Rail Accident Investigation Branch

Rail Accident Report

Freight train derailment at London Gateway, Essex

24 December 2021

Report 14/2023
December 2023

This investigation was carried out in accordance with:

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

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Preface

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

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

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

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

Any information about casualties is based on figures provided to RAIB from various sources. Considerations of personal privacy may mean that not all of the actual effects of the event are recorded in the report. RAIB recognises that sudden unexpected events can have both short- and long-term consequences for the physical and/or mental health of people who were involved, both directly and indirectly, in what happened.

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

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Freight train derailment at London Gateway, Essex, 24 December 2021

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Summary

At around 05:45 hrs on 24 December 2021, 5 wagons of a 33-wagon intermodal freight train derailed at low speed as the train was entering the rail terminal at London Gateway port, Essex. The derailment started when wheels on a wagon in the middle part of the train suddenly lifted off the track, just before reaching the port boundary, with the other wagons becoming derailed as they passed over points within the rail terminal. While no one was injured, infrastructure damage disrupted rail freight access into and out of the port for 14 days.

The first derailed wagon was the unloaded centre wagon of a triple-wagon, which was made up of three individual wagons permanently coupled together. The wagons on the train either side of the unloaded centre wagon were all loaded, and a train brake application had recently been made when the derailment occurred. A longitudinal train dynamic simulation model, specially developed as part of the investigation, showed that compressive forces generated in the train were larger towards the middle of the train, where the triple-wagon was located, and rapidly increased to a maximum as the centre wagon approached the place where it became derailed. Data from the train's on-train data recorder showed that this was shortly after brake forces acting on the locomotive had peaked and that the train's brakes would have been starting to release.

Derailments in 2015 involving an earlier version of the type of triple-wagon involved demonstrated that triple-wagons of this design configuration were susceptible to derailment when large longitudinal compressive forces are suddenly applied. Early derailment simulation studies had confirmed this and helped inform a decision to lengthen the bar coupler on the earlier version of these wagons to improve derailment resistance. The wagon designers identified the need to make other design changes when the new version of the triple-wagon was developed for unrelated reasons. However, although the risks due to longitudinal compressive force continued to be recognised, the need to make further design improvements to address them was not deemed to be necessary. Derailment simulations undertaken in support of the investigation helped show that the new version of the triple-wagon remained similarly susceptible to derailment and confirmed that the lack of payload on the centre wagon, and possibly in-service degradation of the bogie, increased the derailment risk.

The investigation found that the risks associated with the longitudinal dynamic behaviour of long freight trains are not well understood in the rail industry and that there are limited processes, tools, and knowledge resources available to assess and manage them. This was identified as an underlying factor. The investigation has identified the design management arrangements that were adopted during the development of the new version of the triple-wagon as another underlying factor. It is possible that these arrangements limited the designers' ability to understand the dynamic behaviour of the triple-wagon and did not result in the identification of critical performance requirements.

RAIB has made three recommendations. One is directed to VTG Rail, the owner and developer of the triple-wagon, covering the need to identify and implement any necessary design changes and operating restrictions. The second is directed to GB Railfreight, the operator of the train, covering the need to develop instructions and best practice guidance for its operations staff. The third is directed to RSSB covering the need to raise the rail industry's understanding of the derailment risks associated with longitudinal compressive forces and the management strategies that need to be introduced.

Introduction

Definitions

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

2 All mileages are taken from a datum at London Fenchurch Street station. Left and right orientations relate to the direction of travel of the train when the accident occurred.

3 The term ‘rail industry’ refers to the various organisations and parties, each with individual responsibilities and duties, that co-operate to deliver rail services on the mainline railway in Great Britain.

4 The term ‘wagon’ refers to an item of freight rolling stock that is braked but unpowered. A freight train comprises a number of wagons that are coupled together and hauled by a locomotive. The term ‘triple-wagon’ refers to three wagons that are permanently coupled together, while ‘twin-wagon’ refers to two permanently coupled wagons. The term ‘single wagon’ is used to refer to a wagon that is not permanently coupled to another wagon. The term ‘vehicle’ is used to refer to an item of rolling stock in general, in this case either a wagon or a locomotive.

5 The term ‘coupler’ refers to any arrangement of equipment designed to connect two vehicles, thereby controlling the degree to which they can separate or draw closer together.

6 The report refers to ‘Ecofret 1’ and ‘Ecofret 2’ wagons. These are variants of the FWA type of intermodal wagon (see paragraphs 47 to 58).

7 The report contains abbreviations. These are explained in appendix A.

The accident

Summary of the accident

8 At around 05:45 hrs on 24 December 2021, five wagons within freight train reporting number 4L47[1] derailed on the Thames Haven line on the approach to London Gateway port, near to Stanford-le-Hope, Essex (figure 1). Train 4L47 was the scheduled GB Railfreight (GBRf) 22:35 hrs (on 23 December) intermodal service from the freight terminal at Hams Hall, near Birmingham, to London Gateway port. The service was carrying freight containers.

9 Train 4L47 had been routed off the Down Tilbury line at Thames Haven Junction. The train had just started to enter the port infrastructure when the derailment occurred. The 12th wagon derailed to the left on a section of line without points or crossings (termed as 'plain line') approaching LG11 signal, just before reaching the boundary between Network Rail's infrastructure and that managed by the port operator (figure 2). The locomotive's on-train data recorder (OTDR) registered that the train brakes were being applied at the time of the derailment and that the train was rapidly slowing to a speed of 9 mph (14.5 km/h). The 11th, 13th, 14th and 15th wagons subsequently derailed as a consequence.

10 Realising something was wrong, the driver brought the train to a stand on the Port Arrivals line, 740 metres beyond LG11 signal. The train remained coupled together during the derailment, with all the wagons staying upright. Figure 3 shows the position of the train after the derailment.

Figure 1: Extract from Ordnance Survey map showing the location of the accident at London Gateway.

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[1] An alphanumeric code, known as the 'train reporting number', is allocated to every train operating on Network Rail infrastructure.

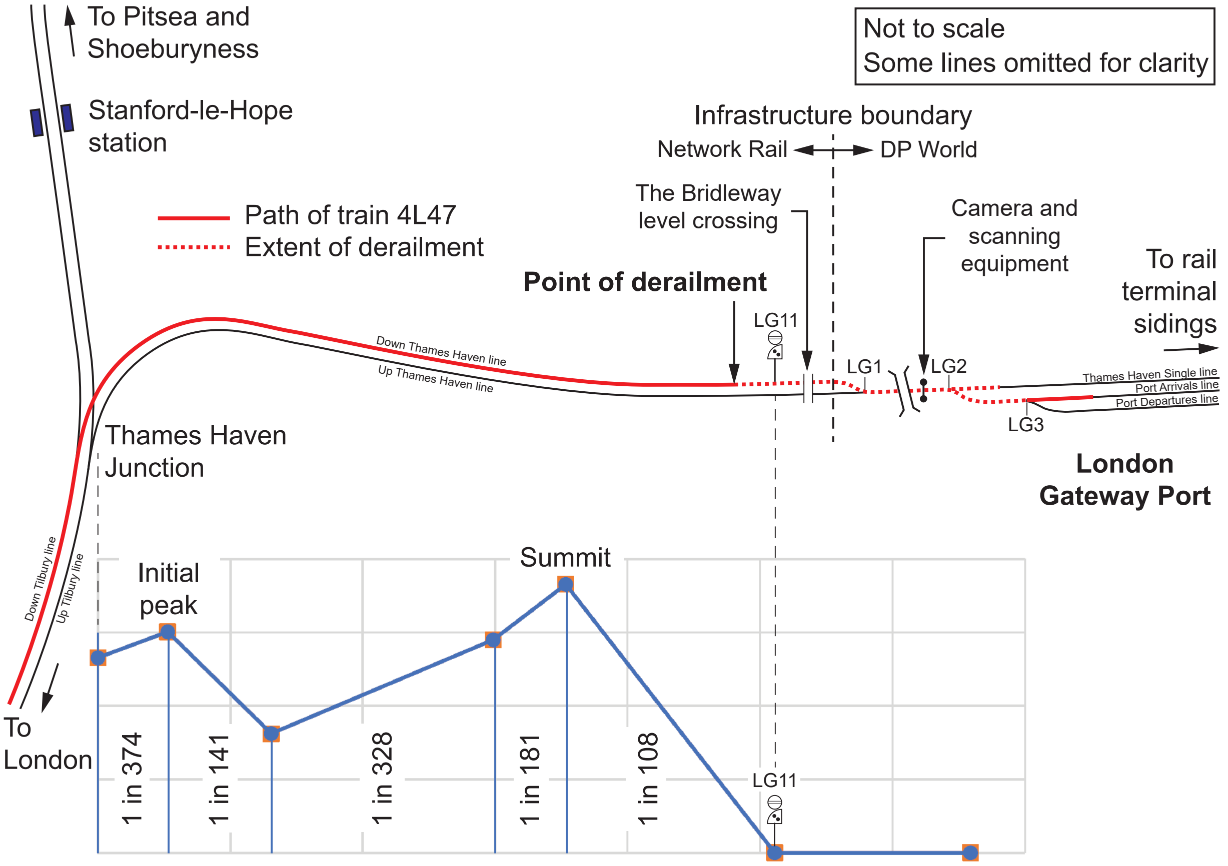

Figure 2: Track layout on Thames Haven line showing the gradient profile and the route of the train.

11 No one was injured in the accident, although there was major damage caused to the railway infrastructure and six wagons required repair. The derailment also resulted in major disruption to rail freight access into the port.

Context

Location

12 London Gateway port is a deepwater container terminal on the Thames, located around 40 km east of central London. Constructed on the site of a former oil refinery, it opened for operation in 2013. The Thames Haven line connects the mainline railway to the rail terminal at the port. The line and associated railway infrastructure were redesigned and renewed as part of the construction work for the new port. The new rail terminal is capable of handling trains up to 775 metres long.

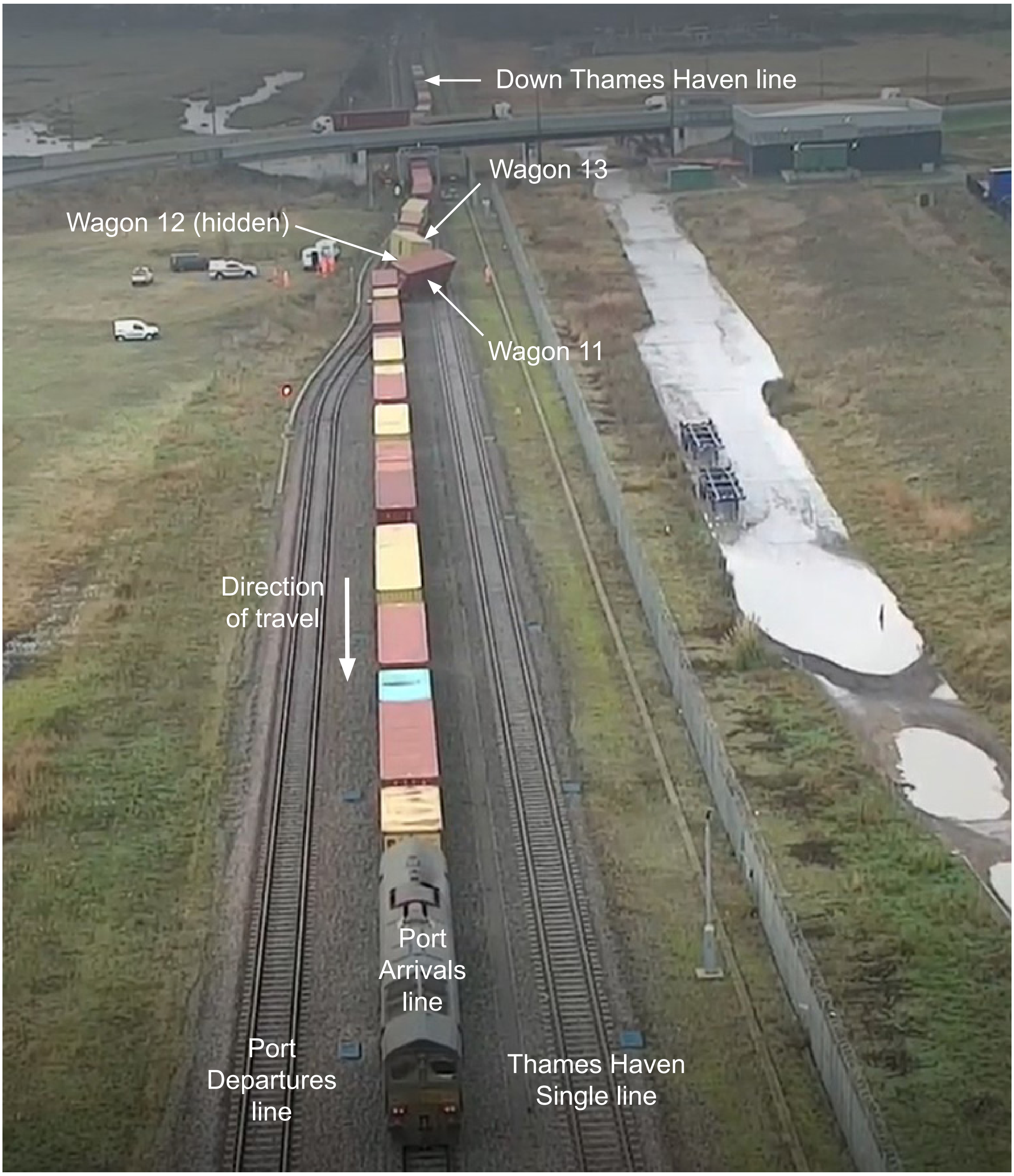

Figure 3: Position of the train after the derailment (image courtesy of British Transport Police).

13 Trains join the Thames Haven line at Thames Haven Junction (26 miles 41 chains) on the London, Tilbury, and Southend line. It initially comprises two lines: the Down Thames Haven, used by trains entering the port, and the Up Thames Haven, used by departing trains. Trains entering the port pass LG11 signal, then a user worked level crossing (The Bridleway) (28 miles 7 chains) and, shortly afterwards, the infrastructure boundary (28 miles 9 chains) between the mainline railway and the port. The two lines then join to form the Thames Haven Single line at LG1 points. The single line continues under the overbridge carrying the port access road, after which LG2 and LG3 points provide access to the Port Arrivals and Port Departures lines and the rail terminal sidings (figure 2).

14 Trains routed towards London Gateway port enter the Down Thames Haven line on a right-hand curve and climbing gradient. After reaching an initial peak, the curvature on the line eases to the left and the railway continues to climb, reaching a final summit at 27 miles 45 chains, just over one mile (1.7 km) beyond the junction. The line then descends on a gradient of 1 in 108 and becomes level shortly before LG11 signal. The gradient profile is shown at figure 2.

15 Various maximum permitted line speeds apply for trains routed into the port rail terminal. These are:

- a 25 mph (40 km/h) limit from Thames Haven Junction on the Down Thames Haven line to 28 miles 33 chains on the Thames Haven Single line, shortly after the overbridge
- a 15 mph (24 km/h) limit from 28 miles 33 chains to 29 miles 74 chains on the Thames Haven Single line, and also on the Port Arrivals and Port Departures lines
- a 5 mph (8 km/h) limit beyond 29 mile 74 chains on the Thames Haven Single line.

16 Train movements outside the port rail terminal are controlled by lineside signals operated from Network Rail's Upminster signalling control centre. LG11 signal controls access into the rail terminal. LG11 signal, and the signals used to control movements within the rail terminal, are operated from the London Gateway rail control centre.

Organisations involved

17 Network Rail owns, manages, and maintains the railway infrastructure on the approach to the infrastructure boundary where the 12th wagon (wagon 12[2]) derailed. This section of line lies within Network Rail's Anglia route, which is part of its Eastern region.

18 DP World owns, manages, and maintains the railway infrastructure within London Gateway port (beyond the infrastructure boundary) where the four other wagons (wagons 11, 13, 14 and 15) consequently derailed and train 4L47 came to a stand.

19 GBRf operated train 4L47 and employed its driver. It leased wagon 12, an FWA type wagon, and the 11 other FWA type wagons on the train. It also either leased or owned the other vehicles on the train, including the locomotive, and was responsible for the maintenance for most of them. DP World contracted GBRf to operate the port rail terminal and to provide the ground staff required.

20 VTG Rail owned and maintained the FWA wagons on the train, including wagon 12, and leased them to GBRf. All the FWA wagons on the train were of the Ecofret 2 variant, a wagon of recent design. VTG Rail specified the Ecofret 2 design requirements and led the development, procurement and approval work needed to obtain authorisation for placing the wagons into service. VTG Rail appointed consultants to assist it with the work.

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[2] Wagons are referred to in the report by their position along the train.

21 Wabtec UK Ltd[3] (referred to as 'Wabtec' in the remainder of this report) designed, manufactured, and supplied the bogies that VTG Rail required be fitted to the Ecofret 2 wagons. It supported VTG Rail with the approval work needed to obtain authorisation for placing Ecofret 2 wagons into service.

22 WH Davis designed and manufactured the Ecofret 2 wagon underframe. It was based on the design of the Ecofret 1 wagon, an earlier FWA wagon variant, the design rights for which VTG Rail already owned. WH Davis also assembled the wagons and supported VTG Rail with the approval work needed to obtain authorisation for placing Ecofret 2 wagons into service.

23 VTG Rail appointed AEGIS Certification Services Limited (ACS) to undertake conformity assessments for the Ecofret 2 wagon against applicable technical standards and safety requirements. This was part of the approval work needed to obtain authorisation for placing Ecofret 2 wagons into service.

24 The Rail Safety and Standards Board (RSSB) is the organisation that supports the rail industry in improving its safety performance. Its principal activities include: managing research and development programmes; developing, agreeing and maintaining standards; and providing insight, analysis and guidance on railway systems, safety and health.

25 Network Rail, DP World, GBRf, VTG Rail, Wabtec, WH Davis, ACS and RSSB freely co-operated with the investigation.

Train involved

26 Train 4L47 was formed of a class 66 diesel-electric locomotive and a mixture of 33 intermodal flat wagons. These were:

- four Ecofret 2 triple-wagons, each comprising three wagons permanently coupled with a bar coupler between each wagon (12 wagons altogether)
- six FEA type twin-wagons (a mixture of FEA-A, FEA-B and FEA-C types), each comprising a pair of wagons permanently coupled with a bar coupler between them (12 wagons altogether)
- nine FEA-S type single wagons.

Each triple-wagon, twin-wagon, single wagon and the locomotive were coupled to each other using a conventional screw coupling and side buffer arrangement.

27 Wagon 12, the first wagon to derail, was the centre wagon of an Ecofret 2 triple-wagon. As such, it was permanently coupled (by a bar coupler) to two outer wagons. These were wagon 11 in front, and wagon 13 behind. Except for wagon 12, all the wagons on the train carried at least one freight container. Table 1 is a summary of the consist of train 4L47 and the payload recorded on the train document. The train had an approximate length of 621 metres.

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[3] Previously known as Wabtec Rail Ltd.

Vehicle	Type	Number	Payload[4]	Connection to next vehicle	Outcome
Locomotive	Class 66	66779	-	SC+B	
Wagon 1	FEA-C	650026	Two containers (29.3t + 30.0t)	BC	
Wagon 2	FEA-C	650025	Two containers (29.7t + 19.4t)	SC+B	
Wagon 3	FEA-S	640632	Two containers (31.9t + 29.8t)	SC+B	
Wagon 4	FWA-Ecofret 2	7045202301	One container (20.7t)	BC	
Wagon 5	FWA-Ecofret 2	7045210510	Two containers (30.1t + 26.6t)	BC	
Wagon 6	FWA-Ecofret 2	7045202319	One container (12.0t)	SC+B	
Wagon 7	FEA-A	630037	Two containers (16.0t + 29.8t)	BC	
Wagon 8	FEA-A	630038	Two containers (13.8t + 27.2t)	SC+B	
Wagon 9	FEA-S	640666	Two containers (4.4t + 29.3t)	SC+B	
Wagon 10	FEA-S	640909	Two containers (27.4t + 29.7t)	SC+B	
Wagon 11	FWA-Ecofret 2	7045202574	One container (18.9t)	BC	Derailed later
Wagon 12	FWA-Ecofret 2	7045210643	No container	BC	First to derail
Wagon 13	FWA-Ecofret 2	7045202566	One container (20.0t)	SC+B	Derailed later
Wagon 14	FEA-B	643020	Two containers (29.3t + 10.0t)	BC	Derailed later
Wagon 15	FEA-B	643019	One container (29.9t)	SC+B	Derailed later
Wagon 16	FWA-Ecofret 2	7045202335	One container (29.4t)	BC	
Wagon 17	FWA-Ecofret 2	7045210528	One container (28.4t)	BC	
Wagon 18	FWA-Ecofret 2	7045202327	One container (29.4t)	SC+B	
Wagon 19	FEA-A	630019	One container (14.2t)	BC	
Wagon 20	FEA-A	630020	Two containers (43.4t + 28.4t)	SC+B	
Wagon 21	FEA-S	640915	Two containers (18.6t + 25.6t)	SC+B	
Wagon 22	FEA-C	650032	Two containers (29.4t + 30.4t)	BC	
Wagon 23	FEA-C	650031	One container (30.4t)	SC+B	
Wagon 24	FEA-S	640686	Two containers (28.4t + 29.3t)	SC+B	
Wagon 25	FEA-S	640660	Two containers (17.9t + 29.8t)	SC+B	
Wagon 26	FEA-B	640621	Two containers (27.8t + 13.8t)	BC	
Wagon 27	FEA-B	640622	Two containers (29.2t + 29.3t)	SC+B	
Wagon 28	FEA-S	640642	Two containers (29.3t + 29.2t)	SC+B	
Wagon 29	FWA-Ecofret 2	7045202111	One container (4.4t)	BC	
Wagon 30	FWA-Ecofret 2	7045210411	Two containers (29.0t + 29.8t)	BC	
Wagon 31	FWA-Ecofret 2	7045202103	One container (11.0t)	SC+B	
Wagon 32	FEA-S	640662	Two containers (26.4t + 28.0t	SC+B	
Wagon 33	FEA-S	640691	Two containers (29.3t + 30.2t)	-	

SC+B	Screw coupling plus side buffers
BC	Bar coupler

Wagon type:

Single wagon
Twin-wagon
Triple-wagon

Table 1: Train 4L47 consist and recorded payload.

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[4] Payload in tonnes (t). Containers on the derailed wagons were examined and weighed after the derailment. The measurements suggested that the actual train payload may have differed from that recorded on the train document. RAIB has taken account of this in the supporting wagon derailment simulation work (appendix D).

Railway and port infrastructure

28 The track on the Thames Haven line was laid for the port's opening in 2013. It comprises CEN60 rail[5] supported on concrete sleepers and stone ballast. The rails are seated on polymer pads and secured to the sleepers with steel rail fastenings.

29 Network Rail's track geometry measurement train ran over the Down Thames Haven line on 13 July 2021. This was the last recording run before the derailment. No track geometry faults were recorded in the vicinity of the derailment that required intervention[6] before train 4L47 ran over the line on 24 December 2021. RAIB compared data from the recording run with track gauge and cross level measurements that Network Rail made immediately after the derailment. This indicated that the track had not significantly deteriorated in the meantime.

30 On entry to the port rail terminal, trains pass a set of lineside cameras and optical character recognition (OCR) scanners. These collect information about the train and the container payload (figure 4). The equipment is located just after the port access road overbridge (figure 2). It includes lights to illuminate the train as it passes.

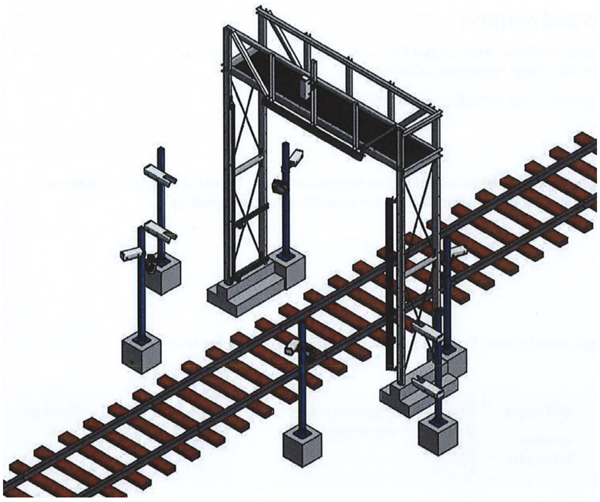

Figure 4: Camera and scanning equipment on entry to the port (diagram courtesy of DP World).

Staff involved

31 The driver of train 4L47 joined GBRf in January 2019 with no prior experience as a train driver. They were assessed as competent to operate class 66 locomotives in October 2019 and assessed as competent to operate trains over the route into London Gateway port in January 2021. They had regularly driven trains into and out of the port since then. The driver had no previous safety incidents recorded by GBRf.

External circumstances

32 The nearby weather station in Corringham (2.5 km to the north-east) recorded an air temperature of 7.7°C at the time of the derailment and a wind speed of 1 km/h. There was no report of precipitation. It was dark when the derailment occurred.

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[5] A type of flat-bottom rail having a weight of 60 kilograms per metre.

[6] According to Network Rail company standard NR/L2/TRK/001 'Inspection and maintenance of permanent way'.

The sequence of events

Events preceding the accident

33 Train 4L47 departed from Hams Hall on time at 22:35 hrs on 23 December 2021. The train was routed via Whitacre Junction, Rugby and Watford Junction and arrived at Wembley European Freight Operating Centre (EFOC) at 00:52 hrs on 24 December where there was a change of drivers.

34 After preparing the locomotive and checking the handbrakes on the train were released, the driver who operated train 4L47 from Wembley EFOC to London Gateway port was ready to depart. GBRf drivers needed to know if the train included Ecofret 2 wagons because this required them to apply the brake in a specific manner (see paragraph 138a). GBRf stated that drivers would know if there were Ecofret 2 wagons as this was detailed on the train document. The driver who operated train 4L47 to London Gateway, however, stated that they used the running brake test[7] (required to take place at the start of the journey) to determine if there were Ecofret 2 wagons, since it was their experience that trains containing this type of wagon responded differently during these tests.

35 The train departed from Wembley EFOC at around 03:45 hrs, three minutes early. It was routed along the North London line to Stratford and then onto the London Tilbury and Southend line at Barking. The driver recalled that the train felt “heavy”, and that the journey had been slow because of an unusually large number of restrictive signals, but that nothing untoward occurred during this part of it. Train 4L47 passed over Thames Haven Junction and onto the Down Thames Haven line at 05:22 hrs, six minutes later than scheduled.

Events during the accident

36 Figure 5 is an analysis of the locomotive OTDR recording of the journey along the Down Thames Haven line, starting at Thames Haven Junction. It shows:

- the throttle number (between 1 and 8) that was selected by the driver to control traction effort
- the train brake pipe pressure (which is measured at the locomotive) and the corresponding locomotive brake cylinder pressure generated in response to braking changes made by the driver
- the gradient profile (track elevation)
- the train’s speed and the maximum permitted line speed at the location
- the location of important infrastructure features and of train 4L47 at the time of the derailment, including the position of wagon 12 (leading bogie).

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[7] Running brake tests are required to test the effectiveness of the train’s brakes in accordance with the Rule Book GERT8000 Module TW1 ‘Preparation and movement of trains’ (issue 17, September 2021).

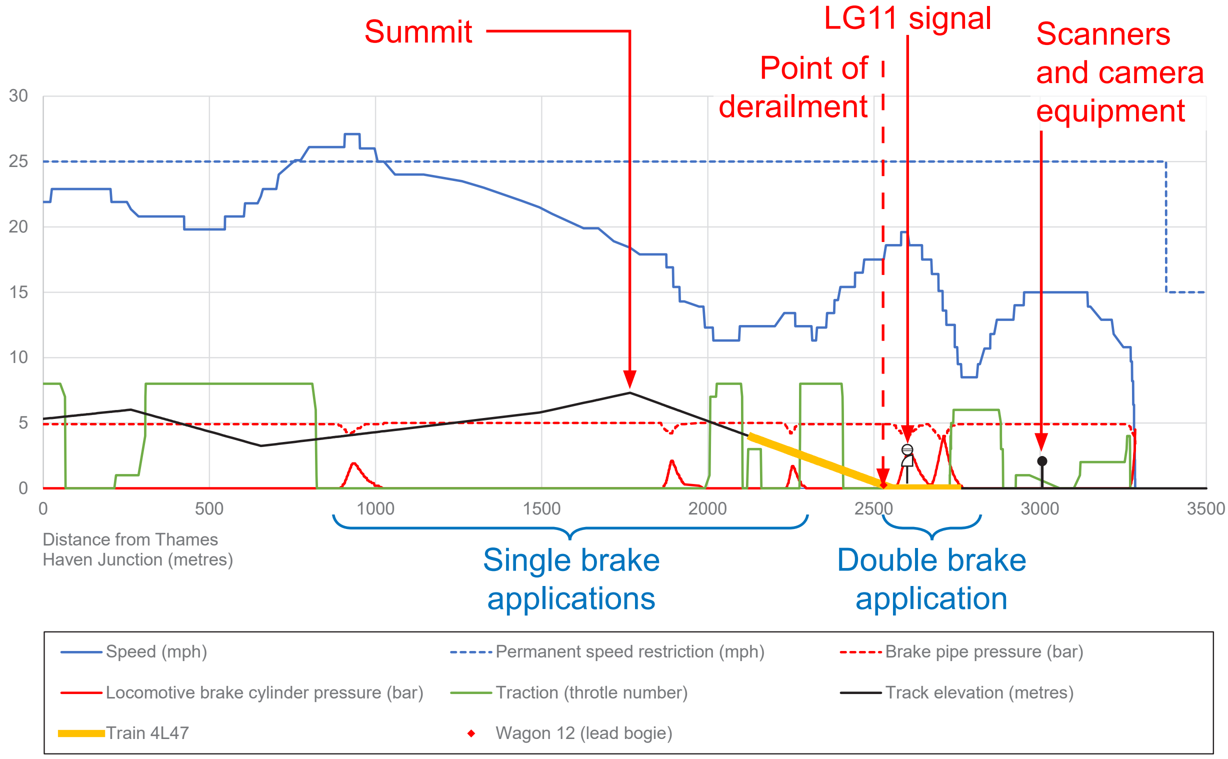

Figure 5: Analysis of the locomotive OTDR for the journey along the Down Thames Haven line.

37 Train 4L47 passed over Thames Haven Junction at around 22 mph (36 km/h). The locomotive OTDR recorded a mixture of traction effort demands and single brake applications as it continued to the summit and then descended the 1 in 108 gradient to LG11 signal. The driver recalled the signal clearing as the train approached. The OTDR recorded two consecutive brake applications (a ‘double brake application’) shortly after the front of the train passed the signal. At this time, wagon 12 was approaching the point of derailment. Together with the derailment marks and other evidence (see paragraphs 42-44), the OTDR analysis shows that the leading bogie on wagon 12 derailed as the brakes were releasing after the second of the two brake applications.

38 The driver recalled a sudden jolt and, looking back, noticed dust coming from the train. On realising something was wrong, they brought the train to a stand.

Events following the accident

39 The driver secured the train and walked back to confirm what had happened. On returning to the cab, they made a GSM-R call to the signaller to report the derailment. The signaller notified the London Gateway rail control centre. A member of ground staff arrived, and both they and the driver acted to protect the train.

40 After the accident, the driver was tested for the presence of both non-medical drugs and alcohol at London Gateway port. The driver tested clear for both.

41 It was 14 days before temporary repairs could be made to the railway and the rail connection into the London Gateway port reopened. An assessment of final infrastructure repairs identified the need for extensive renewal work including the replacement of nearly 700 metres of track and the installation of a complete new set of points.

Background information

Examination of the track and derailment site

42 Marks and damage on the track were found on the approach to LG11 signal. They were consistent with:

- both left-hand wheels on a single bogie lifting up onto the rail
- the left and right-hand wheels of both wheelsets then becoming airborne for around two metres
- the right-hand wheels then landing on the sleepers between the rails (the 'four-foot') and the left-hand wheels landing in the track bed alongside the railway (the 'cess').

43 The first identified derailment mark was on the left-hand rail, approximately 11 metres on the approach to LG11 signal. This was designated the point of derailment and numbered as sleeper 0.[8] The second derailment mark was identified at sleeper -3, around 2 metres beyond the point of derailment (figure 6). The separation of the marks was consistent with the 1.8 metre wheelbase of the TF20 bogies fitted to wagon 12 (see paragraphs 49 and 58). This, and the form of the marks (short, and at an angle to the rail), shows that both wheelsets on the same bogie had lifted suddenly, and simultaneously left the track on a trajectory towards the left.

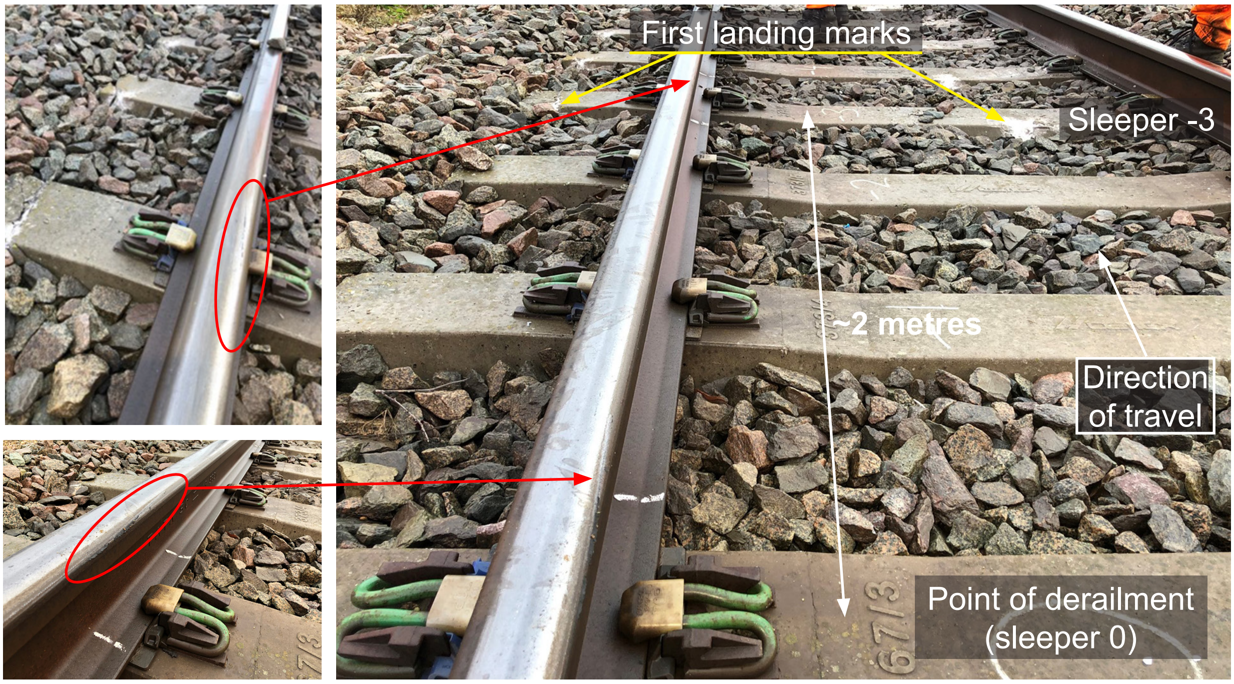

Figure 6: Derailment marks and track damage in the vicinity of the designated point of derailment (photographs courtesy of Network Rail).

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[8] The sleepers were sequentially numbered as part of the track examination, with sleeper 0 being the nominal point of derailment and negative numbers indicating sleepers beyond this point.

44 Other marks were found further along the track. These took the form of damage to sleepers in the four-foot and cess. There was an absence of marks between sleeper 0 and sleeper -3, evidence of one wheelset running derailed between sleeper -3 and sleeper -6 and, after this, evidence of two wheelsets running derailed. This indicates that the two wheelsets on the bogie landed more or less at the same time, the leading wheelset close to sleeper -6 and the trailing wheelset close to sleeper -3. They had remained airborne in the meantime (figure 7). There were no marks to suggest that more than one bogie ran derailed on the Down Thames Haven line. RAIB has concluded, from other evidence, that the wheelsets which derailed at this point were on the leading bogie of wagon 12 (see paragraph 66).

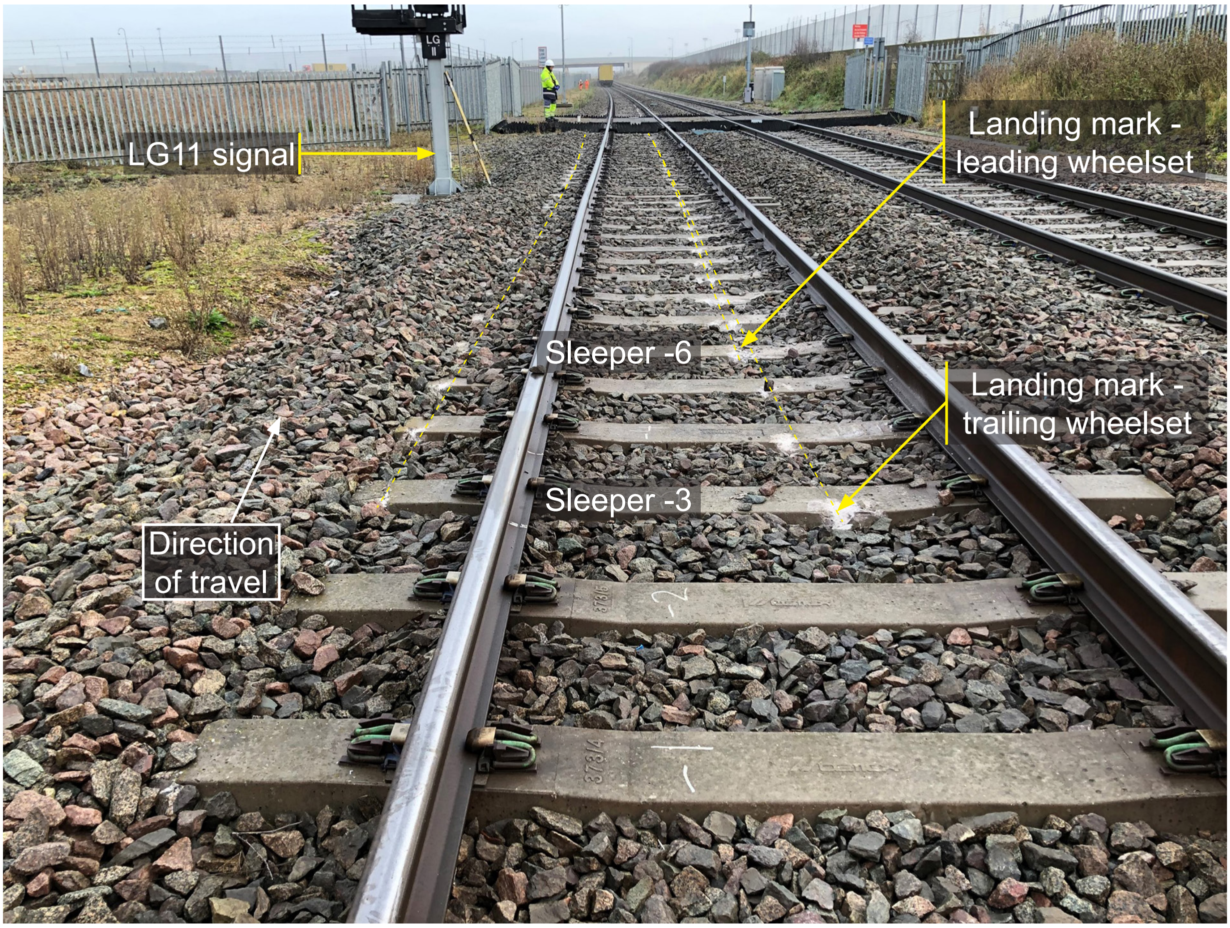

Figure 7: Derailment marks and track damage on the approach to LG11 signal and The Bridleway level crossing beyond (photograph courtesy of Network Rail).

45 Closed-circuit television (CCTV) images from the lineside cameras (paragraph 30) showed that three bogies in total had derailed by the time wagon 12 was running on the Thames Haven Single line (figure 8). These were the trailing bogie on wagon 11 and both bogies on wagon 12. All three of these bogies were shown running derailed to the left. RAIB concluded that the trailing bogie on wagon 12 and the trailing bogie on wagon 11 had been drawn into derailment due to the path that the already derailed leading bogie of wagon 12 was forced to take as it ran through LG1 points, where the Up Thames Haven and Down Thames Haven lines join to form the single line (paragraph 13). Marks and damage on the track at LG1 points support this.

Figure 8: CCTV images of train 4L47 passing the London Gateway port cameras and OCR scanners (images courtesy of DP World).

46 When the derailed train reached LG2 points, the leading bogie on wagon 11 and both bogies of wagon 13 also derailed (figure 9).

Figure 9: Final position of Wagons 11, 12 and 13 (photograph courtesy of VTG Rail).

Ecofret 2 wagons

47 Intermodal wagons operating on the mainline railway in Great Britain (GB) have been historically designed to accommodate container payloads of up to 60 feet (18.3 metres) in length. This means that they can typically carry a 40-foot container plus a 20-foot container, three 20-foot containers or two 30-foot containers. Examples of such wagons include the FEA type wagons within train 4L47.

48 With 40-foot containers becoming more popular (and 20 and 30-foot containers becoming scarcer), freight train operators were finding many of their wagons were carrying solitary 40-foot containers, resulting in wasted capacity. VTG Rail identified a market for a shorter intermodal wagon that carried only a single 40-foot container.[9] This led to it contracting an engineering consultant to design the Ecofret 1 wagon. A prototype Ecofret 1 triple-wagon was in built in 2012, with Ecofret 1 production versions being built both in triple-wagon and twin-wagon configurations.

49 A continuing demand for intermodal wagons led to the development of the Ecofret 2 wagon, based on the earlier Ecofret 1 design. VTG Rail identified that the following changes to the Ecofret 1 design were needed:

- A bogie that would enable compliance with new ride requirements.[10] VTG Rail opted to specify a bogie of the TF20 type that Wabtec was in the process of developing.
- Brake equipment from a different supplier. The aim was to avoid problems that had been experienced with the brake equipment fitted to Ecofret 1 wagons.
- Flexibility to carry one 40-foot or two 20-foot containers on any of the three wagons (rather than only the centre wagon which Ecofret 1 allowed) of a triple-wagon.

50 In other areas it was decided to keep the wagon designs as similar as possible. This was to aid maintenance and spares management. The objective of minimising change led to VTG Rail deciding to specify the same longer bar coupler that had been retrofitted to Ecofret 1 triple-wagons during early service (see paragraphs 76 and 77).

51 VTG Rail led a team to project manage the various development tasks and engaged consultants to assist. The team included representatives from its suppliers, Wabtec and WH Davis. The division of the engineering responsibility can be summarised as below:

- VTG Rail – wagon technical specification and overall design, and the management of the approval work needed
- WH Davis – modifications of the Ecofret 1 wagon underframe design including incorporation of the new brake equipment, the revised container securing arrangements and the interfaces for the TF20 bogie
- Wabtec – design and development of the TF20 bogie and work needed to demonstrate compliance with wagon ride and running safety requirements that were identified as relevant.

52 Figure 10 shows the three wagons making up a typical Ecofret 2 triple-wagon. Each has a welded steel underframe comprising a central longitudinal rectangular box (the ‘underframe spine’) from which the bolster, headstock and other fabrications provide the interfaces for the bogies, couplers and buffers, brake equipment and the spigots needed for securing the containers.

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[9] The ability to carry two 20-foot containers was also required, but this flexibility was only provided on the centre wagon of an Ecofret 1 triple-wagon.

[10] VTG Rail identified Railway Group standard GM/RT2141 issue 4 as an applicable requirement. This introduced the need to demonstrate that vehicles are not at risk of derailment due to repeated vertical track geometry irregularities (also known as ‘cyclic top’).

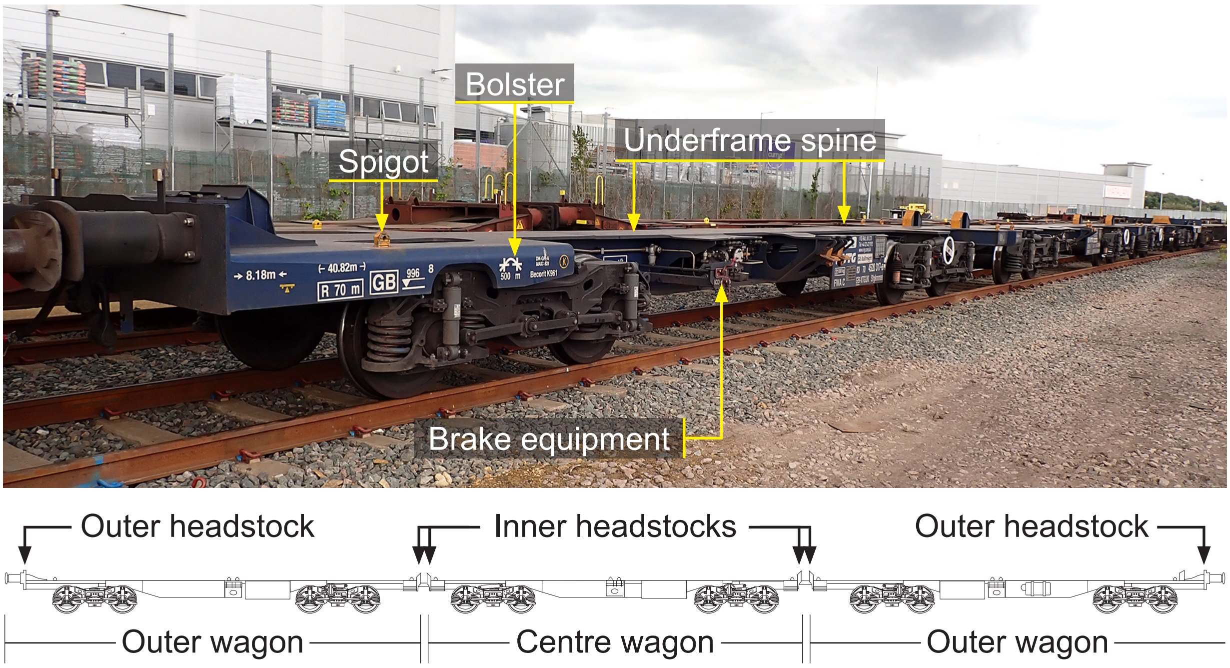

Figure 10: An Ecofret 2 triple-wagon.

53 The bar couplers that connect Ecofret 2 triple-wagons together (paragraph 26) are anchored within a central pocket on the inner headstocks (the 'headstock pocket'). With reference to figure 11, the bar coupler arrangement comprises a rigid drawbar[11] (1) that connects to spring units (2), one on each wagon, via spherical bearings (3). Each spring unit is made up of three elastomeric ring elements. These are preloaded by being clamped between two steel plates (4), which locate and secure each spring unit within the headstock pocket (5). The spring units enable the drawbar couplings to compress (or extend) when the externally applied longitudinal force exceeds the preload amount in either compression (causing the coupled wagons to draw closer together) or tension (causing the coupled wagons to separate). The material used in the spring components enables the bar coupler arrangement to absorb energy when alternating forces apply.

54 The spherical bearings allow the rigid drawbars to pivot in both the vertical longitudinal ('pitch' rotation) and horizontal ('yaw' rotation) planes. Relatively large angles of movement are possible. No mechanism or design feature is provided to restrict these rotations before the rigid drawbar contacts the sides, or top and bottom, of the headstock pocket.

55 The outer wagons are nearly a metre longer than the centre wagons. This is to accommodate the conventional screw coupling and side buffer arrangement needed to couple to other vehicles (paragraph 26). With reference to figure 12, the arrangement comprises a conventional draw hook and screw coupling (6). This connects to a drawgear spring unit (7) on the outer headstock via a clevis and pin (8). The drawgear spring unit comprises two side-by-side stacks of elastomeric ring elements. These are also preloaded. Conventional buffer units (9) with internal spring elements (10) are bolted to the outer headstock, one on either side.

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[11] 1.6 metres long, as adopted for the lengthened Ecofret 1 bar coupler arrangement (see paragraphs 76 and 77).

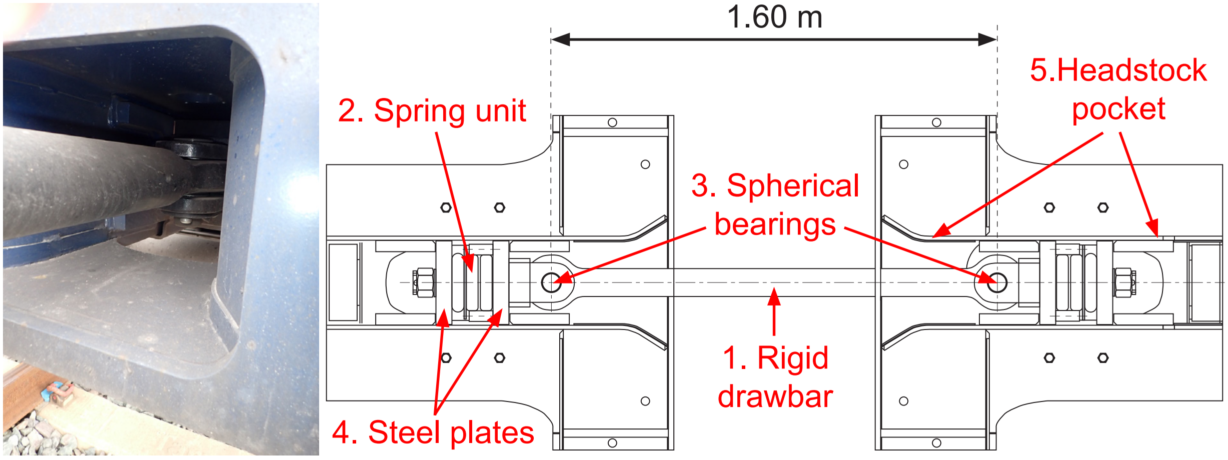

Figure 11: Bar coupler arrangement at the inner headstock locations. Photograph shows the general arrangement and the space available for pitch and yaw rotation within the headstock pocket.

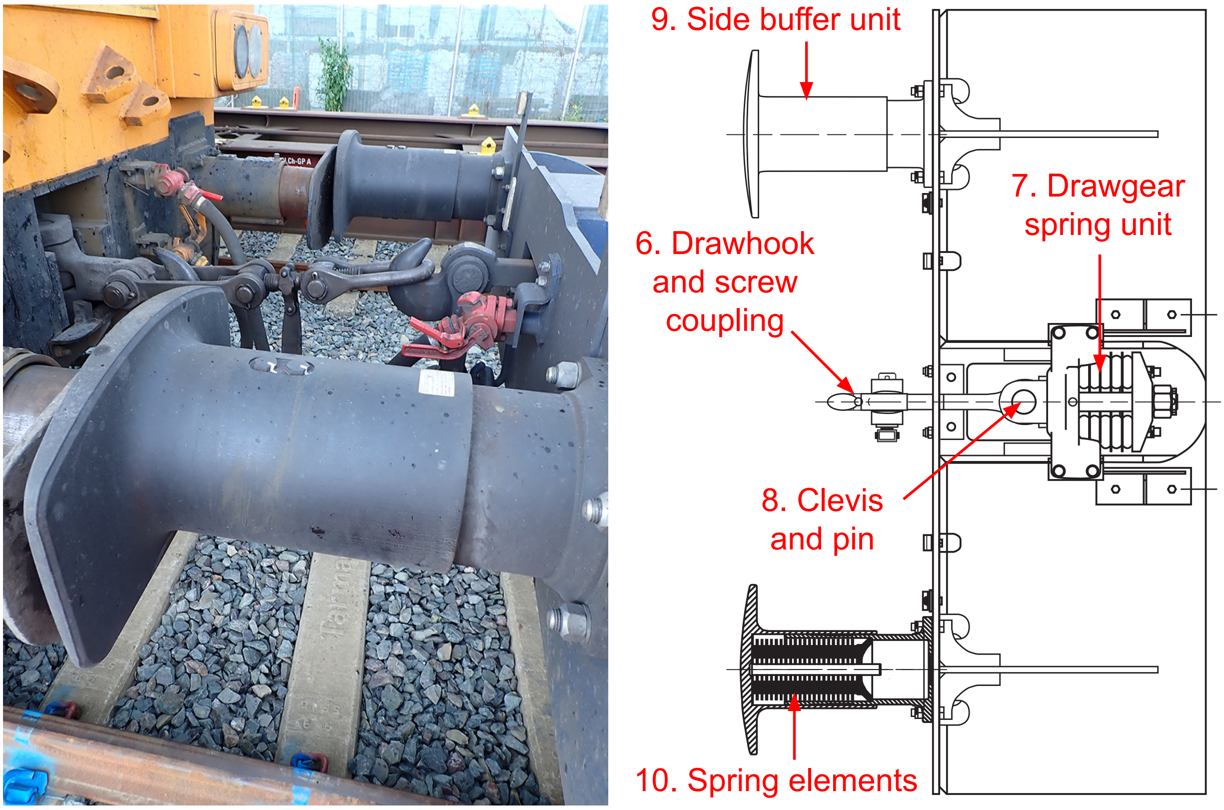

Figure 12: Screw coupling and side buffer arrangement at outer headstock locations. Photograph shows the general arrangement when coupled to another vehicle – a class 66 locomotive.

56 When coupled, the link on the screw coupling is placed on the draw hook of the other vehicle (or vice versa) and the screw coupling tightened. If this results in the buffer faces being in contact (without buffer unit compression),[12] then any longitudinal compressive force generated along the train will act only on the buffer unit pairs, with the coupled vehicles coming closer together as the buffer units deflect. Insufficient tightening of the screw coupling results in a gap between the buffer faces. This is referred to as ‘slack’, which needs to be taken up (closed) before the buffer units can touch and start to deflect.

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[12] The discussion on the behaviour of a screw coupling and side buffer arrangement relates to operation on nominally straight track. It does not take into account effects such as vehicle yaw rotation that occurs on curved track.

57 With the buffer faces in contact (but without buffer unit compression), any longitudinal tensile force generated acts only on the connected drawgear spring unit pairs. In this case, the coupled vehicles will separate, but only once the drawgear spring unit preload is overcome and the drawbar spring units can start to deflect. If any slack was present (buffer faces not in contact), then this would need to be taken up before this force can act. The material in the spring components enables the arrangement to absorb energy when alternating forces apply.

58 The TF20 bogie (figure 13) has a fabricated steel bogie frame supported by four coil spring primary suspension units, one at each axlebox, with the axleboxes being also connected to the bogie frame via a primary traction rod arrangement. The bolster on the wagon underframe is supported by a pair of rubber secondary suspension springs. Primary and secondary hydraulic dampers are fitted to help control dynamic behaviour. The bogie is designed to run with the ‘P8’ type wheel profile that was developed by British Rail.

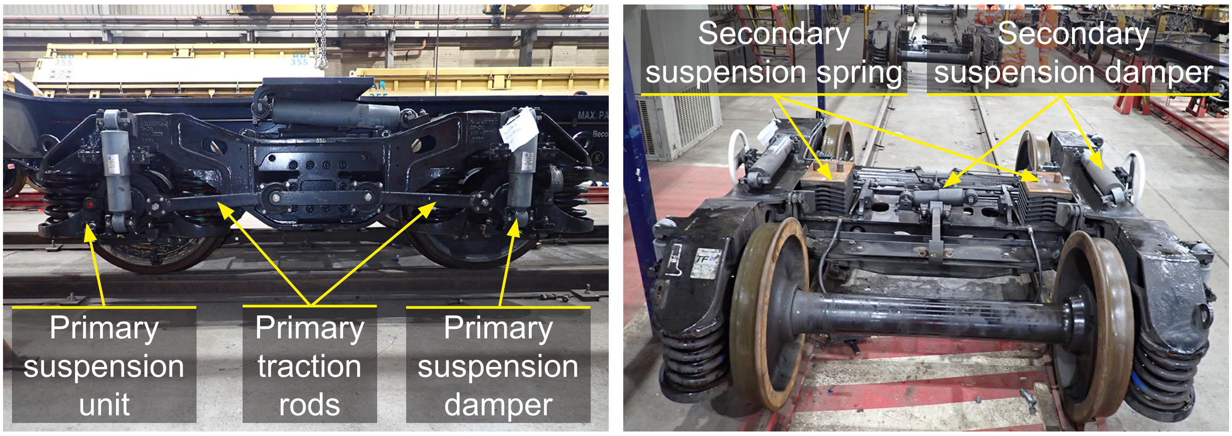

Figure 13: TF20 bogie.

Ecofret 2 wagons - design approval and maintenance

59 In September 2019, VTG Rail drafted a document setting out its strategy for obtaining authorisation from the Office of Rail and Road (ORR)[13] for placing Ecofret 2 wagons into service on the GB mainline railway. This included demonstrating that the wagons complied with technical specifications for interoperability (TSI) and national technical rules (NTR), as was then required by The Railways (Interoperability) Regulations 2011.[14] VTG appointed ACS to act as both the Notified Body[15] (NoBo) and Designated Body[16] (DeBo) for the verification work required.

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[13] The safety authority for railways in Great Britain.

[14] https://www.legislation.gov.uk/uksi/2011/3066/contents/made.

[15] A body which assesses and verifies the conformity of projects and systems to TSIs. TSIs have now been replaced in the UK by National Technical Specification Notices (NTSNs). The assessment and verification of conformity to NTSNs is by an Approved Body (ApBo). ACS also carried out this independent assessor role. https://www.orr.gov.uk/sites/default/files/2021-07/guidance-on-approach-to-authorisation-under-the-interoperability-regulations.pdf.

[16] A body which assesses and verifies the conformity of projects and systems to NTRs.

60 VTG Rail also recognised that the new Ecofret 2 wagons constituted a significant change under the Common Safety Method on Risk Evaluation and Assessment[17] (CSM REA), primarily due to the change of bogie. Because of this, they needed to carry out a programme of hazard identification (recording the identified hazards in a hazard log), risk evaluation and hence demonstrate that risks were managed. VTG Rail appointed ACS to act as the Assessment Body (AsBo) to undertake the required independent assessment of compliance with the CSM REA.

61 Ecofret 2 wagons were to be the first wagons to use the new TF20 bogie. Wabtec sought to use this opportunity to gain approval for the bogie as an ‘interoperability constituent’.[18] The intent of this was to avoid extensive additional testing and analysis work when supplying the bogie to other wagon manufacturers. Wabtec carried out the approval work for the bogie, arranged for its assessment and obtained approval certificates. These certificates were referenced by ACS as evidence of compliance within the overall wagon approval documentation.

62 Wabtec used an industry-standard railway vehicle dynamics computer simulation package to help assess compliance with requirements for dynamic behaviour and safety against derailment on twisted track.[19] This only required development and validation of computer simulation models that represented Ecofret 2 wagons as single vehicles. No need was identified to develop a simulation model representing a coupled triple-wagon. Supporting analysis work identified a running behaviour issue that led Wabtec to conclude that special devices were needed to control primary lateral suspension movement. It was this that resulted in Wabtec making a late modification to the TF20 bogie (see paragraph 67).[20]

63 On 30 March 2021, ORR issued an ‘authorisation to place into service’ for the batch of Ecofret 2 wagons that included wagons 11, 12 and 13 of train 4L47. ORR can only issue this where an applicant has satisfied ORR that the ‘*project sub-system*’ (in this case the Ecofret 2 wagon) is technically compatible with the railway on which it is to operate, that the various required tests have been satisfactorily completed and that the relevant supporting information and documents have been drawn up or prepared.[21] The batch comprised 84 triple-wagons, or 252 wagons in total.

64 VTG Rail’s inspection and maintenance regime for Ecofret 2 wagons comprised a weekly in-service inspection, which is essentially a visual examination of the overall wagon condition, and a more detailed annual vehicle inspection and brake test (VIBT). The triple-wagon comprising wagons 11, 12 and 13 entered service on 19 April 2021. The first VIBT was not due until 19 April 2022, after the derailment.

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[17] A regulation which describes how the safety impacts of significant changes are assessed. https://www.orr.gov.uk/sites/default/files/2023-07/common-safety-method-for-risk-evaluation-and-assessment.pdf.

[18] A component, group of components or assembly of equipment that is incorporated or intended to be incorporated into a subsystem upon which the interoperability of the rail system depends directly or indirectly. The concept of a constituent includes both tangible objects and intangible objects such as software.

[19] Chapters 4, 5, 6.1 and 7 of BS EN14363:2016 ‘Railway applications – Testing and Simulation for the acceptance of running characteristics or railway vehicles – Running Behaviour and stationary tests’.

[20] Wabtec explained that when no payload was carried (‘tare condition’), these devices were not required at speeds below 50mph (80 km/h).

[21] ‘Approach to authorisation under the Interoperability Regulations’, Guidance to Applicants, ORR, 2021.

Examination of the derailed wagons

65 RAIB examined wagons 11, 12 and 13 (which together formed a Ecofret 2 triple-wagon). It recorded the condition of the suspension, wheels, bogie brake equipment and couplers and found that the damage to the wheel treads and flanges and the brake equipment was consistent with all the bogies of these wagons having run derailed. RAIB also measured the wheel profiles and relevant wheelset dimensions for use in subsequent wagon derailment simulation studies (see paragraph 82c and appendix D).

66 RAIB identified witness marks on the headstock pockets where wagon 11 and wagon 12 were coupled together (figure 14). The marks were consistent with the leading end of wagon 12 running derailed to the left and the rigid drawbar coming in to contact with the headstock pockets as a result. The marks were only found on one side of the headstock pockets. From this, and the available CCTV evidence (paragraph 45), RAIB has concluded that the leading bogie of wagon 12 was the first to derail.

Figure 14: Witness marks on the headstock pockets on wagon 11 and wagon 12 after recovery (rigid drawbar is shown disconnected from wagon 11, and after a weld repair had been done).

67 Special suspension movement control devices were added to the TF20 bogie as a late modification (paragraph 62). Referred to as ‘primary lateral buffers’ (PLBs), they comprise a sliding frame designed to capture and restrain a vertical metal lug on top of each axlebox. The lug is informally known as the ‘shark fin’. With reference to figure 15, the sliding frame (11) is secured to the underside of the bogie frame, the shark fin passing through a rectangular void (12). Two friction strips (13) attached to the sliding frame are designed to bear against the sides of the shark fin. These allow the shark fin (and axlebox) to slide up and down. The side-to-side (lateral) movement of the axlebox is restrained by two laminated elastomeric springs (14).

68 RAIB identified signs of significant damage and degradation on several PLBs. On wagon 12, nearly all the friction strips had detached and there was evidence that some of the laminated elastomeric springs had split. Degradation of the PLBs on Ecofret 2 wagons was a problem that existed before the derailment, and work was being carried out to investigate it when the derailment occurred.

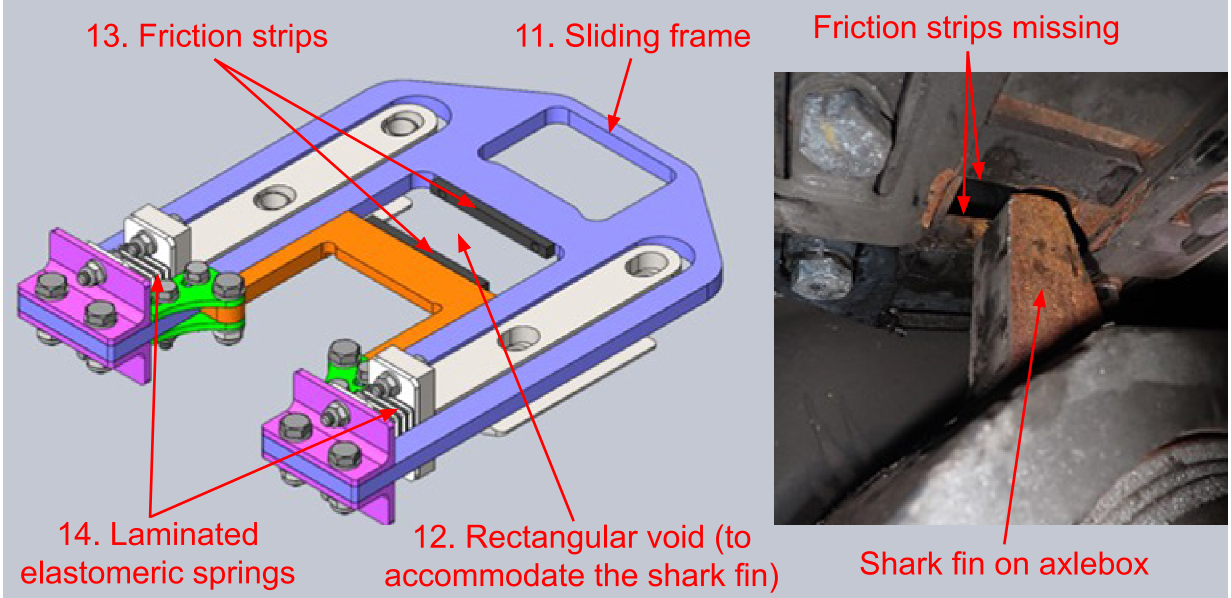

Figure 15: Primary lateral buffer device (diagram courtesy of VTG Rail). Photograph shows the condition of a PLB device as found on wagon 12.

Derailment risk due to longitudinal train dynamics

69 Design and operational issues associated with longitudinal train dynamics have long been recognised as factors affecting derailment risk. British Rail's internal derailment investigation guidance from the 1980s[22] provides useful historical context. It mentions traction and braking effects, buffer interaction, and coupling tightness as important influences.

70 RAIB has investigated one previous derailment event where longitudinal train dynamic behaviour was identified as a factor, at Neville Hill depot on 13 November 2019 (RAIB report 13/2020). The accident involved a relatively new Intercity Express Train which collided at low speed with the rear of another train moving in the same direction. The longitudinal compressive forces that were generated resulted in wheelsets on the Intercity Express Train derailing to the side by up to 1.25 metres, on three separate vehicles.

71 Following discussions with RSSB, RAIB has concluded that the rail industry maintains an awareness that such issues can affect the safe running of freight trains. However, there has been little recent rail industry research aimed at understanding the risks relevant to current freight operations, or developing guidance, processes, or standards to manage them.

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[22] 'A guide to the investigation of derailments', 5th edition, British Railways Board, 1985.

72 The wagons involved in this derailment were of a type that is currently outside the scope of European Standard BS EN15839:2012, 'Railway Applications – Testing for the acceptance of running characteristics of railway vehicles - Freight wagons - Testing of running safety under longitudinal compressive forces'.[23] This European standard is identified in the TSI for freight wagons (WAG TSI) as an '*additional optional condition*' which defines an acceptance criteria for vehicles with standard side buffers and screw couplings which are operated in trains where '*high longitudinal compressive forces may occur'*. The standard cites S-shaped curves (where side buffer contact could occur) to be the special concern and specifies a test track comprising curves of 150 metre radius separated by a nominal 6-metre-long straight section. There are plans to revise this European standard to incorporate wagons of the type that were first to derail at London Gateway (see paragraph 152).

Previous derailments involving Ecofret 1 and Ecofret 2 wagons

73 Two derailments of Ecofret 1 triple-wagons occurred after they entered service, at Felixstowe on 28 August 2015 and at Peterborough on 17 September 2015 (see paragraphs 174 and 175). The two trains were of similar length, and both were braking at the time. In each instance, the triple-wagons that derailed were in the middle part of the train, with the centre wagons carrying no load. Nearly all the other wagons on the trains were loaded. Neither derailment occurred on Network Rail managed infrastructure.

74 GBRf and VTG Rail investigated both derailments and identified that high longitudinal compressive forces were the likely cause. VTG Rail subsequently commissioned a vehicle dynamics specialist to undertake detailed computer simulations to understand the effect of longitudinal compressive forces on Ecofret 1 triple-wagons. It used the same vehicle dynamics computer simulation package that was used in this investigation to evaluate the susceptibility of wagon 12 to derailment by this means (see paragraph 82c). The simulations included the effect of track geometry irregularities.

75 The centre wagon was found to be most prone to derailment by this means. VTG's specialist reported that an increasing longitudinal compressive force resulted in:

- the wagon underframes initially rotating when viewed from above (yaw rotation), all in the same direction
- the flanges of the left-hand wheels on the leading bogies then contacting the rail, with the flanges of the right-hand wheels on the trailing bogies doing the same
- the wheel flanges being further pressed into rail contact as the developed lateral forces increased, and the wheelsets on the most prone bogie (in some cases the leading bogie on the centre wagon, in others the trailing bogie) starting to roll about the wheel flange-rail contact point with the wheel opposite to the contacting wheel then lifting off the rail
- the whole bogie then finally lifting and derailing.

The longitudinal compressive forces were simulated by applying equal and opposite end loads on the outer wagons.

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[23] BS EN 15839:2012 lists 'permanently coupled units with a bar coupler between the vehicles' as one of the types of vehicles that are out of scope.

76 VTG Rail’s engineering consultant (paragraph 48) later developed a simulation model that was simpler, and which became referred to as the ‘quasi-static model’. The consultant concluded that, for an Ecofret 1 triple-wagon, the quasi-static model predicted similar behaviour to the earlier detailed computer simulations. Other simulations using the quasi-static model suggested an Ecofret 1 triple-wagon was more susceptible to derailment than an Ecotfret 1 twin-wagon. The quasi-static model was also used to evaluate options for improving the derailment resistance. It included work supporting a decision to lengthen the bar coupler.

77 The decision to change the bar couplers on Ecofret 1 triple-wagons was recorded in engineering documentation issued in March 2017. VTG Rail explained that an operating restriction was imposed until the modification work was complete. This restriction was intended to prevent Ecofret 1 triple-wagons from running in certain payload conditions identified as making derailment more likely. VTG Rail reported that Ecofret 1 wagons have operated without incident since the modification was implemented.

78 A collision involving a GBRf intermodal train and agricultural equipment at Kisby user worked crossing on 19 August 2021 resulted in the derailment of an Ecofret 2 triple-wagon (RAIB Report 12/2022). The collision occurred on a section of nominally straight track, with the Ecofret 2 triple-wagon being part way along the train and none of the wagons carrying a container. The Ecofret 2 triple-wagon derailed in the same manner as an Ecofret 1 triple-wagon was predicted to under longitudinal compressive force (paragraph 75), with the wheels on the leading bogie of the centre wagon derailing to the left and the wheels on the trailing bogie derailing to the right (figure 16).

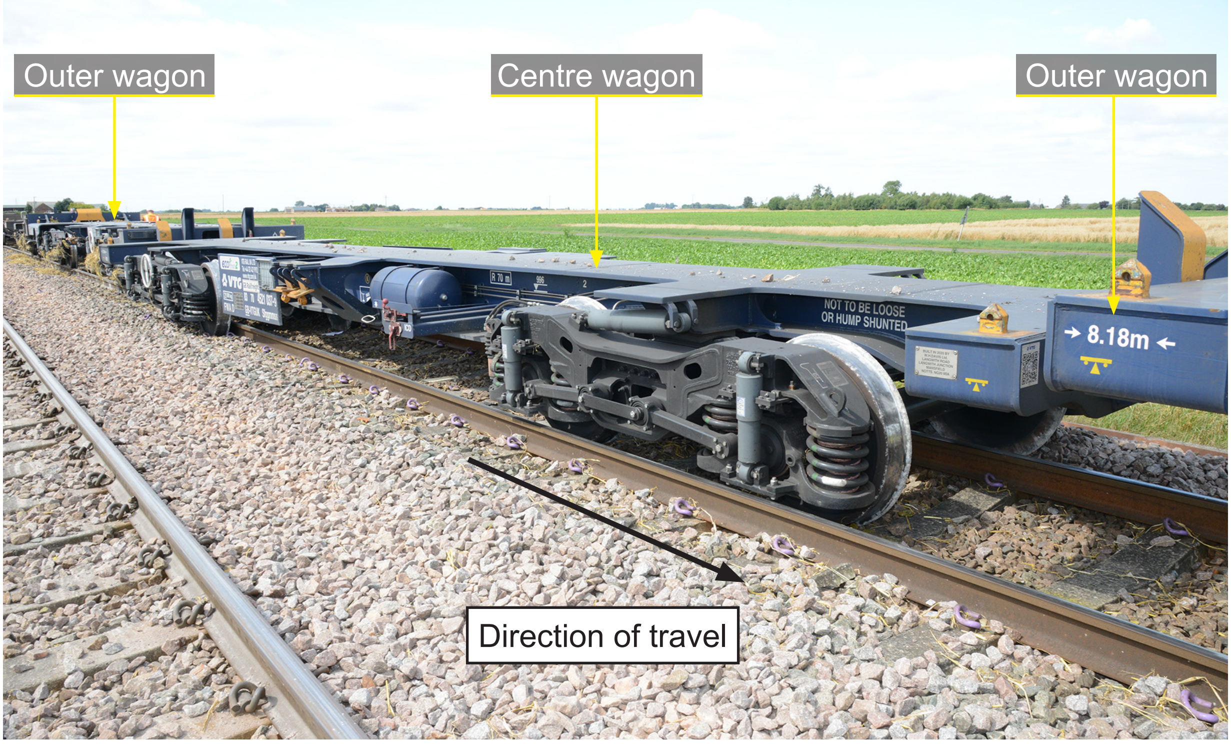

Figure 16: Ecofret 2 triple-wagon that derailed at Kisby on 19 August 2021.

79 The damage to the front of the train at Kisby indicates that significant longitudinal compressive forces were generated in the accident, just as they were during the collision at Neville Hill depot (paragraph 70). Therefore, this damage, the observed position of the wheels after derailment and the design similarities between Ecofret 1 and Ecofret 2 triple-wagons have led RAIB to conclude that the derailment of the wagon at Kisby was probably caused by longitudinal compressive force.

Testing and analysis

80 The accident at Kisby demonstrated the probability of an Ecofret 2 triple-wagon derailing in a similar manner to that seen at London Gateway because of longitudinal compressive force. However, unlike Kisby, no collision occurred at London Gateway, and therefore, for longitudinal compressive force to have initiated this derailment, it needed to have been generated in another way. Longitudinal train dynamic effects due to brake applications were identified as the reason for the unsafe longitudinal compressive forces in the Ecofret 1 triple-wagon derailments at Felixstowe and Peterborough. Given the brake application changes at the time of the derailment at London Gateway (paragraph 37), this was identified by RAIB as a potential cause of the derailment of wagon 12.

81 The simulation models developed by VTG Rail’s vehicle dynamics specialist and its engineering consultant both predicted that longitudinal compressive forces of around 400 kN[24] would be sufficient to cause an Ecofret 1 triple-wagon to derail with bar couplers of the original length (paragraphs 74 and 76). In seeking to compare this with the longitudinal compressive forces likely to be experienced in service, VTG Rail’s engineering consultant hypothesised a worst-case force of around 500 kN during braking. However, this hypothesis largely relied on assumptions and simplifications relating to retardation rates and speed-dependent braking effects published in RSSB research.[25] This meant that the supporting analysis could not be extended and used to establish how the actual brake applications, made around the time that train 4L47 derailed, related to the nature and significance of the longitudinal compressive forces generated.

82 Understanding the nature of the actual braking forces acting along train 4L47 (and the traction forces provided by the locomotive), their effect on the longitudinal train dynamics, and ultimately the risk of derailment, became critical to determining the likelihood of the derailment having been caused by this mechanism. Developing this understanding involved:

a. Estimating the brake and traction torques acting on the wheelsets of the locomotive and the individual wagons of train 4L47 and how these varied as the train travelled along the Down Thames Haven line. These are referred to in this investigation report as the ‘locomotive brake torque time history’, the ‘locomotive traction torque time history’ and the ‘wagon brake torque time history’. Their derivation involved use of measurements made on the brake system of representative test trains and data from the OTDR on train 4L47 recording how it was operated. Appendix B contains further explanation on how the estimated torque time histories were derived, and the testing involved.

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[24] A force of 10 kN is approximately equal to the weight of a mass of one tonne.

[25] RSSB report, T999-01 ‘Review of braking tables in RGS GK/RT0075 Lineside signal spacing and speed signage’.

b. Determining how the derived traction and brake torque time histories affected the longitudinal compressive forces generated within train 4L47 as it travelled along the Down Thames Haven line. This involved the development of a computer model to simulate the longitudinal train dynamic behaviour of train 4L47. This was then used to undertake baseline simulations and sensitivity studies to understand how longitudinal compressive force (determined from the forces calculated in the couplers connecting the locomotive and wagons together) was affected by factors including coupler characteristic and brake application. Appendix C includes further explanation on how the computer model was developed and the findings from the baseline simulations and sensitivity studies.

c. Evaluating the susceptibility of wagon 12 to derailment under longitudinal compressive force. This involved the development of a vehicle dynamics simulation model representing the complete Ecofret 2 triple-wagon comprising wagons 11,12 and 13, and use of this to understand the behaviour of wagon 12 when a longitudinal compressive force is suddenly applied, the derailment sequence and the forces associated. Appendix D includes further explanation on how the wagon derailment simulation model was developed and the findings from the baseline simulations and sensitivity studies.

Train braking

83 All the wheels on train 4L47 were braked using a conventional single pipe automatic air brake system. With reference to figure 17, the system comprises a distributor valve (15) and an auxiliary air reservoir (16) on the locomotive and each wagon. These are connected by a single brake pipe (17) that runs the length of the train, with flexible hoses (18) provided between the individual vehicles. Brakes blocks on each wheel (19) apply when the distributor valves feed air to the brake cylinders (20) from the auxiliary air reservoirs.

84 The automatic air brake is controlled from the driver’s brake valve (21) in the locomotive cab. The driver’s brake valve is used to vary the pressure in the brake pipe, either by venting the brake pipe or by feeding it with air from the main air reservoir (22). The brake distributor valves vary the pressure in the brake cylinders (and therefore the force applied to the brake blocks) depending on the brake pipe pressure. The brakes are released (no pressure in the brake cylinders) when the brake pipe is fully charged (at nominally 5 bar). A full service brake application is made when the brake pipe is vented to a pressure of approximately 3.35 bar. An emergency brake application is made when it is fully vented (zero pressure). The automatic air brake system is charged from an air compressor on the locomotive (23).

85 The brake pipe pressure signal needs to propagate along the length of the train and command the individual distributor valves to vary the local brake cylinder pressure. This means that on a long train it can take several seconds more for the brakes to apply (or release) on a wagon at the rear of the train compared to the front. This can lead to a significant variation in braking force along the train.

86 Brake distributor valves have a set of chokes that can be set to either ‘passenger’ or ‘goods’ settings. In the passenger setting, the train can stop in a shorter distance because the wagon brakes apply more quickly. In the goods setting a slightly delayed brake application is made. This helps ensure that the brakes on the wagons throughout a long freight train apply in a more consistent manner. The brake distributor valves on train 4L47 were all in the passenger setting. This was so the train was able to achieve the braking performance needed to be compatible with its maximum operating speed, which was 75 mph (121 km/h), and the signal spacing on the route.

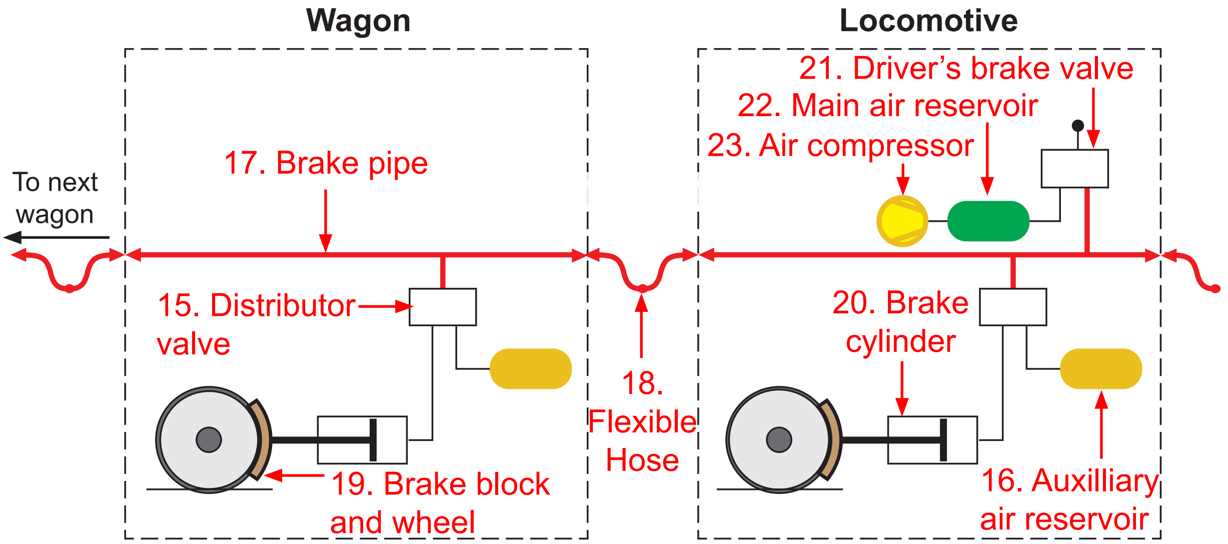

Figure 17: Single pipe automatic air brake system (simplified).

Analysis

Identification of the immediate cause

87 Longitudinal compressive forces generated within train 4L47 during braking were sufficient to cause the wheels on the leading bogie of wagon 12 to suddenly lift and run derailed.

88 The witness marks on the track (paragraphs 42 to 44), CCTV images from the port lineside cameras (paragraph 45), and the contact damage to headstock pockets from the bar coupler between wagon 11 and wagon 12 (paragraph 66), were all consistent with:

- the left-hand wheels on the leading bogie of wagon 12 rapidly and simultaneously contacting the left-hand rail and then lifting over the railhead
- both bogie wheelsets then becoming airborne, landing to the left and running derailed parallel to the track.

89 The derailments at Felixstowe, Peterborough and Kisby (paragraphs 73 and 78) had significant similarities with the circumstances and outcome of the derailment at London Gateway. All three involved FWA type triple-wagons (either Ecofret 1 or Ecofret 2) that were in the middle part of the train, and the individual wagons were connected using the same (or near identical) bar coupler arrangement. The first wagons to derail were unloaded centre wagons and there is evidence suggesting that the wheels derailed rapidly, probably by lifting,[26] when significant longitudinal compressive forces would have been suddenly generated (either during braking or as the result of a collision). This supports the conclusion that wagon 12 was susceptible to derailment by this means.

90 The wagon derailment simulations undertaken in support of the investigation of this derailment (paragraph 82c and appendix D) predicted behaviour that was consistent with the characteristics of these earlier derailments. In summary, and with reference to figure 18, as a sustained longitudinal compressive force of increasing magnitude was suddenly applied:

- The underframe of wagon 12 started to lift (stage A).
- The underframe of wagon 12 then started to rotate when viewed from above (yaw rotation) (stage B).
- As the compressive force was increased further, the wheel flanges on the leading bogie started to contact one of the rails, while on the trailing bogie the wheel flanges started to contact the opposite rail (stage C).
- Wheels opposite to the wheel flanges in contact then started to unload, eventually lifting off the rail (stage D).
- Finally, one of the bogies rose clear of the rails, derailing fully as a result (stage E, not illustrated).

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[26] No wheel flange marks were identified on the railhead at Felixstowe. This suggested to investigators that the wheels did not climb over the rail, but rather that they lifted.

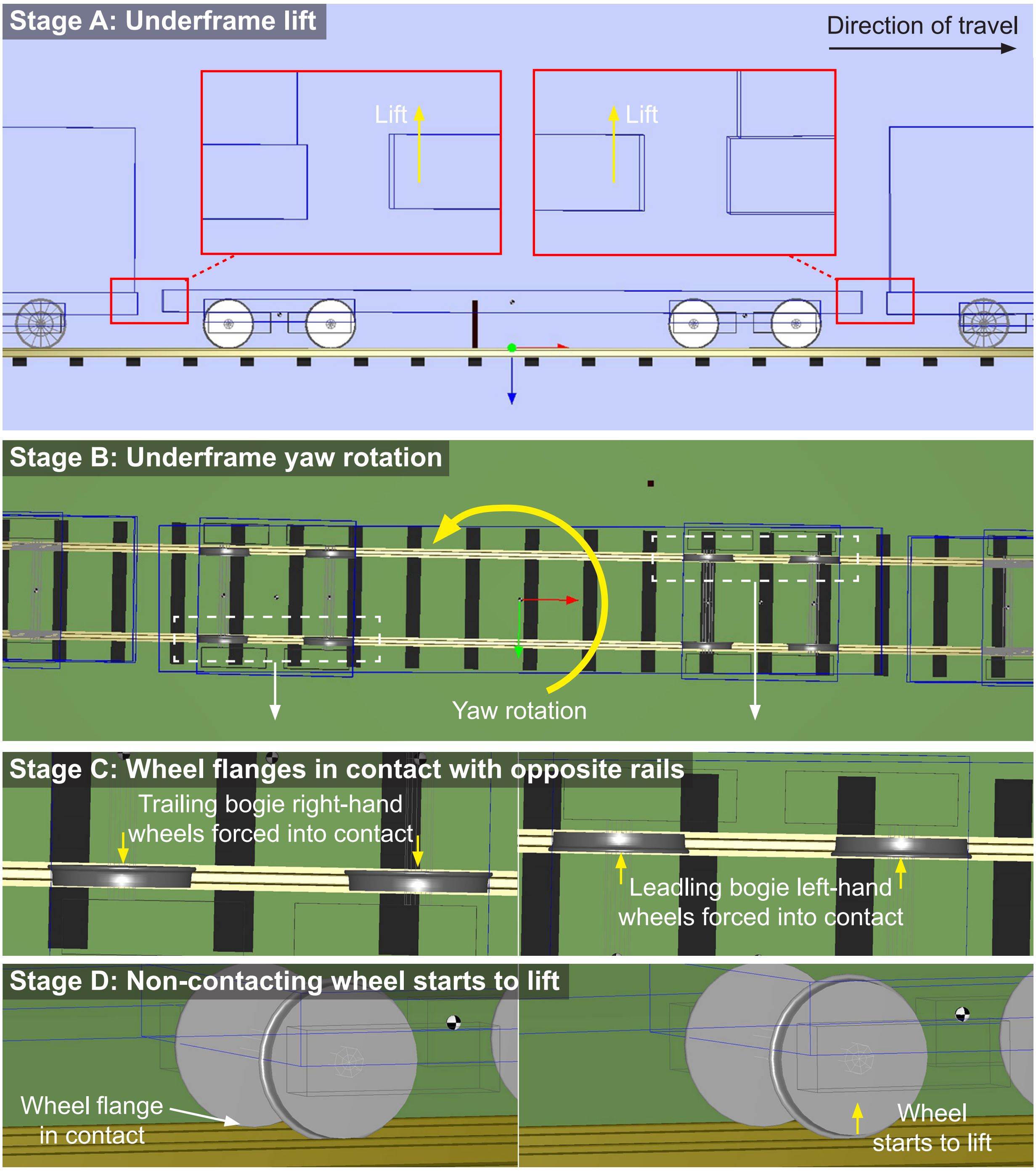

Figure 18: Predicted wagon derailment sequence.

91 VTG Rail’s specialist had predicted similar behaviour for an Ecofret 1 triple-wagon in simulation studies undertaken following the derailments at Felixstowe and Peterborough (paragraph 75).

92 The longitudinal train dynamics simulation studies showed that a high longitudinal compressive force would have been rapidly generated within the train at the time of the derailment (paragraph 82b and appendix C). Baseline simulations predicted that the maximum longitudinal compressive force occurred as the leading bogie of wagon 12 was approaching the point of derailment. Sensitivity studies showed that refining the traction and brake torque time histories, so that the calculated speed profile better matched that recorded by the locomotive OTDR, significantly increased the magnitude of the maximum longitudinal compressive force but did not alter its location. Altering the characteristics of the couplers, for instance, by introducing the effect of slack (at side buffer and screw coupling arrangements) and reducing their capacity to absorb energy was also found to increase the magnitude of the maximum longitudinal compressive force, again without altering its location. Figure 19 shows the calculated forces in the couplers on wagon 12 and speed profile for sensitivity study C4. Of the sensitivity studies undertaken, this study calculated the greatest maximum longitudinal compressive force (451 kN).

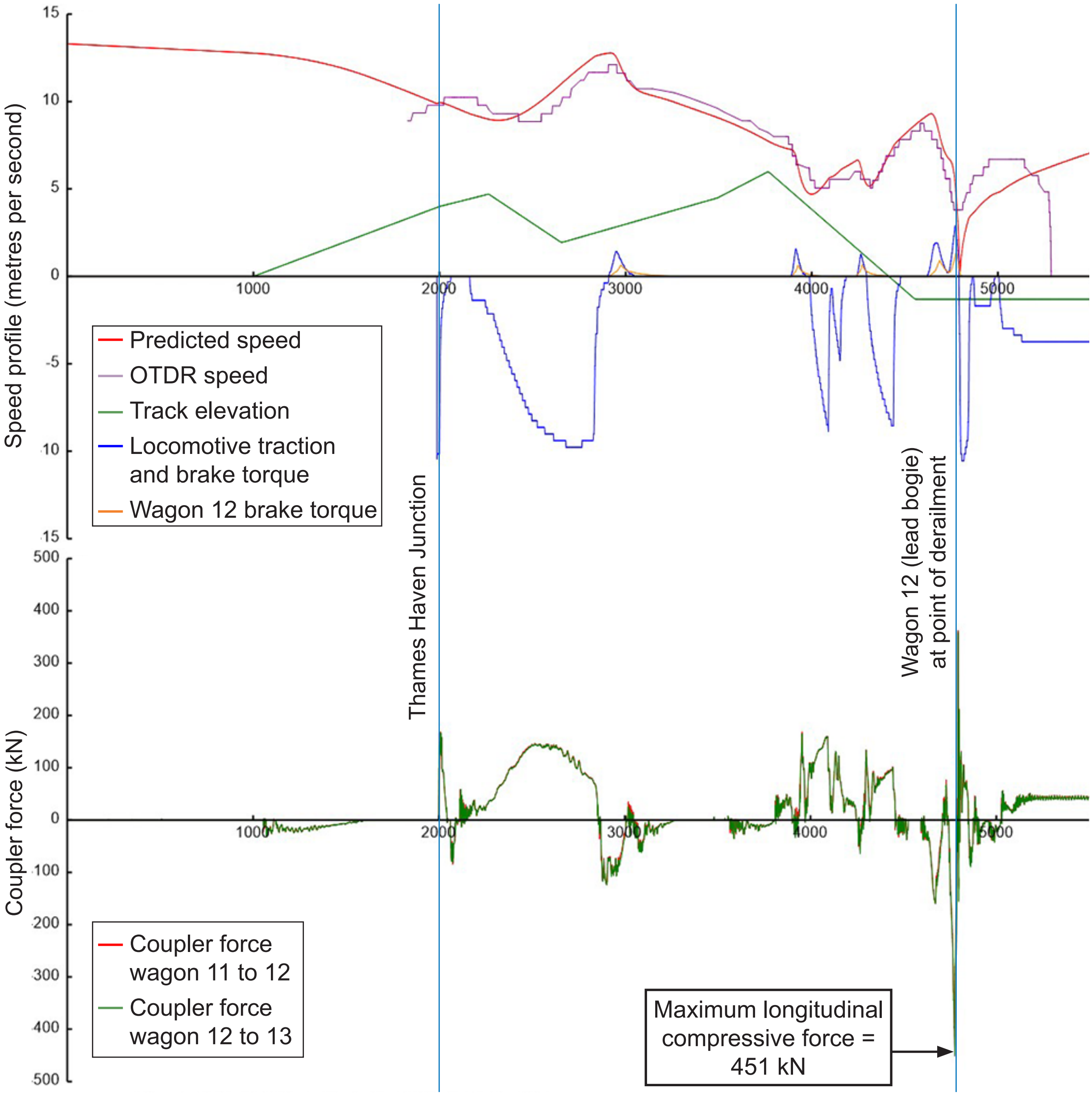

Figure 19: Predicted speed profile and coupler force – sensitivity study C4.

93 The upper graph plot shows the predicted speed profile and that recorded by the locomotive OTDR. The track gradient profile and applied traction and brake torques (at the locomotive and wagon 12) are shown for pictorial reference. The lower graph plot shows the predicted variation of the force in the couplers at either end of wagon 12. OTDR analysis shows how the double brake application made by the driver of train 4L47 coincided with wagon 12 approaching the point of derailment location (paragraph 37). Figure 19 shows that the maximum longitudinal compressive force was predicted to occur at the same time. Other sensitivity studies show how replacing the double brake application with a brake application of different form and size could significantly affect both the magnitude and location of the maximum longitudinal compressive force (appendix C). Together these show that the high longitudinal compressive force that occurred was because of the double brake application and that it is evident that the force generated was sufficient to result in the derailment of the leading bogie of wagon 12.

94 RAIB has investigated several freight derailments on plain line track. It has found that these more usually involve conventional flange climb mechanisms (such as the derailment at Reading West Junction on 28 January 2012, RAIB report 02/2013), or behaviours associated with cyclic top (such as the derailment near Gloucester on 15 October 2013, RAIB report 20/2014). RAIB found no evidence that the causes frequently associated with these types of derailment mechanism were relevant to the accident at London Gateway. Routine track geometry measurements had not recorded any significant faults in the vicinity (paragraph 29) and the train had not been travelling at a particularly high speed (paragraph 9).

95 The longitudinal train dynamics studies predicted a maximum longitudinal compressive force location that was consistent with the derailment outcome. However, RAIB was mindful that the greatest magnitude calculated (451 kN, for sensitivity study C4) was less than the baseline wagon derailment simulations predicted as being needed for full derailment (650 kN (see paragraph 119)).

96 RAIB has concluded that the gap between the predictions probably arises from data uncertainties and assumptions that were then needed to allow the simulation work to proceed. Therefore, the inconsistency is explainable and, given the significance of the other supporting evidence (and the lack of evidence supporting an alternative derailment means), does not negate the conclusions drawn. RAIB did not explore further refinement and validation of the simulation models as it considered this would not to be proportionate to the identification of relevant safety learning.

97 The significance of the data uncertainties and assumptions is discussed in paragraphs 170 to 172.

Identification of causal factors

98 The accident occurred due to a combination of the following causal factors:

a. Wagon 12 was susceptible to derailment under longitudinal compressive force; its condition, and the loading of the Ecofret 2 triple-wagon of which it was a part, increased this risk (paragraph 99).

b. The longitudinal compressive forces generated within train 4L47 during braking and which acted on wagon 12 were large, significant, and sudden. (paragraph 125).

Each of these factors is now considered in turn.

Susceptibility to derailment under longitudinal compressive load

99 Wagon 12 was susceptible to derailment under longitudinal compressive force; its condition, and the loading of the Ecofret 2 triple-wagon of which it was a part, increased this risk.

100 The Ecofret 2 triple-wagon comprising wagons 11, 12 and 13 was a development of the Ecofret 1 triple-wagon, a type of triple-wagon that had previously derailed on plain line track because of longitudinal compressive forces generated during train braking (paragraphs 73 and 74). Although wagon 12 was fitted with the longer bar coupler (paragraph 76), this improvement did not fundamentally alter the behaviour of the bar coupler arrangement under longitudinal compressive force, since the bar coupler remained free to rotate within the headstock pocket (paragraph 54). Ecofret 2 triple-wagons remained susceptible to derailing in the same way, with a derailment outcome depending on the magnitude (and nature) of the longitudinal compressive force, the payload on the three wagons (paragraph 77) and the effects of changes introduced as part of the Ecofret 2 wagon development (paragraph 49).

101 This causal factor arose due to a combination of the following:

a. The design process for Ecofret 2 wagons did not fully recognise the need for there to be a change in design from the Ecofret 1 wagon to improve behaviour under longitudinal compressive forces (paragraph 102).

b. It is possible that degradation and wear had resulted in the bogies on wagon 12 being in a condition that made the wheel flanges more prone to being forced into contact with the rail under longitudinal compressive force (paragraph 117).

c. The way that wagons 11, 12 and 13 were loaded made the wheels of wagon 12 more prone to lifting under longitudinal compressive force (paragraph 121).

Each of these sub-factors is now considered in turn.

Wagon design

102 The design process for Ecofret 2 wagons did not fully recognise the need for there to be a change in design from the Ecofret 1 wagon to improve behaviour under longitudinal compressive forces.

103 Earlier derailments and follow-up simulations had led to an understanding of the mechanism by which the centre wagon of an Ecofret 1 triple-wagon was susceptible to derailment under longitudinal compressive force (paragraphs 74 to 76). Witness marks and damage to the track and derailed wagons were all consistent with a mechanism of this nature resulting in the derailment at London Gateway (paragraphs 42 to 44 and 66), while the wagon derailment simulations (paragraph 82c and appendix D) further supported this as the derailment cause. The derailment at Kisby showed how the centre wagon of an Ecofret 2 triple-wagon was similarly susceptible to derailment by this means (paragraph 79).

104 A further conclusion of the early derailment simulation studies was that triple-wagons of this type are likely to be more susceptible to derailment than twin-wagons (paragraph 76).

105 Other options for improvement had been considered before it was decided to lengthen the bar coupler on Ecofret 1 triple-wagons. A number of these may have benefited the wagon design by changing the fundamental characteristic behaviour of the Ecofret 1 triple-wagon under longitudinal compressive force. They included:

- Fitting side buffers between the centre and outer wagons, either in a conventional (two buffer units per headstock) or diagonal (one buffer unit per headstock) arrangement. The objective was to provide a means of energy absorption that would reduce the effect of the longitudinal compressive force. The buffers may also have helped to provide a moment to resist underframe yaw rotation (paragraph 90).
- Fitting cup-and-cone devices between the centre and outer wagons to protect against the wagons overriding each other as they get closer together, so in effect locking the wagon ends together.
- Restricting bar coupler rotation by some means, thereby helping prevent the coupled wagons coming out of line.

106 All these options were discounted for Ecofret 1 triple-wagons because of the complexity of the design and modification work involved. The development of the new Ecofret 2, however, presented an opportunity to reconsider improvement options. Despite this, design activities and objectives either led to the conclusion that the Ecofret 2 triple-wagon would behave satisfactorily under longitudinal compressive force or did not result in work that might have indicated otherwise. This meant that there was no reconsideration of potential options to improve the design's performance in this respect. The design activities and objectives involved are discussed below in more detail (see paragraphs 107 to 116).

Design commonality

107 Other than the bogie and brake equipment changes, VTG Rail sought to keep the Ecofret 1 and Ecofret 2 wagon designs as similar as possible (paragraph 50). This particularly concerned the wagon underframe and the bar coupler arrangement. The technical specification prepared for the Ecofret 2 wagon required the wagon underframe to be '*essentially the same as on Ecofret 1*', with some '*minor change*' needed to accommodate specified equipment differences. It specifically required use of the same, longer bar coupler that had been later fitted to Ecofret 1 triple-wagons.

108 VTG Rail explained that no Ecofret 1 triple-wagons had derailed because of longitudinal compressive force after the bar coupler was lengthened. On this basis, use of the same, lengthened, bar coupler arrangement was felt to be justified for Ecofret 2 triple-wagons.

Design process

109 VTG Rail and its suppliers separately assessed aspects of vehicle behaviour. Each used different methods to do so.

110 Wabtec focused on the wagon ride and derailment resistance performance (traditionally concerning the risk of derailment by flange climb and cyclic top mechanisms) and developed single-vehicle dynamic simulation models to assist with this (paragraph 62). Related performance requirements are generally specified in TSI and NTR documents, and simulation models of this type are often used for assessing and demonstrating compliance.

111 The assessment of risks due to longitudinal compressive forces was excluded from Wabtec's work. VTG Rail sought to focus on this issue because of its overall responsibility for vehicle design (paragraph 51). It used the quasi-static simulation model to support this, with VTG Rail asking Wabtec to supply the parameter data needed to represent the bogie in the model.[27] The need to enhance the single-vehicle dynamic model to carry out this assessment was not considered necessary. Such a model could have provided greater insight into the behaviour of the Ecofret 2 triple-wagon under longitudinal compressive force (see paragraph 169).

Design approval – interoperability requirements and technical standards

112 VTG Rail identified the standards applicable to its strategy for obtaining authorisation for the Ecofret 2 wagon to enter service (paragraph 59). In doing this, VTG Rail found no requirement which mandated a demonstration of safe running under longitudinal compressive force or any criterion that could have been used to assess this and to highlight concern. Its conclusion was consistent with a list of standards provided to RAIB that RSSB considered would have been applicable.

113 Criteria for assessing safe running under longitudinal compressive force are defined in EN15839 and included as an '*additional optional condition*' in the WAG TSI (paragraph 72). ACS listed the standard in the technical file it prepared as part of its NoBo role, but subsequently concluded that compliance was not required since the Ecofret 2 triple-wagon was out of scope. Even if the wagon had been within the scope of EN15839, RAIB has not been able to determine any fundamental changes to the design which are likely to have resulted. This is because EN15839 cites operation over S-shaped curves to be the special concern, whereas wagon 12 derailed on a section of plain line track comprising mainly straight track and plain curves of large radius.

Design approval – residual risk

114 ACS reviewed VTG Rail's hazard log as part of its AsBo role (paragraph 60). It identified the risks due to longitudinal compressive force as one of two issues that remained open. ORR required the resolution of these issues as a condition of its letter authorising the placing into service of the wagons (paragraph 63). VTG Rail used the explicit risk estimation approach permitted by CSM REA to develop an argument justifying closure.

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[27] The outer wagons were treated as being fully loaded and the centre wagon unloaded.

115 The safety justification that VTG Rail developed was based on a combination of calculation and evidence of service performance for the Ecofret 1 twin-wagon. The quasi-static simulation model had predicted that the longer bar coupler increased the capacity of the Ecofret 1 triple-wagon to resist longitudinal compressive force from around 400 kN to 600 kN (paragraph 76). However, when the same simulation model was used to assess the derailment resistance for the Ecofret 2 triple-wagon (paragraph 111), the TF20 bogie parameters meant that the capacity to resist derailment due to longitudinal compressive force was predicted to be 510 kN, again with the longer bar coupler.

116 VTG Rail's engineering consultant had hypothesised a worst-case longitudinal compressive force during braking of around 500 kN for the Ecofret 1 wagons (paragraph 81). In the file note[28] that it prepared, VTG Rail stated this to be the '*maximum expected*' longitudinal compressive force '*to be experienced in service*'; in an earlier file note[29] it argued that the fact that no Ecofret 1 twin-wagon had derailed since their introduction in 2012 helped to justify this figure. As this value was less than the capacity of 510 kN calculated for the Ecofret 2 design, the likelihood of derailment due to longitudinal compressive force was considered *'improbable[30]'.* On this basis, while the severity level was deemed '*catastrophic*', the derailment risk was assessed as being '*tolerable*'.

Bogie condition

117 It is possible that degradation and wear had resulted in the bogies on wagon 12 being in a condition that made the wheel flanges more prone to being forced into contact with the rail under longitudinal compressive force.

118 Wagon derailment simulations (paragraph 82c and appendix D) established that lateral clearances within the bogie primary and secondary suspension needed to be taken up before the longitudinal compressive force acting on the bar coupler arrangement could result in a wheel flange being brought and forced into rail contact. Sensitivity studies showed that the size of the lateral clearances could detrimentally affect the capacity of the Ecofret 2 triple-wagon to resist derailment.

119 RAIB identified signs of significant damage and degradation on several PLB devices on wagon 12 (paragraph 68). The PLBs were fitted to remedy a running behaviour issue that was unrelated to the concerns about the risk of derailment due to longitudinal compressive forces (paragraph 62). In the baseline derailment simulation case, they were modelled with additional clearance to account for the degradation resulting from the detachment of the friction strips, with a longitudinal compressive force of 460 kN predicted as being needed for the wheel flanges to contact opposite rails (stage C in the derailment sequence (paragraph 90)) and 650 kN for full derailment (stage E in the derailment sequence). Sensitivity studies predicted that when the PLBs were modelled as being intact, the forces predicted as being needed increased to 500 kN and 680 kN respectively. This supports the degradation of the PLBs reducing the amount of longitudinal compressive force required for the wheel flanges to contact the opposite rails, and for a bogie to ultimately derail.

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[28] VTG Rail file note, FWA-FN10, issue 3.

[29] VTG Rail file note, FWA-FN10, issue 2.

[30] 'Improbable' in this context was defined as an event which occurs at intervals between 100 and 1000 years.

120 It is possible that some of the PLB damage and degradation observed occurred after the derailment and as a consequence of it occurring. In addition, the sensitivity studies suggest that PLB degradation has a much less significant effect than other factors such as payload condition (see paragraph 124). However, the studies highlight the important role that the bogie suspension is likely to play in the resistance to derailment under longitudinal compressive force, particularly with respect to the control of lateral suspension movement.

Payload condition

121 The way that wagons 11, 12 and 13 were loaded made the wheels of wagon 12 more prone to lifting under longitudinal compressive force.

122 Wagon 12 carried no container payload. This was the same loading condition as the centre wagons in previous reported Ecofret 1 and Ecofret 2 triple-wagon derailments (paragraph 89). This lack of payload resulted in two vulnerabilities which made wagon 12 more prone to lifting under longitudinal compressive force and its attendant consequences:

- The lack of payload caused the bar couplers to become inclined, because the outer wagons (wagons 11 and 13) were loaded and therefore lower on their suspension. This provided a line of action resulting in forces that tended to lift the centre wagon (figure 20).
- The lack of payload reduced the wheel load that the lifting forces needed to overcome.

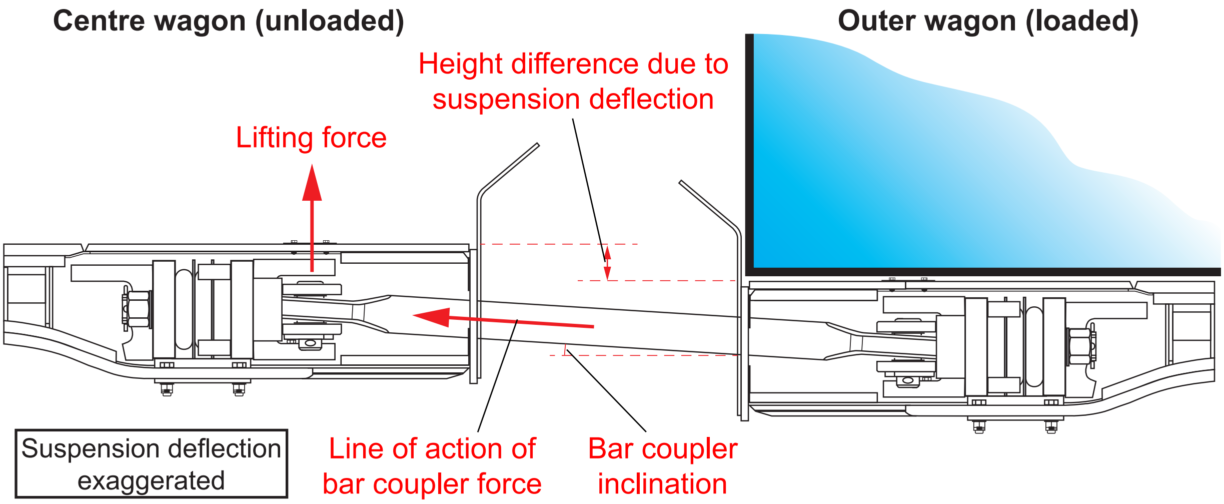

Figure 20: Bar coupler inclination and resulting centre wagon lifting force.

123 The modification to lengthen the bar coupler on the Ecofret 1 triple-wagon (paragraph 76) had helped to address the first vulnerability because it reduced the angle of inclination and hence the tendency for the centre wagon to lift when longitudinal compressive forces were applied. A loading restriction had been introduced to manage this vulnerability following the derailments at Felixstowe and Peterborough. The bar coupler modification had allowed this restriction to be removed (paragraph 77). A loading restriction of this nature was never applied to Ecofret 2 wagons, and RAIB found no evidence of any other instruction that meant wagons 11, 12 and 13 had been loaded contrary to the rules and guidance in force at the time of the accident.

124 The lightest container on the driver's train document had a mass of 4.4 tonnes (table 1). Sensitivity studies predicted that, for this relatively modest payload, the longitudinal compressive force needed for the wheel flanges to contact the opposite rails (stage C in the derailment sequence) increased to 540 kN (from 460 kN in the baseline derailment simulation case) and to 930 kN (from 650 kN in the baseline derailment simulation case) for full derailment (stage E in the derailment sequence) (appendix D). With none of the three wagons loaded, the longitudinal compressive forces predicted as being needed increased to 510 kN and 850 kN respectively.

Generation of longitudinal compressive force

125 The longitudinal compressive forces generated within train 4L47 during braking and which acted on wagon 12 were large, significant, and sudden.

126 Under normal operation, longitudinal train dynamic forces are generated within the couplers on a train (such as the bar couplers and the conventional screw coupling and side buffers on train 4L47) and act on the individual vehicles at the coupler attachment points. The magnitude, sense (compressive, acting to squeeze the vehicles together, or tensile, acting to separate the vehicles) and variation of these forces depends on the complex interaction of the train's physical properties and the applied forces and torques acting. For long locomotive-hauled freight trains, the following elements are important:

- the traction torques provided by the locomotive that are used to propel (accelerate) the train
- the brake torques that are applied to the wheelsets on the locomotive and each wagon to decelerate the train
- the gravitational forces acting on the locomotive and each wagon as the train progresses over the gradient profile
- the resistance forces acting to slow the motion of the train (for instance, due to the effects of track curvature and friction in the axle bearings)
- the masses of the locomotive and wagons and the rotational inertia of the wheelsets (and other rotating parts) that the applied forces and torques need to accelerate and decelerate
- the force-displacement (stiffness), slack and friction properties of the couplers that, together with the train mass and inertia properties, help to characterise the natural longitudinal dynamic behaviour of the train.

127 Traction torques generally result in longitudinal forces that are tensile. Brake torques can result in negligible longitudinal forces if they apply simultaneously on each vehicle and are in proportion to the mass of the vehicle being braked. With an automatic air brake system, this will rarely be the case because propagation and timing effects mean that brake torques do not apply simultaneously along the train (paragraph 85). As a result, significant longitudinal compressive (or tensile) forces can be generated.

128 RAIB sought to characterise and understand the significance of the above elements on the longitudinal compressive forces generated within train 4L47 at the time of the derailment by:

- test and analysis work to estimate the brake and traction torques that were acting along train 4L47 (appendix B)
- the development and use of the longitudinal train dynamic simulation model (appendix C).

129 This work provided evidence that:

a. Wagon 12 was within a part of the train where the longitudinal compressive force generated during braking was likely to be higher than at other locations along the length (paragraph 130).

b. A double brake application, made shortly after passing LG11 signal, resulted in a sudden and large longitudinal compressive force being generated that acted on wagon 12. This coincided with wagon 12 approaching the point of derailment (paragraph 133).

Each of these sub-factors is now considered in turn.

Wagon location

130 Wagon 12 was within a part of the train where the longitudinal compressive force generated during braking was likely to be higher than at other locations along the length.

131 Wagon 12 was in the middle part of the train. The longitudinal train dynamics simulation model predicted that, around the time of the derailment, the longitudinal compressive forces were highest in the coupler connecting wagons 16 and 17, which was the coupler at the centre of train 4L47. The longitudinal compressive forces acting in the couplers either side of wagon 12 were predicted to be only slightly less (figure 21).

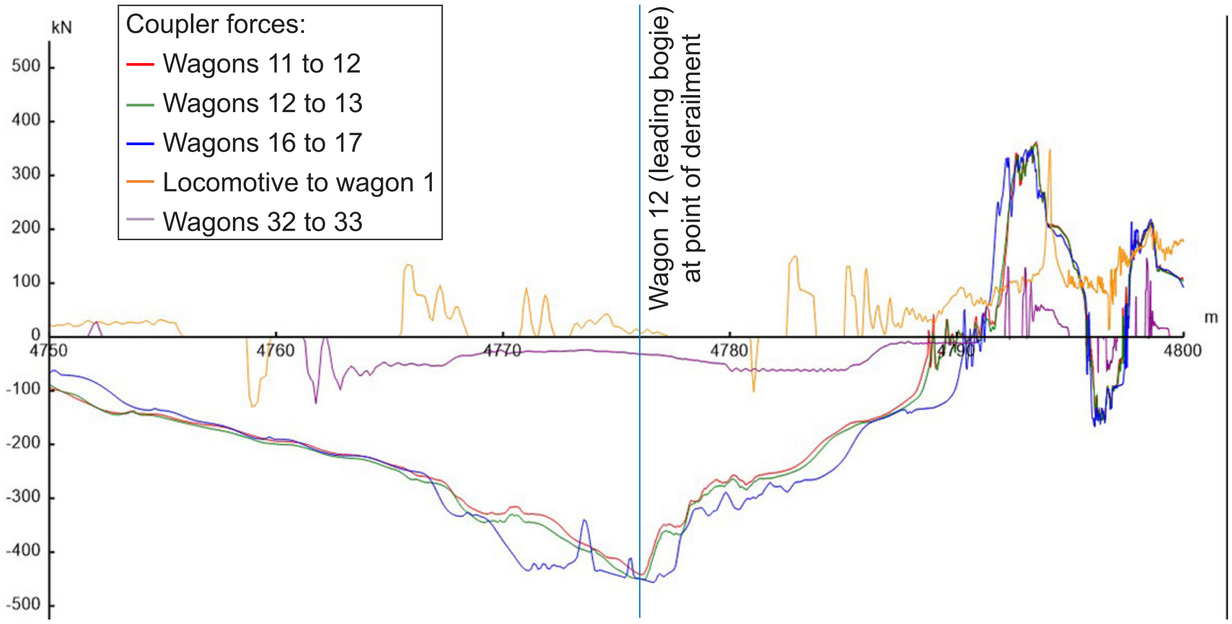

Figure 21: Predicted variation of the force in the couplers at different positions along train 4L47 around the time of the derailment – sensitivity study C4. Plot shows the forces predicted in the couplers: either side of wagon 12; between wagons 16 and 17; between the locomotive and wagon 1; and between wagons 32 and 33.

132 While wagon 17 was the centre wagon of an Ecofret 2 triple-wagon, it was carrying a relatively heavy container (table 1). RAIB concluded that the high longitudinal compressive force generated in this part of the train, in combination with the lack of container payload (paragraph 121), made wagon 12 particularly vulnerable to the effects of longitudinal compressive force. The compressive forces in the couplers at the outer ends of the train (between the locomotive and wagon 1, and between wagons 32 and 33) were predicted to be negligible by comparison.

Train brake application

133 A double brake application, made shortly after passing LG11 signal, resulted in a sudden and large longitudinal compressive force being generated that acted on wagon 12. This coincided with wagon 12 approaching the point of derailment.

134 OTDR data from train 4L47 shows three single brake applications being made before the double brake application (figure 5). The last two of these were made while the train was descending the gradient on the approach to LG11 signal. Each was followed by a full traction effort demand. It is possible that this indicates that the driver was having difficulty in accurately controlling the train's speed. RAIB found evidence that other drivers of trains that included Ecofret 2 wagons had experienced difficulty like this, especially when attempting to control their train at low speed.

135 The double brake application was made shortly after the last of these full traction effort demands, and OTDR analysis shows that wagon 12 was approaching the point of derailment as the brakes were then releasing (paragraph 37). Baseline simulation and sensitivity studies predicted that the longitudinal compressive forces acting on wagon 12 would have suddenly reached a maximum at this point (appendix C). Sensitivity study C4 predicted the greatest maximum longitudinal compressive force, 451 kN (paragraph 92 and figure 19).

136 Further sensitivity studies investigated the significance of the double brake application (appendix C) by replacing the associated brake torques in sensitivity study C4 with those from:

- one of the single brake applications made on the approach to LG11 signal (sensitivity study C5), where the maximum longitudinal compressive force reduced to 125 kN
- a larger single brake application of approximate equivalence to the double brake application (sensitivity study C6), where the maximum longitudinal compressive force reduced to 335 kN.

137 The significant force reduction shown in these studies led RAIB to conclude that the sudden longitudinal compressive force that caused the derailment was the result of the double brake application. Other effects, such as gradient profile, were less significant.

138 Witness and other evidence indicated a number of possible reasons why the double brake application was made when it was. These were:

a. Enhanced initial brake applications

In May 2021, GBRf issued urgent operating notice UON/21/006 because of technical issues that were believed to concern how the brake distributors fitted to Ecofret 2 wagons interacted with the brake cylinders (appendix E). GBRf had worked with VTG Rail to understand the issues and decide the action needed before issuing this notice.

When making an initial brake application, testing had shown that drivers needed to reduce the brake pipe pressure to the lower value of 4.3 bar (instead of a usual 4.6 bar). This was to avoid a reported problem with the brake system venting air on the Ecofret 2 wagons.

This became referred to as making an ‘enhanced initial brake application’. Drivers were required to brake in this way when operating any trains that included Ecofret 2 wagons, which meant that it became more difficult to make a long sustained single brake application without the train decelerating too rapidly. Many drivers had found it necessary to adapt their normal driving style, and the need to make a traction effort demand after an enhanced initial brake application was cited as a means of avoiding an unplanned stop. It is possible that the double brake application was an attempt to limit an increase in train speed following a traction effort demand such as this.

b. Line side lighting

The driver regularly operated into London Gateway port (paragraph 31) and reported finding the brightness of the lights located by the port camera and OCR scanner equipment to be a distraction (paragraph 30). Knowing there was a 15 mph (24 km/h) permanent speed restriction shortly after the lights, they might have decided to make the double brake application to reduce the train’s speed in advance, so avoiding the need to make a further brake application as the train passed the lights.

c. Train mass

The driver recalled that train 4L47 felt “heavy” on the journey from Wembley EFOC (paragraph 35). It is possible this influenced their decision regarding the amount of braking force that was required while most of the wagons on the train were still descending the gradient (figure 5).

Driver guidance and training

139 Freight train operators are responsible for defining the driving techniques they expect their drivers to use and for managing how drivers comply. GBRf’s instructions for train operation are defined in a company document called the ‘General Operating Appendix’. The document is divided into modules, including:

- Module A6 – Automatic air brake regulations
- Module B2 – Professional driving mindset
- Module B3 – Professional driving skills
- Module B7 – Economic driving
- Module B8 – Seasonal risk.

140 These modules included considerations such as the need to check that the automatic air brake is functioning correctly (the running brake test, paragraph 34), precautions when braking on the approach to signals and other places where it is necessary to stop, and the need to anticipate low adhesion conditions. However, RAIB found no reference in these modules to a need to drive in a particular way with the aim of controlling or limiting train longitudinal forces and shocks. Derailment risk mitigation is identified in the modules, but only in the context of avoiding excessive speed and operations involving points. GBRf's manual for the class 66 locomotive includes no other driving instructions or guidance relevant to the control of longitudinal train dynamic effects.

141 Although not documented in standards or guidance, GBRf explained that brake and traction management is covered by instructor feedback during the 225 hours of initial training that its drivers need to complete. This includes teaching drivers that '*large shocks*' can result in buffer and coupling damage and failure. However, there is nothing similar concerning how train handling effects can also cause derailment.

142 GBRf's employee development system (EDS) includes various routine assessments and reviews for managing driving competency after the initial training period. GBRf provided a list of the driving-related criteria that are covered. Included were topics such as the economic use of the traction controller and braking techniques for mitigating the risk of wheel slide. RAIB did not identify any criteria relating to derailment risk resulting from the generation of longitudinal compressive forces.

143 GBRf operations standards managers (OSMs) routinely review OTDR records as part of the EDS process. RAIB asked an OSM from GBRf about the OTDR record from train 4L47. They concluded that an OTDR review would not have raised undue concern or triggered the need for a support plan or further reviews. It would probably have only resulted in constructive feedback about the benefits of braking earlier and longer.

Identification of underlying factors

Understanding of derailment risk due to longitudinal compressive force

144 Derailment risks associated with the longitudinal dynamic behaviour of long freight trains are not widely understood within the rail industry and there are limited supporting processes, tools and knowledge available to assess and manage them.

145 Although the rail industry was historically aware of issues such as traction and braking effects and buffer interaction, RAIB found that it had undertaken little research to further develop its understanding of longitudinal train dynamic behaviour and the risk it poses to modern freight train operation (paragraphs 69 and 71). Longitudinal train dynamics have not been a recurrent factor in RAIB freight derailment investigations, and it is probable that derailments of this nature have not been occurring as regularly as they once did. This may be due to the type of rolling stock now in service and recent operating trends. With fewer derailments of this type occurring, it is possible that the need to develop understanding in the field has not been considered a priority by the rail industry.

146 The derailments involving Ecofret 1 and Ecofret 2 wagons are a reminder that the risks arising from longitudinal compressive forces remain. In addition, the demand for shorter intermodal wagons, the increased use of permanently coupled wagons with bar couplers in between, and proposals to operate longer and heavier trains suggest that such risks may become more significant. The passenger train derailment at Neville Hill (paragraph 70) highlights that these risks are not only relevant to freight train operation.

147 The investigation identified four areas where there was a particular lack of understanding and supporting resources.

Derailment resistance assessment

148 An assessment of rail vehicle derailment resistance requires:

- a criterion for quantifying derailment resistance; in this case, for instance, the longitudinal compressive force needed to cause the first wheel to derail (‘full derailment’) or to bring it to position where it is about to derail (‘incipient derailment condition’)
- running conditions against which derailment safety is to be assessed; in this case, for instance, the magnitude of the maximum longitudinal compressive force that is considered likely to act.

149 The parties involved in the development of the Ecofret 2 wagon did not know of a standard criterion for assessing the capacity of a triple-wagon to resist derailment under longitudinal compressive force (paragraph 112). It was decided to adopt an approach that involved the use of the simplified quasi-static simulation model to determine the longitudinal compressive force at which the ‘Y/Q derailment quotient’[31] exceeded a standard critical value of 1.2[32] (paragraph 111). VTG Rail’s engineering consultant had previously looked to validate this approach via comparison with the detailed Ecofret 1 triple-wagon computer simulations (paragraph 74).

150 The Y/Q derailment quotient is conventionally used to assess resistance to derailment due to flange climbing. In this mechanism, sustained forces need to act at the wheel-rail contact point to promote the wheel flange to gradually climb onto and over the railhead. The short derailment marks (paragraph 43) and supporting wagon derailment simulations (appendix D) showed that the mechanism which caused wagon 12 to derail was more complex. It involved forces at the wheel-rail interface that acted suddenly, and a sequence of intermediate steps, with full derailment probably occurring in a chaotic fashion. RAIB is not aware of work to fully validate the ability of standard simulation methods to predict full derailment by a mechanism of this complexity, or to determine the degree to which earlier steps in the sequence are indicative of an incipient derailment condition.

151 The parties involved were also not aware of a standard that defined the maximum longitudinal compressive force likely to act. RSSB was similarly not aware of any such standard. VTG Rail’s engineering consultant had instead needed to hypothesise a worst-case force (paragraph 81).

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[31] The ratio of the lateral (Y) and vertical (Q) forces acting at the wheel-rail contact point.

[32] As defined in several technical standards, including BS EN14363.

152 RAIB found evidence of longitudinal compressive force values (termed '*endurable longitudinal compressive force*') in the assessment criteria defined in EN15839 (paragraph 72). However, it was not able to determine the degree to which this assessment method was considered relevant to the derailment location (paragraph 113). While the Ecofret 2 triple-wagon is a type of wagon that is currently out of scope of EN15839, a footnote in the standard explains that '*acceptance conditions*' are being developed for inclusion. At the time of writing this report, RAIB has not been able to establish the progress of this work.

153 A suitably developed and robust derailment resistance assessment method would have simplified the work undertaken to develop the Ecofret 2 wagon design and given greater confidence regarding its ability to resist derailment due to longitudinal compressive forces. Such a method may also be applicable to the assessment of other wagon types.

Longitudinal train dynamic analysis

154 RAIB found evidence that the parties involved in the development of the Ecofret 1 and Ecofret 2 wagons had discussed the idea of a longitudinal train dynamics simulation model. This occurred both when they were developing an understanding of the early Ecofret 1 triple-wagon derailments and as part of the work to obtain authorisation for the Ecofret 2 triple-wagon to enter service. RAIB found no evidence of work to develop such a model. This was probably due to a lack of knowledge of a suitable existing analysis tool, or due to the complexities inherent in developing one.

155 These complexities were illustrated by the work needed to develop the longitudinal train dynamic simulation model that was critical to determining and understanding the cause of the derailment at London Gateway (paragraph 82b and appendix C). This involved the need for fundamental checks to validate model behaviour against both basic physical principles and data recorded by the locomotive OTDR (paragraph 92). It also involved the need for external expert review and advice, including help from those having experience of the longitudinal dynamic behaviour of freight trains operating overseas.

156 Certain simulation model parameters required information that could not readily be provided. Further validation of the simulation model, for instance, using dynamic vehicle testing, was outside of the scope of RAIB's investigation (paragraph 96).

157 A suitably developed and validated simulation model and readily accessible parameter information would have helped those developing the Ecofret 2 wagon to evaluate the maximum longitudinal compressive force likely to act. Such a model would also help operators of long freight trains to assess train configuration and operation options designed to limit such forces, and thereby define restrictions that should be applied.

158 RAIB is aware of alternative simulation tools that have been developed for longitudinal train dynamics analysis.[33] It has not assessed the use of these, or their limitations and benefits.

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[33] For instance, Wu Q et al, 'International benchmarking of longitudinal train dynamics simulators: results', Vehicle System Dynamics, 2018, Vol 56, No 3, 343-365.

Train brake force analysis

159 RAIB concluded that neither GBRf nor VTG Rail knew of brake testing or other data that could be used to help determine the forces acting on the individual wagons within the train. The static brake testing undertaken on the two representative intermodal trains was the pragmatic means of acquiring the data needed to allow RAIB's investigation to proceed (paragraph 82a and appendix B). RSSB had commissioned some potentially relevant laboratory testing in the late 1990s. However, this was limited and RSSB knew of no other testing that had sought to measure brake system pressures on a long freight train or a laboratory equivalent.

160 A literature search undertaken as part of this investigation found reference to the use of pneumatic simulation tools for predicting brake pipe and cylinder pressure values on long freight trains.[34] However, RAIB was not able to find evidence of wide-scale rail industry adoption of such tools.

161 The availability of relevant and reliable brake test data, or a suitably developed and validated pneumatic simulation tool of the train air brake system, would have helped those developing the Ecofret 2 wagon to assess the brake forces acting along the train. This could have been used to help determine the maximum longitudinal compressive force likely to act. A pneumatic simulation model could be of use to the rail industry in general as it could help operators of long freight trains assess options for brake system configuration (such as choice of passenger or goods distributor timings) and manage the implications of brake system performance issues. It could also be used to inform the development of operating standards and restrictions.

Freight train operation and handling

162 GBRf had provided no specific guidance to its operating staff on how to manage the effects of longitudinal train dynamic behaviour to avoid the risk of derailment (paragraphs 140 and 141). RSSB does not publish standards that it would expect to be used for this purpose.

163 The specification of rules and guidance in the relevant train operating standard could have reinforced practice that was designed to help control and limit train longitudinal forces. As well as driving techniques, such rules and guidance could also cover relevant aspects of train preparation, such as the degree to which screw couplings need to be tightened (and slack allowed) and any necessary restrictions on train consist configuration and loading.

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[34] For instance, Catone L, 'TrainDy: the new Union Internationale de Chemins de Fer software for freight interoperability', Proceedings of the Institution of Mechanical Engineers, Vol 225 Part F: Journal of Rail and Rapid Transit.

Approach to wagon design

164 VTG Rail adopted design management arrangements that possibly limited its ability to understand the dynamic behaviour of the triple-wagon as a complete vehicle system and did not result in it identifying critical subsystem performance requirements that were associated with the behaviour of the train as a whole.

165 VTG Rail established a steering group to co-ordinate the work of its main suppliers (Wabtec and WH Davis) in developing the design of the Ecofret 2 triple-wagon (the ‘vehicle system’). They worked together using a consortium-type project management arrangement, with engineering responsibilities being largely divided between these suppliers according to the subsystems within their scope, principally the underframe, couplers and bogie (paragraph 51).

166 The responsibilities for evaluating vehicle ride and running safety (largely to demonstrate compliance with identified standards (paragraph 62)) were separated from those for evaluating derailment resistance under longitudinal compressive force (paragraphs 111 and 114 to 116). RAIB found evidence that this did not result in use of what would possibly have been the best approach for understanding the dynamic behaviour of the vehicle system or the forces relating to it.

167 A technical specification was prepared for the wagon, and this effectively defined the vehicle and the subsystem requirements. However, the technical specification largely cascaded vehicle system requirements to the subsystems according to the desired design solution (or feature) rather than on the basis of performance. For instance, the bar coupler (part of the coupler subsystem) was specified with reference to the supplier’s component drawing, its size (1600 mm long) and its design features (incorporation of a ‘*rubber damper*’).

168 While the ‘*draw force*’ (the longitudinal tensile force acting on the bar coupler) was mentioned as a performance-related requirement, the technical specification was silent on the maximum longitudinal compressive force to be catered for. In the absence of published values (paragraph 112), efforts to define and validate the maximum longitudinal compressive force by consideration of the overall behaviour of the train (for instance, by calculation, simulation or test) could have provided greater confidence in the derailment resistance of an Ecofret 2 triple-wagon.

169 The division of responsibilities also meant that a computer simulation model representing the dynamic behaviour of the complete Ecofret 2 triple-wagon was not available. Such a model (like that developed for the wagon derailment simulations carried out during the investigation (appendix D)) could have provided greater insight into the behaviour of the triple-wagon under longitudinal compressive force and the complex interactions of the coupler and bogie subsystems. Obtaining approval for the bogie as a separate interoperability constituent (paragraph 61) may have reinforced the responsibility division.

Data uncertainties and assumptions

170 RAIB was mindful that the magnitude of the maximum longitudinal compressive forces predicted by the longitudinal train dynamics model were less than that calculated as being needed for full derailment by the wagon derailment simulation model. This probably arose from data uncertainties and the assumptions that were then needed (paragraphs 95 and 96).

171 Assumptions necessary in the development of the longitudinal train dynamics model are probably particularly important in this respect. Several of these related to uncertainties associated with effects that could result in greatly increasing the magnitude of the predicted maximum longitudinal compressive force. They included:

a. Coupling tightening and slack

The rail industry has long recognised the importance of coupling tightness and slack as a contributor to the generation of longitudinal forces and derailment risk. However, there was a lack of information on the amount of slack within train 4L47. In sensitivity study C1 it was assumed to be zero (appendix C). In sensitivity study C2 a nominal slack of ±25 mm was introduced. This increased the predicted maximum longitudinal compressive force by around 30 kN. The actual amount of slack could have been much greater than this nominal figure and the amount of longitudinal compressive force thereby also greater.

b. Coupler friction losses

Coupler friction is also recognised as a factor that is important to longitudinal train dynamic behaviour. The only reliable information on this was for the Ecofret 2 wagon coupler components.[35] In the baseline simulation, it was assumed that the friction model developed for the Ecofret 2 bar coupler was appropriate to all other couplers on the train (appendix C). Sensitivity study C4 predicted that a 50% reduction in friction, when combined with slack of ±25 mm, increased the longitudinal compressive force by around 130 kN.

c. Air brake system equipment

It was not possible to use the actual brake pipe and brake cylinder pressures from train 4L47 when determining the wagon brake torque time histories. Measurements from representative trains were instead processed to estimate representative values (appendix B). There was insufficient information to establish the degree to which the air brake system equipment on the representative trains differed in detail from that on train 4L47, for instance, in terms of specification, setting, condition, behaviour, and performance. Sensitivity study C1 showed how the magnitude of the vehicle brake torques could affect the maximum longitudinal compressive force (appendix C). As well as affecting the brake torque magnitude, air brake system equipment differences may have affected the time at which the brake torques applied. Other brake equipment differences, such as the configuration and condition of the mechanical brake rigging, may also have affected the brake torque.

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[35] There was some limited information for some components on the FEA wagons.

d. Speed dependent braking effects

The double brake application resulted in train 4L47 rapidly slowing. The OTDR recorded the locomotive's speed reducing to less than 9 mph (14.4 km/h) before starting to increase as traction was demanded (figure 5). The trajectory of the reducing speed suggests that it is possible that wagons on the train (whose speed is not recorded by the locomotive's OTDR), may have momentarily been travelling significantly slower. Sensitivity study C4, which used the refined traction and brake torque time histories, predicted something similar (figure 19). Data published by RSSB suggests that train brake forces can rapidly increase at slow speed. This is due to variation in the brake block and pad friction characteristic. VTG Rail's engineering consultant hypothesised that this speed dependent effect could as much as double the longitudinal compressive force.

e. Train resistance

In the absence of experimental or other data, the longitudinal train dynamics simulation studies assumed that the train resistance forces would act to slow the locomotive and each wagon at the same rate. Deviation from this would result in the generation of additional longitudinal compressive (or tensile) forces.

Other uncertainties, such as the lack of information on the characteristics of some of the coupler-related components, and the actual mass of the containers, might also have affected the accuracy of the calculations.

172 Other assumptions led RAIB to conclude that the baseline wagon derailment simulation model probably overpredicted the capacity of wagon 12 to resist derailment due to longitudinal compressive force. These principally concerned the friction elements used to represent the friction losses in the bar coupler (appendices C and D). The formulation of the friction elements meant that their line of action remains fixed and does not follow that of the 'pinlink' elements they are parallel to, which are able to rotate. As a result, the friction-related component of the bar coupler force was not accurately aligned. Separate simulation studies suggested that this alignment inaccuracy could result in an overprediction of resistance of around 100 kN or more. If correct, then this would mean that the wagon was more vulnerable in practice to derailment due to longitudinal compressive force.

Previous occurrences of a similar character

173 Research published in 2006[36] reviewed UK railway derailment data for the ten-year period between 1992 and 2002. It identified 33 derailment events that were due to longitudinal train dynamic effects. Of these, 27 events related to the presence of sudden severe longitudinal braking forces. The research identified a further four derailments that were due to buffer interaction (referred to as '*buffer locking/forces*').

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[36] RSSB report 'Cost effective reduction of derailment risk: initial analysis', January 2006. Research project T357.

174 The first known derailment of an FWA type wagon due to longitudinal compressive force occurred on 28 August 2015 on the entry line to the north and central rail terminals within the Port of Felixstowe. The train comprised a class 66 locomotive hauling 31 container flat wagons, which were a mixture of FEA and Ecofret 1 type wagons. The centre and leading outer wagons of an Ecofret 1 triple-wagon derailed, which were the 14th and 15th wagons on the train. Another derailment occurred at Peterborough on 17 September 2015. On this occasion, the train comprised two class 66 locomotives (one of which was not providing any traction effort) and 32 container flat wagons. These were a mixture of FEA and Ecofret 1 type wagons. The centre and trailing outer wagons of an Ecofret 1 triple-wagon derailed. These were also the 14th and 15th wagons on the train. Both trains were operated by GBRf.

175 Both derailments occurred at low speed on straight plain line track. Only the leading outer wagon of the Ecofret 1 triple-wagon at Felixstowe was carrying a container, while the centre wagon was not loaded in either derailment. The rail industry investigation work undertaken in response to these derailments led VTG Rail to decide to increase the length of the bar coupler on Ecofret 1 triple-wagons (paragraph 76).

176 The derailment of an empty Ecofret 2 triple-wagon occurred as a result of the collision of a GBRf intermodal train at Kisby level crossing on 19 August 2021. RAIB has considered the mechanism that caused the wagon to derail as part of this investigation (paragraph 79).

177 The only similar derailment that RAIB has investigated occurred at Neville Hill depot on 13 November 2019 (paragraph 70). This involved the collision of a relatively new Intercity Express Train. The investigation found that the train was susceptible to derailment due to high longitudinal compressive forces. This susceptibility was due to the design of the bar coupler arrangement which connected the vehicles together. This arrangement allowed the bar coupler to rotate relatively freely, and in this regard was like the Ecofret 2 triple-wagon. The impact of these features on derailment resistance had not been appreciated when the train was designed.

Summary of conclusions

Immediate cause

178 Longitudinal compressive forces generated within train 4L47 during braking were sufficient to cause the wheels on the leading bogie of wagon 12 to suddenly lift and run derailed (paragraph 87).

Causal factors

179 The causal factors were:

a. Wagon 12 was susceptible to derailment under longitudinal compressive force; its condition, and the loading of the Ecofret 2 triple-wagon of which it was a part, increased this risk (paragraph 99). This causal factor arose due to a combination of the following:

   i. The design process for Ecofret 2 wagons did not fully recognise the need for there to be a change in design from the Ecofret 1 wagon to improve behaviour under longitudinal compressive forces (paragraph 102, **Recommendation 1**).

   ii. It is possible that degradation and wear had resulted in the bogies on wagon 12 being in a condition that made the wheel flanges more prone to being forced into contact with the rail under longitudinal compressive force (paragraph 117, **Recommendation 1**).

   iii. The way that wagons 11, 12 and 13 were loaded made the wheels of wagon 12 more prone to lifting under longitudinal compressive force (paragraph 121, **Recommendation 1**).

b. The longitudinal compressive forces generated within train 4L47 during braking and which acted on wagon 12 were large, significant, and sudden (paragraph 125). This causal factor arose due to a combination of the following:

   i. Wagon 12 was within a part of the train where the longitudinal compressive force generated during braking was likely to be higher than at other locations along the length (paragraph 130, **Recommendation 2**).

   ii. A double brake application, made shortly after passing LG11 signal, resulted in a sudden and large longitudinal compressive force being generated that acted on wagon 12. This coincided with wagon 12 approaching the point of derailment (paragraph 133, **Recommendation 2**).

Underlying factors

180 The underlying factors were:

a. Derailment risks associated with the longitudinal dynamic behaviour of long freight trains are not widely understood within the rail industry and there are limited supporting processes, tools and knowledge available to assess and manage them (paragraph 144, **Recommendation 3**).

b. VTG Rail adopted design management arrangements that possibly limited its ability to understand the dynamic behaviour of the triple-wagon as a complete vehicle system and did not result in it identifying critical subsystem performance requirements that were associated with the behaviour of the train as a whole (paragraph 164, **Learning point 1**).

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

181 Following the Ecofret 2 wagon derailments at Kisby and London Gateway, VTG Rail asked its engineering consultant to revisit the earlier quasi-static simulation studies (paragraphs 111 and 115). The conclusion drawn from this revised simulation was that the derailments were due to the effects of longitudinal compressive forces and that a centre wagon payload of more than five tonnes greatly increased derailment resistance. As a result, VTG Rail issued temporary loading instructions which required the centre wagon of an Ecofret 2 triple-wagon to always carry a container, unless both the outer wagons were unloaded. GBRf issued urgent operating notice UON/21/007 to ensure loading is undertaken in compliance with this instruction.

182 GBRf is assisting VTG Rail to progress modification work to remedy the brake distributor issues on Ecofret 2 wagons that had led to GBRf issuing an urgent operating notice (paragraph 138a). It is anticipated that this will remove the requirement for drivers to make enhanced initial brake applications when operating trains that include Ecofret 2 wagons.

183 Wabtec is progressing work to resolve the underlying reasons for the in-service degradation of the PLBs on TF20 bogies. It has reported that the bogies on the majority of wagons have now been retrofitted with PLBs of a new stronger design.

Recommendations and learning point

Recommendations

184 The following recommendations are made:[37]

1 *The intent of this recommendation is to ensure that the vulnerability of the Ecofret 2 triple-wagon to derailment due to longitudinal compressive forces is fully understood and that the risk of this occurring is appropriately controlled.*

VTG Rail, supported by Wabtec UK Ltd, should investigate the dynamic behaviour of Ecofret 2 triple-wagons to better understand the operating conditions that result in longitudinal compressive forces acting on these wagons, their behaviour under such forces, and their capacity to resist derailment. This investigation should be used to identify appropriate mitigation measures such as design changes and operating restrictions, and should specifically include consideration of:

- improvements to the bar coupler arrangement
- control of lateral suspension movement
- wagon payload restrictions

(paragraphs 179a.i, 179a.ii and 179a.iii).

This recommendation may also be applicable to other owners or operators of rolling stock made up of freight wagons that are permanently coupled together using bar couplers at both ends.

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

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

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

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

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

2 *The intent of this recommendation is to ensure that freight trains are configured and operated in such a way that the longitudinal compressive forces generated in service are not sufficient to cause derailment.*

GB Railfreight, working where appropriate with relevant industry working groups, should review the risks associated with longitudinal train dynamics when operating freight trains. It should use this to inform the development of instructions, best practice guidance and training for operations staff so that longitudinal compressive forces are not generated that exceed the derailment resistance of the wagons forming the train. This work should include consideration of:

- the management of brake application and traction demands
- the effects of the train air brake system configuration, setting, degradation and operation
- the control of slack and pre-load in screw coupling and buffer arrangements
- the need for train configuration and payload restrictions and limits

(paragraphs 179b.i and 179b.ii).

This recommendation may also be applicable to other freight operating companies.

3 *The intent of this recommendation is to establish a robust and pragmatic industry-wide framework for managing the risks of freight train derailments due to longitudinal train dynamic effects.*

RSSB working with the freight operating companies should initiate a programme of work to raise the rail industry's understanding of longitudinal compressive forces in freight trains and the associated derailment risk. This work should incorporate:

- identifying, developing and validating analysis tools and techniques
- determining and validating relevant derailment criteria
- reviewing and developing a suitable derailment resistance assessment process
- identifying limits for longitudinal compressive force that can be generated in operational service, and the practical means by which it can be assured that these are not exceeded.

RSSB should develop a timebound programme for the implementation of any appropriate changes identified, such as new or revised standards, guidance and operating rules (paragraph 180a).

Learning point

185 RAIB has identified the following learning point:[38]

1 It is important that parties responsible for the introduction of rail vehicle products and equipment into service, such as new and modified rolling stock and interoperable components, adopt processes and procedures which ensure the use of best available engineering design and analysis practice.

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

Appendices

Appendix A – Glossary of abbreviations and acronyms

ACS	AEGIS Certification Services Limited
ApBo	Approved Body
AsBo	Assessment Body
CCTV	Closed-circuit television
CSM REA	Common Safety Methods for Risk Evaluation and Assessment
DeBo	Designated Body
EDS	Employee development system
EFOC	European Freight Operating Centre
GB	Great Britain
GBRf	GB Railfreight
GSM-R	Global system for mobile communications - railways
NoBo	Notified Body
NTR	National Technical Rule
NTSN	National Technical Specification Notice
OCR	Optical character recognition
ORR	Office of Rail and Road
OSM	Operations standards manager
OTDR	On-train data recorder
PLB	Primary lateral buffer
RSSB	Rail Safety and Standards Board
TSI	Technical Specification for Interoperability
VIBT	Vehicle inspection and brake test
VTG	Vereinigte Tanklager und Transportmittel GmbH
WAG TSI	Technical specification for interoperability relating to the subsystem ‘rolling stock – freight wagons’

Appendix B – Derivation of traction and brake torques

B1 In line with normal practice, the locomotive OTDR only recorded the brake pipe and brake cylinder pressures on the locomotive itself (paragraph 36). Although some historical supplementary rail industry data was available, it was not possible to use this to work out the corresponding brake pipe and brake cylinder pressures at each individual wagon.[39] RAIB concluded that brake system pressure measurements on a representative train were needed.

B2 Two intermodal trains were made available on separate dates for brake testing. Each was formed of a class 66 locomotive and a similar number of wagons. Ecofret 2, FEA-A, FEA-B and FEA-C type wagons were included on both trains. Pressure transducers were added to various brake pipe and brake cylinder test points. The driver's brake valve was operated with the train stationary and the resulting pressure measurements were recorded using a data acquisition unit (figure B1).

Figure B1: Brake testing arrangements. Inset shows pressure transducer fitted to a test point in the train brake pipe. (Main photograph courtesy Railway Braking Associates Limited).

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[39] In the late 1990s, RSSB commissioned research that investigated the effect of train length on braking distance. Supporting laboratory testing measured the pressures within a single pipe automatic air brake system at various train length positions. However, the work was focused on brake application and did not include measurements relating to brake release which were also needed.

B3 This testing had two main objectives:

- To obtain pressure measurements to help characterise the behaviour of the various wagon brake equipment types on train 4L47. The first train was mainly used for these tests.
- To simulate the brake applications made by the driver of train 4L47 on the Down Thames Haven line and record the corresponding brake pipe and brake cylinder pressures at selected positions along the train: the locomotive; the first wagon; the 33rd wagon (the location of the last wagon on train 4L47); and nominated wagons in between. The second train was used for these tests.

B4 The wagon brake equipment included 'load weigh valves' which are used to vary the brake cylinder pressure (and therefore the wagon brake force) according to wagon suspension displacement (which is proportional to the wagon payload).

B5 Many of the wagons on the tested trains carried no container payload, whereas nearly all the wagons on train 4L47 were laden (table 1). As a means of accounting for this, the load weigh valves on the wagons of the second train were manually configured to behave as though a full container load was being carried.

B6 RAIB used the test data, the locomotive's OTDR record (figure 5), and a combination of brake system design and parameter information to estimate:

- the magnitude of brake torque acting on the wheelsets[40] of each wagon of train 4L47
- how this varied in time as the train travelled from Thames Haven Junction to where it came to rest.

This is referred to in the report as the 'wagon brake torque time history'.

B7 RAIB used a combination of locomotive design and test data to estimate the brake torque time history for the locomotive ('locomotive brake torque time history').[41] For this it was able to use the brake pipe and brake cylinder pressures recorded by the locomotive's OTDR directly (paragraph B1). It estimated the traction torques acting to accelerate the train ('locomotive traction torque time history') in a similar way.

B8 When aggregated, the individual torque time histories define how the traction and brake forces distribute along the train and vary with time.

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[40] The wagons in the longitudinal train dynamics model were represented as having only two wheelsets, whereas each wagon in train 4L47 had four (see appendix C). Therefore, the brake torques were calculated for each pair of wheelsets.

[41] The locomotive in the longitudinal train dynamics model was represented as having only two wheelsets, whereas a class 66 locomotive has six. Therefore, the brake torques were calculated for a set of three wheelsets.

Appendix C – Simulation of longitudinal train dynamics

C1 In work arising from the investigation of the early Ecofret 1 triple-wagon derailments, it had been necessary to make some significant assumptions and simplifications when hypothesising a worst case longitudinal compressive force (paragraph 81). RAIB concluded that a longitudinal train dynamics simulation model was needed to assess and understand these forces and how they varied. With no pre-existing analysis available, the development of a simulation model was required. For train 4L47, this needed to take into consideration:

- the inertia properties of the locomotive and each of the 33 wagons
- the characteristics of the couplers connecting the locomotive and wagons
- the gradient
- the traction and braking forces.

C2 A simulation model was developed using the longitudinal analysis capabilities of an industry-standard railway vehicle dynamics analysis package. The train was modelled as a string of 34 mass elements connected using pairs of special spring elements ('bumpstop' elements) to represent the coupler non-linear stiffness, with friction elements added in parallel to represent the energy absorbing characteristics. The mass elements represented the inertia properties of the non-rotating parts of each of the vehicles. Separate 'wheelset' elements, two per vehicle for simplicity, were used to represent the rotating parts (figure C1).

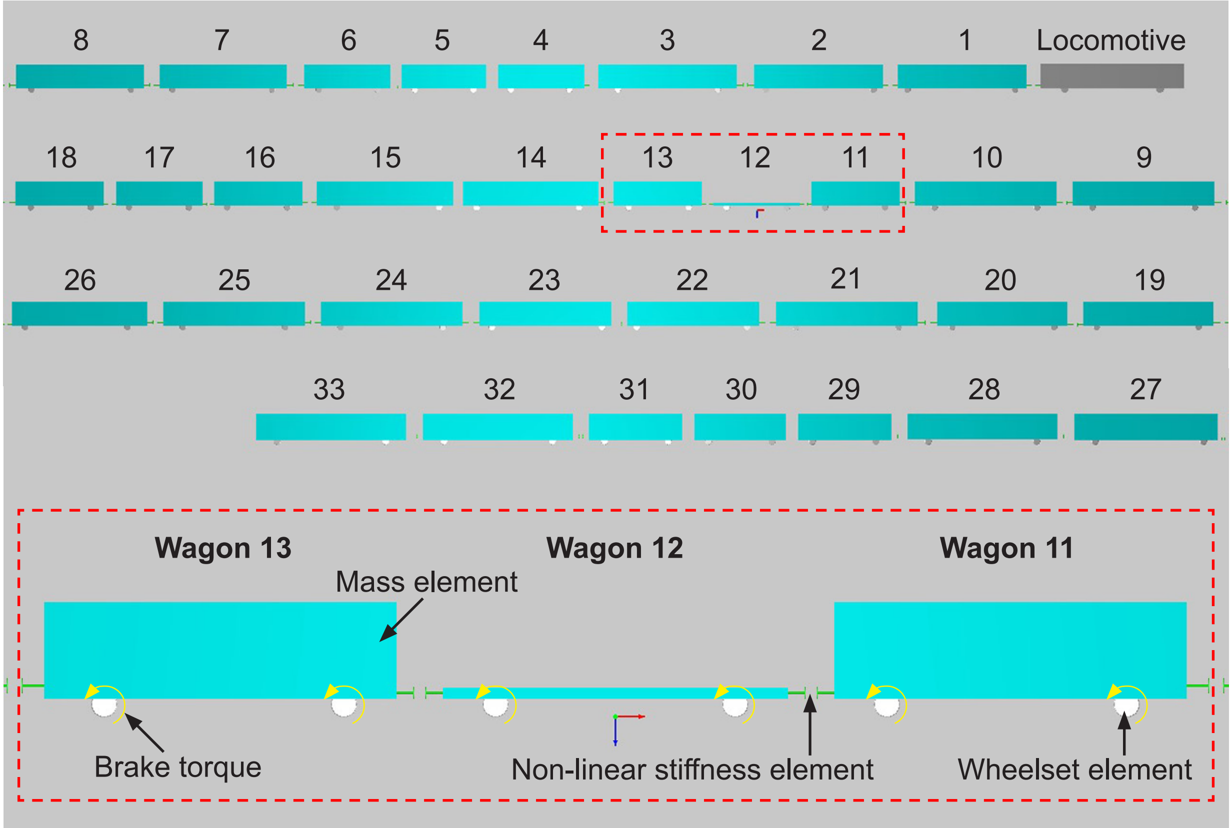

Figure C1: Longitudinal train dynamics simulation – model of train 4L47.

C3 The gradient profile of the Down Thames Haven line was defined in a separate track model.[42] Simulations of train 4L47 running along the line involved defining a starting speed and the traction and brake torques acting on the wheelset elements to accelerate and decelerate the train as it progressed, step by step.

C4 Data of sufficient integrity was available for most of the model elements. However, there was some information that not could not easily be sourced. Table C1 summarises the main assumptions that were adopted for the baseline simulation case.

Information deficiency	*Assumption adopted - baseline simulation case*
Lack of design and test data for the bar coupler, screw coupling and side buffer arrangements on some of the FEA wagon types	Parameter data for components of the same generic type used
Characteristics of the screw coupling and side buffer arrangements on locomotive 66779	Parameter data for components of the same generic type used
Lack of data on the degree to which screw couplings were tightened and the resulting slack or additional preload (paragraphs 56 and 57)	Parameters for all side buffer and screw coupling arrangements based on the buffer faces just touching (no slack or additional preload)
General lack of data on coupler friction (and other energy absorption) characteristics likely in service	Generic friction model developed and validated for a coupler for which standard test data was available (the Ecofret 2 bar coupler arrangement). The same friction model was then used for all other couplers. In the generic friction model, the force in the friction elements (friction force) was equal to 50% of the force in the corresponding bumpstop element

Table C1: Parameter assumptions adopted for the longitudinal train dynamics baseline simulation case.

C5 In the baseline simulation, the locomotive traction torque, locomotive brake torque and wagon brake torque time histories were used as derived (appendix B). It predicted a train speed profile that favourably matched that recorded by the locomotive OTDR. It also predicted that the maximum compressive force in the bar couplers on wagon 12 (that is to say, the longitudinal compressive force acting on wagon 12) occurred as the double brake application was releasing (paragraph 37). This coincided with the time that wagon 12 would have been approaching the point of derailment (figure C2). The maximum longitudinal compressive force was calculated to be 203 kN and it had rapidly increased to this value. Other longitudinal compressive force peaks coincided with brake application events.

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[42] Two kilometres of track, level for one kilometre then an uphill constant gradient for another kilometre, were added ahead of Thames Haven Junction. This was to ensure that the locomotive and all wagons were subject to the same gradient effects before the train reached the junction and the traction and braking torques were applied.

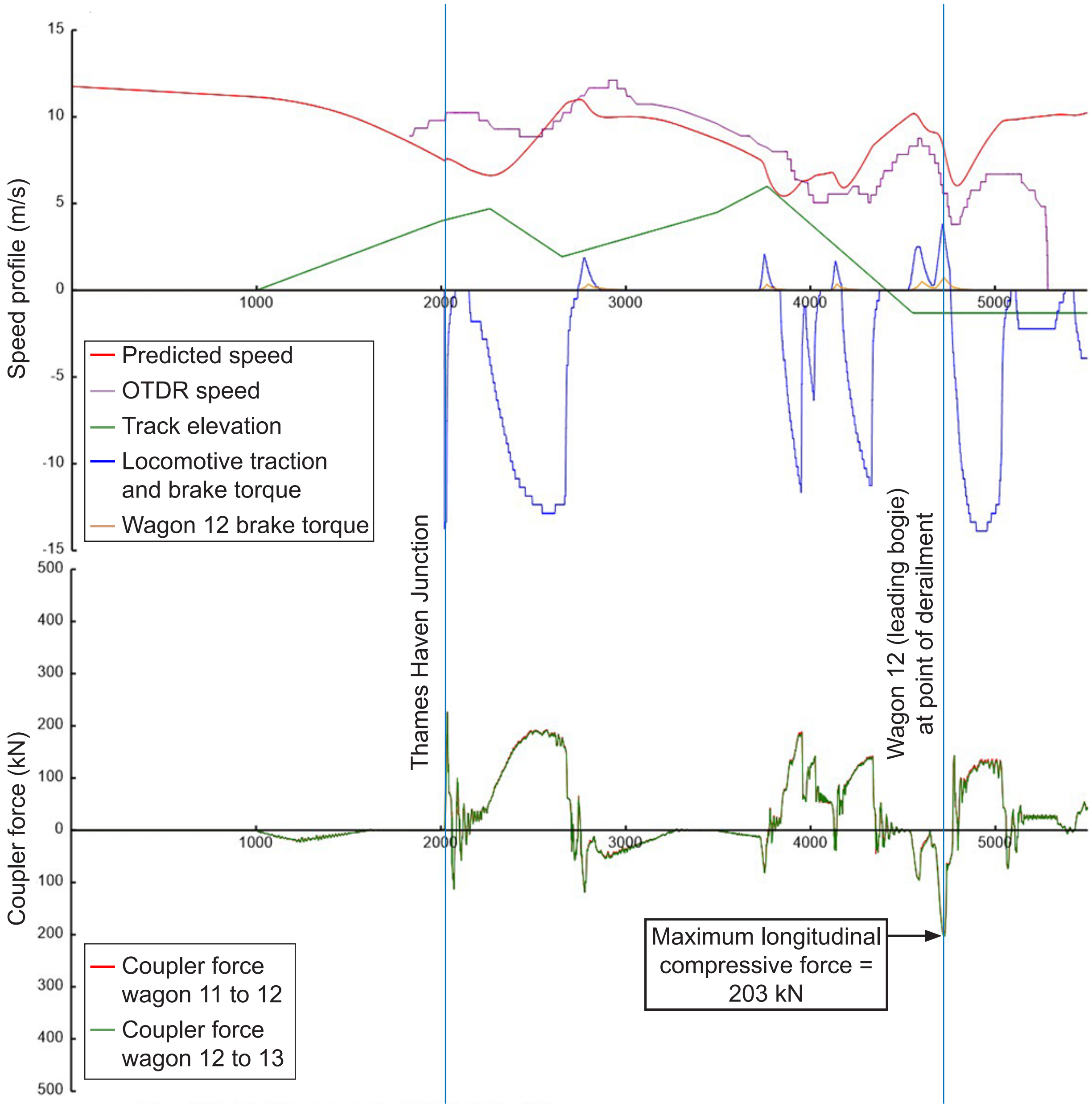


Figure C2: Predicted speed profile and coupler force – baseline simulation. The upper graph plot shows the predicted speed profile and that recorded by the locomotive OTDR. The track gradient profile and applied traction and brake torques (at the locomotive and wagon 12) are shown for pictorial reference only. The lower graph plot shows the predicted variation of the force in the couplers at either end of wagon 12.

C6 Several steps and assumptions were involved in estimating the traction and brake torque time histories and, because of this, a degree of uncertainly must be recognised in the results. RAIB found that an improved speed match could be obtained by factoring the traction and brake torque values (referred to as the ‘refined traction and brake torque time histories’). No change was made to the time at which the torques applied. Simulations using the refined traction and brake time histories are referred to as sensitivity study C1. They predicted the maximum longitudinal compressive force occurred at the same location, but its magnitude was greatly increased.

C7 Other sensitivity studies investigated the significance of the following on the magnitude and location of the maximum longitudinal compressive force acting on wagon 12:

- coupler slack (sensitivity study C2)
- coupler friction (sensitivity study C3)
- coupler slack and friction (sensitivity study C4)
- the double brake application that was made before the derailment (sensitivity studies C5 and C6).

C8 Table C2 summarises each of the sensitivity studies and the magnitude and location of the predicted maximum longitudinal compressive force event.

Sensitivity study	*Description*	*Predicted maximum longitudinal compressive force*	
		Magnitude	*Location*
	Baseline simulation	203 kN	Coincident with leading bogie of wagon 12 passing over the point of derailment
C1	Refined traction and brake torque time histories (paragraph 92) Other parameters as baseline simulation	322 kN	Coincident with leading bogie of wagon 12 passing over the point of derailment
C2	±25 mm slack at all couplers comprising screw coupling and side buffer arrangements Other parameters as sensitivity study C1	353 kN	Coincident with leading bogie of wagon 12 passing over the point of derailment
C3	Friction force equal to 25% of the force in the bumpstop element at all couplers Other parameters as sensitivity study C1	324 kN	Coincident with leading bogie of wagon 12 passing over the point of derailment
C4	±25 mm slack at all couplers comprising screw coupling and side buffer arrangements; and friction force equal to 25% of the force in the bumpstop element at all intervehicle connections Other parameters as sensitivity study C1	451 kN	Coincident with leading bogie of wagon 12 passing over the point of derailment

Sensitivity study	*Description*	*Predicted maximum longitudinal compressive force*	
		Magnitude	*Location*
C5	Brake torques associated with a single brake application instead of the double brake application. Brake torques for the replacement single brake application equivalent to that of a single brake application made earlier on the Down Thames Haven line. Other parameters as sensitivity study C4	125 kN	Coincident with replacement single brake application
C6	Brake torques associated with a single brake application instead of the double brake application. Brake torques for the replacement single brake application increased to match the approximate overall magnitude of the double brake application. Other parameters as sensitivity study C4	325 kN	Coincident with replacement single brake application

Table C2: Sensitivity studies – summary and results. Baseline simulation results are included for reference.

C9 In summary:

- Sensitivity study C1 showed how refinement of the traction and brake torques resulted in greatly increasing the magnitude of the maximum longitudinal compressive force, without altering its location and, therefore, its significance to the derailment. The calculated speed profile closely followed the speed recorded by the locomotive’s OTDR up to where the double brake application started to release. At this location the predicted speed continued to reduce, initially following the trajectory recorded by the locomotive OTDR, but reaching a lower minimum value before rising again.
- Sensitivity studies C2, C3 and C4 showed how changing the coupler characteristics could also greatly increase the magnitude of the maximum longitudinal compressive force, again without altering its location on the line. The speed profile calculated in all three studies was nearly identical to that calculated in sensitivity study C1.
- The greatest maximum longitudinal compressive force was calculated for sensitivity study C4. Sensitivity studies C5 and C6 showed how making an alternative brake application could have reduced the magnitude of this force.

C10 Figure 19 shows the predicted speed profile for sensitivity study C4 and the predicted variation of the force in the couplers at either end of wagon 12.

Appendix D – Wagon derailment simulations

D1 RAIB concluded that a new wagon derailment simulation study was needed to understand the longitudinal compressive forces likely to present a derailment risk to wagon 12. The bar coupler and bogie changes (paragraphs 49 and 76) introduced to the Ecofret 2 design meant that it was not possible to reuse analysis from the earlier Ecofret 1 triple-wagon derailment studies (paragraph 74).

D2 Wabtec constructed a vehicle model of the Ecofret 2 triple-wagon that derailed using the single-vehicle computer models that it had already developed and validated (paragraph 62). RAIB provided the design information for the bar coupler components, as supplied by VTG Rail, and the details of the container payload, as recorded on the train document (table 1).

D3 'Pinlink' elements were needed to represent the behaviour of the bar couplers connecting the wagons to each other. These are special rod-like elements that can rotate freely about their end pivot points, and transfer axial forces. The location and movement of the pivot points (on the connected vehicle underframes) determine the element length and the line of action of the axial force. A pinlink element can suddenly rotate (buckle) if the applied compressive force becomes too great. This is an important characteristic of the element since it means the resulting rapid change in the direction of the axial force, and how it acts on the connected underframes, is represented.

D4 The non-linear stiffness characteristic of the two spring units in the bar coupler arrangement (figure 11) were defined by reference to supplied test information. The friction losses in the bar coupler were represented using a friction model like the one adopted in the longitudinal train dynamics simulation model (appendix C). The containers on wagons 11 and 13 were represented as separate mass elements, tied to the wagon underframe at the spigot locations.

D5 RAIB adjusted the model that Wabtec supplied. For the baseline simulation case, this included:

- Introducing nominal lateral drawbar pivot offsets; VTG Rail's engineering consultant (paragraph 76) had found that such offsets can be significant to initiating the behaviour found to occur during such derailments; the value chosen (±10 mm) was within what could easily be explained due to the general build and maintenance tolerances and possible relative positioning of wheelsets on the track.
- Altering the mass properties of the containers on wagons 11 and 13 to reflect measurements made after the derailment (table 1); the heights of each of the drawbar pivots were corrected to account for the corresponding change in suspension deflection.
- Altering the stiffness characteristics of the PLBs to account for degradation (paragraph 68).

D6 Track geometry recordings from 13 July 2021 (paragraph 29) and wheel profile measurements (paragraph 65) were used to create the required track irregularity and wheel-rail contact definitions.

D7 The baseline simulation study focused on the effect of rapidly applying a sustained longitudinal compressive force on wagon 12 as the Ecofret 2 triple-wagon approached the derailment location. This was achieved by defining equal and opposite longitudinal forces that acted on wagon 11 and wagon 13 and increasing these in 10 kN steps. The same approach had been used by VTG Rail's vehicle dynamics specialist in the earlier Ecofret 1 triple-wagon derailment studies. The baseline simulations predicted a derailment sequence that was similar to that described for the earlier Ecofret 1 studies (paragraphs 90 and 91); with reference to figure 18, the following longitudinal compressive forces were required:

- 460 kN for the wheel flanges on both bogies of wagon 12 to contact opposite rails (stage C)
- 600 kN: for a non-contacting wheel to start lifting off the rail (stage D)
- 650 kN: for full derailment (stage E).

D8 Sensitivity studies investigated the significance of the following on the longitudinal compressive forces required:

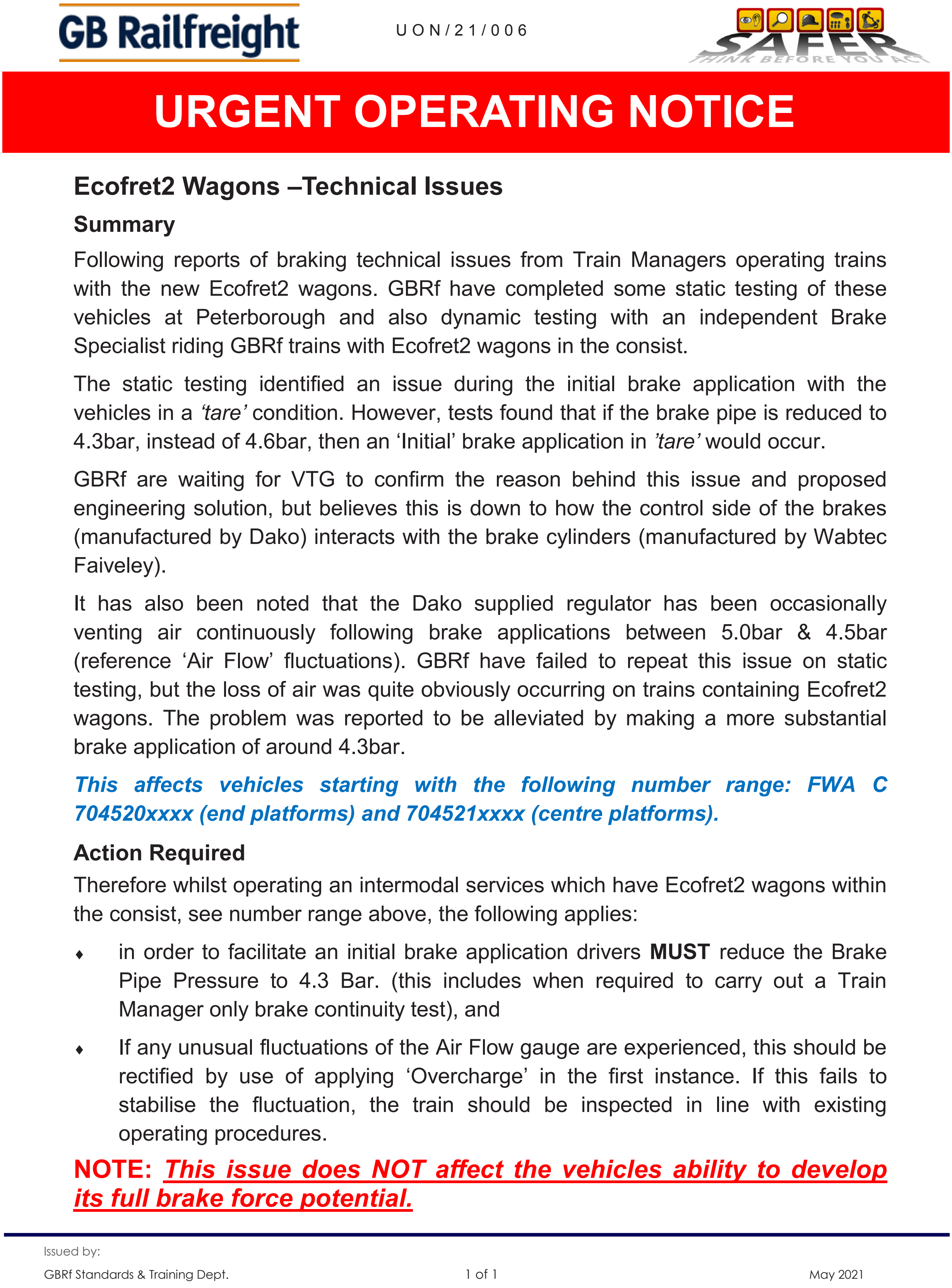
- PLB condition (sensitivity study D1)
- wheel profile condition (sensitivity study D2)
- wagon payload (sensitivity studies D3 and D4).

D9 Table D1 summarises each of the sensitivity studies and the required longitudinal compressive forces that were predicted.

Sensitivity study	*Description*	*Predicted longitudinal compressive force required*		
		Stage C *Wheel flanges in contact with opposite rails*	*Stage D* *Non-contacting wheel starts to lift*	*Stage E* *Full derailment*
	Baseline simulation	460 kN	600 kN	650 kN
D1	PLBs intact Other parameters as baseline simulation	500 kN	600 kN	680 kN
D2	Wheel profiles in accordance with specified P8 wheel profile Other parameters as baseline simulation	440 kN	600 kN	640 kN
D3	Container payload of 4.4 tonnes on wagon 12 Other parameters as baseline simulation	540 kN	790 kN	930 kN
D4	No container payload on wagon 11, 12 or 13 Other parameters as baseline simulation	510 kN	740 kN	850 kN

Table D1: Wagon derailment simulations. Sensitivity studies – summary and results. Baseline simulation results are included for reference.

Appendix E – Urgent operating notice concerning trains with Ecofret 2 wagons



GB Railfreight

UON/21/006

SAFER
THINK BEFORE YOU ACT

URGENT OPERATING NOTICE

Ecofret2 Wagons –Technical Issues

Summary

Following reports of braking technical issues from Train Managers operating trains with the new Ecofret2 wagons. GBRf have completed some static testing of these vehicles at Peterborough and also dynamic testing with an independent Brake Specialist riding GBRf trains with Ecofret2 wagons in the consist.

The static testing identified an issue during the initial brake application with the vehicles in a *'tare'* condition. However, tests found that if the brake pipe is reduced to 4.3bar, instead of 4.6bar, then an 'Initial' brake application in *'tare'* would occur.

GBRf are waiting for VTG to confirm the reason behind this issue and proposed engineering solution, but believes this is down to how the control side of the brakes (manufactured by Dako) interacts with the brake cylinders (manufactured by Wabtec Faiveley).

It has also been noted that the Dako supplied regulator has been occasionally venting air continuously following brake applications between 5.0bar & 4.5bar (reference 'Air Flow' fluctuations). GBRf have failed to repeat this issue on static testing, but the loss of air was quite obviously occurring on trains containing Ecofret2 wagons. The problem was reported to be alleviated by making a more substantial brake application of around 4.3bar.

This affects vehicles starting with the following number range: FWA C 704520xxxx (end platforms) and 704521xxxx (centre platforms).

Action Required

Therefore whilst operating an intermodal services which have Ecofret2 wagons within the consist, see number range above, the following applies:

- in order to facilitate an initial brake application drivers **MUST** reduce the Brake Pipe Pressure to 4.3 Bar. (this includes when required to carry out a Train Manager only brake continuity test), and
- If any unusual fluctuations of the Air Flow gauge are experienced, this should be rectified by use of applying 'Overcharge' in the first instance. If this fails to stabilise the fluctuation, the train should be inspected in line with existing operating procedures.

NOTE: ***This issue does NOT affect the vehicles ability to develop its full brake force potential.***

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