



Rail Accident Investigation Branch

Rail Accident Report



**Runaway of a road rail vehicle and the resulting collision in Queen Street High Level Tunnel,
Glasgow
21 April 2013**

Report 15/2014
July 2014

This investigation was carried out in accordance with:

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

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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	

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Runaway of a road rail vehicle and the resulting collision in Queen Street High Level Tunnel, Glasgow, 21 April 2013

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Summary

At about 03:00 hrs on Sunday 21 April 2013, a road rail vehicle (RRV) ran away as it was being on-tracked north of Glasgow Queen Street High Level Tunnel on a section of railway sloping towards the tunnel. The RRV ran through the tunnel and struck two scaffolds that were being used for maintenance work on the tunnel walls. A person working on one of the scaffolds was thrown to the ground and suffered severe injuries to his shoulder. The track levelled out as the RRV ran into Glasgow Queen Street station and, after travelling a total distance of about 1.1 miles (1.8 kilometres), it stopped in platform 5, about 20 metres short of the buffer stop.

The RRV was a mobile elevating work platform that was manufactured for use on road wheels and then converted by Rexquote Ltd to permit use on the railway. The RRV's road wheels were intended to provide braking in both road and rail modes. This was achieved in rail mode by holding the road wheels against a hub extending from the rail wheels. The design of the RRV meant that during a transition phase in the on-tracking procedure, the road wheel brakes were ineffective because the RRV was supported on the rail wheels but the road wheels were not yet touching the hubs. Although instructed to follow a procedure which prevented this occurring simultaneously at both ends of the RRV, the machine operator unintentionally put the RRV into this condition. He was (correctly) standing beside the RRV when it started to move, and the control equipment was pulled from his hand before he could stop the vehicle.

The RRV was fitted with holding brakes acting directly on both rail wheels at one end of the vehicle. These were intended to prevent a runaway if non-compliance with the operating instructions meant that all road wheel brakes were ineffective. The holding brake was insufficient to prevent the runaway due to shortcomings in Rexquote's design, factory testing and specification of maintenance activities. The lack of an effective quality assurance system at Rexquote was an underlying factor. The design of the holding brake was not reviewed when the RRV was subject to the rail industry vehicle approval process because provision of such a brake was not required by Railway Industry Standards.

The RAIB has identified one learning point which reminds the rail industry that the rail vehicle approval process does not cover all aspects of rail vehicle performance. The RAIB has made four recommendations. One requires Rexquote to implement an effective quality assurance system and another, supporting an activity already proposed by Network Rail, seeks to widen the scope of safety-related audits applied by Network Rail to organisations supplying rail plant for use on its infrastructure. A third recommendation seeks improvements to the testing process for parking brakes provided on RRVs. The final recommendation, based on an observation, relates to the provision of lighting on RRVs.

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 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 Metric units are used throughout this report, except for speeds and locations, which are given in imperial units in accordance with industry practice. Where appropriate, the equivalent metric value is also given¹.
- 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.
- 6 All mileage is measured from the *buffer stops* at Glasgow Queen Street station.

¹ In this report, brake retarding and brake cylinder forces have been measured using kilogram-force (kgf). For consistency with test documentation, the abbreviation 'kg' has been used throughout to refer to kilogram-force and has been considered equivalent.

The accident

Summary of the accident

- 7 At about 03:00 hrs on Sunday 21 April 2013, a *road rail vehicle* (RRV) ran away as it was being *on-tracked* north of Glasgow Queen Street High Level Tunnel (figure 1). The RRV ran downhill through the tunnel and struck two scaffolds that were being used to provide access for maintenance work on the tunnel walls. A maintenance worker, who was working on one of the scaffolds, was thrown to the ground and suffered severe injuries to his shoulder. The RRV narrowly missed two other workers in the tunnel.



Figure 1: Location of accident

- 8 The RRV was a Genie Z60/34 *Mobile Elevating Work Platform* (MEWP), which was owned and operated by TXM Plant Ltd (figure 2).
- 9 The RRV ran into platform 5 at Glasgow Queen Street High Level station, and came to a stop about 20 metres short of the buffer stop.
- 10 The maintenance worker who was working on the tunnel walls was knocked unconscious and suffered severe shoulder injuries that required urgent hospital treatment. The operator of the RRV suffered minor injuries to his neck and back when he fell while running beside the RRV after it had started to run away, but these did not require hospital treatment.
- 11 The two scaffolds were destroyed by the collision (figure 3). There was minor damage to the RRV.



Figure 2: The RRV in Glasgow Queen Street station after the accident



Figure 3: One of the scaffolds in the tunnel after the accident (Courtesy of British Transport Police)

Context

Location

- 12 The RRV was being on-tracked onto the *down line* at Keppochill Road *rail access point* (RRAP), which is located at 1 mile 06 *chains* on the line from Glasgow Queen Street to Edinburgh via Falkirk (figures 4 and 5).

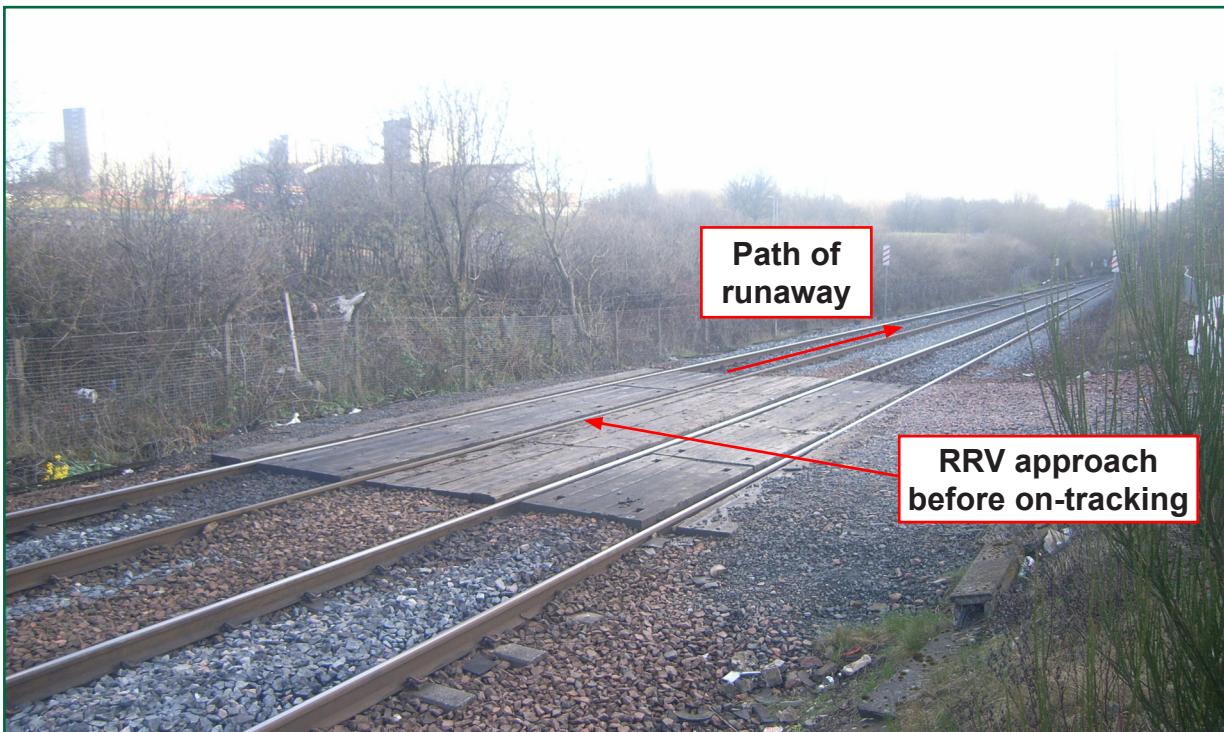


Figure 4: RRAP at Keppochill Road

- 13 The line at the RRAP is non-electrified double track, consisting of an *up line* and a *down line*. The down direction at this location is towards Glasgow Queen Street station.
- 14 The gradient on the down line, in the middle of the RRAP, is 1 in 41, although the average gradient over the 74 metres around the RRAP was measured as 1 in 44.
- 15 Glasgow Queen Street High Level Tunnel is located between 0 mile 60 chains and 0 mile 15 chains. The average gradient is approximately 1 in 45 downhill from the RRAP to the station end of the tunnel, where the line levels out into the platforms.

Organisations involved

- 16 Network Rail owns and operates the railway infrastructure. The accident location is within Network Rail's Scotland route.
- 17 The maintenance work on the tunnel was contracted out by Network Rail's Route Programme Manager to the AMCO Rail division of Amalgamated Construction Ltd.
- 18 AMCO Rail subcontracted the tunnel brickwork repairs to CK Contracts Ltd, who employed the worker who was injured when he fell from the scaffold.
- 19 AMCO Rail subcontracted supply of the RRV (including the *machine operator* and the *machine controller*) to the Trac Rail division of Trac Engineering Ltd.

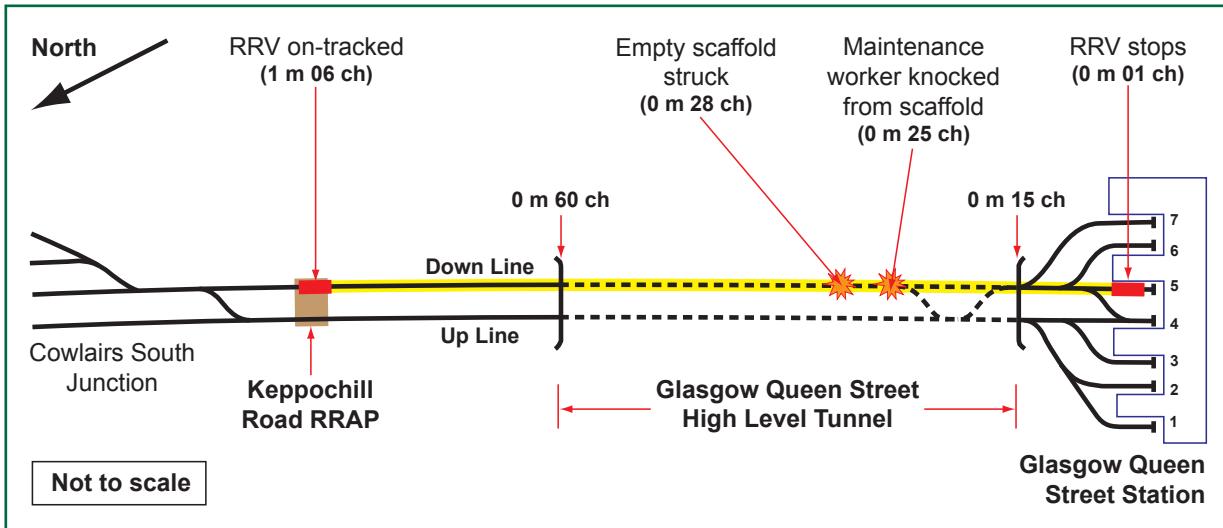


Figure 5: Track diagram showing runaway and collision locations

- 20 Trac Rail further subcontracted the provision of the RRV and the machine operator to TXM Plant Ltd. TXM Plant Ltd both owned the RRV and employed the machine operator. TXM Plant Ltd was previously known as Network Rail (NDS Plant), and as Hydrex prior to that. Where appropriate, this report uses TXM Plant to include all these organisations.
- 21 Trac Rail also subcontracted provision of the machine controller to Orion Rail Services Ltd, who employed the machine controller.
- 22 The RRV was converted for use on rails, and supplied to TXM Plant, by Rexquote Ltd (referred to as Rexquote in the remainder of the report).
- 23 Delta Rail Group Ltd (referred to as Delta Rail in the remainder of the report) carried out the *vehicle approvals certification process* for the RRV.
- 24 All of the above organisations freely co-operated with the investigation.

Rail equipment involved

- 25 The RRV involved in the accident was a Rexquote Genie Z60/34 Accessrailer MEWP. This was a road based MEWP, manufactured by Genie (part of Terex Corporation) in the USA, which was converted for use on the UK rail network by Rexquote. There is no evidence that Genie, or Terex Corporation, played any part in the factors relating to the accident.
- 26 This RRV is known as a type 9B-II *high ride*² RRV. Machines of this type have rail wheels that are driven and braked by friction forces transmitted through the tyres of the road wheels. On this RRV, one set of wheels has a rail wheel holding brake that is applied when the vehicle is not being driven forwards or backwards on the railway track. This is primarily designed to prevent unintended movement when the vehicle is being on-tracked or off-tracked.

² The friction forces used to power or to brake the rail wheels on high ride RRVs are provided by pressing the rubber road tyres into contact with either the tread of the steel rail wheel (type 9B-I RRVs) or with an extended hub which protrudes from the rail wheel (type 9B-II RRVs, figure 7). For clarity in this report, contact of a road wheel with a rail wheel means contact of the rubber tyre with the extended hub of the rail wheel. There are also low ride type RRVs (type 9C) where, when operating on the railway, the traction and braking forces are transmitted to the rails by the road wheels with the load shared between the road and rail wheels; and direct drive machines (type 9A), where the traction and braking forces are transmitted directly to the rail wheels (ie the rail wheels are self-powered).

- 27 Each set of rail wheels is mounted on a hinged sub-chassis which is raised and lowered hydraulically (figure 6). When a set of rail wheels is lowered, it lifts the adjacent set of road wheels clear of the ground. Contact between the road wheels and the rail wheel hubs is not made until the rail wheels have almost completed their travel (figure 7). The machine has two pairs of road wheels, one steerable and the other fixed³.
- 28 When it is being on-tracked, the RRV is operated using a remote-control pendant (figure 8), which is attached to the vehicle by a cable. When the RRV is being driven along the track, it is operated from a control panel in the operator's basket (figure 2).



Figure 6: RRV showing rail wheel mechanisms raised



Figure 7: Rail wheel mechanism when deployed, showing contact between road wheel and rail wheel extended hub

³ The steerable road wheels are locked in the straight ahead position immediately after the RRV has successfully on-tracked.



Figure 8: Control pendant

- 29 The machine involved in the accident was converted in 2009. Before this type of machine was introduced onto Network Rail infrastructure, Delta Rail assessed its compliance with the relevant technical standard applicable at the time, RIS-1530-PLT Issue 1 '*Rail Industry Standard for Engineering Acceptance of On-Track Plant and Associated Equipment*', issued by the Rail Safety & Standards Board (now known as RSSB). Delta Rail then issued the *certificate of engineering acceptance* and the *certificate of conformance for vehicle maintenance* for each individual RRV of this type. Delta Rail was employed by Rexquote to undertake this work.
- 30 Documentary evidence indicates that the RRV had been maintained by TXM Plant in accordance with the manufacturer's service intervals, and no major defects were noted in its logbook. Records show that it had last been maintained on 19 April 2013, two days before the accident. This was a planned weekly inspection which was carried out at the RRAP (paragraph 38), and involved the checking of fluid levels, a visual check for damage, checking of tyre wear, damage and pressures and a test of systems such as lights, horns etc. The only remedial action required during this examination was the topping up of hydraulic oil, which was carried out at the time. Records also show that the machine had undergone more detailed monthly and 3-monthly inspections on 2 April 2013 and 5 March 2013 at the TXM Plant depot. Again no remedial action was recorded other than topping up fluid levels. An annual inspection, which included brake tests (paragraph 108), was carried out on 11 December 2012, and no remedial action was recorded as having been necessary.
- 31 Documentation from the RRV indicated that the machine operator had completed pre-use inspection checks at the start of his shift, prior to using the RRV. No problems were recorded.

Staff involved

- 32 The machine operator had been employed by TXM Plant, and had held the Network Rail machine operator competency for 3 years. This was the only type of MEWP used by him at TXM Plant, and he had driven, and on/off-tracked, them many times. He had also driven other types of RRV, such as excavators and dumpers. He had never used the Keppochill Road RRAP before, and was unaware of the magnitude of the gradient, but he stated that he believed it was safe to on-track the RRV at that location. There were no performance incidents on his employment record.
- 33 The machine controller had held the Network Rail machine controller competency since September 2012, but he had been qualified as a *Controller of Site Safety* (COSS) since 2005 and held many other safety-related competences. There were no performance incidents recorded on his employment record. The machine controller was required to ensure that the RRV did not expose those working in the vicinity to additional risks. This required him to be present during on-tracking, and to assist the machine operator if requested. Machine controllers are not given detailed training in how individual RRVs are operated and their role does not include detailed supervision of the machine operator's actions. The machine controller was familiar with the location and stated that he understood that the planning process would have ensured that the RRV was certified for use on such a gradient. He had never worked with this machine operator before.

External circumstances

- 34 The weather was dry at the time of the accident, but it had rained earlier and the ground was wet. However, adhesion between the rail wheels and the rails is not considered to be a factor in the accident because the RRV rolled away rather than slid along the track.
- 35 It was dark at the time of the accident, with minimal surrounding street light illumination. There was no site lighting provided, and personnel were working using the light from torches and the headlights of a vehicle which was already on the track near the RRAP. Neither the machine controller nor the machine operator considered the available lighting to be inadequate for on-tracking the RRV.
- 36 Witness evidence indicates that there were no distractions from external noise or other activity in the vicinity of the RRAP.

Events preceding the accident

- 37 The RRV was being on-tracked at the Keppochill Road RRAP to facilitate access for maintenance work on the tunnel walls in Queen Street High Level tunnel. This was being undertaken when both the up and down lines were closed to normal traffic and under *possession* from near Cowlairs South Junction (1 mile 22 chains) to the buffer stops in Glasgow Queen Street station (0 mile 0 chains). The possession was scheduled by Network Rail to start at 00:55 hrs and to end at 07:45 hrs.

- 38 This was the third of four consecutive weekends of work on the tunnel walls. The same MEWP had been used on the previous weekend, but with a different machine operator and a different machine controller. The RRV had remained adjacent to the Keppochill Road RRAP since its last use, two weeks previously.

Events during the accident

- 39 The machine operator was controlling the RRV during on-tracking using the remote-control pendant, which was connected to it by a cable (figure 8). The machine controller assisted the machine operator in aligning the RRV with the track, having gained permission to on-track from the *engineering supervisor*, who was with the *Plant Operator Licence holder* representative⁴ and near to the RRAP at the time. Neither of these individuals was required to, or did, closely supervise the on-tracking process.
- 40 The machine operator aligned the fixed axle (downhill end) rail wheels and then partly lowered them onto the rails. He then manoeuvred the machine to align the steering axle with the track and lowered the steering axle (uphill end) rail wheels onto the rails. The RRV immediately started to run away. A more detailed explanation of the on-tracking of the RRV is given in paragraphs 63 and 64.
- 41 The machine operator then attempted, unsuccessfully, to raise the fixed axle rail wheels from the rails, to drop the RRV back onto the road wheels, on which the brakes were already applied. As the RRV accelerated, the pendant was pulled from his hands, and the machine operator tripped and fell. The RRV ran over the remote-control pendant cable as it was being dragged along the track.
- 42 The RRV engine shut down as it accelerated down the gradient. It is possible that this was because the operator stopped the engine, or that vibration or damage from the pendant bouncing along the track disturbed either the engine stop or emergency stop pushbutton contacts (paragraph 70).
- 43 The RRV ran down the gradient through the tunnel, hitting two scaffolds that had been erected to carry out the work on the tunnel walls. A maintenance worker was thrown to the ground from the second of those scaffolds.
- 44 The personnel working in the tunnel could not be contacted to warn them of the runaway RRV because there was no mobile phone signal available in the tunnel. Other personnel who were working in the station area were warned of the runaway RRV by a phone call from the COSS⁵, who was in the vicinity of the RRAP at the time.
- 45 The RRV came to a stop in platform 5 of Glasgow Queen Street High Level station, about 20 metres short of the buffer stop.

Events following the accident

- 46 The maintenance worker who was knocked off the scaffold was attended by paramedics in the tunnel. He was then taken to the RRAP on a rail trolley, from where he was taken to hospital.

⁴ The Plant Operator Licence holder was Trac Rail.

⁵ The COSS was not required to, and did not, undertake close supervision of the on-tracking process.

The investigation

Sources of evidence

47 The following sources of evidence were used:

- witness statements;
- maintenance instructions and records for the RRV;
- design documentation for the RRV;
- approvals documentation for the RRV;
- testing of the RRV (focusing on its braking system);
- closed circuit television (CCTV) recordings of the station platforms;
- site photographs and measurements;
- weather reports and observations at the site;
- medical advice; and
- a review of previous RAIB investigations that had relevance to this accident.

Key facts and analysis

Background information

- 48 The Rexquote Genie Accessrailer Z60/34 RRV was certified by Delta Rail in July 2009 for use on gradients of up to 1 in 29, in accordance with Rail Industry Standard RIS-1530-PLT Issue 1⁶. This certification remained valid for use of the RRV on Network Rail infrastructure until July 2016, after which the RRV would need to be reassessed against the latest version of standard RIS-1530-PLT. The July 2009 certification (paragraph 137) was based on tests undertaken on the incident vehicle and on an assessment of the RRV design completed in January 2008 before certification of the first RRV of this type.
- 49 Standard RIS-1530-PLT Issue 1 specified requirements for both *service brake* stopping distances and the *parking brake*. These only applied when the rail wheels were fully deployed and in contact with the road wheels. Issue 1 did not require any engineered safeguards to prevent runaway during on/off-tracking. Instead it required there to be a documented system for on-tracking the vehicle, so that at all times there was no inadvertent movement (paragraph 77). This system could include engineering controls and/or procedural controls.
- 50 The RRV involved in the accident has two separate braking systems. The primary braking system operates on all four of the road wheels, and is used in both *road mode* and *rail mode*. In rail mode, the braking force provided by the road wheels acts through contact between the road wheels and the extended hubs of the rail wheels (figure 7). This system provides both service braking and parking braking for the RRV at all times in normal use.
- 51 The RRV is also fitted with a secondary braking system, which consists of a rail wheel holding brake intended to prevent a runaway during on-tracking. This system operates directly on the rail wheels at the fixed axle end (figure 9). This holding brake is only released when the RRV is in rail mode and a joystick control is operated to move it along the track. When this control is released, the service brake and the rail wheel holding brakes are both applied. Consequently, the rail wheel holding brake pads experience some wear during normal operation.
- 52 Standard RIS-1530-PLT Issue 1 did not require provision of a brake directly applied to the rail wheels. As a result there was no defined specification for the rail wheel holding brakes. However, the Office of Rail Regulation (ORR) served an *Improvement Notice* on Network Rail requiring high ride MEWP RRVs to be provided with engineering measures to prevent a runaway during on-tracking. In response to this, Network Rail required all high ride RRVs to be provided with such engineering measures (paragraph 159a), and Rexquote chose to install a rail wheel holding brake in addition to the brakes required by the standard. Rexquote adopted the same *brake retarding force* criteria as specified for the parking brake. Rexquote has stated that it believes this additional safeguard was added because its designers were aware of additional requirements due to previous runaway incidents during on-tracking of other RRVs.

⁶ Rail Industry Standard RIS-1530-PLT Issue 1 came into force in April 2006.

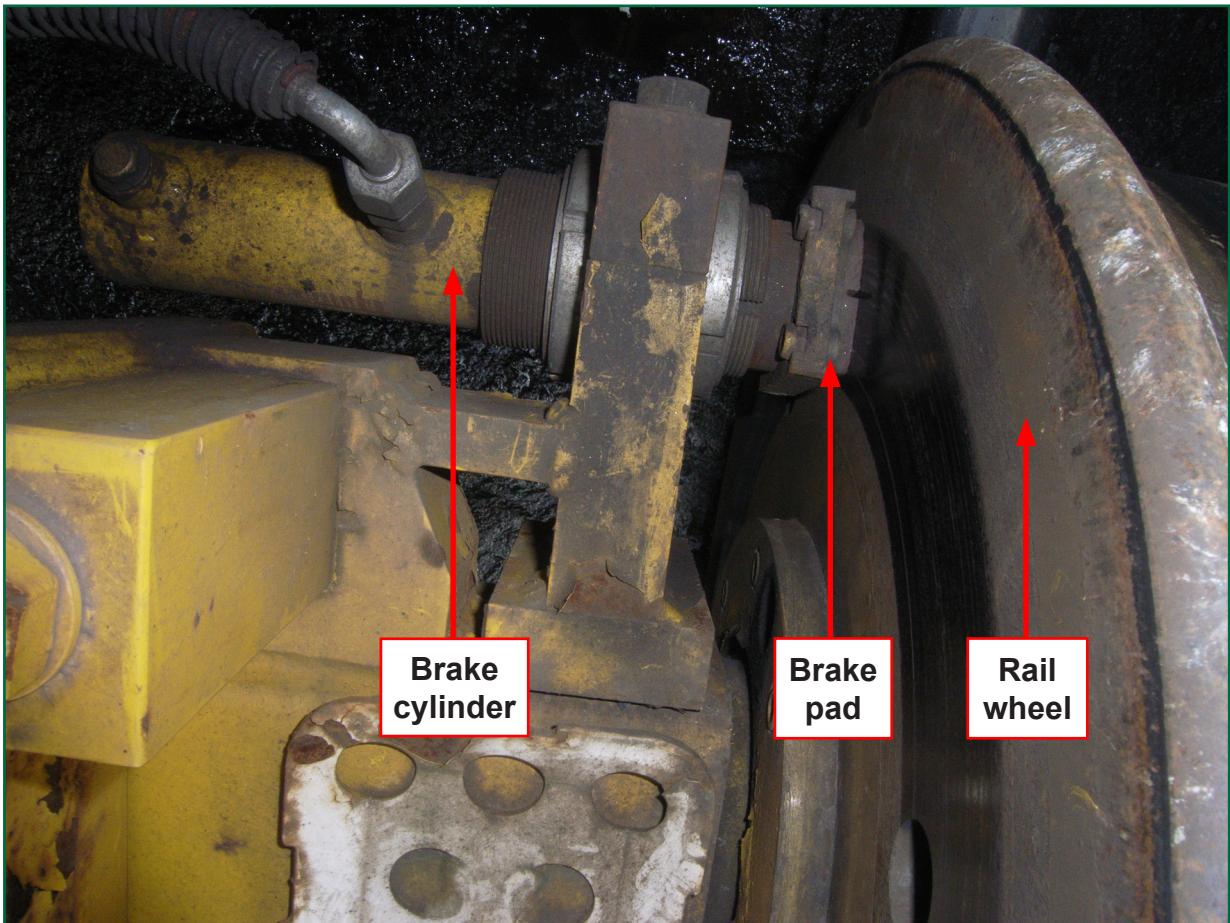


Figure 9: Rail wheel holding brake

Identification of the immediate cause⁷

- 53 The RRV ran away on the gradient because only the rail wheel holding brakes were acting to prevent movement and these were inadequate to do so.
- 54 When the RRV ran away, none of the road wheels were in contact with either the ground or with the rail wheels, and so the road wheel braking was not effective. The rail wheel holding brake was applied at that time, but did not prevent movement. RAIB calculations of the rail wheel holding brake performance indicate that it was providing some retardation, but this was insufficient to hold or stop the RRV until it reached the level track in Glasgow Queen Street station.

⁷ The condition, event or behaviour that directly resulted in the occurrence.

Identification of causal factors⁸

- 55 The accident occurred due to a combination of causal factors, which are considered in turn in subsequent paragraphs:
- the machine operator put the machine into the position where only the rail wheel holding brake was acting to prevent movement, contrary to the on-tracking procedure in which he had been trained;
 - the machine operator was unable to operate the correct controls to apply braking by either fully raising or fully lowering the rail wheels when the RRV was moving;
 - the RRV was not fitted with any physical means of preventing the machine operator from putting it into the position where only the rail wheel holding brake was acting to prevent movement;
 - deficiencies in the design and setup of the rail wheel holding brake meant that it was inadequate to hold the RRV on the gradient;
 - the design calculations for the rail wheel holding brake assumed a higher *coefficient of friction* between the brake pads and the wheel than was available in practice;
 - the RRV rail wheel holding brakes were not set up to provide sufficient braking force to prevent a runaway on the 1 in 41 gradient at the RRAP, and there was no maintenance instruction requiring appropriate setup;
 - one of the RRV brake cylinder springs had been assembled incorrectly (possibly causal); and
 - the factory testing regime for the RRV rail wheel holding brakes did not identify shortcomings in the design of these brakes.

Operating procedures and actions of the machine operator

- 56 **The machine operator put the machine into the position where only the rail wheel holding brake was acting to prevent movement, contrary to the on-tracking procedure in which he was trained.**
- 57 During on-tracking of a high ride RRV, the weight is transferred from the road wheels to the rail wheels. During this transition, there is a phase when a pair of road wheels is neither in contact with the ground nor in contact with the rail wheels. Any braking provided by the road wheels is not effective during this transition phase. As a result, it is important that the on-tracking procedures (and any associated engineering controls) are designed to provide alternative braking during this phase.
- 58 The simplest precaution is to ensure that when the rail wheels at one end of the RRV are traversing the unbraked phase, those at the other end are either fully raised or fully lowered and thus the road wheel braking is effective. If both sets of wheels were to enter the transition phase at the same time, then the RRV would be in the state where neither set of rail wheels was being braked by the road wheels while in contact with the rails.

⁸ Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

- 59 The Rexquote on-tracking procedure was intended to avoid the condition where none of the road wheel brakes were acting. However, as an additional safeguard, Rexquote fitted a rail wheel holding brake to the fixed end, which was designed to remain applied and to be sufficient to prevent the RRV from running away if all the road wheel brakes were ineffective.
- 60 A procedure for on-tracking the RRV was described in the Rexquote operation and maintenance manual and in the cab instructions which were kept on the RRV. This procedure was as follows (illustrated in figure 10, showing which road wheels are providing braking at each stage):
- manoeuvre the RRV so that the fixed end rail wheels are in line with the track, but do not lower the rail wheels into contact with the rails;
 - manoeuvre the RRV so that the steering end rail wheels are in line with the track and lower the steering end rail wheels part way to lift the steering end road wheels from the ground;
 - ensure that the steering end road wheels are straight, then fully lower the steering end rail wheels so that the road wheels come into contact with the rail wheel hubs; then
 - fully lower the fixed end rail wheels to lift the road wheels from the ground and into contact with the rail wheel hubs.

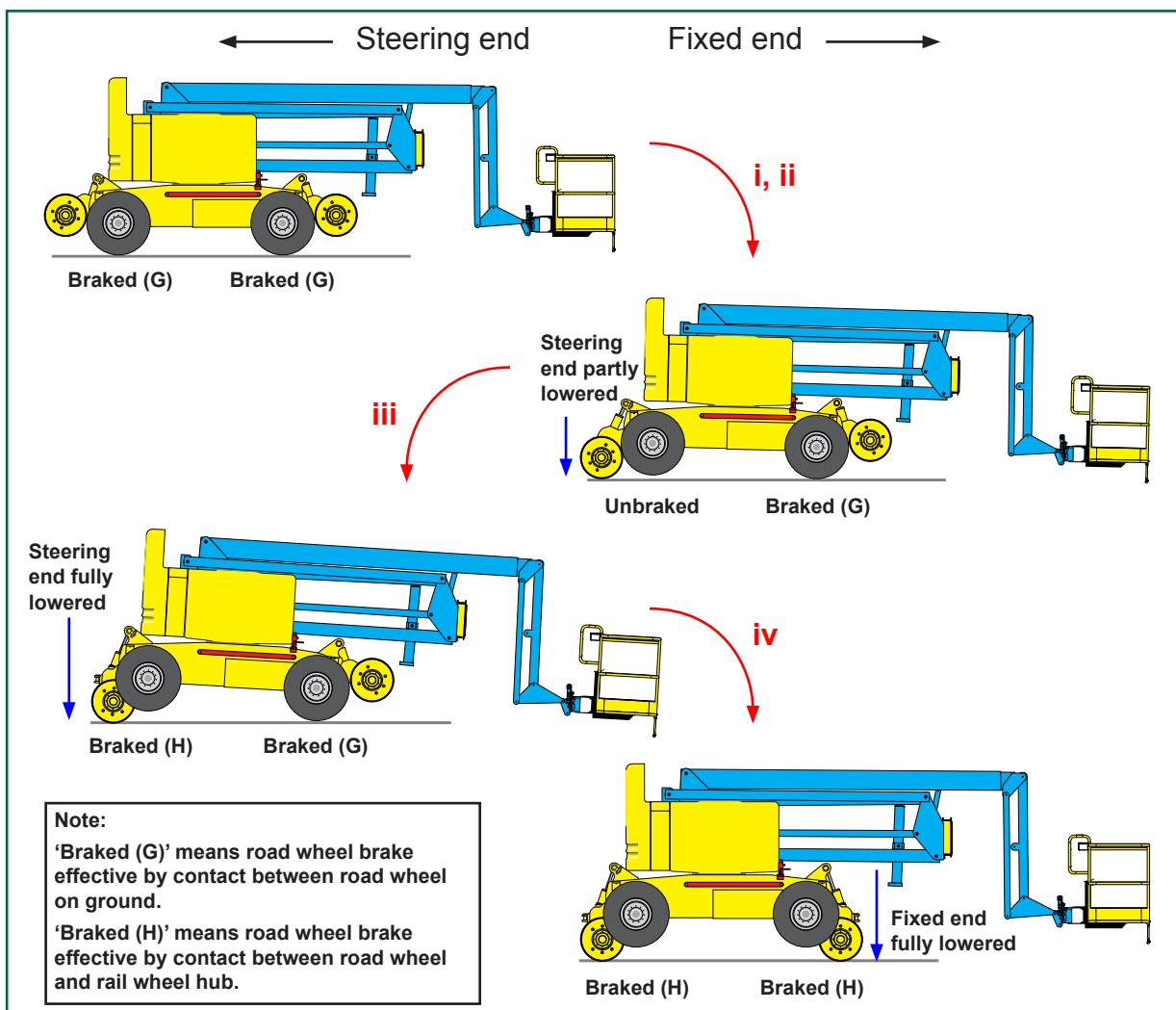


Figure 10: Rexquote operation and maintenance manual on-tracking procedure

61 TXM Plant considered that this procedure was flawed because, in the second step, manoeuvring the RRV to align the steering end rail wheels with the track would normally disturb the alignment of the fixed end rail wheels. As a result, TXM Plant adopted a revised on-tracking procedure, which had been briefed to all of its operators and incorporated into their training and assessments. This procedure was used for all of the high ride RRVs that TXM Plant operate, and was as follows (illustrated in figure 11):

- i. manoeuvre the RRV so that the fixed end rail wheels are in line with the track, and lower the fixed end rail wheels part way to lift the fixed end road wheels from the ground (this ensures that the fixed end rail wheels stay aligned with the track during alignment of the steering end);
- ii. manoeuvre the RRV so that the steering end rail wheels are in line with the track;
- iii. fully lower the fixed end rail wheels so that the road wheels come into contact with the rail wheel hubs; then
- iv. ensure that the steering end road wheels are straight, before fully lowering the steering end rail wheels to lift the road wheels from the ground and into contact with the rail wheel hubs.

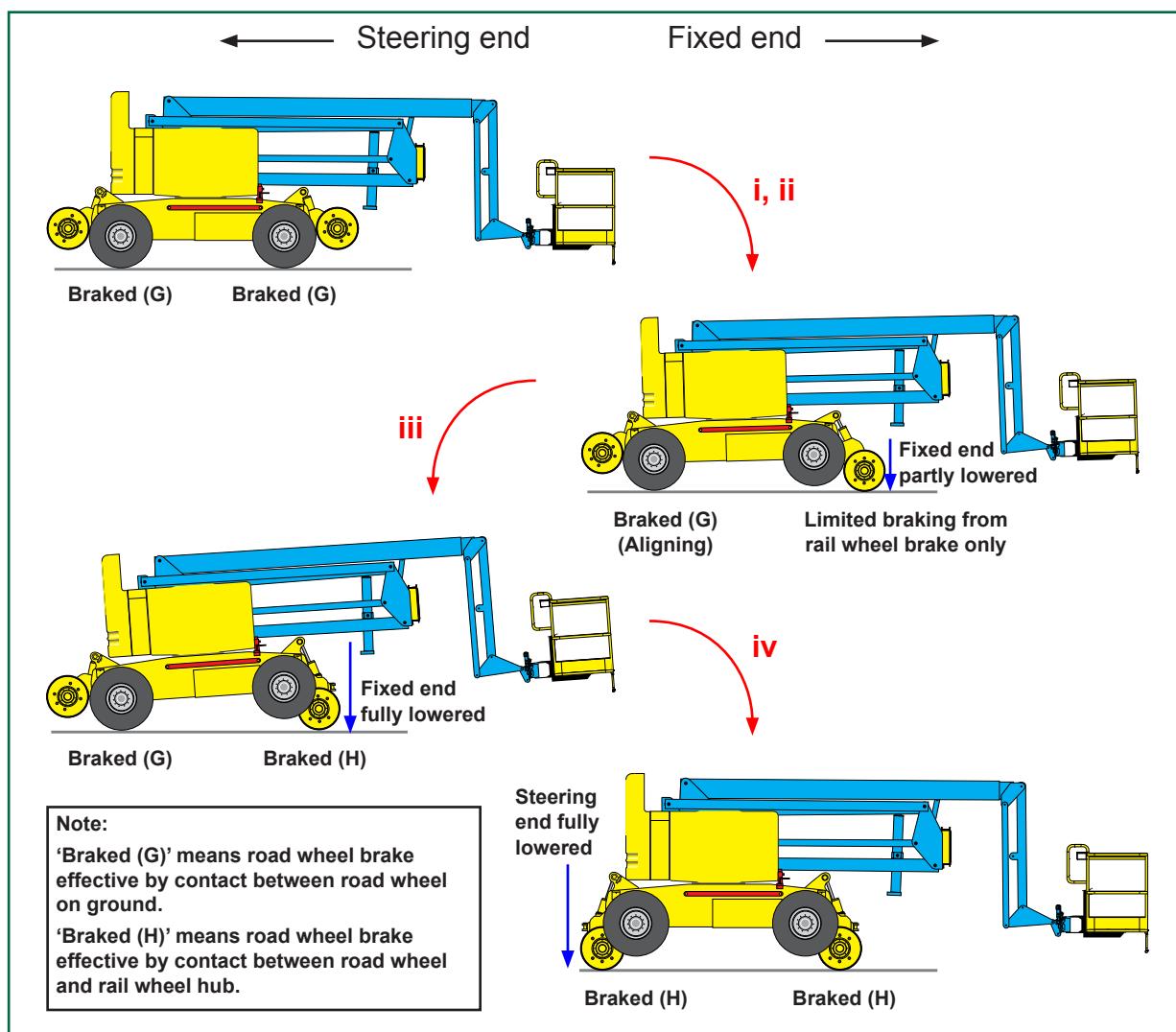


Figure 11: TXM Plant on-tracking procedure

- 62 RAIB considers that the TXM Plant procedure was more practical to implement than the Rexquote procedure, because it kept the fixed end aligned with the track while the steering end was being aligned (paragraph 61), and that it was no less safe. Neither of these two procedures relied on the correct operation of the rail wheel holding brake.
- 63 Witness evidence indicates that the machine operator was attempting to on-track the RRV in a sequence that was different from that specified in both the Rexquote and TXM Plant procedures. He reversed the third and fourth steps of the TXM Plant procedure, and his intended sequence was as follows (illustrated in figure 12):
- manoeuvre the RRV so that the fixed end rail wheels are in line with the track, and lower the fixed end rail wheels part way to engage the *flanges* with the rails, but not to take any weight so that the fixed end road wheels stay on the ground to provide braking;
 - manoeuvre the RRV so that the steering end rail wheels are in line with the track;
 - ensure that the steering end road wheels are straight, before fully lowering the steering end rail wheels so that the road wheels come into contact with the rail wheel hubs; then
 - fully lower the fixed end rail wheels to lift the road wheels from the ground and into contact with the rail wheel hubs.

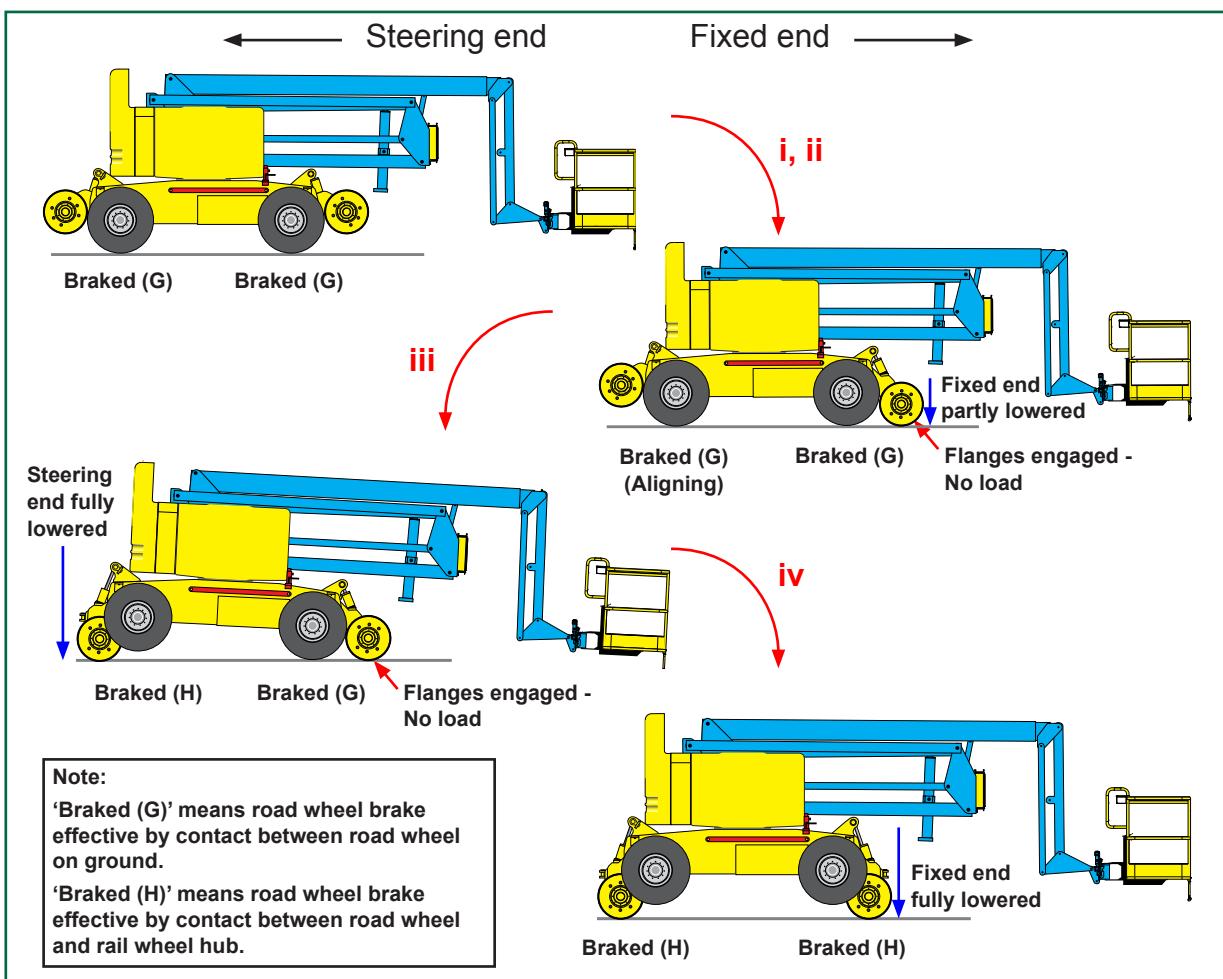


Figure 12: On-tracking sequence intended by machine operator

- 64 If done correctly, this procedure did not rely on the rail wheel holding brake to prevent movement of the RRV. However, this procedure relied on the machine operator accurately positioning the fixed end rail wheels during stage i, so that they were not taking any weight. On the night of the accident, the machine operator unintentionally put the RRV into the position where only the holding brake was acting to prevent movement, as follows (illustrated in figure 13):
- the machine operator manoeuvred the RRV so that the fixed end rail wheels were in line with the track, and lowered the fixed end rail wheels part way to engage the flanges with the rails. In doing so, he lowered the rail wheels further than he intended, so that they took the weight of the RRV, but without them coming into contact with the road wheels. In this condition the fixed end road wheels provided no braking, but the rail wheel holding brake was applied;
 - the machine operator manoeuvred the RRV so that the steering end rail wheels were in line with the track. This took a number of attempts at alignment; then
 - the machine operator lowered the steering end rail wheel.

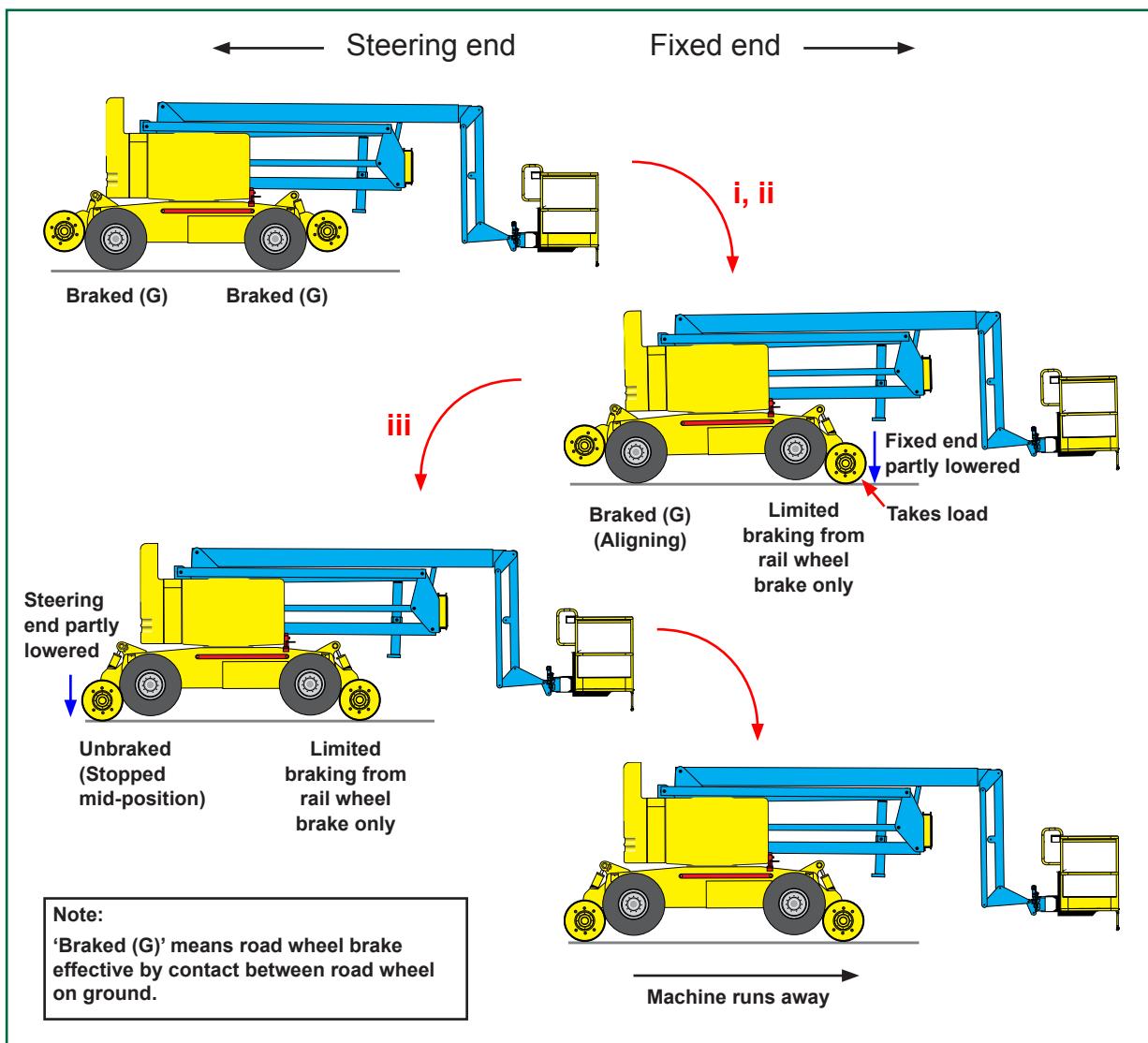


Figure 13: On-tracking sequence carried out by machine operator on 21 April 2013

- 65 The RRV started to roll down the hill as soon as the steering end rail wheels took the RRV's weight (when the road wheel braking was no longer acting on the ground), despite the rail wheel holding brake, which was intended to prevent such a runaway, still being applied (paragraph 51).
- 66 The machine operator consciously followed a different procedure to the TXM Plant procedure in which he had been trained. RAIB has been unable to determine why the machine operator adopted an on-tracking procedure different to that in which he was trained. It is possible that he perceived that his procedure was faster to implement because it required fewer moves between the fixed and steering ends of the RRV. RAIB has been unable to establish his reason with certainty as RAIB was unable to contact the machine operator after identifying this possibility. However, the machine operator stated that he was aware of the need to keep a braked road wheel in contact with either the ground or a rail wheel during on-tracking.
- 67 TXM Plant Ltd carries out random monitoring of machine operators at site, and two-yearly formal assessments. The assessments and monitoring include compliance with on-tracking procedures. The machine operator had successfully passed a routine assessment in October 2012, and had not been subject to a random site assessment subsequently.

Operation of the controls

- 68 **The machine operator was unable to operate the correct controls to apply braking by either fully raising or fully lowering the rail wheels when the RRV was moving.**
- 69 The RRV started rolling away as the machine operator was moving it through the position where only the rail wheel holding brake was acting, at which point he stopped lowering the steering end rail wheels. The machine operator, who had been standing on the up line, started moving alongside the RRV, in the dark, as it started rolling down the gradient, while trying to operate the controls to move the rail wheels. The machine controller saw what was happening and shouted at the machine operator to raise the rail wheels, and thus lower the braked road wheels onto the ground. The machine operator stated that he knew that he had to get the rail wheels back up and that he repeatedly attempted to press the buttons on the control pendant to achieve this. However, he was unable to operate the correct buttons on the control pendant or did not press them for long enough. There is no evidence to suggest that the absence of lighting contributed to the machine operator's inability to raise the rail wheels.
- 70 It is possible that the machine operator could have pressed the engine stop button on the control pendant while attempting to press the buttons to raise the rail wheels. This would have stopped the RRV's engine, and would have prevented the rail wheels from being moved to engage the braking effect from the road wheels. Although witness evidence shows that the RRV engine had stopped during the runaway, it has not been possible to determine if it stopped while the machine operator was still attempting to operate the controls, or if it stopped after the control pendant was pulled from his hands and was damaged when being dragged along the ballast.
- 71 It is likely that the machine operator, in a stress reaction to the situation, was unable to determine or to implement an appropriate course of action in response to the emergency situation he was faced with.

- 72 As the RRV accelerated further, the machine operator was still moving alongside it when he stumbled and fell, and the control pendant was pulled from his hands.
- 73 RAIB has not been able to establish how far the RRV moved before the operator fell. However, the initial movement would have been slow, due to the rail wheel holding brake being applied, but insufficiently effective, at the time. RAIB has estimated the acceleration rate of the RRV, based on the line gradient and the post accident measurements of the available retardation from the rail wheel holding brake while the RRV was moving (paragraph 87). This indicates that the RRV is likely to have taken between 10 and 15 seconds to exceed 1 m/sec (2.2 mph).
- 74 The damage sustained by the control pendant meant that it was not possible to ascertain its condition before the accident. Witness evidence indicates that the machine operator had not had any problems in operating the rail wheels prior to the runaway. In addition, the RRV controls were found to be operating correctly after the accident (when operated with a replacement control pendant).
- 75 The machine operator was taking medication to control the symptoms of a medical condition. He had declared this to his employer. An occupational physician consulted by RAIB was unable to give a definitive statement as to whether the medical condition, or the associated medication, adversely affected the machine operator's actions.

Design and interlocks

- 76 **The RRV was not fitted with any physical means of preventing the machine operator from putting it into the position where only the rail wheel holding brake was acting to prevent movement.**
- 77 The control system on the RRV was designed to allow raising and lowering of each of the two rail wheel axles to be carried out independently of the position of the other rail wheel axle. There was no interlock fitted to prevent the machine operator from manually positioning the rail wheel axles such that only the rail wheel holding brake was acting to prevent movement of the RRV. Compliance with the specified on-tracking procedure (paragraphs 59 and 61) was the intended means of avoiding this situation. This was consistent with the requirements of standard RIS-1530-PLT Issue 1 (paragraph 48), which applied to the RRV and required a documented system to describe placing of the vehicle on the track, so that at all times during the operation, there was no inadvertent movement of the vehicle. Although additional to the requirements of issue 1, the rail wheel holding brake addressed Network Rail's requirement for an engineered safeguard against a runaway (paragraph 52).
- 78 Although standard RIS-1530-PLT Issue 1 did not require the fitting of an interlock to prevent the operator being able to manually partly deploy both sets of rail wheels, it did require an interlock to prevent simultaneous movement of both rail axle mechanisms. This interlock was fitted, but was neither intended, nor did it, prevent the machine operator from deploying the rail wheel axles sequentially into a position where both were partly deployed.

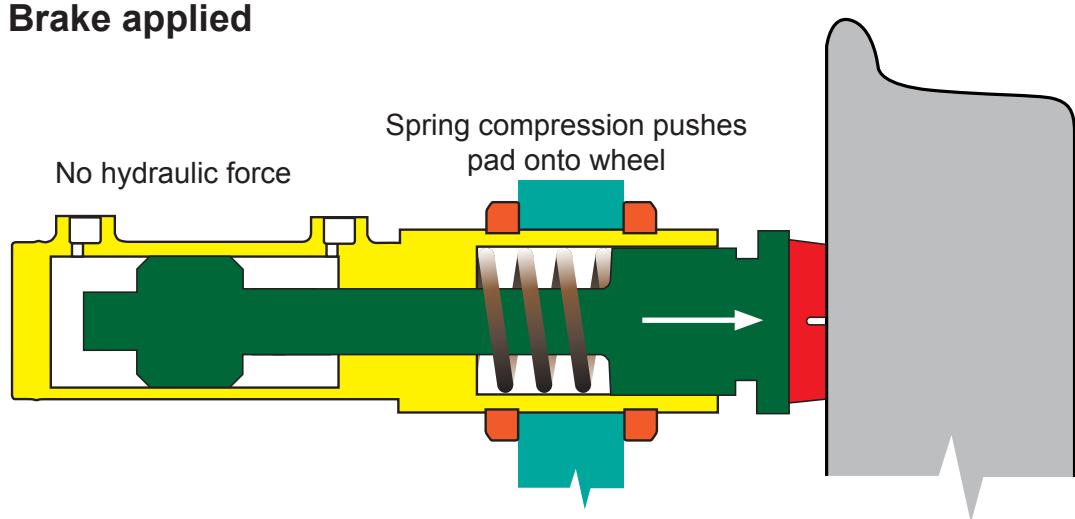
- 79 The Rail Safety and Standards Board issued a Technical Note (TN-039 – ‘Assessment of on and off tracking procedure’) in October 2008. This was intended to clarify the interpretation of the requirements in standard RIS-1530-PLT Issue 1 by requiring that it should not be possible to have both rail wheel axles partly deployed at the same time (the situation which led to the runaway). The technical note applied only to assessments undertaken when certifying ‘first of type’ and so did not apply to the incident machine which was certified based on the ‘first of type’ assessment completed in January 2008 (paragraph 48).
- 80 From issue 2 of standard RIS-1530-PLT (applicable from December 2009), there was a requirement for similar new RRVs to be designed so that the second rail wheel axle cannot be deployed until the first rail axle is fully deployed and locked in position, thus preventing the operator from manually placing the machine into the position where only the rail wheel holding brake was acting to prevent movement.

Design and setup of the rail wheel holding brake

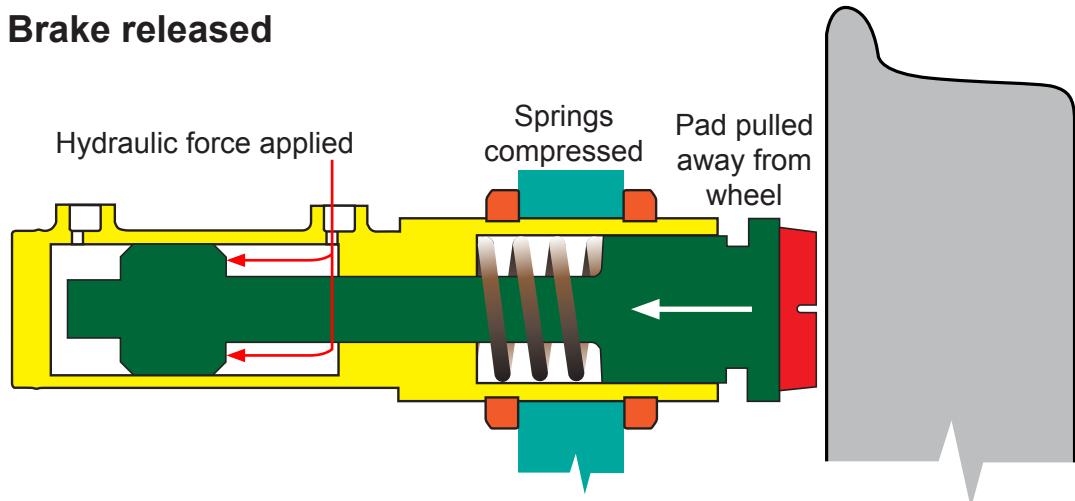
- 81 **Deficiencies in the design and setup of the rail wheel holding brake meant that it was inadequate to hold the RRV on the gradient.**
- 82 The rail wheel holding brake was unable to hold the RRV on the gradient because of deficiencies in its:
- design (paragraph 83);
 - setup (paragraph 97); and
 - assembly (paragraph 112).
- 83 **The design calculations for the rail wheel holding brake assumed a higher coefficient of friction between the brake pads and the wheel than was available in practice.**
- 84 The RRV rail wheel holding brake is provided by two brake cylinders, one operating on each of the two fixed end rail wheels. There is no rail wheel holding brake fitted to the steering end rail wheels.
- 85 Each rail wheel holding brake cylinder contains a spring assembly which pushes a brake pad against the inside face of the rail wheel (figure 14). Friction between the brake pad and the wheel causes a brake retarding force, which is dependent on the magnitude of the force applied by the spring assembly, and on the coefficient of friction between the brake pad and the rail wheel. The force applied by the spring assembly is related to the amount by which it is compressed. The brake retardation force is released by operation of a hydraulic piston which applies a fixed force to pull the brake pad away from the rail wheel, thus compressing the spring assembly⁹.

⁹ Note that the available hydraulic force is less than that required to fully compress the spring assembly.

Brake applied



Brake released



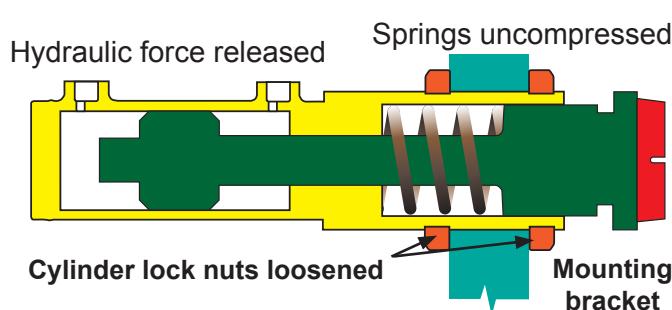
Note: The helical spring is shown for illustration only. The brake cylinders use a stack of disc springs, as shown in figure 21.

Figure 14: Sketch showing operation of the rail wheel holding brake cylinder

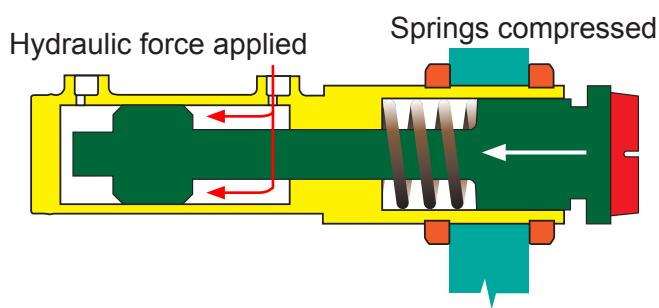
- 86 In order to maximise the available braking force, the cylinders need to be positioned relative to the rail wheels so that the maximum practical spring compression is present when the brake is applied. This is described as the optimal position in this report¹⁰. The maximum practical spring compression is limited by the force that the hydraulic piston applies to compress the springs. This is because the hydraulic force must overcome the spring force to release the brake. A practical way of achieving the optimal brake cylinder position is to set them up as follows (figure 15):
- i) with the hydraulic pressure released, the brake cylinder is positioned arbitrarily in its mounting;
 - ii) apply hydraulic pressure to compress the spring assembly;
 - iii) move the cylinder towards the rail wheel, until the brake pad has ‘minimal clearance’ from it and secure the cylinder in place; and
 - iv) release the hydraulic cylinder to allow the spring assembly to push the brake pad against the wheel.
- 87 If the brake cylinder is positioned during setup with a gap between the brake pad and the wheel, then the spring compression when the pad is in contact with the wheel will be less, and so the resulting brake pad force will be lower. A similar reduction in brake pad force occurs when the brake pads wear, if the cylinder position is not readjusted to accommodate the wear.
- 88 RAIB established the range of likely brake conditions at the start of the runaway by undertaking tests and measurements on both the incident RRV and a similar RRV which appeared to be in good condition. The tests and measurements, summarised in appendix D, encompassed:
- *pull tests* to establish the amount of force needed to start an RRV moving on level track when restrained only by the rail wheel holding brakes;
 - pull tests to establish the force required to keep the RRV moving after overcoming the initial brake retardation force
 - measurements of rail wheel holding brake pad thickness;
 - measurements of the brake cylinder positions relative to the rail wheels; and
 - measurements of the force applied to the wheel by the brake cylinder with various spring compressions.
- 89 RAIB has also taken account of a test undertaken during recovery of the incident RRV by TXM Plant. This test showed that, approximately 24 hours after the runaway, the rail wheel holding brake was able to hold the RRV on the 1 in 41 gradient at the Keppochill Road RRAP.
- 90 Examination of RRVs showed that a film of surface rust formed on the wheels if the RRVs were not used for a period of time (figure 16). Tests on the incident machine showed that the available brake retardation force was about 280 kg when a surface layer of rust was present on the wheels. This was likely to have been the condition of the RRV wheels when the runaway occurred, after the RRV had been standing at the RRAP for two weeks.

¹⁰ The spring compression associated with the optimal position for the left-hand brake cylinder would have been different from that for the right hand brake cylinder because its springs were assembled incorrectly (paragraph 112).

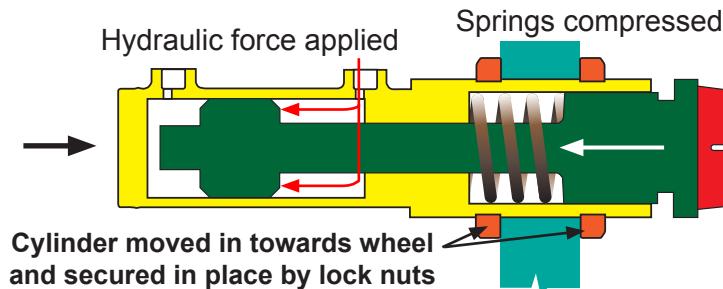
i) Cylinder ready for setup



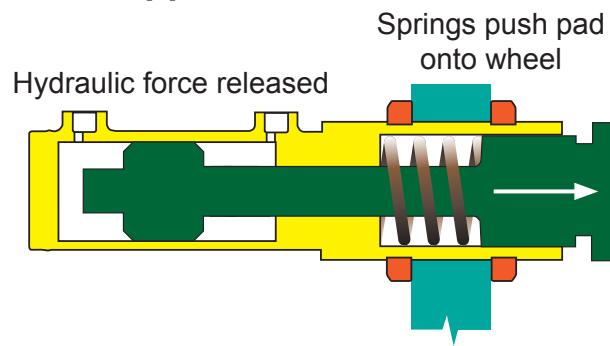
ii) Cylinder retracted prior to setup



iii) Cylinder set up with minimal gap



iv) Brake applied with maximum force



Note: The helical spring is shown for illustration only. The brake cylinders use a stack of disc springs, as shown in figure 21.

Figure 15: Sketch showing a practical optimal setup procedure for the rail wheel holding brake cylinders



Figure 16: Surface rust present on wheel photographed during testing

91 The tests also showed that the brake retardation force increased to around 310 kg when this rust layer rubbed off (figure 17). Calculations, based on the test during recovery of the RRV, show that the brake retardation force would have been at least 400 kg when the brake pads were acting on the polished surface present after the runaway (figure 18).

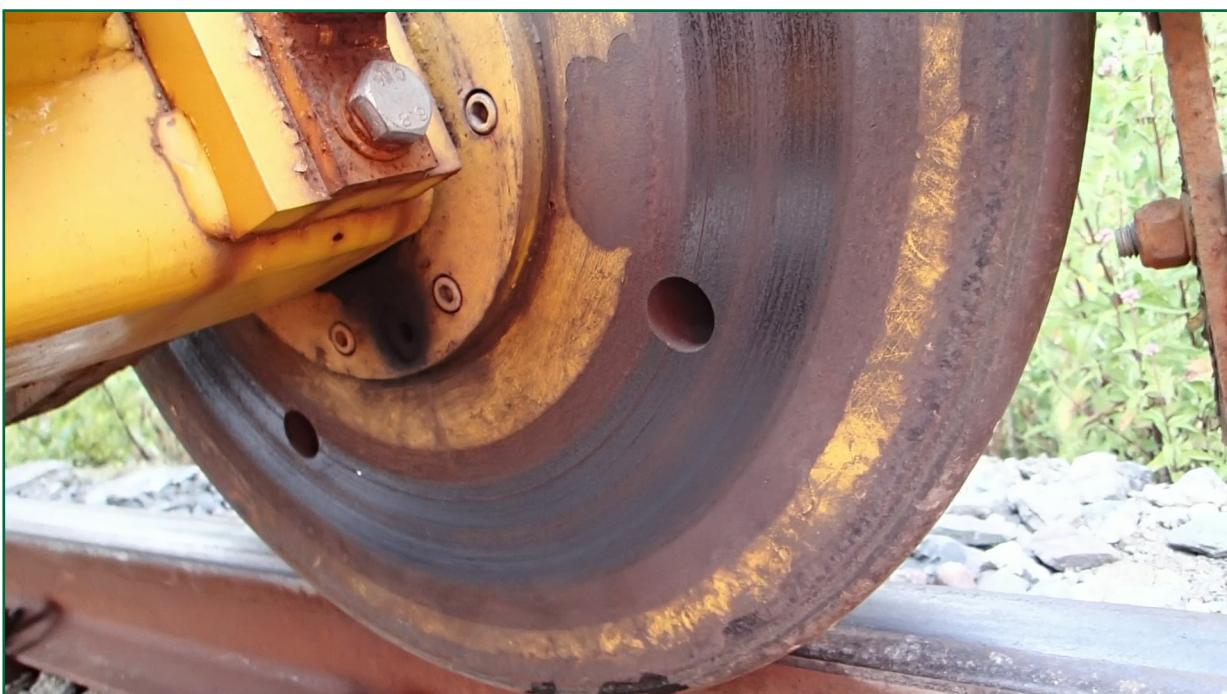


Figure 17: Typical in-service wheel contamination present photographed during testing



Figure 18: Clean (reflective) brake contact surface immediately after runaway

- 92 RAIB calculations based on the physical test results indicated that the coefficient of friction was about 0.27 when a layer of surface rust was present, about 0.30 with typical in-service rail wheel contamination, and at least 0.40 with the polished surface present after the runaway. The results from individual tests provide firm evidence that the brake retardation force increased by about 30 kg as surface rust wore off, and then by at least another 90 kg when the wheel surface was polished.
- 93 RAIB also tested a second RRV of the same type and specification, which was in good condition and had typical in-service wheel surface contamination. The coefficient of friction between the brake pads and the wheels of the good condition RRV was found to be approximately 0.29, which is similar to the corresponding value for the incident RRV¹¹.

¹¹ The quoted coefficient of friction values are only accurate to ± 0.04 because of imprecision in the measurement of the forces between the brake pad and the wheel, and variability in the level of contamination where the pad contacts the rail wheel. Test results and accuracies are presented in appendix D.

- 94 The brake pads specified by Rexquote for use on the RRV were of a type normally used on cars. RAIB was unable to obtain a data sheet for these pads but evidence from the manufacturer who supplies¹² these brake pads shows that such car brake pads typically deliver a coefficient of friction of between 0.3 and 0.4 when used against a car brake disc, depending on the specification. Because car brake discs are normally used relatively frequently, they normally have a smooth, uncontaminated surface, similar to the condition of the RRV rail wheel after the runaway. RAIB test results are therefore consistent with the performance which would be expected from RRVs fitted with car brake pads.
- 95 Rexquote's design calculations for the rail wheel holding brake assumed that the coefficient of friction between the brake pad and the rail wheel would be 0.5. Rexquote has been unable to provide any evidence to explain the selection of this figure. Rexquote has acknowledged that this assumption was incorrect.
- 96 Based on the factory test results (paragraph 124) and maintenance testing (paragraph 121), RAIB has calculated that, when set up with minimal clearance between the rail pad and the wheel, the holding brake was sufficient to hold the RRV on the 1 in 41 gradient with the reduced coefficient of friction of 0.27.
- 97 The RRV rail wheel holding brakes were not set up to provide sufficient braking force to prevent a runaway on a 1 in 41 gradient, and there was no maintenance instruction requiring appropriate setup.**
- 98 Post-accident examination and testing of the incident RRV could not provide a direct indication of the amount of brake force available when the runaway occurred. This is because brake pad wear would have occurred during the runaway, reducing the amount of spring compression and thus reducing the brake force observed during testing. There is no record of the pad thicknesses when the RRV was being on-tracked, and so there is no evidence showing the amount of brake wear that occurred during the runaway.
- 99 The effect of differing amounts of brake pad wear has been assessed using relationships between compression of the brake cylinder spring stacks and the force applied to the brake pad. These are based on manufacturer's published data for the springs with allowances for misassembly of the LHS spring assembly (paragraph 112) and for friction in the cylinder determined from RAIB testing (figure 19 and appendix D).
- 100 The effect of pad wear is shown in figure 20, assuming a layer of surface rust on the brake pads. This is the most likely condition when the runaway started, because the RRV had been standing unused at the RRAP for two weeks before the runaway. Figure 20 is based on direct pull tests (appendix D), the slope of the brake cylinder force characteristic (figure 19) and the post-accident position of the brake cylinder (paragraph 101).
- 101 Post-accident examination of the incident RRV showed that the left-hand cylinder was positioned 8 mm away from the optimal position (paragraph 86) with 3.5 mm of pad wear and 4 mm of spring compression. The right-hand cylinder was positioned 5.5 mm away from the optimal position with 2.5 mm of pad wear and 5 mm of spring compression.

¹² It is possible that the brake pads were manufactured by a third party for supply by this manufacturer.

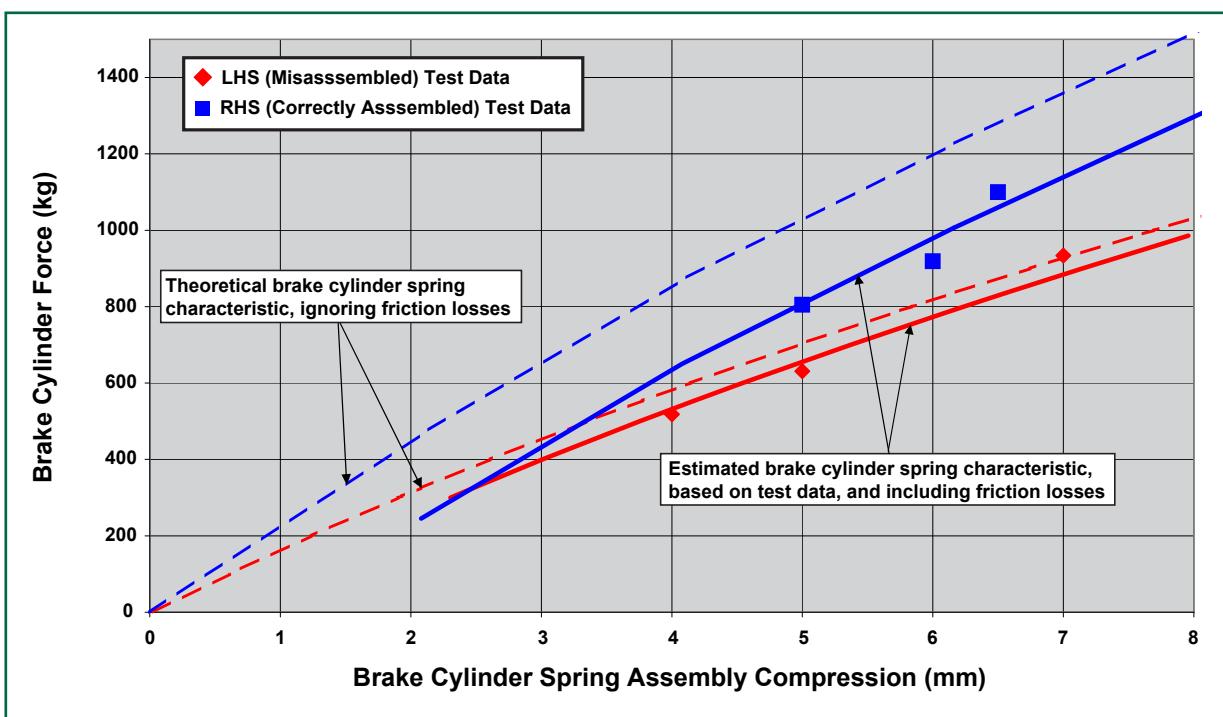


Figure 19: Rail wheel holding brake cylinder spring characteristics

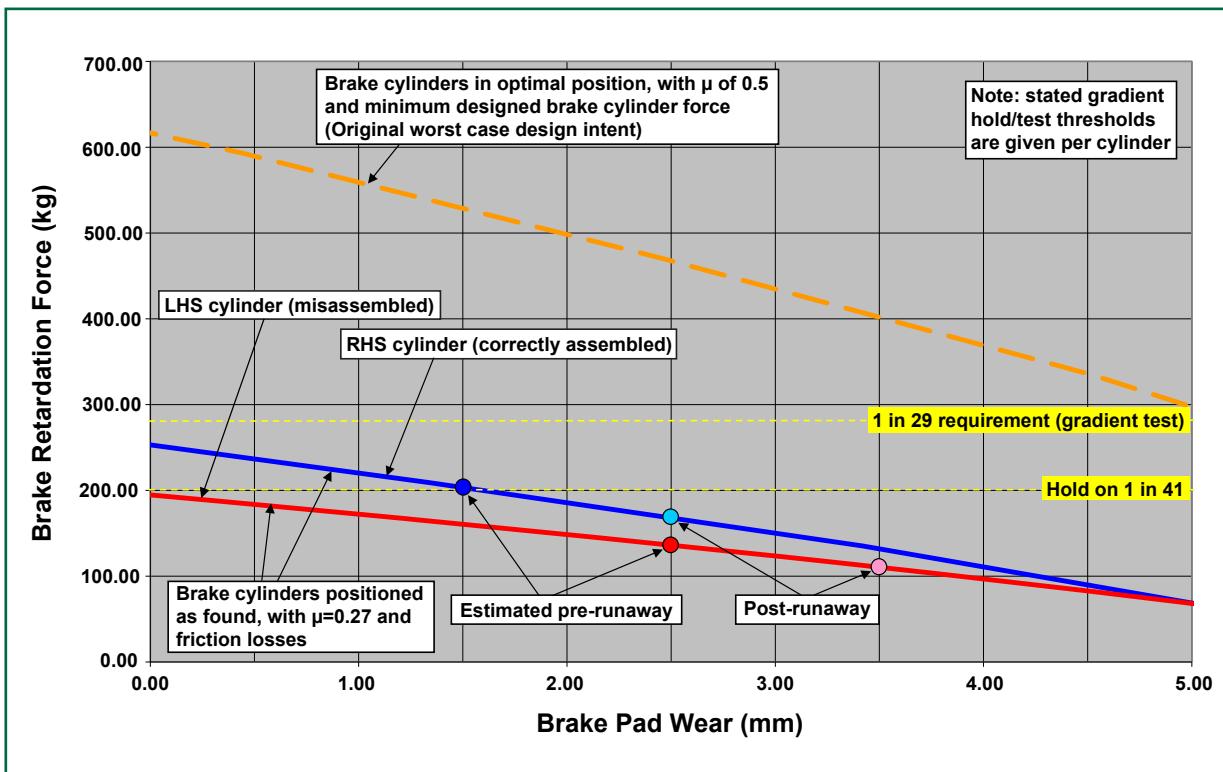


Figure 20: Rail wheel holding brake characteristic, set up as found, showing effects of pad wear

- 102 If the RRV had been on-tracked in this configuration, but with a layer of surface rust on the wheels, the available brake retardation force would have been about 280 kg (paragraph 90). This is based on testing which directly replicated the condition, and would have been insufficient to hold the RRV on the 1 in 41 gradient (a situation requiring approximately 400 kg of brake retardation force).

- 103 If the RRV had been on-tracked with the brake cylinders in the same position, and with rusty wheels, but with the brake pads unworn (but slightly used so that they were fully bedded in), the available brake force would have been about 440 kg (190 kg from the LHS cylinder and 250 kg from the RHS cylinder with zero pad wear, figure 20). This force would have been sufficient to hold the RRV on the 1 in 41 gradient.
- 104 Although there is no record of the amount of pad wear on the incident RRV when the runaway started, an indication of possible wear has been obtained by considering the amount of wear on a similar RRV of the same age. Maintenance records show no evidence that the brake pads had been changed on either RRV since they were delivered in 2009, so RAIB considers it likely that the pads on both vehicles would have experienced similar levels of wear since then. The brake pads of the similar RRV showed lifetime wear of about 2 mm, whereas those on the RRV involved in the accident were seen to be worn by between 2.5 mm and 3.5 mm after the accident. This implies about 1 mm of wear during the runaway.
- 105 If, as is possible, approximately 1 mm of pad wear occurred during the runaway, the brake cylinder spring compressions at the start of the runaway would have been 1 mm greater than the post-accident values recorded in paragraph 101. Assuming the presence of a layer of surface rust, RAIB estimates that about 340 kg of brake retarding force would then have been available when the runaway started (135 kg from the LHS cylinder and 205 kg from the RHS cylinder with estimated pre-runaway pad wear of 1.5 mm and 2.5 mm respectively, figure 20). Approximately the same brake retarding force would have been available if both brake pads had 2 mm of wear before the runaway. The 340 kg of brake retardation would have been less than the 400 kg required to hold the RRV on the 1 in 41 gradient at the RRAP.
- 106 It is also possible that more than 1 mm of brake wear occurred during the runaway. For example, if only 1 mm of pad wear was present prior to the runaway (equivalent to 1.5 mm and 2.5 mm wear to the RHS and LHS brake pads respectively during the runaway), then there would have been approximately 390 kg of brake retardation when the runaway started (220 kg from the RHS cylinder and 170 kg from the LHS cylinder). This is close to the 400 kg required to hold the RRV on the 1 in 41 gradient. Given the uncertainties about pad wear, it is possible that the actual brake force was just sufficient to hold the RRV on the 1 in 41 gradient and a jolt during lowering of the rail wheels provided an impulse force sufficient to initiate the runaway. In this situation, movement would have been likely to continue because testing by RAIB showed that the available brake retardation force when the RRV was moving was lower than the corresponding brake retardation force when the RRV was stationary.
- 107 If the brake cylinders had been positioned at the optimal location when the brake pads were unworn (paragraph 86), the brake cylinder spring compression at the time of the runaway would have been greater. RAIB calculations show that, assuming a rust layer on the wheel, a brake retardation force of at least 650 kg would have been available with new (but bedded in) brake pads and at least 440 kg would have been available with the pad wear found after the runaway. These values exceed the 400 kg required to prevent the runaway.

- 108 Given the low rate of brake pad wear¹³ in normal service, RAIB has considered the apparent anomaly between the data presented in figure 20 and maintenance records which state that the RRV stood on a 1 in 29 gradient during testing on 11 December 2012 (paragraph 30). It is likely that there was no surface rust and/or less contamination on the wheels when the RRV passed the test in December 2012. This is because the Rexquote operation and maintenance manual, and TXM Plant's testing procedure, both specified repeated application of the service brake, and hence repeated application of the rail wheel holding brake (paragraph 51), before the holding brake was tested. This would tend to remove contamination from the area where the rail wheel holding brake pad contacts the rail wheel. It is also possible that the RRV was subjected to a jolt during on-tracking during the incident but not during the brake test.
- 109 RAIB test results and calculations show that the available holding brake retardation force for this type of RRV is very sensitive to the position of the brake pads. The optimal position is with the pads just clear of the rail wheel when the brake is released. A 1 mm offset in the position of both pads from this optimal position reduces the holding brake's capability by approximately 70 kg. If the brake pads were positioned so that they were only 3 mm away from the optimal position¹⁴, the RRV would have lost enough of the rail wheel holding brake's capability to only just comply with the 1 in 29 requirement. This condition could arise from either 3 mm of brake pad wear, or from the brake pad being positioned 3 mm away from the back of the rail wheel when the brake cylinder was being set up. Any subsequent pad wear from this position would introduce the risk of the RRV running away on a gradient on which the rail wheel holding brake was intended to be sufficient to hold it.
- 110 The only maintenance activity specified in the Rexquote operation and maintenance manual relating to the rail wheel holding brakes is a check of the thickness of the friction material on the brake pad. If the material was worn to less than 5 mm thick, equivalent to approximately 5 mm of pad wear, then the manual required the pads to be changed. It did not specify any need for adjustment of the brake cylinder position, and there was no procedure to describe how to do this if the maintainer identified that the brakes were not performing adequately.
- 111 It was observed that one of the RRV rail wheel holding brake cylinders was found to be sticking during testing after the accident. However, it was only found to be sticking during brake release, and testing showed that it was providing the expected braking force when applied. As a result, this is not considered to have been contributory to the accident.

¹³ Rexquote stated that it has supplied very few replacement brake pads for these RRVs. TXM plant also stated that the rail wheel brake pad wear rate experienced in service was low, and that very few brake pads had required replacement since the RRVs were supplied.

¹⁴ This is equivalent to the condition of the RRV when set up as found after the accident, but with new brake pads and with both brake cylinders correctly assembled.

112 One of the RRV brake cylinder springs had been assembled incorrectly; this is a possible causal factor.

113 The spring in the brake cylinder consists of a stack of 16 disc springs, intended to be assembled as 8 back to back pairs, giving the intended spring force to compression characteristic for the brake cylinder. During inspection of the RRV after the accident, the rail wheel holding brake cylinders were disassembled, and this showed that the left-hand side brake cylinder spring stack was assembled incorrectly, with two of the discs inserted upside down (figure 21).

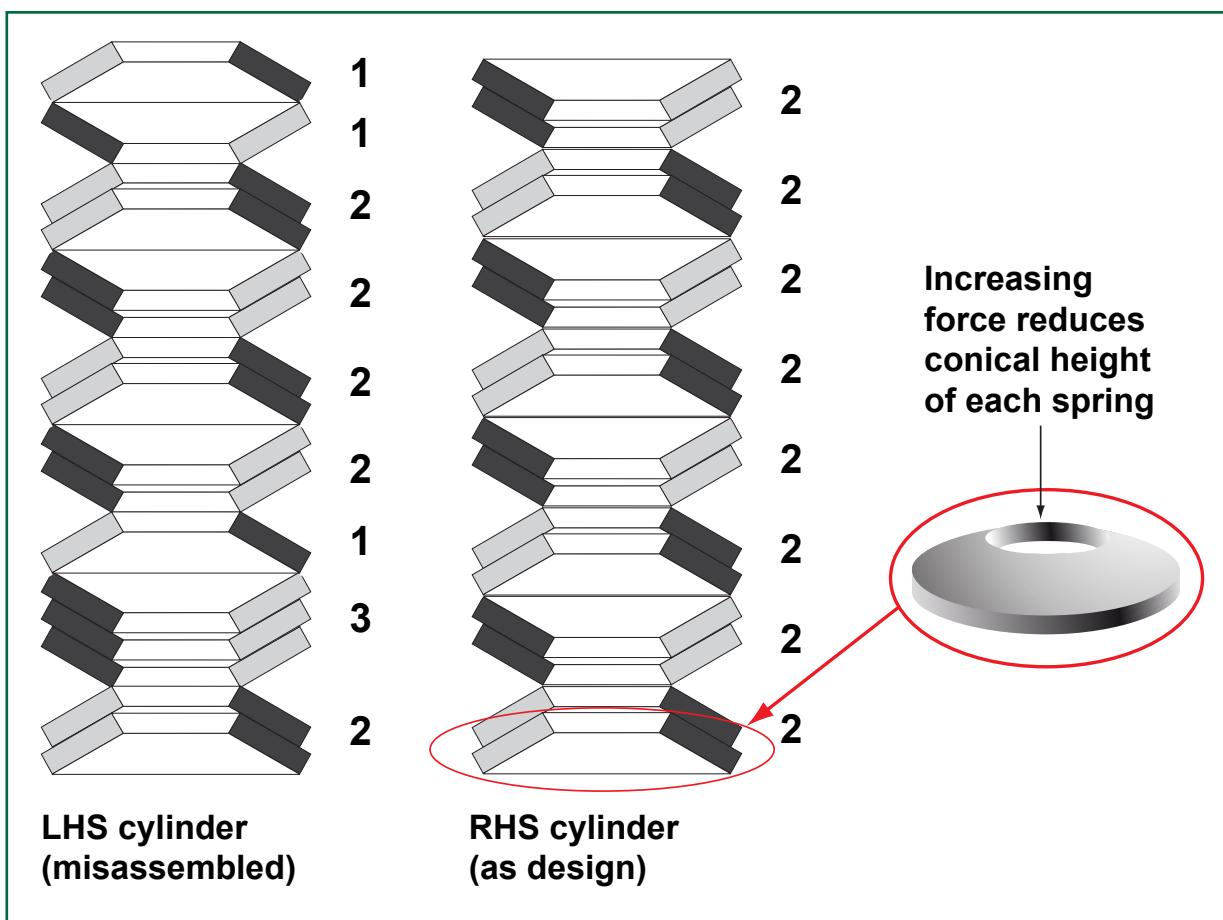


Figure 21: Holding brake cylinder disc spring assembly (misassembled and as designed)

114 This misassembly meant that for a given force applied to the springs, the compression would have been larger than intended. For the 1750 kg of compression that the hydraulic cylinder was able to provide, the misassembled spring assembly would have compressed by approximately 12 mm, instead of 10.5 mm for a correctly assembled cylinder. Figure 19 shows the calculated effect of misassembly of the springs in one brake cylinder on the relationship between spring compression and brake cylinder force.

115 The misassembled spring resulted in a lower brake cylinder force than a correctly assembled spring would have delivered with the brake cylinder in the same position as found after the runaway. It is possible that the reduced force provided by the incorrectly assembled spring may have been a factor in the runaway.

- 116 The maintenance records for the incident RRV give no indication that any work had been carried out on the rail wheel holding brakes. The operation and maintenance manual also did not require TXM Plant to carry out any work on the rail wheel holding brakes that would have necessitated disassembly.
- 117 RAIB has been unable to identify whether the brake cylinder was misassembled prior to delivery by Rexquote, or during subsequent maintenance by TXM Plant. However, both Rexquote and TXM Plant have stated that the competence of individual technicians and engineers is assessed and subject to periodic monitoring. RAIB has not investigated this further as any shortcomings should be addressed by the quality assurance and auditing required in response to the RAIB recommendations given in paragraphs 160 and 171.
- 118 The rail wheel holding brake test, undertaken prior to the accident using a 1 in 29 gradient, is unlikely to have identified the misassembly of the brake cylinder (paragraph 121).

Testing regime

- 119 The testing regime for the RRV rail wheel holding brakes did not identify shortcomings in the design of these brakes.**
- 120 The RRV rail wheel holding brakes were tested by TXM Plant at 12-monthly intervals, in accordance with the Rexquote operation and maintenance manual. The manual stated that the test should be undertaken using either one of two alternative methods. The first of these was to position the RRV on a 1 in 29 gradient and confirm that the rail wheel holding brake alone was able to prevent movement. The second method (known as a pull test) was to position the RRV on a level piece of track, with only the rail wheel holding brake effective, and then to ensure that the force required to pull the RRV through the brakes was greater than the equivalent braking force required to hold a fully laden RRV on a 1 in 29 gradient.
- 121 In practice, TXM Plant Ltd used a 1 in 29 gradient to carry out this test. The last such test before the accident was carried out in December 2012. Maintenance records show that the machine was able to remain stationary with only the rail wheel holding brake acting to prevent movement during this test. The maintenance records for the RRV indicated that all other testing specified in the operations and maintenance manual had been carried out as scheduled, and that the tests had been passed.
- 122 The Rexquote design calculations showed that the rail wheel holding brake had been intended to provide approximately 1200 kg of brake retarding force, based on a coefficient of friction of 0.5 and with the brake cylinders providing their maximum intended spring force of 1544 kg.
- 123 The brake cylinder which was used on the as-built RRV was capable of applying approximately 1750 kg to the brake pad, but the coefficient of friction achieved was only around 0.3. This resulted in the maximum rail wheel holding brake retarding force being between 750 kg and 800 kg with the optimal brake cylinder position.
- 124 Records of factory testing of the RRVs show that a pull test through the rail wheel holding brakes was carried out. The pass/fail criterion was the 596 kg brake retarding force required to hold a fully laden vehicle on a 1 in 29 gradient. Typical test results for this type of RRV show that factory testing gave brake retarding forces of between 700 kg and 750 kg.

- 125 The factory tests demonstrated that the rail wheel holding brake retarding force was about 40% below that anticipated by the design calculations. There is no evidence of any action being taken by Rexquote in response to this.
- 126 The 596 kg acceptance criterion does not provide any allowance for future brake pad wear. It also does not provide any safety factor, account for any adverse effects from moisture, or provide an allowance for future normal contamination (such as rust) on the brake pad to wheel interface.
- 127 No testing of the rail wheel holding brake was carried out to demonstrate the available brake retarding force with worn brake pads. Post-accident testing and analysis by RAIB has shown that a test of this type would have demonstrated that the rail wheel holding brake was unable to hold a fully laden machine on a 1 in 29 gradient with brake pads worn by more than about 4 mm.
- 128 The Rexquote Operating and Maintenance Manual required annual testing of the rail wheel holding brake to demonstrate that it was sufficient to hold the RRV either against a pull load of 596 kg or on a 1 in 29 gradient. The test was routinely carried out with the RRV in the unladen condition which, in accordance with the operations and maintenance manual and with the TXM Plant procedure, was the condition required during normal on-tracking. In this unladen condition, a force of 569 kg is sufficient to hold the RRV on a 1 in 29 gradient and is a less onerous test than the 596 kg pull test which reflects the force needed to hold a fully laden RRV on a 1 in 29 gradient. Neither of these test criteria provided any significant allowance for future brake wear, or any safety margin.

Identification of underlying factors¹⁵

Quality assurance

- 129 The manufacturer's quality assurance processes were inadequate to identify the deficiencies in the rail wheel holding brake design.**

130 The following aspects of Rexquote's work indicates the absence of an effective quality assurance process:

- the incorrect value adopted for the coefficient of friction in the design calculations for the rail wheel holding brake was not detected and corrected (paragraph 83);
- Rexquote was unable to provide any evidence of peer review or checking of the design assumptions, design calculations, factory test programme, or the routine maintenance procedures contained in the operation and maintenance manual (paragraphs 95, 110, 126 and 128);
- factory testing did not identify that the designed brake retarding force was not being achieved, despite results being available to indicate this (paragraph 125);
- the operation and maintenance manual did not specify that the rail wheel holding brake had to be adjusted during maintenance to maintain its performance (paragraph 110); and
- deficient design of the rail wheel interlock was not detected and corrected (paragraph 145).

¹⁵ Any factors associated with the overall management systems, organisational arrangements or the regulatory structure.

- 131 Rexquote was not operating a documented quality assurance system intended to avoid shortcomings such as those described in paragraph 130, and was not subject to an externally monitored system based on a relevant standard (eg BS EN ISO 9001 - Quality management systems - requirements).
- 132 Rexquote is certified under Link-Up¹⁶ with a product code of '17.01.01 SMP', which covers the supply and manufacture of plant. Certification under this code does not require operation of a formal quality assurance system, nor does it require any external auditing of Rexquote's internal management processes.
- 133 Network Rail also carries out technical audits of its rail plant suppliers, to ensure that technical compliance with standards is maintained, and to monitor the quality of plant that is supplied. This audit process covers suppliers such as TXM Plant. However, these audits were not carried out on manufacturers or converters of plant, such as Rexquote, that did not supply plant directly to Network Rail. Network Rail relied on its plant suppliers to assure themselves of the quality of plant supplied to them. TXM Plant has stated that, at the time these RRVs were supplied, it had assumed that the Vehicle Acceptance Body (VAB) process provided this assurance. Network Rail has stated that its plant suppliers had tended to believe that this assurance was provided by the VAB process for the engineering acceptance of RRV designs, but that this misconception was being addressed by a technical audit process which had been introduced for other reasons in 2008.

Approval of the design

- 134 **The approval process did not examine the specification or effectiveness of the rail wheel holding brake.**
- 135 Before any RRV can be used on Network Rail infrastructure, Network Rail requires it to have been issued with a certificate of engineering acceptance. This certificate is issued by a VAB after it has verified compliance with standard RIS-1530-PLT (which contains requirements for braking systems; paragraph 49) and other relevant Railway Group Standards.
- 136 Standard RIS-1530-PLT Issue 1 states that the vehicle approval certification process does not provide evidence of compliance with statutory, legislative or other standards or imply that the vehicle is safe in all respects. The VAB assessment process does not check quality of manufacture against the certificated design or whether the RRV performance meets the original design specification.
- 137 The certificate of engineering acceptance for the RRV involved in the accident was issued by Delta Rail in July 2009, acting as the VAB. As part of its assessment for this type of RRV, which was completed by January 2008, Delta Rail reviewed the design of the road wheel braking when used in both road and rail modes. Delta Rail also witnessed detailed testing of the road wheel brakes on the first of these RRVs to be manufactured. Sample witnessing of tests on later machines, including this one, was also carried out before issuing the certificates of engineering acceptance for each machine.

¹⁶ Link-Up is a scheme designed to register contractors as approved to tender for work. It is used by Network Rail, its contractors, London Underground and some train operators to support their procurement and risk management activities. For companies working on railway infrastructure a condition of qualification is an ongoing programme of annual questionnaires and audits to verify that the supplier concerned is compliant with the minimum standards required.

- 138 Because the rail wheel holding brake was not required by standard RIS-1530-PLT Issue 1, assessment and testing of its adequacy was outside the scope of the VAB process. As a result, Delta Rail was not required to, and did not, carry out any assessment or testing of the capability of the rail wheel holding brake.
- 139 Later issues of standard RIS-1530-PLT (from issue 2 in December 2009 onwards) included requirements for interlocking of rail wheel deployment and/or the provision of rail wheel braking adequate to prevent runaways during on-tracking and off-tracking. This brought rail wheel brakes within the scope of the VAB process, but did not require retrospective action in respect of RRVs that had already been approved (paragraph 48).

Observations¹⁷

RRV lighting

140 The RRV lighting was not illuminated as it ran down the gradient.

- 141 The RRV was fitted with two sets of lighting for use when operating on the railway. Work lights were fitted to the operator's basket and to the body of the RRV. These were designed to provide illumination for working in the vicinity of the RRV. The work lights are manually activated using a control in the operator's basket. When the RRV was being on-tracked, these lights were not lit because the operator had not switched them on. Both the machine operator and the machine controller were using torches and residual light from adjacent vehicles and street lighting during on-tracking, and both considered that this was adequate.
- 142 The RRV was also fitted with rail mode lights, as mandated by standard RIS-1530-PLT. These are designed to be illuminated when the RRV is on the track, with white lights facing the direction of travel and red lights facing backwards. The lighting was designed so that it was automatically illuminated when either one of the rail wheel axles had been fully deployed and was in contact with the relevant road wheel. Because the machine operator had not fully deployed either of the rail wheel axles when the RRV started to run away (paragraph 64), this lighting was not illuminated.
- 143 The RRV ran down the gradient, into the tunnel, with none of its lights on. The maintenance worker who was injured stated that he did not see or hear the RRV as it approached. However, he also believed that he would have been unlikely to have seen it if the lights had been on, because he was focused on the work on the tunnel wall. The first warning he had of the danger was the sound of the RRV hitting the first empty scaffold, which was approximately 50 metres away from him, about 5 seconds before the RRV knocked him off the second scaffold.
- 144 The maintenance worker also indicated that if he had heard vehicle movement or seen lights, he would have assumed that it was a vehicle bringing materials to site, and would probably have not appreciated the approaching hazard. For these reasons, the absence of lighting on the RRV is not considered to be causal to the injury sustained by the maintenance worker. However, the presence of lighting could provide a warning in other circumstances.

¹⁷ An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the accident but does deserve scrutiny.

Rail wheel holding brake release interlock

- 145 An interlock intended to prevent release of the rail wheel holding brake when the rail wheels were not fully deployed was not always effective.
- 146 The RRV is fitted with a rail wheel holding brake release interlock which is intended to prevent release of the rail wheel holding brake unless both rail wheel axles have been fully deployed and so the road wheel brakes are effective through contact with the rail wheel hubs. This interlock uses microswitches to detect when the rail wheel axles have been fully deployed.
- 147 During post-accident testing of the RRV by RAIB, it was found that hysteresis in the operation of the microswitches meant that they did not always provide the intended function¹⁸. If the rail wheels were fully deployed and then raised until the road wheels were just out of contact with the rail wheel hubs, the road wheel brakes were no longer effective, but the rail wheel holding brake could be released by an operator trying to move the RRV along the track.
- 148 This condition is not considered causal to the runaway because witness evidence indicates that the rail wheel axles did not reach the fully deployed state and so the interlock would not have been released, and because the brakes could only then be released using the controls in the basket (which were not being used at the time). Rexquote has carried out modifications to address this condition (paragraph 167).

Operator briefing

- 149 The machine operator was not briefed about the gradient at the RRAP.
- 150 The machine controller knew of the gradient at the RRAP, but he did not brief the machine operator that this was a hazard. The checklist in the industry code of practice COP0016 'Code of Practice for RRV Machine/Crane Controller Checklists' highlighted to the machine controller that gradient was a possible hazard in operating an RRV. The machine controller filled in the COP0016 checklist to record that he had briefed the machine operator on specific site hazards. Because the gradient was within the certified capability of the RRV, it is unlikely that a briefing of the gradient at the site would have affected the actions of the machine operator.

Post-accident drug testing

- 151 The machine operator was not tested for drugs immediately after the accident.
- 152 Railway staff involved in accidents are routinely tested to establish whether they are compliant with industry requirements concerning the use of alcohol and drugs. A test on the day of the accident confirmed that the machine operator was compliant with the requirements relating to alcohol. He was not tested for the presence of drugs on the day of the accident because he had been injured and was in shock. A sample taken on the following day for drug testing was damaged in transit, so no result could be obtained.

¹⁸ The microswitches closed at the appropriate position during lowering of the rail wheels, but remained closed after the rail wheels passed this position when they were being raised.

Summary of conclusions

Immediate cause

153 The RRV ran away on the gradient because only the rail wheel holding brakes were acting to prevent movement and these were inadequate to do so (**paragraph 53**).

Causal factors

154 The causal factors were:

- a. the machine operator put the machine into the position where only the rail wheel holding brake was acting to prevent movement, contrary to the on-tracking procedure in which he was trained (**paragraph 56, action taken paragraph 161**);
- b. the machine operator was unable to operate the correct controls to either fully raise or lower the rail wheels once the RRV was moving (**paragraph 68**);
- c. the RRV was not fitted with any physical means of preventing the machine operator from putting it into the position where only the rail wheel holding brake was acting to prevent movement (**paragraph 76, actions in progress paragraph 159f**);
- d. deficiencies in the design and setup of the rail wheel holding brake meant that it was inadequate to hold the RRV on the gradient (**paragraph 81**);
- e. the design calculations for the rail wheel holding brake assumed a higher coefficient of friction between the brake pads and the wheel than was available in practice (**paragraph 83, Recommendation 1**);
- f. the RRV rail wheel holding brakes were not set up to provide sufficient braking force to prevent a runaway on a 1 in 41 gradient, and there was no maintenance instruction requiring appropriate setup (**paragraph 97, Recommendation 1**); and
- g. the testing regime for the RRV rail wheel holding brakes did not identify shortcomings in the design of these brakes (**paragraph 119, action taken paragraph 163, Recommendation 4**).

155 A possible causal factor was that one of the RRV brake cylinder springs had been assembled incorrectly (**paragraph 112, some action in progress, paragraph 162, Recommendations 1 and 2**).

Underlying factors

156 The underlying factors were:

- a. the manufacturer's quality assurance processes were inadequate to identify the deficiencies in the brake design (**paragraph 129, Recommendations 1 and 2**); and
- b. the approval process did not examine the specification or effectiveness of the rail wheel holding brake (**paragraph 134, Learning point 1**).

Additional observations

157 Although not linked to the accident, RAIB observes that:

- a. the RRV lighting was not illuminated as it ran down the gradient (**paragraph 140, Recommendation 3**);
- b. an interlock intended to prevent release of the rail wheel holding brake when the rail wheels were not fully deployed was not always effective (**paragraph 145, action taken paragraph 167**);
- c. the machine operator was not briefed about the gradient at the RRAP (**paragraph 149**); and
- d. the machine operator was not tested for drugs immediately after the accident (**paragraph 151**).

Previous occurrences of a similar character, and actions arising from them

- 158 RAIB conducted a class investigation into runaways of RRVs and their trailers (RAIB report 27/2009). Appendix E of the class investigation report contains a table of 18 reported runaway events from 2001 to March 2009. Appendix F of the same report gives the underlying factors to those events.
- 159 Network Rail has been implementing a programme of activities to reduce the risk of RRV runaways. This is on-going and is being monitored by ORR. The activities reported by ORR and Network Rail included:
- a. Serving of an Improvement Notice by ORR on Network Rail following the runaway of a RRV MEWP at Copenhagen Tunnel in London in October 2006 requiring high ride MEWP RRVs to be provided with engineering measures to prevent a runaway during on-tracking by December 2007. Network Rail complied with this Improvement Notice and required that all high ride RRVs operating on its infrastructure were fitted with such engineering measures. This led to the issue of TN-039 (paragraph 79) and inclusion of such a requirement in issue 2 of RIS-1530-PLT from December 2009 (paragraph 80).
 - b. Serving of an Improvement Notice by ORR on Network Rail in March 2011 requiring it to undertake a risk assessment on the use of high ride excavator RRVs when operating on gradients and/or in wet conditions and/or in low adhesion conditions. Network Rail complied with this Improvement Notice.
 - c. Nationwide restrictions on the use of high ride RRVs not fitted with *direct rail wheel braking*. These machines are prohibited from working on gradients of 1 in 75 or steeper. The prohibition was applied in a phased approach, targeting high ride excavator RRVs and areas with the steepest gradients first, and this now covers all high ride RRVs in all areas of the country.
 - d. The fitting of direct rail wheel braking to all high ride RRVs to significantly improve braking performance and remove reliance on the road tyre/rail wheel interface. Following a risk based approach, the first phase of the direct rail wheel braking programme covered high ride excavator RRVs, and since June 2013 non-direct rail wheel braked high ride excavator RRVs have been prohibited from use on Network Rail infrastructure. The second phase of the programme covers all other types of high ride RRVs and is due for completion in August/September of 2014. Network Rail has funded both these direct rail wheel braking retrofit programmes.
 - e. Audits of the engineering safety management systems of rail plant suppliers by Network Rail's Rail Plant Support Engineers. This did not include rail plant manufacturers or converters, such as Rexquote, that do not directly operate plant on Network Rail infrastructure (paragraph 133).

- f. Rail Industry Standard RIS-1530-PLT was updated to issue 4 in December 2012 with full compliance required for new RRVs intended to be used on Network Rail infrastructure from 31 March 2013. This required the fitting of direct rail wheel service braking to all newly supplied and recertified high ride RRVs (except those that are driven and braked by the road tyres being in contact with rail wheels fitted with extended hubs). This requirement was extended to cover all high ride RRVs in standard RIS-1530-PLT Issue 5, which was published in June 2014. The direct rail wheel braking requirements in the standard are augmented by the retrofit programme described in paragraph 159d. The standard also introduced requirements for the performance of safety-related systems, such as brakes, thus requiring greater scrutiny of the design and verification processes.

Previous RAIB recommendation relevant to this investigation and being implemented

160 Since the publication of the class investigation report, RAIB completed an investigation into a runaway which occurred when on-tracking a dumper RRV at Bradford Interchange station in March 2012. The RAIB report (report 09/2013) was published in July 2013 and included the following recommendation:

Recommendation 4

Network Rail should review the processes for audits of engineering safety management systems and the competence of technical staff that it conducts, or requires others to conduct, on rail plant suppliers. The objective of the review is to identify ways of improving the focus on engineering safety management and the quality of the end products. The findings of this review should be implemented and documented in revised management processes. In addition, Network Rail should take steps to improve the extent to which plant suppliers' own audits are directed in a similar manner.

ORR reported to RAIB in January 2014 that Network Rail was taking action to implement this recommendation (paragraph 162). ORR also reported that it would monitor progress.

Actions reported as already taken, or in progress, and addressing factors which otherwise would have resulted in a RAIB recommendation

- 161 TXM Plant has briefed machine operators about the circumstances of the accident, and about the need to use the documented TXM Plant procedure when on-tracking all high ride RRVs.
- 162 Network Rail reported to RAIB in January 2014 that it intends to amend its response to recommendation 4, in the Bradford Interchange investigation report (paragraph 160), to include audits of engineering safety management systems of rail plant manufacturers and converters who do not directly supply Network Rail, but whose equipment is used on Network Rail infrastructure.
- 163 ORR served a *Prohibition Notice* on Network Rail, prohibiting the use of RRVs of the same type as that involved in the accident where there was a risk of a runaway during on-tracking. ORR reported that Network Rail had complied with this requirement by prohibiting this type of RRV from use on its infrastructure until each machine had been demonstrated as being able to meet the following pull test criteria, intended to allow for both a safety factor and the effects of contamination and pad wear:
 - immediately following repair or adjustment: 750 kg (26% more rail wheel holding brake retarding force than that required to prevent movement of a fully laden machine on a 1 in 29 gradient); and
 - at any time: 680 kg (14% more rail wheel holding brake retarding force than that required to prevent movement of a fully laden machine on a 1 in 29 gradient).
- 164 Rexquote revised the operation and maintenance manual to adopt the increased pull test figures as required by Network Rail (paragraph 163). This revision also incorporated a requirement to adjust the brake cylinder positions if required to meet the pull test figures, along with instructions for carrying this out.
- 165 TXM Plant, along with other operators, tested the rail wheel holding brakes on all examples of this type of RRV, and adjusted them, where necessary, to meet the revised performance criteria. TXM Plant also incorporated the higher 750 kg brake pull test (paragraph 163) into the 3-monthly maintenance checks on the RRV, instead of testing the rail wheel holding brakes annually as specified in the operation and maintenance manual.
- 166 Rexquote made available a redesigned rail wheel holding brake cylinder, with the same maximum available brake retardation, but which used a longer spring assembly, and so had a lower rate of reduction of brake retarding force with brake pad wear. These cylinders were only fitted to RRVs that had been unable to meet the higher brake retarding force pull tests with the existing cylinders.
- 167 Rexquote modified the rail wheel holding brake release interlock circuit to prevent the possibility of the rail wheel holding brake being released when the road wheel braking is not effective through contact with the rail wheel hubs (paragraph 145).

168 ORR has reported to RAIB that Network Rail has committed to extending the direct rail wheel braking retrofit programme (paragraph 159d) to cover all remaining high ride RRVs, including the type involved in the accident, and that this programme is intended to be complete by August 2014. This will replace the rail wheel holding brake on this type of RRV with a direct rail wheel service brake, which will provide higher brake retardation.

169 Network Rail has reported to RAIB that it is undertaking tests of RRV direct rail wheel braking performance with varying levels of brake pad wear. The results of these tests are intended to inform the future development of standards and guidance for brake performance and testing.

Learning point

170 RAIB has identified a key learning point for the railway industry¹⁹:

- 1 Although the vehicle approvals process assesses compliance of plant design with the relevant mandatory requirements of railway industry standards, it does not provide assurance concerning all aspects of the design and manufacture of that plant (paragraph 134). For this reason it is important that designers, manufacturers and convertors of plant for use on railway infrastructure apply established principles of engineering safety management to the specification, design, manufacture and testing of plant. Reliance should not be placed on approvals bodies identifying that new plant may prove to be unsafe when placed into service. Guidance on applying good practice in this field is to be found in the RSSB document 'The principles of the safe management of engineering change: Guidance' (Issue 1, May 2012).

¹⁹ 'Learning points' are intended to disseminate safety learning that is not covered by a recommendation. They are included in a report when RAIB wishes to reinforce the importance of compliance with existing safety arrangements (where 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.

Recommendations

171 The following recommendations are made²⁰:

- 1 *The intention of this recommendation is to ensure that Rexquote adopts a formalised approach to managing the quality of equipment that it manufactures or converts.*

Rexquote should implement a quality assurance process commensurate with good practice in engineering safety management.

Development of the process should include, but not be limited to, consideration of the following measures:

- undertaking peer review or checking of design assumptions and design calculations;
- ensuring that the intended design performance of equipment is used as the basis for assessing the results of design validation testing;
- ensuring that maintenance procedures and the associated tests are consistent with the intended design performance of equipment;
- ensuring that the design of safety related systems, such as brakes, and of any associated maintenance processes, takes account of foreseeable degradation mechanisms, such as brake pad wear, the need for adjustments and environmental conditions; and
- formal certification by an external body.

(paragraphs 154e, 154f, 155 and 156a)

continued

²⁰ 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 intention of this recommendation is to extend an existing RAIB recommendation relating to adequate quality assurance processes so that it covers all suppliers of rail plant used on Network Rail infrastructure, not only those who supply directly to Network Rail.*

Network Rail should extend its process for auditing the engineering management system of rail plant suppliers (linked to Bradford Interchange Recommendation 4; paragraph 160) so that it includes auditing the engineering safety management processes of all organisations manufacturing and/or converting rail plant likely to be used on Network Rail infrastructure (paragraphs 155 and 156a).
- 3 *The intention of this recommendation is to prevent RRVs running away with no lighting illuminated.*

Network Rail, in conjunction with RSSB, should review the requirements for RRV lighting in standard RIS-1530-PLT, with the objective of reducing the risk of RRVs running away without active lights. This should include consideration of:

 - requiring rail mode lighting to be activated when rail wheels start to be deployed (when on-tracking is taking place); and
 - requiring all illuminated lights to remain lit on activation of engine stop or emergency stop controls.

(paragraph 157a)
- 4 *The intention of this recommendation is to reduce the likelihood of RRV parking brakes being inadequate by improving the quality of RRV parking brake tests.*

Network Rail, in conjunction with the M&EE Networking Group, should review and improve the requirements and guidance for testing of RRV parking brakes so that such tests reliably demonstrate that the brake will be effective in all foreseeable operating conditions. The review should include, but not be limited to, consideration of:

 - demonstrating sufficient safety margins (including any related to uncertainties in the testing method);
 - allowing for foreseeable degradation, such as brake pad wear;
 - allowing for varying environmental conditions, including variations in contamination at the brake/wheel interface;
 - ensuring that test methods used are repeatable and consistent; and
 - testing to be carried out by RRV suppliers, users and maintainers.

(paragraph 154g)

Appendices

Appendix A - Glossary of abbreviations and acronyms

CCTV	Closed Circuit Television
COSS	Controller of Site Safety
MEWP	Mobile Elevating Work Platform
ORR	Office of Rail Regulation
RRAP	Road Rail Access Point
RRV	Road Rail Vehicle
VAB	Vehicle Acceptance Body

Appendix B - Glossary of terms

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

Brake retarding force	The decelerating force applied to a vehicle by its brakes.
Buffer stop	A device used to stop the progress of rail vehicles at the end of sidings and other dead-end lines.*
Certificate of conformance for vehicle maintenance	A certificate issued by a VAB to confirm that the maintenance regime for a vehicle conforms to the relevant railway industry and railway group standards.
Certificate of engineering acceptance	A certificate issued by a VAB to confirm that a vehicle conforms to the relevant railway industry and railway group standards.
Chain	An imperial unit of length measurement that is equivalent to 22 yards (approximately 20 metres).
Coefficient of friction	The ratio of the force required to cause a body to slide along a plane (in the direction of sliding) to the normal force pressing the body and surface together.*
Controller of site safety (COSS)	A person who holds a safety critical qualification demonstrating his competence to arrange and implement a safe system of work. In this instance, his role was to protect staff working on the line from approaching trains.
Direct rail wheel brake	A braking system fitted to act directly on RRV rail wheels to provide both service and parking brake functions.
Down line (at this location)	The track on which the normal passage of trains is towards Glasgow Queen Street.
Engineering Supervisor	The person nominated to manage the safe execution of works within an engineering worksite. This includes arranging the marker boards, authorising movements of trains and RRVs in and out of the work site and managing access to the site by Controllers of Site Safety (COSS).
Flange	The extended portion of a rail wheel that provides it with directional guidance.*
High ride RRV	A road rail vehicle where the road wheels are not in contact with the ground, or with the rails, when used in rail mode.
Holding brake	A brake provided to prevent runaway during on-tracking and off-tracking of RRVs.
Improvement notice	A notice issued by ORR that requires the recipient to make improvements to safety within a defined period of time.
Machine controller	A person trained and authorised to control and supervise an item of on-track plant other than a rail crane.

Machine operator	A person trained and authorised to operate an item of on-track plant other than a rail crane.
Mobile elevating work platform (MEWP)	A machine with a lifting personnel carrying basket or platform, used for access at height. This type of MEWP is also known as a 'cherry picker'.
Off-track	To remove an RRV from the track, while changing from rail mode to road mode.
On-track	To place an RRV onto the track, while changing from road mode to rail mode.
Parking brake	A brake that is intended to prevent a stationary vehicle from moving.
Plant Operator Licence holder	Corporate entity licensed by Network Rail as capable to operate rail plant in engineering possessions.
Possession	The closure of a specific section of line to railway traffic to allow engineering work to take place on the infrastructure in accordance with module T3 of the rule book.
Prohibition notice	A notice issued by ORR that prohibits a work activity until remedial action is taken.
Pull test	A test of brake retarding force, carried out by measuring the force required to pull a vehicle through its applied brakes.
Rail industry standard	A document which defines technical standards, for use by the UK railway industry.
Rail mode	The condition when an RRV is operating on the railway.
Rail wheel brake	A brake that is applied directly to the rail wheels.
Road mode	The condition when an RRV is operating on the road.
Road rail access point (RRAP)	A location on the railway designed to allow an RRV to be driven onto the line and to change from road mode to rail mode.
Road rail vehicle (RRV)	A road vehicle that has been adapted to make it capable of running on railway track as well as on the road.
RSSB	A cross-industry organisation, formerly known as the Rail Safety and Standards Board, undertaking safety and standards related activities.
Service brake	A brake that is designed to stop a vehicle when it is moving.
Up line (at this location)	A track on which the normal direction of trains is away from Glasgow Queen Street.
Vehicle approvals certification process	The process by which a VAB, accredited by RSSB, assesses the compliance of vehicles and related maintenance procedures with rail industry standards and issues certificates of engineering acceptance.

Appendix C - Key standards current at the time

RIS-1530-PLT Issue 1 (Rail Safety and Standards Board – April 2006)
Superseded by Issue 2 in December 2009, Issue 3 in March 2011, Issue 4 in December 2012 , and Issue 5 in June 2014

Engineering Acceptance of Possession-only Rail Vehicles and Associated Equipment

Appendix D - Summary of Pull Test Results

The pull required to start to move the RRV through the rail wheel brake was measured using a calibrated load cell.

Recorded pull values have been adjusted to compensate for track gradient and angle of pull, to give a measure of rail wheel brake retarding force. Rolling resistance of the RRV has been ignored, as it was found to be very low (the weight of the pulling chain was sufficient to move the unbraked RRV).

Brake cylinder compression was measured during these tests, and further testing was carried out later to measure the related brake cylinder forces applied to the brake pads (figure 19). This was then used to calculate the coefficient of friction between the brake pads and the rail wheels (tables D1 and D2).

RRV involved in the accident

Brake cylinder spring compressions: LHS 4 mm, RHS 5 mm (± 0.5 mm)

Brake cylinder forces (measured by load cell): LHS 520 kg, RHS 805 kg (± 60 kg)

Test Number	Brake contamination	Brake retarding force	Coefficient of friction (calculated ± 0.03)	Likely value of coefficient of friction (± 0.04)
1	Rusty	280 kg	0.27	0.27
2	Rusty	280 kg	0.27	
3	Normal*	320 kg	0.31	0.30
4	Normal*	290 kg	0.28	
5	Normal*	300 kg	0.29	
6	Normal*	320 kg	0.31	
Post -accident recovery (held on 1 in 41 gradient)	Clean	>400 kg (by calculation)	>0.40	0.40

* The precise nature of the contamination varies between individual tests and varies dependent on the position of the pad on the rail wheel.

Table D1: Incident RRV test and analysis results

Similar RRV, in good condition

Brake cylinder spring compressions: LHS 9 mm, RHS 9 mm (± 0.5 mm)

Brake cylinder forces (interpolated from tests): LHS 1530 kg, RHS 1730 kg (± 80 kg)

Test Number	Brake contamination	Brake retarding force	Coefficient of friction (calculated ± 0.03)	Likely value of coefficient of friction (± 0.04)
1	Normal*	720 kg	0.28	0.28
2	Normal*	760 kg	0.29	
3	Normal*	720 kg	0.28	
4	Normal*	720 kg	0.28	
5	Normal*	720 kg	0.28	
6	Normal*	750 kg	0.29	

* See table D1

Table D2: Similar RRV test and analysis results

Accuracies

Pull test values (equivalent to brake retardation force) were recorded to the nearest 10 kg.

Brake cylinder positions, used to determine spring compression, were measured to ± 0.5 mm.

Brake cylinder force was measured using a load cell that was certified as accurate to at least ± 0.5 %. However, insertion of the load cell to measure the cylinder forces required the brake cylinder position to be adjusted to achieve the required spring compressions recorded during the pull tests. The compound effect of this is an accuracy of approximately ± 10 %.

The combination of the above accuracies makes the calculated coefficients of friction accurate to ± 0.03 . In addition to this, the coefficient of friction during testing was seen to have a variability of ± 0.01 , depending on the specific contamination on the rail wheel where the brake pad made contact. This gives a combined effect of ± 0.04 .

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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	