Rail Accident Investigation Branch

Rail Accident Report

Dangerous occurrence involving an engineering train at Blatchbridge Junction, near Frome, 19 March 2012

Report 15/2013
September 2013

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.raib.gov.uk
DE21 4BA	

This report is published by the Rail Accident Investigation Branch, Department for Transport.

Dangerous occurrence involving an engineering train at Blatchbridge Junction, near Frome, 19 March 2012

Contents

Summary 5

Introduction 6

Preface 6

Key definitions 6

The incident 7

Summary of the incident 7

Context 8

Events preceding the incident 12

Events during the incident 12

Events following the incident 13

The investigation 15

Sources of evidence 15

Key facts and analysis 16

Background information 16

Identification of the immediate cause 20

Identification of causal factors 20

Identification of underlying factor 35

Discounted factors 38

Factors affecting the severity of consequences 39

Previous occurrences of a similar character 39

Summary of conclusions 40

Immediate cause 40

Causal factors 40

Underlying factor 40

Actions reported as already taken or in progress relevant to this report 41

Actions reported that address factors which otherwise would have resulted in a RAIB recommendation 41

Other reported actions 41

Recommendations 42

Appendices 46

Appendix A - Glossary of abbreviation and acronyms 46

Appendix B - Glossary of terms 47

Appendix C - Key standards current at the time 49

Summary

At approximately 19:27 hrs on Monday 19 March 2012, train 6Y33 was approaching Blatchbridge Junction, near Frome in Somerset. The train was made up of a number of engineering vehicles including a track renewal unit (known as a P95 machine). Part of the P95 machine included two control cabs, which were attached to an overhead supporting beam. One of these cabs, weighing around 1.25 tonnes, became detached from the overhead beam and fell to the track below (a distance of around 450 mm).

The unsecured control cab remained loosely connected to its vehicle by electrical control cables and an *air brake* hose. These helped to guide the control cab in a relatively straight line as it slid along the top of the rails beneath the train, until the train stopped around 1 ½ miles further on. A foot crossing was damaged as the control cab slid along the rails. The control cab itself was significantly damaged and was rebuilt following the incident.

The incident occurred because all eight bolts securing the control cab broke. The bolts broke due to a combination of factors, including:

- When the P95 machine was in its working mode (moving at less than walking pace) the bolts securing the cab experienced very high stress for very short periods. This cycle of strain events occurred several times each shift and caused fatigue in the bolts.
- The fatigue strength of the bolts was reduced by the presence of corrosion on the bolts. The design of the bolt mounting arrangement allowed moisture to reach the bolts.
- Some of the bolts had broken before the incident and maintenance of the P95 had not identified this because the maintenance instructions were not clear and lacked technical detail.
- It is possible that a previous incident adversely affected the fatigue performance of some of the bolts securing the control cab. Other bolts may have been affected by the uneven change in load.
- Following the previous incident the bolts were not inspected because it was believed damage to the control cab was only superficial and the maintenance instructions did not indicate that the bolts needed to be removed for inspection following an incident directly affecting the control cab.

The RAIB has made seven recommendations. Four are addressed to Network Rail (three of which require working with AmeyColas, the operator and maintainer of the P95) and three recommendations are addressed to Matisa (UK) Ltd who represent the vehicle manufacturer.

Introduction

Preface

1 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.

2 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.

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

Key definitions

4 All dimensions in this report are given in metric units, except speed and locations which are given in imperial units, in accordance with normal railway practice. Where appropriate the equivalent metric value is also given.

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

The incident

Summary of the incident

6 At approximately 19:27 hrs on Monday 19 March 2012, train 6Y33 was approaching Blatchbridge Junction, near Frome in Somerset (figure 1). Train 6Y33 was made up of a number of engineering vehicles including a track renewal unit (known as a P95 machine- see figure 3). Part of the P95 machine included two control cabs, which were attached to an overhead supporting beam. One of these cabs, weighing around 1.25 tonnes, became detached from the overhead beam and fell to the track below (a distance of around 450 mm).

7 The unsecured control cab remained loosely connected to its vehicle by electrical control cables and an *air brake* hose. These helped to guide the control cab in a relatively straight line as it slid along the top of the rails beneath the train.

8 As the control cab slid along the rails, the air brake hose which was underneath the control cab wore through. The resulting loss of air pressure from the air brake hose caused the train's brakes to apply automatically, and the train stopped.

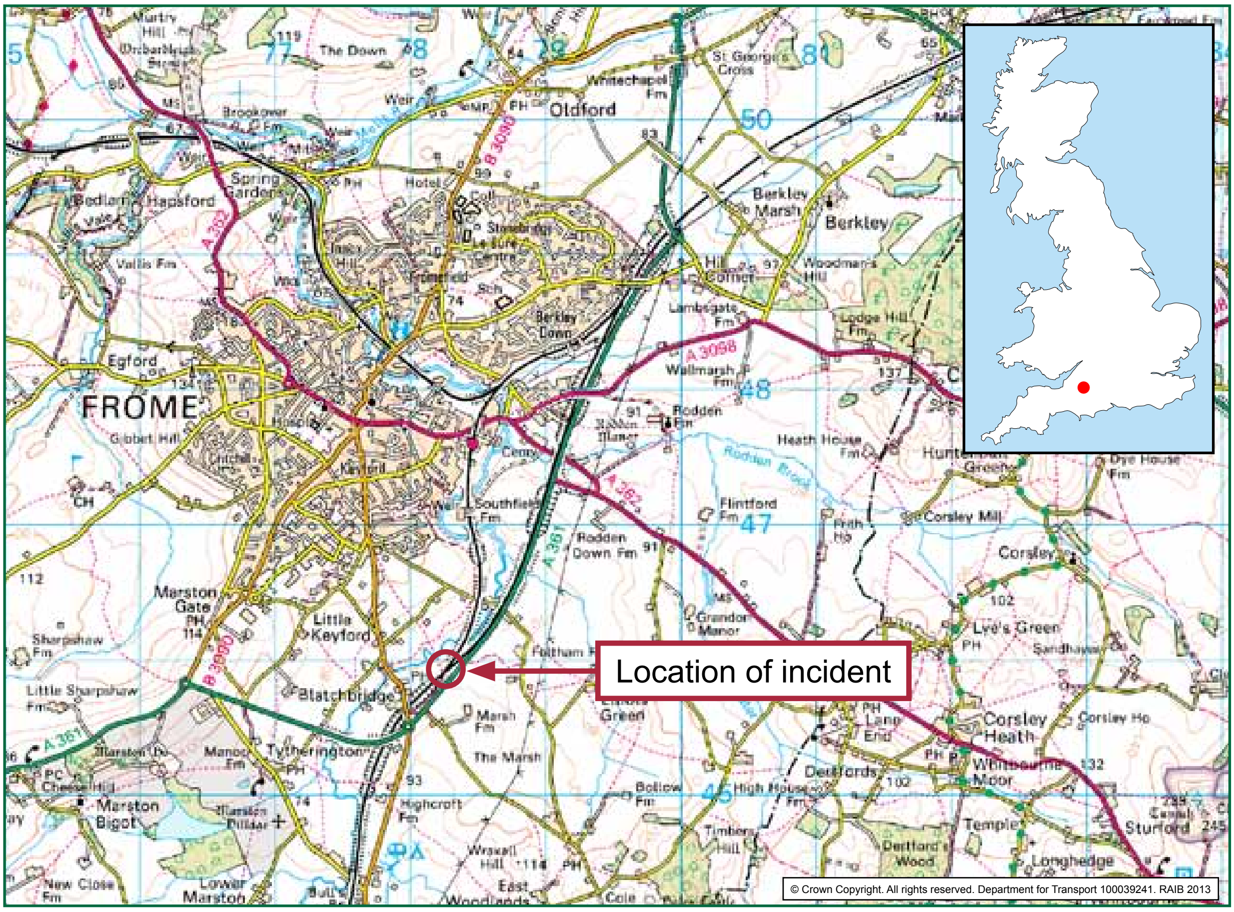

Figure 1: Extract from Ordnance Survey map showing location of incident

9 Part of a wooden foot crossing was destroyed by the control cab as it slid along the track. The control cab itself was damaged and had to be rebuilt following the incident. Nobody was injured. The incident had the potential for a more serious outcome if the cab had become unrestrained and then derailed train 6Y33, or had collided with a platform or a train travelling on an adjacent line.

Context

Location

10 Blatchbridge Junction is located 116 miles and 37 chains[1] from London Paddington station. The railway at this location is non-electrified double-track, and is used by passenger, freight and *engineering* trains.

11 The junction comprises *trailing* and *facing* points. Approaching from the west, the facing points allow trains to be routed either to Frome station or onto the Frome avoiding line. The maximum permitted speed on the avoiding line (the route taken by train 6Y33) is 100 mph (160 km/h). A wooden foot crossing is provided between the two sets of points at Blatchbridge Junction.

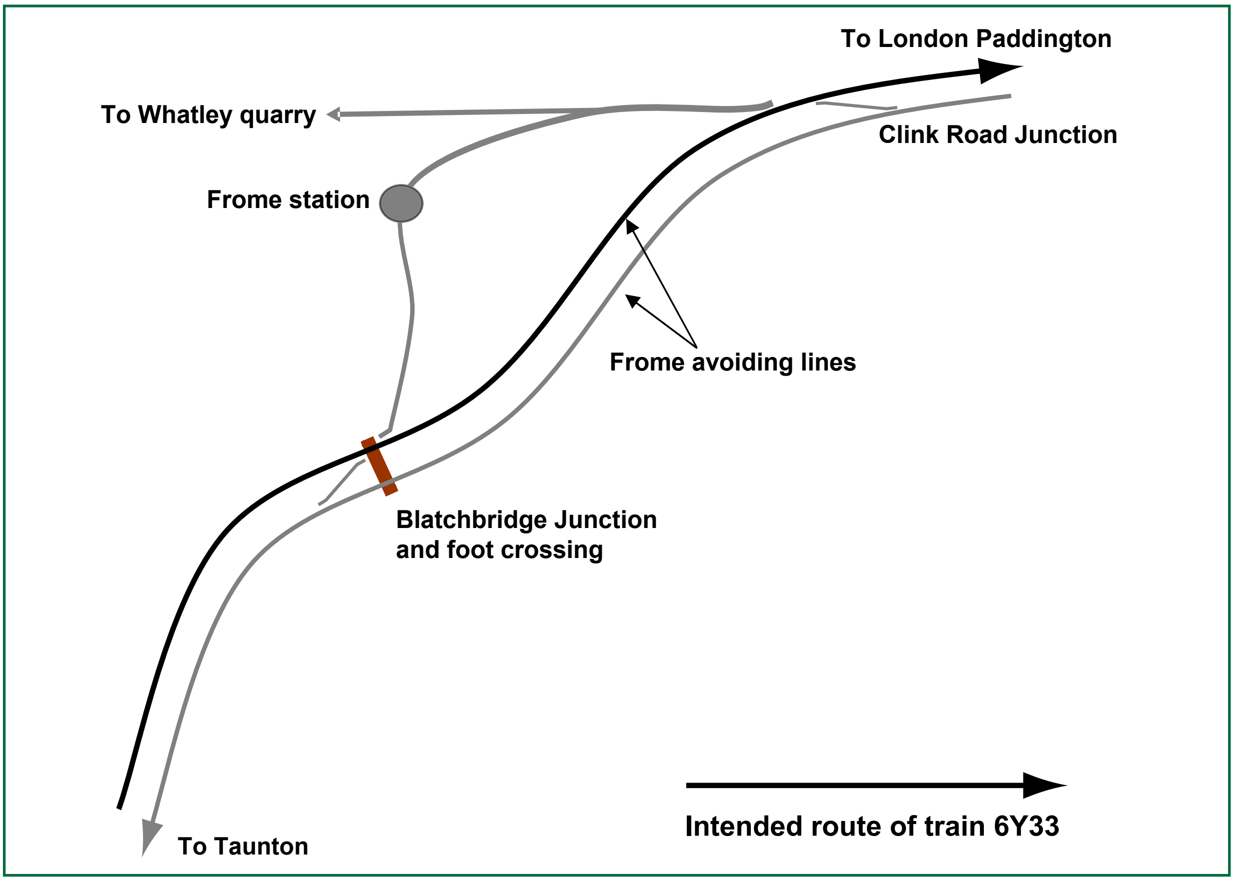

Figure 2: Layout of location and intended route of train 6Y33

Organisations involved

12 The P95 machine is owned by Network Rail and was built by Matisa Matériel Industriel S.A in Switzerland (referred to as Matisa within this report). From its introduction in 2006, until January 2010, it was operated and maintained by Babcock Rail Ltd who engaged sub-contracted technical staff to maintain the P95. From January 2010 the machine was operated and maintained by AmeyColas (a joint venture between Amey and Colas Rail).

13 Train 6Y33 was being hauled to a *work site* by a locomotive and driver supplied by Freightliner Ltd. Neither the locomotive, nor the way in which it was driven were implicated in the incident.

[1] A chain is a unit of length, equal to 22 yards or 20.1 metres. There are 80 chains in one mile.

14 Interfleet was the *Conformance Certification Body* (CCB) and *Vehicle Acceptance body* (VAB) contracted by Network Rail as part of the vehicle acceptance process.

15 All the organisations freely co-operated with the investigation.

Train involved

16 Train 6Y33 was an engineering train running from Taunton Fairwater yard, Somerset, to a site where track was to be renewed near Lavington, Wiltshire.

17 Train 6Y33 was hauled by a class 66 locomotive, with another class 66 locomotive at the rear of the formation. Each locomotive had a driver (although the rear locomotive was not operating during the journey from Taunton). The train consisted of 20 vehicles including seven vehicles that formed the P95 machine. The train was 488 metres long, weighed 1,674 tonnes and was permitted to travel up to a maximum speed of 60 mph (96 km/h).

Rail equipment/systems involved

18 The P95 machine is a track renewal train. This type of machine has been in use outside the UK since 1992. The UK version of the machine is known as the P95/1 UK. In 2010 Network Rail introduced a second P95 machine into service, the P95/2 UK.

19 The seven vehicles comprising the P95/1 UK are semi-permanently coupled (figure 3). It is not able to travel to sites where it is to work on its own; it has to be hauled as part of a train. Once at the site of work it is uncoupled from the train and works under its own power at less than walking pace as it renews the track (this is known as 'working mode').

Figure 3: The track renewal train with support wagons (image courtesy of Stuart Graham of Stuart's Railway Photography)

20 The P95 machine is able to renew long sections of track in a continuous operation. The sequence is:

- the track clips are removed;
- old rail is raised and moved out of the way;
- old sleepers are removed;
- ballast is ploughed to provide a flat track bed;
- new sleepers are placed on the flat track bed;
- new rail is placed onto the new sleepers; and
- the new rails are clipped into place.

21 In working mode, two operators generally control the P95/1 UK from an under-slung operator's cab, known as the P3 cab, using video displays (figure 4).

Figure 4: The P3 operators cab (circled)

22 The P3 cab is suspended from the vehicle using a supporting frame which is welded to an overhead beam. To minimise transmission of vibration to the occupants of the P3 cab when the machine is working, the cab is secured to the supporting frame by eight flexible mounts. Each flexible mount is secured to the frame by two steel bolts. Each flexible mount secures the P3 cab to the supporting frame by one steel bolt (figure 5). It was the failure of these bolts that allowed the P3 cab to fall onto the track.

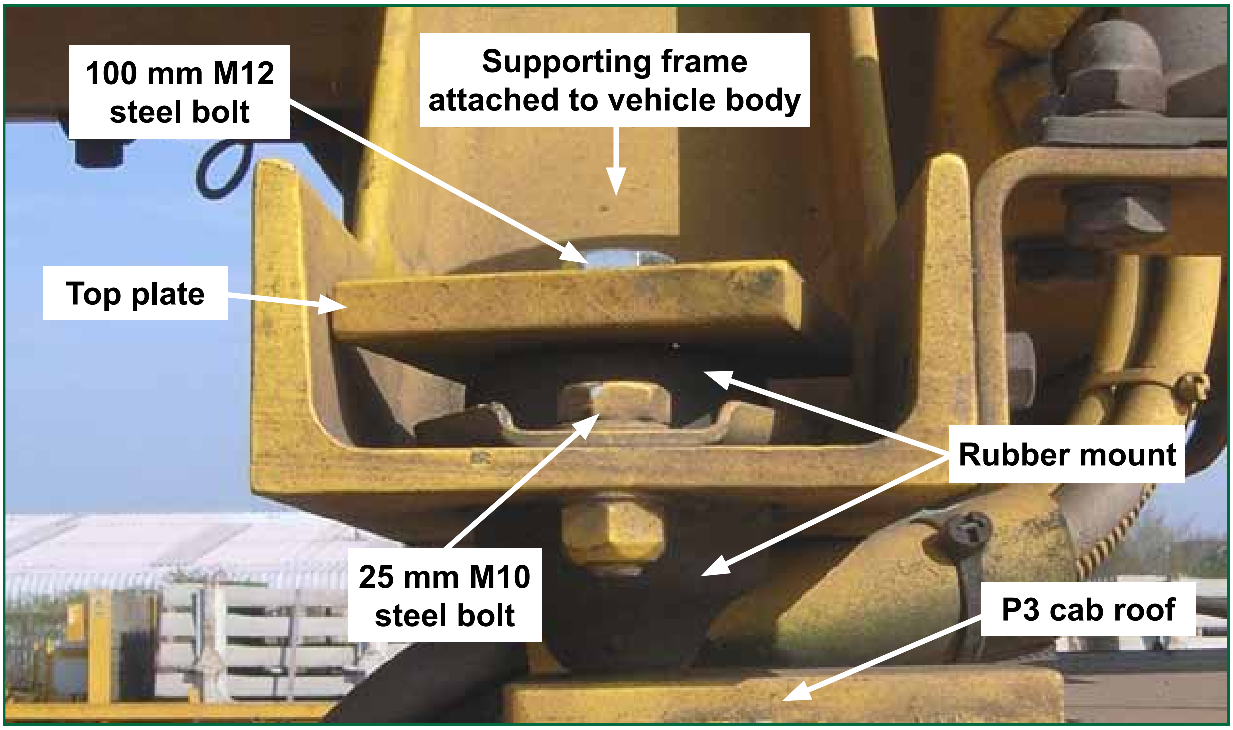

Figure 5: The flexible mounting arrangement

Staff involved

23 At the time of the incident, the P95/1 UK was maintained by a team of technicians based at Fairwater yard, Taunton. The technicians also maintained other track maintenance machines that operated out of the same base. Normally, routine maintenance activities on the P95/1 UK required the work of three technicians. The P95/2 UK was maintained at a depot in London under similar arrangements.

24 The technicians were originally sub-contracted to maintain the P95 /1 UK and other track maintenance machines by Babcock Rail Ltd, but transferred to AmeyColas in 2010 when AmeyColas took over operation and maintenance of both of Network Rail's P95 machines. The technicians were supervised by a maintenance supervisor whose responsibilities included checking that activities specified in the maintenance instructions had been complied with. He was also responsible for ensuring that problems arising during maintenance, such as defective equipment, were rectified or brought to the attention of the maintenance manager.

25 Overall management of the maintenance of the track maintenance machines was the responsibility of the maintenance manager. The maintenance manager's role was to make sure that maintenance was completed on time and to make day-to-day safety related maintenance decisions.

26 The competence of the technicians, supervisor and maintenance manager was subject to Colas Rail's *competence management system* (CMS).

External circumstances

27 It was a cold and dry night. The temperature was above freezing. External circumstances were not a factor in the incident.

Events preceding the incident

28 Train 6Y33 was prepared for service at Fairwater yard, Taunton in the afternoon of the day of the incident. Preparation of the train involved a maintenance technician checking that the P95/1 UK was configured for safe travel (ie equipment correctly stowed) and a *shunter* checking that the train consist was correct and that the support wagons and locomotives were correctly coupled.

29 At around 18:30 hrs, train 6Y33 departed from Fairwater yard crewed by two drivers, one on each locomotive. At Cogload Junction, around 5 miles east of Taunton, the train was routed onto the Westbury line.

30 Train 6Y33 passed through stations at Castle Cary and Bruton and passed one passenger and one freight train on the adjacent down line during this part of the journey. The *on-train data recorder* (OTDR) fitted to the leading locomotive of the train recorded that it was travelling close to its maximum permitted speed of 60 mph (96 km/h) as it approached Blatchbridge Junction.

Events during the incident

31 Approaching Blatchbridge Junction, the P3 control cab became detached from the supporting structure and fell onto the track beneath the train. The control cab continued to slide along the surface of the rails partially restrained by electrical cables and the brake hose. Timbers forming part of the foot crossing at Blatchbridge Junction were damaged as the detached control cab passed over it (figure 6).

Figure 6: Blatchbridge Junction and the partially destroyed foot crossing (path of train 6Y33 indicated by white arrow)

32 The driver of train 6N62, travelling in the opposite direction on the adjacent down line, saw sparks underneath train 6Y33 and reported this to the signaller at Westbury signal box. The signaller at Westbury called the Network Rail operations control centre located at Milton Keynes and requested an emergency stop broadcast[2] for train 6Y33.

33 Meanwhile, around one minute after passing over Blatchbridge Junction, the brakes on train 6Y33 automatically applied as air pressure was lost when the brake hose became worn through from sliding along the rails. The train came to a stop around ¼ mile (400 metres) on the approach to Clink Road Junction (figure 2). Around this time the emergency stop broadcast was received by the driver.

Events following the incident

34 The Westbury signaller set the signal on the approach to Clink Road Junction to red to stop any other trains approaching along the line adjacent to train 6Y33. The driver examined the train and found that the detached control cab had rotated to the left and had moved closer to the adjacent line (figure 7).

Figure 7: The detached control cab (path of train 6Y33 indicated by white arrow)

[2] Network Rail operations control has the facility to send an emergency message requiring trains to stop. This message is sent via radio communication to a specific area or a specific train. On receiving an emergency stop message, drivers are required to bring their train to a stop and to confirm when this has been done.

35 On-call staff were mobilised by Network Rail and AmeyColas. The hoses and cables attached to the control cab were disconnected and the P3 cab was moved clear of the tracks. The damaged brake pipe was disconnected allowing the train to return to Taunton Fairwater yard. The P3 cab was recovered separately and transported by road to Fairwater yard.

36 An inspection by the local Network Rail track maintenance team found no obvious damage to the track or the points at Blatchbridge Junction, other than the damage to the foot crossing. However, once the control cab had become detached, there existed the potential for the cab to become unrestrained and derail train 6Y33 (either directly or by colliding with the facing points at Blatchbridge junction), collide with another train, or hit a person on the trackside.

The investigation

Sources of evidence

37 The following sources of evidence were used:

- witness statements;
- data from the train's on-train data recorder (OTDR);
- site photographs and measurements;
- observations at the site;
- metallurgical analysis of the failed bolts and un-failed bolts from the P95/2 UK;
- *finite element analysis* of a P3 cab mounting bolt;
- acceleration data for the P3 cab and strain gauge data for the mounting bolts during in-service transit runs and working operations;
- fatigue assessment of the P3 cab mounting bolts, using strain data measured during service operations;
- inspection of the threaded holes in the P3 cab roof;
- signalling records;
- P95/1 UK maintenance records;
- design and approvals documents for the P95;
- a review of previous reported occurrences involving the P95 machines; and
- a review of previous RAIB investigations that had relevance to this incident.

Key facts and analysis

Background information

The flexible mounting arrangement

38 The P3 control cab is suspended from the supporting framework of its vehicle by eight flexible mounts: four at the front relative to the direction of travel (referred to in the report as F1 to F4) and four at the rear (referred to in this report as R1 to R4).

39 Each flexible mount is bolted to the control cab roof by means of one 100 mm long M12, grade 8.8 steel bolt passing through a steel washer and steel top plate into a threaded *blind hole* in the roof via a steel tube incorporated within the rubber mount (figure 8). The steel tube serves as a spacer, against which the bolt is tightened in order to generate a *preload* without compressing the rubber mount. The rubber mount is attached to the vehicle's supporting structure by two 25 mm M10 steel bolts. Witness evidence indicates that the bolts supplied to Matisa were zinc plated, for protection from corrosion.

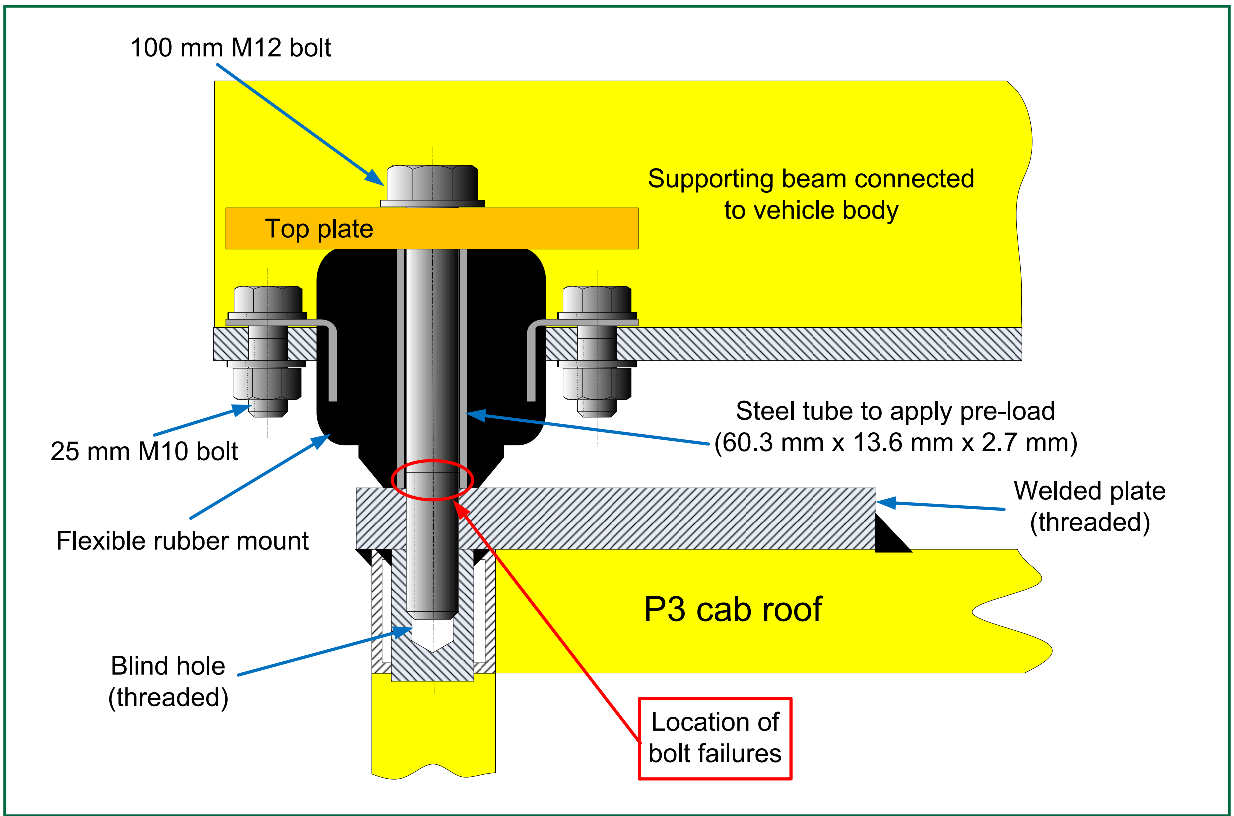

Figure 8: Representation of the flexible mounting arrangement (not to scale)

Examination of the P3 control cab on site

40 The RAIB examined the detached control cab at the site of the incident before it was moved clear of the track. All eight bolts had failed at the interface between the bottom of the flexible rubber mount and the top of the cab roof. Figure 9 and table 1 show the condition and type of failure exhibited by each of the eight bolts within the cab's flexible mountings.

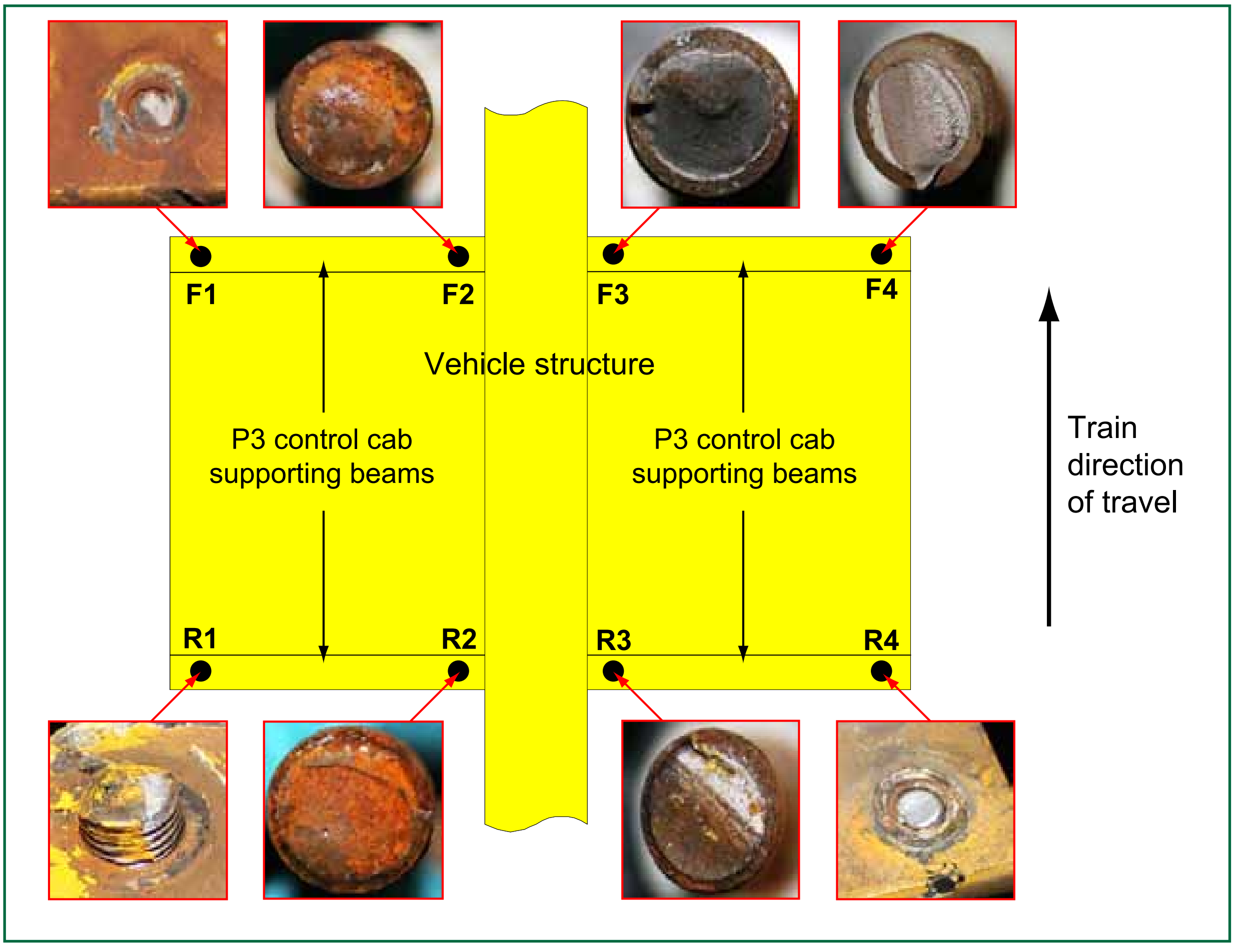

Figure 9: Bolt condition and location

Bolt	Failure mode of bolt (based on metallurgical analysis)
F1	*Rapid rate fatigue* failure leading to final failure by *overload.*
F2	*Slow rate fatigue failure*.
F3	Some evidence of fatigue cracking with the final failure by overload.
F4	Rapid-rate fatigue failure.
R1	The fractured face of this bolt was damaged during the incident. There is evidence of overload failure on part of the undamaged surface of the fracture. The top half of bolt R1 was not found after the incident.
R2	Slow-rate fatigue failure.
R3	Slow-rate fatigue failure.
R4	Overload failure.

Table 1:Bolt identification and failure type

41 The fracture faces of bolts F2 and R2 had rusted over, indicating that these two bolts were probably the first to fail and had done so some time before the incident (figure 10). Bolts F3, F4 and R4 exhibited overload failure and are most likely to have failed shortly before the control cab detached (figure 11). The remaining three bolts, F1, R1 and R3 exhibited evidence of pre-existing fatigue failure with final failure caused by overload as the cross-sectional area of the bolt diminished (figure 12).

Figure 10: Lower section of bolt F2 (inserted into cab roof) showing rusted-over fracture face

Figure 11: Lower section of bolt R4 (inserted into cab roof) showing clean-break indicating overload failure of the bolt

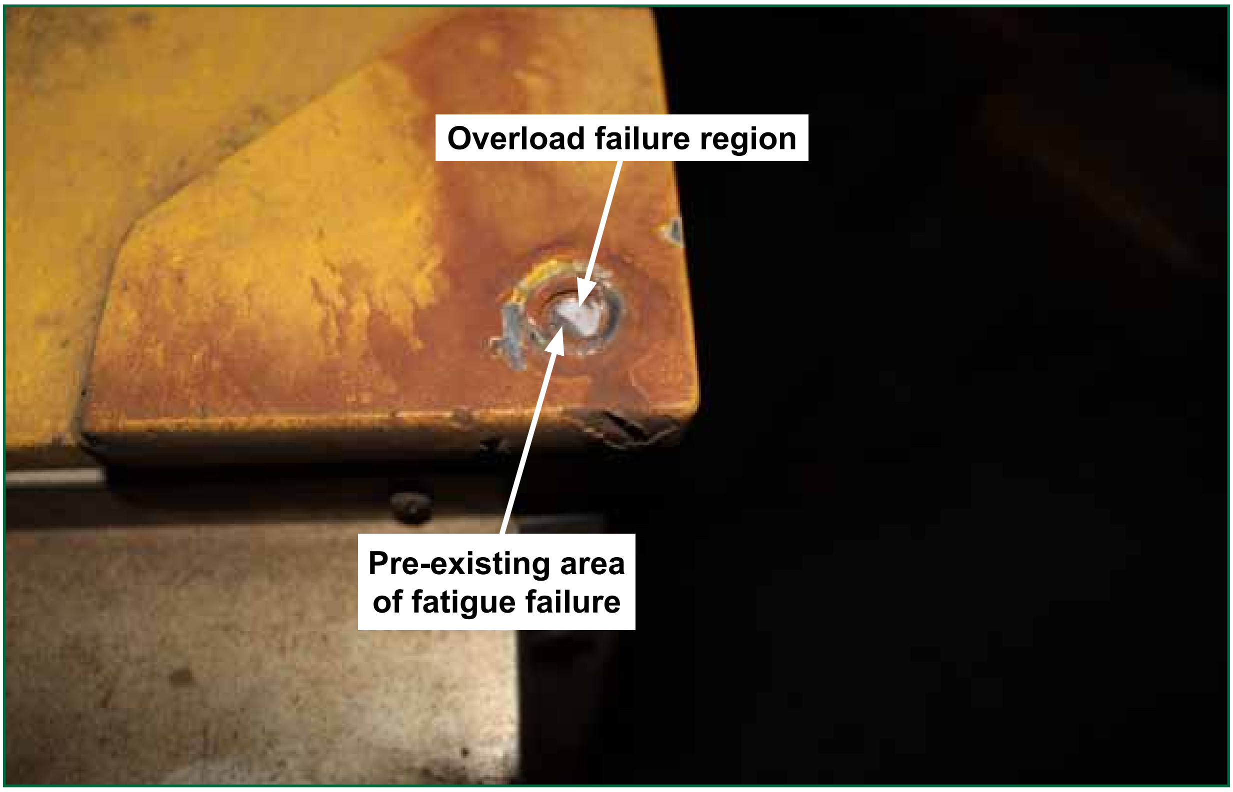

Figure 12: Lower section of bolt F1 (inserted into cab roof) showing evidence of pre-existing fatigue and final overload fracture

42 The top sections of bolts F1, R1 and R4 could not be found despite a search of the area. It is likely that they were ejected from the cab supporting framework as the cab detached and fell towards the track. The lower sections of these bolts were still in place in the cab roof fixing points.

Post-incident examination of the P3 cab and supporting bolts

Metallurgical failure analysis of the bolts

43 AmeyColas and Network Rail arranged for a metallurgical analysis[3] of both parts of failed bolts F2, F3, F4, R2 and R3, along with the remains of failed bolts F1, R1 and R4, to be undertaken by an independent third party with RAIB's agreement and input into the scope of the analysis. In addition, four used bolts from a different operator's cab on the P95/1 UK and two used bolts from the P3 control cab on the P95/2 UK were also analysed for comparison. The analysis comprised:

- examination of the 'as received' condition of the bolts;
- examination of the bolts following de-rusting;
- *magnetic particle inspection*;
- *chemical analysis*;
- hardness testing; and
- sectioning of the bolts.

44 There was no evidence that any of the bolts had any material abnormalities or manufacturing defects that could have led to their failure.

[3] The metallurgical analysis was undertaken by a company that was independent of AmeyColas, Network Rail and Matisa.

Identification of the immediate cause[4]

45 **The eight bolts within the flexible mountings supporting the cab structure failed and the unsupported cab fell onto the track below.**

46 Bolts F2 and R2 had completely failed some time before the incident. A further four bolts were already in the process of failing, although it is not possible to conclude with certainty how many of these bolts failed before or after the train departed from Taunton on the evening of the incident. The remaining two bolts failed when they became overloaded as a consequence of the failure of the other bolts as the train approached Blatchbridge Junction.

Identification of causal factors[5]

47 The RAIB has identified a number of factors that were, or may have been, causal to this incident:

- The cab supporting bolts were subject to short periods of high stress when the P95/1 UK was operating in working mode. These stress cycles contributed to the fatigue failure of the affected bolts (probably causal).
- The design of the cab mounting arrangement allowed moisture to penetrate internally and corrosion to form on the bolts. This eventually led to the formation of corrosion pits in the threads, some of which may have caused the initiation of fatigue cracks (probably causal).
- Some of the bolts may have been exposed to a sudden impact force in an incident that occurred at Thatcham Station in January 2011. This may have led to joint slip and/or bolt damage which adversely affected the fatigue performance of those bolts. Other bolts may then have progressively failed as the load of the P3 cab became unevenly distributed (possibly causal).
- Following the incident at Thatcham in January 2011, the bolts were not inspected or replaced (possibly causal).
- The failing bolts were not discovered during routine maintenance because the maintenance instructions were not clear and lacked technical detail (causal).

Each of these factors is now considered in turn.

The stresses affecting the control cab supporting bolts

48 **The P3 cab supporting bolts were subject to short periods of high stress when the P95/1 UK was operating in working mode. These stress cycles contributed to the fatigue failure of the affected bolts. This was a probable causal factor.**

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

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

Finite element modelling of the bolts

49 Following the incident at Blatchbridge Junction, Matisa undertook a computerised *fatigue assessment* of the M12 cab mounting bolts using *finite element analysis*. The *accelerations* applied to the computer model were those specified in Railway Group Standard GM/RT2100, 'Structural Requirements for Railway Vehicles' Issue 3, October 2000[6], to which the cab mountings had originally been designed. These accelerations apply to transit runs, not working runs. The fatigue assessment was more detailed than the original bolt fatigue assessment that Matisa had undertaken during the design of the machine model. Matisa's conclusion was that the M12 bolt was correctly sized for the P3 cab flexible mount. Bolt *strains* measured during the RAIB's investigation (paragraphs 50 to 55) confirm that the bolt stresses during transit runs are insufficient to cause fatigue failure.

Bolt strain and acceleration analysis

50 At the RAIB's request, Network Rail and AmeyColas commissioned tests to quantify the mounting bolt strains and cab acceleration environment on the P95/1 UK in order to better understand the operating environment. *Accelerometers* (two tri-axial and eight single-axis) and two proximity sensors (to measure small movements) were fitted to various locations, including the floor and roof of the P3 cab and the supporting frame from which the cab was suspended. A pair of M12 mounting bolts, fitted with strain gauges[7], were installed at positions F4 and F3 (refer to figure 9 for positioning of bolts). Each bolt was fitted with four strain gauges (at the 3, 6, 9 and 12 o'clock positions) located on the bolt where the failures occurred (figure 8). The sensitive axes of the strain gauges were orientated along the length of the bolt. Data was collected during two transit runs (when the P95/1 UK was being hauled within a train) and two working shifts (when the P95/1 UK was working under its own power).

51 Test data recorded from the two transit runs did not identify any bolt strains that could have led to fatigue failure of the bolts. However, data from the two working shifts identified several high strain events on the outermost bolt (F4). Figure 13 shows a time history of the highest recorded strain, during the whole of the second working run, measured by one of the four strain gauges on the bolt. The highest bolt strain variation recorded was 1005 *microstrain*, which represents a bolt stress variation of 208 MPa (approximately 26% of the bolt material's tensile strength). There is also a static tensile strain in the bolts caused by the preload created by torque tightening of the bolts at installation. This was not recorded in the strain time-histories because the strain gauge readings were reset to zero after the bolts were tightened. The presence of a high tensile mean stress can result in an otherwise benign dynamic stress causing the failure of a bolt through fatigue.

52 A detailed plot of a typical high strain event is illustrated in figure 14 and shows two distinct components. There is a short duration strain excursion lasting around 0.25 seconds (shown by the blue line), on which is superimposed an oscillating strain with a regular frequency of around 50 Hz (shown by the red line). Unusually, the high strains were not reflected in the simultaneous acceleration signals measured in any of the vertical, lateral or longitudinal directions and therefore further checks were made to confirm the validity of the results.

[6] Available at http://www.rgsonline.co.uk/Pages/Withdrawn_Documents.aspx.

[7] A strain gauge is a device that is used to measure the extension and/or compression experienced by an object when it is subjected to forces. Knowledge of the strains seen by the material can be used to calculate the stresses acting on the material.

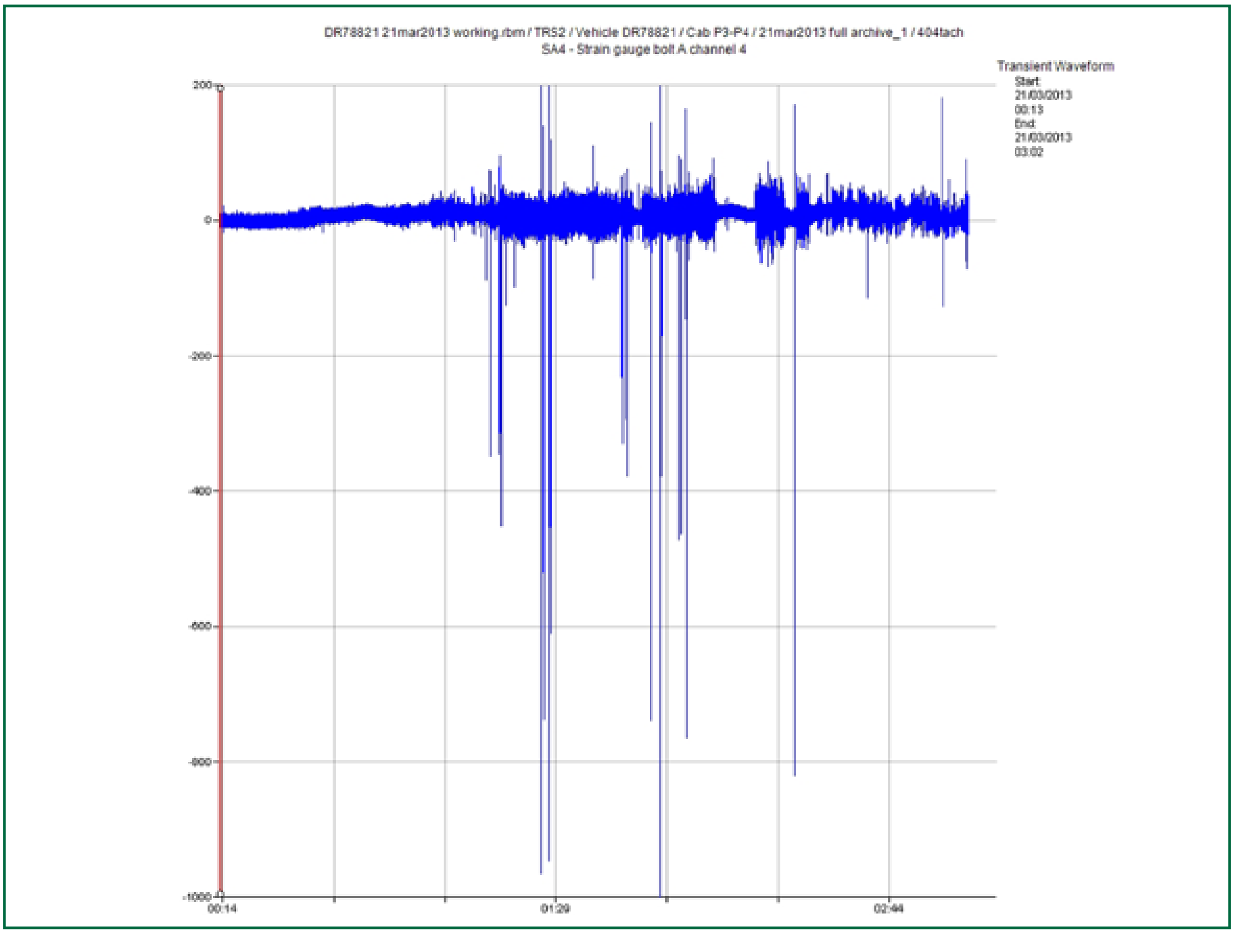

Figure 13: Strain signal plot for bolt at position F4

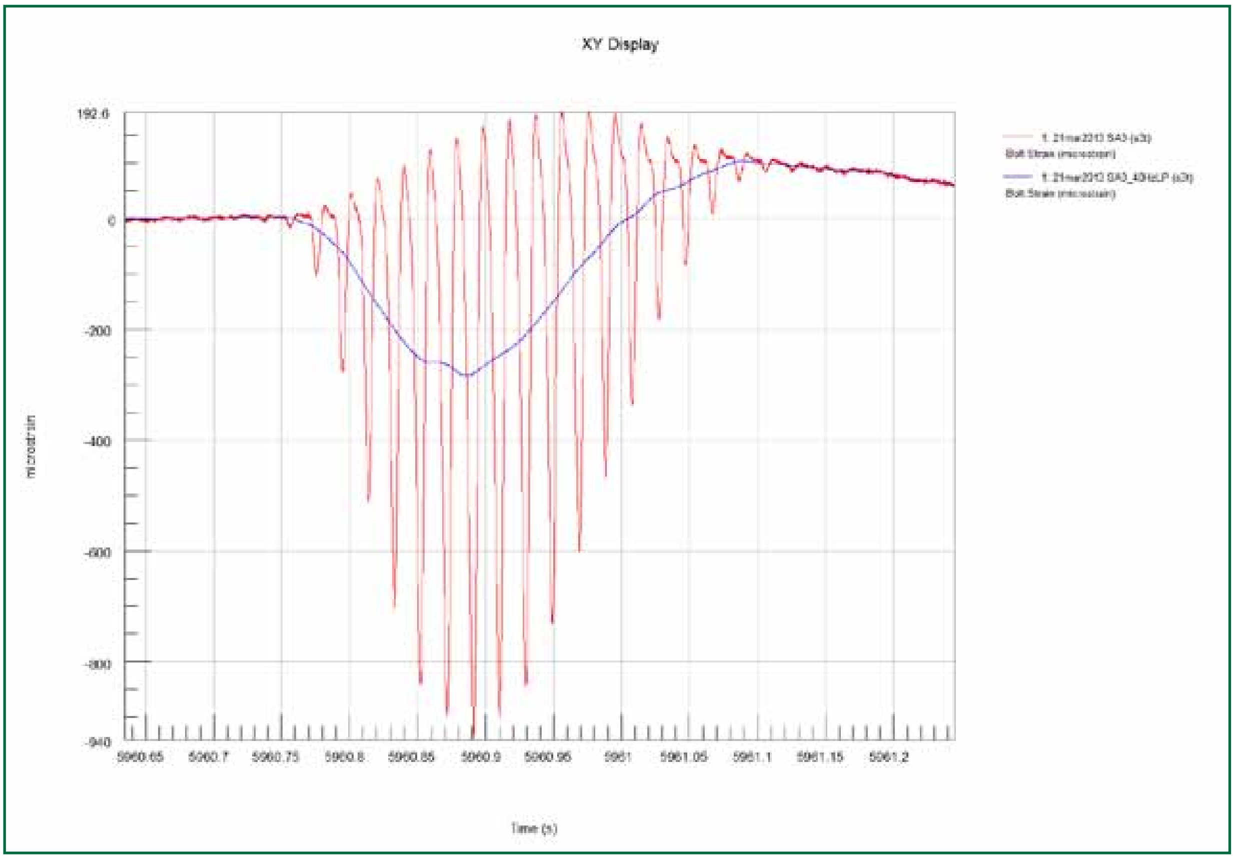

Figure 14: High strain event (blue line) and oscillating 50 Hz stress (red lines)

53 The frequency of the alternating current power supply to the strain gauges was 60 Hz, so it could not have been the cause of the observed 50 Hz oscillation. To understand if some other *electromagnetic interference* was being recorded, rather than genuine strains, a 'dummy' strain gauge was fitted to the cab. This dummy strain gauge was fitted to a metal block located close to the strain gauged bolts but structurally disconnected from the mounting structure. This meant that the dummy strain gauge would only detect any false strains caused by electromagnetic interference. Data collected during the second working shift was analysed and this showed that the dummy strain gauge had not recorded any activity when compared to the eight strain gauges mounted on the bolts. This indicated that the data collected during both working shifts had not been corrupted by electromagnetic interference, and were real. The cause of the high strain events has not been determined (see paragraphs 56 to 59).

54 In order to check if the strains measured in the bolts could explain the observed failures, a *fatigue analysis* of the bolt at location F4 (figure 9), which recorded the highest strains in the test, was undertaken. A tensile mean stress of 470 Mpa, calculated by Matisa for the prescribed installation torque of 83 Nm, was applied in the analysis. Standard bolt fatigue data from British Standard BS 7608 'Code of practice for fatigue design and assessment of steel structures', which relates applied stress to fatigue life, was used for the assessment. In accordance with this standard, allowance was made for the corroded condition of the bolts. Corrosion tends to reduce the fatigue life of bolts for a given stress spectrum because of the stress raising effect of the corrosion pits. A correction was made for the dimensional differences between the strain gauged bolts and standard M12 bolts; the former were made slightly thinner so that the strain gauges could be fitted, and therefore would have recorded higher stresses than normal service bolts.

55 The fatigue analysis predicted a mean fatigue life (with a 50% chance of being higher or lower) of around two to three years, based on between 220 and 250 working shifts (of around three hrs duration each) per year. The P95/1 UK had operated for six years before the incident, but at least two bolts had failed some time during this period (paragraph 41). The results of the fatigue assessment are therefore consistent with the observed fatigue lives of the bolts, given that there is always some scatter in the fatigue performance of bolts in service, due to differences in factors such as material composition, surface condition, and loading. This indicates that if the stresses in the cab mounting bolts during its life before the incident had been of similar magnitude to those measured during the test working run, then those stresses alone would have been sufficient to cause fatigue failure of the bolts.

Observations of the machine in working mode

56 A possible explanation of why high strain signals were recorded without corresponding accelerations being present (paragraph 52) may be the way in which the P95/1 UK operates during a working shift. When the strain gauge and accelerometer data were compared to a log of key events associated with the machine operating in working mode, it showed that all the high strain readings occurred when the machine's dynamic plough was deployed and working.

57 When the P95/1 UK is in working mode a single-piece steel plough is deployed to produce a flat bed of ballast on which the machine places new sleepers. It remains deployed all the time the P95/1 UK is replacing the sleepers and rails. The plough is operated through a control unit located in the P3 cab. Hydraulic cylinders and a cable and pulley system control the lowering and raising of the plough. The ploughing depth can be varied by the operators in the P3 cab.

58 The dynamic plough and old sleeper removal horn are two of the tools attached to the P95/1 UK (figure 15). These tools are attached to a two-part overhead supporting beam. The front of the plough and horn assembly is supported by two hydraulic cylinders attached to the supporting beam, and the rear of the plough and horn assembly is suspended by a single hydraulic cylinder. The two parts of the overhead supporting beam are connected by a ball joint which permits movement between the two parts of the overhead supporting beam when the caterpillar wheel sets are deployed on the vehicle ahead of the working group. Loading of the bolts during operation of the machine in working mode was not considered in the original design of the cab mounts (paragraph 97).

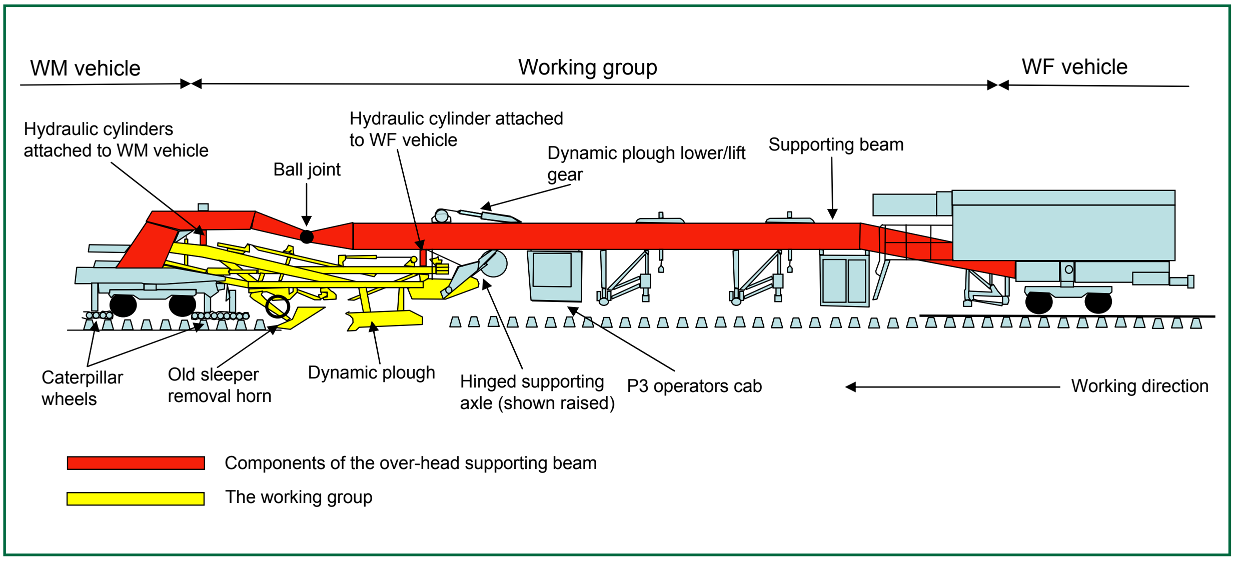

Figure 15: Simplified plan of the working group and adjacent vehicles, including the working group (yellow) and overhead supporting beam (red)

59 When the plough and horn are deployed, the forces acting on them may be reacted through the overhead supporting beam. Data from the service tests (paragraph 50) appears to indicate that these forces may cause the beam to flex in such as way as to cause high strains in the cab mounting bolts without significant accelerations in the cab (paragraph 52). However, it was not possible from the measurements to determine exactly how the bolts were becoming loaded and it is not known if the bolts on the other P95 machines experience the same loading as the P95/1 UK machine.

Corrosion of the mounting bolts

60 **The design of the cab mounting arrangement allowed moisture to penetrate internally and corrosion to form on the bolts. This eventually led to the formation of corrosion pits in the threads, some of which may have caused the initiation of fatigue cracks. This was a probable causal factor.**

61 The metallurgical analysis (paragraphs 43 and 44) of the failed bolts from the P3 control cab and the used bolts from the smaller P2 cab on the P95/1 UK and the used bolts from the P3 cab of the P95/2 UK found that they were all severely corroded. When this corrosion was cleaned off the failed P3 cab bolts, there was evidence of cracking at the end of the threaded region (figures 16 and 17). The metallurgical analysis did not identify any irregularities at the thread roots, such as defects during the manufacture of the bolts, and so the most likely starting point of the fatigue failure was from a point at the bolt thread root affected by corrosion. Bolts F2, R3 and R2 appeared to have failed by fatigue from the *thread root* at a relatively slow rate. Bolt F4 showed signs of fatigue failure from the root, but this had occurred relatively rapidly in a small number of cycles. Although the majority of bolt F3 had failed by rapid overload, there were signs of fatigue cracks in the root of the bolt thread.

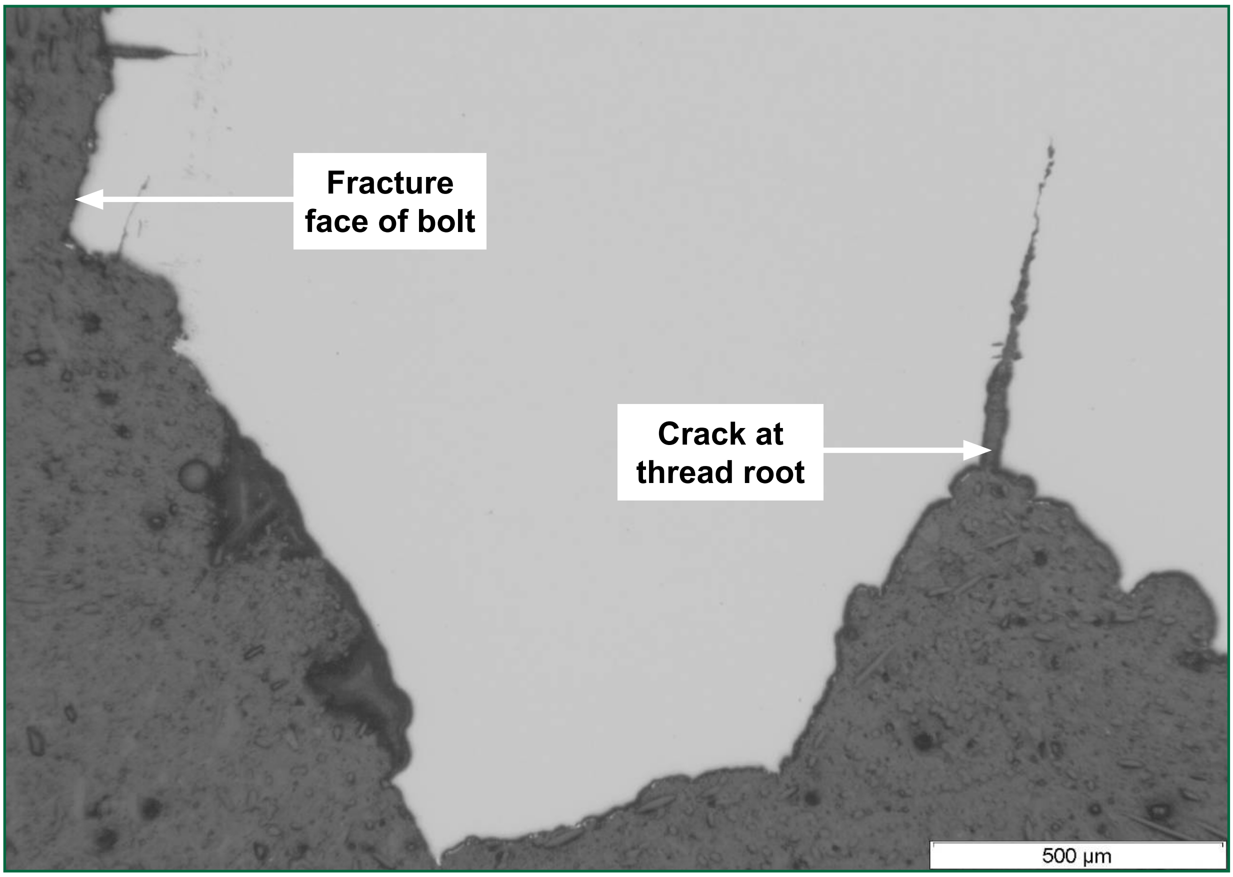

Figure 16: Cross sectional evidence of fatigue cracking and corrosion of the teeth of bolt F2 (picture courtesy of SERCO)

Figure 17: Corrosion on bolt R3

62 The corrosion on the threads was most likely to have been caused by moisture ingress through capillary action at imperfections around the interface between the bottom of the flexible mount (which was not designed to seal against the P3 cab) and the cab roof (figure 8). Bolts that had corrosion along their shanks, right up to the bolt heads, may have been exposed to moisture ingress from the interface between the bolt head and the top of the flexible mount, once the bolt had failed and the joint was no longer tightly clamped. Although the bolts were zinc plated for corrosion protection, contact between the threads of the bolt and the threaded hole of the cab roof appears to have removed this protection (figure 19 insert). It is also possible that the corrosion protection was imperfect at the thread roots. In either case, unprotected metal could have been exposed to moisture, allowing corrosion to develop and fatigue cracks to initiate from some of the corrosion pits in the presence of service stresses (paragraphs 50 to 54) until the affected bolts eventually fractured.

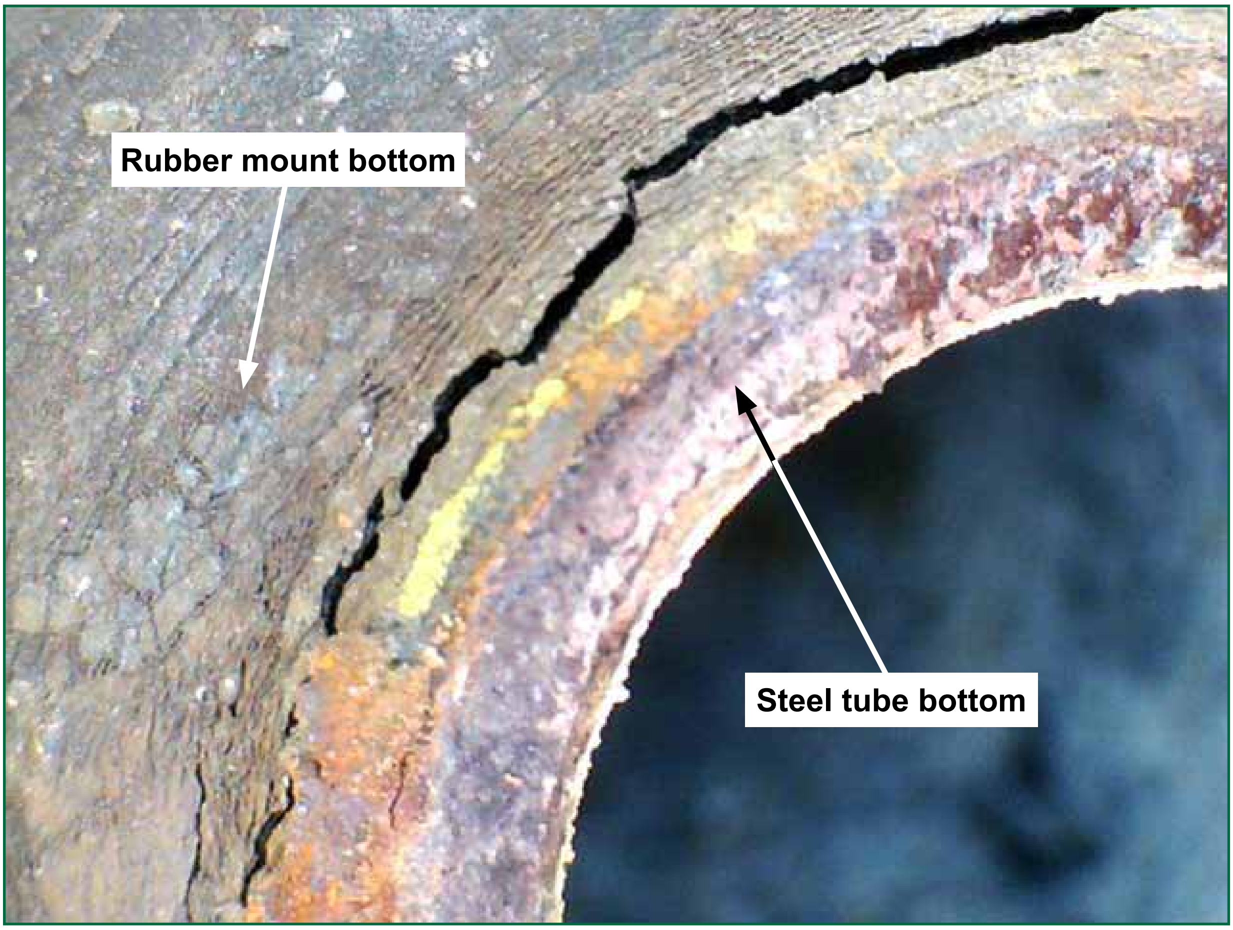

Figure 18: Imperfections of the steel tube and the bottom face of the rubber mount allowing moisture to reach the bolt threads

63 The RAIB inspected the new P3 cab bolts that had been installed after the incident at Blatchbridge Junction, rubber mountings and contact areas during a visit in April 2013, around 12 months after the P3 cab had been rebuilt and refitted to the P95/1 UK. Corrosion was already evident on the replacement bolts. The area of corrosion was near the top of the bolt threads at the point where the failed bolts had previously corroded. Since installation, the bolts had been regularly checked to make sure they were correctly torque tightened. There was little evidence of corrosion of the bolt shank or the bolt head or washer. This indicates that moisture was reaching the bolt at the interface between the bottom of the rubber mount and the cab roof surface. Figure 19 shows replacement bolt R4. The length inserted into the blind hole in the cab was 28 mm which corresponded to the length exhibiting signs of corrosion. The worst corrosion corresponded to the interface between the bottom of the rubber mount and the cab roof surface. At this point corrosion was clearly visible for 3 to 4 turns down the threaded length of the bolt with lighter corrosion propagating further down the threaded length.

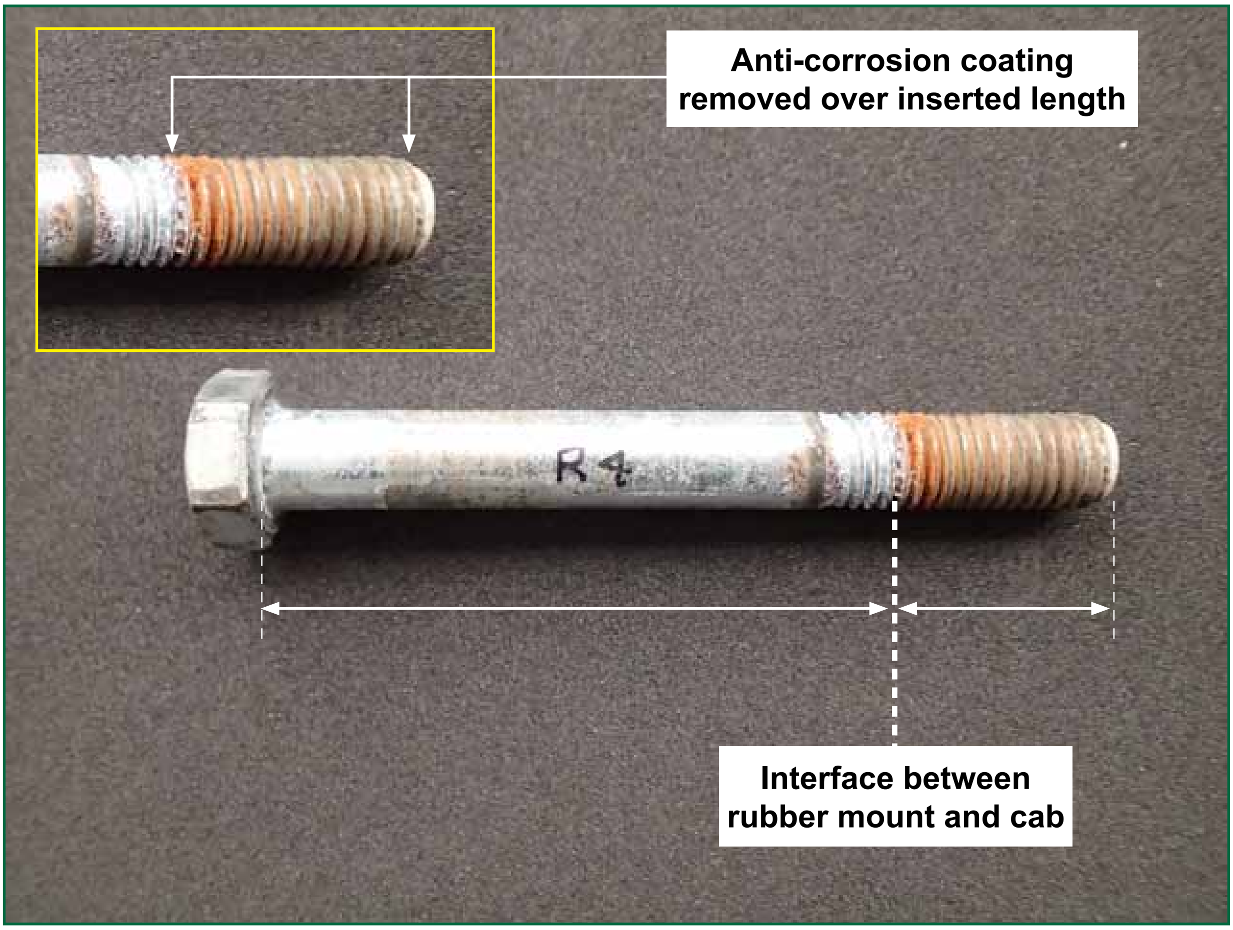

Figure 19: Bolt R4 removed for inspection with evidence of corrosion forming at the interface between the rubber mount and cab roof surface. Inset: anti-corrosion coating removed by the action of inserting the bolt into the blind hole.

64 Six used bolts were also analysed (paragraph 43) for comparison with the failed bolts from the P3 control cab. Four came from the smaller P2 control cab on the P95/1 UK, and two from the P3 control cab on the P95/2 UK. All the used bolts showed evidence of corrosion around the top of the threaded region. The location of the corrosion was identical to that seen on the failed bolts from the P95/1 UK P3 control cab that has identical, but fewer (four) flexible mountings (figure 20).

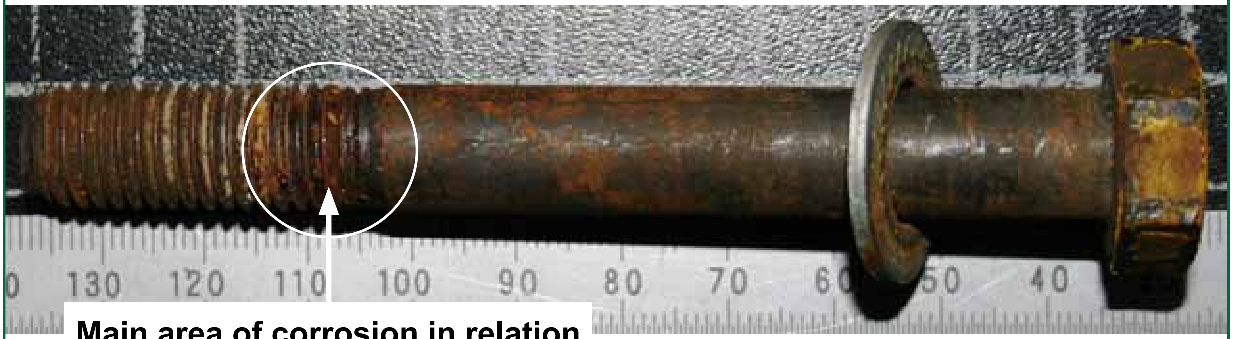

Figure 20: Location of corrosion seen on the used bolts from the smaller P2 cab from the P95/1 UK

Previous cab impact incident

65 **Some of the bolts may have been exposed to a sudden impact force. This may have led to joint slip and/or bolt damage which adversely affected the fatigue performance of those bolts leading to their failure. Other bolts may then have progressively failed as the load of the P3 cab became unevenly distributed. This was a possible causal factor.**

66 The RAIB considers that the factors described in paragraphs 48 to 64 are causal, or probably causal factors in the incident at Blatchbridge Junction on 19 March 2012. However, other P95 machines had been operating in Europe since 1992 without any similar incident having occurred. Given the similarity in design, operating environment and maintenance arrangements, the RAIB considered why the mountings on the P3 cab of the P95/1 UK were the only ones to have failed.

67 On 26 January 2011, the P95/1 UK was being hauled from Taunton to Theale in Berkshire. During the journey a rail-handling clamp attached to one of the vehicles (one of 16 clamps fitted to the P95/1 UK) moved laterally from its stowed position into an out-of-gauge[8] position. The clamp, weighing around 200 kg, struck platforms at Castle Cary, Bedwyn, Hungerford and Thatcham. The clamp became detached as the train passed through Thatcham station, having struck a brick platform supporting column (figure 21). Several items of equipment along the side of the P95/1 UK, including the leading left edge of the P3 cab, were struck by the detached clamp (figure 22).

68 The RAIB did not investigate the Thatcham incident because, as reported to the RAIB at the time, it was considered to be a relatively low-risk event. The cause appeared to be understood by the railway industry, which launched its own investigation.

69 The clamp became detached because there was no positive locking mechanism fitted to prevent the clamp moving into an unsafe position, and there was no requirement to check that the clamp was correctly stowed prior to the machine entering service.

[8] In railway terms, 'out-of-gauge' refers to a situation where any part of a train does not fit within a defined envelope and is thus at risk from striking objects it will pass such as platforms, tunnels or other trains, unless special arrangements are made.

Figure 21: The damaged brick platform support at Thatcham station and the detached clamp (inset)

70 Following the incident at Blatchbridge Junction on 19 March 2012, the P3 control cab had to be rebuilt. When the body panels were removed, a 40 mm x 40 mm x 2 mm steel cross member was found to be deformed. There was no evidence that the P3 cab had been involved in any other collisions or impacts before or since the incident at Thatcham, and so this deformation had almost certainly been caused by the impact with the clamp on 26 January 2011. It was estimated that the cross member had deformed by no more than 50 mm (figure 23).

Figure 22: The damaged leading left edge of the P3 control cab following impact from the detached clamp on 26 January 2011

Figure 23: Damaged steel section removed for replacement during re-build of the P3 cab after the incident at Blatchbridge Junction. The front of the cab is lying face down in this image.

71 The magnitude of the impact force sustained by the cab in the incident is not known, and may have been affected by a number of factors including other impacts between the clamp and the train/infrastructure before it struck the cab. However, an estimate of the magnitude of the impact force can be made for an assumed speed of impact between the clamp and cab. At a relatively low impact speed of 12 mph (20 km/h), the RAIB has assessed that the impact forces could have been greater than the loads for which the flexible cab mountings were designed. In reality, it is likely that the impact speed was higher than 12 mph (20 km/h) as the train was travelling at around 60 mph (96 km/h) when it was travelling through Thatcham station. It is therefore possible that the impact would have resulted in movement or slip within some of the flexible mount assemblies as a result of these forces overcoming the friction grip of the bolted joints. Possible consequences of such slip within the bolted joint could have been:

- a reduction in bolt pre-load, allowing the bolts to loosen under normal operational vibrations, which in turn could make a bolt more vulnerable to fatigue[9]; and
- some of the bolts could have become permanently bent[10] and this may have adversely affected the bolt's fatigue performance as the yield-strain cyclic load increases fatigue.

72 It is impossible to know if the bolts were affected by the impact force. As explained earlier at paragraph 54, damage from a sudden impact force is not a pre-requisite to explaining the fatigue failure of the bolts. However, had there been damage to the bolted joints in the Thatcham incident, it could have made the bolts fail earlier.

Actions following the January 2011 Thatcham incident

73 Neither the maintainer nor the owner inspected the flexible mounting arrangements, or replaced the bolts within the flexible mount, following the impact between the clamp and P3 cab in January 2011. This was a possible causal factor.

74 Following the incident at Thatcham in January 2011, Network Rail and AmeyColas inspected all the vehicles and prepared a plan to carry out the repairs necessary for the machine to re-enter service. Railway Group Standard GM/RT2400 issue 3 'Engineering design of on-track machines', dated December 2010 stated at clause 3.25.1.4 that *'any structural damage shall be repaired in such a way that the structural design integrity is restored to the requirements of this document'*. The P3 cab bodywork was inspected by AmeyColas and Network Rail, and it was decided the damage was superficial only, so the flexible mountings and bolts were not inspected. Network Rail and AmeyColas believed the necessary repairs were made to restore the P3 cab structure to its original integrity.

---

[9] Usually, in a fully clamped or preloaded bolted joint, approximately 75% of the load is taken by the joint and 25% is taken by the bolt itself. If there is slip within the joint, joint preload is lost and a greater proportion of the loads applied to the joint pass through the bolt.

[10] Because all the bolts from the P3 cab had broken in the Blatchbridge Junction incident, it was not possible to identify with certainty that any of the bolts had bent before they failed or had bent as the P3 cab detached from the supporting framework. Permanently bent bolts can have tensile mean stresses on some parts of the bolt which, if sufficiently large, can reduce the bolt's fatigue performance.

75 Paragraph 71 explains that the impact between the clamp and P3 cab may have caused movement within some of the flexible mount assemblies as a result of the applied forces overcoming bolt grip. Figure 22 indicates that the damage to the P3 cab looked superficial in nature. It was not until the cab was rebuilt following the incident at Blatchbridge Junction that a deformed cross member was found, which indicated that the impact force could have been significant (figure 23).

76 Information provided by Matisa (including text relating to safety measures associated with the P95) did not specify any requirement for inspecting the P3 cab flexible mountings following a heavy impact (such as a collision or derailment). Neither AmeyColas nor Network Rail were aware that the flexible mounting arrangement may be at risk of damage in the event of the P3 cab being involved in a direct impact even if the damage appeared relatively insignificant (paragraph 74).

Maintenance of the P95/1 UK

77 **The failing bolts were not discovered during routine maintenance because the maintenance instructions were not clear and lacked technical detail. This was a causal factor.**

78 Had the bolts been checked for tightness using a torque wrench during routine maintenance, bolts with strength properties that had been sufficiently affected by fatigue cracking would have broken during the torque tests, and any loose or broken bolts would have been identified and tightened.

79 At the time the P95/1 UK was being designed, the requirements for the maintenance of rail vehicles were set out in Railway Group Standard GM/RT2004 issue 2, dated October 1999 'Requirements for rail vehicle maintenance'. This standard required the vehicle operator to have a maintenance plan. The requirements of the plan were to identify the components of the rail vehicle that presented an element of risk and to describe in detail the maintenance required to make sure vehicles continued to conform to the requirements of the relevant group standards. The Matisa maintenance manual was seen to fulfil the role of maintenance plan by those involved in the introduction into service of the P95/1 UK.

Hazard identification

80 Babcock Rail, Interfleet and Network Rail undertook a joint exercise to identify potential hazards with the P95/1 UK before its introduction. This exercise involved cross-checking that hazards identified by these parties were mitigated by appropriate design, maintenance and inspection activities and operational procedures. The hazard log included a general hazard of 'structural failure of vehicle' but the specific failure of the supporting bolts and subsequent detachment of the P3 cab was not specifically identified.

81 The mitigations against structural failure of the vehicle recorded by these parties were:

- the train had been designed in compliance with the relevant railway group standards, including those for structural integrity and crashworthiness, and
- the maintenance manual provided by Matisa defined the necessary requirements for maintenance, including what items to maintain and the frequencies of inspections and overhauls.

Maintenance plan reviews

82 Before the P95/1 UK was introduced into service the documentation provided by Matisa, including the maintenance arrangements, was subject to review by Babcock Rail (as the operator and maintainer) and Network Rail (as the owner). Matisa's P95/1 UK maintenance manual contained the maintenance plan, general advice on safety matters and planned inspection frequencies. Of particular relevance to this investigation was a requirement in section 1.4.7 of the maintenance manual:

> *'all screws or bolts which can become loose and therefore present a hazard, must be tightened with their appropriate tightening torque'.*

83 The RAIB has found no evidence that reviews of the maintenance plan undertaken by Babcock Rail or Network Rail had considered whether the cab bolts should be subject to the requirements of section 1.4.7 of the maintenance manual.

Maintenance of the P3 cab flexible mounts

84 Maintenance of the P3 control cab was covered within section 5 'Maintenance-other elements' of the Matisa P95/1 UK operation and maintenance instruction manual. Matisa specified that the 'cabin supports' (flexible mounts) on the P3 control cab must be checked for integrity once per month, with rubbers and fastenings specifically identified. The maintenance manual did not define the term 'integrity', and there were no specific technical details about how the check of the rubber mount and fastenings should be carried out (eg dismantling the flexible mount assembly to inspect the bolts or checking the torque value of the bolts). It is unusual for bolts to be checked for tightness at such short intervals. Typically, bolted joints are inspected at much longer frequencies on railway vehicles. Matisa was unable to provide the RAIB with any evidence as to the reasons for the monthly inspection cycle of the P3 cab flexible mountings.

85 Maintenance check-lists were provided within Matisa's P95 maintenance manual. The P3 cab flexible mount arrangement is listed on a monthly check-list to be completed by a technician and signed-off by the supervisor following completion of the relevant maintenance task. The check-list for the P3 cab specified that all elements of the P3 cab must be *'checked and renewed or fixed if necessary'* although no technical details were provided on how to undertake these tasks. Matisa's P95 maintenance manual also detailed the checks it had identified as 'important operations' and included the periodicity of those checks. The cabin support rubbers were to be checked monthly, with the check detailed as *'check (wear and condition without dismantling), renew or fix if necessary'.* There is no mention of the inspection of the P3 cab bolts, which would require dismantling of the flexible mount assembly to check their condition.

86 When the P95 entered service in the UK, Matisa provided staff to train the technicians that would maintain the P95 in the UK. The RAIB has not seen any documents that specifically detail the training the technicians received on how to maintain the P3 cab and its flexible mountings, and it has not been possible to identify if any of those staff that were trained by Matisa were still maintaining it before the Blatchbridge Junction incident, or had passed this training on to others. The maintenance technicians carried out the requirements of paragraphs 84 and 85 by visually inspecting the flexible mounting arrangement from a ladder (the mounting arrangements are not visible from the ground as they are around 2.3 metres above ground level). There was witness evidence that on some occasions the technicians checked the bolts' tightness with a spanner; a torque wrench was not used. The technicians indicated that the main focus during the visual inspections was on the condition of the rubber mount.

87 The RAIB observed that technicians did not refer to the maintenance instructions when replacing the P3 cab bolts following inspection (paragraph 63). As the instructions lacked technical detail this did not affect how the P3 cab was inspected. It would however, be important for maintenance instructions to be referred to when technical detail is provided, such as how an inspection is to be carried out and the relevant torque values to be applied. At the time of the incident, the maintenance of the P3 cab mounting arrangements was not part of the checks incorporated in the Colas Rail CMS. This was because the part of the CMS that dealt with the risk of items of equipment falling from the machine referred to 'under-slung' components. The P3 cab had not been interpreted as an 'under-slung' component because it was suspended above the solebar level of the vehicle and the solebar normally suspends under-slung equipment such as the vehicle bogies, suspension and brake equipment.

88 Matisa considered that the maintenance instructions it provided were clear: each flexible mount bolt should be torque checked for tightness every four weeks. Torque values were provided in Matisa's P95 maintenance manual and related to the size of bolt – not to a specific application of a bolt, such as the P3 cab flexible mount bolts – and the values were not cross-referenced to the relevant task in the manual. The RAIB contacted owners of other P95 machines operating outside the UK and found that none were checking the tightness of the P3 cab bolts using the torque values specified in the Matisa P95 maintenance manual, or removing the bolts for inspection. This evidence indicates that the maintenance instructions were not being interpreted as Matisa considered they should be. Had the torque tightness of the P3 cab mounting bolts been checked at sufficiently close intervals, it is likely that any bolts that had failed completely or had nearly cracked right through, would have been detected. This would have alerted the operator to the problem at an early stage, since the evidence from the bolt fracture faces indicates that they did not fail simultaneously.

89 Maintenance records reviewed by the RAIB indicated that the P3 cab monthly maintenance check-lists had been signed as completed by a technician and the check-list signed-off by the supervisor at the required frequency. Before the incident, there were no outstanding faults raised in relation to the P3 cab flexible mounts.

Identification of underlying factor[11]

Engineering acceptance process

90 **The design and maintenance review processes did not identify that the bolts were subjected to high stress cycles during the machine's working mode, that a corrosion trap existed which made the bolts at risk of fatigue failure, and that the maintenance instructions for the P3 cab bolts were unclear. This was an underlying cause.**

91 Before new rail vehicles enter service on the national railway network, they are subject to a process known as engineering acceptance. Railway Group Standard GM/RT2000 issue 2, dated October 2000 ('Engineering acceptance of rail vehicles') applied to the P95/1 at the time it was going through this process.

92 Engineering acceptance formed part of the process known as 'Route acceptance' (figure 24). The route acceptance process was described in Railway Group Standard GE/RT8270 issue one, dated February 2003 (now superseded). The purpose of route acceptance was to ensure the safe operation of vehicles on the infrastructure, safe interworking with other vehicles, the safety of persons on or near the line, the safety of the general public and the safe operation of any adjacent or connecting railway systems.

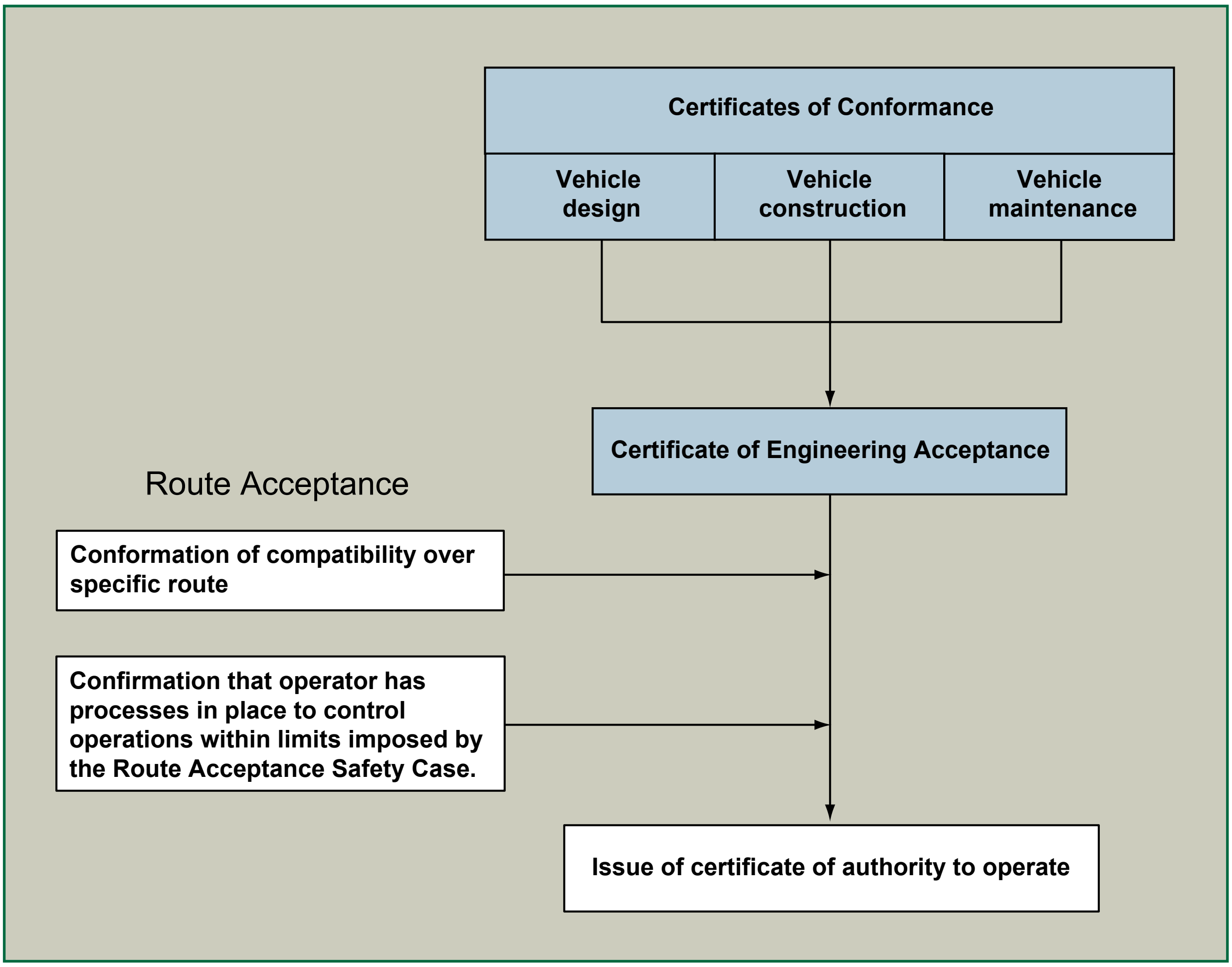

Figure 24: Route acceptance and the engineering acceptance process (blue)

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

93 Interfleet was appointed as the Conformance Certification Body (CCB) and Vehicle Acceptance Body (VAB) for the P95 UK/1. A company independent of Interfleet and Network Rail provided a review of the vehicle acceptance process applied to the P95/1 UK. In its role as a CCB and VAB for the P95/1 UK, Interfleet's responsibilities included:

- identifying all the relevant mandatory requirements for the P95/1 UK in the suite of railway group standards;
- satisfying itself that the P95/1 UK conformed to each individual mandatory requirement identified; and
- obtaining evidence that an appropriate safety examination process was defined to check that equipment was safe to operate following maintenance activities.

94 Standard GM/RT2000 also required the CCB and VAB to determine the scope and depth of the scrutiny of the design and the maintenance plan. Interfleet produced a plan, based on its consideration of the elements that posed the greatest risk.

Design scrutiny

95 The design scrutiny process is prescribed in Railway Group Standard GM/RT2001. At the time the P95/1 UK was being scrutinised issue 1 applied. In accordance with GM/RT2001, Interfleet was required to check the conformance of the P95/1 UK's design with mandatory requirements. In this context, the P3 cab and its mounting arrangements were required to comply with the requirements of Railway Group Standards GM/RT2400 issue 2 'Engineering acceptance and design of on-track machines' dated December 2002 and GM/RT2100 issue 3 'Structural requirements for railway vehicles' dated October 2000. Railway Group Standard GM/RT2100 issue 3 stated that 'equipment *and components attached directly, or indirectly, to vehicle bodies should have locally generated accelerations, forces and resonances calculated in addition to whole vehicle accelerations, forces and resonances'*. Railway Group Standard GM/RT2100 also required that '*all items mounted on vehicles shall remain attached under normal operating conditions'*. Matisa assumed that forces affecting the P3 cab flexible mountings would be greatest when the machine was being hauled. However, testing and analysis of the mounting arrangement has shown that the bolts were subjected to much higher levels of stress during working mode than when the P95/1 UK was being hauled (paragraph 51).

96 Railway Group Standards GM/RT2001 issue 1 (and the current issue 2) and GM/RT2100 issue 3 (and the current issue 5) do not make specific reference to applying the scrutiny process to all modes that the vehicle can operate (ie working modes and hauling modes).

97 During the design scrutiny process, Interfleet had identified that the P3 cab was an item that would need to be examined in detail as it was a substantial piece of equipment that was attached to the vehicle structure. Interfleet referred to Standard GM/RT2100 to identify the relevant proof load factors affecting the P3 cab. Data about locally generated accelerations, forces and resonances, as referred to in standard GM/RT2100 (paragraph 95), such as those experienced by the P95/1 UK machine in working mode, was not considered by Matisa during the design of the machine, and so Interfleet only had information for 'whole vehicle' accelerations, forces and resonances. But Interfleet had not prescribed scrutinising the P3 cab or its mounting arrangements in the machine's working mode in its scrutiny plan, and was not clearly directed to do so by the relevant Railway Group Standards (paragraphs 95 and 96).

98 In October 2004, Interfleet had communicated with Matisa about the calculation of forces affecting the bolted assembly. One of Interfleet's assessors asked Matisa to consider the 'moment effect' (the cab effectively 'swinging' back and forth) due to its low centre of gravity and also identified that Matisa had calculated the loads affecting the bolt in the vertical, lateral and longitudinal directions individually but had not added these together to calculate the worst-case fatigue life.

99 Matisa consequently revised its calculations, based on the accelerations, forces and resonances experienced by the machine during transit. Interfleet's assessor accepted Matisa's modified calculations and considered that the fatigue damage was 'negligible' in the context of the requirements of BS7608. The RAIB found no evidence that forces affecting the P3 cab during its working mode had been considered by Matisa during the machine's design.

Maintenance scrutiny

100 The maintenance plan was also subject to scrutiny under the engineering acceptance process. Interfleet used a compliance checklist based on Railway Group Standard GM/RT2004 issue 2, dated October 1999 'Requirements for rail vehicle maintenance' and GM/RT2402 issue 2 dated June 2003 'Engineering acceptance of rail mounted maintenance machines' to identify the areas for scrutiny. The compliance checklist included rail vehicle structures and, specifically, the security of underframe equipment.

101 The required level of scrutiny of the maintenance of components and equipment was dependent on the assessor's opinion, based on his experience as to whether the securing system or components were a novel or unusual feature. The P3 cab and its flexible mounting arrangement were not considered 'novel or unusual' and therefore were not scrutinised by the Interfleet assessor (the assessor's view was that many track maintenance machines in use in the UK had under-slung equipment and flexible mounting arrangements).

Reviews by the owner

102 As part of the process of route acceptance (paragraph 92 and figure 24), Network Rail issued 'certificates of authority' to allow the P95 UK/1 to complete trials before a full 'certificate of acceptance' was issued by Network Rail on 8 November 2005. This permitted the P95 UK/1 to enter operational service on the mainline network, subject to approval by the rail safety regulator (see paragraph 106).

Reviews by the operator and maintainer

103 Babcock Rail was awarded the contract to operate and maintain the P95/1 UK at quite a late stage in the project after the original company selected had withdrawn. At that stage, the P95/1 UK was almost fully constructed and representatives from Babcock Rail travelled to Switzerland to meet Matisa and review all the information about the machine, including the maintenance instructions.

104 Representatives from Babcock Rail stated that they believed any issues with the maintenance instructions would be identified during the maintenance plan scrutiny process (paragraphs 100 and 101).

105 The RAIB has seen no evidence that any detailed review of the maintenance instructions was undertaken. Babcock Rail was part of the team that undertook hazard reviews with Network Rail and Interfleet, but these were not detailed reviews of the maintenance instructions.

Health and Safety Executive approvals process

106 Before the P95/1 UK was permitted to operate, it required approval from Her Majesty's Railway Inspectorate (at that time part of the Heath and Safety Executive) in accordance with the Railways and Other Transport Systems (Approval of Works Plant and Equipment) Regulations 1994. This process involved a review of documents relating to the concept, design and testing of the P95/1 UK, and may have included an inspection as well, although this was not mandatory. Her Majesty's Railway Inspectorate issued a 'letter of approval' to Network Rail in 2006. This allowed Network Rail to introduce the P95 UK/1 into service.

Discounted factors

Condition of the track approaching Blatchbridge Junction

107 Track inspection and maintenance records for the four-week period week before the incident indicated that there were no track faults[12] that could have applied abnormal forces to the P3 control cab as train 6Y33 approached Blatchbridge Junction. Neither of the two drivers on the locomotives reported any track irregularity as the train approached Blatchbridge Junction.

[12] Track faults that can affect the ride of a vehicle include track twists, dips and alignment irregularities.

Factors affecting the severity of consequences

Secondary retention

108 When the bolts failed, the P3 cab was able to fall from the train onto the track because there was no secondary retention system fitted. Currently Railway Group Standard GM/RT2100 issue 5 'Requirements for rail vehicle structures' specifically requires secondary retention systems to be fitted in situations where the failure of an individual mounting could overload other mountings, or where a single mounting failure could lead to a hazardous situation. At the time of the design of the P95 machine there was a more general requirement for equipment and mountings to be designed taking into account the risks and consequences of failure, and if appropriate, the fitting of emergency restraints amongst other means. Network Rail and AmeyColas designed a secondary retention system for the P3 cab after the incident at Blatchbridge Junction. Matisa approved this modification for the two UK P95 machines.

109 Many items of under-slung equipment, such as engines and fuel tanks, do not have secondary retention systems fitted. The integrity of the fastening systems for these items of under-slung equipment is enhanced by appropriate design and detailed and clear maintenance instructions. For this reason, the RAIB has not made a recommendation about secondary retention systems, but has made a recommendation about the integrity and clarity of vehicle maintenance instructions, and the design of mounting arrangements.

Previous occurrences of a similar character

110 In March 2012 a *traction motor* detached from a track relaying machine (not a P95) during a transit move from Carlisle to Crewe. The traction motor became detached because the securing bolts failed. The traction motor assembly was normally secured by four M12 grade 8.8 steel bolts. Of relevance to the investigation into the Blatchbridge incident was that the vehicle maintenance documents did not provide sufficient technical detail regarding maintenance of the traction motor and its fixing arrangements.

Summary of conclusions

Immediate cause

111 The eight bolts within the flexible mountings supporting the cab structure failed, and the unsupported cab fell onto the track below (**paragraph 45**).

Causal factors

112 The following factors are considered to have been causal, or probably causal:

a. The P3 cab supporting bolts were subject to short periods of high stress when the P95/1 UK was operating in working mode. These stress cycles contributed to the fatigue failure of the affected bolts. This was a probable causal factor (**paragraphs 48 and 117, Recommendations 6 and 7**).

b. The design of the cab mounting arrangement allowed moisture to penetrate internally and corrosion to form on the bolts. This eventually led to the formation of corrosion pits in the threads, some of which may have caused the initiation of fatigue cracks. This was a probable causal factor (**paragraph 60, Recommendations 1, 5 and 7**).

c. The failing bolts were not discovered during routine maintenance because the maintenance instructions were not clear and lacked technical detail. This was a casual factor (**paragraph 74, Recommendations 1, 2, 3 5 and 7**).

113 It is possible that the following factors were causal:

a. Some of the bolts may have been exposed to a sudden impact force. This may have led to joint slip and/or bolt damage which adversely affected the fatigue performance of those bolts leading to their failure. Other bolts may then have progressively failed as the load of the P3 cab became unevenly distributed (**paragraph 65, Recommendations 1, 3, 4 and 7**).

b. Neither the maintainer nor the owner inspected the flexible mounting arrangements, or replaced the bolts within the flexible mount, following the impact between the clamp and P3 cab in January 2011 (**paragraph 73, Recommendations 1, 3, 4 and 7**).

Underlying factor

114 The design and maintenance review processes did not identify that the bolts were subject to high stress cycles during the machine’s working mode, that a corrosion trap existed which made the bolts at risk of fatigue failure, and that the maintenance instructions for the P3 cab bolts were unclear (**paragraphs 90 and 117, Recommendations 1, 2, 3, 4, 6 and 7**).

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

Actions reported that address factors which otherwise would have resulted in a RAIB recommendation

115 Following the incident at Thatcham (paragraph 67), Matisa designed a locking mechanism which was fitted to prevent the clamp from moving out of gauge. It is now also a requirement for the clamp and locking mechanism to be checked before the train enters service.

116 Following the incident at Blatchbridge Junction Matisa issued a technical bulletin to all owners of P95 machines recommending that they check the integrity of the cabin supports by checking the torque of the all the bolts on the P3 and P2 cabs on a monthly basis. The technical bulletin included the required torque values.

117 RSSB has issued a new version of Group Standard GM/RT2400 which requires component mounting arrangements for on-track machines to be subject to design and maintenance scrutiny when operating in travelling mode and has also published Rail Industry Standard RIS-1702-PLT 'Design of On-Track Machines in Working and Travelling Modes' which includes the requirements for on-track machines to be assessed in working mode and travelling mode.

Other reported actions

118 Matisa approved a secondary retention system design by Network Rail and AmeyColas. This has been installed on both the UK P95 machines (figure 25).

Figure 25: Secondary retention system fitted to each of the four corners of the P3 cab

Recommendations

119 The following recommendations are made[13]:

1 *The intent of this recommendation is to reduce the risk of items of attached equipment falling from on-track machines onto the track.*

Network Rail should arrange for the maintainers and operators of its on-track machines to carry out a review of those machines and identify items of attached equipment that have the potential to be a threat to safety should the securing systems fail. For each item identified, the following steps should be taken:

a) improve the design and/or maintenance arrangements to decrease the likelihood of the securing system failing; or fit secondary retention systems to prevent attached equipment falling onto the track should the securing system fail;

b) consider the use of movement 'tell tales' to help identify bolts that are becoming loose; and

c) describe the action that should be taken if attached equipment has been subjected to unusual loadings (such as impact or derailment forces) that may have affected the security of the fastening arrangements (for example, an assessment of the integrity of the fastening arrangements by a competent person) (paragraphs 112b, 112c, 113a, 113b and 114).

continued

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

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

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

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

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

2 *The intent of this recommendation is to reduce the risk of staff misunderstanding the activities that need to be undertaken while maintaining on-track machines.*

Taking into account the output from implementing recommendation 1, Network Rail, in consultation with the maintainers and operators of its on-track machines, should review and improve the maintenance instructions for each machine. As a minimum, the review should include consideration of:

a) the clarity of the description of activities to be performed and the sufficiency of the technical detail included;

b) the provision of key information such as torque settings at those points within maintenance instructions where the maintainer is required to use them;

c) the clarity with which technical terms are described; and

d) mandating checks to confirm that maintenance technicians are referring to maintenance instructions and that, where prescribed in the manufacturers maintenance instructions, the correct torque values are being used (paragraphs 112c and 114).

3 *The intent of this recommendation is to extend the scope of recommendations 1 and 2 to include all on-track machines that may operate on Network Rail infrastructure.*

Network Rail should implement a process to require that the owners of all on-track machines that operate on its infrastructure implement measures consistent with the intent of Recommendations 1, 2 and 5 (paragraphs 112b, 112c, 113a, 113b and 114).

continued

4 *The intent of this recommendation is for Matisa to provide clear instructions so that the necessary maintenance tasks are carried out.*

Matisa (UK) Ltd should, in consultation with its customers, improve the clarity of the maintenance instructions for its on-track machines. As a minimum, the following improvements should be made:

a) describe maintenance activities with sufficient technical detail;

b) define the meaning of key terms that are otherwise open to interpretation such as ‘check the integrity’;

c) identify which fastenings could pose a risk to safety should they fail;

d) include key values, such as torque settings, at those points within maintenance instructions where the maintainer is required to use them; and

e) describe the action that should be taken if attached equipment has been subjected to unusual loadings (such as impact or derailment forces) that may have affected the security of the fastening arrangements (for example, an assessment of the integrity of the fastening arrangements by a competent person) (paragraphs 112c, 113a, 113b and 114).

5 *The intent of this recommendation is to promote the early identification of corrosion on the bolts/fastenings of high-risk equipment so that corrective action can be taken.*

Network Rail, in consultation with the maintainers of its on-track machines, and taking into account the output from implementing recommendation 1, should enhance the inspection arrangements for its on-track machines by including a periodic cycle of visual inspections of high-risk fastenings (dismantling the mounting arrangement if necessary) to detect the presence of corrosion. Where corrosion of a bolt/fastening is identified, the source of the corrosion should be found and eliminated where possible. Where this is not possible, the relevant maintenance instructions should be enhanced to include the requirement for more frequent replacement of affected bolts/fastenings (paragraphs 112b and 112c).

6 *The intent of this recommendation is for Matisa to consider all working modes of a machine when designing component mounting arrangements.*

Matisa (UK) Ltd should modify its processes for designing on-track machines so that it includes the assessment of all modes of operation when designing component mounting arrangements. This includes the mounting arrangements on machines that can operate in a defined ‘working mode’ (ie at slow-speed) as well as travelling at higher speeds (ie being hauled) (paragraphs 112a and 114).

continued

7 *The intent of this recommendation is to reduce the risk of the P3 cab of P95 machines outside the United Kingdom detaching due to fastening failure.*

Matisa (UK) Ltd should communicate the findings from this report to operators and maintainers of P95 machines outside the United Kingdom with advice on necessary measures to reduce the likelihood of the P3 cab becoming detached and falling onto the track due to the failure of the fastening system (paragraphs 112a, 112b, 112c, 113c, 113b and 114).

Note: Recommendations 1, 2, and 5 may also apply to other infrastructure owners and managers.

Note: Recommendations 4 and 7 may also apply to other on-track machine manufacturers.

Appendices

Appendix A - Glossary of abbreviation and acronyms

CCB	Conformance Certification Body
CMS	Competence Management System
OTDR	On-Train Data Recorder
RAIB	Rail Accident Investigation Branch
SRP	Systems Review Panel
VAB	Vehicle Acceptance Body

Appendix B - Glossary of terms

Accelerations	The change in the velocity of a body with time (ie along the vertical, lateral or longitudinal plane). A common method of expressing acceleration is in units relative to the acceleration due to gravity (g) which is 9.81 m/s^2.
Air brake	A train braking system operated by air pressure. The pressure within the air brake system can be controlled by the driver or by on-train systems.
Blind hole	A hole that does not pass through a component and has only one opening.
Conformance Certification Body	An organisation with the authority to carry out the reviews necessary to issue certificates of conformance.
Chemical analysis	The process of determining the chemical properties within a metal object, such as a bolt or weld.
Electromagnetic interference	A naturally occurring phenomenon where the electromagnetic field of a device affects the electromagnetic field of another device by coming into proximity with it.
Engineering train	A train hauling wagons or specialised vehicles that are used to repair, maintain or replace the track and other infrastructure.
Facing points	A set of points that divert a train onto a different route.
Freight operating company	A railway company that generally operates freight trains. Some freight operating companies also haul engineering trains.
Fatigue analysis	A prediction of the fatigue life of a component.
Finite element analysis	A computer based method of analysing structures to calculate stresses in components, amongst other responses, when subjected to forces or deflections. It is used often used as a design tool to check that the component or structure can withstand the forces applied to it without breaking
Magnetic particle inspection	A non-destructive testing process used for defect detection.
Microstrain	Strain can be positive (in tension) or negative (in compression). Usually, the magnitude of measured strain is very small. Therefore, strain is often expressed as microstrain.
On-train data recorder	A device that records certain events associated with the operation of a vehicle (such as a locomotive). Events recorded can include speed, brake pressures and distance travelled.
Overload failure	A type of failure where an excessive load causes a bolt to fracture. This type of failure often occurs at the last stages of a fatigue failure when the crack has grown through most of the material.

Preload	The force generated in a bolt when it is extended (or stretched) as it is tightened. The preload has the effect of clamping the joint together.
Rapid-rate fatigue failure	Failure resulting from the repeated application of a relatively small number of stress cycles.
Shunter	A person who carries out operational activities such as coupling and uncoupling vehicles and forming vehicles into train consists.
Slow-rate fatigue failure	Failure resulting from the repeated application of a large number of stress cycles.
Strain	The (dimensionless) ratio of the extended (or compressed) length of an object to its original length, when the object is placed under stress.
Thread root	A thread profile consists of a root (the bottom of the thread), the crest (the top of the bolt thread) and the flanks (the sides of the bolt thread).
Top and Tailed	The practice of providing a locomotive at both ends of a train (ie one at the front and one at the back).
Traction motor	A motor used to drive the powered wheels of a rail vehicle.
Trailing points	A set of points where two routes converge.
Vehicle Acceptance body	An organisation with the authority to undertake the process of engineering acceptance.
Wheel unloading	A reduction in downwards force of a rail wheel. This reduced force can be a factor that permits a rail wheel to derail.

Appendix C - Key standards current at the time

GM/RT2004 issue 2, dated October 1999 (now superseded)	Requirements for rail vehicle maintenance
GM/RT2000 issue 2, dated October 2000 (now superseded)	Engineering acceptance of rail vehicles
GM/RT2100 issue 3, dated October 2000 (now superseded)	Structural requirements for railway vehicles
GM/RT2100 issue 5, dated June 2012 (current)	Requirements for rail vehicle structures
GE/RT8270 issue one, dated February 2003 (superseded)	Route acceptance of rail vehicles including changes in operation or infrastructure
GM/RT2400 issue 2 dated December 2002 (superseded)	Engineering acceptance and design of on-track machines
GM/RT2400 issue 3, dated December 2010 (superseded)	Engineering design of on-track machines
GM/RT2402 issue 2, dated June 2003	Engineering acceptance of rail mounted maintenance machines
BS 7608	Steel code of practice for fatigue design and assessment of steel structures
VDI 2230	Systematic calculation of high-duty bolted joints

This page is intentionally left blank

This report is published by the Rail Accident Investigation Branch,
Department for Transport.

Any enquiries about this publication should be sent to:

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