Transportation Safety Board
of Canada

Bureau de la sécurité des transports
du Canada

RAILWAY INVESTIGATION REPORT
R04T0161

DERAILMENT

CANADIAN NATIONAL
FREIGHT TRAIN Q-111-31-25
MILE 184.4, BALA SUBDIVISION
BURTON, ONTARIO
25 JULY 2004

Canada

Railway Investigation Report

Derailment

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Summary

At approximately 0923 eastern daylight time on 25 July 2004, Canadian National freight train Q-111-31-25, proceeding northward at 43 mph, derailed 13 multi-platform intermodal cars carrying 88 containers at Mile 184.38 of the Bala Subdivision near Burton, Ontario. Approximately 2300 feet of track was destroyed. There were no injuries. No dangerous goods were released.

Ce rapport est également disponible en français.

Other Factual Information

The Accident

On 25 July 2004, at approximately 0923 eastern daylight time,[1] Canadian National (CN)[2] expedited intermodal freight train Q-111-31-25 (the train) departed Parry Sound, Ontario, destined for Winnipeg, Manitoba (see Figure 1). The train consisted of 2 locomotives, CN 2542 and CN 5546, and 28 loaded intermodal cars, a mix of single-platform, three-platform, and five-platform articulated well cars. It was 5919 feet long and weighed approximately 5750 tons. The train crew was composed of a locomotive engineer and a conductor. They met fitness and rest standards and were familiar with the subdivision. The conductor, designated by CN as a conductor locomotive operator (CLO),[3] was at the locomotive controls. Two other operating personnel were in the second locomotive.

At approximately Mile 184, the train was proceeding along an ascending grade at 43 mph. It entered a right-hand compound curve, then a left-hand curve in the direction of travel. No brakes were applied.

The crew experienced two surges in the train, followed by an undesired emergency brake application (UDE). The head end of the train came to a stop at Mile 185.5, approximately 6.7 km (4.2 miles) north of the siding at Burton, Ontario (see Figure 1).

Weather conditions were sunny and 24°C.

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[1] All times are eastern daylight time (Coordinated Universal Time minus four hours).

[2] See Glossary at Appendix C for all abbreviations and acronyms.

[3] Conductor locomotive operator (CLO) is a CN job designation. After successful completion of a company-designed and delivered training and certification program, CN allows CLO–designated conductors to operate locomotives under the direction of a qualified locomotive engineer. A CLO is not an operating personnel designation recognized in the regulations governing locomotive operation.

Figure 1. Location of derailment
(Source: Railway Association of Canada, *Canadian Railway Atlas*)

After making the necessary emergency broadcast, the conductor initiated an inspection of the train. The conductor identified a train separation of approximately 400 feet (250 m) and a broken knuckle. The train was pulled forward to replace the knuckle, and then reversed to couple back onto the tail-end portion of the train. At this time, the conductor observed that a portion of the tail end of the train had derailed. The train journal indicated that some of the derailed containers contained dangerous goods. The rail traffic controller (RTC) was immediately notified of the train status and location.

Site Inspection

Car DTTX 728396, an articulated three-platform well car, was the 11th car in the train consist and the most northerly derailed car. The trailing truck of the third car body (B-platform) was derailed. All following cars, up to and including the 23rd car, NKCR 1229, were derailed (see Figure 2).

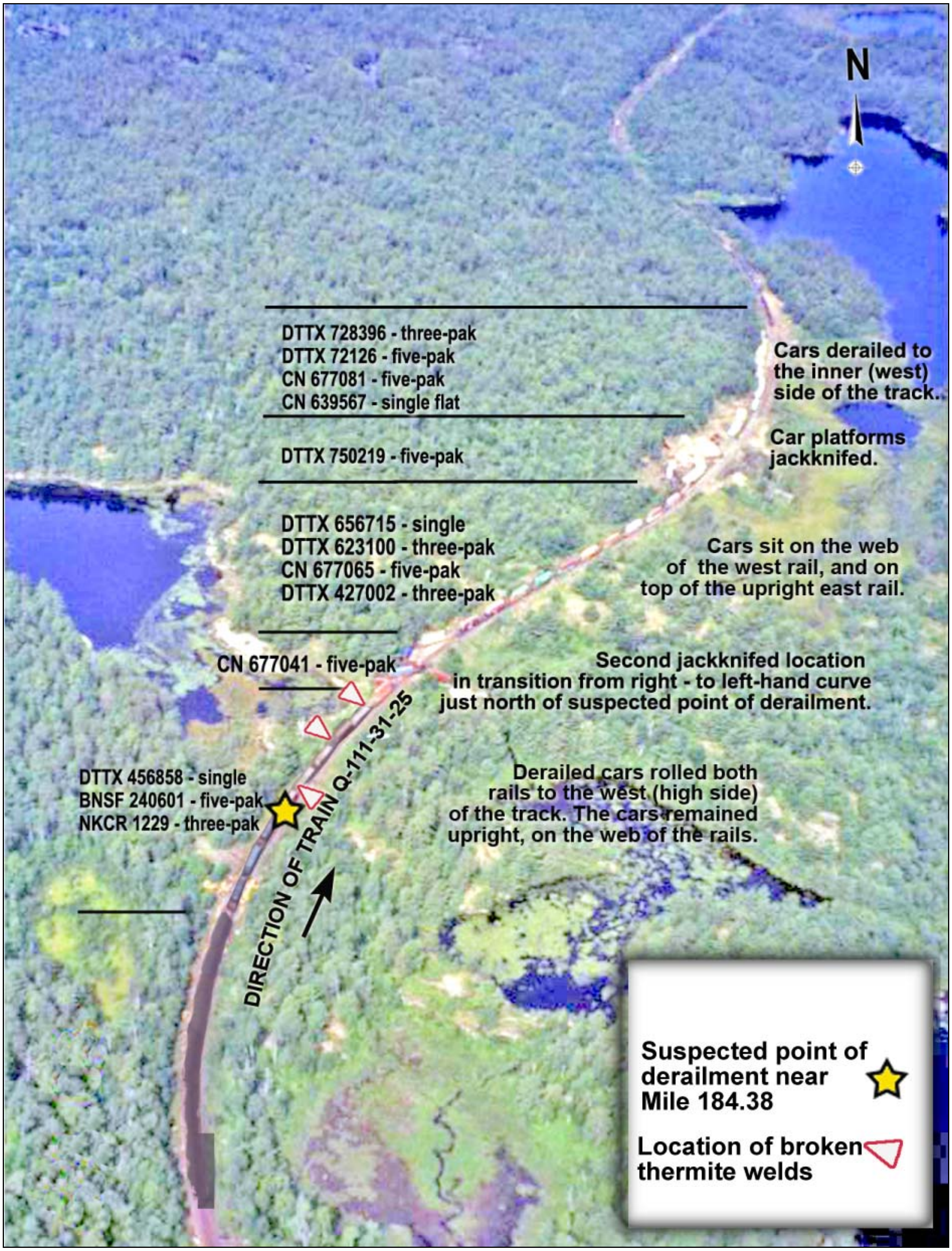

Figure 2. Aerial view of derailment site (Source: TSB photo)

The three cars behind car DTTX 728396 (the 12th, 13th, and 14th) were all derailed in a stringline manner to the inside of the left-hand curve, with the west rail rolled to the field side. The 14th car, CN 639567, was upright on the track bed and coupled to the 15th car, DTTX 750219.

Car DTTX 750219 was an articulated five-platform intermodal well car with the A-end of the car leading. It was derailed to the west in a jackknifed position. Containers were heavily damaged with product leaking from one of the containers. The product was identified as a non-dangerous liquid.

The next four cars (the 16th, 17th, 18th and 19th) were derailed upright. The west rail had rolled to the field side and wheels were resting on the web of the west rail and on top of the upright east rail. The trailing platform of the 18th car had derailed and tracked westward from the rolled rail, coming to rest against the south slope of a narrow rock-cut. The 20th car, a five-platform articulated well car, jackknifed across the track. The 23rd car (NKCR 1229) and most southerly of the derailed cars remained upright with all wheels resting on the web of the canted rail. Although dangerous goods were involved in the derailment, there was no release of product and no injuries.

The first sign of wheel drop-off was on the east rail at approximately Mile 184.38. The rail was canted out with wheel flange marks on the gauge face and gauge-side web. To the north of this point within 400 feet were three rail breaks at thermite welds, two in the high rail and one in the low rail. The rail break in the low (east) rail was at Mile 184.42. North of the break, the low rail was rolled to the gauge side with wheel flange marks (and wheels resting) on the field side of the web. One break located in the high (west) rail at Mile 184.45 was at the transition point between two different rail-fastening systems. After the train was pulled back, multiple wheel flange marks and batter were observed on the gauge side of both rails.

Approximately 2300 feet of track was destroyed.

The Bala Subdivision

The Bala Subdivision is part of CN's transcontinental mainline and extends northward from Toronto, Ontario (Mile 0.0), to Capreol, Ontario (Mile 276.1). It is a single main Class 4 track[4] with a maximum allowable operating speed of 60 mph for freight trains and 70 mph for passenger trains.

In 2004, the amount of rail traffic over this subdivision was 39.7 million gross tons (MGT), a 4 per cent increase over 2002 (38.1 million). Intermodal traffic has made up 50 per cent of the train traffic since 2001.

Movements over the Bala Subdivision are governed by the Centralized Traffic Control System (CTC), as authorized by the *Canadian Rail Operating Rules* (CROR) and supervised by an RTC located in Toronto.

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[4] Transport Canada, *Railway Track Safety Rules*, Part II, A. CLASSES OF TRACK: Operating Speed Limits

Track Information

In the vicinity of the derailment, the track consists of a compound right-hand, five- to three-degree curve followed by a left-hand, three-degree curve with a 0.5 per cent ascending grade. The maximum operating speed for freight trains in the derailment area was 45 mph.

The rail in the five-degree portion of the curve through the derailment area was 1998 Nippon head-hardened rail. The high rail was secured on hardwood ties with elastic fasteners (Pandrol "e" type clips) and ductile iron plates measuring 7 ½ inches by 16 inches, each fastened to the ties with three lag bolts, two on the field side and one on the gauge side partway through the curve. The remainder of the curve was secured with four spikes and box-anchored with Fair anchors. This latter work was performed in the two months before the accident in response to wide gauge conditions in the curve.

The low rail was on 14-inch double-shouldered standard tie plates, each fastened with four spikes, and box-anchored with Fair anchors. Defective tie counts on each side of the destroyed area ranged between 25 and 30 per cent. No rail movement was evident up to the point of destroyed track. The ballast consisted of mixed crushed rock and slag with sandy material below the ties. The cribs were full and the shoulders extended 12 inches beyond the tie ends.

The Sperry car tested the subdivision for rail defects in late May/early June 2004. No exceptions were noted. The Bala Subdivision receives eight rail tests annually, with most done during the winter months.

The last track evaluation system (TEST) car run was on 15 July 2004. The July 15 TEST car run recorded a number of urgent,[5] near urgent and priority geometry defects through the derailment area. The body of the five-degree, right-hand curve had an average of 5.55 inches of superelevation. This included two urgent superelevation defects over a length of 60 feet that exceeded 6 inches. According to CN's Standard Practice Circular (SPC) 1305,[6] a 45 mph (Class 4) five-degree curve with 2 inches of imbalance should have a superelevation of approximately 5 1/8 inches. The 6 inches of superelevation was closer to the balance speed superelevation of 7 1/8 inches required for 45 mph and equilibrium (load evenly distributed on high and low rails). Nevertheless, urgent defects were marked because CN standards do not permit a maximum superelevation exceeding 5 inches without the permission of the chief engineer. Without that permission, the amount of superelevation placed on a curve ranges from the minimum as given by 2 inches of imbalance to the lesser of 5 inches or the equilibrium superelevation.

In addition to the urgent superelevation defects, there were five priority and two near urgent WRP62SPR (Warp 62 spiral) defects and one near urgent WRP31 defect (Warp 31 spiral). All these defects were between 184+1904 and 184+3530 (1626 feet), which includes the five- to three-degree, right-hand compound curve and the south spiral of the three-degree, left-hand

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[5] For the purposes of this report, "urgent" defects are defined as per CN's definitions, which deviate from the Transport Canada *Railway Track Safety Rules* (TSR).

[6] CN's Standard Practice Circulars (SPCs) contain CN's maintenance standards for track.

curve to the north (see Table 1). WRP62SPR is defined as the difference in cross-level between any two points less than 62 feet apart on spirals. WRP31 is defined as the difference in cross-level between any two points 31 feet apart in spirals. Near urgent defects are defined as defects within 90 per cent of the urgent value. CN's SPC 3101 defines track geometry maintenance standards.

Table 1. Track Geometry Defects

Defect	Length (feet)	Measured Value (inches)	Severity	Urgent Threshold (inches)	Priority Threshold (inches)	Location in Curve
Superelevation	38	6.11	Urgent	1	1	Body 5R
Superelevation	22	6.10	Urgent	1	1	Body 5R
WRP62SPR	12	1.49	Priority	1 3/4	1 1/8	ES 3R
WRP62SPR	12	1.49	Priority	1 3/4	1 1/8	SS 3L
WRP62SPR	3	1.51	Near Urgent	1 3/4	1 1/8	SS 3L
WRP31	6	0.92	Near Urgent	1	15/16	SS 3L
WRP62SPR	8	1.49	Priority	1 3/4	1 1/8	SS 3L
WRP62SPR	3	1.52	Near Urgent	1 3/4	1 1/8	SS 3L
WRP62SPR	4	1.49	Priority	1 3/4	1 1/8	SS 3L
WRP62SPR	12	1.49	Priority	1 3/4	1 1/8	SS 3L

ES = end spiral SS = start spiral

A detailed review of the track geometry TEST records near the event location determined that alignment, surface, and gauge were all within the respective *Railway Track Safety Rules* (TSR) limits. The curvature was smooth and uniform, with an alignment variation of 0.4 inch over 32 feet and a gauge variation of 0.6 inch over 15 feet near the point of derailment (POD).

Track Fastening Systems

Track components respond and interact with each other when subjected to train wheel loads. Train loads are transferred from the rail into the subgrade through the fasteners, tie plates, ballast and sub-ballast. Curved track with conventional cut spikes and tie plates can have problems supporting heavy axle traffic. The spikes become loose and work their way out of the tie, creating wide gauge, enlarging the spike holes and exposing the untreated interior of the tie to moisture and decay. This occurs because the spike serves the dual role of positioning the rail in the tie plate and securing the tie plate to the tie to maintain gauge.

In contrast, cast or rolled plates provide a separation of the fastener function. The rail is attached to the tie plate with an elastic fastener, an “e”-shaped, heat-treated steel bar 20 mm in diameter. The plate is attached to the tie with lag screws or a combination of screws and spikes. The tie plate has wedge-shaped grooves in the bottom that embed in the wood tie to add extra holding power.

Elastic fastening systems provide a much stronger track structure that is more resistant to high lateral and longitudinal forces and to the development of wide gauge, and rail cant, which can result in tie damage. The screw fasteners provide increased resistance to tie plate movement, thereby increasing gauge widening strength and the gauge widening life of the track. This reduces “spike kill” caused when fasteners are removed and reapplied during rail change-outs. Elastic fasteners also provide increased rail hold-down strength, which increases resistance to rail rollover.

The practice of installing elastic fasteners on only one rail (with conventional cut spikes on the other rail) had existed on the Bala Subdivision and elsewhere on CN trackage for several years. Curves greater than or equal to six degrees on the Bala Subdivision had elastic fasteners installed on both rails during major tie programs in the late 1990s. In 2001 and 2002, an effort was made to convert curves greater than or equal to four degrees to this fastener system. Elastic fasteners were installed on either the high or low rail as rail was replaced in the curve. This practice has been extended to installing elastic fasteners on the high rail of curves that are developing excessive wide gauge and cant. Field experience has shown that high rails develop these conditions faster than low rails and installation of elastic fasteners on the high rail has proven effective at correcting wide gauge and cant conditions. Anchors removed from the high rail during the installation of the elastic fasteners are added to the low rail to increase longitudinal restraint on that rail. While industry testing has shown that elastic fasteners offer superior rail restraint when installed on both rails, no testing has been done regarding the installation of elastic fasteners on only one rail of a curve.

CN’s SPC 3600 specifies the use of elastic fasteners in Class 3 to Class 6 tracks on curves greater than four degrees carrying 20 to 40 MGT annually. On tracks carrying greater than 40 MGT, elastic fasteners are specified for curves greater than two degrees. By comparison, Canadian Pacific Railway’s (CPR) SPC 16 specifies the use of elastic fasteners on curves greater than eight degrees with more than 10 MGT and speeds greater than 50 mph, or on curves where broken spike conditions are evident. Installation of elastic fasteners on a single rail (high or low, depending on timing of rail change-out) has been common practice for at least 10 years. CPR’s *Train Accident Cause Finding Manual*, pages 6-28 and 6-29, states “due to the increased holding ability of this system, positive restraint (elastic) fasteners should be installed on both rails (if installed on only one rail with conventional spiking on the other rail, the spiked rail could be susceptible to rail rollover due to additional lateral forces exerted on that rail).” CN’s SPC does not address the subject of installation of elastic fasteners on one rail only, or only partway through a curve.

Mechanical Records

Following the identification of the first car to derail, service and repair records for this car (DTTX 750219) were obtained and analysed (see Table 2). The records show that the car had frequent high impact and high flange problems.

Table 2. Recent Wheel Service Records of Car DTTX 750219

Date	Wheel*	Service
01 December 2003	RX	High flange (code 64)
21 January 2004	L8	High impact (code 65)
03 February 2004	RZ	High impact
16 February 2004	L8	High impact (code 65)
04 April 2004	RY and LY	High flange
07 June 2004	RX	High flange
19 July 2004	R3	High flange

* Axles are numbered from the B-end as follows: 1, 2 – B-end; 3, 4 – between B and C platform; 5, 6 – between C and D platform; 7, 8 – between D and E platform; 9, Z – between E and A platform; Y, X – A-end. Designations R and L indicate the side of the car, from the perspective of someone standing at the B-end facing the car.

TSB Engineering Laboratory Report LP 105/2004 – Rail Analysis[7]

Rail pieces from the east and west rail breaks were forwarded to the TSB Engineering Laboratory to determine mode and cause of failure. Key conclusions were as follows:

- the fracture faces on both rails showed features consistent with torsional instantaneous overstress rupture;
- the fracture faces on both rails had no signs of progressive failure; and
- the condition of the thermite welds in both the east and west rail samples was acceptable.

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[7] TSB Engineering Laboratory report LP 105/2004 is available upon request from the Transportation Safety Board of Canada.

TSB Engineering Laboratory Report LP 129/2004 – Train Dynamics Analysis[8]

Detailed train handling information, including locomotive event recorder (LER) data, was forwarded to the TSB Engineering Laboratory for analysis. With no end-of-train information or acceleration channel information available from the LER of locomotive CN 2542, accelerations and decelerations were calculated from the recorded speed and time data to help identify the UDE and the first derailed car. The resolution levels of the LER data (time ± 1 second, mileage ± 0.01 miles and speed ± 1 mph) limited the accuracy of train location to 50 to 60 feet. As a result, a calculated difference of less than 50 feet was determined to be within the actual POD. From the information gathered, the following was determined:

- The lead locomotive travelled at a constant speed of 48 mph between Mile 183.71 (0922:51) and Mile 183.91 (0923:06). The varying traction force at the changed throttle position just balanced the train resistance due to track grade changing.

- When the lead locomotive travelled between Mile 183.91 (0923:06) and Mile 184.96 (0924:28), the deceleration was minor and smooth, matching the increasing resistance as the train entered the 0.5 per cent ascending grade section.

- Beginning at Mile 184.96 (0924:28), recorded deceleration dramatically increased until it reached a maximum at Mile 185.19 (0924:49) – more so than can be accounted for by track grade and geometry.

- The UDE signal arrived at the lead locomotive at 0924:53. For a signal propagation speed of 820 to 830 feet per second and train length of 5919 feet, the signal propagation time could not be longer than 7.2 seconds. This indicated that the UDE was triggered somewhere in the train between 0924:45 and 0924:53.

- At Mile 185.3 (0925:04), there was another deceleration peak.

- It was determined that the source of the UDE was the 15th or 16th car. Further calculations showed the location of these cars to be around Mile 184.62, very close to the location of the jackknifed 15th car. Since the 16th car was derailed but remained upright, it is concluded that the 15th car, DTTX 750219, was likely the first car to derail.

- Car DTTX 750219 likely rolled the low rail and derailed around Mile 184.383, on the five-degree portion of the right-hand compound curve, approaching the transition to the three-degree portion.

- The calculation of car locations indicated that car DTTX 750219 was at the POD at Mile 184.383 when deceleration dramatically increased.

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[8] TSB Engineering Laboratory report LP 129/2004 is available upon request from the Transportation Safety Board of Canada.

Summary of LP 129/2004 Conclusions

The dynamic responses of all wheels were analysed to determine their effect on the derailment. The following was determined:

- The derailment was caused by a combination of factors, including the five-platform articulated car dynamic characteristics, track geometry variations, low wheel conicity, different track fasteners on high and low rails, and wheel flange/rail gauge face friction conditions.

- The first derailment likely occurred when the 15th car, DTTX 750219, an articulated five-platform well car, rolled over the low rail at Mile 184.383 on the five-degree, right-hand curve due to the large angle of attack and high lateral dynamic force produced by the combination of contributing factors, none of which alone would have derailed the car.

- A computer simulation using the Vampire[9] software (see summary in Appendix A; full discussion in TSB Engineering Laboratory report LP 129/2004) showed that the articulated intermodal car DTTX 750219 would produce higher lateral force during dynamic curving than single-platform container cars with independent trucks under the same load and track conditions. Car DTTX 750219's frequent repair and service record is consistent with what would be expected from the simulation results.

- The multiple track geometry conditions at Mile 184.377 triggered the unusually high dynamic responses rolling over the low rail. The alignment and gauge were within track safety limits, but variations in alignment and gauge caused impact on the high rail at a large angle of attack and exerted dynamic lateral forces onto the east, weaker-restrained low rail, causing it to cant. The superelevation had been marked as an urgent defect due to the maximum superelevation limit, but it was close to the balanced superelevation for the travel speed and contributed less to the dynamic responses.

- The stiffer elastic fastenings on the high rail contributes to the lateral stiffness of the track panel as a whole, and therefore increases the dynamic response to track geometry deviations. The stiffer high rail also produces a higher resistance against both track panel shift and high rail rollover. However, the resistance of the low rail to roll over remains unchanged even though the low rail shares a portion of the increased lateral dynamic force. Therefore, the likelihood of a conventional spike-fastened low rail to roll over is increased.

- The dry friction between the wheel flange and rail gauge face increased the dynamic curving difficulty and the lateral forces.

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[9] Vampire is a dynamic modelling software package for analysing vehicle/track interactions in three dimensions.

- The low conicity of the recently changed wheels increased the difficulty of truck curving and the lateral force.

- Even though the alignment and gauge variations at the event location did not reach any TSR defect level, they triggered the unusually high dynamic responses and contributed to the derailment. While the superelevation at the location was marked as an urgent defect, it had a lesser effect on the dynamic forces and was not a significant factor in the derailment.

- The LER download (provided by CN) from locomotive CN 2542 was not equipped with end-of-train and acceleration channels, which are important in helping to identify the source of the UDE and the likely first derailed car.

- Under the baseline Vampire simulation conditions, the A-end leading truck[10] of car DTTX 750219 produced unusually high dynamic responses at Mile 184.377, about 30 feet south of the estimated POD at Mile 184.383. This difference is within the accuracy range of the LER data and is considered to be the same location. The leading axle produced an angle of attack as large as 22 mrad[11] while the normal angle of attack along the section was only about 5 mrad. The unusually high lateral and vertical forces and truck side lateral/vertical (L/V) ratio of truck 1 at the event location were much higher than usual derailment criteria while those at other locations were within the normal ranges. The very high dynamic peaks were clear indications of derailment potential.

- The outputs of the other trucks did not produce dynamic responses consistent with derailment conditions. The articulating truck 2 and truck 3 produced higher average lateral forces than truck 1 through the whole curve, but did not show the unusually high dynamic peaks at the event location. These articulated trucks were subject to heavier axle load and their truck side L/V ratios were approximately 0.3, much less than the derailment criterion of 0.6. Their angles of attack were also within the normal range, with no peak of a large angle of attack at the event location.

Canadian National's Conductor Locomotive Operator Program

The conductor was permitted to operate the train under the terms of CN's CLO program. The CLO program was initiated in 1995 to address a specific need for break relief while operating locomotives on extended runs. Conductors are trained to provide brief, intermittent relief for the locomotive engineer while under the supervision of the locomotive engineer. They operate at the discretion of the locomotive engineer, and CN stated that CLO operations do not occur during complex operating circumstances.

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[10] For the purpose of this simulation, the A-end leading truck was designated truck 1. The subsequent trucks were labelled from this point as truck 2, truck 3, etc.

[11] Angle of attack is expressed in radians rather than degrees (degrees = radians X 180/π)

At CN, candidates for the CLO course must already be fully qualified as conductors. The course is 42 hours, over seven days, and covers the following topics:

- basics of air brakes
- basic troubleshooting of locomotive problems
- train handling
- set up locomotive for various methods of operation
- a small number of simulator runs
- air brake regulations and tests
- train handling and motive power

A test is given at the end of the session.

CN has provided CLO training to over 1700 conductors. Once qualified, there are no requirements for CLOs to undergo regular retraining and recertification, beyond the standard required for rules certification as a conductor. The CLO on this train had not undergone any additional CLO training since he took the course in 1995. CLOs at CN do not receive the refresher training that is presently required for locomotive engineers, such as training on the handling of long trains.

The extent to which CLOs receive practical experience operating a train is dependent on how much of the journey the locomotive engineer chooses to allow the conductor to sit at the controls. CLO and locomotive engineer pairings are frequently changed, so a locomotive engineer must assess the suitability of a CLO for controlling the train at the start of the CLO's portion of the journey. Locomotive engineers do not receive training or guidance in making this assessment or in performing the supervision of CLOs. CLOs may go for long periods without operating a train.

Although extended run operation has decreased, since 1995, the role of the CLO–designated conductor has expanded. CLOs now operate locomotives over long distances on other than extended runs. This includes operating locomotives on longer and heavier trains, during meets, entering and leaving yard limits, and through curved and undulating territory.

Transport Canada's Regulations Regarding Train Operation

Transport Canada's (TC) regulations regarding the minimum qualification standards for locomotive engineers, transfer hostlers,[12] conductors, and yard foremen, cited as the *Railway Employee Qualification Standards Regulations*[13] (REQSR), state that:

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[12] An employee who is assigned to move motive power units over yard tracks and main tracks between the locations where the units are maintained and repaired and the locations where the units are put into or removed from train or yard services.

[13] CTC SOR/87-150, established 16 March 1987 pursuant to Section 46 of the *National Transportation Act*, and Section 227 of the *Railway Act*.

> 5.(1) No railway company shall permit any employee to work as a locomotive engineer, transfer hostler, conductor, or yard foreman unless the employee
>
> (a) has qualified for that occupational category in accordance with section 14; and
>
> (b) in the case of a locomotive engineer or transfer hostler, has received a passing mark for on-job training in the occupational category.

The regulations further state that:

> 10.(1) A railway company shall, at intervals of not more than three years, have each employee in an occupational category re-examined on the required subjects.
>
> 11. An employee who is transferred from one category to another shall
>
> (a) have qualified in accordance with section 14 for the occupational category to which he is transferred.

Section 14 of the REQSR defines the subjects required for a person to qualify in an occupational category and prescribes that no railway company shall qualify a person for an occupational category with an overall mark of less than 80 per cent in the required subjects. CLO is not a defined operational category.

Section 106 of the CROR defines crew responsibilities, effective 01 February 2004. They are as follows:

> CREW RESPONSIBILITIES
>
> (a) A train will run under the direction of its conductor.
>
> (b) The locomotive engineer of a train is in charge of and responsible for the operation of the engine of such train.
>
> (. . .)
>
> (d) The conductor and locomotive engineer, (also pilot if any) are responsible for the safe operation of the train or equipment in their charge and for the observance of the rules.

Regulations do not expressly prevent a conductor from performing locomotive operator duties under the direction of the locomotive engineer. However, the regulations do not identify a CLO as an operating position with specific duties and responsibilities and reclassification requirements.

Analysis

The operation of CN freight train Q-111-31-25 met company and regulatory requirements. An examination of wayside inspection data and the derailed rolling stock did not reveal any obvious pre-existing equipment defects. Laboratory analysis of the rail determined that the thermite welds near the derailment location broke due to torsional instantaneous overstress rupture; therefore, rail or thermite weld failure is not considered causal.

This analysis will focus on the findings from the vehicle/track dynamic analysis and the contributing factors identified in the study. It will consider track conditions before the derailment, track maintenance practices, and the behaviour of intermodal train traffic, particularly car DTTX 750219. The role of CLO–designated personnel in CN's train operation will also be discussed.

Locomotive Event Recorder Analysis and Track/Train Dynamic Simulation

Through analysis of the LER and the observations made at the derailment site, car DTTX 750219 was identified as the most likely first car to derail, in the vicinity of Mile 184.38. Using this information, the train dynamic simulation determined that the 15th car, DTTX 750219, generated a high lateral force on the track structure at Mile 184.38. Therefore, the derailment most likely occurred when the 15th car, DTTX 750219, an articulated five-platform intermodal container car, rolled the low rail at Mile 184.38 on the five-degree portion of the right-hand compound curve. After the train had begun to derail, both rails rolled over, leading to rail breaks due to torsional instantaneous overstress rupture in the high and low rails.

Factors Contributing to the Derailment

The following were identified as contributing factors in the generation of high lateral forces in the simulation:

- Rail Lubrication – The rails were dry (that is, not lubricated).

- Wheel Conicity – The wheels were new, with low conicity.

- Rail Fastening System – The elastic fasteners on the five-degree portion of the high rail increased rail stiffness.

- Track Geometry – The alignment and gauge deviations that triggered high dynamic responses in the articulated car were within TSR limits. However, these variations increased high rail impact, exerting dynamic lateral force onto the low rail in excess of the rail's hold-down capacity.

Articulated Cars

The behaviour of a single-platform car was compared to the behaviour of the five-platform articulated car type involved in the derailment. All other parameters were kept constant. Under the single-platform car condition, the high impact force and large angle of attack for the leading truck disappeared (that is, the articulated car produced higher dynamic response than a similar single-platform car under the similar conditions at the derailment site). Therefore, even though the specific mechanics governing car behaviour are not fully understood, it was empirically determined that articulated car characteristics were one of the necessary factors that led to this derailment.

Rail Lubrication

Rail gauge face lubrication improves truck dynamic curving by reducing the friction force at the wheel flange/gauge face contact point. The absence of lubrication on the gauge face of the high rail resulted in increased flange/gauge friction. This made truck rotation difficult, and led to high lateral forces.

Wheel Conicity

The repair and service records of car DTTX 750219 showed that the wheels had been changed recently and were in nearly new condition. Wheel/rail frictional forces are at their highest with newer profile wheels due to their reduced conicity compared with the conformal profile of a worn wheel. Generally, high conicity or worn wheels improve truck dynamic curving but may induce hunting problems on tangent track. Low conicity or newer wheels are more stable on tangent track but make truck turning relatively more difficult and apply higher lateral forces on curves.

In the high conicity (worn) wheel case, the angle of attack and the dynamic lateral force was reduced along the curve, indicating that low wheel conicity was a necessary condition for generating the unusually high dynamic responses. The newer profile wheels would have contacted the rail head closer to the centreline of the rail. Therefore, the low conicity of the new changed wheels likely contributed to the unusually high dynamic responses that caused the derailment.

Rail Fastening System

In the base simulation case, the elastic fastenings on the high rail provided increased resistance to lateral forces acting on the curve and effectively reduced high rail cant and wide gauge. The high lateral stiffness of elastic fasteners on the high rail produced higher dynamic responses than more flexible fasteners with lesser stiffness. However, the effect of the lateral forces on the low rail with conventional fastenings was problematic. The conventional fasteners on the low rail provided insufficient counterbalance resistance to the high lateral forces on the high rail to prevent the low rail from rolling over.

The simulation scenario of spikes on both rails resulted in reduced angle of attack and lateral forces, and consequently, reduced dynamic response. This is because spikes on the high rail are more flexible than the elastic fasteners and can absorb impacts caused by track geometry variations.

The increased stiffness of elastic fasteners is able to resist the increased dynamic response. In this particular occurrence, if elastic fasteners had been installed on both rails, the high rail likely would have still produced higher dynamic forces but the increased strength of the elastic fasteners on the low rail would have provided increased resistance to the lateral force.

Therefore, ending installation of these types of fasteners in a curve rather than carrying them onto tangent track may not be the best practice. The installation of elastic fasteners in curves on one rail only and/or on only a portion of the curve increases the risk that excessive lateral force will be transferred to the rail with conventional spike and plate fastenings, leading to rail breaks and/or rollover.

Track Geometry

The small gauge and alignment variations near the POD were problematic. The simulation determined that these variations were necessary triggers for the unusually high dynamic responses. The deviations, although within TSR standards, normally would not result in excessive lateral forces. However, in combination with the dynamic characteristics of articulated car DTTX 750219, these deviations likely caused the leading truck to contact the high rail at a very large angle of attack, jarring the truck aggressively into the low rail and increasing the lateral curving forces enough to roll over the less-restrained low rail.

Five Contributing Factors

Together, these five factors —car design, rail lubrication, wheel conicity, track fastening system, and track geometry — produced a high angle of attack, high lateral forces, and a high truck side L/V ratio, forcing the low rail to cant. The wheels dropped into the gauge side of the low rail and started to spread the rail ahead. Wheel/rail friction and contact, the method of track fastening, the curving behaviour of car DTTX 750219, and the presence of alignment and gauge deviations within TSR limits, acting in concert, were sufficient to generate rollover of the low rail.

The simulation determined that, in the absence of just one of these factors, lateral forces would not have been sufficient to generate rail rollover.

The installation of elastic fasteners in curves on one rail only and/or on only a portion of the curve increases the risk that excessive lateral force will be transferred to the rail with conventional spike and plate fastenings, leading to rail breaks and/or rollover.

Although the alignment and gauge variations near the POD were not defects as defined by the TSR, they were one of the critical factors required in the generation of the unusually high dynamic responses under car DTTX 750219. The urgent superelevation defect at the POD did not significantly contribute to the dynamic forces and derailment.

Training and Certification of Conductor Locomotive Operators

With roughly 1700 CLO–designated conductors, and their extended time at the locomotive controls, CN's use of CLOs exceeds the original scope of the program. However, CLOs are not required to maintain locomotive engineer–equivalent locomotive operation training and recertification standards.[14] This practice uses a gap in the regulations governing the roles of locomotive operating crews. The CLO on this train received the CLO course in 1995, but he received no subsequent training or certification to maintain his locomotive operation qualifications, even though sharing locomotive operation duties had become a routine practice.

Extended time at the controls may help to hone locomotive operation skills, but it can also serve to reinforce bad operating habits. The absence of requirements, similar to those for locomotive engineers who must undergo regular training to maintain and upgrade CLO skills and mandatory recertification in locomotive operation every three years, increases the likelihood that CLOs will find themselves in operating situations for which they were not trained. For instance, during an emergency, a locomotive engineer must quickly respond and perform a sequence of actions under extreme pressure.

If locomotive engineers, who receive regular training and certification, rarely execute all safety-critical actions during an emergency event, such as the initiation of the end-of-train braking, it is less probable that a CLO will do so, which was the situation in this occurrence. This emergency braking procedure is not overlearned.[15] Through repetitive practice, the procedure becomes an automatic process requiring less attention and making emergency responses more resistant to stress and interference by other tasks.

CN's use of CLO–designated conductors to operate trains has expanded beyond the scope of the original program. Despite the changes to the CLO program, TC has not formally assessed whether CN's training and certification for personnel operating locomotives continues to meet the requirements for safe railway operation.

Findings as to Causes and Contributing Factors

1. The derailment occurred when the 15th car, DTTX 750219, an articulated five-platform intermodal container car, rolled the low rail at Mile 184.383 on the five-degree portion of the right-hand compound curve.

2. Factors including wheel/rail friction and contact, the method of track fastening, the curving behaviour of car DTTX 750219, and the presence of alignment and gauge deviations within *Railway Track Safety Rules* (TSR) limits, acting in concert, generated sufficient lateral forces to roll over the low rail.

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[14] Locomotive engineers must undergo regular training to maintain and upgrade their qualifications, and be recertified every three years.

[15] J.E. Driskell, R.P. Willis and C. Copper (1992), "Effect of overlearning on retention," *Journal of Applied Psychology*, *77*(5), pp. 615-622.

Finding as to Risk

1. The installation of elastic fasteners in curves on one rail only and/or on only a portion of the curve increases the risk that excessive lateral force will be transferred to the rail with conventional spike and plate fastenings, leading to rail breaks and/or rollover.

Other Findings

1. Canadian National's (CN) use of conductor locomotive operator (CLO)–designated conductors to operate trains has expanded beyond the original scope of the program.

2. Despite the changes to the CLO program, Transport Canada has not formally assessed whether CN's training and certification for personnel operating locomotives continues to meet the requirements for safe railway operation.

3. Although the alignment and gauge variations near the point of derailment (POD) were not defects as defined by the *Railway Track Safety Rules*, they were one of the factors critical to the generation of the unusually high dynamic responses under car DTTX 750219.

4. The urgent superelevation defect at the POD did not significantly contribute to the dynamic forces and derailment.

5. In the absence of just one of five contributing factors (that is, car design, rail lubrication, wheel conicity, track fastening system, and track geometry), lateral forces would not have been sufficient to generate rail rollover.

Safety Action Taken

TSB Rail Safety Advisory 03/05

In April 2005, the TSB issued a Rail Safety Advisory (RSA) concerning the training and certification of personnel operating locomotives. The RSA addressed the expanded use of conductor locomotive engineer (CLO)–designated conductors at Canadian National (CN) to operate locomotives, and indicated that:

> In light of the changes to the CLO program, TC may wish to assess whether CN's training and certification for personnel operating locomotives continues to meet the requirements for safe railway operation.

As a result of the RSA, representatives from the Transport Canada (TC) Surface Ontario Region met with CN Great Lakes District officials to discuss the current status of the CLO training program, and communicated the results of this meeting in a letter dated 03 June 2005.

Use of Elastic Fasteners on Curved Track

TC reported that, in the course of regular monitoring activities, it would give consideration to the practice of using elastic fasteners on a portion of curved track.

Safety Concern

Training and Certification of Personnel Operating Locomotives

In its response to RSA 03/05*, Training and Certification of Personnel Operating Locomotives*, TC discussed the current status of CN's CLO training program. As part of these discussions, CN presented a description of its CLO program, which matches information it had already provided to TSB investigators. Based on CN's information, TC indicated that the CLO program is consistent with safe railway operation.

However, TC's assessment did not address the safety issue that was the basis for RSA 03/05 (that is, that there is a fundamental gap between what CN states as the intended use of CLO–designated conductors and the actual practice). In situations where conductors are sharing equally in train operation, they are no longer providing intermittent relief to the locomotive engineer, as was defined in the CLO program. Rather, they are acting as de facto second locomotive engineers. CLOs operating in this manner will inevitably find themselves at the controls during a complex operating situation.

As a comparison, in air transportation, only persons who have earned and maintained qualification in the operation of that airframe (that is, who have undergone the same minimum qualification, training and regular recertification) are permitted to be at the controls during operation.

TC has been unable to provide documentation indicating that either TC or industry has conducted a formal risk assessment of this practice consistent with safety management practices. In addition, there is no tracking or measurement of CLO operation by TC, and consequently, there are no formal records of how frequently CLOs are placed in complex operating situations. Such instances are only identified after they have led to a reportable occurrence warranting a TSB assessment.

The recent ALERT (Advanced Locomotive Engineer Refresher Training) program has not been provided to CLOs (unless they are also qualified locomotive engineers). It was indicated that the information learned at the training would be passed on to the CLOs by the locomotive engineers. However, there is no process or method to ensure that this occurs.

In view of the above, the Board is concerned that the use of CLO–designated conductors to operate locomotives may not be consistent with safe railway operations.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 26 July 2006.

*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 – National Research Council – Three-Dimensional Vehicle/Track Analysis Using the Vampire Modelling Program

To determine the derailment mechanism(s) in this occurrence, a three-dimensional vehicle/track dynamic analysis was conducted by the National Research Council (NRC) using the Vampire computer modelling program. The model considered car dynamic performance, track geometry defects, wheel/rail profile (conicity), wheel/rail lubrication (friction) and track fastening systems.

Nine simulation cases were carried out to analyse the dynamic responses of the relevant rail cars and the potential influences of different combinations of the above factors in the vicinity of the compound curve.

Simulation Case 2: Baseline Case

The baseline case considered the most likely factors at play at the time of the derailment. The factors analysed include: a five-platform articulated car with the measured track geometry, new wheel (low conicity), measured rail profile, no lubrication (high friction) between wheel flange and rail gauge face, and the elastic fastening system on the high rail and spikes on the low rail.

Simulation Case 1: Single-Platform Car

A single-platform car, with the same dimension and integrity as the end unit of the articulated car but with two independent trucks, was simulated under the same conditions, and then compared with the baseline case.

Both the angle of attack and the lateral forces of the single platform car were smaller than those of the five-platform articulated car. More importantly, the single-platform car did not produce the unusually high dynamic responses at the event location. The angle of attack and the dynamic lateral force of the single-platform car remained within the normal range along the curve, without the large peaks as were generated by the five-platform articulated car.

The comparison showed that an articulated intermodal car of the same design as DTTX 750219 would produce higher lateral force during dynamic curving than a single-platform container car with independent trucks under the same load and track conditions. The results of the simulation are consistent with car DTTX 750219’s unusually high frequency of repairs and service.

Simulation Cases 3, 4, 5 and 6: Track Geometry

Four simulation cases[16] were conducted to determine the effect of combinations of alignment, gauge and surface variations at or near the point of derailment (POD). In the first two cases (simulation cases 3 and 4), a simulation was run with no alignment variations and another with a constant gauge variation of 0.2 inch. In both cases, angle of attack, lateral forces and high dynamic responses at the event location disappeared.

The third simulation (simulation case 5) was conducted using no alignment or surface variations and with the articulated car under the same conditions as the baseline case. Both the angle of attack and the lateral forces in this case were smaller than those of the measured track geometry baseline case – very close to those in the no misalignment case. Similarly, with the alignment and surface variations removed from the measured track geometry, the unusually high dynamic responses at the event location disappeared.

The comparison of the angle of attack and the dynamic lateral force of the no alignment variation case and the no alignment/no surface variation case indicated that the surface deviation at the event location was not a necessary trigger for the unusually high dynamic responses, and therefore contributed little to the derailment.

Finally, a five-inch superelevation case (simulation case 6) was simulated for the articulated car. The same baseline case conditions were used, except that the measured superelevation of approximately six inches was replaced with the Standard Practice Circular's five-inch maximum superelevation. Both the angle of attack and the lateral forces of the five-inch superelevation case were almost identical with those of the measured track geometry baseline case with six-inch superelevation. The unusually high dynamic responses at the event location showed up in both cases. The point of loss of wheel/rail contact was reached a little earlier in the five-inch superelevation case.

The comparison of the angle of attack and the dynamic lateral force in the five-inch and six-inch simulation scenarios indicated that the six-inch superelevation was not an important contributing factor to the high dynamic responses at the event location. Although the six-inch superelevation was marked as an urgent defect, it was close to the balanced superelevation for the travel speed of 43 mph. Reducing the urgent defect for superelevation from six inches to five inches, which is within the safety limit, would have, in fact, resulted in a minor increase in the unusually high dynamic responses at the event location due to the induced one-inch unbalance. Although the urgent superelevation geometry defects in the vicinity of the identified POD exceeded the five-inch maximum, the higher superelevation would have better facilitated curving at 45 mph.

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[16] See TSB Engineering Laboratory report LP 129/2004 for graphic representations of the simulated events

Simulation Case 7: Wheel Conicity

As rail cars negotiate a curve, frictional curving forces increase the truck assembly's tendency to steer towards the outside of the curve. This steering action skews the truck, causing the wheel on the high side of the leading axle and the wheel on the low side of the trailing axle to wedge against the high and low rails. This wedging effect forces the rails apart, producing wide gauge and rail cant.

The unusually high dynamic responses of the leading truck at the event location were achieved with the condition of low conicity, consistent with newer wheels. Newer wheels were considered in the baseline scenario as the repair and service records of car DTTX 750218 indicated that the wheels had been changed recently and should have had nearly new wheel profiles. Under a high conicity (worn wheel) scenario, the unusually high dynamic response at the event location disappeared. Both the angle of attack and the lateral forces for the high conicity wheel case were smaller than those of the low conicity baseline case respectively.

Simulation Case 8: Rail Lubrication

Frictional forces in curve negotiation increase sharply as the curvature increases. This is especially true on rails with inadequate lubrication. Lubrication on the high rail reduces the risk of wheel climb on the high rail. In addition, moderate lubrication on the low rail reduces gauge-widening forces.

In this occurrence, rail lubricators were located at Mile 185.5 to the north of the event location and at Mile 180.0 to the south. The north lubricator, which was closest to the POD, was positioned to provide lubrication to the high rail in the derailment curve. However, the evidence indicates that there was no rail lubrication through the derailment area. A rail gauge face lubrication case was simulated for the articulated car under the same conditions as in the baseline case, except that the friction between the wheel flange and rail gauge face was reduced to represent a lubricated rail gauge condition. The simulated results from the rail gauge face lubrication case were plotted and compared with those of the baseline.

Both the angle of attack and the lateral forces of the rail gauge face lubrication case were smaller than those of the dry friction baseline case. More importantly, in the case of a lubricated rail gauge face, the unusually high dynamic responses at the event location disappeared. The angle of attack and the dynamic lateral force in the rail gauge face lubrication case remained within a small range along the curve. This indicates that the dry friction between the wheel flange and the rail gauge face was a necessary condition for the unusually high dynamic responses.

Simulation Case 9: Track Fasteners

A scenario based on using conventional spikes on both rails was simulated for the articulated car under the same conditions as in the baseline case. In this situation, the lateral stiffness was reduced by approximately 50 per cent and the damping ratio was also changed accordingly. The simulated results from spikes on both rails case were plotted and compared with those of the baseline case.

Both the angle of attack and the lateral forces in the spikes on both rails case were smaller than those for the elastic fasteners on the high rail baseline case. More importantly, with spikes on both rails, the unusually high dynamic responses at the event location disappeared. The angle of attack and the dynamic lateral force remained within the normal range along the curve. Therefore, stiffer elastic fastening on the high rail was a necessary condition for the unusually high dynamic responses.

Appendix B – List of Supporting Reports

The following TSB Engineering Laboratory reports were completed:

LP 105/2004 – Rail Analysis
LP 129/2004 - Train Dynamics Analysis

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

Appendix C – Glossary

ALERT	Advanced Locomotive Engineer Refresher Training
CLO	conductor locomotive engineer
CN	Canadian National
CPR	Canadian Pacific Railway
CROR	*Canadian Rail Operating Rules*
CTC	Centralized Traffic Control System
ES	end spiral
km	kilometres
LER	locomotive event recorder
L/V	lateral/vertical
m	metres
mph	miles per hour
MGT	million gross tons
mm	millimetres
NRC	National Research Council
POD	point of derailment
REQSR	*Railway Employee Qualification Standards Regulations*
RSA	Rail Safety Advisory
RTC	rail traffic controller
SPC	Standard Practice Circular
SS	start spiral
TC	Transport Canada
TEST	track evaluation system
TSB	Transportation Safety Board of Canada
TSR	*Railway Track Safety Rules*
UDE	undesired emergency brake application
WRP31	Warp 31 spiral – difference in cross-level between any two points 31 feet apart in spirals
WRP62SPR	Warp 62 spiral – difference in cross-level between any two points less than 62 feet apart on spirals
°C	degrees Celsius