Australian Government
Australian Transport Safety Bureau

Office of Transport Safety Investigations

Runaway and derailment of loaded grain train 3966

Dombarton (12 km from Wollongong), New South Wales, on 15 December 2020

ATSB Transport Safety Report
Rail Occurrence Investigation (Defined)
RO-2020-022
Final – 24 January 2024

Cover photo: OTSI

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Addendum

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Safety summary

What happened

On Tuesday, 15 December 2020 at 0454, the crew of Qube loaded grain train 3966, consisting of 41 wagons and two CM class locomotives, reported a runaway on the descent of the Moss Vale to Unanderra rail line. The train reached speeds up to 100 km/h on a 30 km/h section of track before it derailed and separated at two points between Dombarton and Farmborough Heights, New South Wales (NSW). Shortly after, the train crew advised they had brought the two locomotives and the remaining two wagons to a stand at Farmborough Heights. The train crew were not physically injured.

What the ATSB found

The investigation identified that ineffective braking caused by several factors contributed to the runaway. The ineffective application of train braking systems was influenced by a heavily loaded train with some overloaded wagons, wagons with variable net brake ratio (NBR), reduced brake cylinder pressure through the train, and train handling and locomotive dynamic braking affected by low track adhesion conditions.

The weight of the train was near, but likely not over, the maximum allowable tonnage limit specified by the Australian Rail Track Corporation (ARTC)'s Train Operating Conditions (TOC) Waiver 16002. It was likely, however, that several individual wagons across the train consist were over the allowable limit for a single wagon.

Measurements of NBR at different times and on different wagons returned varying results ranging from 10.7% to 19.5%. The minimum required NBR for these wagons, specified by Australian Standards was 13%. While modifications were made to improve braking performance on the wagons, the NBR on some wagons continued to change over time. The wagon type test met the NBR requirement when introduced into service and met NBR requirements when tested post modifications, however there was no requirement for regular testing of NBR, which may have identified the changes in NBR.

The mix of wagons with variable NBRs and variability in loading likely reduced braking effort on some of the wagons during the steep descent along the rail line.

During the occurrence, the second automatic brake application made by the driver was made before the brake pipe had fully recharged. This resulted in a reduced amount of available brake cylinder pressure and lessened braking effort on the trailing wagons.

The driver's operation of the train and braking actions did not always conform to the operator (Qube)'s instructions, and it is likely some of the driver's decisions on the morning of the accident were affected by fatigue.

Once control was lost, the driver elected not to use the emergency brake because they believed, in accordance with Qube's procedures, that the locomotive braking would have been diminished. This in turn lessened the opportunity to regain control of the train.

Qube's operational procedure for train management between Moss Vale and Inner Harbour did not consider locomotive configurations that maintained locomotive dynamic braking during emergency applications. This increased the risk of train drivers not applying the emergency brake during a runaway event. This assumption was also found to be embedded within other rolling stock operators' procedures with similarly configured locomotives in NSW.

The conditions on the rail line from Summit Tank to Farmborough Heights on the morning of the incident included wet rail and track contaminant that likely contributed to low track adhesion and also reduced dynamic braking effort by the locomotives. The wheel slip/slide protection system worked as designed to maximise traction through the use of auto sanding to increase friction and derated the dynamic braking effort through the wheels to match the lower adhesion conditions.

Several rail flange lubricators, which provided lubrication to the down and up rail, were less than the 500 m minimum separation requirement specified in ARTC's engineering practices manual RC2411. A review of these to ensure consistency with the engineering practice and to minimise the risk of excess track lubrication on a steep gradient was warranted.

Finally, the brake pipe charging flow indicator on CM class locomotives only provided a numerical display without any corresponding audio or visual warning system to alert the driver of its status. This limited the ability of the driver to detect derailment or train separation events and, as in this incident, effectively monitor recharge of main reservoir air into the brake pipe to ensure it was fully charged before making another brake application.

What has been done as a result

During the investigation, a Safety Advisory Notice was issued by the Office of Transport Safety Investigations (OTSI) in collaboration with the ATSB to the rail industry to raise awareness of variable locomotive braking system configurations on locomotives across Australia. Qube and other affected rollingstock operators took immediate actions to review their locomotive configurations, to ensure their locomotive drivers had a clear understanding of the braking systems on the locomotives they were operating.

A forum was chaired by the Office of the National Rail Safety Regulator (ONRSR) in March 2023 with Rail Infrastructure Managers (RIMs) and Rollingstock Operators (RSOs) that operated on the Moss Vale to Unanderra rail line. This provided an opportunity to discuss and communicate the risks of operating on the rail line and how to manage them to mitigate runaway events.

The two RIMs, Sydney Trains and ARTC conducted a review and alignment of Transport for NSW (TfNSW) TOC Manual Illawarra operations and the ARTC Route Access Standard - Section Page D52 Moss Vale - Unanderra. The focus of the review was on providing interoperable train configuration and operating conditions between the two RIM interfaces. Additionally, conditions for managing degraded dynamic brakes and hauling dead attached locomotives were developed. All changes were held in consultation with RSOs, ARTC operations and Network Control stakeholders.

In consultation with TfNSW, ARTC developed joint assessment criterion for Unanderra Trial train configurations, operating conditions, and implementation plans. The RSO will be required to submit supporting documentation as part of a variation to existing approved train configurations.

ARTC has updated NBRs for vehicle classes following physical testing and has worked with others in the rail industry to promote NBR testing as part of preventive maintenance.

Safety message

The rail line between Summit Tank and Unanderra is one of the steepest sections of rail line in NSW. To prevent runaway occurrences on this rail line, operators must regularly review the effectiveness of their risk controls and proactively manage conditions that present greater risk of runaway.

RSOs should ensure their trains have sufficient braking, are loaded within safe load limits and are operated in accordance with their procedures.

RSOs and RIMs should ensure that risk assessments identify critical operational requirements to safely run trains down such steep sections of track. They should also ensure that there is sufficient error tolerance to enable control of trains on sections of rail line that present increased risks from long and steep descents.

RSOs should review the locomotive specifications and test those locomotives under their control to understand how the braking systems are configured and the associated error tolerance. RSOs must communicate this information through their organisation's procedures and training material to ensure train crew have knowledge of and competence in operating locomotive braking systems, including emergency braking in the event of a runaway.

The use of two-pipe wagon braking systems significantly reduces the recharge times for the brake pipe after a brake application, but the starting air pressure of a wagon's auxiliary reservoir remains a critical consideration. For example, low auxiliary reservoir starting pressure at the beginning of an automatic brake application reduces the response of a wagon's supplementary reservoir, resulting in lower wagon brake cylinder pressure and therefore less effective braking effort.

Finally, while a 'full service' automatic brake application typically provides the maximum pneumatic braking force available on a train, in the unique circumstance of a train with low auxiliary reservoir starting pressure, lowering the brake pipe pressure further through the application of the emergency brake, will result in an increase in the available braking force. However, this increased braking force will remain less than that which would have been available in full service had the auxiliary reservoir been fully charged at the time of the brake application.

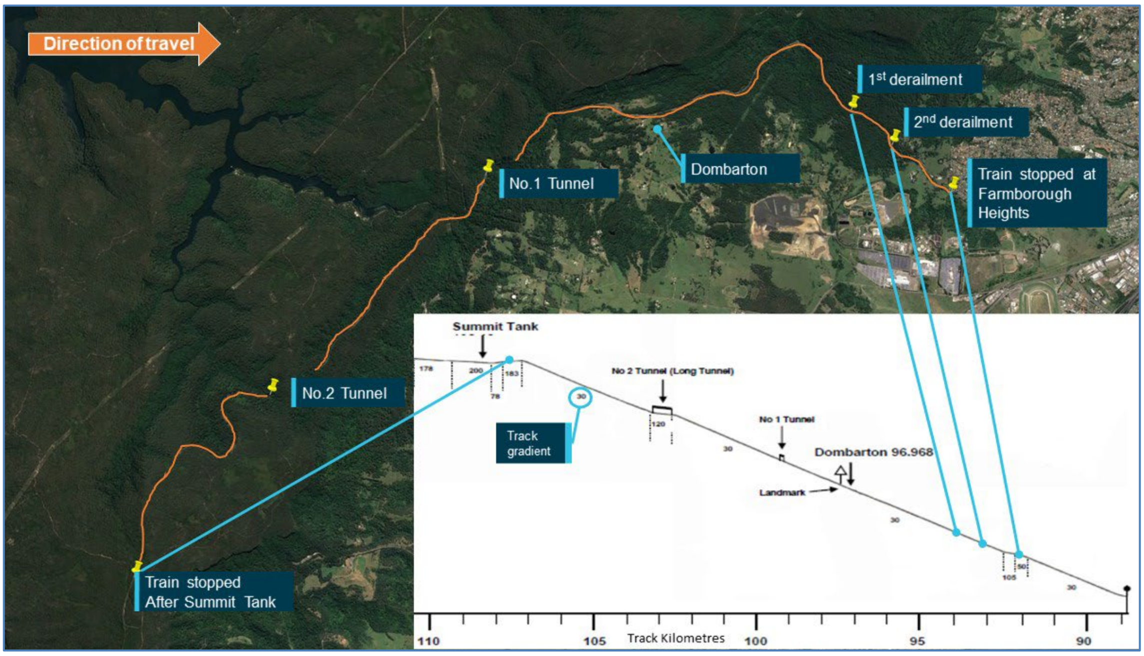
Contents

The occurrence

Overview

On 14 December 2020, at approximately 1815 Eastern Standard Time (EST),[1] Qube loaded grain train 3966 departed Temora, New South Wales (NSW) bound for Inner Harbour Port Kembla, NSW. The train travelled through the night and in the early hours of 15 December 2020 commenced the descent on the Moss Vale to Unanderra rail line. Between Summit Tank and Farmborough Heights, the train ran away,[2] derailed and separated at two locations. The 29th to 41st wagons derailed and separated at approximately 93.730 km from Sydney's Central Station. Then the 3rd to the 28th wagons derailed and separated at approximately 93.220 km, before the locomotives and two remaining wagons came to a stop at Farmborough Heights (Figure 1).

Figure 1: Section of Moss Vale to Unanderra rail line between Summit Tank and Farmborough Heights



This image shows where the train stopped prior to descending the mountain, the points of derailment and where the train stopped. The inset is the track gradient diagram with corresponding stop points and derailments.
Source: Google Earth and QUBE, annotated by OTSI

Start of shift

On 14 December 2020, the train crew, consisting of a driver and driver's assistant, signed on at 2000 at the Junee depot for an 11-hour shift. They were scheduled to start at 1430 but were laid back[3] to 2000. They travelled to Cootamundra and relieved the train crew on service 3966 at approximately 2110. They were rostered to work the train from Cootamundra to Port Kembla. The driver operated the train, for the near seven-hour journey, reporting at interview that the journey was uneventful with the train operating predictably to the start of the descent at Summit Tank.

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1 EST: Coordinated Universal Time (UTC) + 10 hours.

2 A runaway train includes unintended rolling stock movement and instances of loss of control of a train.

3 Train crew can have their start time changed to suit operational needs, to be 'laid back' is to start at a later time from rostered start time.

Start of the descent (~107.5 km)

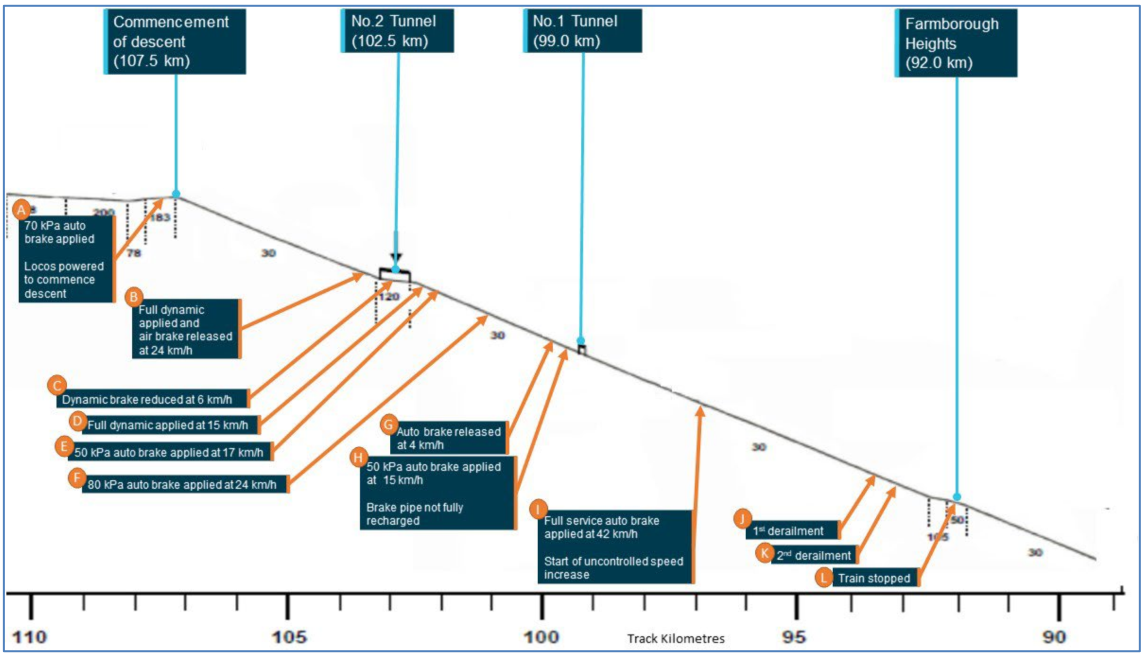
On 15 December 2020, at approximately 0415, the driver made an automatic brake[4] application (about 70 kPa reduction) and brought train 3966 to a stop at the level crossing just after Summit Tank (see A in Figure 2), as required by Qube's operational procedure. Once stopped, the driver applied the independent brake.[5]

After a stop of approximately four minutes, the driver released the independent brake and with the automatic (train) brake still applied, powered the locomotives to commence movement against the still applied train brakes.

This stop and start process conducted by the driver at Summit Tank differed to Qube's operational procedure, which stated that the train should be stopped using a 100 kPa brake pipe reduction (refer to *Brake release rollaway time test* for further information).

The driver then maintained the automatic brake at a 70 kPa brake pipe reduction and graduated the dynamic brake[6] to manage the speed of the train. This form of brake management was known as 'balanced braking'.[7] The driver descended the rail line between Summit Tank and the No.2 Tunnel using this method of braking control.

Figure 2: Sequence of events



This image shows the sequence of events leading up to the loss of control and derailments.

Source: QUBE, annotated by OTSI

No.2 Tunnel (~102.5.0 km) to No.1 Tunnel (~99.0 km)

At 0436 the train entered No.2 Tunnel travelling at 24 km/h. The driver applied full dynamic brake and released the automatic brake (see B in Figure 2).

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4 The automatic brake is used as the main mechanism for slowing and stopping the train (both locomotive/s and wagons) full details are provided in *Train Braking System*.

5 The independent brake is the air actuated friction braking mechanism on the locomotives only. See *Independent brake*.

6 The dynamic brake is a braking mechanism of the locomotives only. It is supplementary and designed to reduce the wear and heat generated by the friction braking mechanisms. Refer to *Dynamic brake.*

7 Balanced braking is a method of train speed control where an automatic brake application is maintained, while the dynamic brake is manipulated to control speed.

Releasing the automatic brake allowed the brake pipe to fully recharge[8] after about 50 seconds. The train slowed to approximately 6 km/h at this time (see C in Figure 2).

The driver then reduced the dynamic brake. Over the next minute, the train speed increased to about 15 km/h.

The driver applied the dynamic brake in full again (see D in Figure 2), then approximately 30 seconds later, with the train travelling at 17 km/h, the driver made a 'minimum service'[9] automatic brake application (see E in Figure 2).

The train continued to increase speed over the next 30 seconds, with auto sanding[10] occurring three times as the train approached 18 km/h. The train then started to slow slightly over the next 45 seconds and auto sanding occurred another three times.

Over the next 2.5 minutes, without any further input from the driver, the train began to increase speed again. Auto sanding occurred 12 times, as the train speed reached 24 km/h. The driver increased the automatic brake application to about an 80 kPa brake pipe pressure reduction and the train started to slow (see F in Figure 2).

The frequent auto sanding on the descent from Summit Tank, in misty and wet weather conditions, indicated the locomotives' wheel slip/slide protection systems were working as designed to maintain dynamic braking under the adhesion conditions. The driver stated at interview that there were no wheel slip indications received on the locomotive to indicate reduced wheel-rail adhesion, and so they felt the dynamic brake was working effectively.[11]

The train speed reduced over the next 2.5 minutes to about 16 km/h, and auto sanding occurred 11 times. With the dynamic brake fully applied and the auto brake at 80 kPa reduction, the train speed continued to decrease over the next 2.25 minutes to 4 km/h, during which auto sanding occurred another four times (see G in Figure 2).

As the train slowed, the driver released the automatic brake and maintained the dynamic brake in full applied mode. The driver then managed the train speed using serial/cycling braking,[12] as per Qube work instruction WI-540 *(Moss Vale to Inner Harbour Train Management*). The braking instruction stated that if train speed could not be managed using a 75 kPa reduction and altering the dynamic braking to maintain speed, then the serial/cycle braking method must be used.

At 0448, at about 99.673 km,[13] with the train travelling at 15 km/h, the driver applied a minimum service brake application (see H in Figure 2). The automatic brake handle had been in the release position and charging for 43 seconds since the brakes were last applied.

Although the brake pipe pressure at the locomotive had, by this stage, recharged to 489 kPa on the cab gauge, the brake pipe charging flow indicator was still registering an air flow of 934 litres per minute. This meant that the brake pipe had not yet fully recharged throughout the length of the train (refer to *Brake pipe charging flow indicator* for further information). In interview, the driver recalled observing the flow meter indicating air flow of 934 litres per minute and judged the train brake pipe to be charged to about 90–95%.

The minimum reduction in brake pipe pressure did not appear to slow the train as the speed increased to 21 km/h over the following 14 seconds. The driver reduced the brake pipe by a

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8 A fully recharged brake pipe has approximately 500 kPa.

9 A minimum service brake application is a reduction of the brake pipe by 50 kPa to 450 kPa.

10 Sanding is the release of sand from the locomotive onto the head of the rail in front of the drive wheels. It improves traction at the interface of wheel and rail head. Auto sanding is the automatic release of sand when the system detects the wheel creep (micro slip or slide) at the interface with the rail.

11 Where the wheel slip/slide was manageable by the locomotive systems, automatic sanding would occur without an indication to the driver.

12 Serial/cycling braking is a method of train speed control where the dynamic brake is fully applied and the application and release of the automatic brake controls the speed.

13 Distances measured from Central Station, Sydney (0.000 km).

further 14 kPa (425 kPa) but the speed continued to increase. The dynamic brake remained in the fully applied position and auto sanding was triggered regularly.

As the train's speed reached the track section speed limit of 30 km/h, the driver reduced the brake pipe pressure by a further 7 kPa (418 kPa) and the train entered No.1 Tunnel.

No.1 Tunnel (~99.0) to Farmborough Heights (~92.0)

In interview the driver indicated that it was at this point they felt the train was behaving 'unpredictably', compared to its responsiveness to the two previous brake applications between Summit Tank and No.1 tunnel.

While in No.1 tunnel, the driver increased the automatic brake application, reducing the brake pipe pressure by a further 14 kPa (404 kPa). The train's speed continued to increase to 32 km/h, just over the track speed limit of 30 km/h. The train passed through the tunnel and auto sanding was triggered eight times.

At 0450, at about 98.5 km, the driver increased the brake application again, reducing the brake pipe by another 7 kPa (397 kPa). The train was travelling at 34 km/h when the driver commented to the driver's assistant, 'I'm on the edge'. Auto sanding occurred two times.

Thirty seconds later, the driver increased the brake application. This reduced the brake pipe pressure by another 7 kPa, to 390 kPa. The train speed remained 34 km/h. Auto sanding occurred three times.

At this time, the head of the train was at about 98.2 km, entering a relatively straight section of track. The rear of the train was still passing through a series of 200 m curve radius left and right-hand turns.

At about 98.0 km, the driver made another brake application (383 kPa). The train remained at 34 km/h.

As the head of the train reached 97.5 km, the speed increased from 34 km/h to 37 km/h over a 20 second period. At this point, the locomotives entered a 200m right hand curve with the full length of the trailing load on straight track behind it. This would have resulted in reduced dynamic locomotive braking and zero curve resistance on the wagons, which likely contributed to the acceleration. Although the driver made a further brake application (376 kPa), the train continued to increase speed over the next 15 seconds.

At 0453, at about 97.1 km, with the train speed at 42 km/h, the driver applied the automatic brake to 'full service'[14] (see I in Figure 2). The train continued to increase speed up to 45 km/h over the next 20 seconds. The driver was heard on the in-cab recorder to say, 'we're not going to stop', and then contacted Network Control. Over the next 90 seconds the speed increased to over 60 km/h.

The driver said to Network Control, 'Can you guarantee me the road there at Unanderra, I'm having trouble stopping this train'. The network controller called Wollongong Panel and requested the rail line to be cleared at Unanderra and Wollongong Panel confirmed it would be done.

At 0455, the network controller called the driver of 3966 and confirmed the scale of the emergency. The driver said, '…I'm doing about 70 [km/h] and I've got it in full service, I don't want to put it in emergency[15] because I'll drop my dyno [dynamic brake] out.' The network controller said, 'so fairly dire then is it?'. The driver replied, 'yeah I'm doing about 80 [km/h] now'.

[14] A 'full service' automatic brake application reduces the brake pipe pressure to 350kPa.

[15] An emergency automatic brake application reduces the brake pipe pressure to 0 kPa. Refer to *Automatic brake* for further information.

The network controller kept the driver on the line while they called Wollongong Panel to confirm that the rail line was clear at Unanderra. Wollongong Panel confirmed it was, then the network controller asked the driver for an update. There was no response from the driver.

At 0456, the driver fully applied the independent brake with no apparent effect on reducing the speed of the train. The train was travelling at about 85 km/h, at track position 94.159 km. At this time wheel slide was recorded on the locomotives.

Seconds later, as the train passed the Dombarton distant signal WG1042U at 93.810 km, it went into a left-hand 200 m radius curve in the direction of travel, reaching a peak speed of about 100 km/h. The train was 70 km/h over the track speed limit of 30km/h. At this time, the 29th wagon and trailing wagons derailed and separated from the front part of the train (see J in Figure 2).

At 0457, with the front of the train at 93.100 km and travelling at about 98 km/h, the 3rd wagon up to the 28th wagon derailed and separated from the front part of the train. The train was on a right-hand 200 m radius curve in the direction of travel (see K in Figure 2).

The train had started to slow after the first separation and at 0458, the two locomotives and remaining two wagons came to a stop at 92.040 km (see L in Figure 2).

As the train came to a stop, the driver advised Network Control 'I'm at Farmborough Heights and all of a sudden it decided to grab [train started to slow]'.

Post occurrence

With the train immobile, the driver's assistant stepped off the lead locomotive to check the rest of the train and secure it. They reported back to the driver, via radio, that there were only two wagons attached to the two locomotives.

The driver conveyed this information to Network Control and the Qube Control Centre shortly after.

Recovery teams and emergency services were arranged to attend the site. Inspection of the rail track and rolling stock commenced at approximately 0700 and at 1140 recovery operations commenced.

The locomotives and two attached wagons were inspected by Qube and Chicago Freight Car Leasing Australia (CFLCA, the owner) before being transferred to Port Kembla.

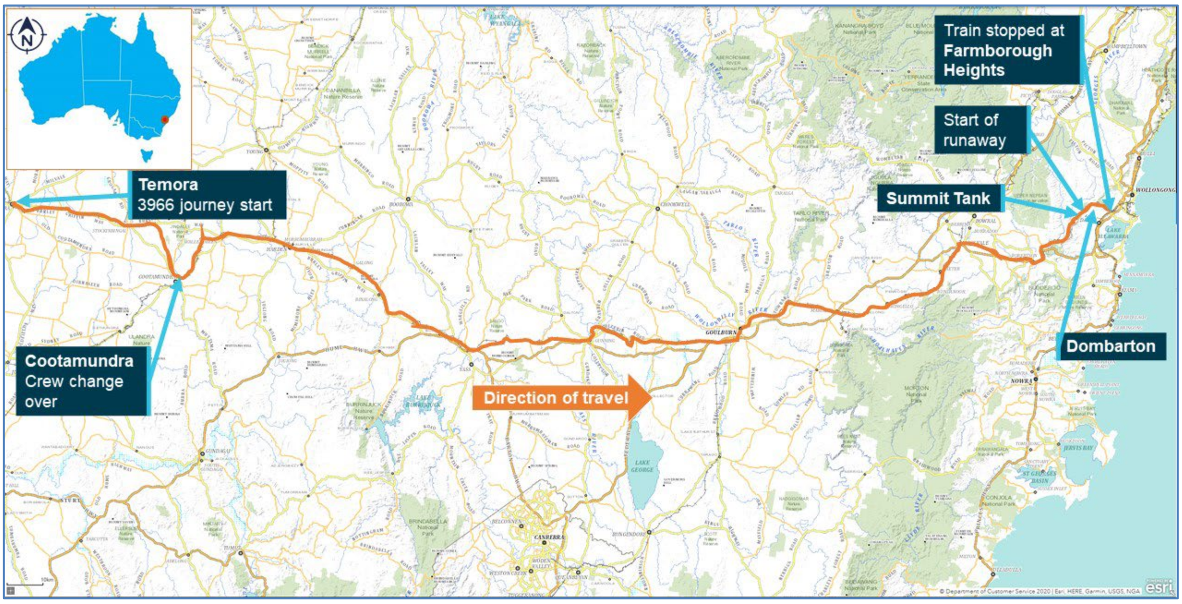
At Port Kembla, the wagons were emptied, and grain weighed to confirm the weight of the remaining two wagons. The tonnage in the wagons was within load limits.

Context

Incident Location

The runaway and derailment occurred between Summit Tank and Farmborough Heights on the Moss Vale to Unanderra rail line, near Dombarton, New South Wales (NSW). Dombarton is on the Illawarra Escarpment approximately 97 rail km south of Sydney Central Station. The train journey started in Temora and the train crew took control of the train at Jindalee (Cootamundra) (Figure 3).

Figure 3: Path of 3966



The orange line represents the rail route of 3966 from Temora to where it stopped at Farmborough Heights. Other key locations are identified.
Source: Google Maps, annotated by OTSI

Moss Vale to Unanderra rail line

The Moss Vale to Unanderra rail line is a 57 km section of track connecting the Main South rail line with the Illawarra rail line. The 20 kilometres of track between Summit Tank and Unanderra traverses down the Illawarra escarpment through multiple curves varying in radius between 185 m and 2020 m, transitions and straights. The grade[16] is primarily 1 in 30, other than small sections through No.2 tunnel and Farmborough Heights where the grades are 1 in 120 and 1 in 105 respectively (Figure 1). It is a single-track rail line at Summit Tank, mostly tree lined (Figure 4) and passes through two tunnels and a Rock Fall Shelter before reaching Dombarton where the rail line becomes double-track.

[16] 1 in 30 grade means that for every 30 metres of distance travelled, the track descends 1 metre. This grade can also be referred to as a percentage which for 1 in 30 the grade is 3.33%

Figure 4: Front of train footage of track

Taken from 3966 front of train camera between 104.000 km and prior to entering No.2 tunnel. Tree foliage lines the track.
Source: Qube

The rail line then remains double-track winding through more tree lined areas before reaching Farmborough Heights. At this location, the grade eases to 1 in 105 then changes back to 1 in 30 grade, winding down through more tree lined areas to Unanderra (see Figure 1 inset for track gradient).

Weather information

There were two Bureau of Meteorology weather stations in proximity to the occurrence: Moss Vale in the Southern Highlands, located at the top of the Illawarra escarpment, and Albion Park in the Illawarra region, located close to the bottom of the escarpment. The site of the incident was between these two locations.

The weather pattern recorded at both weather stations was similar. Recorded weather data logged light rain and moderate winds on the Moss Vale to Unanderra rail line (Table 1). In interview, the driver recalled the weather conditions on departure from Summit Tank to be that of 'very misty rain'. The data logger also indicated the windscreen wipers of locomotive 3316 were activated between Tunnel 2 and Tunnel 1.

Table 1: Weather recorded at Moss Vale and Albion Park

Place/Date	Temperature	Rainfall	Winds
Moss Vale/14 Dec 20	13.4 – 19.1	2.6 mm	ENE up to 41 km/h
Moss Vale/15 Dec 20	14.6 – 23.6	4.4 mm	NE up to 39 km/h
Albion Park/14 Dec 20	16.8 – 24.3	4.0 mm	NE up to 30 km/h
Albion Park/15 Dec 20	18.6 – 25.3	3.2 mm	NE up to 33 km/h

Source: Bureau of Meteorology

Rail Transport Operators

Qube Holdings

Qube Holdings was a logistics and infrastructure company that provides import and export logistics services across Australia. Its rail logistics division, Qube Logistics (Rail) Pty Ltd (Qube), was accredited by the Office of the National Rail Safety Regulator (ONRSR) as a Rail Infrastructure Manager (RIM) and Rollingstock Operator (RSO) on the 20 January 2013, in the states of NSW, South Australia, Victoria, Western Australia and Queensland.

Qube was the RSO responsible for the operation of grain train 3966.

CFCL Australia Pty Ltd

Chicago Freight Car leasing Australia (CFCLA) was the owner and lessor of the locomotives and wagons. They were accredited as a RSO by ONRSR on 20 January 2013 and were primarily a locomotive and rollingstock leasing company providing assets to other RSOs in the Australian rail industry.

In January 2020, CFCLA was acquired by Anchorage Capital Partners and the company was rebranded as Rail First Asset Management in 2021.

Australian Rail Track Corporation

The Australian Rail Track Corporation (ARTC) manages and maintains approximately 8500 km of rail network across five states in Australia.

In NSW, ARTC leases the mainline interstate corridors from the NSW Government (Figure 5). ARTC is responsible for managing and maintaining these rail corridors in accordance with their accredited system standards.

Figure 5: ARTC leased rail network from NSW Government

Dark lines are the corridors managed and maintained by ARTC. The route of 3966 was between Cootamundra and PT (Port) Kembla
Source: ARTC

ARTC was accredited by ONRSR as a RIM and RSO on 20 January 2013 in the states of South Australia, New South Wales, Victoria, Western Australia and Queensland.

ARTC was the RIM responsible for the management and maintenance of the section of track between Summit Tank and Farmborough Heights on the rail line between Moss Vale and Unanderra. Slightly further down the rail line from Farmborough Heights, at 91.080 km, is the interface between ARTC and Sydney Trains rail networks. Above rail operators that use the Moss Vale to Unanderra rail line are required to operate their trains in accordance with the train operating conditions[17] of both RIMs.

Train Crew

The train crew consisted of a driver and driver's assistant. Both were employed by Qube.

Driver

The driver started working for Qube in September 2012. They were qualified as a locomotive driver for 23 years.

[17] The train operating conditions are detailed in the infrastructure manager's TOC Manuals and Waivers.

Before working with Qube, the driver had operated train services on the Moss Vale to Unanderra rail line with another freight operator.

The driver was assessed and deemed competent to operate services on the Moss Vale to Unanderra line by Qube. The driver operated five other services on that line in the week prior to the incident train service on the 15 December 2020.

During post incident interview with the driver, they said (of the incident train, 3966) they had taken a mental note of the train weight and got a feel for the train as they operated the train from Cootamundra, but did not calculate the train's tonnes per operated brake (TOB) as required in their procedure.

The driver's sleep-wake activity in the days prior to the incident was also established (Table 2). The previous train service operated by the driver was an empty grain service from Port Kembla to Cootamundra that departed at 1315 on 13 December 2020. The driver completed this shift at approximately 0100 on 14 December 2020.

At interview, the driver indicated that they were not feeling fatigued at the time of the incident.

The front of train recordings also captured the time when the train passes Robertson station, near the start of the descent of the Illawarra Mountain. The driver was heard yawning, and shortly after the driver's assistant starts a discussion about the use of 'No Doz'[18] to keep you awake. The driver indicated they were not aware of the tablets.

Qube calculated the driver's FAID[19] score at the time of the incident to be 82.99. Scores between 80 to 100 represented high fatigue likelihood.

Table 2: Driver sleep-wake diary

Sleep/Wake Diary	
F	Food
S	Stimulant (Caffiene, Nicotine)
M	Medications or other medicine
A	Alcohol
E	Exercise
X	Go to Bed
SW	Start Work
FW	Finish Work
	Sleep/Nap
	Times you were awake

Day/Date	Work/Off	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Thursday, 10 December 2020	Work										FW								SW						
Friday, 11 December 2020	Off					FW							FC								F				
Saturday, 12 December 2020	Work													F					SW	F					
Sunday, 13 December 2020	Work							FW						FC		SW									
Monday, 14 December 2020	Work	FW											FC									SW	C		
Tuesday, 15 December 2020	Work			F			4:54																		

This is the driver's account of fatigue related factors and activities in the week leading up to the incident. Actual work hours from Qube
Source: OTSI

According to Qube training records, the driver had current qualifications required to operate train services on the Moss Vale to Unanderra rail line. The relevant qualifications included:

- Level 5 – Driver Trainer[20]
- Driver competency against Work Instruction WI-540 (*Train Management Moss Vale to Inner Harbour* [Port Kembla]) was assessed as part of FM-781 (*Train Driver Route*

18 No-Doz is a caffeine tablet readily available at pharmacies and supermarkets that is marketed to help relieve mental fatigue and drowsiness.

19 The Fatigue Audit InterDyne (FAID) is a computerised bio-mathematical model, developed by Interdynamics Pty Ltd. The score is the University of South Australia's Centre for Sleep Research Fatigue Management Index (FMI). The FMI is a measure of fatigue risk arising from reduced sleep opportunity expected to be induced by working a particular pattern of work. This score is primarily used in industry to assist rostering. It does not calculate actual impairment.

20 This competency was developed by Qube for their trainers of train drivers.

Assessment Checklist). It was conducted on 28 and 29 November 2020. Competency was current.

- Rail Safety Worker medical last completed 28 July 2017, valid until 28 July 2022
- FM-780 (*Train Operations Performance Checklist*) last completed 11 February 2020, valid until 11 February 2023, and
- Qualified in CM locomotive operations on 11 April 2014 and competency was current.

Driver's Assistant

The Driver's Assistant started working for Qube in September 2020. They were qualified as a driver's assistant and had no previous rail experience, prior to working for Qube.

According to Qube training records, the driver's assistant had current qualifications required to assist train services on the Moss Vale to Unanderra rail line. Their relevant qualifications included:

- Level 2 – Second Person[21]
- Deemed competent to operate as an assistant under work instruction WI-540 (*Train Management Moss Vale to Inner Harbour* [Port Kembla], sign-off dated 9 October 2020 on Acknowledgement of Safety Critical Documents pro-forma. Competency was current, and
- Rail Safety Worker medical last completed 7 September 2020, valid until 7 September 2025.

Post incident interviews with the driver's assistant established their sleep-wake activity in the days prior to the incident (see Table 3).

Qube calculated the driver's assistant FAID score at the time of the incident to be 79.41.

Table 3: Driver's Assistant sleep-wake diary

Sleep/Wake Diary	
F	Food
S	Stimulant (Caffiene, Nicotine)
M	Medications or other medicine
A	Alcohol
E	Exercise
X	Go to Bed
SW	Start Work
FW	Finish Work
	Sleep/Nap
	Times you were awake

Day/Date	Work/Off	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Thursday, 10 December 2020	Off																								
Friday, 11 December 2020	Work												SW										FW		
Saturday, 12 December 2020	Work													F					SW		F				
Sunday, 13 December 2020	Work					F		FW							SW		F							F	
Monday, 14 December 2020	Work	FW														F				F	C	SW	F		
Tuesday, 15 December 2020	Work						4:54																		

This is the driver's assistant's account of fatigue related factors and activities in the week leading up to the incident. Actual work hours from Qube.
Source: OTSI

Observation

The train crew was working within the special fatigue management program requirements of the Rail Safety National Law National Regulations 2012. However, in high risk operations where train crew are required to descend long steep gradients, an operator's fatigue management program should consider the additional demand this places on train drivers.

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[21] This competency was developed by Qube for their driver's assistants.

Prior train services

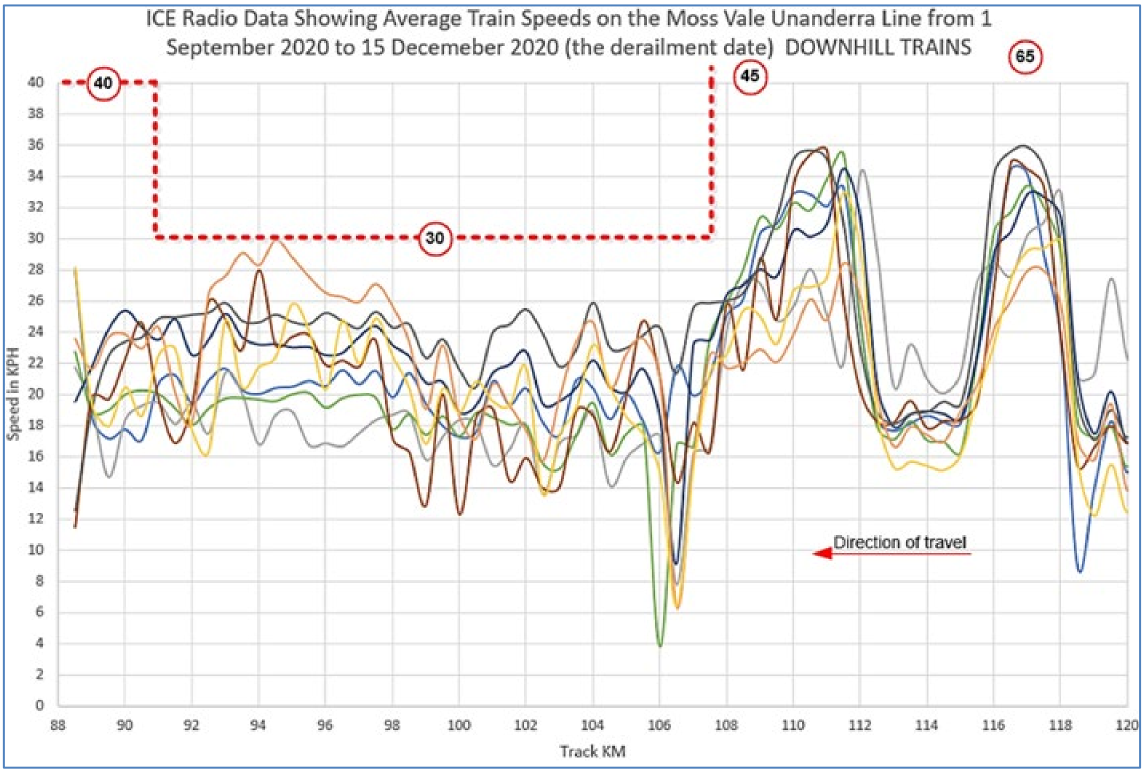
ARTC provided information from ICE train radio[22] data to establish the volume of rail traffic that had descended the Moss Vale to Unanderra rail line in the months leading up to the incident. The data set included the average train speed of all train operators travelling in the Up direction (downhill) between Summit Tank and Unanderra.

Between 1 September 2020 and 15 December 2020 there were 412 services. Each coloured line on Figure 6 represents an RSO and the average speed of their combined services.

ARTC also noted that there had not been any reports of Condition Affecting the Network (CAN)[23] from the drivers of these services specifically related to lack of adhesion. Further, there had not been any reports of CANs from services travelling in the down direction (Uphill) related to lack of adhesion or loss of traction.

Generally, a train travelling up a hill requires a higher coefficient of friction at the wheel rail interface for the wheels to maintain traction (before the wheels start to slip). The same train, coming down the same hill can maintain adhesion (before the wheels start to slide) at a lower coefficient of friction.

Figure 6: Average train speed all RSOs 1 September 2020 to 15 December 2020



Each coloured line represents a RSO and the average speed of all their train services that travelled down the mountain. The red dotted line indicates the speed limit in that section of track.
Source: ARTC

[22] ICE (In-cab Communications Equipment) train radio is the digital train radio system used on the ARTC network.

[23] A Condition Affecting the Network is any condition that can or do affect the safety of rail operations in the rail network, they *must* be reported promptly to the Network Control Officer responsible for the affected portions of track.

Track inspection and measurements

Transport safety investigators inspected the track on the day of the incident. The track area inspected extended from the stop point of the two locomotives and two wagons (approximately 92.000 km) up to 600 m prior to the first derailment site (approximately 94.300 km).

Observations of the track leading up to the first derailment site and the second derailment site were documented and photographs taken (Figures 7, 8 and 9). Initial assessment of the track condition was noted as not having any obvious defects that could be expected to increase the risk of derailment. Track measurements were taken by ARTC post incident. Superelevation[24] measurements were compared against design superelevation and short twist and long twist[25] were calculated.

The track leading up to the first derailment site, 93.810 km to 93.714 km was measured. ARTC had identified a point of first derailment at 93.710 km. The results of the track measurements at this location showed no exceedances of short or long twist.

Figure 7: Rail line leading to first derailment site

Facing Up direction (towards Unanderra and down the mountain)
Source: OTSI

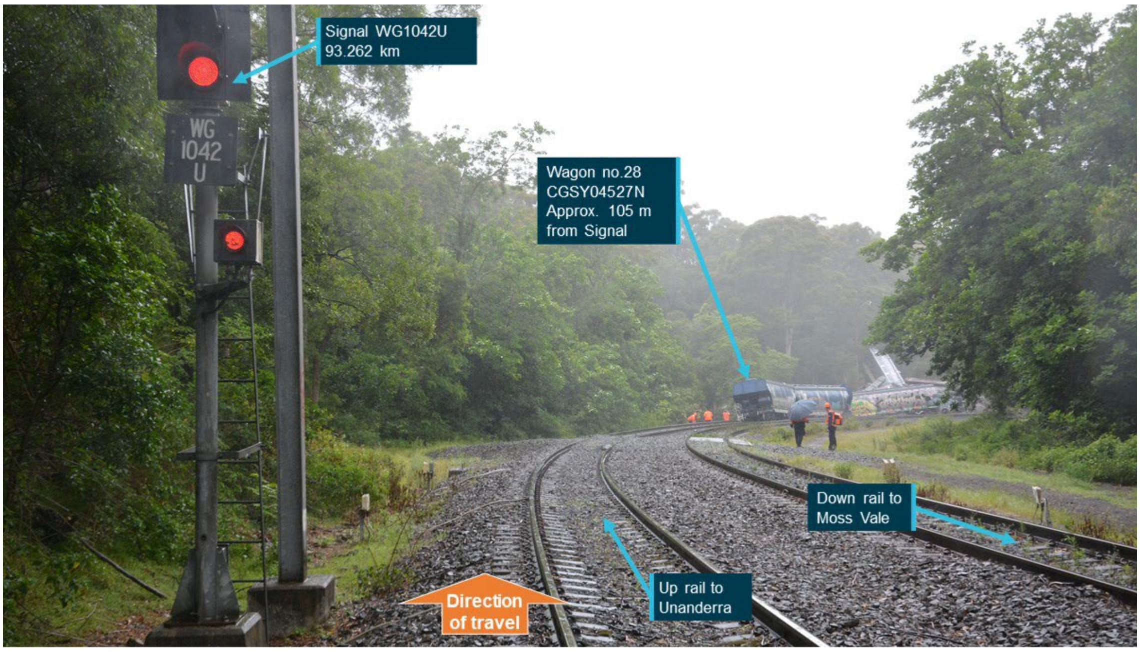
[24] Superelevation is the vertical distance between the inside and outside rails, typically measured in millimetres. Excessive difference between actual and design superelevation is one of many factors that can increase likelihood of derailment.

[25] Twist is the difference in level between the two rails, measured over a defined length. Short Twist – 2 metres, Long Twist – 14 metres. Twist can affect wheel-load and vehicle dynamics and is one of many factors that can increase likelihood of derailment.

Figure 8: Rail line between first derailment site and Signal WG1042U

Facing Down direction (towards Moss Vale and up the mountain)
Source: OTSI

Figure 9: Signal WG1042U to second derailment site



Facing Up direction (towards Unanderra and down the mountain)
Source: OTSI

Qube also contracted an engineering group to inspect the track post incident, who identified evidence of a derailment point, for the second derailment, at 93.220 km. However, the associated wagon and wheelset that made the markings could not be conclusively determined.

ARTC also took measurements of the rail track before and after the second derailment site. There were no exceedances of short or long twist found.

A contaminant was observed on the head of the rail lines across the area of track that was inspected. The contamination was more prominent in areas with more tree foliage. There was evidence of wheels rolling over and skidding through the contaminant at 94.000 km (Figure 10 and Figure 11).

Figure 10: Track contaminant at 94.000 km

Figure 11: Close up of track contaminant at 94.000 km

Pictures of the contaminant in Figures 10 and 11 were taken approximately 300 m prior to the first derailment, evidence of wheels rolling over and skidding through the contaminant
Source: OTSI

Investigators collected a sample of the track contaminant from the rail head, near the site of the second derailment (93.150 km), for testing at the ATSB laboratories.

The ATSB testing indicated the substance was leaf matter. There appeared to be a secondary substance which was described as balled up and highly compressed (dark and greasy) in appearance which was probably from the leaves but could not be ruled out as coming from another source.

Track maintenance

The preceding six months' maintenance history for the Unanderra to Moss Vale rail line was reviewed. ARTC had undertaken inspections of the running line between 91.080 km (the ARTC rail network boundary with Sydney Trains Rail Network) and 150.600 km (Moss Vale Junction).

Inspections undertaken included track geometry, rail wear, front of train inspection, rail lubrication and rail lubrication devices.

The frequency of these inspections was specified in ETE-00-03 (*Civil Technical Maintenance Plan (CTMP)*) and ARTC records indicated these inspections had been completed as required.

However, the requested maintenance history records did not account for a rail lubrication device located at 97.030 km (Figure 12). This lubricator was located close to the Landmark and Dombarton (Figure 1 inset).

Following draft report feedback, ARTC produced a listing of all rail flange lubricators which included a rail flange lubricator at 97.030 km. ARTC also stated that this rail flange lubricator serviced trains travelling on the down (uphill) (Figure 12). No additional maintenance records were provided with the revised list.

Figure 12: Rail flange lubrication device at 97.030 km and grease plume

Facing Up direction (towards Unanderra and down the mountain) device (left) and close up (right), this section of track was bi-directional
Source: Qube

General inspection of rail flange lubrication over this section of the rail line was last conducted between 96.893 km and 150.600 km on 14 June 2020, approximately six months prior to the incident.

The inspection intervals for rail flange lubricators were specified as once every 365 days. All rail flange lubrication devices listed in the maintenance records provided, from the ARTC boundary to Moss Vale Junction were inspected and deemed compliant on 30 August 2020, approximately 3.5 months prior to the incident.

The closest rail flange lubrication device to the one located at 97.030 km to have had a recorded general inspection was at 95.580 km on 30 August 2020.

Track Standards

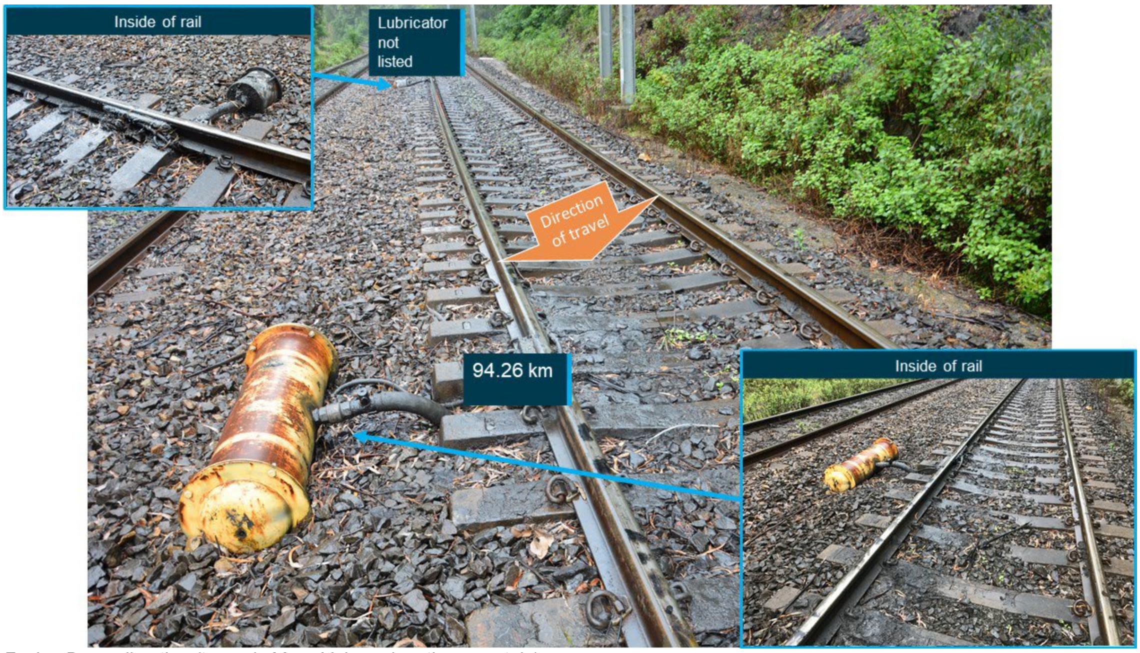
ARTC's Engineering Practices Manual, Civil Engineering, RC 2411 *(Guidelines for Trackside Lubrication)* stated on page 4:

> Under very severe grade conditions (more than about 1:50 in either braking or climbing direction), lubricators on the Up and Down rails should not be positioned any closer than 0.5km of each other.

Approximately 1.2 km before the first derailment site, two rail flange lubricators providing lubrication for the down rail line (uphill) were located at 94.26 km and 94.30 km, 40 metres apart, the rail flange lubricator at 94.30 km was not listed on ARTC's maintenance history records (see Figure 13).

Additionally, two rail flange lubricators listed in ARTC's maintenance history records at 94.958 km and 94.535 km were less than the required 500 m separation stipulated in RC 2411.

Figure 13: Rail lubrication devices leading to left hand curve and site of first derailment



Facing Down direction (towards Moss Vale and up the mountain).
Source: OTSI

ARTC CoP (*Code of Practice Rail*) section 1.2.6.4 Performance Requirements stated:

> Rail lubrication systems should be designed to meet the following performance requirements:
>
> • The friction coefficient on the gauge face of outer rails on curves should be < 0.25
>
> • The friction coefficient on the top of rail contact surfaces of both rails should be > 0.3 (> 0.40 preferred) and > 0.40 on grades steeper than 1 in 50
>
> • A lower friction level may be acceptable on the contact surface in the immediate area of the lubricator (within 50 m)
>
> • It is also desirable that the difference in the running surface friction coefficients between the high and low rails should be < 0.15.
>
> Sufficient rail lubricant shall be applied to the gauge face of the outer rail of curves, so that rail wear and flanging noise are minimised. Note: The friction testing should be carried out with a tribometer[26] and cover at least 100 m in each track section to be assessed.

ARTC was requested to provide results of any friction testing undertaken on the Moss Vale to Unanderra rail line between Summit Tank Service Crossing (100.222 km) and Dombarton Down Signal WG1043 (92.222km), in the period from 1 January 2017 to 31 December 2021. They did not provide any results from friction testing conducted, in the requested period and stated in feedback that the Code of Practice does not require on-going coefficient of friction measurements.

ARTC noted:

> The monitoring of rail friction levels is deliberately not mandated as the risks associated, firstly, could not be effectively managed through a process (not practical or achievable within the variation of the friction over vast track length and rapid change factors).

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[26] Tribometer or tribotester is a generic name for a device which is used to simulate and measure friction and wear at the interface between surfaces in a relative motion under controlled conditions.

Secondly, are not related to any high risk which has been identified as justifying monitoring as a SFAIRP control.

The nature of steel wheel on steel rail is such that the friction coefficient will vary significantly according to various factors including the nature of the steel in the rail and the wheel, temperature and presence of materials such as water (rain), grease, oil, sand and vegetative material such as leaf debris. The reality is that the friction coefficient on any railway changes significantly and vary significantly between the 2 rail lines that run parallel to each other only 4 feet apart. It is impossible in such circumstances for ARTC to be attempting to prescribe a level of friction coefficient, and ARTC has not sought to do so.

The purpose of (the CoP) is to provide guidance in rail management, not to prescribe criteria for operating conditions that are actually beyond the control of ARTC.

ARTC does not warrant, and RSOs should not expect, any particular level of friction coefficient, or for the friction coefficient to be above or below any specified level. What ARTC does embrace, and for the benefit of RSOs, is to manage the Network in a manner that safely reduces the wear on rail and wheels, including the use of rail lubrication devices at appropriate locations, where ARTC seeks to reduce the friction coefficient.

On 3 June 2021, 6 months post the incident, friction tests were conducted by Monash Institute of Railway Technology, commissioned by Qube. The testing was conducted between 97.580km (500 m before Dombarton in the direction of travel) and 95.461km (1.5 km after Dombarton in the direction of travel). The tests were undertaken using a push tribometer as required in the ARTC Code of Practice.

All tribometer measurements were performed under dry conditions and were conducted at four separate sites. The results are in Table 4.

Table 4: Tribometer measurements

Site	Tribometer test/ Grease pot location	Friction coefficient top of rail (range)	Friction coefficient top of rail (average)
1	97.4km to 97.2km	Up rail – 0.17 to 0.22 Down rail – 0.17 to 0.35	0.2 0.26
2	97.11km to 97.078km	Up rail – 0.24 to 0.37 Down rail – 0.19 to 0.24	0.32 0.2
	Lubricator @ 97.03km (Down rail)		
3	97.03km to 96.925km	Up rail – 0.3 to 0.4 Down rail – 0.26 to 0.37	0.36 0.32
4	95.77km to 95.461km	Up rail – 0.16 to 0.29 Down rail – 0.2 to 0.33	0.23 0.26
	Lubricator @ 95.58km (Up rail)		

Observation

Across the four sites tested relevant to this incident, the friction coefficient on the top of the up and down rails was lower than the design standard of 0.4 for grades steeper than 1 in 50. Also of note the friction coefficient in some locations under dry conditions was lower than the design standard of 0.3 for all other gradients.

Rollingstock

The rollingstock was supplied to Qube by CFCLA under a lease agreement. The locomotives were maintained by CFCLA under its agreement with Qube. The wagons were primarily maintained by a contracted rollingstock maintainer to CFCLA and Qube in line with the lease agreement.

The rollingstock involved in the incident included:

- 2 CM Class Locomotives, CM3316 and CM3304
- 39 CGSY bottom dump grain hopper wagons
- 2 CGDY bottom dump grain hopper wagons.

The length of the train was 679.3 m.

CM class locomotives

The CM class locomotives were manufactured in 2012-13. They had a 22 t axle load and maximum gross power of 3300 hp (2460 kW). They were fitted with a Wabtec Fastbrake braking system and dynamic brake. They were also fitted with the Q-Tron QES-III locomotive control system that would provide an adhesion control function. The functional requirements for the adhesion control function as specified in Schedule 3 *(Technical Specifications of MP33 Locomotive for CFCLA Rail JV)* were:

> If poor wheel-to-rail adhesion persists, causing the horsepower of the locomotive to fall below a set percentage of the rated value, or a synchronous slip is detected, sand shall automatically be applied.
>
> A train lined wheel slip indication shall be included.

The Locomotive Information Pack for the CM class locomotives[27] provided the operating conditions which included:

Maximum tractive effort – 414 kN, and continuous tractive effort – 363 kN, at a speed of 16 km/h

Peak dynamic braking effort – 244.6 kN, at a speed of 23.3 km/h.

The locomotive design fully provisioned mass at rail was 132 tonnes. The locomotive can carry 10000 litres of diesel fuel which would weigh 8500 kilograms and the weight of other provisions such as lube oil, water and sand, approximately 1 tonne. Therefore, the dry weight of the locomotive would be approximately 122.5 tonne.

Grain hopper wagons

There were two types of grain hopper wagons, making up the train consist of the grain train 3966. Thirty-nine wagons were CGSY type, brought into service on the NSW rail network in 2015. The other two wagons were CGDY type, brought into service on the NSW rail network in 2013. The grain hopper wagons were manufactured by China International Marine Containers Group Australia (CIMC), for CFCLA.

Before any rail vehicle was permitted to operate on a rail network, they were required to comply with the minimum operating standards of the rail network owner. The measurement of brake block forces was one of several vehicle compatibility tests conducted to ensure the vehicle complied with the minimum operating standards for rollingstock. Tests were conducted on one of every type of vehicle, prior to that type of vehicle operating on the rail network. This is known as the Type Test.

The average measured brake block force was used to calculate the net brake ratio (NBR). NBR is the sum of the measured forces applied by the brake blocks onto the wheels divided by the weight of the vehicle and is determined for both tare and gross (loaded) vehicle mass. For a loaded vehicle the minimum NBR specified by AS7510.2:2014 was 13% with a brake cylinder pressure of

27 The locomotive information pack is submitted by the rollingstock owner to the rail network owner prior to its approval on the network and provides all technical and operational specifications of the locomotive.

350 kPa, for vehicles fitted with high friction composite brake blocks. ARTC's standard WOS 01.400 also recommended an NBR of 13% in order to provide effective braking without skidding wheels. The brake blocks fitted to the CGSY and CGDY wagons were FIP HA30 high friction brake blocks.

The results of the type tests for the CGSY and CGDY wagons were provided by CFCLA. A brake block force test conducted on 13 September 2015, on wagon CGSY 4519A, achieved an NBR of 14.23% for the loaded vehicle. A brake force test conducted on CGDY 4027, on 14 September 2013, achieved an NBR of 15.79%.

Both wagon types had CIMC 120AK brake componentry, a two-pipe train braking system. The two pipes being a brake pipe and main reservoir. This system allowed for an improved recharge time of the brake pipe pressure and greater control of the train braking performance (see Means of operation – wagons).

Two-pipe braking systems on grain wagons was a requirement in ARTC's Route Access Standard for the Moss Vale to Unanderra rail line, where the trailing tonnes was greater than 2400 t, as with 3966.

Inspection and maintenance of the brake blocks and brake adjustments were primarily completed by a contracted rollingstock maintainer, consistent with the lease agreement.

History of CGSY wagons

After delivery of the CGSY wagons into service, issues with the braking performance of the wagons were identified. CFCLA had investigated the issue and concluded the braking performance was unsatisfactory. As a result, CFCLA required the brake rigging ratio to be increased to improve the braking performance.

To achieve this, slack adjuster pivot holes were re-drilled in the brake lever (Figure 14).

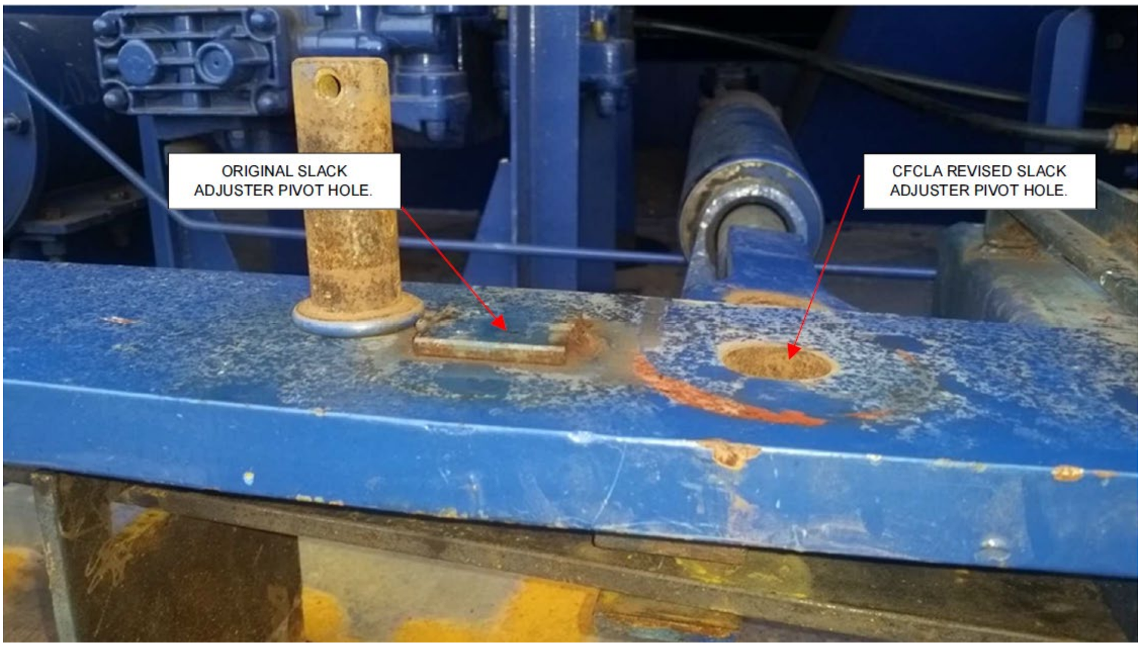
Following this modification to the brake lever, CFCLA found that the braking performance of the wagons had not improved and advised the original engineering manufacturer (OEM) CIMC that they had undertaken modifications to the brake lever ratio to improve brake performance which was not successful and requested advice from CIMC on a possible fix. The detail of the modifications made by CFCLA was not provided to CIMC.

> **Observation**
>
> The configuration and change management processes employed to manage this modification to the wagons was not effective.

CIMC's review of the wagon's design identified an error in the brake rigging system, in the setup of the control rod on the slack adjuster. The control rod on the slack adjuster had been fixed to the wagon structure. This did not permit the slack adjuster to perform its primary function of reducing the slack in the brake system. This resulted in the brake cylinder piston travel increasing as brake blocks wear, with an eventual reduction in brake block forces on the wheels.

CIMC revised the design to incorporate a control lever.

Figure 14: Revised slack adjuster pivot holes



Source: Wayne Clift Consulting

When the revised control lever design was fitted by CFCLA to a trial wagon, they found there was no change to the operation of the brakes. The slack adjuster was still unable to reduce the slack in the brake rigging.

In March 2017, an independent subject matter expert (SME) was engaged by CIMC, to assess and determine the root cause of the braking issue on the CGSY wagons.

Conclusions and recommendations from the SME were as follows:

> 4. CONCLUSIONS
>
> 4.1. The issues relating to the slack adjuster operation were resultant from:
>
> 4.1.1. Change to the brake lever ratio by CFCLA not concisely reported back to the Chinese manufacturer.
>
> *Advising the manufacturer of the changes made to the brake lever ratio, would have ensured the proposed control lever would have had corrected dimension to accommodate.*
>
> 4.1.2. Lack of brake rigging setup and slack adjuster operation training.
>
> 4.2. Once the correct setup geometry was established the slack adjuster performed as per specification.
>
> 4.3. The Brake Cylinder Stroke as specified appears excessive.
>
> 4.4. The change to the brake ratio initiated by CFCLA will deliver high NBR% bordering on excessive.
>
> 5. RECOMMENDATIONS
>
> 5.1. Brake force tests be undertaken with rigging as modified by CFCLA to confirm NBR% for loaded and empty conditions once first wagon is modified with correct control lever. No other wagons should be modified until this is confirmed.
>
> 5.2. Dependent upon outcome of 5.1 all wagons to be fitted with control levers.
>
> 5.3. Brake Cylinder travels be set to achieve either 85mm (Rigging Ratio of 6.45) or 70mm (Rigging Ratio of 5.07)
>
> 5.4. A training course be considered for staff to ensure competency in the principles of brake rigging and slack adjuster operation.

5.5. Critical changes made to the wagon should be reported back to the OEM to ensure continuity.

On 20 April 2017, the same SME was engaged by CFCLA to conduct the first article compliance inspection and testing sign-off and to provide a report on the revised control lever design. The SME conducted testing on CGSY 4542H and found and recommended the following:

> The Control Lever design requires modification to the clevis opening from the current 76mm to 100mm to permit fitment over the existing D Shackle. The brake pin length will need to be extended to suit.
>
> The arrangement drawing requires more detail on location of the control lever fulcrum bracket as per the appended report detail.
>
> The revised control lever pin hole position and fulcrum bracket location is compliant with industry standards and now permits the slack adjuster to operate correctly.
>
> Due to the use of Resilient Chevron pads between the wheelset and bogie frame, block clearance is compromised due to the compression of this pad during loaded brake applications.
>
> - Hence the proposed BC Stroke of 85mm has been amended to 130mm nominally to ensure a minimum block clearance of 9 – 10mm.
> - This stroke setting also permits removal of a new brake shoe without having to lengthen the slack adjuster manually.
>
> The operation of the Slack adjuster was observed and found to be fully compliant with industry practice. The slack adjuster was observed to return the brake cylinder stroke to nominal setting within 3 full-service brake applications.
>
> Brake force testing was conducted in accordance with industry practice and results were compliant with ASA requirements, NBR – 15%
>
> CGSY wagons fitted with the modified slack adjuster control lever in accordance with the findings of this report will provide regulated brake cylinder stroke consistently, irrespective of brake block wear.

On 22 April 2017, a train consisting of 40 CGSY wagons was involved in a runaway down the Illawarra Mountain *(see Related Occurrences)*.

On 18 May 2017, as a result of the runaway on 22 April 2017, the NBR was tested on CGSY 4502V and found to be 13.9%. This wagon was the 38th wagon in the train consist and was randomly chosen for testing.

On 10 July 2017, the CGSY wagons were returned to CFCLA and taken to Goulburn for care and maintenance. During this time, the CGSY wagons were modified with the slack adjuster control lever. They were returned to service on 3 April 2018, to service other bulk grain contracts.

On 16 November 2020, the CGSY wagons recommenced operation on the Moss Vale to Unanderra rail line. Qube provided information to confirm the wagons had received a 28 day periodical maintenance on 5 November 2020 and assurance FX exam brake tests had been conducted post return of the wagons to Qube.

The wagons completed 12 journeys on the Moss Vale to Unanderra rail corridor, including a trip two days prior to this incident journey on 15 December 2020.

Train weight

There were several sources of data providing varying values of the weight of the train.

The load out tonnes[28] from Temora BFB[29] was 2703.9 t in 40 wagons + 1 empty wagon. This equated to a trailing tonnage of (39 x 23.2 t + 2 x 22.7 t + 2703.9 t) = 3654.1 t.

The train driver's hand-written train consist stated the trailing tonnage was 3690 t. However, each loaded wagon was noted as 90 t which equated to a trailing tonnage of (40 x 90 t + 22.7 t) = 3622.7 t.

Qube's computer printed train consist, provided when requested for copies of the train consist, had loaded wagons weighing 89 t each which equated to a trailing tonnage of (40 x 89 t + 1 x 22.7 t) = 3582.7 t.

The train consist provided to ARTC, from Qube, had a declared weight of the train of 3198 t, which included a declared weight of the locomotives at 123 t each. The trailing tonnage, according to this train consist, was (41 x 72 t) = 2952 t. The 41st wagon was indicating it was loaded which was incorrect. This declared weight was significantly lower (by 456.1 t) than the weight of the train calculated on the Temora BFB load out tonnes. This was a 12.5% difference.

The two remaining wagons from the derailment were taken to Port Kembla for unloading and weighing. CGSY 4516T and 4518Y total grain weight was 134.385 t, as observed on the belt weigh system at Port Kembla. The average weight for each wagon was therefore (67.2 t + 23.2 t) = 90.4 t.

Using this figure to estimate the trailing tonnage equated to (40 x 90.4 t + 22.7 t) = 3638.7 t.

This weight was greater than the declared weight to ARTC, the driver's hand-written train consist and Qube's computer printed train consist, but less than the trailing weight calculated using the load out tonnes from Temora BFB and below the maximum allowable trailing weight (3680 t) as per ARTC TOC Waiver 16002[30].

It was noted that the train journey required 3966 to traverse the TfNSW rail network[31]. As per the TfNSW TOC Manual (TS TOC.2.2020 Issue 2 v19.0 2 September 2020), the load tones for freight trains travelling on the rail line from 91.080 km to Unanderra was a maximum of 3300 t for locomotives of class L3, as the CM locomotives were. Based on this, the train weight was greater than the allowable tonnage (on the TfNSW rail network) on all records of the train weight, other than the train consist provided by Qube to ARTC and TfNSW, which had a declared weight of 3198 t.

The trailing load was also measured by ARTC's Exeter wayside detector at 0248 hrs, 15 December 2020. The wayside detector calculates a weight in motion and uses specific locomotive classes as weight references to conduct an automatic calibration at every pass of one of the reference locomotives. ARTC stated the wayside was not a certified weighbridge but achieved a +/- 3% accuracy.

It was noted that the weight of the locomotives provided by the wayside detector were within 1% of the calculated weight of the locomotives, accounting for indicative fuel levels in the locomotives (taken from the data logger) and their tare weight.

It was also noted the wayside detector recorded the last wagon in the consist CGDY 4026 at 27.67 t, approximately 4.5 t higher than its documented tare weight. ARTC provided data from the

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28 The load out tonnes is the total weight of the grain loaded into the grain hopper wagons.

29 BFB is the Brabin, Firman and Block families partnership – BFB Pty Ltd delivering freight, grain, fertiliser and fuel services. Based in Temora, the grain loading terminal is located at Temora West. In 2023, BFB Pty Ltd merged to become Altora[Ag]

30 A TOC waiver is a published variation to the train operating conditions manual.

31 The TfNSW rail network started at 91.080 km to Unanderra, where it joined the South Coast rail line which was also part of the TfNSW rail network.

wayside of the previous two tare weights taken of CGDY 4026, which indicated the tare weight as 25.53 t on 5 December 2020, and 26.0 t on 21 October 2020. The tare weights of other CGDY wagons taken by the wayside monitor on 21 October 2020 indicated the average tare weight of the CGDY wagons was 27.5 t.

These readings indicated the tare weight of the CGDY class wagon was not the documented 22.7 t as registered with the infrastructure manager.

The total trailing weight measured was 3748.5 t. With consideration of the +/-3% accuracy, the train was between 3636.045 t and 3860.95 t (Figure 15). This indicated the train may have been running heavier than allowable tonnage limit of 3680 t.

There was also variability in wagon weights of approximately 7%, ranging from 90.65 t to 96.44 t. The wayside data indicated 20 of the 41 wagons were over the allowable loaded wagon weight limit of 92 t.

Figure 15: Exeter wayside detector read out

Vehicle Tag	Vehicle Number	Operator	Vehicle Weight (t)
CM 003316	1	QUB	128.51
CM 003304	2	CFC	129.13
CGSY 004516	3	QUB	91
CGSY 004518	4	QUB	93.61
CGSY 004512	5	QUB	91.84
CGSY 004525	6	QUB	92.83
CGSY 004511	7	QUB	92.44
CGSY 004509	8	QUB	91.82
CGSY 004505	9	QUB	91.44
CGSY 004523	10	QUB	92.98
CGSY 004530	11	QUB	93.95
CGSY 004506	12	QUB	92.7
CGSY 004524	13	QUB	91.8
CGSY 004519	14	QUB	94.24
CGSY 004522	15	QUB	90.65
CGSY 004539	16	QUB	93.14
CGSY 004538	17	QUB	92.33
CGSY 004501	18	QUB	93.21
CGSY 004520	19	QUB	94.1
CGSY 004532	20	QUB	92.52
CGSY 004535	21	QUB	91.97
CGSY 004531	22	QUB	96.44
CGSY 004540	23	QUB	94.19
CGSY 004517	24	QUB	93.53
CGSY 004536	25	QUB	92.24
CGSY 004526	26	QUB	93.28
CGSY 004521	27	QUB	93.38
CGSY 004537	28	QUB	92.53
CGSY 004508	29	QUB	93.94
CGSY 004527	30	QUB	92.75
CGSY 004510	31	QUB	94.79
CGSY 004529	32	QUB	93.49
CGSY 004528	33	QUB	94.46
CGSY 004533	34	QUB	92.57
CGSY 004502	35	QUB	93.35
CGSY 004504	36	QUB	92.9
CGSY 004507	37	QUB	93.72
CGSY 004534	38	QUB	93.27
CGSY 004514	39	QUB	94.43
CGSY 004515	40	QUB	93.71
CGDY 004010	41	QUB	91.22
CGSY 004541	42	QUB	92.07
CGDY 004026	43	QUB	27.67
			3748.5

Source: ARTC

While it could not be established with 100% certainty what the trailing weight of the train was, the total load out tonnes from Temora BFB plus the tare weight of the wagons was considered most representative as all other sources were only estimates of the grain weight in the wagons.

ARTC's wayside detector at Exeter was considered an indicative source of weight in each wagon, which highlighted a 7% degree of variability in the amount of grain loaded in each wagon across the train consist. It also highlighted specific wagons were likely overloaded.

These combined indicated the weight of the train was near maximum allowable tonnage and probably under the 3680 t limit for the train. However, it was likely a number of these wagons were over the allowable limit for a single wagon and there was variation in loading across the train consist.

Observation

Inaccurate reporting of train weights presents an increased risk to operations, particularly when trains are operating heavier than expected.

Rollingstock inspections

Prior inspections

The most recent wagon periodical maintenance (28 day) inspection was conducted in Goulburn by a contracted wagon maintainer and signed off for release back into service on 25 November 2020, 20 days prior to the incident.

Post-incident inspections

Transport safety investigators' observations of the rollingstock on the day of the incident included the portion of the train which had not derailed, the locomotives and two wagons (Figure 16), and both sites where rollingstock had derailed.

Figure 16: Stop point of runaway train 3966

Source: OTSI

On arrival at the locomotives and two wagons it was observed that the coupler knuckle was closed and locked on the back of the second wagon CGSY 04518Y and that both main reservoir (MR) and brake pipe (BP) isolation cocks were closed. It was later confirmed that the driver's assistant had isolated the cocks post derailment to stop air leaking from the main reservoir and brake pipe.

The locomotives were shut down because noise from the running engines was disturbing nearby residents. Isolation cocks for the locomotive's bogies and brake equipment appeared to be in the correct orientation when inspected.

The wheels on the remaining connected wagons showed some signs of heat (see Figure 17). There were no visual signs of flat spots on the wheels. This was later confirmed when the rolling stock was tested on 17 December 2020, prior to moving to Port Kembla to unload the wagons. Sand was also evident on the rail head located under the wagons and locomotives.

Figure 17: Back of 2nd wagon CGSY 04518Y

Source: OTSI

The brake shoes were in contact with the wheels across both locomotives and wagons. The contact patch of the brake shoes was not aligned with the wheel diameter on some wagons (Figure 18).

Figure 18: Side of 1st wagon CGSY 04516T brake shoe

Source: OTSI

On 17 December 2020, two days after the incident, testing on the rollingstock that had not derailed was conducted, to ensure the braking systems were operating to standard. The wagons were tested for brake pipe leakage rate (5 kPa/min) and given a brake holding test (13 mins). These were within specified limits.

The lead locomotive CM3316 had a functional brake test conducted by CFCLA and was given a Locomotive Ready to Go Certificate prior to the locomotives and two wagons being driven down to Port Kembla to unload and weigh the grain.

The trailing locomotive CM3304 brake function test was not conducted post incident. The locomotive event logger data for CM3304 indicated the control system acted as designed, with the air brake system and dynamic brake system performance recorded.

Net braking ratio tests

The NBR is the ratio of the sum of the measured actual brake block forces in kilograms divided by the total vehicle mass, in kilograms, at rail.

Qube conducted NBR tests on the two remaining CGSY wagons (4516T and 4518Y) that did not derail in the incident. The testing was conducted at Junee on 9 February 2021 by a qualified rollingstock engineer, under the observation of representatives from CFCLA.

The NBR test results were:

- CGSY 4516T was 12.45%
- CGSY 4518Y was 10.7%.

These results did not meet the minimum design standard net braking ratio for vehicles fitted with high friction composition brake blocks. Noting that the standard applied to new vehicles only and there was no requirement to test NBR on an ongoing basis.

The RISSB Standard AS 7510.2: 2014 Braking Systems – Part 2 – Hauled Rolling Stock stated:

> The automatic air brake of a vehicle fitted with high friction composition brake blocks shall be designed to achieve a Net Braking Ratio of 13% to 16% with a Brake Cylinder pressure of 350kPa.

As per ARTC's WOS 01.400 Freight Vehicle Specific Interface Requirements Issue 1.0 Dec 2005, the NBR for vehicles fitted with high friction brake blocks, fully loaded, recommended 13% to provide effective braking without skidding wheels.

Transport for NSW RSU 400 Series – Minimum Operating Standards for Rolling Stock – Freight Vehicle Specific Interface Requirements V2.0, issued 24 August 2017 required 16% NBR to be used as a minimum for all new rollingstock and provided the conditions when the net braking ratio was lower than 16% but higher than 13% (for existing rollingstock):

> Figures less than 16%, down to 13% net brake ratio as a minimum, may be accepted; however the wagons will require a dynamic brake test in the loaded condition in a comparable consist to confirm that the train consisting of these wagons is able to stop within the brake performance curves applicable for the operating corridor.

As mentioned in *Grain hopper wagons*, the type test for the CGSY wagons was found to be greater than 13% but lower than 16%. The type test conducted on CGSY 4519A confirmed the NBR for the wagon was 14.23%.

It was understood by CFCLA at the time that the requirement for all new bulk commodity type wagons became effective as of 1 January 2018. The CGSY wagon type was published in the ASA Train Operating Conditions (TOC) Manual version 11.0 on 15 December 2017 with unrestricted operating conditions.

The two NBR tests on the remaining wagons could not statistically be considered representative of the entire consist. However, the NBR on a freight wagon should not be significantly different to other wagons of the same design assuming they are all built to the same drawings. The CGSY wagons had varying measured NBRs from 19.5% down to 10.7%, as seen from the various tests conducted on different CGSY wagons over their service life.

Post this incident on 15 December 2020, there remained five CGSY wagons in the fleet.

As noted in *Net braking ratio tests*, the NBR tests conducted on 9 February 2021 returned 12.45% and 10.7%.

The other three CGSY wagons not involved in the incident were tested on the 12 May 2021 and results were, CGSY 4542H – 12%; CGSY 4503H – 19.5%; CGSY 4513P – 14.5%.

It was noted that CGSY 4542H was modified by the SME to improve its brake performance. The NBR of this wagon when tested on 20 April 2017, post modifications, was 15.0% (see History of CGSY wagons).

Wagon brake pipe continuity

The 'brake pipe' is critical to the functionality of a train's braking system. This pipe, which runs along the length of the train, provides the means through changes in air pressure to effect application and release of the train's brakes (see Means of operation – wagons). A disruption in the continuity of this pipe, such as a brake pipe tap closed between wagons, will result in less wagons providing braking force.

To ensure brake pipe continuity and the correct functionality of a train's brakes throughout the consist, the brake system is tested prior to commencement of a train's journey. For the accident train, these tests were performed the previous day, with one wagon (of the 41 attached to the train) identified as having its brake components isolated.

In addition, Qube undertook a comparison of the time taken to recharge the brake pipe on the day of the accident (15 December 2020), against that of the train's previous journey on 12 December 2020.

Qube found that there was no appreciable difference in the time taken to recharge the brake pipe between the two services, supporting the brake pipe was fully connected and continuous throughout the train consist on the day of the accident.

Contact patch of brake blocks

It was observed in the post incident inspection that some of the brake blocks on the wagons were not in contact with the wheel on the leading edge of the brake block. Qube also found this during their inspections and considered the gap at the outer edge of the brake blocks a contributor to lowered coefficient of friction[32] at the brake block/wheel interface. The reduced contact area between block and wheel also results in higher heat in the block contact area, which increases the risk of brake fade.

The manufacturer of the brake blocks had conducted tests of the high friction brake blocks in 2017. The testing indicated that brake block friction generally reduced as speed increased; and when the brake blocks were wet. Additionally, brake blocks were more susceptible to reduced friction with the wheel when the block had a gap at the leading edge of the brake block.

Of the 41 wagons attached to the accident train, the two remaining upright wagons with brakes applied were observable and found with gaps at the outer edge of the brake block.

There was evidence of a heat stripe (blue discolouration on metal occurs at approximately 300 degrees Celsius) on the left rear wheel of wagon CGSY 04518Y (see Figure 17). This indicated the contact patch from the brake block to the wheel was not consistent and evenly applied across the wheel. The corresponding right wheel did not show signs of heat build-up (no blue discolouration) to the same extent as found on the left wheel.

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32 The coefficient of friction is a measure of the frictional force (or resistance) between one object moving over another.

The wheels on CGSY 04516T and on the Locomotives showed very little signs of heat (no blue discolouration was present).

Train braking system

General description

There are three braking systems fitted to the CM class locomotive in addition to the parking brake. These comprise of two types of air operated (pneumatic) brake, that is, the automatic and independent, and an electrical dynamic brake. The use of each of the three braking systems is dependent on the circumstance during which braking effort is required.

Automatic brake

Introduction

The 'automatic brake' controls the brakes on the entire train, including the wagons and locomotive/s. Central to this system is the brake pipe, which runs along the length of the train. Changes to air pressure within the brake pipe regulate the application and release of the train's brakes. When fully charged (that is, brakes released), the brake pipe pressure is about 500 kPa. Reduction of this pressure by the driver results in application of the train's brakes.

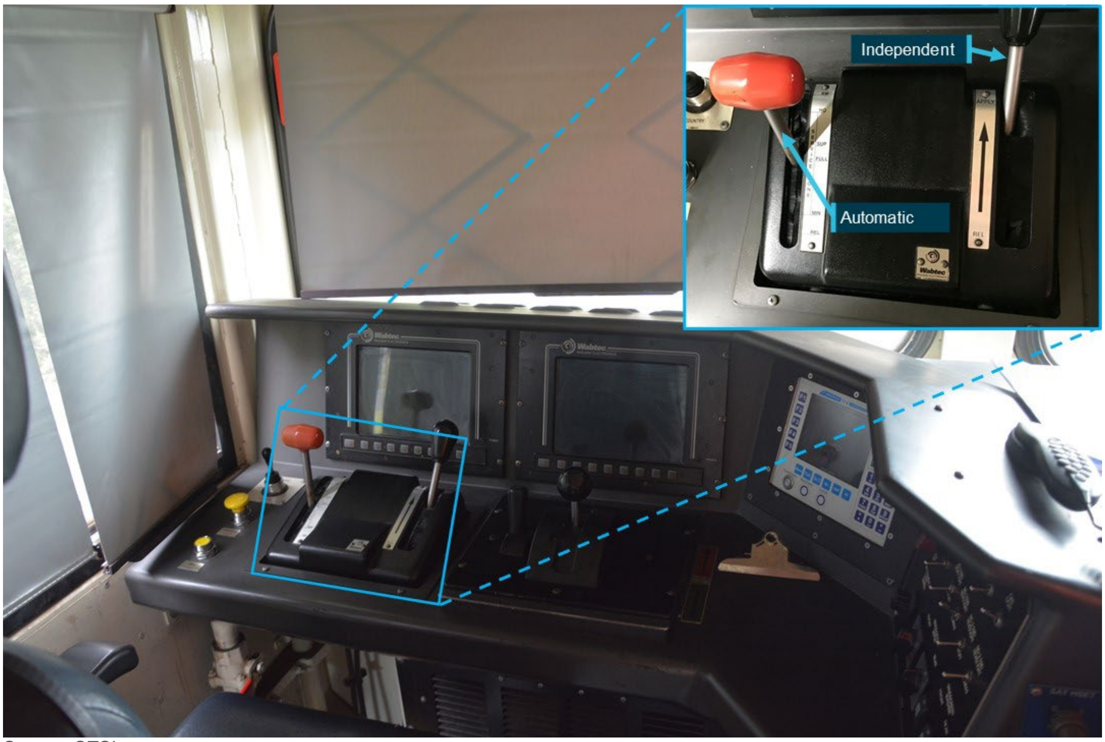
Driver controls

The driver regulates the pressure within the brake pipe through operation of the automatic brake handle (see Figure 19). The brake handle positions on the CM class locomotive are:

1. Release – brake pipe charging or charged up to 500 kPa, which releases any automatic brake applied to the locomotive/s and wagons.
2. Minimum service – reduces the brake pipe pressure to 450 kPa which initiates a minimum application of the brakes on the locomotive/s and wagons.
3. Service zone – a graduated reduction of the brake pipe pressure from 450 kPa to 350 kPa, which correspondingly increases the braking forces at a graduated rate.
4. Full service – reduces the brake pipe pressure to 350 kPa which fully applies the brakes on the locomotive/s and wagons.
5. Suppression – reduces the brake pipe pressure to 350 kPa for the purposes of penalty brake[33] suppression and reset.
6. Handle off – reduces the brake pipe pressure to 0 kPa. This handle position configures the locomotive such that it cannot be used for initiating braking commands.
7. Emergency – rapidly reduces the brake pipe pressure to 0 kPa which quickly provides a full service brake application to the locomotive and wagons (see Means of operation – wagons).

[33] The penalty brake resulted in an automatic reduction of the brake pipe to 0 kPa. This occurred after vigilance and detonator signal detection timeouts, and locomotive overspeed.

Figure 19: Automatic and independent brake handles



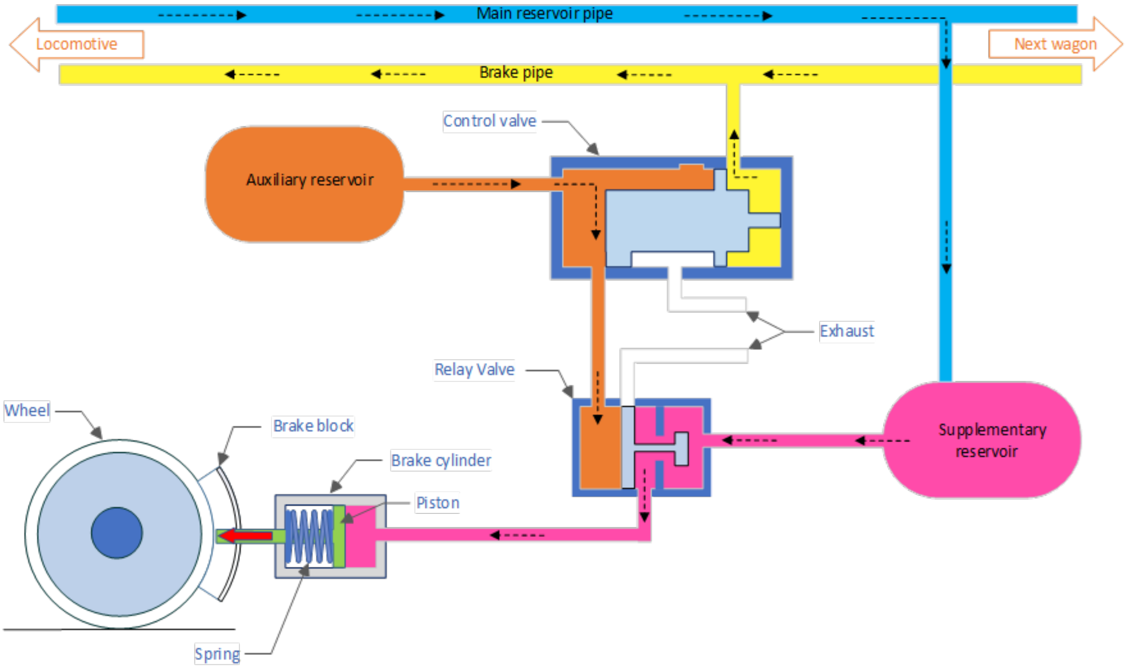
Source: OTSI

Means of operation – wagons

In addition to the brake pipe, each CGDY and CGSY wagon was fitted with a pneumatic control valve, auxiliary reservoir, relay valve, supplementary reservoir and brake cylinders. The control valve responded to changes in pressure within the brake pipe. On sensing a reduction in brake pipe air pressure, the control valve would reduce the auxiliary reservoir air pressure by an equal amount. This auxiliary reservoir air would supply reference (signal) air to a relay valve, in-turn permitting air from the supplementary reservoir (continuously supplied by main reservoir air from the locomotive)[34] to enter the brake cylinder. A piston within the brake cylinder would then push the brake blocks against the wagon wheels, causing friction and slowing of the train (see Figure 20).

34 Where a wagon is fitted with a main reservoir pipe to supply the supplementary reservoir, in addition to a brake pipe, the braking system is termed 'two-pipe'.

Figure 20: Wagon airbrake application process



The image is a simplified representation of an airbrake application on a wagon. The control and relay valves consist of rubber diaphragms, springs and ports that respond to air pressure differences to perform their functions.
Source: OTSI

In effect, on two-pipe trains (as with the CGDY and CGSY wagons) the pressure in the brake cylinder is directly proportional to the air pressure reduction in the auxiliary reservoir. Maximum braking effort is achieved when brake pipe pressure is reduced to 350 kPa, known as a 'full service' brake application. At this point the brake pipe, auxiliary reservoir and brake cylinder pressures equalise with each other at about 350 kPa. Therefore, further reductions in brake pipe pressure do not result in increased braking effort. Table 5 provides an overview of braking system pressures in response to various brake pipe pressures.

Table 5: Automatic brake pressure equalisations for a 500 kPa brake pipe[35]

Automatic brake handle position	Brake pipe (kPa)	Auxiliary reservoir (kPa)	Brake cylinder (kPa)
Release	500	500	0
Minimum service	450	450[1]	118[2]
Service zone (example pressure)	400	400[1]	235[2]
Full service	350	350[3]	350[2]
Emergency	0	350[4]	350

[1] Auxiliary reservoir equalises with the brake pipe.
[2] Brake cylinder pressure equates to about 235% of the pressure loss in the auxiliary reservoir.
[3] Auxiliary reservoir equalises with both the brake pipe and brake cylinder.
[4] Auxiliary reservoir equalises with the brake cylinder, preventing further equalisation with the brake pipe.

In a similar manner to the wagons, a reduction in brake pipe pressure also applies the brakes on the hauling locomotives. For a CM class locomotive, the maximum automatic brake applied locomotive brake cylinder pressure attainable is also 350 kPa.

Once the required speed reduction has taken effect, the driver places the automatic brake handle in the 'release' position which restores the brake pipe pressure to 500 kPa. On sensing an increase in brake pipe air pressure, the control valve allows air from the brake pipe to recharge the

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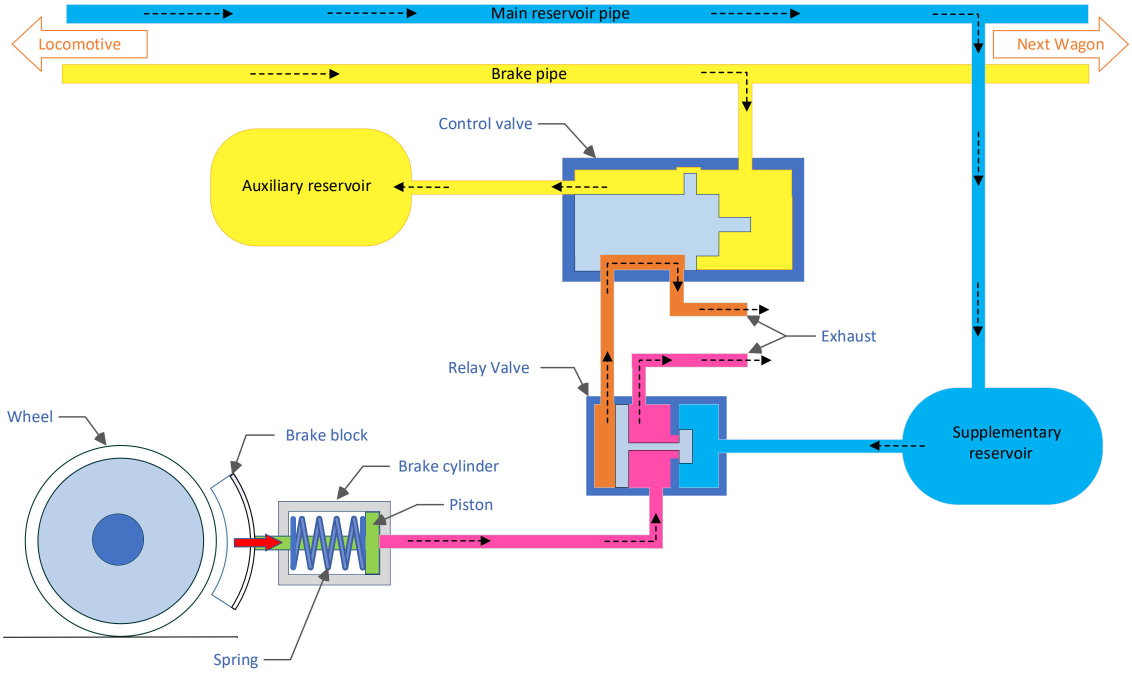
35 Based on information on general airbrake principles supplied by Wabtec Australia.

auxiliary reservoir to 500 kPa.[36] In addition, brake cylinder air pressure is vented to atmosphere allowing a spring within the brake cylinder to force the piston to retract, thereby removing the friction force of the brake blocks from the wagon wheels (see Figure 21).

Figure 21: Wagon airbrake release process



The image is a simplified representation of an airbrake release on a wagon. The control and relay valves consist of rubber diaphragms, springs and ports that respond to air pressure differences to perform their functions.
Source: OTSI

With brake pipe operated pneumatic braking systems, the brakes on the train do not apply simultaneously. As brake pipe pressure is vented from the lead locomotive, the brakes on the leading wagon apply first, followed sequentially by the other wagons towards the rear of the train.

Similarly, when a train's automatic brakes are released (actioned by the lead locomotive), there is a delay in the entire train's brake pipe (and auxiliary reservoirs) recharging, particularly towards the rear of the train. A review of the incident train's data logger indicated that it took about 26 seconds for the brake pipe to fully recharge after a minimum service (50 kPa brake pipe reduction) application. For a 70 kPa reduction in brake pipe pressure, this increased to over 50 seconds for a full recharge. That is, the greater the brake pipe pressure reduction, the longer it took to fully recharge the brake pipe and auxiliary reservoirs back to 500 kPa along the entire length of the train in readiness for another brake application.

Brake pipe charging flow indicator

During an automatic brake release, main reservoir air, produced by the main compressor on the locomotives, recharges the brake pipe to 500 kPa. Although brake pipe pressure is restored relatively quickly at the front of the train, this does not accurately reflect brake pipe pressure along the length of the train. To assist the driver in determining whether the brake pipe is fully recharged in readiness for another brake application, a brake pipe charging flow indicator is provided.

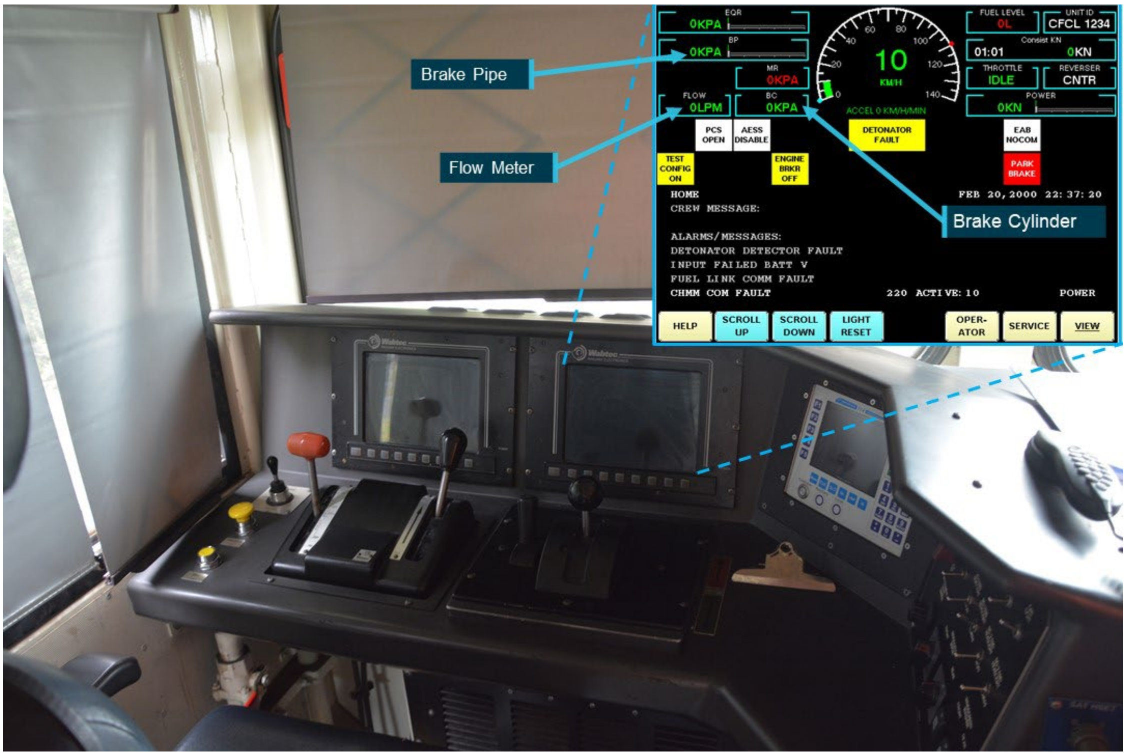
Due to the sensitivity of the brake pipe charging flow indicator, it is possible to detect small losses in brake pipe pressure. This is particularly useful in alerting the driver to a derailment or train

[36] The CGDY and CGSY wagons were fitted with a supplementary reservoir which was recharged by the main reservoir, not the brake pipe. Removing reliance on the brake pipe recharging all aspects of the train's braking system resulted in reduced brake pipe recharge and brake release times.

separation[37] event towards the rear of the train, whereas the brake pipe pressure on the locomotive may indicate little or no pressure loss.

On the CM class locomotive, the brake pipe charging flow indicator is on a computer display unit (CDU) on the driver's control station. The indicator consists of a numeric value of main reservoir to brake pipe air flow expressed in litres per minute. It is located at the bottom of a bank of similar numeric displays including the brake pipe, main reservoir and locomotive brake cylinder pressures (see Figure 22). There is no accompanying visual annunciator tile or audible alarm to draw the driver's attention to the activation of the brake pipe charging flow indicator.

Figure 22: Driver's computer display unit



Source: OTSI

Running out of air

As depicted in Table 5, a full service application of brake cylinder pressure (350 kPa) is achieved when the driver reduces the brake pipe pressure to 350 kPa. However, this is dependent on the auxiliary reservoirs on each wagon being fully charged to 500 kPa at the time the brake application is made.

Where the brake pipe has not been given a sufficient opportunity after an automatic brake application to recharge the brake pipe across the entire length of the train prior to the reapplication of the automatic brake, it will result in a lower auxiliary reservoir starting pressure, particularly on wagons at the rear of the train. As a result, there is a reduced pressure drop in the auxiliary reservoir when equalising with the brake pipe on the subsequent brake application. In response, the relay valve and supplementary reservoir provide less pressurised air to the brake cylinders, resulting in a reduced braking force than would be achieved if the auxiliary reservoir starting pressure is 500 kPa. Table 6 provides an example of this reduced brake cylinder pressure where an auxiliary reservoir has recharged to only 450 kPa prior to the reapplication of the automatic brake.

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[37] Train separation: where the rear of the train detached from the front of the train, either through coupler failure or uncommanded uncoupling.

Table 6: Brake pressure equalisations from 450 kPa auxiliary reservoir starting pressure[38]

Brake pipe (kPa)	Auxiliary reservoir (kPa)	Brake cylinder (kPa)
~500	450[1]	0
450	450[2]	0
425	425[3]	59[4]
400	400[3]	118[4]
350	350[3]	235[4]

[1] **Note:** Braking system still in release mode, with the brake pipe in the process of recharging the auxiliary reservoirs.
[2] Auxiliary reservoir remains equalised with the brake pipe, no brake cylinder pressure effected.
[3] Auxiliary reservoir equalises with the brake pipe.
[4] Brake cylinder pressure equates to about 235% of the pressure loss in the auxiliary reservoir.

In this example, the maximum achievable brake cylinder pressure in full service is about 235 kPa, where the auxiliary reservoir starting pressure is 450 kPa. This is one-third less than the 350 kPa brake cylinder pressure in full service where the auxiliary reservoir starting pressure is fully recharged to 500 kPa (refer Table 5).

This phenomenon of reduced available braking force due to low starting auxiliary reservoir pressure is termed 'running out of air'. In summary, the lower the starting pressure of the auxiliary reservoir at commencement of an automatic brake application, the lower the braking force available.

Partial braking force recovery when running out of air

As explained in Means of operation – wagons, the maximum braking effort achievable is a full service brake application, due to the concurrent equalisation of the brake pipe, auxiliary reservoir and brake cylinder pressures. That is, further reductions in brake pipe pressure below 350 kPa do not result in increased braking effort. The only exception is when the train's braking system is running out of air.

In this unique scenario a further reduction in brake pipe pressure will result in increased brake cylinder pressure. By lowering the auxiliary reservoir pressure below 350 kPa, it is possible to force an equalisation of the brake cylinder pressure at a higher rate than is by then achievable in full service. For example, as discussed in *Running out of air*, where an auxiliary reservoir is only recharged to 450 kPa prior to the reapplication of the automatic brake, the maximum brake cylinder pressure available in full service will be about 235 kPa. However, by reducing the brake pipe pressure further, an equalisation between the auxiliary reservoir and brake cylinder pressures will occur at about 314 kPa (see Table 7).

As described in *Driver controls*, it is not possible for the driver to graduate the brake pipe below 350kPa, for example, to 314 kPa as noted above. The next available command after full service is either 'handle off' or 'emergency', both of which result in 0 kPa brake pipe pressure, at a service (controlled) rate for the former and at a rapid rate for the latter.

Table 7 summarises various scenarios of reduced auxiliary reservoir starting pressures. This is then compared to the maximum brake cylinder pressures available in full service, versus the maximum brake cylinder pressures available with the brake pipe pressure reduced to 0 kPa.

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38 Based on information on general airbrake principles supplied by Wabtec Australia.

Table 7: Approximate maximum brake cylinder pressures from auxiliary reservoir starting pressure[39, 40]

Auxiliary reservoir starting pressure (kPa)	Maximum achievable brake cylinder pressure (kPa)[2] in 'full service'[3]	Maximum achievable brake cylinder pressure (kPa)[2] with brake pipe at 0 kPa
500[1]	350	350
490	329	343
480	306	336
470	282	329
460	259	321
450	235	314
440	212	307
430	188	300
420	165	293
410	141	286
400	118	278
390	94	271
380	71	264
370	47	257
360	24	250
350	0	243

[1] Fully charged auxiliary reservoir, with expected starting pressure during normal operations.
[2] Brake cylinder pressure equates to about 235% of the pressure loss in the auxiliary reservoir.
[3] Brake pipe reduced to 350 kPa.

Importantly, despite the ability to increase available brake cylinder pressure with the brake pipe reduced to 0 kPa in instances of running out of air, it is not possible to again obtain the maximum braking force available as would be provided by full service with a fully charged auxiliary reservoir starting pressure.

Observation

While ordinarily a 'full service' automatic brake application provides the maximum pneumatic braking force available on a train, in the unique circumstance of a train 'running out of air', a lower brake pipe pressure results in an increase in the available braking force. However, this increased braking force would still be less than that available in full service had the auxiliary reservoir been fully charged at the time of the automatic brake application.

This option was available to the driver.

Independent brake

The 'independent brake' applies pneumatic brakes to the locomotive/s only, independently of any trailing wagons. It is operated by the driver using the independent brake handle on the driver's control station (see Figure 19). On the CM class locomotive, it has two positions: 'release' and 'apply', with an intermediate graduated service zone. The independent brake can be graduated in

39 Note: these pressures are an approximation. The exact pressures would be influenced by the number and diameter of the brake cylinders, diameter of the brake cylinder piston and, length and diameter of the pipework from the supplementary reservoir to the brake cylinder/s.
40 Based on information on general airbrake principles supplied by Wabtec Australia.

both application and release. In the fully applied position, the locomotive brake cylinder pressure is about 500 kPa.

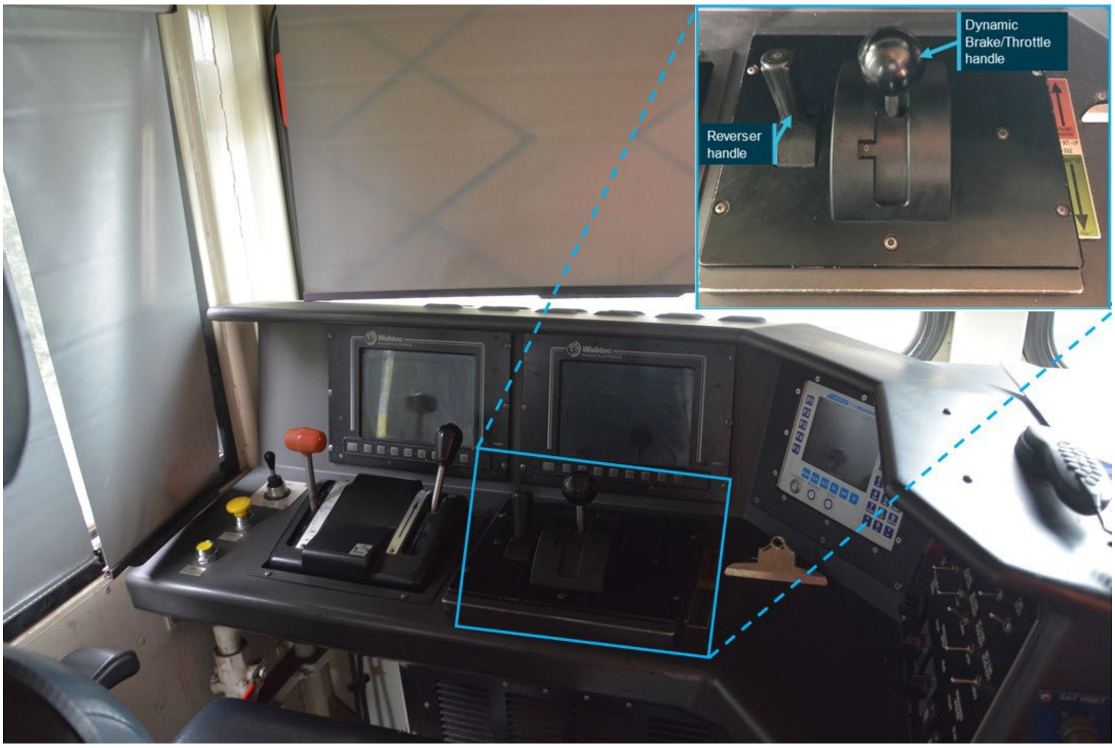
Dynamic brake

The electrical dynamic brake is designed to reduce locomotive fuel usage and wear on wagon componentry as occurs with pneumatically operated friction brakes. It provides a supplementary means of train-speed control that complements the train's pneumatic automatic brake.

When dynamic brake is selected, it alters the locomotive's traction motor fields from a tractive power to a generator configuration. The subsequent power generated by the rotating locomotive wheels is fed to resistor grids and dissipated as heat, resulting in a retarding force. This retarding force is limited to the locomotive wheelsets only, rather than dispersed across the entire train. Increasing or decreasing the amount of electrical resistance varies the braking effort on the rotating locomotive wheels.

On the CM class locomotive, the dynamic brake is selected by the driver moving the throttle/dynamic brake handle on the driver's control station into the dynamic braking zone (see Figure 23).

Figure 23: Dynamic brake / throttle handle



Source: OTSI

Automatic brake relationship with dynamic brake

As described in Means of operation – wagons, when the automatic brake is applied air pressure develops in the locomotive's brake cylinders. Simultaneous application of both the dynamic brake and locomotive brake cylinder pressure can result in potential wheel lock-up and wheel slide. To prevent this, a dynamic brake inhibit (DBI) function[41] is supplied as part of the Fastbrake air brake system. The DBI automatically releases any automatic brake applied locomotive brake cylinder

[41] The DBI function was known on earlier locomotives as a 'dynamic brake interlock'.

pressure whilst dynamic brake is in use. Independent brake applied locomotive brake cylinder pressure is not affected by the DBI.[42]

The Fastbrake system provides the option for the owner/operator to specify during the locomotive design the activation of the dynamic brake knockout (DKO) function during an emergency brake application. When activated, the DKO causes the locomotive's dynamic brake to disengage, and the automatic brake applied locomotive brake cylinder pressure to be restored. Wabtec advised, that where the optional DKO function is not fitted, the dynamic brake is retained during an emergency brake application, resulting in extra available braking effort.

CM class locomotive braking systems

General

Braking system specifications for the CM class locomotives was contained in Schedule 3 (*Technical specifications of MP33 locomotive for CFCLA Rail JV*).

Information (page 12) included:

> Wabtec Fastbrake system shall be provided.
>
> Cut-off brake pipe charging in the event of an emergency application for any source and will provide:
>
> - Instantaneous power knockdown.
> - Instantaneous brake pipe charging cut-off.
> - Continuous DB until the independent brake is applied to 100kPa (15 psi), then DB knockdown [DKO] occurs.[43]

CM class locomotive dynamic brake

As discussed in *Dynamic brake*, Wabtec manual 31394P *(FASTBRAKE Operations and Maintenance MPI-CFCLA Locomotives)* allowed for a DKO option, specifically:

> If the Dynamic Brake is applied when the emergency brake application occurs, it is optional to have the Dynamic Brake CUT-OUT immediately via the Dynamic Brake Knock Off (DKO) or maintained and employed at the operator's discretion.

Neither this manual or the driver's manual[44] for the CM class locomotive stipulated if the DKO function was active or omitted for the CM class locomotive. Wabtec Australia advised that the Wabtec manual included the statement (set out above) as the owner/operator of the locomotive could determine and specify the way they wanted this feature to work.

Subsequent testing found that the CM class locomotive DKO option was not active, resulting in the retention of the dynamic brake during emergency automatic brake applications.

While not related to the incident, additional testing by OTSI also found that retention of the dynamic brake during an emergency brake application resulted in the automatic brake applied locomotive brake cylinder pressure being suppressed by the DBI on the CM class locomotive. This meant that when travelling as a light engine[45] the stopping distance could increase in the event of an emergency, if:

- dynamic brake was engaged
- the automatic brake was placed in the emergency position
- the independent brake was not applied.

---

[42] OTSI found that the CM class locomotive manual stated that the independent brake was released by the DBI. Testing by OTSI confirmed this does not occur.

[43] Wabtec advised this configuration has not been implemented on the CM class locomotive.

[44] developed by MotivePower Inc. - a subsidiary of Wabtec USA, the locomotive builder

[45] Light engine: one or more locomotives coupled without wagons attached.

While Wabtec addressed this issue in earlier brake system designs by stipulating that 'during independent, emergency, or penalty brake applications, the dynamic brake interlock magnet [DBI] **MUST NOT** restrict the flow of air to the [locomotive] brake cylinders',[46] Wabtec Fastbrake did not. Rather, the Fastbrake manual (31394P) stated that during an emergency brake application the:

> …(DBI) function will release the locomotive's brake cylinder pressure developed from the [automatic brake] emergency brake application.

In recognition of the possibility of increased stopping distances on light engines, 31394P advised that in the event of an emergency:

- firstly, the independent brake was to be fully applied
- secondly, the automatic brake was to be applied to the emergency position.

This critical instruction was not replicated in the driver's manual for the CM class locomotive.

CM class locomotive power cut-out switch

The power cut-out switch (PCS) activates in circumstances of low brake pipe pressure, for example, if the driver selects 'handle off' or 'emergency'. Once activated, it automatically removes tractive effort from the traction motors and returns the locomotive to idle. The purpose of this is to prevent locomotive traction power working against the train's brakes in the event of an emergency brake application.

The CM class locomotive was fitted with this function, as stated in the operator's manual *(MP33C Locomotives MP33C Units CM3301 – CM3316)*, page 2-29:

> If emergency braking is activated while the throttle / DB handle is in one of the power notches (1-8), the pneumatic control switch (PCS)[47] opens automatically to cut power to the traction motors. …

Similar information was contained in the driver training materials supplied by Wabtec to CFCLA on handover of the CM class locomotive. For the CM class locomotive, the PCS activated at pressures below ~280 kPa.

Historically, the PCS and DKO were both contained on the same electrical circuit, whereby at low brake pipe pressures both locomotive traction power and dynamic brake would disengage.

However, the electrical circuit configuration allowed for the separation of the two functions. Static testing by OTSI on a CM class locomotive found that:

- An 'emergency' automatic brake application during dynamic braking resulted in a PCS, but dynamic brake stayed engaged.
- A 'handle out' automatic brake application during dynamic braking resulted in a PCS, but dynamic brake stayed engaged.

Qube later repeated these tests on a moving locomotive with the same results.

Operational procedures

Qube had a documented work instruction for operations on the Moss Vale to Unanderra rail line. WI-540 (*Moss Vale to Inner Harbour* [Port Kembla] *Train Management*).

Requirements in WI-540 included a calculation of the tonnes per operative brake (TOB) and a requirement to record a brake release rollaway time at Summit Tank. These actions were in the instruction to ensure train crew were aware of key train handling characteristics, to assist train management.

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[46] Wabco 1988, *"26-L" locomotive air brake equipment and devices.* American Standard Incorporated, Pennsylvania.

[47] Also referred to within the manual as the 'power cutout switch'.

Tonnes per operative brake

TOB is calculated by dividing the gross weight of the train (3966 was 3922.1 t) by the number of wagons with operable brakes. The 14th wagon CGSY4539Q had been identified on the train inspector's certificate for 3966 as having non-operative air brakes. Therefore, the number of wagons with operable brakes was 40. For 3966, the TOB was 98.

WI-540 also specified the TOB for grain trains could vary in value up to 100. Train crews were required to calculate the TOB to determine braking effort required on down grades. Grain trains with a TOB that exceeded 80 generally required higher brake cylinder pressures to bring the train to a stop or control the train speed. Drivers needed to be mindful of this when operating trains down steep grades.

Brake release rollaway time test

The brake release rollaway time test was required to be performed to give the driver an appreciation of the brake release and recharge times of the automatic brake. The train was required to be stopped using a 100 kPa brake pipe reduction. Once stopped, the driver would release the automatic brake and the train crew recorded the time it took for the train to start moving without the application of traction power. If the train moved following the 100 kPa reduction in less than 45 seconds, extra care was required to ensure sufficient recharge of the automatic brake after a stop was made, before continuing down the grade. Further information to clarify what 'extra care' meant was not detailed in the work instruction, but this may have been appropriate due to the subjective nature of the term 'extra care'.

Serial/Cycle Braking

WI-540 specified serial/cycle braking, where the dynamic brake is fully applied and the air brake graduated to control the speed of the train, as the preferred method if the TOB was less than 80 and only two locomotives were provided for dynamic braking. The procedure for serial/cycle braking was:

- When speed reached 15 km/h, apply automatic brake to minimum reduction.
- Apply further reduction in brake pipe pressure to ensure train speed is not increasing on the grade, do not exceed 100 kPa reduction if possible. The dynamic brake must be left in full applied position.
- If train speed increased towards 30 km/h, make a heavier brake pipe pressure reduction or stop the train.
- The train must be brought to a stop using the fourth consecutive brake application cycle.

Balance Braking

WI-540 specified balance braking, where the dynamic brake is graduated, as the preferred braking method if the TOB was more than 80 and two or more locomotives are provided for dynamic brake purposes. The procedure for balance braking was:

- When speed reached 15 km/h, apply automatic brake to minimum reduction.
- Check if weight of the train can be balanced on the grade, maintaining about 25 km/h.
- If train speed increased, reduce brake pipe pressure to 425 kPa. If speed then balanced, maintain control using the dynamic brake.
- If weight and speed could not be balanced using 75 kPa brake pipe pressure reduction and full dynamic brake, serial / cycle braking was to be used.

Additional instructions were provided in section 10 which required the train crew to stop the train and apply the locomotive independent brakes if at any time the brake pipe pressure needed to exceed 100kPa to control the train speed.

Section 13 of WI-540 re-iterated the requirements from the *ARTC RAS General Information 10.6*:

> Where braking problems occur on descending steep grades, the train crew shall advise the Network Controller and:
>
> - Stop the train
> - Rectify the problem
> - Advise the Network Controller before continuing

In an emergency situation, Section 14 of WI-540 provided the Emergency Train Management Procedures which stated:

> If in the event the train operation transition from standard train management to emergency train management, the following steps are to be completed:
>
> - The automatic brake valve handle is to be placed into the full service position ***do not place the handle into the emergency position***
> - The dynamic brake handle is to be placed into the full position
> - The independent brake must be manipulated so that the brake pressure does not exceed 100 kPa (the dynamic brake interlocking will activate at 105 kPa and the train will suffer a loss of dynamic brake capability)
> - Operate the locomotive sands
> - Train crew are to initiate an emergency call utilising the ICE Radio and communicate the current situation to the NCO

Related occurrences

El Zorro Transport, 7 February 2011

Loaded grain train 3996, travelling to Inner Harbour, Port Kembla, ran away as it descended the rail line between Summit Tank and Unanderra. The driver was unable to control the speed of the train towards the end of the descent. The 2988 t train was 691 m in length.

The investigation found that the driver did not test their air brakes at any stage after leaving Moss Vale although this was common practice. Several other RSO's driving procedures included the requirement for a driver to stop in the vicinity of 107.000 km and make a 100 kPa automatic brake application. After coming to a stand and only after all pressures had equalised, was the driver to release the independent brakes on the locomotive and then release the automatic brake. As soon as the brakes were released, the driver was to note the elapsed time in seconds before the train began rolling. This gave the driver an understanding of the recharge rate for the brake pipe and the timing of the release of the exhaust chokes on the wagons.

Between Summit Tank and the point at which 3996 came to a stand, the driver made several brake application and releases. Only on two of these occasions did the brake pipe air pressure return to full pressure (500 kPa). Also, successive brake applications were greater than the preceding application, indicating the driver was having trouble controlling the train as it increased speed due to 'running out of air'.

Qube Logistics, 22 April 2017

Loaded grain train 8960, travelling from Bogan Gate to Inner Harbour, Port Kembla, ran away as it descended the rail line between Summit Tank and Unanderra. After passing Dombarton, the driver realised he had lost control of the train. At 1248, the driver contacted the ARTC network controller who, in conjunction with Sydney Trains' train controller, cleared a pathway for 8960.

The maximum allowable speed for the Dombarton to Unanderra line was 30 km/h; however, the train reached a maximum speed of 107 km/h. At 1255, the train stopped, assisted by a shallower gradient near Unanderra station. There were no injuries or damage because of the incident.

The investigation found that as train 8960 was operated down the rail line between Summit Tank and Unanderra, the train management actions by the driver did not conform to Qube's train handling procedures. After passing Summit Tank, the driver made ten brake applications and releases and in doing so did not allow the train's automatic brake system to fully recharge. This resulted in a loss of necessary braking capability to be able to control the train's speed on the steep continuous descent. The incident was further compounded when the driver's actions (applying the independent brake) caused the locomotive's dynamic braking system to be rendered inoperative, further reducing control of the train.

The braking system of 8960 was operating within specification and wagons were loaded below the maximum allowable payload (3680 t). However, the train was loaded by approximately 10% more than that recorded on the train's consist record. It is probable that the additional mass placed an extra load on the braking system and affected the handling characteristics of the train.

Safety analysis

The loss of control leading to the runaway of the train was influenced by several factors. The primary contributing factors included wagons with variable net brake ratio (NBR), reduced brake cylinder pressure, a heavy train with some overloaded wagons, and dynamic braking affected by low adhesion conditions. Several individual actions by the driver that were inconsistent with the requirements in the work instruction contributed to the loss of control. These are discussed in more detail below.

Operation and braking did not control the train

WI-540 work instruction required the train's tonne per operative brake to be calculated prior to descending the Illawarra Mountain. Qube's internal report documented that this was not performed in this occurrence. The tonnes per operative brake (TOB) of the train was 98. A TOB that exceeded 80 generally required higher brake cylinder pressures to bring the train to a stop or control the train speed. Drivers needed to be mindful of this when operating trains down steep grades.

WI-540 also required the driver stop using a 100kPa reduction and check the brake release and recharge time at Summit Tank. The driver did not do this and stated in Qube's internal investigation that they had made a mental note of the train rollaway time and got a feel for the train brake during operation of the train. According to the data logger, the driver stopped the train using a 69 kPa reduction and did not release the brakes. This led to the driver dragging the train to commence descent down the mountain.

Without conducting this test, the driver was not aware if the train brakes would release in under 45 seconds, which would be an indicator for the driver to use extra care to ensure brakes were recharged after an automatic brake application. The absence of this brake test meant the driver was unable to confirm the effectiveness of the braking system, before commencing descent.

WI-540 also stated 'The brake pipe air flow must indicate a fully charged or almost fully charged brake pipe before second and subsequent brake applications are initiated'. The data logger record shows that a second serial braking application was initiated with 934 lpm flow of air into the brake pipe, indicating a significant flow of air was still filling the brake pipe so it was not yet fully charged.

It was also noted, this instruction presented a challenge to a driver having regard for the small margins for error. Adding 'almost' is not quantifiable and so leaves the driver to make difficult decisions, with little margin for error, on when to apply brakes.

For high risk operations in particular, steep gradient management, drivers must constantly weigh the demand to reduce the fast-accelerating speed against the demand to delay application so that the brake pipe can charge.

WI-540 further required the train to be stopped in the event of a greater than 100 kPa brake pipe reduction or when speed exceeded 30 km/h. During the second serial / cycle braking (final brake application sequence), the data logger record indicated no attempt to stop the train when the speed exceeded 30 km/h. After 42 km/h was reached, the driver applied a full-service brake application. Just prior to this, at 0422:55 a 103 kPa equalising reservoir reduction while travelling at 35 km/h was reached, but full service was still not applied.

At 38 km/h the driver increased the brake pipe reduction to about 120 kPa. The driver increased this to about 135 kPa at 41 km/h and finally to a 'full service' application (150 kPa brake pipe reduction) at 42 km/h. The driver applied the maximum braking effort which they believed to be achievable. However, once the train had reached 42 km/h, control of the train was lost.

The train remained in this braking configuration until it reached a speed of 85 km/h, at which time the driver applied the independent brake. The train did not immediately slow as a result of this brake application and continued to increase speed until the rear portion of the train, from the 29th wagon derailed as it rounded a 200 m left-hand radius curve, at a speed of 100 km/h. The 3rd to the 28th wagons then derailed seconds later as the train rounded a right-hand 200 m radius curve at a speed of 98 km/h. The locomotives and remaining two wagons then slowed significantly, stopping about one kilometre later.

Appreciation of brake recharge time

According to work instruction WI-540 (*Moss Vale to Inner Harbour Train Management*), Qube drivers were required to calculate the train's tonne per operative brake (TOB) prior to descending the Illawarra Mountain to estimate braking effectiveness. The TOB calculated for 3966 was 98, which was at the upper limit of 80−100 for grain trains. This meant that the train was almost at braking capacity limits for the long descending grade from Summit Tank to Unanderra. However, Qube found that the driver did not conduct this calculation prior to the descent.

To further assist drivers in judging the braking characteristics of their train consist, WI-540 required drivers to perform a running brake test enroute (that is, without stopping the train) and a rollaway time check at Summit Tank at the top of the grade. In the 45 minutes prior to arrival at Summit Tank, the driver made 15 running automatic brake applications and releases. In interview, the driver advised that at that stage the train appeared to brake normally.

For the rollaway time check, drivers were required to stop their train at Summit Tank using a 100 kPa brake pipe reduction and verify the amount of time it took for the train to commence rolling once the automatic brake was released. In addition to gauging the release time for the automatic brake, the stop and brake release at Summit Tank provided the driver with an indication of the brake pipe recharge time after a large service brake reduction.

This was one of the most critical checks conducted by train drivers prior to descending the mountain as it provided an indication of how much time it would take for the train's brakes to recharge following a significant brake application (100 kPa).

Although the driver stopped the train on arrival at Summit Tank, they did so with a 70 kPa brake pipe reduction, 30 kPa less than that required by the instruction. Further, once stopped, the driver applied traction power against the still applied automatic brake and commenced the descent, rather than releasing and assessing the brake release, and recharge time as per the instruction.

While the driver stated he had gained an appreciation of how the train was handling along the journey, not conducting this brake stop and release rate test, may have deprived the driver of some critical information, that was, the recharge time of the train's brake pipe following a significant brake application.

Discussions with other train drivers who have descended the same route over many years indicated the stop and check of the recharge time was an important step before descending the mountain because the recharge time on trains can vary.

Reduced dynamic braking

The driver made the first of the cycle braking applications with full dynamic brake at about 17 km/h. Sand operated automatically to assist in increasing the adhesion of the locomotive wheels under the heavy dynamic braking.

Wheel slip and slide occurs when adhesion between the wheel and rail interface is low.[48] The automatic sanding function on a locomotive occurs to improve or increase adhesion during braking. It also improves traction when locomotives are powering. In this case, frequent auto sanding occurred which was indicative that reduced or low friction impacted the ability of the locomotive's dynamic brakes to effectively provide optimal braking force.

Based on the CM class locomotive specifications, the mass of the locomotive and the maximum dynamic braking force, to achieve the maximum dynamic braking force the required coefficient of

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[48] Managing low adhesion 2018; Braking systems 2017

friction at the wheel rail interface was 0.18. The top of rail friction measurements taken approximately 6 months after the event, in dry conditions indicated the coefficient of friction was in the range of 0.2 to 0.36. It is likely that at the time of the train's descent, when the rail line was wet and featured significant leaf matter contamination that the coefficient of friction on the top of rail was lower than the locomotive required.

The dynamic brake was less effective under the low adhesion conditions than it would have been under higher adhesion conditions. The wheel slip/slide protection system, worked to maintain traction by use of auto sanding to increase friction and derating the dynamic braking effort through the wheels (as evidenced in the data logger, as dynamic brake power lowered sanding was initiated)

As the train's speed increased, the driver increased the brake pipe reduction to 83 kPa which was initially effective in slowing the train. With additional braking effort applied to the 40 wagons with operable brakes, the train driver was able to successfully reduce the train's speed. As discussed in *Rollingstock adhesion requirements* the friction level required by loaded freight wagons for braking was not compromised under the prevailing track conditions.

Wagons with variable net brake ratio

Measurements of NBR on various CGSY wagons ranged from 10.7% to 19.5%, which was a significant variation in NBR for a wagon type. These wagons were required by Australian Standards to achieve an NBR of 13% to 16% with a brake cylinder pressure of 350 kPa. ARTC recommended an NBR of 13% in order to provide effective braking without skidding wheels.

When these wagons were placed into service in September 2015, the type test, which was the industry standard requirement was met, with 14.23% NBR.

As stated in *History of CGSY wagons*, a design error that affected the braking performance on the CGSY wagons was identified shortly after their introduction into service. Although a few interventions were made to rectify the braking system, uncertainty remained as to the effectiveness of the modifications.

Evidence supported a degree of variability in the braking system in the CGSY fleet with varying results from NBR tests conducted on different wagons over time:

- 13 September 2015, wagon CGSY 4519A was tested (type test) and achieved an NBR of 14.23%
- 20 April 2017 wagon CGSY 4542H was tested (post modifications) and achieved an NBR of 15%
- 18 May 2017 wagon CGSY 4502V was tested (post incident) and achieved an NBR of 13.99%
- 9 February 2021 the two wagons that remained attached to the incident train, CGSY 4516T and CGSY 4518Y were tested and achieved NBRs of 12.45% and 10.7% respectively.

On 12 May 2021, three CGSY wagons that were not involved in this incident were tested and achieved the following NBR results:

- CGSY 4542H – 12%;
- CGSY 4503H – 19.5%;
- CGSY 4513P – 14.5%.

As CGSY 4542H did not meet the AS requirements for braking while in a loaded condition, Chicago Freight Car Leasing Australia (CFCLA) cleaned and greased the brake rigging and repeated the brake test on the 20 May 2021. This resulted in the wagon returning an NBR of 15.8%.

On 9 July 2021, after consultation of the AAR standard S401, which prevented the addition of grease on brake rigging for testing, CGSY 4542H brake rigging was cleaned and all evidence of grease removed. The NBR test was then repeated several times in the loaded and empty conditions. The NBR in the loaded condition was found to have an average of 13.85%.

CGSY 4542H

This wagon was of particular interest, as modifications and tests could be observed over its life cycle.

Based on the wagon type test conducted in September 2015, it's NBR should have remained in the vicinity of 14.23%

The wagon's slack adjuster pivot holes were re-drilled on its brake levers by CFCLA. It had a CIMC revised control lever design fitted by CFCLA. It was further modified by CFCLA in accordance with the recommendations from the SME.

In April 2017, the SME tested the wagon and made some minor adjustments before determining that the slack adjuster on the wagon was fully compliant with industry practice and brake force testing showed the wagon had an NBR of 15%.

While this wagon was not involved in the runaway of train 8960 that occurred on 22 April 2017, nor was it involved in this runaway of train 3966, it was brake tested on 12 May 2021 and achieved an NBR of 12%.

Following the cleaning and greasing of its brake rigging by CFCLA, a re-test on the 20 May 2021 achieved an NBR of 15.8%.

Then on the 9 July 2021, with removal of the grease and being tested multiple times, it achieved an average NBR of 13.85%.

The modifications and testing on this wagon indicated its braking performance varied over its life cycle. After modifications to improve the brake performance, it did fade over time to drop below the standard requirements. With interventions, such as cleaning and greasing, which were not permitted by Engineering standards (EPR 005), the NBR was raised above requirements and were proven to remain above requirements once the greasing of the brake rigging was rectified.

Reduced brake cylinder air pressure

At 0448 travelling at 15 km/h, and consistent with WI-540, the driver reapplied the automatic brake in 'minimum service' and then increased the brake pipe reduction to 70 kPa. However, as noted by the driver in interview, the brake pipe had not yet fully recharged.

The brake pipe at the locomotive was registering 489 kPa and the brake pipe charging flow indicator was still registering a rate of recharge of 934 litres per minute.

This second cycle braking automatic brake application was made before the brake pipe had fully recharged after the release of the first cycle braking brake application. This resulted in a reduced amount of available brake cylinder pressure to the driver for that and subsequent brake pipe reductions, and a lessened braking effort on the 40 trailing wagons with operational air brakes.

As a result, the train continued to increase speed with this 70 kPa brake pipe reduction.

For the driver, this was likely considered an appropriate brake pipe reduction to slow the train. However, as discussed in *Running out of air*, when the brake pipe has not been given a sufficient opportunity to recharge across the entire length of the train prior to the reapplication of the automatic brake, it will result in a lower auxiliary reservoir starting pressure, particularly on wagons at the rear of the train. As a result, there is a reduced pressure drop in the auxiliary reservoir when equalising with the brake pipe on the subsequent brake application. In response, the relay valve and supplementary reservoir provide less pressurised air to the brake cylinders, resulting in a reduced braking force than would be achieved if the auxiliary reservoir starting pressure was 500 kPa.

As the driver experienced nil effect from the brake application, they continued to reduce brake pipe pressure incrementally against a faster moving train which required greater braking force than was being applied, to stop. Each incremental brake application made by the driver at this time was against a gradually increasing speed of train, with increasing momentum requiring an even greater braking force to slow or stop the train.

Heavy train with some overloaded wagons

The weight of the train was near maximum allowable tonnage and probably under the 3680 t limit. Notwithstanding, it was likely a number of these wagons were over the allowable limit for a single wagon.

As detailed in *Train weight*, the wagons had been loaded inconsistently with some wagons being heavier than others. While the overall weight of the train consist was likely under the allowable weight limit for grain trains, it was apparent there were some wagons that were overloaded.

With a train near peak weight, there would be less scope for error with train handling and maintaining appropriate speed when descending the 1 in 30 grade on the Illawarra Mountain. Minor over speeds result in much greater downhill force for the train braking system to retard.

With individual wagons overloaded, the dynamics of these wagons is also affected impacting the ability of the wagon to operate as designed.

It is likely the driver expected he was operating a heavy train as the handwritten tonnage on the train consist was 3690 t. This should have been a trigger that the train was overloaded, even though the addition of the nominated individual wagon weights of 90 t each equated to 3622.7 t.

At interview the driver said they took a mental note of the weight of the train even though they had not calculated the tonnes per operative brake.

While the driver said they were aware of the train being heavy, it did not appear to change their method of operating the train on the descent.

Train driver decisions affected by fatigue

Fatigue research has shown that increasing fatigue is typically associated with an increasing likelihood of error.

There were factors which may have increased the driver's level of fatigue and consequently influenced their decision-making and handling of the train. Factors considered included prior sleep, wakefulness, hours of service and task demand.

Prior sleep

It is reasonably well established in the literature that sleep loss reduces the duration that a person can sustain alertness.[49] In a working environment (such as train driving) that requires the driver to remain vigilant and alert for several hours during the day and night, it is essential that drivers have enough sleep in the 24 and 48 hours prior to work to maximise opportunity for sustained alertness.

The sleep-wake history established during interview with the driver indicated they had slept 12 hours in the previous 48 hours, with 3 of the sleep hours being in the previous 24 hours leading up to the time of incident. These 3 hours consisted of the last 2 hours in regular sleep time (0500 to 0700) and 1 hour in the afternoon (1500) prior to commencing work.

The driver's block of sleep in the early hours of 14 December was 6 hours (0100 to 0700). The recommended sleep time for adults in the National Sleep Foundation Guidelines is 7-9 hours.[50]

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49 Dawson and McCulloch, 2005, Managing Fatigue: It's about sleep.

50 National Sleep Foundation's sleep time duration recommendations: methodology and results summary - PubMed (nih.gov)

The driver had also worked the night shift on the previous night (17:00 12th December to 06:00 13th December) and had only 5 hours of sleep in the day (07:00 to 12:00). Including the first 4 hours of the driver's sleep block on the 14th December, the driver had 9 hours sleep for that 24-hour period.

It is likely that the 12 hours of sleep in the previous 48 hours created a sleep debt[51]. The typical sleep hours of the driver were 8 hours in a 24-hour cycle.

It is likely a sleep debt contributed to the driver's level of fatigue.

Wakefulness

The time of the occurrence suggests the driver's level of alertness may have been influenced by the natural circadian rhythm or sleep-wake cycle.[52] Humans have a natural circadian rhythm which governs sleeping and waking. In the early hours of the morning (0300 to 0500), the body is driven to sleep and hence is not as alert as it would be later in the morning when the sun has risen.

Due to the time of day leading up to the occurrence, it was likely the sleep-wake cycle contributed to the driver's level of fatigue.

Hours of service

Leading up to the day of the incident, the driver was rostered and had worked an 11-hour night shift, had a 6-hour break, then an 11-hour afternoon shift, then a 20-hour break and was 10 hours into an 11-hour night shift when the incident happened.

The roster for the driver on the 14th December was planned to commence at 14:30, however, due to late running services the driver was informed approximately 2 hours prior to commencement that the shift was laid back to commence at 20:00.

The original roster was assessed by Qube and found to have a FAID score of 82.99. Scores between 80 to 100 represent a high fatigue likelihood. As this score was based on the driver's rostered hours, it is an indicator the rostered working hours likely to contributed to fatigue. Additionally, the layback of the start time on the 14th December would only have exacerbated the driver's level of fatigue.

Task demand

The driver commenced driving duties from Cootamundra and remained at the controls for the entire time leading up to the incident. This meant they were on the task of driving for approximately seven hours before starting the descent.

The second person was unable to relive the driver as they were not qualified to drive the route.

According to the train crew, they did not stop on the journey from Cootamundra, except for a momentary stop at Moss Vale to pick up a crew pass. This stop did not allow enough time for the driver to have a reasonable break from driving duties.

The time the driver spent driving the train without a significant break to relieve him from the task demand of driving the train likely contributed to the driver's level of fatigue.

Considering each of these factors, it was likely the driver's ability to make decisions at the time of driving the train between Summit Tank and Farmborough Heights was affected by fatigue. This was supported in review of the driver's actions and from in-cab recordings described below.

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51 Van Dongen et al, 2003, Sleep debt: Theoretical and empirical issues. Sleep debt may be defined as the cumulative hours of sleep loss with respect to a subject-specific daily need for sleep.

52 Circadian Rhythms first scientific observation in 1729 by Jean-Jaques d'Ortous de Mairan, they are a 24 hour internal cycle that regulates body functions such as sleep and wake times.

While the driver made increasingly heavier automatic brake applications in response to increases in speed, these decisions were delayed. According to WI-540, the balance point at which efforts should have been made to stop the train and fully recharge the braking system was when the brake pipe pressure reduction exceeded 100 kPa or, the speed of the train approached 30 km/h. The driver did not exceed a 100 kPa brake pipe pressure reduction until the train was travelling at 38 km/h (about 25% over speed). The driver also delayed the use of a 'full service' brake application with full dynamic braking (the maximum braking effort they believed to be achievable), until 42 km/h.

Operational decisions made by the driver on the morning of the incident, such as delaying the full service brake application until after the train was travelling above 30 km/h, may have been affected by fatigue.

The driver was an experienced shift worker and had descended that section of track on previous occasions and at similar times of the morning, At interview, the driver indicated they were not feeling fatigued at the time of the incident.

The physiological effects of fatigue result from hours of wakefulness and high cognitive task demands. Individuals are not always aware of the impacts or effects and the momentary lapses in concentration which may occur as a result.

The fact that the driver indicated at interview that he was not fatigued is not necessarily reliable given the high levels of stress and high cognitive workload he would have experienced at the time and in the early hours of the morning.

Driver did not apply the emergency brake

Dynamic braking in an emergency

In interview, the driver advised that during the second cycle braking application after leaving Summit Tank the train began behaving 'unpredictably'. That is, it was not slowing as expected based on the previous braking sequences.

Once the driver identified that control of the train had been lost, the driver advised the network control officer. During an update of the emergency to the network control officer, the driver stated '…I don't want to put it in emergency because I'll drop my dyno [dynamic brake] out'. The driver explained that as the automatic brake was already in the 'full service' position, they believed no further braking effort would be available in the 'emergency' position. Further, the driver believed that if the automatic brake was placed in the emergency position, the locomotive's dynamic brake would disengage, thereby reducing braking capacity and worsening the runaway situation.

The driver's actions were supported by Qube's work instruction WI-540 *(Moss Vale to Inner Harbour Train Management*), which in part, stated that in the event of an emergency:

> …the automatic brake valve handle is to be placed into the full-service position ***<u>do not place the handle into the emergency position</u>***.

This was due to Qube's similar understanding that the loss of dynamic brake with no increase in wagon braking effort would result if the automatic brake was placed in the emergency position.

However, testing by OTSI found that on the CM class locomotive the dynamic brake remained engaged and functional when the automatic brake was placed in emergency.

Low auxiliary reservoir starting pressure

In relation to the automatic brake on the day of the accident, analysis of the data logger of 3966 found that:

- On average, the brake pipe took 10 seconds to reduce to a commanded 'minimum service' brake pipe reduction (50 kPa).

- The second cycle braking sequence commenced before the brake pipe had fully recharged from the first cycle braking sequence. Specifically, at the time of the brake application, the brake pipe charging flow indicator indicated a rate of recharge of 934 litres per minute and the brake pipe pressure at the locomotive was 489 kPa, rather than 500 kPa.
- The brake pipe took 3 seconds, rather than 10 from a full brake pipe, to reduce to the commanded 'minimum service' brake pipe reduction (50 kPa) for the second cycle braking sequence.

During a brake pipe recharge the brake pipe air pressure throughout the length of a train varied, with the rear of the train lower in pressure than the front. Further, as it was recharged by the brake pipe, auxiliary reservoir pressure would lag the brake pipe pressure. As such, the brake pipe pressure reading at the front of the train was an unreliable indicator of auxiliary reservoir pressure, which was markedly lower (particularly at the rear of a train).

The low starting level and rapid drop in brake pipe pressure at the commencement of the second cycle braking sequence, indicated that the auxiliary reservoirs on 3966 were not fully recharged to 500 kPa. Given the rapid attainment of the minimum service brake pipe reduction at commencement of the second cycle braking sequence, it was highly likely that the true brake pipe pressure (and therefore auxiliary reservoirs), particularly towards the rear of the train, was closer to about 450 kPa.

On two-pipe wagons such as the CGSY and CGDY, brake cylinder pressure was provided by a supplementary reservoir which was supplied continuously with main reservoir air pressure. This meant that provided main reservoir air supply was available, the brake cylinders could always be supplied with air pressure. However, this was reliant on a reference (signal) air supply from the auxiliary reservoir acting on the relay valve, which enabled supplementary reservoir air to enter the brake cylinders. So, unless air pressure from the auxiliary reservoir was available to activate the relay valve, the supplementary reservoir could not apply a wagon's brake.

In normal braking circumstances, a full service automatic brake application would result in a concurrent equalisation of the brake pipe, auxiliary reservoir and brake cylinders (via the relay valve) at about 350 kPa. So, reducing the brake pipe further would not increase braking effort. However, in instances of low auxiliary reservoir starting pressure, the equalisation of the brake pipe with auxiliary reservoir in full service would result in a lower brake cylinder pressure. Specifically, for an auxiliary reservoir starting pressure of 450 kPa, the maximum brake cylinder pressure achievable in full service was substantially lower at approximately 235 kPa. This is consistent with the driver's observation that the brakes were not as effective as they had been during the previous brake application sequences since leaving Summit Tank.

However, in the unique circumstance of a low auxiliary reservoir starting pressure as was in this incident, it was possible to force an equalisation of the brake cylinder pressure at a higher rate than was by then achievable in full service. Where the auxiliary reservoir starting pressure was for example, 450 kPa, through further reduction of the brake pipe pressure to zero, an equalisation between the auxiliary reservoir and brake cylinder pressures would occur at about 314 kPa, thereby resulting in an increase in wagon braking effort. As it was not possible for the driver to graduate the brake pipe below 350 kPa, this would have required the driver to select either the 'handle off' or 'emergency' automatic brake positions, both of which would result in 0 kPa brake pipe pressure.

The effect of this increased brake cylinder pressure would have been apparent across the 40 wagons with operating air brakes on the day of the accident, particularly where low rail adhesion was causing a reduction of the dynamic braking effort on the two lead locomotives. Without an indication in the form of an in-cabin warning light and/or alarm the driver lacked awareness of the situation. Although it cannot be said with certainty that the train could have been stopped with this increased braking effort, it is more likely than not that a lower speed could have at the very least been maintained. Particularly if the emergency automatic brake application had been made early during the incident sequence and at a lower speed. That is, at the time the train was found to be exceeding the speed limit and not responding as expected to braking commands.

Operational procedure and training discouraged use of emergency brakes

Work instruction WI-540 *(Moss Vale to Inner Harbour Train Management*) provided specific instructions to be followed in an emergency, including the requirement to place the brake handle into full service, not emergency.

The driver had been trained to respond to a loss of control down the Moss Vale to Unanderra rail line in accordance with the work instruction as recently as two weeks prior to the incident. During that training, the driver completed a route assessment of the Moss Vale to Inner Harbour rail line with one of Qube's trainer assessors and was assessed as competent, including against the requirements of WI-540.

As discussed earlier in the analysis, in a situation where maximum braking from a full service application was not achievable due to less than full auxiliary reservoir starting pressure, the greatest braking power available would have come from reducing the brake pipe to 0 kPa. On the CM class locomotive, this would have resulted in a combination of full train air braking plus electrical dynamic braking from the locomotives.

In summary, Qube's operational procedure for train management between Moss Vale and Inner Harbour did not account for locomotive configurations that maintained dynamic brakes during emergency brake applications. This meant that a driver who lost control while descending the Illawarra Mountain was highly unlikely to use the emergency brakes. The use of the emergency brake in conjunction with the dynamic brake in this accident may have acted to slow or at least better control the speed of the train, thereby reducing the risk of derailment.

Train operators unaware of locomotive specifications

It was evident from the RSO's procedures that there were assumptions about the functionality of the dynamic brake, based on historical locomotive brake configurations and standards. That was, that dynamic brake functionality would be lost if the automatic brake handle was placed into the emergency position. This assumption was incorrect.

Wabtec, the manufacturer of the locomotive including its braking system, had stated in their Operations and Maintenance Manual for the CM class locomotives that the dynamic brake could be configured to remain active or to cut out in the event of low brake pipe pressure, but did not specify how the CM class was configured.

The technical specification provided to CFCLA and Qube was silent on whether the dynamic brake remained active after emergency automatic brake applications.

Post incident testing found the dynamic did in fact remain active with an emergency automatic brake application and Wabtec later advised, through the course of the investigation, that the dynamic brake cut out function had not been implemented on the CM locomotive class.

The Wabtec-developed driver training presentation also did not specifically mention that the dynamic brake would remain active when an emergency brake application was made. Conversely, there was no mention of the dynamic brake cutting out when an emergency brake application was made, so the assumption could be made that the dynamic brake would remain active, which is how the locomotive was configured.

Review of the locomotive handover information from the manufacturer to the owner (CFCLA) and the operator (Qube), did not provide a clear understanding as to what the dynamic brake would do when the emergency brake was applied. Given the significant change in functionality from what was historically understood by the RSO to be common practice, it was reasonable to expect that the details of the dynamic brake function would have been clearly articulated as part of the handover.

However, in the handover of the CM class locomotives, it was apparent that incorrect assumptions were made by the owner and operator about the dynamic brake and how it operated. These incorrect assumptions flowed into their procedures and training materials and so onto their drivers.

Other locomotives with functional changes

Similar functional changes on locomotives were identified more broadly across industry that were unknown to other operators. Dynamic brake functionality was found to be inconsistent across locomotives with electronic braking systems. While some locomotives would disengage the dynamic brake when an emergency brake application was made, this was not the case across all locomotive types.

This inconsistency in dynamic brake functionality coupled with this being unknown by many operators was considered significant as it reduced the ability of drivers to appropriately manage their trains.

As a result, the OTSI in collaboration with the ATSB published a Safety Advisory Notice about this safety issue (see Appendix A – Safety Advisory Notice).

Factors affecting rail adhesion

Wet rail

The weather conditions reported by the Bureau of Meteorology indicated there was moderate wind and light rain on the escarpment in the hours leading up to and at the time of the incident. These conditions likely increased the presence of water and leaf litter on the head of the rail.

At interview the driver stated there was 'very misty rain' when they started the descent between Summit Tank and Unanderra. The train data logger supported this statement, indicating the windscreen wipers activated between Tunnel 2 and Tunnel 1 for a duration over 6 minutes.

The United Kingdom's Rail Safety Standards Board's (RSSB) 2016 study[53] to model and quantify the influence of water on wheel rail adhesion coefficients found that light drizzle conditions had the greatest effect on reducing the adhesion coefficient. In these scenario's friction values could get as low as 0.05, with light quantities of water that would mix with wear debris or surface rust to form a lubricating paste.[54]

Track contaminant

The effect of leaf matter in reducing the wheel rail adhesion coefficient on rail lines is a known issue[55] and was found in a previous ATSB investigation.[56] Trees drop leaves onto the rail track which are then crushed when rollingstock passes over the leaf littered rail head. This plant matter contributes to reduced wheel rail adhesion coefficients.

The wheel rail adhesion coefficient has been found to be lower than 0.05 under severe rail contamination such as dampened leaf contamination.[57]

Front of train footage from the night of the accident showed trees lining the rail corridor from Summit Tank through to Farmborough Heights. Leaf matter was present on various parts of the

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[53] Modelling and quantifying the influence of water on wheel/rail adhesion levels – Phase 2 report, conducted for RSSB by University of Sheffield, L Buckley-Johnstone, University of Sheffield, R Lewis, University of Sheffield, K Six, Virtual Vehicle, G Trummer, Virtual Vehicle, 2016

[54] Wheel/rail adhesion — the overriding influence of water - ScienceDirect

[55] A survey of Wheel/Rail Friction, Federal Railroad Administration, Sept 2017

[56] RO-2013-005 Collision of passenger train T842 with station platform Cleveland, QLD, 31 January 2013

[57] Managing Low Adhesion, AWG Manual, 6th Edition, Jan 2018

rail line and was observed on the rail line at the derailment sites during the post incident inspections.

The weather conditions leading up to the 15 December 2020 had been wet and windy likely causing leaves to fall from the trees onto the rail track.

During the post incident track inspections, the contaminant observed on the head of the rail lines was more prominent in areas where the tree foliage was denser and dissipated as the trees cleared. The condition of the rail line closer to the top of the escarpment near Summit Tank was not observed during the site inspection, however it was considered likely the condition of the rail line at that time would have been similar to that observed at the derailment sites. The front of train footage (see Figure 3) indicated the density of tree foliage to be similar.

The sample of the contaminant tested was found to be primarily leaf matter. Leaf matter on rail head is a known contaminant that reduces adhesion of the wheel rail interface.

Rollingstock adhesion requirements

To help understand whether the condition of the rail line effected braking of the train, braking adhesion requirements were provided by ARTC.

For a loaded wagon, under the assumptions the NBR was 13% and the brake block coefficient of friction was 0.3, the required friction level = 0.039, or 3.9% required braking adhesion.

For the CM class locomotive, given the max dynamic braking power was 230 kN, the required friction level = 0.18, or 18% required braking adhesion. Other factors considered which would have influenced adhesion between the rollingstock and the top of rail includes:

1) on long freight trains the adhesion improves back along the train as wheels successively clean and dry the rail - so the average adhesion for train 3966 was likely higher than the referenced single-wheel adhesion.
2) tread-braked wheels, such as on train 3966, are cleaned and dried by the brake block, which aids maintenance of higher adhesion between wheel and rail. It is noted the referenced report RO-2013-005 was a passenger train with disk-braked wheels.

Considering these values and factors, it is likely the dynamic braking on the CM class locomotives was affected by the conditions on the rail line. This was evidenced by the frequent automatic sanding and dynamic brake power derating seen on the data logger of CM3316.

However, the wagons braking capacity should not have been affected by the conditions as the required braking adhesion levels of loaded freight wagons is significantly lower (at 3.9%) than the dry adhesion levels found on the rail line when measured on the 3 June 2021 (lowest at 20%). Additionally, the braked train wheels would have been successively cleaning and drying the rail line as they ran over making it even less likely the wagon wheels were affected by water and contaminant.

In summary, the conditions on the rail line from Summit Tank to Farmborough Heights on the morning of the incident presented a mix of factors including wet rail and track contaminant that likely increased the risk of reduced adhesion at the wheel-rail interface. This reduced adhesion likely affected the locomotive dynamic braking power but not so much as to affect the braking of the freight wagons.

Management of rail friction

Friction at the wheel-rail interface is the bond linking the tangential and normal forces that varies depending on vehicle speed, vehicle weight, contact patch and other material characteristics.[58]

[58] Yuan et al 2021

Managing the coefficient of friction at the interface of the top of rail and the wheel is important for predictable operation of the train's acceleration and braking systems.

While ARTC specified the design friction coefficients in their Code of Practice, these requirements were for design only. In the operational system, the friction coefficient can vary significantly as a result of various factors, including the nature of the steel in the rail and wheels, temperature and presence of materials such as, water, grease, oil, sand and vegetative material.

It is reasonable to consider the friction coefficient on the top of rail could change between two trains running along the same rail line if water and leaf matter were introduced, such as from a localised storm occurring in between the two trains passing a given location. The introduction of water (rain) and leaf matter on the top of rail could reduce the coefficient of friction at the wheel rail interface.

For this reason, a regular testing and monitoring program, even if conducted monthly is unlikely to provide assurance of the top of rail friction remaining at the value measured on the day.

For the descent of the Moss Vale to Unanderra rail line, the risk of a train running away has been realised on a few occasions. For this incident, it was likely a number of factors contributed to the eventual loss of control and runaway of the train. The top of rail friction was only one element that affected the performance of the train.

In this regard, when known factors present which increase the risk of reducing top of rail friction levels, such as, localised rain and wind events, it would be reasonable to afford some level of warning to train drivers that the line may present added risk and should be taken with extra care. There are existing processes in place, such as reporting of conditions affecting the network (CAN), that once reported by a train driver, warnings to other train drivers are made. However, this control mechanism relies on the first train driver being exposed to the risk without any warning.

Rail flange lubricators and track lubrication

ARTC maintenance records indicated the rail lubrication devices on the rail line between Summit Tank and Unanderra had been serviced in accordance with standards and the general inspection of rail lubrication conducted on 14 June 2020 did not identify any issues with the spread of rail grease from the lubricators.

Approximately six months after the incident, observations made by Qube of a rail track lubricator at Dombarton (97.030 km, in between No.1 Tunnel and the first point of derailment), showed a grease plume extending from the rail track lubricator, indicative of the lubricant being picked up and flung from the wheels and deposited in the surrounding area, including on the top of the rail head.

It was noted that the location of this rail track lubricator did not coincide with any of the rail lubrication devices listed in ARTC's maintenance history records and therefore could not be reconciled as to when its last general inspection was completed. It was not the only unlisted rail flange lubricator in the section as another at 94.30 km could not be reconciled with the maintenance history records. This rail flange lubricator was in very close proximity to the listed rail flange lubricator at 94.26 km. Visual inspection of these lubricators indicated both were operational.

These rail flange lubricators providing lubrication to the down rail, at 94.30 kms and 94.26 kms, were less than the 500 m minimum separation requirement specified in ARTC's engineering practices manual RC2411. Another two listed rail flange lubricators located at 94.95 kms and 94.53 kms, servicing the up rail were also less the 500 m minimum separation requirement.

Although the number and positioning of these rail flange lubricators was possibly intended for the strategic delivery of flange lubrication, a review of these to ensure consistency with the engineering practice and minimise the risk of excess track lubrication on a steep gradient was warranted.

Monitoring air flow

Maximum brake cylinder pressure on wagons is reliant on auxiliary reservoirs being fully charged (500 kPa) before a brake application is made. The brake pipe charging flow indicator instrumentation is available to the driver to help determine when the brake pipe, and therefore the auxiliary reservoirs are fully recharged after a brake release.

Although the brake pipe gauge in the driver's cabin may indicate a 500 kPa at the locomotive, where the brake pipe charging flow rate is above zero litres per minute, it is indicative of an incomplete brake pipe recharge throughout the train, particularly toward the back of the train. That is, main reservoir air is flowing into the brake pipe and auxiliary reservoirs. Whilst this is occurring, they are not fully charged and hence, it is not possible to reach maximum brake cylinder pressure if a brake application was made.

Knowing if and when main reservoir air was flowing into the brake system is important to the driver because it enables them to understand the condition (i.e. whether fully charged) of the brake pipe and auxiliary reservoir pressures across the entire train.

At interview, the driver recalled observing the brake pipe charging flow indicator and the brake pipe pressure gauge and judged the brake pipe to be about 90-95% recharged. The data logger recorded that the brake pipe pressure gauge was reading 489 kPa (that is, close to full pressure of 500 kPa) however, the brake pipe charging flow indicator was still registering a significant air flow of 934 litres per minute. This indicated that the train's brake pipe and auxiliary reservoirs were still charging and not yet fully recharged.

The driver's judgement of the brake pipe being 90-95% recharged was likely in relation to the brake pipe pressure gauge reading 489 kPa. Further, there was limited guidance for drivers of the significance of flow indicator gauge readings, in particular the level of recharge these were quantifying. For example, in this instance, 934 litres per minute, and what that indicated in relation to the physical state of recharge of the auxiliary reservoirs and the brake pipe across the train.

The brake pipe pressure and brake pipe charging flow indicator consisted of small numerical digital displays situated in the top left-hand corner of the driver's HMI screen. In the case of the latter, the display did not provide an obvious or distinct representation of the critical values that could be easily understood or quantified by the driver. For example, at maximum recharge (more than 3000 litres per minute), the value remained the same colour (green) as it did when recharge was almost complete (low litres per minute value). In addition, no audible indication was associated with the recharge. That is, there were no indications, apart from a small numerical display, to alert the driver that main reservoir air flow to recharge the brake pipe was occurring or continuing.

Amongst the other tasks conducted while driving a train, a driver may only make a momentary glance at the gauges. As a result, it is possible a driver could miss the importance of the value the brake pipe charging flow indicator was providing where no further alert stimulus was provided.

In contrast, it was noted during the investigation that on some locomotives fitted with an identical braking system to the CM class locomotive, an audible alarm was provided in conjunction with a red flashing tile when high air flow from the main reservoir to the brake pipe was detected. This assisted in proactively drawing a driver's attention to the state and condition of the brake pipe charging flow indicator. This assisted in the driver's ability to detect uncommanded brake pipe pressure loss (for example, derailment) and monitor when the train's brake pipe and auxiliary reservoirs were fully charged in preparation for an automatic brake application.

Communication of design changes

Prior to the design error in the CGSY wagons being identified by the CIMC, CFCLA considered the braking force on the wagons as not performing as required. CFCLA concluded the brake rigging ratio needed to be increased to improve the braking performance.

To achieve this, slack adjuster pivot holes were re-drilled in the brake lever. CIMC were advised that CFCLA were undertaking these modifications to the brake lever ratio, but the detail of the dimensional changes was not provided to CIMC.

Without the specifics of the design changes to the brake lever ratio, CIMC developed a design fault repair, that being a revised control lever, which when installed made no change to the operation of the brakes with the slack adjuster still unable to reduce the slack in the brake rigging.

Wayne Clift Consulting was engaged by CIMC to determine the root cause of the braking system performance.

The consultant found that changes had been made to the wagons braking system by CFCLA that had not been passed back to CIMC which resulted in the modified design failing to correct the issue.

CFCLA accepted the report from Wayne Clift Consulting and later engaged the consultant to complete the compliance and inspection report of the first modified wagons, in accordance with the Consultants recommendations.

The original change made to the brake levers by CFCLA were instigated without full consultation with the OEM, so the OEM was unaware of the details when they developed a repair. It is unclear whether CFCLA followed a systematic change management process when making the design changes to the brake levers.

Generally, any changes to equipment should be assessed and undertaken following a sound change management process. The rail industry in Australia has standards for management of change, such as AS7472:2018 Railway operations – Management of change.[59]

The standard describes the requirements to be applied by all rail organisations to ensure that safety risks associated with changes to railway operations, assets, or systems are identified and eliminated or reduced so far as is reasonably practicable.

Amongst other requirements in the standard, an integral step in the change process is to consult and communicate with relevant stakeholders. Prior to CFCLA making changes to the design of the braking system, consultation with the OEM (CIMC) would likely have assured a better outcome as input from the designer would have identified the design fault sooner and any ensuing changes would have considered this. However, CIMC was eventually informed of the changes made by CFLCA but the details of the changes, that is, the dimensions of the drilled holes from the original, were not provided, leaving CIMC to design a fault repair without full knowledge of the brake lever configuration.

Only through review of the fault by a contracted rollingstock specialist was the issue identified and further modifications made to address the issue.

CFCLA made changes to the CGSY wagons to improve the brake performance. While CIMC was informed of the changes, the details of the change were not provided which resulted in a design fault repair developed by the OEM being ineffective.

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[59] AS 7472 Railway operations – Management of change was prepared by Rail Industry Safety and Standards Board (RISSB) Development Group consisting of representatives from the Australian Rail Industry.

Findings

ATSB investigation report findings focus on safety factors (that is, events and conditions that increase risk). Safety factors include 'contributing factors' and 'other factors that increased risk' (that is, factors that did not meet the definition of a contributing factor for this occurrence but were still considered important to include in the report for the purpose of increasing awareness and enhancing safety). In addition, 'other findings' may be included to provide important information about topics other than safety factors.

Safety issues are highlighted in bold to emphasise their importance. A safety issue is a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operating environment at a specific point in time.

These findings should not be read as apportioning blame or liability to any particular organisation or individual.

From the evidence available, the following findings are made with respect to the runaway and derailment of loaded grain train 3966 near Dombarton, NSW, on 15 December 2020.

Contributing Factors

- The weight of the train was near, but likely not over, the maximum allowable tonnage limit specified by the Australian Rail Track Corporation (ARTC)'s Train Operating Conditions (TOC) Waiver 16002. It was likely however that several individual wagons across the train consist were over the allowable limit for a single wagon.
- The second automatic brake application was made before the brake pipe had fully recharged. This resulted in a reduced amount of available brake cylinder pressure to the driver for that and subsequent brake pipe reductions, and a lessened braking effort on the 40 trailing wagons with operational air brakes.
- The train driver did not effectively manage the train's speed or comply with operator prescribed braking, which resulted in the last cycle braking sequence not adequately controlling the train's speed, leading to the runaway.
- Some of the driver's decisions on the morning of the accident were likely affected by fatigue.
- Once control was lost, the driver did not select the emergency brake position based on the mistaken understanding that the dynamic brake would cut out when the emergency brake was applied. This resulted in less available braking effort, reducing the ability to control the speed of the train.
- **Qube's operational procedure for train management between Moss Vale and Inner Harbour did not account for locomotive configurations that maintained locomotive dynamic braking during emergency applications. This increased the risk of the train driver not using the emergency brake during a runaway event.** (Safety issue)
- The conditions on the rail line from Summit Tank to Farmborough Heights on the morning of the incident presented a mix of factors including wet rail and track contaminant that likely contributed to a reduced dynamic braking effort by the locomotives.
- Measurements of net brake ratio (NBR) at different times and on different wagons returned varying results ranging from 10.7% to 19.5%. While various modifications were made in order to improve braking performance on the wagons, the NBR on some wagons continued to change over time.

Other factors that increased risk

- The wagon type test met the NBR requirement when introduced into service and met NBR requirements when tested post modifications, however there was no requirement for regular testing of net brake ratio, which may have identified the changes in NBR.
- **The assumptions regarding locomotive configurations that cut-out locomotive dynamic braking during emergency applications was found embedded in other rollingstock operator's procedures with similarly configured locomotives in NSW.** (Safety issue)
- Several rail flange lubricators, which provided lubrication to the down and up rail were less than the 500 m minimum separation requirement specified in ARTC's engineering practices manual RC2411. A review of these to ensure consistency with the engineering practice and to minimise the risk of excess track lubrication on a steep gradient was warranted.
- The brake pipe charging flow indicator on CM class locomotives only provided a numerical display without any corresponding audio or visual warning system to alert the driver. This limited the ability for the driver to detect derailment or train separation events, and in this incident, effectively monitor recharge of main reservoir air to the brake pipe.
- CFCLA made changes to the CGSY wagons to improve the brake performance. While CIMC (the Original Equipment Manufacturer) was informed of the changes, the details of the change were not provided which resulted in a design fault repair developed by the OEM that was ineffective.

Safety issues and actions

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues. The ATSB expects relevant organisations will address all safety issues an investigation identifies.

Depending on the level of risk of a safety issue, the extent of corrective action taken by the relevant organisation(s), or the desirability of directing a broad safety message to the rail industry, the ATSB may issue a formal safety recommendation or safety advisory notice as part of the final report.

The initial public version of these safety issues and actions are provided separately on the ATSB website, to facilitate monitoring by interested parties. Where relevant, the safety issues and actions will be updated on the ATSB website as further information about safety action comes to hand.

Train Operators unaware of locomotive specifications

Safety issue description

The assumptions regarding locomotive configurations that cut-out locomotive dynamic braking during emergency applications was found embedded in other rollingstock operator's procedures with similarly configured locomotives in NSW.

Issue Number:	RO-2020-022-SI-03
Issue Owner:	Qube Logistics
Transport function:	Rail: Freight / Rail: Rollingstock
Current issue status:	Closed – Adequately Addressed
Issue status justification:	The safety issue has been found and addressed with Qube The safety issue was also found with two other major RSOs in NSW.

Response by Qube Logistics

The safety issue was raised with Qube after static testing on 4 May 2022. It was apparent the dynamic brake was not cutting out when emergency brakes were applied. Qube conducted further dynamic tests on 13 May 2022 and found the dynamic brake was not cutting out when emergency application was made.

Further questioning was raised with the other RSOs (s32's on 6 May 2022) to determine if the safety issue spread wider than Qube.

Responses received on 10 May 2022 and 24 May 2022.

ATSB comment

Qube updated their procedures to address the safety issue.

Responses from the other operators indicated there was a misunderstanding of locomotive capability/specification and this presents in the procedural and training information of these above rail operators.

The safety issue was raised verbally with these RSOs on 26 May 2022.

As an issue that potentially spread across a number of Operators, a Safety Advisory Notice was developed and released to the industry.

Safety advisory notice to Rail Transport Operators

SAN number:	RO-2020-022-SAN-02
SAN release date:	28 June 2022

The ATSB advises that all Rollingstock Operators (RSO) should review the specifications and test the locomotives under their control to understand how the braking systems are configured. RSO's must communicate this knowledge through the organisation's procedures and training material to ensure train crew knowledge and competence in operating locomotive braking systems.

Operational procedure and training discouraged use of emergency brakes

Safety issue description

Qube's operational procedure for train management between Moss Vale and Inner Harbour did not account for locomotive configurations that maintained locomotive dynamic braking during emergency applications. This increased the risk of the train driver avoiding the use of the emergency brake during a runaway event.

Issue Number:	RO-2020-022-SI-04
Issue Owner:	Qube Logistics
Transport function:	Rail: Freight / Rail: Rollingstock
Current issue status:	Closed – Adequately Addressed
Issue status justification:	The safety issue was raised with Qube, with initial response to assess what they would need to do to address the safety issue. Qube acknowledged there was an industry lack of knowledge of how particular emergency brake systems operated.

Response by Qube Logistics

The safety issue was raised with Qube after static testing on 4 May 2022. It was apparent the dynamic brake was not cutting out when emergency brakes were applied. Qube conducted further dynamic tests on 13 May 2022 and found the dynamic brake was not cutting out when emergency application was made.

Qube gave a verbal undertaking to commence assessing what they would need to do to rectify the safety issue.

Following release of the first draft report, Qube provided the following feedback:

Qube believes that the driver not selecting the Emergency Brake was not a Contributing Factor to the incident. Qube's analysis and independent report indicated that selecting Emergency in this situation would not have affected the braking performance of the train as the ATSB report suggests. Qube's analysis indicates this more likely would have increased risk and wheel slide on the rail.

Qube acknowledged that there was an industry lack of knowledge for how this particular Emergency Brake system operated but maintains it did not contribute to the incident or its outcomes.

Qube's understanding is that application of emergency braking in this instance would have likely resulted in a worse outcome.

Since receiving the ATSB draft report, Qube has undertaken initial tests on brake cylinder pressures for a train in full emergency.

Qube stated the initial results indicated that no further increase in brake cylinder pressure or brake force would have been experienced in emergency application.

ATSB comment

When ATSB requested these tests be run again in the presence of ATSB, Qube stated they would not be spending any more time on this testing.

Qube has since ceased any further testing.

Qube has updated their procedures to address the safety issue.

General details

Occurrence details

Date and time:	15 December 2020 – 0454 EST	
Occurrence class:	Serious incident	
Occurrence categories:	Runaway and derailment	
Location:	[12 km southwest of Wollongong, New South Wales]	
	Latitude: 34º 27.408' S	Longitude: 150º 46.329' E

Train details

Track operator:	Australian Rail Track Corporation	
Train operator:	QUBE Logistics Pty Ltd	
Train number:	3966	
Type of operation:	Freight	
Consist:	Locomotives: CM3316 and CM3304, Wagons: 39 x CGSY, 2 x CGDY	
Departure:	Temora	
Destination:	Port Kembla	
Persons on board:	Crew – 2	Passengers – 0
Injuries:	Crew – 0	Passengers – 0
Damage:	Substantial damage to track infrastructure, destroyed 39 wagons	

Sources and submissions

Sources of information

The sources of information during the investigation included the:

- Train crew of 3966
- Qube Logistics (Rail) Pty Ltd
- Australian Rail Track Corporation
- Office of the National Rail Safety Regulator
- Wabtec Australia
- Railfirst, formerly Chicago Freight Car Leasing Australia (CFCLA)

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Submissions

Under section 26 of the *Transport Safety Investigation Act 2003*, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. That section allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the following directly involved parties:

- Qube
- ARTC
- Wabtec
- Railfirst
- Office of the National Rail Safety Regulator
- Monash Institute of Railway Technology
- Train driver
- Assistant train driver

Submissions were received from:

- Qube
- ARTC
- Wabtec
- Railfirst
- Office of the National Rail Safety Regulator
- Monash Institute of Railway Technology

The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

Appendices

Appendix A – Safety Advisory Notice

Australian Government
Australian Transport Safety Bureau

Office of Transport Safety Investigations

Safety Advisory Notice

To Rollingstock Operators
Number: RO-2020-022-SAN-002

Unknown functions in locomotive braking systems

An ongoing investigation, conducted by NSW's Office of Transport Safety Investigations on behalf of the Australian Transport Safety Bureau, highlights risks associated with misunderstood functionality of locomotive braking systems. Locomotive drivers require a clear understanding of the braking systems on all the locomotives they are operating.

What happened

On 15 December 2020 a loaded grain train derailed whilst descending the 1 in 30 grade rail line between Robertson and Unanderra, NSW.

Runaway locomotives (Source: ATSB)

Why did it happen

During the descent, the train driver lost control of the train. As the train continued to increase speed, the driver did not apply the emergency brake, believing an emergency application of the air brake would disengage the dynamic brake.

The ATSB identified that the locomotives involved had an electronic braking system that allowed the dynamic brake to remain active while the emergency brake was applied. This feature was unknown to the operator and the train driver.

While the specific circumstances of this incident and contributing factors are still under investigation, the ATSB has issued this safety advisory notice to advise rolling stock operators and operational staff of a potential broader industry safety concern.

The ATSB identified similar functional changes on locomotive braking systems more broadly across industry that were also unknown to Rollingstock Operators.

Importantly, dynamic brake functionality is not consistent across all locomotives with electronic braking systems. While some locomotives will disengage the dynamic brake when an emergency brake application is made, in other locomotives the dynamic brake remains functional.

Safety advisory notice

RO-2020-022-SAN-002: The ATSB advises that all Rollingstock Operators (RSO) should review specifications and test locomotives under their control to understand how the braking systems are configured. RSOs must communicate this knowledge through their organisation's procedures and training material to ensure train crew knowledge and competence in operating various locomotive braking systems.

Ensure understanding of locomotive specifications and operation

Rollingstock Operators must have a complete understanding of the operation of their locomotives. Identifying safety critical information from technical specifications and testing locomotive operations must be completed and used to inform the organisation's procedural and training material.

Read more about this ATSB investigation:
https://www.atsb.gov.au/publications/investigation_reports/2020/rair/ro-2020-022/

Released: 27 June 2022

Australian Transport Safety Bureau

About the ATSB

The ATSB is an independent Commonwealth Government statutory agency. It is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers.

The ATSB's purpose is to improve the safety of, and public confidence in, aviation, rail and marine transport through:

- independent investigation of transport accidents and other safety occurrences
- safety data recording, analysis and research
- fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia, as well as participating in overseas investigations involving Australian-registered aircraft and ships. It prioritises investigations that have the potential to deliver the greatest public benefit through improvements to transport safety.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, international agreements.

Rail safety investigations in New South Wales

Most transport safety investigations into rail accidents and incidents in New South Wales (NSW) are conducted in accordance with the Collaboration Agreement for Rail Safety Investigations and Other Matters between the Commonwealth Government of Australia and the State Government of NSW. Under the Collaboration Agreement, rail safety investigations are conducted and resourced in NSW by the Office of Transport Safety Investigations (OTSI), on behalf of the ATSB, under the provisions of the *Transport Safety Investigation Act 2003*.

- **Office of Transport Safety Investigations (OTSI)** is an independent statutory body which contributes to improvements in the safety of bus, ferry and rail passenger and rail freight services in NSW by investigating safety incidents and accidents, identifying system-wide safety issues and sharing lessons with transport operators, regulators and other key stakeholders. Visit www.otsi.nsw.gov.au for more information.

Purpose of safety investigations

The objective of a safety investigation is to enhance transport safety. This is done through:

- identifying safety issues and facilitating safety action to address those issues
- providing information about occurrences and their associated safety factors to facilitate learning within the transport industry.

It is not a function of the ATSB to apportion blame or provide a means for determining liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner. The ATSB does not investigate for the purpose of taking administrative, regulatory or criminal action.

Terminology

An explanation of terminology used in ATSB investigation reports is available on the ATSB website. This includes terms such as occurrence, contributing factor, other factor that increased risk, and safety issue.