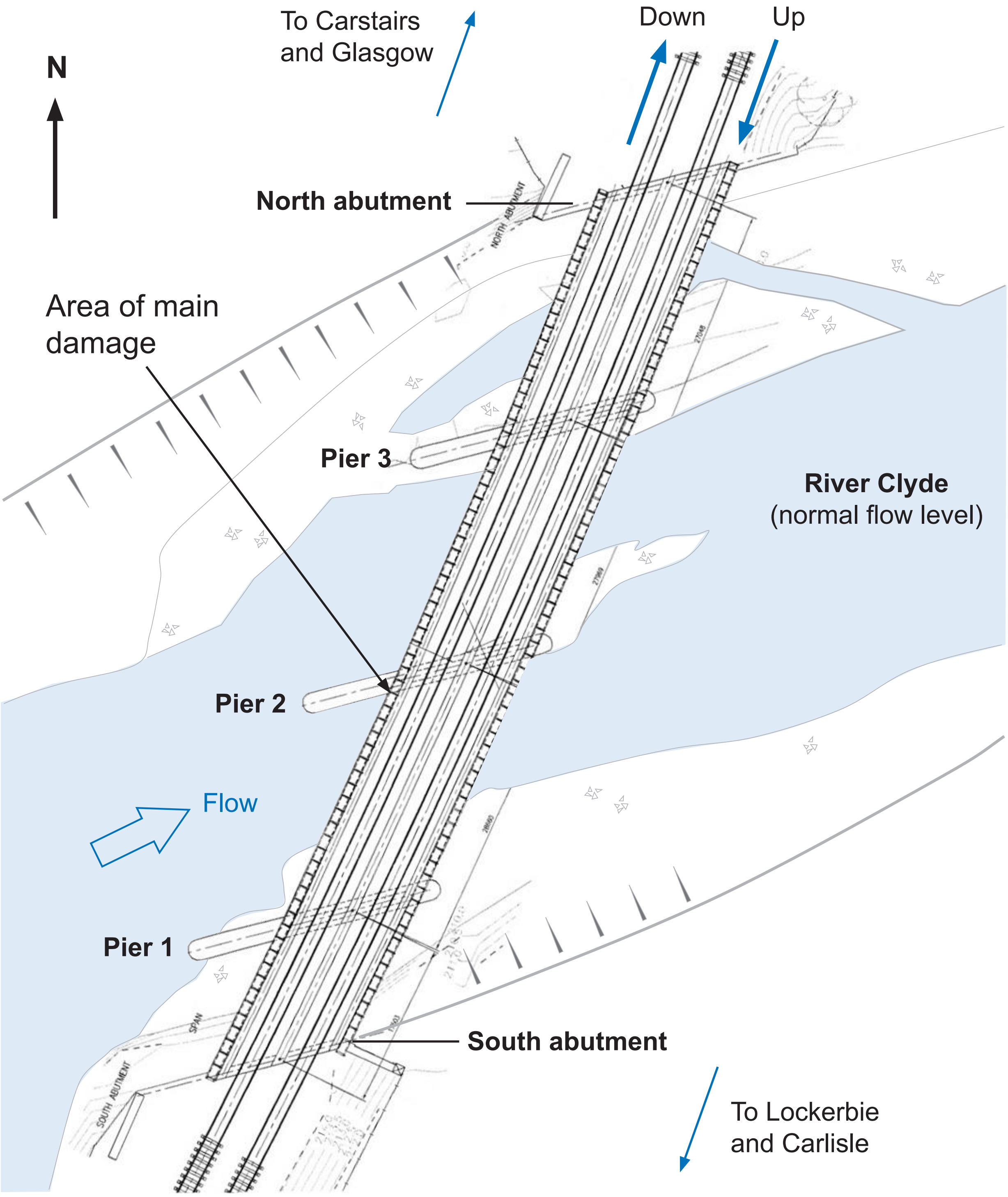

Figure 5: plan of viaduct showing arrangement of piers and abutments

22 Pier 1 is located on the south side of the river channel[4]. Pier 2 is the central pier and adjacent to the deepest part of the river, and pier 3 is on the north side of the channel, adjacent to the north abutment (figure 5).

[4] In accordance with Network Rail standard NR/L3/CIV/006/02C Issue 1 June 2010 'Handbook for the examination of Structures, Part 2C: Condition marking of Bridges', the labelling convention commences at the point of lowest mileage and the major elements are numbered with increasing mileage. Pier 1 is therefore adjacent to the south abutment as the mileage increases from Carlisle northwards.

23 The viaduct carries two tracks which are electrified with 25 kV overhead equipment. The track comprises *continuous welded rail* supported on concrete sleepers. There is an *insulated rail joint* on the up line, used by southbound trains, just south of the viaduct.

24 The Lamington area is provided with four-aspect colour light signalling, controlled from Motherwell signalling centre.

25 The viaduct had *telemetry* equipment fitted to allow water levels to be remotely monitored using an ultrasonic transducer. At the time of the incident, this equipment was not in use (refer to paragraph 112).

Staff involved

26 Track maintenance staff responsible for the section of West Coast Main Line between Beattock summit and Cambuslang (Glasgow), including the Lamington area, were based at Carstairs depot. Three members of staff from this depot, two of whom had over 20 years' experience in track (permanent way) maintenance, attended in response to the initial incident. The depot was led by the Carstairs *section manager (track)* (SM(T)) who reported to the *track maintenance engineer* (TME) at Motherwell delivery unit. During extreme weather, track maintenance staff were also responsible for monitoring vulnerable infrastructure (refer to paragraph 133).

27 The TME reported to the Motherwell infrastructure maintenance engineer (IME), who in turn reported to the Motherwell infrastructure maintenance delivery manager (IMDM). Motherwell was one of four maintenance delivery units covering Network Rail's Scotland Route[5].

28 The signaller was located at Motherwell signalling centre. Route Control staff, responsible for regulating the train service, were located at an integrated control centre in the West of Scotland Signalling Centre at Springburn, Glasgow. These staff will be referred to collectively as control room staff.

29 Civil engineering staff (asset engineers) responsible for managing the inspection and maintenance of structures in Scotland Route reported to the route asset manager for structures and buildings (RAM (structures)), and were based in Glasgow. The RAM (structures) team, together with teams responsible for other disciplines (eg *earthworks*, track, electrification & plant) reported to the director of route asset management (DRAM). For consistency, the term 'RAM (structures) team' will be used throughout this report, although the leader of this team was designated the territory structures engineer (TSE) until 2012.

30 The Route's minor works delivery team comprised technical staff responsible for managing contractors undertaking maintenance work on structures.

31 Drivers employed by various train operating companies were involved as described in the report.

External circumstances

32 The initial driver's report concerning the dipped (locally lowered) rail was made before dawn. Track maintenance staff arrived on site as it got light.

[5] In 2012, Network Rail devolved responsibility for day-to-day operation of Britain's main line railway to eight strategic routes.

33 The weather was damp when the initial report was made, but this followed a prolonged period of heavy rain during the previous 48 hours. The month of December overall had been exceptionally wet. Flow from the River Clyde into the sea was 249% of the December average measured between 1971 and 2000[6], setting a new record. For many Scottish regions, this was the wettest calendar month since records began in 1910.

[6] Hydrological Summary for the United Kingdom - December 2015, National Hydrological Monitoring Programme (NHMP).

The sequence of events

Events preceding the incident

34 During the 24 hours preceding the incident, the volume of water flowing under the viaduct was unusually high because of rainfall in south-west Scotland associated with the storm designated by the Met Office as *Storm Frank*. This weather system had been forecast in advance and Network Rail Scotland Route had implemented its *extreme weather plan* (EWP).

35 River flow gauges are located upstream of Lamington at Abington on the River Clyde, and at Maidencots on Duneaton Water, a major tributary which joins the Clyde near Abington (figure 6). These gauges are operated by the Scottish Environment Protection Agency (SEPA). The volume of water passing each gauge peaked at 12:00 hrs on 30 December 2015. The combined flow at the two gauges was the highest recorded since the Abington gauge was installed in 2004.

36 The peak flow reached Lamington viaduct, 10 km downstream of Abington gauging station, several hours later (figure 7). The discharge volume may have reached 360 m^3/s, based on the combined flow recorded at Abington and Maidencots gauging stations (337 m^3/s), plus an allowance for inflow from other watercourses which join the Clyde between the gauging stations and Lamington. The next SEPA gauging station downstream is at Sills of Clyde between Carstairs and Lanark, 31 km beyond Lamington. Peak flow here did not occur until 23:00 hrs on 30 December.

37 There was some disruption to train services due to speed restrictions imposed during the severe weather, but Lamington viaduct remained open with no special precautions relating to the safety of the structure. Between midnight and 07:28 hrs on 31 December, 18 trains crossed the viaduct without incident.

38 At 07:28 hrs on 31 December, the morning after the river had peaked at Lamington, the driver of the 06:52 hrs Edinburgh to London Euston via Birmingham service (*train reporting number* 9M50) crossed the viaduct on the up line at 110 mph (177 km/h). About one minute later, the driver used the train's *GSM-R* cab radio and informed the signaller "I've just come round the curve at Lamington, over the bridge which runs over the river and, I've never noticed it before, but there was a bit of a dip in the rail directly on the bridge". The driver subsequently stated that he had felt the train rock as the right-hand side of the train dipped down and back up again, and that this was something he had not noticed before at this location.

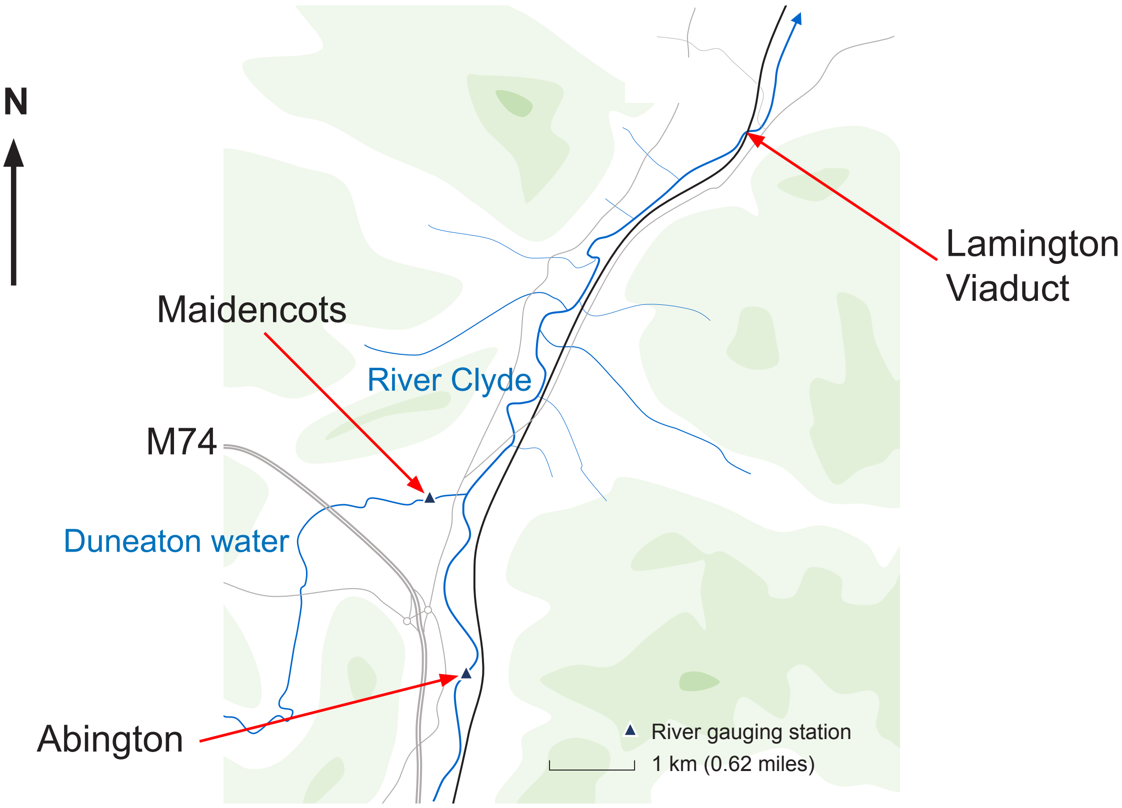

Figure 6: Map of part of the upper Clyde valley showing location of SEPA river gauging stations

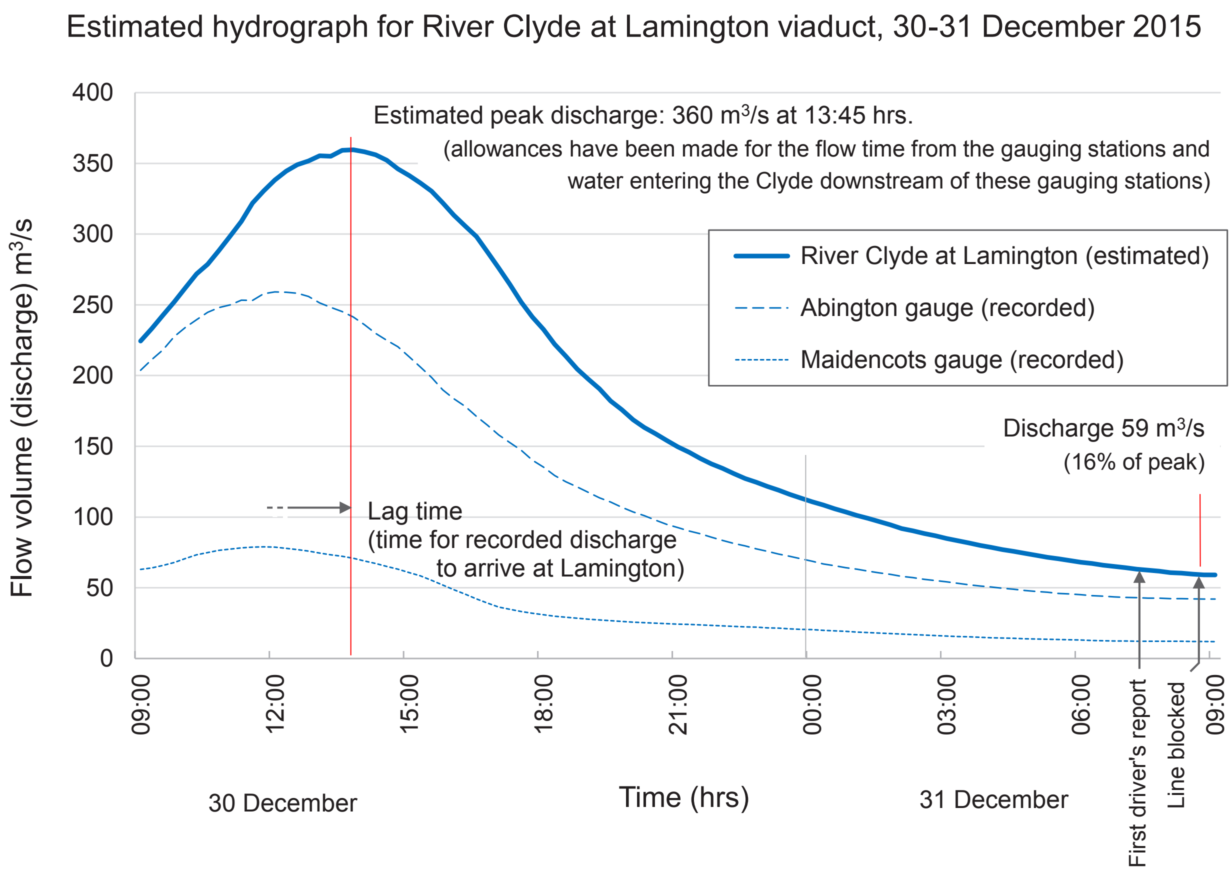

Figure 7: Hydrograph showing estimated river flow at Lamington viaduct for 24 hours from 09:00 hrs on 30 December

39 The driver's description indicates that the *six-foot rail*, close to the centre main beam, was affected, and implies that the west (upstream) end of the concrete pier extension which supports this beam had subsided. At this stage the track movement was probably quite small and would have been difficult to identify (see appendix D).

40 The signaller set the nearest *controlled signals* to danger on both lines so that drivers could be asked to provide further information on the reported track dip as they crossed the viaduct at low speed. He also informed Network Rail's control room staff who contacted track maintenance staff at Carstairs depot and asked them to go to Lamington and examine the track.

41 At 07:51 hrs, the 05:00 hrs Manchester Piccadilly to Glasgow Central service (1S30) crossed the viaduct on the down line, followed about a minute later by the 07:09 hrs Glasgow Central to Manchester Airport service (1M92) on the up line. Both services were travelling at low speed as instructed by the signaller. Both drivers reported that they neither saw nor felt anything amiss. The signaller had taken the additional precaution of instructing the driver of 1M92 to wait until 1S30 had crossed the viaduct before proceeding in case the dipped rail meant that the up line train leant sideways sufficiently to touch the train on the down line. A freight service followed at low speed on the up line, passing at 08:07 hrs (table 1).

Time passing	Head code	Service	Operator	Line	Speed (mph)[a]
07:03	1M07	06:30 Glasgow Central to London Euston	VTWC	Up	115
07:28	**9M50**	06:52 Edinburgh to London Euston via Birmingham	VTWC	Up	110
07:51	1S30	05:00 Manchester Piccadilly to Glasgow Central	FTPE	Down	10
07:52	1M92	07:09 Glasgow Central to Manchester Airport	FTPE	Up	10
08:07	4M25	06:06 Mossend to Daventry	DBS	Up	-
08:16	1M08	07:37 Glasgow Central to London Euston	VTWC	Up	20
08:36	9M51	08:00 Glasgow Central to London via Birmingham	VTWC	Up	80
08:40	**1S34**	05:57 Crewe to Glasgow (class 221)	VTWC	Down	110
08:50	1M93	08:12 Edinburgh to Manchester Airport	FTPE	Up	5
[a] Estimated by train drivers.					

Table 1: Trains crossing Lamington viaduct after 07:00 hrs on 31 December 2015

42 The track maintenance staff arrived on site at 08:12 hrs and started to inspect the track. Initially they focused on an insulated rail joint on the up line located just south of the viaduct. They believed this to be the most likely cause of the reported dip as it required occasional *packing* to maintain track alignment. They then inspected the track over the viaduct which had no history of maintenance issues.

43 At 08:16 hrs, the 07:37 Glasgow Central to London Euston service (1M08) passed on the up line at low speed.

44 At about 08:35 hrs the track maintenance team leader informed the signaller that that there were a couple of minor dips on the up line that he wanted to attend to[7]. When asked, he confirmed that the down line was "fine", and authorised the signaller to remove the speed restriction on both lines. Shortly afterwards, the 08:00 Glasgow Central to London Euston via Birmingham (9M51) passed on the up line at 80 mph (129 km/h) without incident.

Events during the incident

45 At 08:40 hrs, the 05:57 hrs Crewe to Glasgow service (1S34), a class 221 Super Voyager, approached on the down line at 110 mph (177 km/h). The track maintenance staff watched this train cross and noticed an unusual up and down movement between the carriages. The train driver did not notice anything unusual, but when asked following his arrival at Glasgow, he informed his employer that he had felt a slight dip on the driver's side (ie a dip in the *cess rail* adjacent to the outer main beam adjacent to the down line, and affecting the left-hand side of the train).

46 Immediately after this train had passed, the track maintenance team leader contacted the signaller to request a 10 mph (16 km/h) emergency speed restriction on both lines, stating that he had observed "quite a dip" on the down line across the viaduct. At 08:45 hrs, he contacted the signaller again, stating that he had spoken to his supervisor who advised him to impose a 5 mph (8 km/h) temporary speed restriction on both lines until the bridge had been examined. The track maintenance staff were unaware that the viaduct had been assessed as being vulnerable to scour and did not immediately associate the track movement with possible structural damage.

47 At the same time, another member of the track maintenance team informed control room staff that he had observed "great big sweeping dips in the track" (figure 8). He also reported that the *cant* of the track had deteriorated on both lines in the middle of the viaduct and that there may have been subsidence. He requested the attendance of a bridge examiner.

Figure 8: 'Sweeping dip' affecting down line on 31 December 2015 after closure. At this stage, the track had dropped by 70 mm (photograph courtesy of Network Rail)

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[7] Minor dips can often be corrected without restricting train movements.

48 At 08:50 hrs, the 08:12 hrs Edinburgh to Manchester Airport service (1M93) crossed on the up line at 5 mph (8 km/h). The driver reported that he did not feel any unusual movement as the train crossed the viaduct.

49 At 08:52 hrs, the track maintenance team leader instructed the signaller to close the line, stating that they had discovered structural problems on one of the supports holding the viaduct up. The team had seen that a masonry block was missing and that there was a visible crack in the pier (figure 9). A bridge examiner arrived on site at approximately 11:00 hrs to commence an examination.

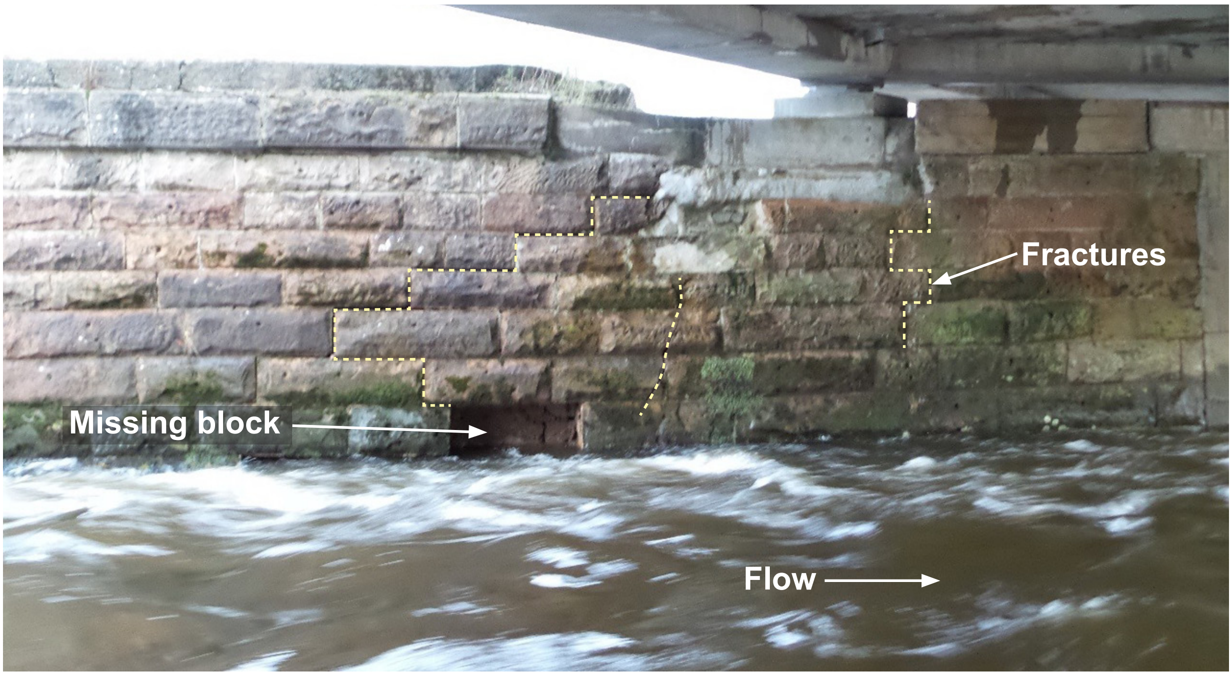


Figure 9: South face of pier 2 on 31 December 2015 showing missing block and fractures (photograph courtesy of Network Rail)

Events following the incident

50 An underwater survey was attempted by divers on 1 January, but abandoned until the following day because the river flow was still too fast (figures 10 and 11). The survey found substantial scour damage affecting the masonry section of pier 2 and a void under the full width of the concrete pier extension.

51 Pier 2 continued to move after the line was closed. By early January, the outer main beam adjacent to the down line had dropped by 130 mm. The pier had also tilted by 180 mm towards the south abutment, displacing the bearings supporting the main beams (figure 12), causing the deck to subside and twist. A civil engineering contractor, brought in by Network Rail to stabilise and repair the structure, imposed an exclusion zone on and below the deck because of the risk that the pier might overturn or collapse.

Figure 10: Aerial view on 1 January 2016 (photograph courtesy of Network Rail Air Operations)

Figure 11: South face of pier 2 on 1 January 2016 prior to start of emergency stabilisation works. Note that the operative's safety harness is anchored to the adjacent overhead electrification mast (photograph courtesy of Network Rail Air Operations).

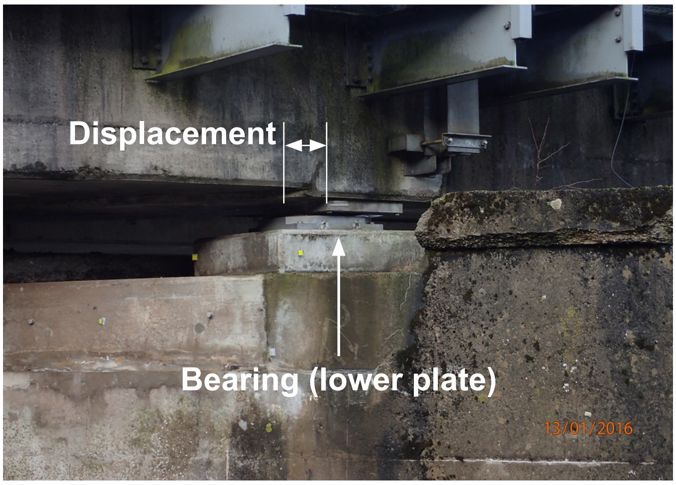


Figure 12: Bearing supporting outer main beam adjacent to the up line at the east end of pier 2. The bearing's lower plate is displaced to the left of its upper plate due to tilting of the pier

52 Network Rail did not notify the RAIB of this incident until 7 January 2016 due to an administrative oversight.

53 A stone causeway was built into the river on the west side of the viaduct to protect the south face of pier 2 and to provide access for emergency stabilisation works. This forced the river flow through the two northern spans (figure 13). The void under pier 2 was filled using approximately 50 m³ of concrete. To prevent further pier rotation, a further 400 m³ of concrete was placed on the south side of this pier in a major operation that ran continuously from 9 to 12 January. The total weight of concrete placed in the river exceeded 1000 tonnes.

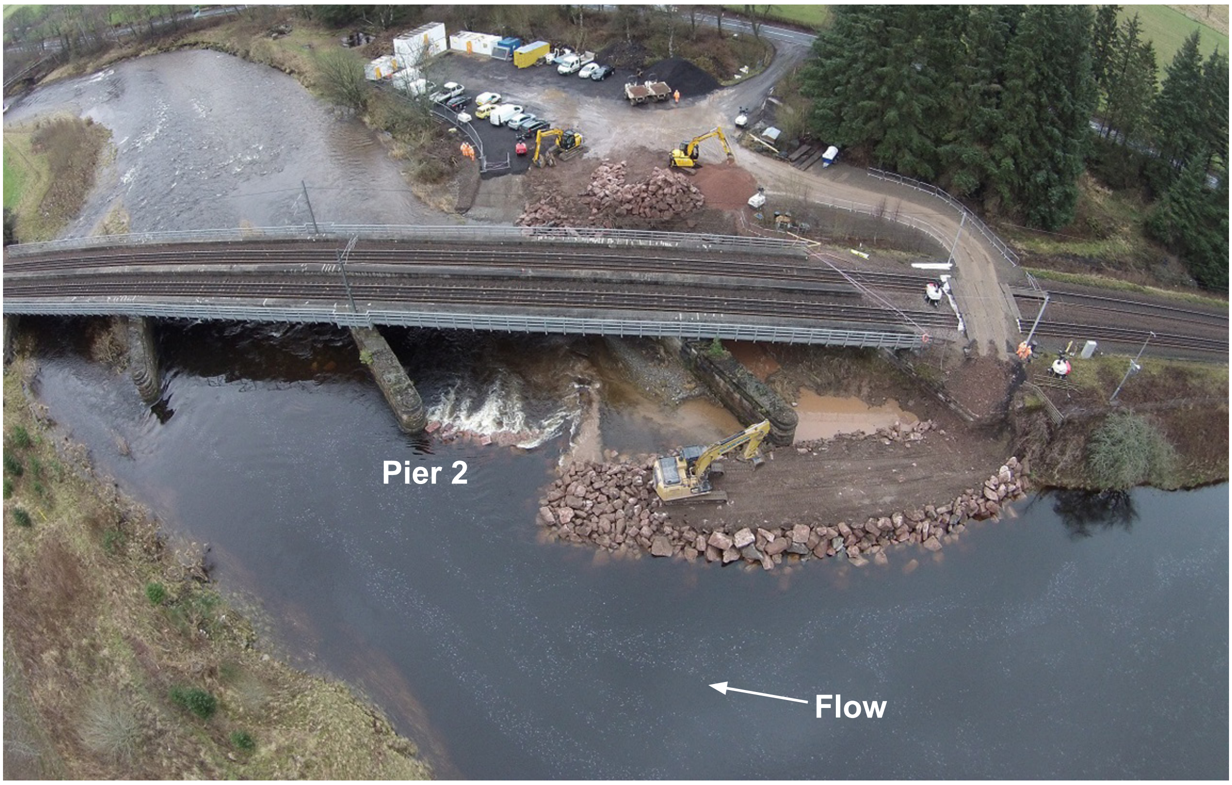


Figure 13: Stone causeway under construction from the south abutment to provide access to pier 2 on 6 January 2016 (photograph courtesy of Network Rail Air Operations)

54 Subsequent periods of high river flow caused further scour damage. On 10 January, a 7 m redundant section of pier 3 collapsed (figure 14). On 27 January, a similar length of the north abutment and part of the approach embankment, including a disconnected overhead electrification mast, collapsed into the river (figure 15). On both occasions, the flow was significantly less than on 30 December 2015, but it was constricted by the stone causeway which would have increased the water velocity.

Figure 14: Scour damage to redundant section of pier 3 on 10 January 2016 (photograph courtesy of Network Rail Air Operations)

55 Pier 2 was stabilised in its final position by the construction of an additional reinforced concrete jacket on each side, attached with steel dowels to the original masonry and mass concrete pier, and anchored into the underlying ground. The steel bearings were replaced on modified concrete plinths, and the deck jacked back into its correct position to allow the line to reopen on 22 February 2016 (figure 16). Services were seriously disrupted while repairs were completed as trains were either diverted or replaced by road transport.

Figure 15: Scour damage to north abutment and embankment on 27 January (photograph courtesy of Network Rail Air Operations)

Figure 16: Pier 2 stabilisation works after removal of upstream end (photograph courtesy of Network Rail)

Key facts and analysis

Immediate cause of the dangerous occurrence

56 **A train passed over the subsiding viaduct at high speed.**

57 The 05:57 Crewe to Glasgow Central service crossed the viaduct on the down line at 08:40 hrs, travelling at approximately 110 mph (177 km/h). Although the train driver saw and felt nothing unusual, the track maintenance staff observed unusual movement between the carriages. After the train has passed, they noticed large dips in the track which had developed since their inspection a few minutes earlier. The sudden change in the track condition suggests that the viaduct deck moved beneath this train.

Identification of causal factors

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

a. High river flow velocity undermined a viaduct pier (paragraph 59).

b. Scour protection for the piers and abutments was not provided in a timely manner (paragraph 70).

c. Trains were allowed over the viaduct at high speed before the possible presence of scour damage had been assessed (paragraph 95).

Each of these factors is now considered in turn.

Water action

59 **High river flow velocity undermined a viaduct pier.**

60 The sudden movement of the viaduct deck was caused by scour damage to pier 2. The scour damage is likely to have been initiated during the period of peak flow, when the water velocity was highest, during the afternoon of 30 December (paragraph 36). The exact failure sequence is unknown, but subsidence of the concrete pier extension was apparent by 07:28 hrs on 31 December (paragraph 38).

61 A diving survey on 2 January 2016 reported scour damage over a 21 metre length of the 28 metre long pier. The masonry section had partially collapsed and divers found a 1 metre deep scour hole underneath the concrete pier extension, with only its downstream end remaining supported (figure 17). It is probable that the masonry section also had its foundation undercut by scour with masonry falling into the resulting scour hole. Weak or missing mortar (refer to paragraphs 89 and 90), made it more likely that the water action would allow scour to displace the lowest level of blocks, with further blocks dropping downwards as each successive course was undermined.

62 The missing block reported by the track maintenance staff at 08:52 hrs on 31 December (paragraph 49) was at the top of a pyramid-shaped void in the south face of pier 2, suggesting that significant damage had already occurred below water level. The void extended down by seven courses (2.8 metres) to the base of the structure. At its widest, the erosion extended 1.8 metres into the 2.1 metre wide solid masonry pier (figure 18), and beneath the concrete pier extension. The survey data shows that the total volume of masonry lost exceeded 20 m^3, comprising 50 or more sandstone blocks, each weighing between 0.3 tonnes and 0.9 tonnes. It is likely that this damage occurred over a number of hours, gradually weakening the pier, although its north face remained intact providing residual support to the deck.

63 The relationship between scour damage and the dip felt at 07:28 hrs (paragraph 38) is illustrated in appendix D. The dipped rail on the up line was directly above a scour void beneath the concrete pier extension. It is likely that the loads imposed by train 1S34 passing over the viaduct at high speed at 08:40 hrs were the trigger for the large track movements seen after this train passed. It is likely that these loads fractured the already weakened masonry pier causing it to suddenly subside. Earlier trains would have imposed similar loads, but at a time when scour damage had not developed sufficiently for these loads to trigger a significant track movement.

64 Irregular surfaces, such as those created by scour damage, increase water turbulence and so increase the scour risk. The likelihood of this occurring is higher when the flow velocity is increased. Pier 2 is adjacent to the main flow channel in the centre of the river where the water velocity is usually highest. The upstream bend causes the flow to strike the south side of the pier with an *angle of attack* of approximately 5-10 degrees[8]. Scour assessments by JBA Consulting (refer to paragraphs 76 to 79) have shown that even a slight angle of attack can increase the risk of *local scour* affecting a structure.

65 The missing masonry blocks were not found above river bed level by the divers and would have been too heavy to wash downstream. In addition, there is no abnormal surface turbulence visible in photographs taken on 31 December 2015 and 1 January 2016 (figure 9, figure 10 and figure 11). This evidence suggests that a scour hole had developed in the river bed that was of sufficient size and depth to accommodate the missing masonry from the pier. Once the angular masonry blocks started to pile up on the scoured river bed, they will have created a weir-effect, increasing turbulence and the risk of further scour occurring upstream and downstream.

River conditions on 30 December 2015

66 If the river’s peak discharge volume reached 360 m^3/s at Lamington viaduct on 30 December (paragraph 36), this would be equivalent to a flood with a 1 in 50 probability of being exceeded in a given year. This figure was established in a detailed scour assessment undertaken in 2013 (refer to paragraph 79).

[8] JBA initial scour assessment report, April 2005.

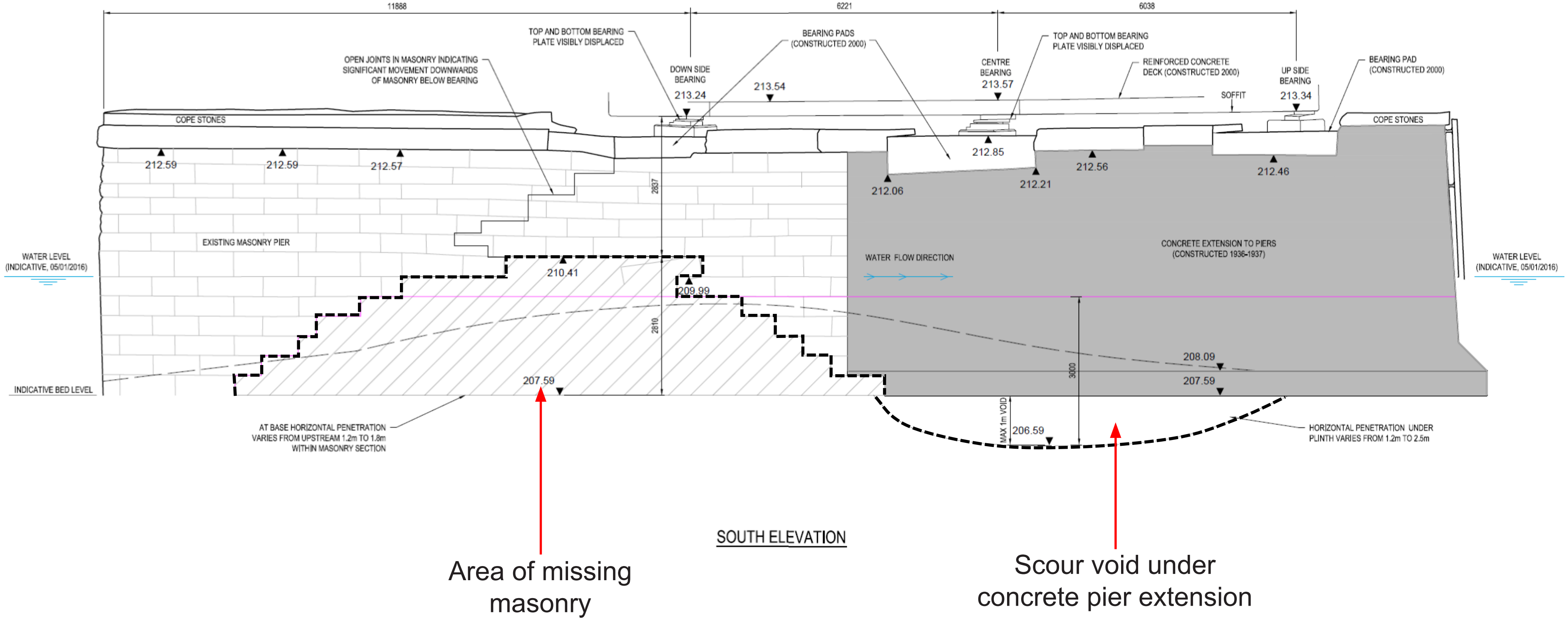
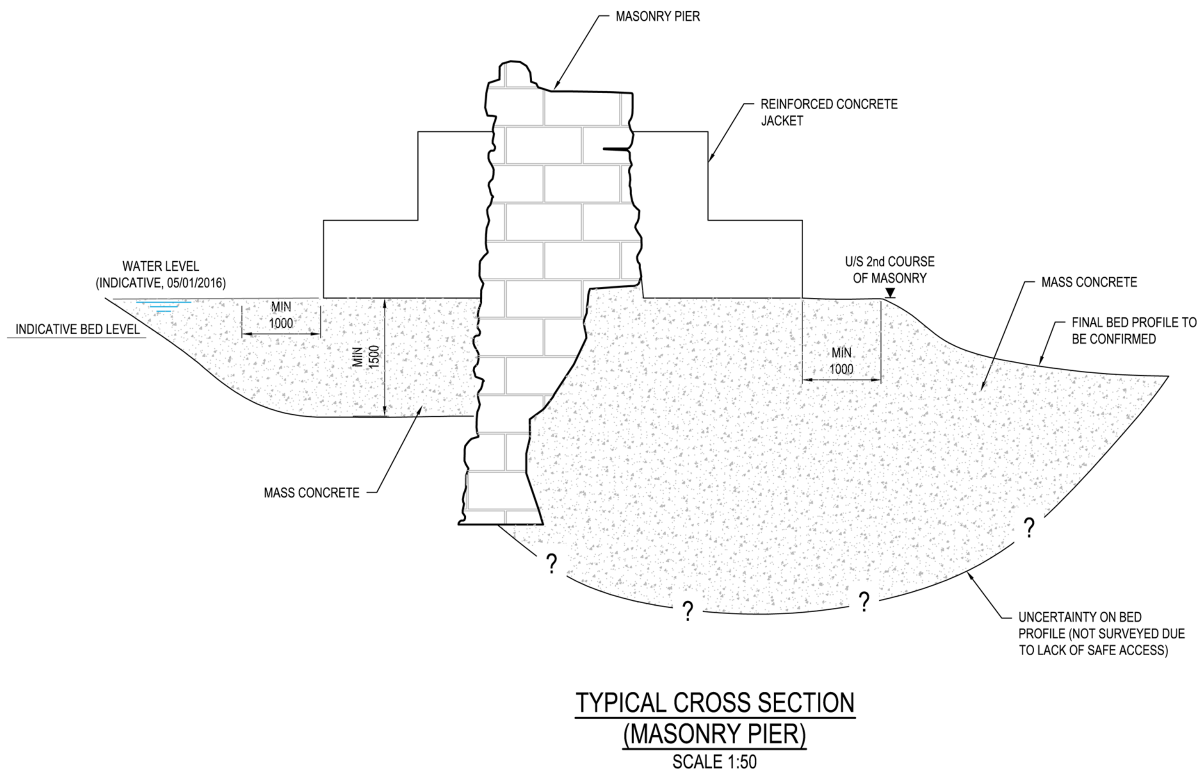


Figure 17: South face of pier 2 showing scour damage recorded by divers on 2 January 2016 (courtesy of Network Rail)



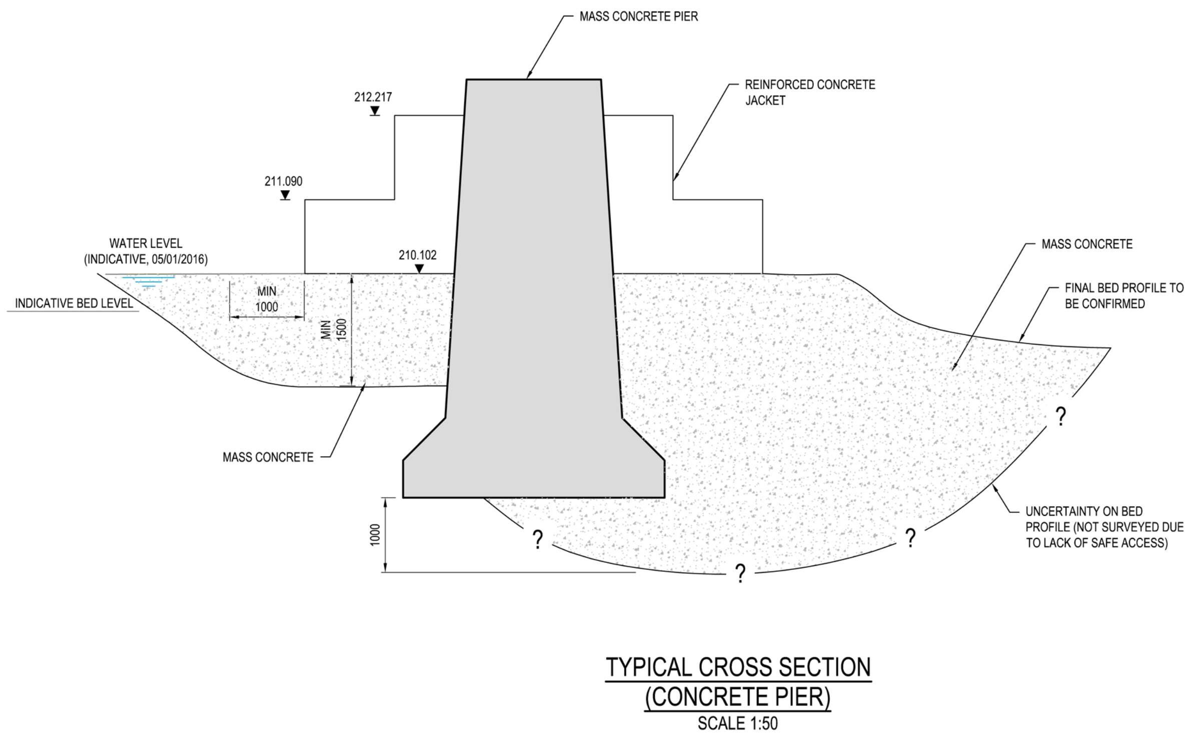


Figure 18: Cross-sections through pier 2's masonry section (upper) and concrete pier extension (lower) showing extent of scour damage recorded by divers on 2 January 2016. The reinforced concrete jackets installed to stabilise the pier are also shown (courtesy of Network Rail).

67 Historic river flow evidence is consistent with this assessment of probability. Although the river level on 30 December 2015 was high, witnesses confirm that it was not unprecedented. Comparable floods[9] also occurred on 20 November 2009 and 30 December 2013 without apparently damaging the structure (figure 19). Although the structure may have been at significant risk during these events, the absence of significant damage shows that previous behaviour may not be a reliable indicator of risk.

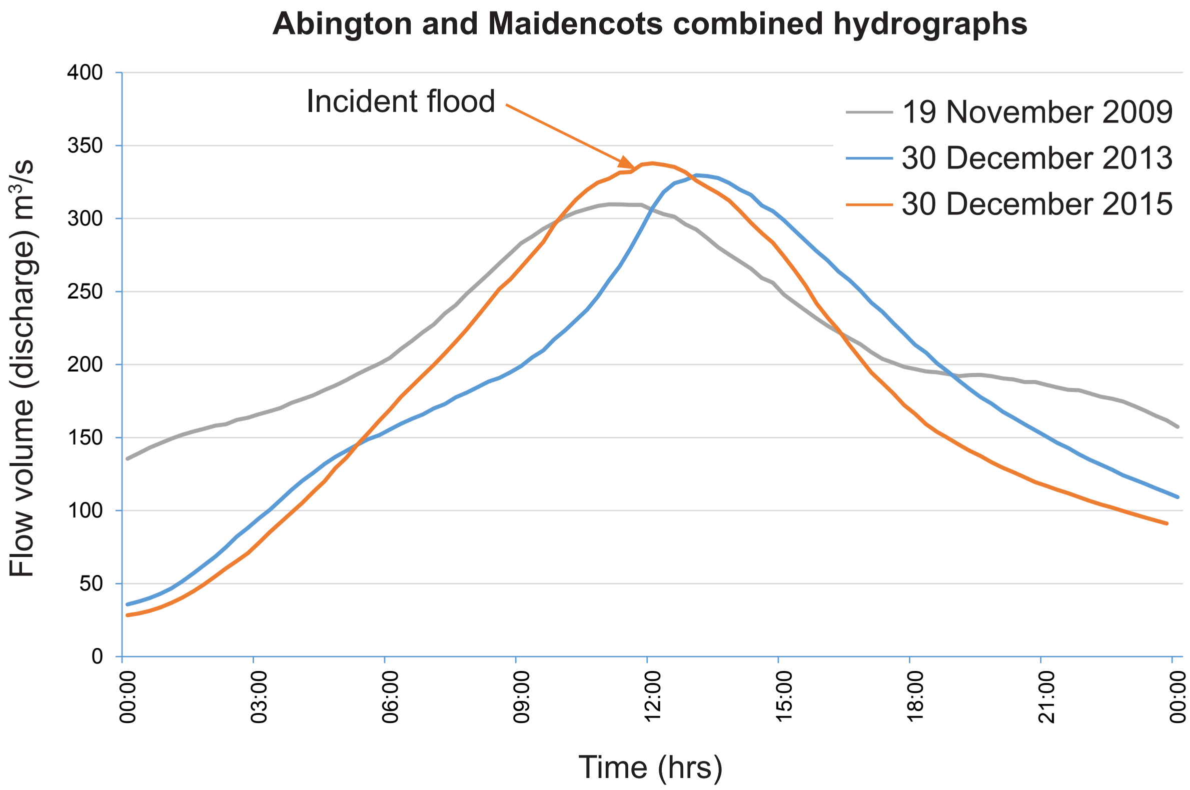


Figure 19: Hydrographs for flood events in 2009, 2013 and 2015, recorded by SEPA's Abington and Maidencots gauging stations

68 The reason that scour damage occurred on this occasion when the structure had withstood previous similar flood events cannot be established with certainty. It is probable that it was a combination of the following factors:

a. Changes to the river bed profile, first observed in July 2000 (refer to paragraph 93).

b. The cumulative effect of repeated flood events during December 2015 (paragraph 33). Scour holes will sometimes form naturally during periods of fast river flow, and then fill during periods of slower flow. The frequent high flows during late 2015 may have prevented the voids being refilled.

69 In some circumstances, general structural deterioration can reduce resistance to scour. However, the RAIB has found no evidence that this played a significant role in the incident on 31 December (refer to paragraph 152).

[9] SEPA hydrological data.

Scour protection

70 **Scour protection for the piers and abutments was not provided in a timely manner despite strong evidence that the structure was at risk, and an opportunity to address the problem when the deck was renewed.**

Scour risk management

71 Scour has the potential to undermine bridge foundations and cause a collapse with serious consequences. Network Rail manages this risk using a process introduced following the collapse of a bridge due to scour at Glanrhyd[10], on the Central Wales line in 1987. This caused four deaths (refer to paragraph 168).

72 Network Rail assessed the risk to its bridges over flowing water using a method developed by British Rail and Hydraulics Research Wallingford (HR Wallingford) following the Glanrhyd accident. A process known as EX2502[11] was used to undertake an initial assessment, and to establish a *scour priority rating* for each structure. This allows the structures at highest risk to be identified for further detailed assessment and possible remedial action.

73 The assessment process considers factors such as the gradient of the river, its width and depth, the ratio of the channel width to the bridge width, the river bed material, the water flow's angle of attack, the foundation depth and the pier shape and dimensions. Local scour risk is assessed by comparing the calculated scour depth with the structure's foundation depth if known. An EX2502 priority rating of 10 indicates that the risk is low. A priority rating greater than 16 indicates that a structure is 'high priority' (ie at high risk of scour). Each element of a structure (eg abutments, piers) is scored individually, with the highest rating reported.

74 Railway scour protection schemes are designed to provide protection against a 200-year design flow, which represents a flood with a 1 in 200 probability of being exceeded in a given year (sometimes described as a 200-year return period, or as a 1 in 200-year event). This is in accordance with published industry guidance[12]. At Lamington, this would correspond to a flow of 430 m^3/s, almost 20% greater than the estimated maximum flow on 30 December 2015 (paragraph 66).

Scour assessments for Lamington viaduct

75 The location of the viaduct on a bend in the river means that it has always been vulnerable to scour. To mitigate this risk, it has received underwater examinations most years since at least 1994.

[10] Department of Transport: Report on the collapse of Glanrhyd Bridge on 19th October 1987. HMSO.

[11] Report EX2502 'Hydraulic Aspects of Bridges: Assessment of the Risk of Scour', HR Wallingford, February 1993, incorporated in Group Standard GC/TT0140, British Railways Board, January 1994.

[12] RSSB T554 'Safe management of railway structures - flooding and scour risk' (2005), and CIRIA C742 'Manual on scour at bridges and other hydraulic structures' (2015).

76 In 2005, JBA Consulting undertook an initial (stage 1) scour assessment using the EX2502 process on behalf of Network Rail. This was the first formal assessment of the scour risk at this site, undertaken as part of a national programme to manage the risk arising from scour and flooding following the publication of Network Rail standard NR/SP/CIV/080[13] in April 2004. As part of this assessment, three inclined core holes were drilled into the viaduct's substructure. The core holes were drilled through the masonry and concrete sections of pier 1, and through the concrete section of pier 2. This investigation found that the piers were founded on gravel and clay. It also provided information on the depth of each foundation below the adjacent river bed, but without relating this information to a datum level. Pier 2 was found to have a foundation depth of just 0.375 metres.

77 The assessment categorised the viaduct as high priority with an EX2502 scour priority rating of 16.95. It identified that pier 2 was at greatest risk because of its shallow foundation. The assessment report recommended:

a. arranging for the receipt of flood warnings and acting accordingly;

b. seeking specialist advice to carry out more detailed hydraulic studies;

c. undertaking regular inspections for scour and flood damage; and

d. carrying out underwater inspections each year.

78 JBA Consulting undertook a second initial scour assessment in 2010. It is not clear why a second initial assessment was commissioned at this stage instead of a detailed (stage 2) assessment, but the conclusions were very similar to the 2005 assessment.

79 A detailed scour assessment was not undertaken until 2013, eight years after the initial scour assessment, and after planning for a permanent scour protection scheme had commenced (refer to paragraph 81). This assessment was also undertaken by JBA Consulting, who gave a final scour priority rating of 16.66 for pier 2 and confirmed Lamington viaduct as a high priority structure. This was relatively unusual as the initial scour assessment method uses conservative assumptions, and most detailed assessments result in the priority rating being reduced. The study confirmed that pier 2 was vulnerable to scour because of its shallow foundations. The assessment derived flows for a range of flood events using a hydraulic model and the Flood Estimation Handbook, a UK industry-standard reference. This assessment found that the profile of the river bed meant that the water velocity in the channel adjacent to pier 2 would be high (ie over 2 m/s), resulting in a risk of bed erosion, even during a relatively common flooding event with a 1 in 2 probability of being exceed in a given year.

Scour protection proposals

80 Prior to the development of a scour protection scheme for Lamington viaduct, it received underwater examinations during most years. The intention was to give the RAM (structures) team the information necessary to manage the structure safely until work to strengthen its resistance to scour could be justified. The shortcomings in this approach are apparent from the fact it did not prevent dangerous scour at Lamington.

[13] Network Rail standard NR/SP/CIV/080 Issue 1 April 2004 'Management of existing bridges and culverts', clause 9.3.

81 In August 2012, the RAM (structures) team listed a scour protection scheme for Lamington as a major works renewal item for the first time. This followed a review of historic scour assessment reports in preparation for additional funding expected to be available from April 2014 (refer to paragraph 149). Lamington was prioritised due to its location on the West Coast Main Line and known shallow foundations.

82 Network Rail's Infrastructure Projects division was instructed to progress the scheme, and it commissioned JBA Consulting to design the scour protection. In August 2014, the RAM (structures) team received drawings for a proposed scheme, designed to provide the required scour protection for a 200-year design flow. The scheme encompassed the three intermediate piers, both abutments, and a section of the south approach embankment where the railway runs parallel to the river for about 300 metres (figure 2).

83 Options to reduce the scope and cost of the scheme were then considered, but in January 2015 the RAM (structures) team approved the full scheme, for implementation during the following summer. However, in August 2015, Network Rail Infrastructure Projects requested authority to defer the scheme until the next financial year due to environmental permissions not being sought in time for the work to be completed during the low flow summer period. Two other Scotland Route scour protection schemes were deferred for the same reason.

84 A formal deferred renewal risk evaluation was then undertaken and, as there were no new defects noted by the latest visual examination, the RAM (structures) team concluded that deferral was acceptable, and set a review date of February 2016. The risk evaluation proposed that structure be added to the list of structures at risk in extreme weather. However, it was already on this list (refer to paragraph 109).

Deck renewal project

85 In 1990, British Rail commissioned ground investigation work at Lamington to determine the nature and condition of the soils and the construction make-up of the bridge supports. Holes were drilled into the masonry and concrete sections of piers 1 and 2. These showed that the sandstone masonry was solid and resting directly on the underlying gravel which was described as 'very dense'. It is likely that this work was undertaken either in response to the Glanrhyd bridge failure (paragraph 168), or in anticipation of the need to renew the viaduct deck which was almost life-expired (paragraph 20).

86 In May 1999, Railtrack (British Rail's successor) let a *design and build* contract to renew the viaduct deck during a 5-day track *possession* in October 1999. This major investment provided an opportunity to install scour protection to pier 2. This had been recommended in underwater examination reports undertaken in 1997 and 1998 during the planning phase of this project.

87 Railtrack had already commissioned a civil engineering consultancy to 'assess the suitability of the existing substructure (bridge piers and abutments) and foundations to support a renewed superstructure or bridge deck.' The consultancy engaged a ground investigation contractor to drill boreholes to sample the underlying strata, and to drill core holes into the substructure to determine its condition. It also engaged a diving engineer to examine the substructure.

88 The site investigation took place in May 1999. This revealed that the masonry sections of piers 1, 3 and the north abutment were founded on sand and gravel at shallow depth, and not on a masonry/concrete foundation slab or rock as could be inferred from a pier construction drawing[14] dating from 1863. Holes were not drilled into pier 2 as Railtrack had limited the site investigation to land-based locations.

89 It is unclear whether the consultancy had access to the 1990 coring records (paragraph 85), but the two investigations taken together encompassed the masonry sections of both abutments and all three piers. In every case, the sandstone masonry was founded directly onto gravel. As this material was very dense, it is possible that the foundation slab was considered unnecessary.

90 The diving engineer found evidence of a foundation layer, reporting that '*the base course of blocks appears to be resting on a semi-circular stone or concrete plinth*.' This description suggests that a plinth was built below the rounded upstream end of pier 2, known as the 'bullnose', although possibly nowhere else. The diving engineer also reported that there was evidence of scour damage, and that the mortar was soft and had been washed out of the joints between blocks over the lower metre of the structure, affecting the underwater sections of all three piers. He found voids behind the north side of the pier 2 bullnose, but was unable to examine the south side of the pier due to the strong current.

91 The ensuing report, 'Investigation of Existing Piers and Abutments', was issued to Railtrack in October 1999. It included the following conclusions and recommendations:

> *'The 1930's concrete used to extend the original substructures is voided and honeycombed in places and it is recommended that this concrete is grouted.*
>
> *We recommend the masonry be pressure grouted and repointed where necessary to ensure their adequate performance.*
>
> *The dive survey revealed damage to the piers and it is recommended that additional scour protection is provided to the existing piers.'*

92 Further correspondence between the main parties involved in this project referred to the need for additional works driven by the condition of the substructure and the discovery that the piers were not founded on rock as previously believed. As this work was not part of the original viaduct deck renewal contract, it would have required an instruction from Railtrack and additional funding. A letter from the deck renewal contractor to Railtrack in December 1999 asked for a list and specification of the works required. There is no record of Railtrack instructing the deck renewal contractor to carry out this additional work.

[14] Drawings held by the National Records of Scotland.

93 A routine underwater examination in July 2000 found evidence that the deck renewal works had caused long-term change to the river bed. Some of this may have been inevitable as the river had to be temporarily narrowed during the works, increasing the flow velocity and risk of bed erosion. However, the report found that there had been 'poor overall attention to bed sculpting exercised after completion of works' and that the main flow was through a 'significantly deeper channel alongside pier 2'. It also observed that an opportunity had been missed to remove material from the outer spans and lower the flood impact on the structure. The deck renewal contractor has stated that construction materials, including temporary piers founded on the existing river bed, were fully removed to the satisfaction of Railtrack on completion of the works.

94 Evidence of changes to the river flow caused by the deck renewal project has been corroborated by local residents. They have observed changes to the river's behaviour during flood conditions since the project was completed, including an increase in water being funnelled through the centre spans. These changes would have been taken into account during subsequent scour assessments (paragraphs 76 to 79).

Dangerous occurrence

95 **Trains were allowed over the viaduct at high speed before the possible presence of scour damage had been assessed.**

96 The lack of information on river conditions available to control room staff meant that they were unaware that the track dip reported at 07:29 hrs on 31 December might be linked to scour damage. They were also unaware that Lamington viaduct had been assessed as being at high risk of scour because the procedure listing these structures was not in use (refer to paragraph 128). As a result, control room staff did not advise the signaller to stop or place limitations on train movements.

97 If structural damage had been suspected, signallers and control room staff would not have been permitted to use trains to examine the line[15].

98 Although the vast majority of track faults are directly related to track condition, the driver of 9M50 specifically identified that the dip in the rail was on a bridge (paragraph 38). This suggests that signalling and control room staff should have given consideration to the possibility of damage to the structure rather than just considering possible track defects.

99 Evidence from site, including train driver reports (paragraph 41) and initial observations by track maintenance staff (paragraph 44) did not suggest there was a significant track defect. As structural damage had not been considered, the signaller had no reason to continue the speed restriction after track maintenance staff authorised the restoration of line speed.

[15] Railway Rule Book module TS1 clause 20.1

Identification of underlying factors

Management of scour risk

100 **There was no effective process for managing scour risk on Scotland Route and this had not been recognised by Network Rail.**

101 Scour risk mitigation required during high river flows was not applied at Lamington, or at almost all other Scotland Route structures requiring similar mitigation. This was due to technical and organisational shortcomings in the mitigation process. This required control room staff to initiate Network Rail's response to high river flows, but these staff were not using the document describing this requirement.

102 The requirement to identify and manage scour risk at structures was mandated by Network Rail standard NR/L1/CIV/032[16] which stated (clause 9.3.1):

> *'For their relevant geographic area, the Territory Civil Engineer (TCE) is responsible for the production of local EWP that defines (a) the procedure for receiving a formal notification of an extreme weather event (or of such an impending event), and (b) the actions to be followed on receipt of a formal or informal notification of such an event.'*

103 Further details were given in clause 6.1 of Network Rail standard NR/L3/TRK/1010[17] which stated:

> *'The Territory Civil Engineer (TCE) shall produce a local procedure (Extreme Weather Plan (EWP)) in accordance with NR/L1/CIV/032 Management of Existing Structures covering actions to be taken in the event of scour, storms, flooding or high tides. This plan includes a register of structures, earthworks other key locations (such as location cabinets and cuttings) at risk of damage from water and where sea water may affect the operation of traffic. … [The plan shall contain details] of the lines of communications and interactions between the TCE, Infrastructure Maintenance Delivery Manager (IMDM), Infrastructure Maintenance Engineer (IME), and the Environment Agency (EA) or the Scottish Environment Protection Agency (SEPA).'*

104 The territory civil engineer, and territory structures engineer who reported to the territory civil engineer, were asset manager roles. Their responsibilities included identifying actions needed to maintain structure safety and arranging for these to be carried out by other parts of Network Rail or by other organisations. In 2012, director of route asset management (DRAM) teams were set up in each route as part of Network Rail's devolution programme. The territory civil engineer's responsibilities under standard NR/L3/TRK/1010 transferred to the director of route asset management[18] and the territory structures engineer's responsibilities transferred to the RAM (structures) (paragraph 29). Similarly, responsibility for earthworks transferred from the territory earthworks engineer to the RAM (earthworks) and for track from the territory track engineer to the RAM (track).

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[16] Network Rail standard NR/L1/CIV/032 Issue 2, September 2009: 'The management of structures'.

[17] Network Rail standard NR/L3/TRK/1010 Issue 2, July 2013: 'Management of responses to extreme weather conditions at structures, earthworks and other key locations'.

[18] Network Rail Letter of Instruction: NR/BS/LI/292, 18 July 2013.

105 The extreme weather planning requirements related to structures were covered by several Network Rail standards, principally NR/L1/CIV/032 and NR/L3/TRK/1010. These required the identification of at risk structures and associated mitigation. As part of this process, standard NR/L1/CIV/032 (clause 9.3.2) required structures to be assessed for their susceptibility to flooding and water action (ie including susceptibility to scour), and for this to be recorded. The standard included a list of factors to be considered in this assessment which included:

- the depth and type of the foundations to the structure (including piers and abutments);
- the destabilising effects of a high water level acting alone and in combination with the effects of scour; and
- the condition of the structure.

106 The Scotland Route's EWP consisted of several documents with structures covered by the route's Flood Action procedure[19]. This was published in 2004 as an operating procedure, and acted as a flood warning plan for structures which had been assessed as being susceptible to damage as a result of scour in accordance with Network Rail standard NR/SP/CIV/080. The procedure described how warnings would be received and the actions to be taken, and included a list of the structures affected, which were categorised as either 'High Risk' or 'At Risk'.

107 The Flood Action procedure described scour mitigation arrangements being triggered by control room staff receiving an adverse weather warning or flood/scour alarms for specific structures. The arrangements required control room staff to inform the TME and section manager (track) for the area affected. They would then arrange for a competent person (watchman) to manually monitor river levels at all High Risk and At Risk structures in their section, unless installed telemetry equipment provided remote monitoring of water levels.

108 In addition to monitoring the water level, the watchman's duties included checking for debris and unusual water turbulence as indicators of increased scour risk or possible damage. On all High Risk structures and some At Risk structures, yellow and red markers were painted onto a pier or abutment for the guidance of staff. The Flood Action procedure included a flow chart which required the following actions to be taken dependent on water level:

- below the yellow marker, visit site intermittently;
- above the yellow marker, position watchman;
- at the red marker, block the line to traffic.

109 The Flood Action procedure issued in 2004 listed 106 structures as being vulnerable to scour, including Lamington as one of 16 structures classified as 'High Risk'. The remainder were classified as 'At Risk'. These were a subset of the 1540 rail bridges (excluding *culverts*) which cross rivers and are the responsibility of the Scotland Route's RAM (structures) team. All these 1540 bridges had scour assessments.

[19] NRSOP/SCO/CE/P/320/SC Issue 2, November 2004: 'Standard Operating Procedure, Flood Action procedure'.

110 Shortcomings in the processes needed to maintain and implement the Flood Action procedure are now described under the following headings:

- The validity of management actions for risk posed by water action (paragraph 111).
- Procedures and organisational arrangements (paragraph 120).
- Planning and implementing the responses to warnings of extreme weather (paragraph 132).
- Ensuring the line is safe before trains use structures which could have been damaged due to an extreme weather event (paragraph 137).

The validity of management actions for risk posed by water action

111 The following extracts from Network Rail standard NR/L1/CIV/032 established the need for asset managers to consider, and take appropriate action, when new information becomes available:

> *'The purpose of an evaluation is determine from the findings of an examination or assessment, what actions (if any) need to be implemented so that no unacceptable risk to the safe use…of railway infrastructure arises from the… condition…of a structure… An evaluation shall be carried out in response to…* (NR/L1/CIV/032, clauses 7.4.1 and 7.4.2).
>
> - *receipt of an assessment report [and/or…]*
> - *receipt of a report that the safe use or performance of the structure…might be compromised; for example, a report of the presence of a defect, occurrence of damage, or a worsening of the condition of a structure [and/or…]*
> - *receipt of new information relevant to the safe use of…railway infrastructure.*
>
> *[The validity of management actions for risks posed by water action (scour) at]… structures that have been assessed as being susceptible to such effects… shall be reviewed, and where necessary, changed in a timely manner, for example… following the receipt of new information that the actual (or likely) effects of… water action on a structure have been wrongly estimated.'* (NR/L1/CIV/032, clause 9.3.4)

112 The Flood Action procedure was updated by the RAM (structures) team in October 2008 and renamed as 'Structures: Flooding & Scour Action'[20]. However, there is no evidence that this revised document was formally issued.

113 The RAM (structures) periodically updated the list of High Risk and At Risk structures. The last version to be issued before the incident was dated June 2012. The RAM (structures) issued this list by email stating: 'This list is to be used in conjunction with route plans for extreme weather and replaces the list issued in January 2011.' The email was sent to various people including an incident management information specialist in the control centre, who provided the main link between control room staff, the RAM (track) and the IMDM. A copy of the list was also kept within an information pack used by on-call members of the RAM (structures) team when assisting with the management of adverse weather events (refer to paragraph 136).

[20] Safety Manual Section 7.8 'Structures: Flooding & Scour Action'.

114 The June 2012 list of High Risk and At Risk structures included 104 structures. References to telemetry equipment included in the 2004 version had been removed as most of the systems (including equipment fitted at Lamington) had stopped working after maintenance ceased in about 2006 when the team responsible was disbanded (refer to paragraph 141).

115 The list of High Risk and At Risk structures was updated several times after 2004, but there is no evidence that the trigger level to close the line at Lamington, as indicated by the red marker, was reviewed after 2004. A photograph taken in May 2003 shows a red marker painted on the upstream end of pier 1 (figure 20). Photographs taken in 2011 show that the red marker was still at the 2003 level and had almost worn off. It was no longer visible when the RAIB visited site in January 2016, shortly after the incident.

Figure 20: Red marker visible on upstream end of pier 1 in 2003 (photograph courtesy of Network Rail)

116 The level of the marker may originally have been set to avoid the risk of debris, carried by a flood, from striking the deck. As the structure was at risk of scour, the red marker should also have been set to correspond with a river flow at which line closure was justified by scour risk. No evidence was found that the red marker level had been set to take account of this.

117 Network Rail standard NR/L1/CIV/032 effectively required a reappraisal and, if necessary, a modification to the intervention criterion on receipt of updated information about scour risk (paragraph 111). However, there is no evidence that the intervention criterion was reviewed as a result of the 2005 initial and 2013 detailed scour assessment reports which identified that pier 2 had shallow foundations and was at high risk of scour with water levels significantly below the red marker (paragraph 79). Similarly, there was no evidence that the criterion was reviewed when underwater examination reports provided evidence of structural defects (refer to paragraph 152).

118 The water level and velocity at Lamington peaked during the afternoon of 30 December 2015 and was sufficient to cause scour (paragraph 60). A post-incident survey[21] of debris on the river bank suggests that the water level may not have reached the level of the red marker line, and therefore, even if a watchman had been monitoring water levels and relying on this line (if still visible), they may not have taken the action needed in response to the risk of scour damage. Damage below water level was not visible until the water level had dropped sufficiently, in this case some 12 to 18 hours later (figure 7). During this period, trains continued to run normally so, even if the Flood Action procedure had been implemented, the line would probably have remained open after significant scour damage had occurred.

119 Events at Lamington demonstrate that watchmen cannot directly identify scour damage until it has caused movement or cracking of the structure. Therefore, in addition to watching water levels, Network Rail required watchmen to look for signs of abnormal turbulence as an indication of scour. Although sometimes associated with scour, it is not always present as demonstrated on the morning of 31 December when the pier damage was seen at Lamington, but there was no abnormal turbulence to indicate scour (paragraph 65 and figure 9).

Procedures and organisational arrangements

120 The Flood Action procedure which formed the EWP for structures in Scotland Route stated (clause 9):

> *'Review of this procedure shall be carried out by the Territory Track Engineer in the event of organisational changes, re-issue of company specifications or any associated instructions.'*

121 Network Rail standard NR/L1/CIV/032 (clause 9.3.7) stipulated that;

> *'the currency and efficacy of a EWP shall be reviewed:*
>
> *following changes in the criteria or methods used for issuing formal notifications of extreme weather events.*
>
> *at least every three years - this shall include a check of the offices and contact numbers of the relevant authorities that issue formal notifications, but need not include a re-assessment of the susceptibility of structures to extreme weather conditions.'*

[21] A trash line (high water mark) survey of the river bank upstream and downstream of Lamington viaduct was commissioned by an independent consultant on behalf of Network Rail, and undertaken in March 2016.

122 The RAM (structures) team reviewed and updated the Flood Action procedure in 2008 (paragraph 112), but the requirement for a three-yearly review was overlooked, in part, because the Flood Action procedure did not contain details of offices or contact numbers for the relevant authorities so these did not need checking. The RAM (structures) attended periodic peer meetings with RAMs from other routes and the central Head of Structures team, and believed that any significant changes in procedure (other than the list of structures to which the procedure should apply) would be identified by this meeting.

123 An effective review of the EWP would have considered how flood warnings were transmitted to control room staff in the context of the following Network Rail standards:

> *'Information on extreme weather conditions such as flooding may come to the Integrated Control Centre, (ICC), in a number of ways which include but are not limited to: Route Operations Control (ROC), Environment Agency, Water Authority, Meteorological Office . . .'* (Standard NR/L3/TRK/1010 clause 6.3)
>
> *The Environment Agency has in place a system whereby flood warnings are advised to Control via email, fax or telephone message. On receipt of a flood warning the Route Control Manager shall advise the Infrastructure Fault Control / Incident support Control of the information received. The Infrastructure Controller shall have procedures in place to receive all appropriate river and coastal flood warnings issued by the relevant authorities.'* (Standard NR/L3/OCS/043/7.1[22] clause 6.1)

124 An effective check would have revealed the absence of a mechanism to provide control room staff with flood warnings (as required by the Flood Action procedure), and would probably have revealed that control room staff were not using the Flood Action procedure. The arrangement by which the Environment Agency provided flood warnings via email, fax or telephone message did not work in Scotland because its Scottish equivalent, the Scottish Environment Protection Agency (SEPA), did not provide flood warnings in this way. The need for an alternative arrangement had not been recognised.

125 SEPA issued information about river conditions by email to members of the public and organisations that had signed-up to receive this service. For Scotland Route, automated emails were sent to a list of operations staff, including the route control manager in the control room. SEPA issued this information in three formats:

a. Flood guidance statement: a daily overview for the whole of Scotland, which included a weather summary and an assessment of the flood risk by geographical area. Individual rivers were not named.

b. Flood alert: issued as required to cover areas where the potential impact of flooding was considered low (eg agricultural land). SEPA has confirmed that a flood alert was in place for West Central Scotland, which included Lamington, between 29 and 31 December 2015. The alert advised that there was a risk of flooding to land and property from rivers, and a risk of widespread disruption to travel and infrastructure.

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[22] Network Rail standard NR/L3/OCS/043/7.1 Issue 12, Dec 2012: 'National Control Instructions: Weather Management'.

c. Flood warning: issued as required for specific locations where the potential impact of flooding was considered high. For the River Clyde, flood warnings were only available downstream of Lanark (40 km below Lamington).

126 Scotland Route operations staff were signed-up to receive flood guidance statements and flood alerts for the whole of Scotland. However, they were only signed-up to receive SEPA flood warnings for one area covering part of the River Tay in central Scotland. This followed repeated flooding of a section of the main line between Perth and Inverness, including Dalguise viaduct.

127 The flood guidance statements and flood alerts were not a substitute for the lack of flood warnings because Network Rail had no documented link between these general alerts and individual at risk structures. A manual check would have been required to determine if any flood alerts affected the infrastructure and there were no arrangements in place to do this. Control room staff also received rainfall data, but this could not provide a substitute for flood warnings because there is no direct link between rainfall at a location and nearby river levels. This is due to differences in the porosity of the ground and the extent of each river basin.

128 At the time of the incident, most control room staff, including the operations manager, were unaware of the Flood Action procedure which had not been in use for many years. As a consequence, they did not consider it when preparing to deal with extreme weather events. They have informed the RAIB that they believed that Network Rail operations standards NR/L3/OCS/043/7.1 and NR/L2/OCS/021[23] covering weather management, and the list of High Risk and At Risk structures, constituted the whole of the required EWP. The operations manager has suggested that the demise of the telemetry systems (paragraph 114) may have caused control room staff to assume that they were no longer expected to take an active part in controlling scour risk.

129 Within the control centre, the Flood Action procedure was originally in the Network Rail Safety Manual with other procedures which were not part of the Operations Manual. The Safety Manual was withdrawn sometime after 2004. There was no overarching EWP document so the procedures were held as a series of standalone documents, lacking any formal document control or audit arrangements. The RAIB has been informed that there were approximately 65 control instructions which were not included in the audit process.

130 Network Rail standard NR/L3/TRK/1010 (clause 6.2) stipulated;

> *'The Track Maintenance Engineer (TME) shall in consultation with IME review the EWP and identify precautions, intervention levels and actions for which the need for response may arise. These shall be documented locally and briefed to all staff involved with extreme weather management and reviewed at least annually. The TME shall review the requirements of the EWP with the IMDM and the Section Manager (Track) to confirm that there are appropriate resources at each depot to enable inspections or suitable mitigation should the adverse weather require it.'*

[23] Network Rail standard NR/L2/OCS/021 Issue 5, June 2011: 'Weather – managing the operational risk'.

131 The Motherwell TME reviewed the EWP each year, but the reviews did not include structures because he was unaware of any structures issues that he was responsible for through the EWP. He had not received a copy of the 2012 High Risk and At Risk list, issued by the RAM (structures), which included 30 structures in his area. He received a winter working briefing from Scotland Route's Seasons Delivery Specialist in October 2015, which referred to various issues related to heavy rainfall (including track flooding and earthworks), but did not mention structures or refer to the Flood Action procedure.

Planning and implementing the responses to warnings of extreme weather

132 Network Rail's weather forecaster provided the control centre with daily forecasts for rainfall, wind and temperature. When the forecast warned of an extreme weather event, the *Extreme Weather Action Team* (EWAT) process was invoked as required by Network Rail standard NR/L2/OCS/021. This included regular meetings (normally teleconferences) involving key staff.

133 During previous periods of heavy rainfall, and during the heavy rainfall on 29 and 30 December 2015, the EWAT had deployed staff to monitor infrastructure considered at risk due to heavy rainfall. The Carstairs section manager (track) would have been responsible for deploying staff to Lamington viaduct if this had been instructed by control room staff. He had regularly been instructed to deploy staff to monitor at risk earthworks sites and other areas where the track could flood. The current holder of this role, appointed in 2008, had never been instructed to deploy staff to structures.

134 Control room staff and senior managers believed that the EWP for structures was operating effectively. This was because regular flood alerts for three bridges in central Scotland between Perth and Inverness (near Dalguise and Kingussie) led to the RAM (structures) team being consulted by control room staff, and the deployment of watchmen. Following the incident at Lamington, it became apparent that the structures extreme weather plan was not in operation throughout Scotland Route. The three bridges near Dalguise and Kingussie were covered by local instructions. There was no effective scour risk mitigation for over 100 other structures on the High Risk and At Risk list.

135 Extreme weather responses for earthworks (ie cuttings and embankments) provided control room staff with further reassurance that an effective EWP was operating on Scotland Route. The plan was cross-functional, requiring the RAM (earthworks) team to identify earthworks at risk of landslips during periods of wet weather, control room staff to respond to weather warnings, and the local TME's staff to deploy to site and advise control of any defects. All parties were aware of the arrangements and the Operations Manager has stated that the plan was regularly implemented and worked successfully during the period covered by this incident.

136 An on-call member of the RAM (structures) team participated in EWAT meetings and had a copy of the list of High Risk and At Risk structures in an information pack provided for this purpose. Structures were not a standing item on the EWAT agenda. The on-call structures staff responded to specific issues as required, but did not identify that the procedure was not working.

Ensuring the line is safe before trains use structures which could have been damaged due to an extreme weather event

137 The Flood Action procedure required a senior engineer to make appropriate checks before authorising a closed line to be re-opened. This was not applicable at Lamington as the line had not been closed. It is unlikely to have provided effective mitigation if the line had been closed because it is possible that damage would not have been visible above water level until after the watchman had left site (paragraph 118).

138 Scour risk management processes must take account of the possibility that scour damage remains hidden below water level, but continues to get worse, for a considerable period after the peak flow has subsided. This was demonstrated by events at Lamington. It is therefore important that relatively minor track defects are considered as a possible indicator of a serious structural problem if they occur on a structure over water, particularly one known to be at risk of scour damage. However, there was no guidance or instruction to advise control room staff that a track defect on a structure over water could be a consequence of structural damage caused by water action or scour, particularly if the structure had been defined as a High Risk or At Risk structure.

Management of organisational change

139 **Organisational changes led to loss of knowledge and ownership of some infrastructure issues**

140 In 2012 Network Rail devolved responsibility for day-to-day operation of the rail network to ten (later reduced to eight) strategic routes. Maintenance leadership was decentralised and this reorganisation, known as devolution, made Scotland Route semi-autonomous.

141 Devolution was preceded by other reorganisations following Network Rail's take-over of Railtrack in October 2002, and the absorption of staff who had formerly worked for its infrastructure maintenance contractors. Successive programmes to reduce corporate overheads led to the disbanding of the team responsible for remote monitoring equipment in about 2005, the merging of the previously separate infrastructure fault control[24] and operational control[25] functions, and the adjustments to the various asset management teams.

[24] Infrastructure Fault Control was a term used for the infrastructure control organisations inherited from Railtrack's infrastructure maintenance contractors.

[25] Operational control was responsible for running trains, delay attribution and electrical control room operations.

142 Where the duties of staff (rather than the staff themselves) were affected by reorganisations, reallocation of their duties was to be covered in safety-validated ‘disposition statements’. However, there is evidence that a clear understanding of what the duties of the displaced people were was not always obtained. This led to some instances of remaining staff forgetting or not taking ownership of processes. Examples include the disbandment of the team responsible for co-ordinating remote monitoring and telemetry without their duties being effectively transferred to other staff, and the removal of the post of incident management information specialist (IMIS) without the Operations Manager being consulted or informed of what responsibilities the IMIS had. The IMIS role had an infrastructure focus and acted as the link between the RAM (structures) and the control centre (paragraph 113). The Operations Manager inherited some of the IMIS’s duties including the link to the DRAM team, but without the background knowledge to recognise the absence of an EWP for structures.

Funding for scour protection

143 **Scour protection works were not prioritised by Scotland Route when allocating funding determined by the ORR.**

144 Between 2005 and 2012, although categorised as a high priority structure, scour protection works were not progressed at Lamington. This was because Scotland Route gave other structure renewal works higher priority within the overall funding requirement that Network Rail had justified to its regulator, the Office of Rail and Road (ORR)[26].

145 Network Rail’s funding is divided into five-year *control periods*. Prior to the start of each control period, Network Rail was required to make a case for the funding needed to meet its Network Licence obligations and other statutory requirements[27]. In October 2007, Network Rail published its strategic business plan and its case for funding during Control Period 4 (CP4), which started in April 2009 and continued until March 2014. The plan proposed significant increases in its civils activity (ie all works (except routine inspection) to bridges, tunnels, walls, earth structures, coastal defences), and funding requirements.

146 The ORR did not consider that the proposal had been fully substantiated and its Final Determination for CP4, published in its Periodic Review 2008[28], was based on the global amount (not the individual work items) ORR considered had been adequately justified. Once the global funding had been determined, Network Rail was responsible for determining which schemes that money was to be spent on. During CP4, Scotland Route only implemented one or two scour protection schemes each year.

[26] Formally known as the Office of Rail Regulation.

[27] Including those under the Health and Safety at Work Act 1974 and associated legislation.

[28] ORR Periodic Review 2008, published October 2008. Determination of Network Rail’s outputs and funding for 2009-14.

147 Network Rail, in response, stated in its CP4 delivery plan[29];

'The overall level of activity in the early years of CP4 will be broadly similar to the later years of CP3, during which activity increased steadily. However, the final determinations provided for a significantly lower level of activity and expenditure than forecast in our SBP (strategic business plan). This reduction has required the reprioritisation of our work-banks, based on risk assessment.

On our underbridges and overbridges, we will be undertaking a lower level of preventative maintenance works, such as painting and water-proofing than was our initial intention.'

148 Scotland Route's minor works budget was relatively small (below £5M/year) during the first years of CP4, and the RAM (structures) team was only able to address high priority items. This may explain why the scope of repairs for pier 2 in 2008/09 was limited (refer to paragraph 152). The deferral of essential work was subsequently recognised as being undesirable, and spending increased over the last three years of CP4 in anticipation of CP5. By mid-CP5 (2015/16), the Route's minor works budget had increased to between £15M and £20M/year.

149 In preparation for CP5, Network Rail made a case for increased funding based on the need to address historical under-investment on structures and earthworks assets. A recovery plan was proposed, spread over CP5 and CP6 (2014-2023). In December 2012, Network Rail's CP5 asset policy set a policy target to implement proactive scour risk mitigation measures for all sites with a risk score over 16 (the category including Lamington viaduct), where reasonably practicable, by 2023. Planning for the Lamington scheme had commenced shortly beforehand (paragraph 81) in anticipation of funding being available.

150 ORR's Final Determination for CP5, published in its Periodic Review 2013[30] stated:

'We have developed a new approach to spending on civil engineering assets. The level of civils spend (on assets such as bridges and tunnels) will rise in the short-term to address the backlog of work and improve the asset base, but the quality of information on civils assets means it is difficult to forecast exactly how much work will need to be done and at what cost.

Network Rail proposed expenditure of £2.6bn on civils renewals during CP5, whereas we have assessed expenditure required to be £2.4bn. However, there is high uncertainty around the civils plans and we agree with Network Rail that civils should be dealt with differently. Recognising that the volume of work needs to increase we will provide increased funding (compared to CP4) for the first two years of CP5 where plans are more robust. For years three, four and five of the period we have assumed an increased level of expenditure but actual funding will be assessed by a "civils adjustment mechanism" which requires Network Rail to submit further plans in the first year of CP5. This will allow us to review the work that is planned, to assess the efficiency of that work and to adjust accordingly.'

[29] Network Rail 2009 Control Period 4 delivery plan.

[30] ORR Periodic Review 2013: Final determination of Network Rail's outputs and funding for 2014-19.

151 In 2012, Network Rail was awarded £250M by the UK Government as part of a national fiscal stimulus package for England and Wales[31]. Scour protection works were allocated £24M, which allowed 132 scour schemes to be completed to protect at risk structures. This funding was not available in Scotland.

Observations

General condition of pier 2

152 **The risk presented by the deteriorating condition of other areas of pier 2 was not fully addressed.**

153 The upstream end of pier 2 had a long history of structural defects where voids had developed and masonry blocks had been displaced. Repairs were undertaken in 2008 and 2009, but these were limited in scope and did not address underlying structural issues. Despite these problems, the section of pier 2 that failed was downstream of the known voids and in an area with few recorded defects.

154 Lamington viaduct was scheduled to receive annual underwater examinations because it had been assessed as being at risk of scour. It was also scheduled to receive annual visual examinations as required by standard NR/L3/CIV/006/1C[32] in common with other Network Rail structures. The most recent visual examination took place three weeks before the incident, on 9 December 2015, but it was listed as incomplete because of the 'limited view from either end due to deep river' (figure 21). The deck and visible parts of the sub-structure received detailed examinations on a 12-year cycle, the standard interval for a reinforced concrete bridge considered to be in good condition[33]. The next detailed examination was scheduled for 2016.

Figure 21: Upstream end of pier 2 on 9 December 2015, seen during a visual examination three weeks prior to the incident (photograph courtesy of Network Rail)

[31] Independent Reporter (Part C) Mandate CN/027 Audit of £250m Fiscal Stimulus Civils spend. Office of Rail Regulation and Network Rail.

[32] Network Rail standard NR/L3/CIV/006/1C, 'Handbook for the examination of Structures Part 1C - Risk categories and examination intervals'.

[33] At the time of the last detailed examination in 2004, Lamington viaduct had a Structure Condition Marking Index (SCMI) score of 79 (out of 100).

155 From the earliest available underwater examination report dated 1994, the main areas of concern noted by examiners have been similar. These have included the effect of scour on pier 2's upstream bullnose, voids within the pier close to the bullnose, and the weakness or absence of mortar between individual masonry blocks. A separate underwater examination in May 1999, undertaken in connection with the deck renewal project, made similar findings (paragraph 90).

156 In April 2005, the RAM (structures) team issued an instruction to 'repair masonry to pier 2 bullnose', taken directly from an underwater examination report recommendation. Despite having overall responsibility for the structure, the professional engineers in this team were not responsible for investigating the underlying structural issues, or specifying the repair.

157 The instruction was issued to an in-house minor works delivery team, a small unit made up of experienced staff who worked autonomously and were not supervised by a qualified structures engineer. This team had responsibility for specifying and delivering the work which was subject to budgetary and deliverability constraints.

158 The RAM (structures) team had little influence over delivery timescales, and repair work did not start for over three years. During the intervening period, routine underwater examinations revealed that the condition of pier 2 was deteriorating. By June 2008, the upstream end was reported to be in poor condition with large underwater voids and missing masonry. The report warned of a 'significant potential for washout and potential collapse in flood conditions'. It recommended urgent work to fill the voids with concrete or brick. When the report was received by Network Rail, the evaluator within the RAM (structures) team marked the recommendation as a duplicate in the database[34] used to manage this process. This was because this item of work was already listed and was being progressed.

159 During 2008, the minor works delivery team took steps to investigate the defects by commissioning an underwater CCTV survey of the voids in pier 2, and a report from an independent consultant on the use of *rock armour* to fill a scour hole upstream of pier 2. The independent consultant advised on the rock armour, but also recommended that all voids within pier 2 were carefully infilled with concrete.

160 In November 2008, *dry-mix bags* of concrete were 'bolted onto structure as a temporary measure to repair voiding to upstream face of pier 2.' This was followed by *repointing* of open joints above the waterline in May 2009.

161 It is unclear why temporary void repairs were undertaken as there was nothing in the instructions issued by the RAM (structures) team that suggested that the repair should be anything other than permanent. A completion report submitted by the contractor stated simply that the scour voiding had been repaired. It made no reference to the works being a temporary measure, and included no other information. As a consequence, the RAM (structures) team believed that all scour related defects in pier 2 raised in underwater examinations prior to that date had been remediated. They were not aware that a more permanent solution was required to prevent water entering the pier and ensure longer-term stability.

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[34] Network Rail's 'Civil Asset Register and electronic Reporting System' database (CARRS). CARRS was introduced in Scotland in 2008, and replaced the 'Railway Infrastructure Manager Database' (RIMD).

162 The next underwater examination did not take place until February 2011 after Amey had taken over this work (paragraph 16). The report identified a void affecting the pier 2 bullnose. A subsequent report in August 2012 included a diagram showing the location of several voids in this location, suggesting that some parts of the 2008 temporary repairs had been washed out. It was unusual to find a diagram in this type of report, but it proved valuable on this occasion. Although the reports again recommended repair, the defects were given a risk score which was below the normal threshold for taking action, and consequently, no action was taken. While the pier 2 bullnose was not affected during this incident, its vulnerability to scour was demonstrated by the loss of the pier 3 bullnose less than two weeks later (paragraph 54 and figure 14).

163 **The lack of a consistent site datum level made it difficult to identify change.**

164 Network Rail standard CIV/006/02A[35] clause 4.11.2 required a datum level to be clearly marked on the structure and used for underwater surveys. It states:

> *'Bed levels shall be surveyed around piers, abutments and at sections across the river, and referenced to a common datum clearly marked on the Bridge. The datum used shall be that for previous surveys, unless otherwise agreed with the Structure Manager.'*

165 Despite this requirement, there was no datum level (eg *Ordnance Datum*) marked on Lamington viaduct. Most underwater surveys used the underside of the eastern main beam in the centre of the middle span as a reference point. The level of this reference point changed when the viaduct deck was renewed in 1999, but underwater survey results were not adjusted to take account of this.

166 Core hole surveys, used to determine foundation depth, were not referenced to a datum level (paragraph 76). This meant that the foundation level could not be established or related to changes in river bed levels despite this relationship being a critical parameter for safely maintaining the structure. Underwater examination reports did not refer to this relationship either, because the report template did not include a reference to foundation levels (where known).

167 Most underwater examination reports identified year-on-year change to the river bed profile. However, the lack of a consistent datum level, or the ability to compare this information with foundation levels, made it difficult for the RAM (structures) team to accurately assess the risk due to these changes.

[35] Network Rail standard NR/L3/CIV/006/02A Issue 2, June 2010; 'Handbook for the examination of structures, Part 2A, Bridges'.

Previous occurrences of a similar character

168 A railway viaduct over the River Towy at Glanrhyd, near Llangadog in mid-Wales, collapsed on 19 October 1987. A passenger train fell into the water and the leading carriage was swept away with the loss of four lives. The single track bridge, supported on four intermediate masonry piers failed when a river pier was undermined by scour. The Inquiry report[36] found that there had been no attempt to find the depth or form of construction of the piers before the bridge was re-decked prior to the accident. Other relevant findings include:

- *Gravel shoals* can move in flood conditions.
- External pier repairs can change the pier shape and increase risk of scour.
- There can be a general deepening of the channel during a flood.
- Piers alter flow locally and this may lead to scour.
- Flood warnings were not received.
- There was a lack of knowledge of construction details, especially foundations, and no attempt was made to establish the depth of the foundations when the bridge was re-decked.
- An At Risk list should be drawn up by the civil engineer and given to operations staff.
- A train should not be used to prove the line following reports of bridge damage (and that despite contrary publicity, this was not the intention of the railway staff involved with the Glanrhyd accident).

169 Since Glanrhyd, there have been 16 scour incidents causing severe damage to UK railway structures, including the River Ness viaduct at Inverness which failed in February 1989. In addition to the safety risk which can be mitigated by line closures, the cost of replacement and disruption associated with the structural failure of bridges is high.

170 The most recent similar scour incident to affect Network Rail's infrastructure involved the failure of an arch bridge carrying the railway over the River Crane in Feltham, west London in November 2009 (figure 22). The bridge's foundations failed without warning after the river was partly blocked by debris, causing part of the bridge to subside (RAIB report 17/2010). The first indication of a problem was a track defect reported by a train driver. Track maintenance staff were called to the site and immediately blocked the line to all traffic when they became aware of a serious defect with the bridge. A total of 21 trains crossed the failing bridge between the first report and closure of the line. There was no derailment and no injuries occurred, but the bridge had to be demolished and rebuilt (refer to Recommendation 2).

[36] Department of Transport: Report on the collapse of Glanrhyd Bridge on 19th October 1987. HMSO.

Figure 22: Bridge RDG1 48, spanning the River Crane between Whitton and Feltham in west London. The arch failed after its abutment was undermined by scour erosion on 15 November 2009.

Summary of conclusions

Immediate cause

171 A train passed over the subsiding viaduct at high speed, causing significant distortion of the track.

Causal factors

172 The causal factors were:

a. High river flow velocity undermined a viaduct pier (paragraphs 59 and 93, **Learning points 1 and 2**).

b. Scour protection for the piers and abutments was not provided in a timely manner (paragraph 70, **Recommendation 1**, **Learning point 1**).

c. Trains were allowed over the viaduct at high speed before the possible presence of scour damage had been assessed (paragraphs 95 and 138, **Recommendation 2**).

Underlying factors

173 The underlying factors were:

a. There was no effective process for managing scour risk on Scotland Route and this had not been recognised by Network Rail (paragraph 100). Shortcomings included:

   i. Ineffective processes for taking account of new information concerning scour risk (paragraph 117, **Recommendation 1**);

   ii. Inappropriate reliance on water level monitoring when it is not a reliable measure of scour risk (paragraphs 118 and 119, **Recommendation 1**);

   iii. Ineffective or absent checking that procedures remained valid and effective (paragraphs 124 and 131); no recommendation due to action taken (paragraph 184);

   iv. Ineffective means of disseminating key information, or verifying that the processes functioned correctly (paragraphs 127 to 129, **Recommendation 3**);

   v. No mitigation against circumstances when scour damage is not apparent until flood water subsides (paragraph 138, **Recommendation 2**).

b. Organisational changes led to loss of knowledge and ownership of some infrastructure issues (paragraph 139, **Recommendation 3**)

c. Scour protection works were not prioritised by Scotland Route when allocating funding determined by the ORR (paragraph 143); no recommendation due to action taken (paragraph 183).

Observations

174 Although not linked to the incident on 31 December 2015, the RAIB observes that:

a. The risk presented by the deteriorating condition of pier 2 was not fully addressed (paragraph 152, **Recommendation 1**)

b. The lack of a consistent site datum level made it difficult to identify change (paragraph 163, **Learning point 4**).

Previous RAIB recommendations relevant to this investigation

175 In September 2010, the RAIB published a report 'Failure of the River Crane railway bridge near Feltham, West London, 14 November 2009' (RAIB report 17/2010). The incident involved the failure of a brick arch bridge following scour damage. Recommendation 6 is relevant to this investigation because it relates to the response by track maintenance staff to a track defect reported in the vicinity of a structure.

Recommendation 6

Network Rail should review the guidance provided for non-specialist staff who may be required to assess the failure of track support in the vicinity of a structure, and determine whether it is safe for trains to run over that structure.

Action taken as reported to RAIB by ORR:

ORR informed the RAIB on 9 April 2013 that Network Rail had published Infrastructure Group Safety Bulletin, IGS 244, 'Action to be taken in the event of loss of ballast support on bridges', in January 2011. This provided guidance for Track Maintenance, Operations and Customer Services Staff, detailing the actions that must be taken with respect to adjacent tracks when a track over a bridge is closed due to loss of ballast support.

ORR also informed the RAIB that it was satisfied that Network Rail had taken action in response to this recommendation and that the recommendation had been 'implemented'.

176 In August 2013, the RAIB published a report 'Partial failure of a structure inside Balcombe Tunnel, West Sussex, 23 September 2011' (RAIB report 13/2013). The incident involved the detachment of a large steel structure in the roof of the tunnel after bolts connecting it to the tunnel lining fell out. Recommendation 4 is relevant to this investigation because it relates to the management of repairs to defects affecting pier 2 for which a temporary repair was made in place of a permanent repair (paragraph 161).

Recommendation 4

Network Rail should review and, if necessary, modify the management arrangements that are now in place to provide an appropriate engineering response when structure defects are reported. This should include assessing the risk in the period prior to rectification, the means to verify that work requested has been carried out, and whether the reported defect is an indication of a wider problem.

Action taken by Network Rail (as reported to RAIB by ORR):

ORR informed the RAIB on 16 December 2015 that this recommendation is implemented in all respects, bar the roll-out of CSAMS[37] (scheduled for mid-late 2016), which will provide additional recording functionality. ORR also noted that Network Rail has introduced interim arrangements to address the intent of the recommendation for the period prior to CSAMS implementation. Recommendation status: Implemented.

[37] Civil Strategic Asset Management Solution (CSAMS): a database which will consolidate several existing systems used for the management of civil assets, and will replace CARRS.

177 In October 2014, the RAIB published a report 'Dangerous occurrence at Denmark Hill station, London, 1 August 2013' (RAIB report 23/2014). The incident involved the failure of loose concrete cladding, which fell onto a platform used by passengers. Recommendation 1 is relevant to this investigation because it relates to issues identified in the management of defects affecting pier 2.

Recommendation 1

Network Rail should carry out a review of the means by which defects identified by the structures examination process are evaluated by asset managers, and repairs actioned. Network Rail should then make the improvements necessary. As a minimum, this review should consider:

a. ways of improving the integration of asset management and works delivery management systems (by means of technology and/or improved management arrangements);

b. the ways in which contractors are remitted to carry out work, particularly for works reliant on the application of judgement, and the degree of supervision that is required;

c. the robustness of processes for confirming that works with an impact on safety have been completed in the manner intended by asset managers; and

d. the process for assessing the implications of repeat, or similar, defects at the same location.

Action taken by Network Rail (as reported to RAIB by ORR):

ORR informed RAIB on 24 July 2016 that Network Rail is undertaking a review of the end to end processes that govern the management of works items raised as a result of all types of examination. ORR will continue to monitor implementation of this recommendation. Current recommendation status: Implementation ongoing.

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

178 Since completion of the emergency repairs (paragraph 55) and reopening of the viaduct, about eight metres of the redundant masonry section of each pier has been removed and replaced with a reinforced concrete bullnose to improve water flow. Although the strengthening work has significantly changed the shape of the pier, scour protection has been installed across the full width of the river bed to mitigate any resulting increase in scour risk. The damaged section of the north abutment has been rebuilt in reinforced concrete.

179 The Scotland Route RAM (structures) team has issued a document titled 'Extreme Weather Plan, Bridges at Risk of Scour and Flooding' to replace the Flood Action procedure. This plan relies on watchmen to monitor structures when required. Relevant staff have been re-briefed. Scotland Route is also developing a new, integrated extreme weather plan to integrate the various current plans which it intends to implement during 2016.

180 Network Rail has issued a safety bulletin to all its line managers giving a brief overview of the Lamington incident and promoting discussion about what to look for to detect signs of scour, and the need to consider that a track geometry fault in the vicinity of a bridge may be a sign of distress in the structure. Network Rail also issued safety advice to signallers and controllers in Scotland to emphasise that if they receive a report of a track defect and the driver gives a location that is below or above a structure, then the signaller should deem this a structural failure report and not use a train to examine the line in accordance with existing rules (paragraph 96).

181 Network Rail has commissioned SEPA to link flood warnings and gauging station data to the location of vulnerable structures. This will bring the provision of flood warnings in Scotland into line with provisions in England and Wales.

182 Following the incident, the Scotland Route RAM (structures) instigated an emergency programme to inspect 329 structures, and to undertake 42 underwater examinations. One significant scour-related defect was found at Laggansarroch, between Girvan and Barrhill on the Stranraer line. This line was closed until remedial works were implemented.

183 Scotland Route currently has plans and funding to remediate 20 higher-risk scour sites during CP5. A further 12 structures have been identified for scour protection works during CP5 and CP6 to reduced disruption due to weather related safety restrictions.

184 Network Rail has undertaken an internal review of scour, flooding and associated extreme weather events across all its Routes. This review identified a range of issues, particularly relating to the completeness and accuracy of scour assessments, and proposed a programme for improvement.

185 Network Rail has sponsored research into the use of high-resolution sonar for bridge scour inspections. Three sonar technology systems have been tested by Southampton University on a tidal river bridge in southern England which had been assessed as being at medium risk of scour. A research paper[38] published in the Proceedings of the Institution of Civil Engineers stated:

'Three different sonar systems and a laser scanner produced a holistic assessment of the viaduct structure above and below the waterline. A three-dimensional record of all scour erosion features was digitally mapped along with the condition of the substructure. Significant scour was identified, contradictory to previous diver-based assessments.'

186 The potential to use remote monitoring for detecting structure movement caused by scour is being demonstrated by Network Rail's use of movement monitoring equipment during enhancement work at Box tunnel (Wiltshire), and at a number of earthworks. By March 2016, it had installed arrays of battery powered tilt measuring devices at around 60 sites as part of a project intended to monitor possible earthwork movement at 180 sites across the UK. The instrumentation used for structures and earthworks uses wireless technology, has a battery life of several years and measures very small movements. Similar equipment may therefore provide a practical means of identifying scour induced movement if fitted at locations where there is prior knowledge of scour risk such as pier 2 at Lamington. The RAIB notes that in the early 1990s, HR Wallingford developed flexible 'tell-tale' gauges that were buried in the river bed beside piers and gave out an electrical signal when they were exposed and free to move around in the water, demonstrating how scour holes develop and fill in again. Although the gauges were only installed for a 10-month trial, this is an example of a potential scour detection system.

187 Network Rail's Wessex Route has developed an extreme weather plan for structures and earthworks which provides specific instructions for each at risk bridge. It includes guidance on the actions to be taken by control room staff, the on-call structures engineer and the RAM team. This plan is an example of the information that can be provided in advance to assist in the safe management of infrastructure during flood conditions. An extract of this plan is included in appendix E. Wessex Route is also arranging trials of additional remote monitoring equipment to assess the benefit of using cameras, flow sensors and sediment detection accelerometers to monitor scour.

[38] High-resolution sonars set to revolutionise bridge scour inspections, Clubley, Manes and Richards, proceedings of the Institution of Civil Engineers. Paper 1400033 Volume 168 Issue CE1, February 2015.

Recommendations and learning points

Recommendations

188 The following recommendations are made[39]:

1 *The intent of this recommendation is to improve the management of scour risk and increase the quality of information available to staff responsible for making decisions about the safety of structures.*

Network Rail should review and improve the management of scour risk by Scotland Route. The review should encompass formal procedures, the way in which they are implemented and the competencies of staff. Any lessons learnt should be applied to other Routes where appropriate. The improved measures for the management of scour risk should provide for:

a. Prompt holistic evaluations of all relevant existing information (including poor structure condition, shallow foundation depth, possible future changes in river bed level and scour assessments) whenever new information is received about a structure at risk of scour damage (paragraphs 172b and 173a.i), followed by timely:
   - implementation of necessary remedial work; or
   - effective risk assessment (including any necessary investigations) for any decision to defer or omit remedial work recommended by the examination regime or other specialists; and
   - implementation of any temporary mitigation found necessary by these risk assessments.

b. Circumstances where water level monitoring is not a reliable measure of risk from scour or water action (paragraph 173a.ii.

c. Circumstances where structure degradation, climate change and other factors mean that historic behaviour of a structure and the surrounding environment is not a good indicator of future behaviour (paragraph 174a).

continued

[39] 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.

d. Enhanced measures for automatic monitoring of parameters such as water level, flow rate, bed level (ie direct measure of scour) and structure movement (paragraph 187).

2 *The intent of this recommendation is to enhance response arrangements for operations staff dealing with structures over or adjacent to water, which can suffer damage (including scour damage) that is not immediately apparent.*

Network Rail should review, and if necessary, enhance its processes for operations staff responding to defect reports (eg track faults) where these may relate to structures over, or adjacent to, water. The enhancements should provide responses which take account of the risk that the defect is a consequence of structural damage caused by water action (eg scour, impact from floating debris, debris blockage etc.). (paragraphs 172c and 173a.v).

3 *The intent of this recommendation is to ensure that the latest version of all relevant documentation and processes are being used by control room staff. The documentation and other processes should be updated and checked periodically to ensure that they remain fit for purpose.*

Network Rail should review and improve the management and assurance systems for all control centre processes relating to the safety of railway infrastructure used by Scotland Route. The review should encompass both documented processes and the way they are implemented. It should include:

- procedures directly relevant to control room staff;
- inputs required from other parts of Network Rail;
- inputs required from external organisations; and
- arrangements for prompt updating and periodic verification of processes.

Any lessons learnt should be applied to other Routes as necessary (paragraph 173a.iv and 173b).

Learning points

189 The RAIB has identified the following key learning points[40]:

1 Previous behaviour of a structure or river bed in flood conditions may not be a reliable indicator of future behaviour if other factors have changed (paragraphs 172a and 172b).

2 Attention should be paid to river bed re-profiling and post-construction monitoring following projects affecting river bed profiles (paragraph 93).

3 Diagrams showing the location of underwater defects and the relationship between bed levels and foundation levels are useful for understanding and monitoring change (paragraph 162).

4 Asset information needs to be recorded using a consistent reference system, particularly a recognised datum level, so that it can be used to monitor change over time. Datum points should be re-established if necessary, after any works to a structure (paragraph 174b).

5 Wessex Route's extreme weather plan for structures provides specific instructions for the management of each of its at risk structures in flood conditions. This could provide a useful template for other Routes (paragraph 187, appendix E).

[40] '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

CARRS	Civil Asset Register and Electronic Reporting System
CEFA	Civil Examinations Framework Agreement
CIRIA	Construction Industry Research and Information Association
CP	Control Period
CSAMS	Civil Strategic Asset Management Solution (to replace CARRS)
DBS	DB Schenker (now renamed DB Cargo)
DRAM	Director of Route Asset Management
EWAT	Extreme Weather Action Team
EWP	Extreme Weather Plan
EX2502	Report EX2502 ‘Hydraulic Aspects of Bridges: Assessment of the Risk of Scour’.
FTPE	First TransPennine Express
GSM-R	Global System for Communications – Railways
IMDM	Infrastructure Maintenance Delivery Manager
IME	Infrastructure Maintenance Engineer
IMIS	Incident Management Information Specialist
NHMP	National Hydrological Monitoring Programme
ORR	Office of Rail and Road
RAM	Route Asset Manager
RSSB	Formerly known as Rail Safety and Standards Board
SCMI	Structure Condition Marking Index
SEPA	Scottish Environment Protection Agency
SM(T)	Section Manager (Track) which replaced the TSM role.
TCE	Territory Civil Engineer, replaced by DRAM
TME	Track Maintenance Engineer
TSE	Territory Structures Engineer, replaced by RAM (structures)
TSM	Track Section Manager, replaced by SM(T)
VTWC	Virgin Trains West Coast

Appendix B - Glossary of terms

Some definitions are partly based on those given in Ellis's British Railway Engineering Encyclopaedia © Iain Ellis. www.iainellis.com.

Angle of attack (for river flow)	Angle between the approach current and the longitudinal axis of a pier or abutment.
Ashlar	Masonry made of large square-cut stones.
Cant	The amount by which the outer rail in a curve is elevated above the inner rail.
Cess rail	The rail adjacent to the area along the edge of the outermost railway track(s).
Continuous (beam)	A beam which is structurally continuous over its intermediate supports.
Continuous welded rail	Comprises rails welded together to form a single rail length over 37 metres (120 feet).
Control Period	The five-year periods used by Network Rail for financial and other planning purposes.
Controlled signal	A railway signal which can be set to proceed or stop by the operator.
Coursed (masonry)	Masonry where stones in a particular course are of equal height.
Culvert	An underbridge spanning less than 6 feet (1.8 metres) and normally carrying a watercourse under the railway.
Design and build	A form of contract arrangement where the successful contractor is responsible for the detailed design and construction.
Detailed examination	A close examination of all accessible parts of a structure, generally within touching distance, of sufficient quality to produce a record that includes the condition of all parts of the structure, the uses to which the structure is being put, recommendations for remedial action, and any other relevant facts.
Diesel-electric multiple unit	A self-contained diesel-powered train comprising two or more cars that can be driven and controlled as a single unit from the leading driving cab. Diesel engines are located beneath each vehicle and the transmission system between the engines and the wheels is electric.
Down (line)	A track on which, at Lamington, the normal passage of trains is away from London.
Dry-mix bags	Porous (eg hessian) bags filled with dry sand and cement that hardens after contact with water.

Earthworks	A collective term for cuttings, embankments and natural slopes.
Electric multiple unit	An electrically powered train comprising two or more cars that can be driven and controlled as a single unit from the leading driving cab.
Enhanced permissible speed	The maximum permissible speed for tilting trains, which is above the permissible speed for conventional trains.
Extreme weather plan	A plan for action to be taken in the event of scour, storms, flooding or high tides. It includes a register of structures, earthworks other key locations (such as location cabinets and cuttings) at risk of damage from water and identifies locations where sea water may affect the operation of traffic.
Extreme weather action team (EWAT)	A team of senior managers drawn from the operations, engineering, communications and commercial functions within a Network Rail route which is activated when extreme weather conditions are forecast.
GSM-R	A national radio system which provides secure voice mobile communications between trains and signallers, relaying calls via radio base stations built alongside the railway or on suitable vantage points.
Local scour	Local scour results from the interaction of structures with flowing water and is generally found close to a structure – typically at the upstream nose of piers.
In situ concrete	Cast-in-place concrete.
Insulated rail joint	A rail joint, in which one rail is electrically insulated from the abutting rail, provided either as part of train detection or to isolate traction power areas.
Ordnance datum	The national height system for mainland Great Britain in which heights are measured above mean sea level at Newlyn, Cornwall.
Packing	Ballast placed under a sleeper to increase its level.
Possession	A period during which the operation of normal service trains is suspended on a designated section of line for the purposes of maintenance and/or engineering works.
Reinforced concrete	Concrete in which metal bars or wire is embedded to increase its tensile strength.
Repointing	To fill in or repair mortar joints.
Rock armour	Angular rocks placed on or below the river bed to provide scour protection.

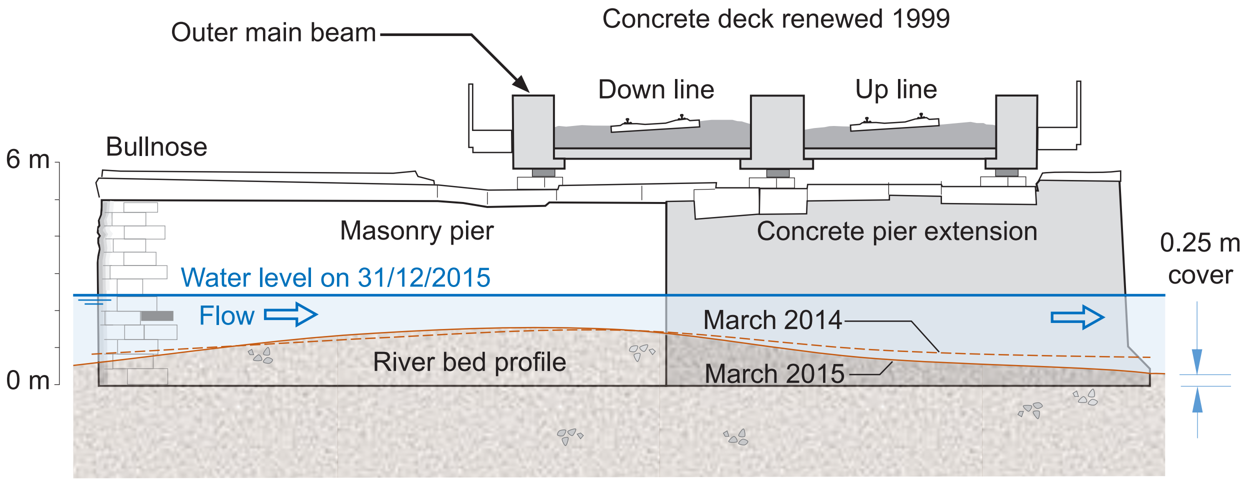
Scour	The removal of material from under or adjacent to structural supports, foundations or earthworks by the action of flowing water.
Scour priority rating	The calculated score from the EX2502 scour assessment calculation procedure. The calculation has a valid range from 10.0 to 21.0.
Section manager (track)	The local Network Rail manager directly responsible for managing teams of track engineering staff.
Shoal (gravel)	A natural submerged gravel ridge.
Six-foot rail	The inner rail adjacent to the opposite track on a two track railway.
Storm Frank	The name given by the UK Met Office to a severe depression which passed over the UK on 29-30 December 2015. The first storm to be named was Storm Abigail in November 2015.
Telemetry	An automated communications process by which measurements and other data are collected at remote or inaccessible points and transmitted to receiving equipment.
Track maintenance engineer	The Network Rail manager responsible for the delivery of track maintenance, and the line management of the track section managers, within a defined area.
Train reporting number	A four character identifier for a specific train movement.
Underbridge	A bridge that carries the railway over an obstruction.
Underwater examination	An examination of the underwater parts of a structure. This includes recording the levels of the bed of the watercourse, and the condition of those parts of the structure that are exposed (permanently or intermittently) to water and any change.
Up (line)	A track on which, at Lamington, the normal passage of trains is towards London.
Visual examination	An examination to identify changes in the condition of a structure carried out from a safe observation location, without using special access equipment but using permanent access ladders and walkways, binoculars and hand held lighting where necessary.
West Coast route modernisation project	A programme to increase train speeds along the West Coast Main Line from 2004/05.

Appendix C - Investigation details

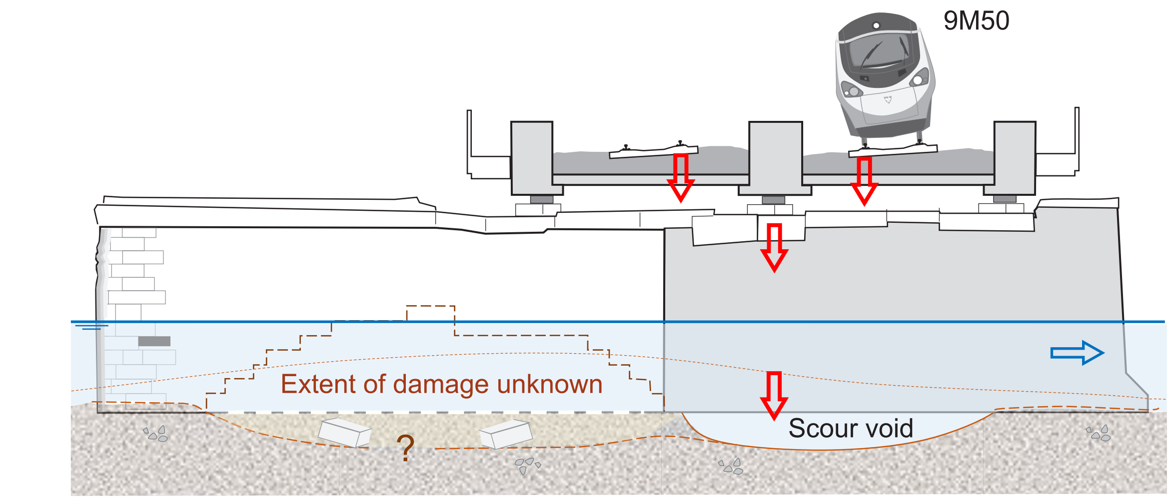
The RAIB used the following sources of evidence in this investigation:

- information provided by witnesses and train drivers;
- signalling data;
- voice recordings, including radio and telephone calls to and from the signaller and control room staff;
- site photographs and measurements;
- asset maintenance and examination records;
- scour assessment reports;
- hydrological data provided by SEPA;
- reports by an independent consultant into scour risk at Lamington viaduct (November 2008) and the scour failure (April 2016), commissioned by Network Rail; and
- a review of previous RAIB investigations that had relevance to this accident.

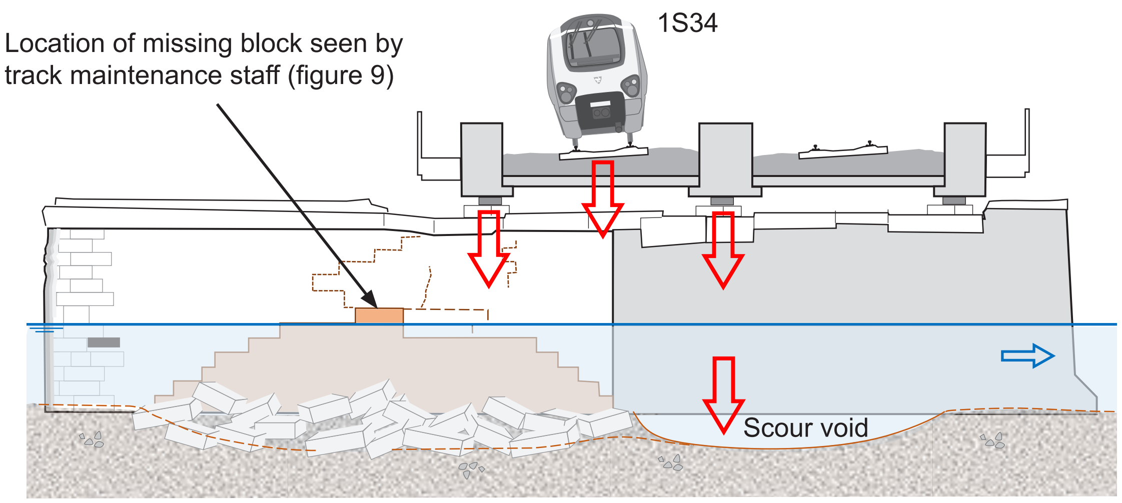
Appendix D - Probable failure sequence



D1: South face of pier 2 prior to the incident, showing river bed profile as recorded in March 2015



D2: At 07:28 hrs on 31 December, the driver of 9M50 felt a dip in the track. This occurred because the supporting pier had been partially undermined by scour.



D3: At 08:40 hrs on 31 December, track distortion on down line revealed damage to the masonry section of the pier which had partially collapsed (refer to figure 16).

Appendix E - Extract from Wessex Route extreme weather plan

'Procedure for Managing Severe Weather and Asset Failure', version 5.2, March 2016

The following extract is an example of the level of detail provided for each at risk structure within the Wessex Route's plan. The table explains the reason for inclusion in the plan with a brief description of the structure and a photograph. It lists the controlling signal box and nearest river level gauge. It also provides guidance on the actions to be taken by Wessex integrated control centre (WICC), the on-call structures/civil engineer and the RAM team.

ELR	Miles Yards	ID No. Name	Reason for inclusion - brief description of structure	Controlling Signal Box and Protecting Signal	Nearest EA River Level Gauge	Image (Upstream face)	WICC ACTION			ON CALL CIVIL ENGINEER ACTION			BUILDINGS & CIVILS RAM TEAM ACTION			
							Flood Alert or Water Level	Flood Warning or Water Level	Severe Flood Warning or Water Level	Flood Alert or Water Level	Flood Warning or Water Level	Severe Flood Warning or Water Level	Flood Alert or Water Level	Flood Warning or Water Level	Severe Flood Warning or Water Level	Time Based
BAE2	98.1789	E4/289	Scour - High Risk Hydrostatic or inundation – Low Risk Masonry arch with some evidence of previous scour damage, scour protection due in late 2012/13 FY	**Salisbury ASC Up Loop Down (Down Direction): SY83 Up Main Down (Down Direction):SY81** **Basingstoke ASC Up Exeter (Up Direction): SE4672 Gillingham Down Loop (Up Direction): SE4674**	River Nadder at Tisbury Site ID 3330 http://www.environment-agency.gov.uk/homeandleisure/floods/riverlevels/120717.aspx?stationId=3330		Flood Alert No Action River Level N/A	Contact On Call Civil Engineer.	Contact On Call Civil Engineer	Flood Alert No Action River Level N/A	Caution Traffic to 20mph unless watchman can be deployed safely to confirm safe to run at line speed. Arrange one visual exam per day during daylight See Flood Warning Database for detailed actions.	Stop Traffic unless watchman can be deployed safely to confirm safe to run at line speed. Arrange one visual exam per day during daylight See Flood Warning Database for detailed actions.	No Action	Arrange post event underwater exam	Arrange post event underwater exam	Underwater exam every 3 years
BAE2	110.1021	E4/321	Scour – Medium Risk Hydrostatic or inundation – Medium Risk Masonry abutments with ballasted track on metallic deck. Risk of inundation and track wash out.	**Basingstoke ASC Up Exeter (Down Direction): SE4683 Gillingham Down Loop: SE4681 Up Exeter (Up Direction) SE4690**			Remote monitoring installed. See section 9.8 for procedure	Remote monitoring installed. See section 9.8 for procedure	Remote monitoring installed. See section 9.8 for procedure	Remote monitoring installed. See section 9.8 for procedure	Remote monitoring installed. See section 9.8 for procedure	Remote monitoring installed. See section 9.8 for procedure	Remote monitoring installed. See section 9.8 for procedure	Remote monitoring installed. See section 9.8 for procedure	Remote monitoring installed. See section 9.8 for procedure	Remote monitoring installed. See section 9.8 for procedure

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Any enquiries about this publication should be sent to:

RAIB
The Wharf
Stores Road
Derby UK
DE21 4BA

Telephone: 01332 253300
Fax: 01332 253301
Email: enquiries@raib.gov.uk
Website: www.gov.uk/raib