Transportation Safety Board
of Canada

Bureau de la sécurité des transports
du Canada

RAILWAY INVESTIGATION REPORT
R09T0092

MAIN-TRACK TRAIN DERAILMENT

CANADIAN NATIONAL
TRAIN NUMBER M36231-20
MILE 247.20, KINGSTON SUBDIVISION
BRIGHTON, ONTARIO
21 MARCH 2009

Canada

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Railway Investigation Report

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Canadian National
Train Number M36231-20
Mile 247.20, Kingston Subdivision
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Synopsis

On 21 March 2009, at approximately 0540 Eastern Standard Time, Canadian National freight train M36231-20, proceeding eastward at about 50 mph, derailed 6 cars at Mile 247.20 of the Kingston Subdivision, near Brighton, Ontario. The derailed cars included three dangerous goods tank cars loaded with molten naphthalene (UN 2304). There was no loss of product and no injuries.

Ce rapport est également disponible en français.

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Appendices

Figures

1.0 Factual Information

On 21 March 2009, at about 0225,[1] Canadian National (CN)[2] freight train M36231-20 (the train) departed Toronto, Ontario, and proceeded eastward on the Kingston Subdivision, destined for Montréal, Quebec. The train was powered by three head-end locomotives hauling 137 cars (75 loads and 62 empties). It was approximately 8850 feet long and weighed about 11 845 tons. The crew consisted of a locomotive engineer and a conductor. They were both familiar with the subdivision, met fitness and rest standards, and were qualified for their respective positions.

1.1 The Accident

At 0540, the train was proceeding eastward at 50 mph on the south main track, with the train brakes released and the throttle in position five, when it experienced a train-initiated, undesired emergency brake application (UDE). As the train came to a stop, the locomotive independent brake was not continuously bailed off.

The train came to rest at Mile 247.20, near Brighton, Ontario (see Figure 1). The crew conducted the necessary emergency procedures and determined that six cars, the 98th to the 103rd, had derailed. The derailed cars included three dangerous goods tank cars (98th, 102nd and 103rd) loaded with molten naphthalene (UN 2304), one of which was on its side. No product was released and there were no injuries.

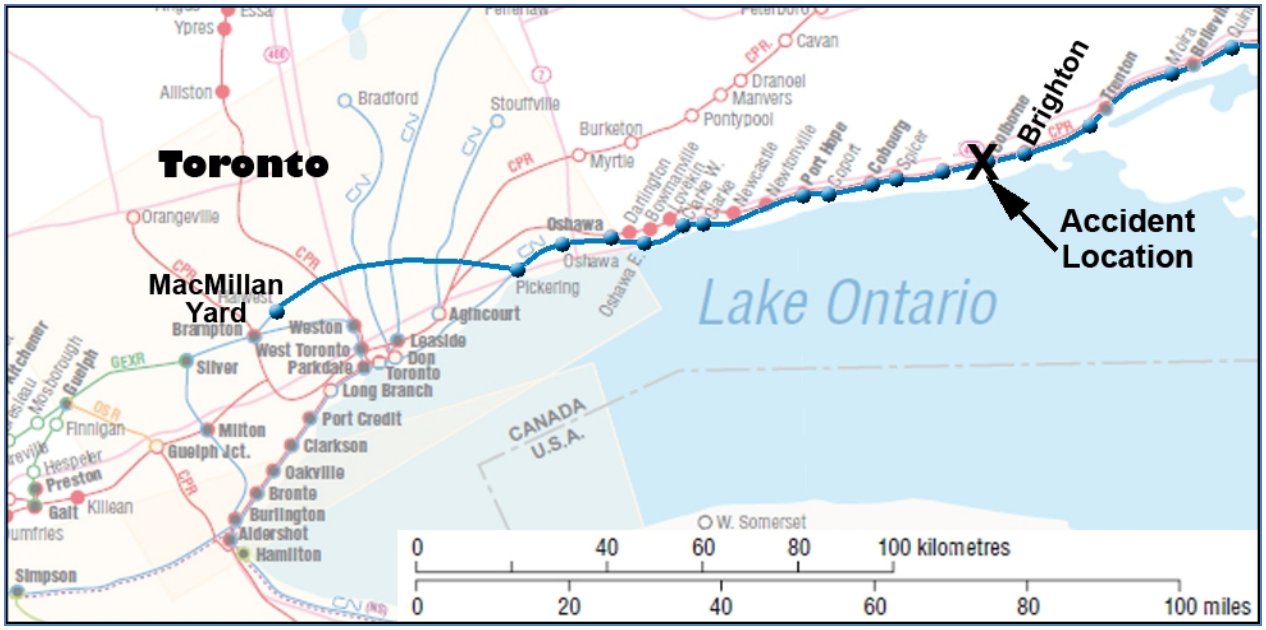

Figure 1. Accident location (source: Railway Association of Canada, *Canadian Railway Atlas*)

At the time of the occurrence, it was – 8°C, the sky was clear and there was a light wind from the north.

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[1] All times are Eastern Standard Time.

[2] See Appendix B – Glossary for a list of abbreviations and acronyms used in this report.

1.2 Site Examination

The derailed cars came to rest at the bottom of a sag [3] in undulating territory. [4] The first derailed car was PLCX 221245 (the 98th car), which had the two south wheels on the leading truck and all wheels on the trailing truck derailed. The 99th and 100th cars were long, empty flat cars. They remained upright and jackknifed to the north and south side of the track respectively. The 101st car came to rest on its side with its lead truck pushed south of the track. The 102nd and 103rd cars remained parallel to the track with the 102nd car on its side and the lead truck of the 103rd car derailed to the south (see Figure 2). The draft gears on cars that did not derail were compressed. On some cars, the coupler horn was contacting the centre sill striker face. There were no pre-existing defects observed on the derailed cars.

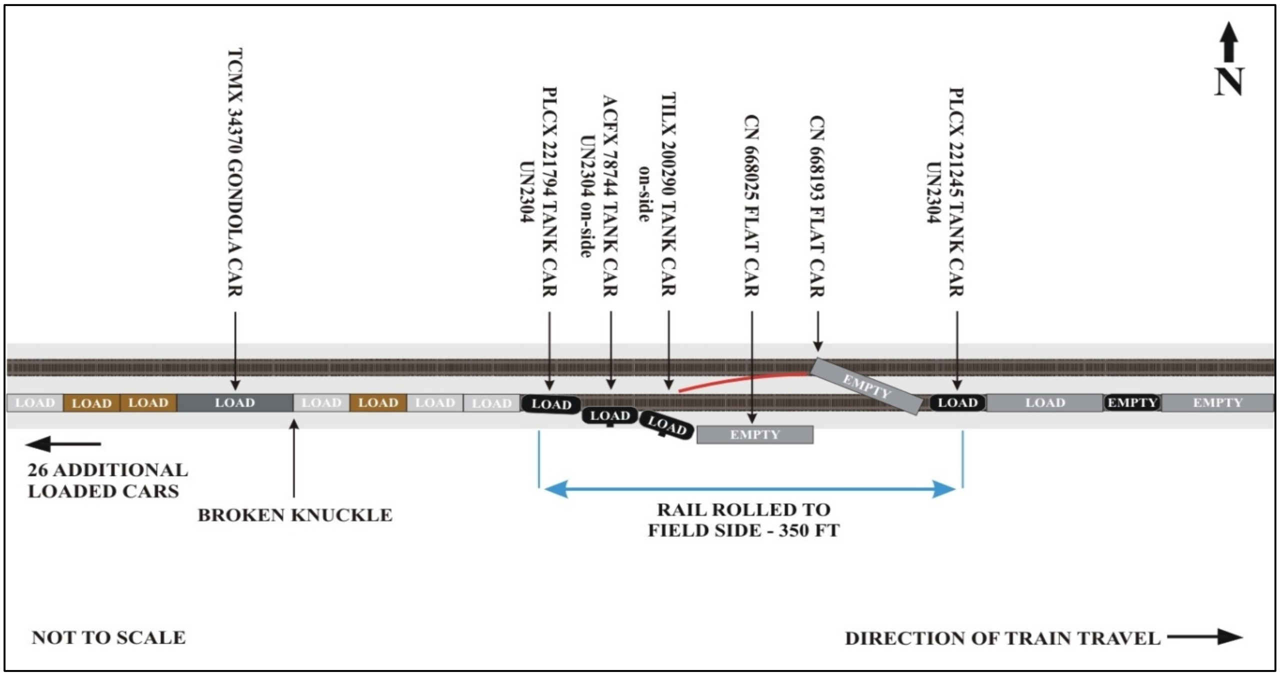

Figure 2. Accident site diagram

The four tank cars were between 48 and 53 feet long and were equipped with standard friction draft gears and type F couplers. The two flat cars were each 93 feet long and equipped with hydraulic end-of-car cushioning devices (EOCCDs) and long shank type E couplers. A broken knuckle was observed on the east end of the 108th car, TCMX 34370, indicating that a train separation had occurred. During the accident, the tail-end portion of the train ran in and contacted the head-end portion. The pulling face of the knuckle had broken away and could not be located. The remaining portion of the failed knuckle was sent to the TSB Laboratory for analysis.

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[3] A decrease in grade followed by an increase in grade sufficient to result in an increase in slack adjustment resulting in increased in-train forces.

[4] A track profile with grade changes so often that an average train has some cars on three or more alternating ascending and descending grades. Train slack adjusts because cars on descending grades tend to roll faster than cars on the ascending portion.

Broken knuckles and knuckle pins from previous train events were found about the right-of-way. Inspection of the track revealed that spikes were either pulled out or sheared off. Extending eastward from the 103rd car to the 98th car, both rails had rolled to the field side (approximately 350 feet). Where the rail had first rolled, wheel impact marks were observed on the ties about six inches inboard of the gauge side of the north rail.

1.3 Track Information

The Kingston Subdivision consists of double main track, extending from Dorval, Quebec (Mile 10.3), to Toronto (Mile 333.8). It is a main corridor for passenger and freight traffic, including dangerous goods, and handles approximately 42 trains per day (22 passenger trains and 20 freight trains). The track is classified as Class 5 track according to the *Railway Track Safety Rules* with a maximum track speed of 100 mph for passenger trains and 65 mph for freight trains. Train movements are controlled by the Centralized Traffic Control System, authorized by the *Canadian Rail Operating Rules* and supervised by a rail traffic controller located in Toronto.

The track in the vicinity of the derailment is undulating and tangent, oriented in an east-west direction. The rail on the south main track was 132-pound continuous welded rail laid on 14-inch double-shouldered tie plates secured to hardwood ties with two spikes. The ballast was crushed rock. The cribs were full and the shoulders at least 18 inches beyond the ends of the ties. The track had been inspected in accordance with company and regulatory requirements and was in good condition.

1.4 Train Information

The head-end portion of the train (1st car to 103rd car) primarily contained empty cars. About half of the cars on the train were equipped with long travel hydraulic EOCCDs, the majority of which were in the head-end portion of the train. The tail-end portion of the train (104th car to 137th car) was primarily loaded cars equipped with conventional (standard friction) draft gears.

The cars were divided into five blocks. The first block comprised 21 cars and was to be set off at Belleville, Ontario. The second block, comprising 64 cars, was destined for Garneau, Quebec. The last three blocks were destined for Taschereau Yard in Montréal and comprised 8 cars, 15 cars and 29 cars respectively.

1.5 Train Marshalling Practices at Canadian National

It is not uncommon for CN to marshal train M362 with loaded cars destined for Taschereau Yard on the tail end. Other than compliance with the Transport Canada (TC) *Transportation of Dangerous Goods Regulations*, there are no regulatory requirements for train marshalling or tonnage distribution within a train.

CN freight trains are made up using destination block marshalling where blocks of cars are placed in the train in a manner that expedites their set-out or pick-up along the train's route. CN uses a computerized system that identifies any train marshalling that does not comply with either the *Transportation of Dangerous Goods Regulations* or CN's General Operating Instructions

(GOIs). CN's GOIs have placement restrictions (for example, dimensional loads) and trailing tonnage restrictions for certain types of cars (for example, skeleton cars, spine cars). However, there are no operational restrictions on the marshalling of most types of freight cars, whether empty or loaded.

A tonnage profile of the occurrence train in relation to the track elevation and point of derailment is contained in Figure 3.

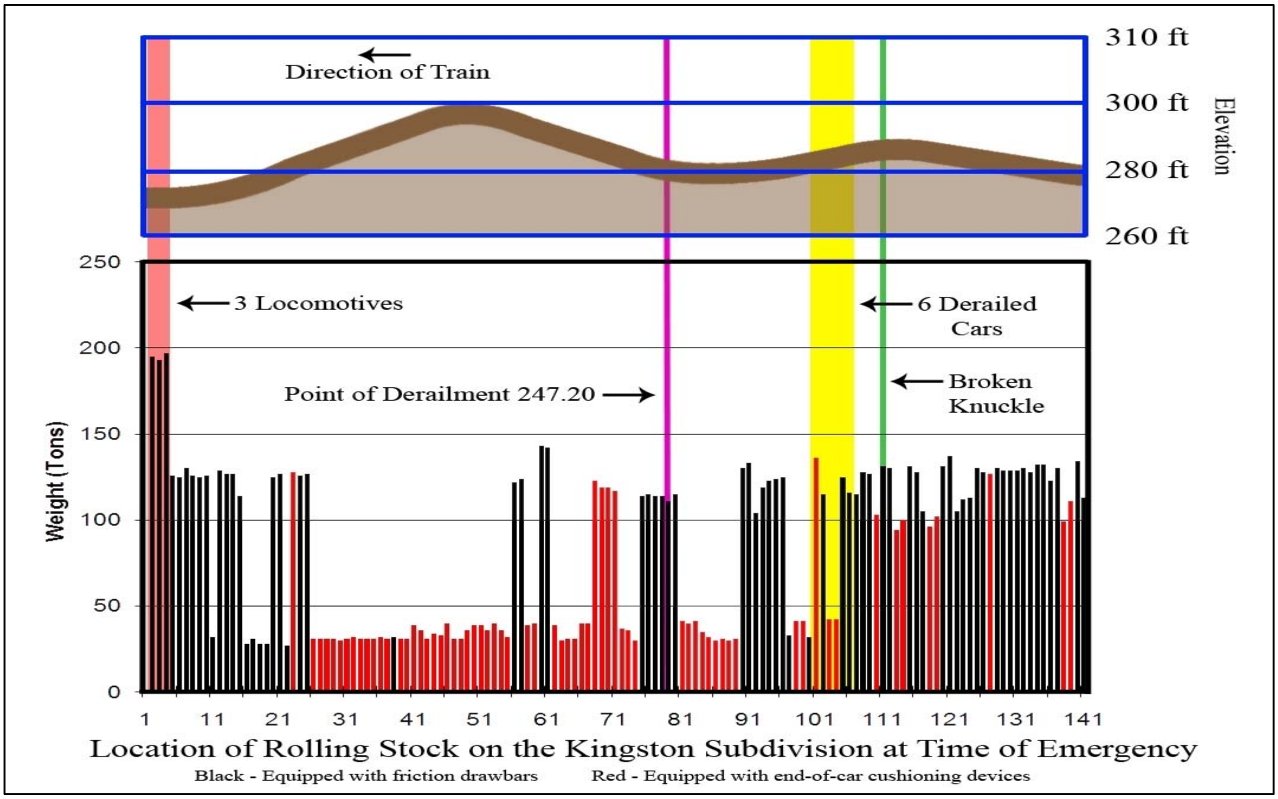

Figure 3. Train tonnage profile in relation to track elevation and point of derailment

1.6 *Other Train Marshalling Practices*

Canadian Pacific Railway (CPR) considers weight distribution during train marshalling. CPR has developed and implemented Train Area Marshalling (TrAM), a computer-based train marshalling system, to minimize the effect of in-train forces. TrAM rules include trailing tonnage limits for specific types of car equipment. The limits vary depending on factors such as type of car, length of the car, weight of the car (content plus tare weight), length of adjacent car, as well as curvature and grade of the track over which the car will operate.

The system also considers and assists with the placement of cars with EOCCDs and remote locomotive consists. TrAM requires that freight trains be made up, to the maximum extent practicable, with the loads located closest to the locomotives. For mixed conventional trains (head-end power), the marshalling of heavy blocks of cars at the rear of the train is prohibited unless blocks ahead are equally as heavy. Light cars (empties) or blocks of light cars are marshalled as close as possible to the rear unless the cars behind are also relatively light. While CPR uses destination block marshalling, it does not take precedence over TrAM marshalling restrictions.

1.7 In-Train Forces

Train operations have changed significantly in recent years. Before the mid-1990s, an average train in main-track service was about 5000 feet long and weighed 6000 to 7000 tons. Some of today's trains are over 12 000 feet long and weigh over 12 000 tons and some as much as 18 000 tons. With the significant increase in average train length and weight, there have been associated increases in normal in-train forces for conventional trains equipped with head-end power.

The Association of American Railroads (AAR) *Train Make-Up Manual*[5] indicates that cars equipped with EOCCDs add to train slack and can greatly increase in-train forces. Specifically, the manual states that large blocks of EOCCD–equipped cars should not be placed ahead of large blocks of loaded cars with conventional draft gears.

United States Federal Railroad Administration studies[6] have been conducted to evaluate the operation of freight train air brakes. These studies have shown that, during emergency brake applications, run-in on a train configured with empties ahead and loads behind can generate significantly higher buff force impacts as compared to trains with a uniform weight distribution.

To assist in managing in-train forces during emergency braking, CN has taken the following steps:

- CN locomotive engineers are trained to bail off the independent brake[7] when a UDE occurs. However, the decision to bail off is left to the locomotive engineer's discretion because there may be situations when it may be preferable to keep the independent brake applied.

- CN directs locomotive engineers to activate the emergency toggle switch on the input and display unit (IDU) in the locomotive cab to manually initiate an emergency brake application from the tail end of the train.

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[5] Association of American Railroads, Research and Test Department, Report R-802, *Train Make-Up Manual*, January 1992.

[6] United States Department of Transportation Federal Railroad Administration, DOT/FRA/ORD-84-16, *Freight Train Brake System Safety Study,* November 1984, R-185-Track.

[7] The independent brake valve bail function is used to reduce or release locomotive brakes.

- CN has equipped much of its main-line locomotive fleet with Trainlink-ES, which has a feature that automatically initiates an emergency brake application at the sense and braking unit (SBU) on the tail end of the train, whenever an emergency brake application occurs. This feature helps reduce excessive buff forces generated due to the run-in of train slack during emergency braking. The occurrence train was equipped with Trainlink-ES.

- Many newer locomotives are equipped with enhanced Train Information Braking System (TIBS) functionality that includes an end-of-train auto-emergency feature that is separate from Trainlink-ES.

1.8 *Canadian National Study of Train Pull-Aparts on the Kingston Subdivision*

Due to the number of train pull-aparts CN had experienced on the Kingston Subdivision before this occurrence, in April 2009, CN contracted Rail Sciences Inc. (RSI) to conduct a Break-in-Train Analysis (train separation) for the subdivision. CN train M30831-08 (train 308) was selected as being representative of long trains that have had separation problems on the subdivision. Train 308 comprised 3 head-end locomotives, 88 loaded cars, and 60 empty cars, with a weight of 11 504 tons and an overall length of 10 536 feet.

Dynamics simulations were conducted on train 308 and five other train configurations using the Train Operations and Energy Simulator (TOES) software to estimate the magnitude of longitudinal forces present on the trains. The slack forces for the actual (long) train and a modified (short) train were further analyzed. To better control in-train forces on the Kingston Subdivision, RSI suggested the use of head-end and mid-train distributed power (DP) with a train configuration limited to a length of 8000 feet and a weight of 8000 tons.

1.9 *Train Dynamics Simulation*

The TSB Laboratory and RSI conducted a train dynamics simulation using the TOES software. The simulation focussed on determining the magnitude of longitudinal draft forces present on the occurrence train leading up to the train separation and the magnitude of the buff force involved as the two portions of the train came back into contact. The simulation concluded that "a run-out event (draft) occurred at the 108th car at the time that a train line emergency occurred." The magnitude of the force was between 200 and 250 kips. This magnitude of slack action, although considered slightly higher than usual, is not excessive.

Additional TOES modelling estimated the magnitude of in-train forces from the time that the two portions of the train came back into contact until they stopped. Using the actual train handling data from the locomotive event recorder, several simulations were performed to estimate the in-train forces generated during the actual occurrence and in other scenarios.

The following additional observations were made after reviewing the simulation results:

- For the derailment scenario where the train breaks apart at the 108th car, the maximum buff [8] force is 1895 kips and occurs when the heavier tail-end cars run in and strike the lighter head-end cars. The buff force on the cars that derail is 1500 kips. Since the in-train buff force is extremely high, bailing off the locomotive independent brake has only a marginal effect, reducing the maximum buff force to approximately 1677 kips.

- In the scenario where the train does not pull apart and a UDE is introduced at the 108th car, the maximum in-train buff force is 676 kips.

- In the scenario where a UDE occurs in the front half of the train and the locomotive independent brake is left applied, the maximum buff force is between 684 kips and 775 kips. Bailing off the independent brake lowers the buff force to between 435 kips and 480 kips.

- In the scenario where the train is marshalled with the tail-end block of loaded cars (109th car to the 137th car) at the head end, a train separation at the 108th car does not result in the two train sections coming back together again. The maximum buff force is 219 kips. Bailing off the locomotive independent brake has little effect.

- In the scenario where a UDE is initiated in the front half of the train without a train separation occurring, marshalling the train with the tail-end block at the head end reduces the maximum in-train buff force by as much as 70 per cent.

1.10 Knuckle Information

1.10.1 Manufacturing Standards

Knuckle manufacturing is governed by Section S of the AAR *Manual of Standards and Recommended Practices* (MSRP). Within Section S, Specification M-211 sets forth requirements (in part) for foundry and product approval for the manufacture of knuckles. The specification identifies that quenched and tempered Grade E steel castings, as defined in Specification M-201, shall be used for all couplers, knuckles, locks, coupler yokes, and follower blocks. Specification M-201 further indicates that Grade E cast steel hardness readings must be taken on the knuckle exterior at one of three locations identified in Appendix A of the standard.

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[8] Compressive coupler force that occurs during a slack bunched condition.

Specification M-201 sets forth requirements (in part) for steel castings. Subsection 7.0 outlines the following criteria for mechanical properties and tests:

- For tensile test specimen coupons, the specification outlines that, at the manufacturer's option, coupons shall be either cast attached to the casting or produced from keel blocks and prepared in accordance with American Society for Testing and Materials (ASTM) Designation A370. The coupons for Grade E cast steel must have a minimum tensile strength of 120 (ksi). However, specimens made directly from knuckle castings (excluding flawed specimens) must have at least 80 per cent of the minimum tensile properties, which equates to 96 ksi.

- For impact testing, the specification for Grade E cast steel identifies that the steel impact properties may be determined by testing standard Charpy-V Notch Type A specimens prepared in accordance with ASTM Standard A370. Similar to tensile coupons, Charpy specimens are to be removed from coupons that were either cast attached to the casting or produced from keel blocks. The test consists of determining the average energy absorbed from three impact specimens from the same heat. For Grade E cast steel, the specimens must absorb 20 foot-pounds of energy at -40°C. There are no standards for specimens removed directly from the knuckle casting.

- Material hardness readings must be within the range of 241 and 311 Brinell (BHN).

1.10.2 Examination of the Failed Knuckle

TSB Laboratory examination of the failed knuckle revealed the following:

- The features observed on the knuckle fracture are consistent with instantaneous brittle fracture under a tensile load.

- The coupler material was consistent with the major alloying elements specified for Grade E coupler steel.

- Brinell hardness testing was performed in accordance with AAR Specification M-201. The hardness results averaged 207 BHN.

- Charpy impact testing was performed to evaluate the coupler material low-temperature performance. At -40°C, the Charpy impact energy averaged 9.9 foot-pounds, which was approximately half of the specified Charpy impact toughness requirement for coupons prepared from keel blocks. At the occurrence temperature of -8°C, the Charpy impact energy averaged 9.7 foot-pounds.

- The microstructure for quenched and tempered Grade E cast steel should consist primarily of tempered martensite. The failed knuckle had a ferrite–pearlite microstructure, which indicates that it was improperly heat treated.

1.11 *Failed Knuckle Occurrences*

From January 2007 to June 2009, CN reported that there were 353 failed knuckles or drawbars on CN's Kingston Subdivision. Most of these failures resulted in train separation and a subsequent emergency brake application.

In contrast, CPR experiences fewer than 20 failed knuckles and drawbars per year across its entire system.

1.12 *Other Related Occurrences Involving In-Train Forces*

The TSB has conducted nine other derailment investigations that involved high in-train forces in long trains (see Appendix A for a summary of TSB investigations R07D0009, R07T0110, R07T0323, R05C0082, R05V0141, R02W0060, R01M0061, R01T0006, and R00W0106). In each case, the Board determined that train marshalling and the management of in-train forces were contributing factors. While most trains were marshalled in accordance with railway and regulatory requirements in place at the time, they were not configured in a way that allowed for the effective management of in-train forces.

During the investigation into a 15-car derailment in the township of Drummond, New Brunswick (TSB investigation report R01M0061), the Board determined that, due to the track profile and train configuration, an excessive run-in of train slack after a UDE generated high buff forces, leading to rail rollover and derailment. The Board recommended that:

> Transport Canada encourage the railway companies to implement technologies and/or methods of train control to assure that in-train forces generated during emergency braking are consistent with safe train operation.
>
> (R04-01, issued April 2004)

TC accepted the Board's recommendation and informed its stakeholders. TC noted that CN has adopted Trainlink-ES technology and that approximately 500 road locomotives were equipped by the end of 2006. CPR has adopted enhanced TIBS technology that includes an end-of-train auto-emergency feature and converted 94 per cent of its locomotives. All newly purchased road locomotives are to be equipped with the new technology. The Board assessed the response to Recommendation R04-01 as being Fully Satisfactory.

In March 2010, the Board issued its *Watchlist*, which includes a systemic safety issue associated with the operation of longer, heavier trains. The *Watchlist* states that "inappropriate handling and marshalling can compromise the safe operation of longer, heavier trains" and calls on railways to "take further steps to ensure the appropriate handling and marshalling of longer, heavier trains."

2.0 Analysis

2.1 Introduction

The train was operated in accordance with company and regulatory requirements. The track was in good condition. There were no pre-derailment defects observed on the rolling stock that would have contributed to the accident. The analysis will focus on the generation of in-train forces, train marshalling and train handling practices.

2.2 The Accident

The train dynamics simulation determined that a higher-than-usual run-out (draft) event, in the magnitude of between 200 and 250 kips, occurred at the 108th car at the time that the UDE occurred. This indicates that, while the train was travelling through undulating territory, a moderate run-out of train slack resulted in a broken knuckle between the 107th car and 108th car.

The compressed state of the draft gears of the cars remaining on the track and the rolled-over rail are indicative of a derailment involving high in-train buff forces. However, the fracture features of the broken knuckle from the 108th car are consistent with brittle fracture under a tensile (draft) load. The knuckle material had lower-than-specified hardness, and had been improperly heat treated. Although samples had been taken from the original casting, the Charpy impact toughness test on the knuckle itself was less than half of the specified value and was even lower at the occurrence temperature. While the knuckle had been in service for some time without incident, these properties made it more susceptible to sudden failure in tension at the occurrence temperature, in the presence of higher-than-usual in-train forces.

When the train line air hose separated, a UDE was initiated and the train separated into a head-end portion (1st car to 107th car) and a tail-end portion (108th car to 137th car). Both portions of the train went into emergency and began to slow and separate. Because the heavy tail-end portion was situated on a descending grade, its braking was not as effective as the head-end portion of the train. The more rapidly moving tail-end portion subsequently collided with the slower moving head-end portion. Since both portions of the train were already in compression, the collision generated a high buff force estimated to be near 1500 kips. The force came to bear on two long, empty flat cars coupled together between shorter, loaded tank cars, a combination susceptible to derailment during high buff force events. The flat cars jackknifed and applied a lateral force to the gauge side of both rails causing them to roll over and the cars to derail.

Train marshalling and train length affects the magnitude of in-train forces. When trains are marshalled with light cars at the head end and heavy cars at the tail end, the head end slows down quicker than the tail end, particularly when the locomotive independent brake remains applied. With greater momentum, heavier tail-end cars will run into the slowing cars at the head end, generating high run-in buff forces. The amount of train slack and the run-in buff forces are further increased on long trains, and on trains containing cars equipped with long travel hydraulic EOCCDs. The risk of derailment can be further increased when long, empty cars are coupled to short, loaded cars (long car/short car combination). All of these characteristics were present in this occurrence. While the train was marshalled in accordance with CN and regulatory requirements, it was not configured in a manner that effectively manages in-train forces.

2.3 *Managing In-Train Forces During Emergency Braking*

Destination block marshalling is a common operating practice throughout North America. The primary benefits of this marshalling approach are increased operational efficiency and simplified service delivery for the carrier. While this approach is not inherently unsafe, weight distribution within the train may not always be the primary consideration. Consequently, lighter cars can be placed ahead of heavier cars, leading to higher in-train forces during train operation.

CN has taken some steps towards managing in-train forces by installing Trainlink-ES on much of its main-line fleet. In addition, CN has trained its locomotive engineers to activate the end-of-train emergency braking feature, as well as bail off the independent brake during emergency braking. CN had also taken the additional step of contracting RSI to conduct a study on train pull-aparts on the Kingston Subdivision. However, the RSI suggestions had not been implemented.

When the track structure is sound and in-train forces are effectively managed, a train should not derail solely because it experiences an emergency brake application. Yet, a significant number of previous TSB investigations demonstrate that this has continued to occur on CN. In addition, the high number of broken knuckles and couplers that CN trains experience on the Kingston Subdivision indicates the railway's difficulties with effectively managing in-train forces.

At CN, a computerized system is used to identify train marshalling that does not comply with the *Transportation of Dangerous Goods Regulations* or CN's GOIs. These GOIs have placement and trailing tonnage restrictions for certain types of cars. However, there are no operational restrictions on the marshalling of most types of freight cars. In the absence of a comprehensive train marshalling protocol that effectively manages in-train forces and takes weight distribution within a train into consideration, there is an increased risk of derailment during an emergency brake application.

2.4 *Regulatory Overview*

Before the mid-1990s, trains averaged 5000 feet in length and weighed 6000 to 7000 tons. Other than compliance with the *Transportation of Dangerous Goods Act* and *Transportation of Dangerous Goods Regulations*, railways were left to marshal their trains to suit their operations. Regulatory overview consisted primarily of monitoring for compliance to the *Transportation of Dangerous Goods Act* because there were no other regulatory guidelines, regulations or rules in place that required railways to manage and minimize in-train forces. Since the mid-1990s, train operations have changed significantly. Some of today's trains are over 12 000 feet long and weigh over 12 000 tons, and some as much as 18 000 tons. With such an increase in train length and weight, there have been associated increases in normal in-train forces.

Including this occurrence, since 2001, 10 TSB derailment investigations have identified these high in-train forces in long trains as problematic. These investigations identified that, while most trains were marshalled in accordance with railway and regulatory requirements, they were not configured in a way that allowed for the effective management of in-train forces. While train operations have changed significantly in recent years, regulatory overview has not kept pace. The absence of effective regulatory overview of train marshalling presents a risk that some railways will continue to marshal trains for operational efficiencies without consideration for effectively managing and minimizing in-train forces.

2.5 *Effect of Re-Marshalling the Occurrence Train*

TOES analysis determined that the maximum in-train buff force was 1895 kips on the occurrence train. Had the train been re-marshalled with the tail-end block of loaded cars (108th car to 137th car) placed at the head end, a train separation between the 107th car and 108th car would not have resulted in the two train sections coming back together. In this scenario, it was also determined that the maximum in-train buff force would be 219 kips. Re-marshalling the occurrence train with the tail-end block of loaded cars placed at the head end would have reduced the maximum in-train buff force by approximately 88 per cent.

2.6 *Managing In-Train Forces at Canadian Pacific Railway*

CPR recognizes the risk associated with undesirable train configurations and has implemented a marshalling system to manage in-train forces while accommodating destination blocking to a certain extent. Such a system effectively manages in-train forces, reduces the number of train separations and minimizes the risk of derailment.

The following TSB Laboratory reports were completed:

LP 040/2009 – Analysis of Coupler Knuckle
LP 017/2010 – Analysis of RSI Train Simulation

These reports are available from the Transportation Safety Board of Canada upon request.

3.0 Conclusions

3.1 Findings as to Causes and Contributing Factors

1. While the train was travelling through undulating territory, a moderate run-out of train slack resulted in a broken knuckle between the 107th car and 108th car and the separation of these cars.

2. The knuckle material had lower-than-specified hardness, had been improperly heat treated and its Charpy impact fracture toughness was less than half of the specified value. These properties made it more susceptible to sudden failure in tension at the occurrence temperature, in the presence of in-train forces that were slightly higher than usual.

3. When the train line air hoses separated, an undesired emergency brake application (UDE) was initiated and both portions of the train began to slow. Because the heavier tail-end portion had greater momentum and was situated on a descending grade, its braking was not as effective as the head-end portion of the train.

4. The more rapidly moving tail-end portion collided with the slower moving head-end portion. Since both portions of the train were already in compression, the collision generated a high buff force estimated to be near 1500 kips.

5. The force came to bear on two long, empty flat cars coupled together between shorter, loaded tank cars, a combination susceptible to derailment during high buff force events. The flat cars jackknifed and applied a lateral force to the gauge side of both rails causing them to roll over and the cars to derail.

6. While the train was marshalled in accordance with Canadian National's General Operating Instructions and regulatory requirements, it was not configured in a manner that effectively managed in-train forces.

3.2 Finding as to Risk

1. In the absence of a comprehensive train marshalling protocol that effectively manages in-train forces and takes weight distribution within a train into consideration, there is an increased risk of derailment during an emergency brake application.

3.2 Other Findings

1. Re-marshalling the occurrence train with the tail-end block of loaded cars placed at the head end would have reduced the maximum in-train buff force by approximately 88 per cent.

2. Canadian Pacific Railway recognizes the risk associated with undesirable train configurations and has implemented a marshalling system that effectively manages in-train forces and reduces the number of train separations.

4.0 Safety Action

4.1 Action Taken

4.1.1 Transport Canada

Transport Canada (TC) Rail Safety inspectors conducted a series of focussed inspections concerning empty/load configurations of Canadian National (CN) trains on the Kingston Subdivision. TC Rail Safety inspectors conducted 16 such inspections between Brockville and Oshawa in 2009-2010.

On 07 April 2010, a TC Rail Safety inspector issued a Notice under Section 31 of the *Railway Safety Act* to CN concerning failure to effectively manage in-train forces on freight trains operating on the Kingston Subdivision.

On 16 April 2010, CN replied with corrective actions to the Notice indicating that:

- CN will limit, on an interim basis, conventional freight trains to a maximum of 8500 feet in length and 12 000 tons.

- CN will monitor its train configurations for exceptional marshalling issues, such as large blocks of empties ahead of large blocks of loads.

- CN will begin implementing the use of distributed power (DP) trains on the Kingston Subdivision with the intention that in future all trains operating at this location will be DP trains.

TC will continue to perform onboard train monitoring as well as continue to review and analyze train separation data on a quarterly or bi-annual basis. TC is contracting a research firm to undertake a complete and thorough parametric analysis of in-train forces and the associated train/track interaction. The research will be used to develop relationships between train marshalling and track geometry that include consideration of track grade, track curvature, train length, train weight, total power requirement, power placement within the train, longitudinal in-train forces, wheel lateral forces and the potential for train derailment. The research results will be used to establish policies and guidelines relating to train marshalling, power distribution and related track geometry/superelevation factors that minimize or optimize in-train forces to ensure safe train operations.

The study will be undertaken in five phases with analytical deliverables provided at the end of each phase. The five phases will include analysis of subdivisions with undulating terrain and significant curves, severe mountainous terrain and flat terrain with curves. The study will also include analysis of the benefits of using the TrAM (Train Area Marshalling) software planning tool to control in-train forces. The entire study is expected to take 21 months to complete, but with actionable results being generated at the end of each phase.

4.1.2 Canadian National

CN conducted a Break-in-Train Analysis and identified four undulating cluster locations on the Kingston Subdivision as problematic (Miles 151 to 158, 180 to 184.5, 191 to 193 and 244 to 251, respectively). CN is currently attempting to write train handling instructions or "scripts" for these areas based on in-train force simulations.

To further address in-train forces, CN has put the following measures in place:

- It developed a new air hose and gasket to reduce air hose separations.
- It tested trip optimizer software.
- It improved detection and handling of equipment with non-alignment control couplers (April 2010).
- It limited train lengths for both conventional and DP freight trains on the Kingston Subdivision (April 2010).
- It implemented an intermodal train marshalling rule to restrict empty cars at the head end (July 2010).
- It continued investment in locomotive DP technology that can reduce in-train forces. CN plans that, by the end of 2010, about 34 per cent of CN's road locomotive fleet will be DP–capable, increasing to 41 per cent by the end of 2012.
- It implemented a series of marshalling rules primarily related to train weight distribution. The rules have been developed to reduce in-train and track-train forces and are based on science, experience, benchmarking with other railroads and a review of historical accident root causes including analyses in TSB reports.
- It developed "Rules Engine" software to review marshalling rule compliance on a historical basis, to assist in identifying priority locations and trains and to review train designs to facilitate improved marshalling. The effectiveness of the marshalling rules has been verified and supported by reviewing historical accidents in the context of the proposed rules, including all the accidents listed in this TSB investigation report.
- It modified its information system (Service Reliability Strategy or SRS) so that it flags marshalling rules compliance. SRS notifies operating personnel of marshalling issues and a daily automated report has been developed to measure performance to the marshalling rules.
- It implemented a rule that limits tonnage trailing a block of 10 or more empty cars. This rule is presently in effect on the Kingston and Wainwright subdivisions and is being applied at distant terminals that build trains operating over these subdivisions. Initial results have yielded nearly a 50 per cent reduction in train separations on these subdivisions.

- It will continue to implement train weight distribution marshalling rules on additional subdivisions on an ongoing basis, based on risk, topography, and the use of mitigating technology such as DP. CN met with TC to review its train marshalling initiatives. A follow-up meeting and update is planned for the fall of 2010.

4.2 *Safety Concern*

4.2.1 *Managing In-Train Forces*

Train operations have changed significantly in recent years. Before the mid-1990s, an average train in main-track service was about 5000 feet long and weighed 6000 to 7000 tons. Some of today's trains are over 12 000 feet long and weigh over 12 000 tons and as much as 18 000 tons. With the significant increase in average train length and weight, there have been associated increases in normal in-train forces. While some railways, such as Canadian Pacific Railway (CPR), identified this risk and have taken steps to minimize in-train forces, with marshalling processes that consider weight distribution within a train and the use of distributed power, other railways, such as CN, continued to run longer, heavier conventional trains equipped with head-end power that experienced elevated in-train forces. Recently, CN has begun to take a more comprehensive approach towards managing in-train forces.

Including this occurrence, since 2001, the TSB has conducted 10 derailment investigations that involve high in-train forces in long trains (see Appendix A). In each case, the investigation determined that train marshalling and the management of in-train forces were contributing factors. Nine of these investigations involved CN and demonstrate that its defences have not always controlled in-train forces in a manner consistent with safe train operation. In March 2010, the Board issued its *Watchlist*, which includes a safety issue associated with the operation of longer, heavier trains. The *Watchlist* states that "inappropriate handling and marshalling can compromise the safe operation of longer, heavier trains" and calls on railways to "take further steps to ensure the appropriate handling and marshalling of longer, heavier trains." While the Board is encouraged with the recent CN initiatives, the initiatives are evolving and have not yet been widely implemented on the system. Therefore, the issue will remain on the *Watchlist* and the Board will continue to monitor CN's progress.

Despite a number of TSB investigations that identified train marshalling and the inability to effectively manage in-train forces as contributing factors, there has yet to be any long-term strategy formulated by the regulator to address these emerging issues. Consequently, other than compliance with the *Transportation of Dangerous Goods Act* and the *Transportation of Dangerous Goods Regulations*, TC does not require railways to manage and minimize in-train forces. While train operations have changed significantly in recent years, regulatory overview with regards to train marshalling and the management of in-train forces has not kept pace and permitted gaps in the system to occur. While the Board recognizes that TC is contracting research on managing in-train forces with a view to establishing comprehensive train marshalling guidelines, such guidelines are at least two years away. In the meantime, the Board is concerned that TC may not have adequate tools in place to effectively monitor train marshalling practices and a railway's ability to manage in-train forces.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 29 September 2010.

Visit the Transportation Safety Board's Web site (www.bst-tsb.gc.ca) for information about the Transportation Safety Board and its products and services. There you will also find links to other safety organizations and related sites.

Appendix A – Other Related Occurrences Involving In-Train Forces

The TSB has conducted investigations into the following derailments:

1. **R07D0009** – On 12 February 2007, Canadian National (CN) freight train M31031-10 derailed eight cars near Drummondville, Quebec. A broken knuckle on the 75th car caused an emergency brake application to propagate to the head end of the train. The train consisted of 5 head-end locomotives and 105 cars (80 loads and 25 empties), was approximately 7006 feet long and weighed about 10 815 tons. The investigation determined that the marshalling of the train (that is, empties ahead and loads behind) was a contributing factor.

2. **R07T0110** – On 28 April 2007, CN freight train M36321-26 derailed a Herzog track maintenance machine and 21 empty multi-level cars at Cobourg, Ontario. The train consisted of 3 head-end locomotives and a mix of 84 empty and loaded cars. It was 9602 feet long and weighed about 9000 tons. The investigation determined that the marshalling of the train, with placement of a car equipped with non-standard couplers at the head end of a train with significant trailing tonnage, was a contributing factor.

3. **R07T0323** – On 30 October 2007, CN freight train M38461-29 derailed while stopping to set off a block of intermodal cars at Malport, Ontario. The train consisted of 4 head-end locomotives and 131 cars (59 loads and 72 empties), was approximately 7839 feet long and weighed about 7810 tons. The investigation determined that the marshalling of the train, with placement of equipment with non-standard couplers at the head end of a train with significant trailing tonnage, was a contributing factor.

4. **R05C0082** – On 27 May 2005, Canadian Pacific Railway (CPR) freight train 277-26 derailed 2 locomotives and 24 cars, including 3 pressure tank cars last containing anhydrous ammonia (UN 1005), near Bowden, Alberta. The train consisted of 2 head-end General Electric AC4400 operating locomotives followed by 2 isolated rear-facing General Motors GP 9 locomotives, 77 cars (22 loads and 55 empties), was 5050 feet long and weighed 4512 tons. The investigation determined that high buff force caused by the abrupt dynamic brake (DB) application and the marshalling of the train, with placement of a locomotive equipped with non-alignment control couplers at the head end of a train, was a contributing factor. The magnitude of the buff force application was exacerbated by the marshalling of 18 cars with cushion drawbars immediately behind the locomotive consist. The train was not marshalled in accordance with CPR General Operating Instructions (GOIs).

5. **R05V0141** – On 05 August 2005, CN freight train A47151-05 derailed nine cars, including one load of sodium hydroxide (UN 1824), also known as caustic soda, and eight empty cars near Garibaldi, British Columbia. Approximately 40 000 litres of the caustic soda spilled into the Cheakamus River, causing extensive environmental damage. The train consisted of 5 head-end locomotives, 144 cars (3 loads and 141 empties), and 2 remote locomotives behind the 101st car. It was about 9340 feet long and weighed 5002 tons. The investigation determined that the combination of excessive locomotive tractive effort and trailing tonnage, along with long–short car coupling, produced high lateral forces and a correspondingly high lateral/vertical ratio and wheel lift, causing the train to stringline the curve.

6. **R02W0060** – On 26 April 2002, CN freight train E20131-24 was departing Winnipeg, Manitoba, along the north main-line track of the Redditt Subdivision. As the train traversed a crossover with the DB applied, eight cars derailed. The derailed equipment included three loaded box cars containing dangerous goods. The train consisted of 3 locomotives and 85 cars (76 loads and 9 empties), was 5412 feet long, and weighed 9363 tons. The investigation determined that the run-in of slack from significant trailing tonnage, combined with a sustained DB level, generated buff forces severe enough to initiate wheel lift derailing an empty 80-foot-long bulkhead centre-beam flat car marshalled near the head end of the train.

7. **R01M0061** – On 06 October 2001, CN freight train M30631-05 derailed 15 cars after striking an automobile on a farm crossing in the township of Drummond, New Brunswick. Seven of the derailed cars were tank cars carrying liquefied petroleum gas (UN 1075). The train consisted of 3 head-end locomotives, 130 cars (60 loads and 70 empties), was about 8700 feet long and weighed approximately 10 000 tons. The investigation determined that an undesired emergency brake application (UDE) occurred when the train struck the automobile. Due to the track profile and train configuration, there was excessive run-in generating high buff forces, resulting in rail rollover and the derailment.

   The report indicated that "CN has equipped six per cent of their locomotive fleet with an end-of-train system that automatically initiates synchronous braking from both the locomotive and the tail-end during emergency and service applications. However, CN and other Canadian railways have not committed to a program which would accelerate the replacement of existing systems with the newer technology. Therefore, the remaining existing locomotives will continue to use older end-of-train units until they reach the end of their service life. Given that Canadian railways are equipped with a relatively young locomotive fleet, and given the evolution of freight train operations to longer trains, the risks inherent to emergency situations on long freight trains will remain unaddressed." Therefore, the Board recommended that:

   > Transport Canada encourage the railway companies to implement technologies and/or methods of train control to assure that in-train forces generated during emergency braking are consistent with safe train operation.

   (R04-01, issued April 2004)

TC accepted the Board's recommendation and informed its stakeholders. TC noted that CN has adopted Trainlink-ES technology and that approximately 500 road locomotives were equipped by the end of 2006. CPR has adopted enhanced Train Information Braking System (TIBS) technology that includes an end-of-train auto-emergency feature and equipped 94 per cent of its locomotives. All newly purchased road locomotives are to be equipped with the new technology. The Board assessed the response to Recommendation R04-01 as being Fully Satisfactory.

8. **R01T0006** – On 16 January 2001, CN freight train M31031-15 derailed 26 cars near Mallorytown, Ontario. The derailed cars included two tank cars loaded with propane. The train consisted of 2 head-end locomotives, 149 cars (76 loads and 73 empties), was approximately 9450 feet long and weighed about 11 700 tons. The investigation determined that a combination of the geometric alignment of the track, train marshalling and the buff forces generated during the emergency brake application resulted in a wheel lift derailment.

9. **R00W0106** – On 16 May 2000, CN freight train E20531-15 derailed 19 of its 136 cars in the vicinity of Mile 155.0 of the Redditt Subdivision. Four of the derailed cars contained dangerous goods. The train consisted of 2 head-end locomotives, 136 cars (51 loads and 85 empties), was approximately 8800 feet long and weighed about 9440 tons. The investigation determined that, during throttle reduction while in a curve on a descending grade, the train experienced a wheel climb derailment that was a result of high lateral forces created by excessive run-in of the rear portion of the train.

Appendix B – Glossary

AAR	Association of American Railroads
BHN	Brinell hardness number
CN	Canadian National
CPR	Canadian Pacific Railway
DB	dynamic braking
DP	distributed power
EOCCD	end-of-car cushioning device
GOIs	General Operating Instructions
IDU	input and display unit
mph	miles per hour
MSRP	*Manual of Standards and Recommended Practices*
RSI	Rail Sciences Inc.
SBU	sense and braking unit
SRS	Service Reliability Strategy
TC	Transport Canada
TIBS	Train Information Braking System
TOES	Train Operations and Energy Simulator
TrAM	Train Area Marshalling
TSB	Transportation Safety Board of Canada
UDE	undesired emergency brake application
°C	degrees Celsius