Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

RAILWAY INVESTIGATION REPORT
R07T0110

MAIN-TRACK DERAILMENT

CANADIAN NATIONAL
TRAIN M36321-26
MILE 264.94, KINGSTON SUBDIVISION
COBOURG, ONTARIO
28 APRIL 2007

Canada

Railway Investigation Report

Main-Track Derailment

Canadian National
Train M36321-26
Mile 264.94, Kingston Subdivision
Cobourg, Ontario
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Report Number R07T0110

Summary

At approximately 1044 eastern daylight time on 28 April 2007, westward Canadian National freight train M36321-26, travelling at 46 mph, experienced a train-initiated emergency brake application and derailed at Mile 264.94 of Canadian National's Kingston Subdivision in Cobourg, Ontario. A Herzog track maintenance machine and 21 empty multi-level cars derailed. During the derailment, the fuel tank on the Herzog multi-purpose maintenance-of-way power unit was punctured, spilling approximately 9084 litres (2400 gallons) of diesel fuel. The fuel ignited, setting fire to approximately 1000 feet of track structure, including the Burnham Street level crossing. The local fire department responded and extinguished the fire. There were no injuries.

Ce rapport est également disponible en français.

Other Factual Information

On 28 April 2007, at 0440 eastern daylight time, [1] Canadian National (CN) freight train M36321-26 (train 363) arrived at Belleville, Ontario, destined for Toronto, Ontario. A crew change was made, and the empty Herzog multi-purpose maintenance-of-way equipment (Herzog machine), composed of a 430-foot articulated flat/gondola car combination (HZGX1750) and a Herzog locomotive (HZGX175), was marshalled at the head end of the train behind three high-capacity dynamic brake (DB) locomotives [2] and ahead of 45 empty multi-level cars. Before placing the Herzog machine in train 363, the conductor sought direction for marshalling this equipment. The only General Operating Instruction restriction deemed relevant required the Herzog machine to be marshalled within 2000 feet of the head end, where the crew could monitor it.

The remainder of the train contained a mix of 83 empty and loaded cars (see Appendix A). The train weighed approximately 9000 tons and was 9602 feet long. 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.

The train departed Belleville at approximately 0930 and proceeded westward on the north main track of the Kingston Subdivision (see Figure 1). Train speed was controlled using the throttle and DB, as per normal train handling practices. The journey to Cobourg, Ontario, was uneventful.

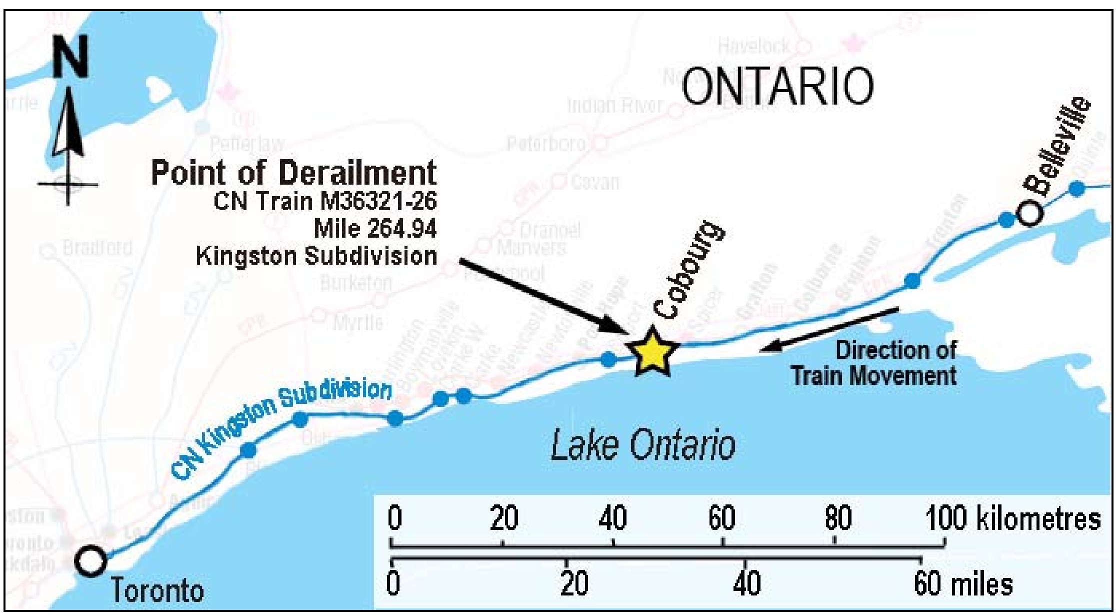

Figure 1. Derailment location (Source: Railway Association of Canada, *Canadian Railway Atlas*)

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

2 One General Electric ES44DC locomotive and two General Electric Dash 9-44CW locomotives

Entering Cobourg, the train was in full throttle (position 8), proceeding at 49 mph. No braking had occurred for over 7 ½ minutes. Then, over an 18-second period, the throttle was stepped down from position 8 to idle. Eight seconds later, the DB was activated in preparation for an anticipated restricting signal at Mile 264.45 (Cobourg West). The braking effort began to take hold as the train entered a 1.19-degree right-hand curve on a 0.35 per cent descending grade approaching the Burnham Street level crossing.

As the lead locomotive occupied the crossing, the train surged. The dynamic braking effort was immediately reduced. Thirteen seconds later, there was a train-initiated undesired emergency brake application (UDE).

As the train derailed, the fuel tank on HZGX175 (eight car bodies behind the operating locomotives) was punctured, spilling approximately 9084 litres (2400 gallons) of diesel fuel onto the track structure. The fuel ignited, setting fire to the Herzog locomotive and the track structure.

The crew members followed emergency procedures to bring the train to a controlled stop and to advise the rail traffic controller (RTC) of their status. The lead locomotive came to rest approximately 1000 feet west of the crossing.

The conductor detrained and attempted to extinguish the fire on HZGX175. Shortly thereafter, local fire crews arrived to put out the fire. There were no injuries.

Site Examination

The head end of the train came to rest at Mile 265.27. The three locomotives and the first six articulated car bodies of HZGX1750 (units B, G, F, E, D, and C in order) were not derailed. The trailing truck of car body HZGX1750A was derailed upright, as was HZGX175, the Herzog locomotive in a cab-trailing configuration. The Herzog locomotive was connected to HZGX1750A by a fixed non-standard coupler arrangement (see Photos 1a and 1b). The coupler arrangement was composed of a fabricated drawbar connector with orbital joint castings at both ends, 45 ¾ inches from centre to centre of the orbital joints, and a matching "U"–shaped connector that mounts inside the draft sill and is pin-connected to the yoke of each car. [3] Side plates restricted the side-to-side movement of the drawbar to roughly 30 degrees.

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[3] S. Landrum, P.E., Report No. HR065-080406, *Drawbar Evaluation*, prepared for Herzog Contracting Company, Transportation Technology Services, Southlake, Texas, United States, 16 August 2006.

Photo 1a. Non-standard coupling system between car HZGX1750A on the left and car HZGX175 (the Herzog locomotive) on the right

Photo 1b. Close-up of orbital joint showing fresh strike mark from lateral movement to limits

The leading truck of the Herzog locomotive came to rest upright with all wheel sets straddling the south rail. The drawbar between the two cars had swung sharply to its limits during the derailment, producing matching fresh strike marks on the drawbar and restricting side plates of the “U”–shaped connector.

The bottom of the leading L4 truck pedestal (north side), and the attached bottom support plate, brake beam slider and bolt, were missing. The safety strap, which provides support in the event the spring assembly fails, was bent and fractured in two places. The bottom spring plank, which was twisted and fractured, was driven into the bottom of the fuel tank, where it became lodged (see Photo 2). There was a deep impact mark on the side of the spring plank, and a longitudinal tear on the bottom of the fuel tank.

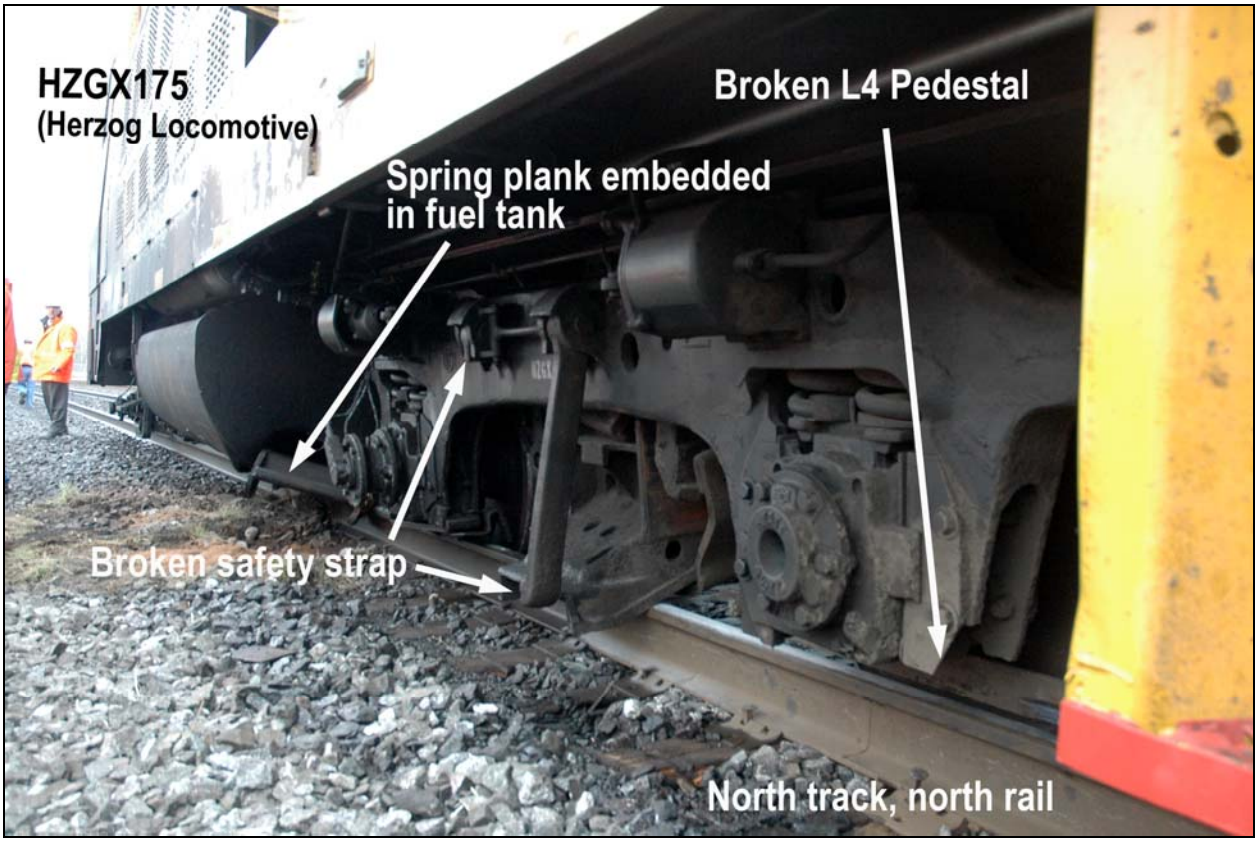

Photo 2. Damage to north side of HZGX175 (Herzog locomotive)

From the Herzog locomotive, there was an approximate 350-foot gap back to the remaining derailed cars east of the Burnham Street crossing (see Photo 3). The first two cars were lying end to end on their sides, rolled to the north of the track. The next 17 cars were jackknifed, stacked side to side, perpendicular across the entire right-of-way, blocking both main tracks. The final three derailed car bodies were upright, parallel to the right-of-way.

Track damage, including wheel flange marks, extended from the derailed Herzog machine back to the most westerly (the 5th) jackknifed car east of the crossing (for a total of approximately 1000 feet). The track structure had fire damage throughout. East of the crossing, the south rail (high rail) was rolled out to the field side and the low rail remained fixed and upright under the derailed cars. Under the jackknifed cars (between the 5th and the 21st derailed car), the north track and portions of the south track were destroyed.

Photo 3. Aerial view of derailment site looking west (Source: Canadian National)

In Photo 4, the aerial view of the derailed cars depicts a piece of rail pinned under the east end of car TTGX941885, with the east-facing end of the north rail elevated. The missing pedestal, bottom plate and brake beam slider from locomotive HZGX175 were found as one piece embedded into the slope on the north side near where the leading truck of car TTGX978605 came to rest.

Photo 4. Aerial view of derailed rolling stock looking west (Source: Canadian National)

TSB Engineering Laboratory specialists were dispatched to the accident site. A thorough examination of the Herzog unit was conducted. Fracture surfaces from the R4 pedestal, as well as a portion of the spring plank, and rail from the vicinity of the point of derailment were secured and sent to the TSB Engineering Laboratory for analysis.

Recorded Information

The lead locomotive, CN 2252, was a General Electric ES44DC, equipped with an advanced locomotive event recorder (LER) and updated instrumentation. This instrumentation displays dynamic braking effort as tractive effort (TE). TE is defined as the amount of braking resistance exerted at the wheel/track interface in kilo-pound-feet. However, given that the relationship between TE and amperage (that is, dynamic braking effort) is non-linear, the speed of the train must be considered, as illustrated in the table of LER data that follows.

Time	Mile Post (CN 2552)	Speed (mph)	DB Position	TE per locomotive (kilo-pound-feet)	DB Amperage
1043:29	264.40	49	activated	0	
1043:35	264.49	49	Position 2	0	
1043:56	264.77	45		26	715
1044:06	264.89	44	Position 8	33	815 [4]
1044:10	264.94	43	Position 8	45	920 – maximum retarding force
1044:16	265.01	44	Position 6	37	850 [4]
1044:17	265.03	45	Position 3	26	715
1044:18	265.04	46	Position 4	17	570 [4]
1044:24	265.11	44	Position 6	26	715 amperes – head end in emergency
1044:27	265.15	37	Position 8	37	tail end in emergency
1044:50	265.27	0	Position 8	0	stopped

The LER data indicated that:

- At 1043:56, braking commenced. In excess of 700 amperes (A) of dynamic braking was being applied by each locomotive.
- Fourteen seconds later, at 1044:10, with the head end of the train already into the 1.19-degree right-hand curve, maximum retarding force was reached.
- Between 1044:16 and 1044:18, there was a sudden acceleration of the train, resulting in a speed increase of 2 mph.
- While the acceleration was occurring, the locomotive engineer reduced dynamic braking to 45 per cent.
- At 1044:24, when HZGX1750A and HZGX175 were in the vicinity of Mile 264.94, a train line emergency occurred, initiating the emergency braking event.
- At 1044:27, the automated end-of-train braking system was activated.
- At 1044:34, the locomotive engineer bailed off the locomotive independent brake.
- The train came to a stop 16 seconds later at Mile 265.27.

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[4] Values are interpolated from LER data

Kingston Subdivision

The CN Kingston Subdivision consists of double main track, extending from Montréal, Quebec, to Toronto. It is a main corridor for passenger and freight traffic, including dangerous goods. The maximum permissible track speed is 100 mph for passenger trains and 65 mph for freight trains. Train movements are controlled by the Centralized Traffic Control System (CTC), authorized by the *Canadian Rail Operating Rules* and supervised by an RTC located in Toronto.

Track Information

In the derailment area, the track consisted of 136 RE rail, hardwood ties and crushed granite and slag ballast. The ballast was in good condition with 12-inch shoulders. The rail was fastened on 14-inch double-shouldered tie plates with six spikes to No. 1 hardwood ties. The rail was box-anchored every second tie with a mixture of Fair and Wooding anchors.

The north main track was last inspected by the Sperry car on 12 April 2007, and CN's TEST car on 30 March 2007. A number of sub-urgent and urgent cross-level, warp and wide gauge defects were identified in the vicinity of the derailment. Three days before the derailment (25 April 2007), track maintenance activities had been undertaken to address these track geometry issues. The necessary procedures to stabilize the track structure after the track maintenance and before the removal of speed restrictions were followed. The track was last inspected 26 April 2007 by hi-rail vehicle. No exceptions were noted.

Herzog Machine

The Herzog machine is a customized 495-foot maintenance-of-way machine designed for self-propelled operation at up to 50 mph (see Photo 5). In work mode, the machine is operated using a portable remote control device that can be mounted in the control cab at either end, or carried by the operator.

Photo 5. Herzog articulated maintenance-of-way machine

At one end is a flat car with an operator cab and space for storing a high-hoe, mounted on rails. Shared articulated trucks connect the flat car and six gondola car bodies, and together, these seven car bodies are identified as car HZGX1750. This car is in turn connected to a locomotive (HZGX175). When in work mode, rails on top of the gondola cars are connected so the hoe can travel the length of HZGX1750. The locomotive provides motive power to the Herzog machine. The Herzog machine was placed in train 363 with the locomotive in the trailing position. The machine was en route from Kingston, Ontario, and due to arrive in Hornepayne, Ontario, two days later.

Train Handling Procedures

CN train handling procedures are set out in its *Locomotive Engineer Operating Manual* – Form 8960, Section G, Train Handling. This document includes the following:

G1: Train Handling Policy

- Locomotive engineers should have a thorough knowledge of the physical characteristics of the territory they will be operating and use this knowledge and good judgement to ensure proper train handling techniques.

- Locomotive engineers must utilize "forward planning" in consideration of territory profiles, planned stops, required speed adjustments and slack control, avoiding aggressive use of the locomotive throttle and train braking systems.

- Throttle manipulation must be used as the primary means of controlling the train.

- Dynamic brake must be fully utilized as the initial braking force.

In section G1.1, Locomotive Consist, the manual describes the effect of adding locomotives to a consist. The section indicates that "As the number of locomotives increases, so does the tractive effort, dynamic braking force and weight. Extra caution is required." The section also notes that the locomotive's loadmeter measures the amount of current in amperes being applied to the traction motors for only that unit, not the sum total of current being applied to all operating locomotives in the consist.

Use of Dynamic Braking in Train Operations

The three locomotives powering train 363 were high-capacity DB locomotives. According to Section F of the CN *Locomotive Engineer Operating Manual* – Form 8960 (January 2005):

> The DB controller should be moved through the operating range slowly and smoothly, monitoring the loadmeter to prevent high compression or buff forces throughout the train. The loadmeter indicates the amount of dynamic brake current and is an indication of DB force.
>
> Excessive buff forces may result in a derailment or gradual deterioration of the track structure, particularly if the forces occur at a turnout, crossover, point of sharp curvature or other type track irregularity.
>
> To avoid train handling problems, the following DB restrictions must be adhered to:
>
> * 1 or 2 locomotives in a consist: No DB restrictions.
> * 3 or more locomotives in a consist: DB usage restricted to a maximum of 500 Amps when the head-end is entering a turnout, crossover or curve, until at least half the train has passed through. (Section 7.3).

Further, in Section 1.2.1, Jackknifing, operators are instructed to:

> . . . exercise "extreme caution . . . when making bunched stops or decreasing speed giving due consideration to grade, curvature and weight distribution of the train consist."

and to

> . . . exercise "care" when using the . . . dynamic brake without train air brakes to effect a slow down or stops, particularly when three or more locomotives in the consist. These cautions are particularly important when . . . the cars next to or near the locomotive are empty cars or a combination of short and long cars.

Section G7, Train Makeup, states that a string of empty cars situated ahead of a number of loaded cars, particularly on a long train, can cause train handling difficulties. Problematic circumstances discussed include the use of excessive DB in curved or undulating territory, and the coupling of long, empty cars (especially if followed by heavy trailing tonnage).

In Section G8.1, Train Speed Control With DB Only, the manual instructs:

> . . . when the train has both empties or light loads at the head-end, and heavy loads on the rear-end, a harsh bunching of slack or run-in combined with track curvature can cause very high lateral forces and/or cause derailment or damage to the track structure.

In 1979, the Association of American Railroads (AAR) produced a set of guidelines for train operation. [5] Section 4.6.2 of the AAR Research Reference R-185 (November 1979) [6] states:

> If possible, avoid heavy braking forces when trains are being slowed or stopped, especially on curves, since the resulting longitudinal and lateral forces may be of sufficient magnitude to cause track shift, wheel climb or rail turnover.

Locomotives acquired by CN before 2005 display dynamic braking in amperage (see Photo 6a). Locomotives purchased after 2005 display dynamic braking effort as tractive effort (see Photo 6b). At the time of this occurrence, the lead locomotive did not carry an English version of the operating manual to explain the operator interface or the LER recorder functions, although copies of the manual were available at the crew office in Belleville.

Photo 6a. Analog loadmeter display

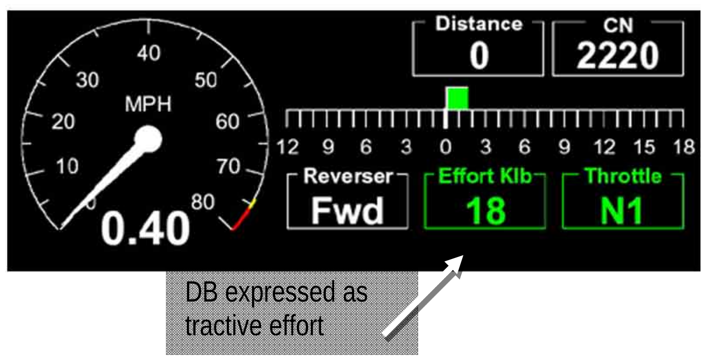

Photo 6b. Digital tractive effort display in locomotives purchased 2005 and later

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5 AAR Research Reference R-185, *Track Train Dynamics Report to Improve Freight Train Performance*, "TTD Guidelines for Optimum Train Handling, Train Makeup, and Track Considerations," November 1979

6 AAR Research Reference R-185, *Track Train Dynamics Report to Improve Freight Train Performance*, "TTD Guidelines for Optimum Train Handling, Train Makeup, and Track Considerations," November 1979

As early as 2001, CN locomotive engineers were advised of the concept that tractive effort or dynamic braking retarding force could be expressed in terms of pounds of force on some locomotives, [7] and on request, crews operating the newer locomotives had been provided a document entitled *New Load Meter - GE ES44DC Locomotives CN 2220 - 2254*. The document includes a table that aids in understanding the relationship between tractive effort and traction motor load amperage. [8] However, the crew members of train 363 were not in possession of this document.

The locomotive engineer last received training in DB operation in 2003. The locomotive engineer also received specific training on distributed power in a one-day course on 12 December 2006 where the DB function of the new locomotives was discussed. The current *Locomotive Engineer Operating Manual* makes no reference to locomotives that display dynamic braking effort as tractive effort.

Train Marshalling at Canadian National

CN uses a computerized system for train service design. This system is designed to recognize train marshalling conflicts that are in violation of CN's General Operating Instructions (GOIs). Within the GOIs regarding marshalling, there are no constraints on tonnage distribution within the train. Therefore, CN's train design planning system does not take weight distribution within the train into consideration when the train service plan is produced. In comparison, other Canadian railway companies require that freight trains be made up, to the maximum extent practicable and subject to destination blocking, with the loads marshalled closest to the locomotives to reduce the probability of undesirable track/train dynamics occurrences.

Marshalling of Potentially Troublesome Equipment

AAR Research Reference R-185, Section 3.9, Special Type and Potentially Troublesome Equipment, specifies (in part):

> Many specific cars and special loads require special handling due to the design of the equipment, the lading on the cars or the configuration of a series of these cars. Equipment which is recognized as potentially troublesome should be analysed dynamically, considering the loading of the car, the location of the car within the train and the physical features of the track to be traversed.

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7 Operating Bulletin GLD 1101 dated 27 August 2001 limits tractive effort or dynamic braking approaching any bridge structure to 100 000 pounds per locomotive. This restriction, applied to foreign AC locomotives, is now carried as Item F7.4 of the *Locomotive Engineer Operating Manual*.

8 The document was distributed to CN Engine Service officers on 01 May 2006. However, it was not widely distributed to locomotive engineers on the CN Great Lakes District until March 2007, at which time copies were sent to terminals (including Belleville) across the District and were made available to locomotive engineers.

The Herzog machine is a custom machine designed to automate specific maintenance-of-way activities. These machines can be marshalled in train consists to facilitate movement between operating regions. [9] CN's GOIs, while addressing the marshalling of some specialized equipment, do not have any specific instructions for the marshalling of this machine.

Other Class 1 railways that operate the Herzog machine have directives in their operating instructions that restrict the marshalling of the Herzog machine to the tail end of trains.

Marshalling of Empty Cars on the Kingston Subdivision

In April 2006, the TSB issued Rail Safety Advisory (RSA) 02/06, *Marshalling of Long Merchandise Trains on CN's Kingston Subdivision,* following a derailment on the Kingston Subdivision. The safety advisory stated that:

> In consideration of the safety critical nature of the presence of excessive in-train forces, the expanding use of long, heavy merchandise trains on CN's Kingston Subdivision, and the potential risk to public safety of a derailment on the Montreal – Toronto corridor, Transport Canada may wish to review CN's procedures for marshalling general merchandise trains on the Kingston Subdivision.

In discussions with Transport Canada after the release of RSA 02/06, CN reported that it had in place an unwritten company practice that requires trains carrying in excess of 25 empty multi-level cars in a block, or any block of 25 empty flat cars, to marshal the block of empty cars at the tail end of the train. Although this restriction is specific to the Kingston Subdivision, there is no record of a formal risk assessment to validate the safety benefits of this practice, or to document the railway's level of compliance to the practice. Train 363 had 45 empty multi-level cars in a block near the head end.

Except for the unwritten company practice, CN instructions for marshalling general merchandise trains for the Kingston Subdivision are silent on the issue of tonnage distribution and train length.

Related Occurrences

This occurrence was the second recent CN derailment involving the same Herzog machine marshalled immediately behind the locomotives. A previous accident occurred on 27 May 2006 near Armstrong, Ontario. CN freight train M30041-26 derailed the same first car body (HZGX1750A) during a routine stop. The CN incident/accident report identified train make-up as a contributing factor. The Armstrong derailment was categorized as high priority and CN's incident/accident report indicated that corrective action would be taken.

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[9] T. Judge, Editor, "Choosing the Best M/W Machine," *Railway Track and Structures*, August 2006, pp. 21-22 and 43.

The TSB has investigated several occurrences involving high in-train buff force levels on long trains, made up in empties-ahead/loads-behind or loads/empties/loads configurations (including R01M0061 and R02W0060).

Association of American Railroads Requirements for the Testing and Certification of Rail Cars

AAR's *Manual of Standards and Recommended Practices*, Section C, Part II, Specifications for Design, Fabrication and Construction of Freight Cars, M-1001, Chapter II, paragraph 2.1.6, specifies that rail cars should produce a lateral/vertical (L/V) ratio (that is, the ratio of lateral force over vertical force) of less than 0.82 under a pull force of 200 000 pound-force when on a 10-degree curve. However, in the AAR guideline, there is no requirement to check the L/V ratio under buff conditions (that is, the jackknife scenario).

The Herzog machine had been independently tested against AAR design standards and was determined to be in compliance. The independent test report noted that the calculations were based on a drawbar pull, not a compressive force. For the jackknife scenario (that is, a compressive force with the train on a 10-degree curve), it would take 336 000 pound-force to exceed an L/V ratio of 0.82.

Although compliant with AAR requirement M-1001, paragraph 2.1.6, the non-standard coupler on the Herzog machine permits a drawbar angle exceeding 30 degrees. Such angles accentuate lateral coupler forces during the run-in of train slack, even under moderate buff forces and on tangent track. Coupler angularity was identified as a causal factor in two recent derailments involving locomotives not equipped with alignment control couplers (that is, R05C0082 and R02C0050).

Canadian National Accident Investigation Protocol

For major derailment events, CN has implemented a rapid response protocol to accelerate accident site response and to minimize service disruption. This rapid response protocol includes the 24/7 strategic placement of contracted personnel and heavy equipment, and the development and training of staff and other agency personnel (including nearby communities) in a structured incident command protocol. This approach has dramatically improved the speed at which accident site rehabilitation work is completed.

CN has a corporate process for accident and incident reporting, investigation and analysis. This process is documented in the company's *Injury/Accident Investigation Standard* and *Guidelines for Reporting Accidents and Injuries.* In addition, the process for tracking, follow-up, and evaluation of corrective action related to injuries/accidents is outlined in CN's *Corrective Action/Safety Measure Management Standard*. Local or regional supervisors and management are responsible for entering data into the company's tracking and reporting system (called SAP) and regional and corporate risk management groups are responsible for monitoring the system data and performing data quality checks.

TSB Engineering Laboratory Analysis

Rail specimens from the derailment site and equipment components from the Herzog machine were collected and sent to the TSB Engineering Laboratory for analysis (TSB Engineering Report LP 042/2007, available upon request). Based on laboratory analysis, the following was determined:

- The fracture mode for the rail specimens was through overstress rupture. There was no evidence of a progressive failure. The hardness and microstructure for the rail specimens were typical for this type of rail. No material anomaly was found.

- The pedestal from the Herzog power unit fractured in overstress from a direct impact to the bottom, inboard corner. The two mating fracture surfaces on the pedestal were overstress in nature and showed no signs of progressive failure. No material anomaly was found.

- The spring plank from the Herzog power unit was torn from its support by an impact with a foreign object. The profile of the impact mark matches the rail head profile of the sample rail pieces collected at the site (see Photos 7a and 7b).

Photo 7a.

Photo 7b.

Portion of the spring plank leading surface showing impact mark in relation to the profile of sample rail seized from the derailment site

Based on site measurements and train data, an analysis of L/V forces was conducted for the likely first equipment to derail (that is, HZGX1750A (empty gondola) and HZGX175 (Herzog locomotive)). This equipment was connected by a non-standard coupler that permits a maximum drawbar angle exceeding 30 degrees. The results of these calculations (see Appendix B) indicate:

- In this derailment, in-train buff force was excessive, as defined by the operator for normal train operating conditions, and exceeded the sustainable limit of the Herzog unit. The large drawbar angle at the Herzog empty car transformed the in-train buff force into an excessive lateral force, which resulted in the derailment.

- The maximum permissible drawbar angle at car HZGX1750A was 37.3 degrees. At this angle, with a dynamic braking force of 135 000 pounds, the truck side L/V ratio for the trailing truck on HZGX1750A was 4.51 (rebuilt even height case), more than five times the derailment criteria. Even in the normal designed condition, the truck side L/V ratio would have reached 3.10, well in excess of derailment criteria. The truck side L/V ratio for the leading truck on HZGX175, the Herzog locomotive, was in the range of 0.59 to 1.06.

The truck side L/V ratio for the trailing truck on HZGX1750A was large enough to enable wheel lift/rail rollover to the low side and for the leading truck of HZGX175 to cant the high rail. Given the high truck side L/V ratio for HZGX1750A, the trailing truck of HZGX1750A likely derailed first, releasing the constraint on drawbar angle at the locomotive end and permitting the drawbar angle to continue to enlarge. The transformed lateral force almost simultaneously canted out and rolled the high rail under the leading truck of HZGX175.

Analysis

Introduction

Before the occurrence, track issues in the vicinity of the derailment had been identified and addressed in a timely manner. Consequently, track conditions, inspections, and maintenance were not considered contributory to the derailment. The analysis will address the role of the equipment in the derailment sequence. Specifically, it will focus on train marshalling, use of dynamic brake, and equipment design.

The Accident

The point of derailment (POD) was in the vicinity of Mile 264.94. Wheel marks on the track structure extended westward from this location to where the Herzog machine came to rest. These marks, combined with damage to the crossing structure, indicate that the trailing truck of HZGX1750A derailed to the low (north) side of the right-hand curve and the leading truck of HZGX175 derailed to the high (south) side. The derailed equipment continued in this position from the POD to their final resting place approximately 350 feet west of the crossing.

The POD coincided with a run-in of train slack during an excessive dynamic braking event. The run-in acted on the non-standard coupler arrangement between HZGX1750 and HZGX175. The coupler, which permits a drawbar angle exceeding 30 degrees, helped magnify the translated lateral drawbar force, leading to a lateral force sufficient to produce a high L/V ratio. Consequently, with the excessive lateral forces acting on HZGX1750A, an empty car, the trailing truck of this car lifted and derailed to the low side as it entered the 1.19-degree right-hand curve.

Once HZGX1750A derailed to the inside of the curve, track structure constraints on the drawbar angle were removed, allowing the drawbar to swing to its maximum limits. This condition further increased the magnitude of the lateral forces. These forces caused the leading truck on the Herzog locomotive to push to the high side of the curve, cant and roll the high rail, and drop into gauge on the low side.

Although there was an unwritten CN train marshalling practice for the Kingston Subdivision, train 363 was marshalled with 45 empty multi-level cars along with the Herzog machine at the head end. When an excessive and rapid application of dynamic braking occurred as train 363 entered the curve at Mile 264.94, the longitudinal forces produced during the braking action, exacerbated by the train's empties-before-loads configuration, caused a run-in of train slack at the head end of the train.

Based on AAR's train handling guidelines, the non-standard coupler system between the power unit (HGZX175) and the first gondola car body (HZGX1750A) can be described as potentially troublesome. Other Class 1 railways have operating instructions that limit the placement of the Herzog machine to the tail end of trains. Although CN had experienced a similar derailment of the same Herzog equipment 11 months earlier, an incident considered high priority by CN, the problematic nature of the Herzog machine's coupler arrangement was not documented nor addressed in CN's operating instructions. When the conductor of train 363 sought direction for marshalling the Herzog machine before departing Belleville, the only GOI restrictions applicable required the Herzog machine to be marshalled within 2000 feet of the head end, where the crew could monitor it. Consequently, it was marshalled directly behind the locomotives. The placement of the Herzog machine directly behind the locomotives, where in-train forces are the greatest, increased the magnitude of lateral forces translated laterally through the non-standard coupler arrangement.

Testing of Non-Standard Couplers Under Buff Conditions

The Herzog machine's non-standard coupler was independently tested and certified to be in compliance with AAR requirements (that is, L/V ratio is less than 0.82 on a 10-degree curve under a pull force of 200 000 pound-force). However, these requirements only address rail car behaviour under draft conditions. In this derailment, the Herzog machine could not safely negotiate a 1.19-degree curve under a buff force of only 135 000 pound-force. During normal train operation, when exclusively using dynamic braking to control the train, or during an emergency brake application, elevated buff forces will occur. In the absence of a requirement for testing non-standard couplers under buff force conditions before being permitted to be marshalled on a train, cars with couplers not designed to withstand buff force conditions will continue to be placed in train consists without appropriate restrictions where they may exceed track structure constraining abilities.

Restrictions on the Marshalling of Specialized Equipment

The Herzog machine, with its non-standard coupler system, is often marshalled into a larger train consist for shipment from one region to another. In May 2006, the same truck on the Herzog machine, marshalled at the head end behind the train's locomotive power, derailed in a curve under braking in Armstrong. CN classified its internal accident investigation as high priority. In CN's investigation, train handling and marshalling were identified as causal factors. Following this occurrence, operating crews were coached on proper train handling technique. However, even though other Class 1 railways had experienced similar problems and had implemented restrictions that limit the marshalling of the Herzog machine to the tail end of train consists, no changes were made to CN's operating instructions for this machine. In this situation, CN's GOIs did not keep pace with the introduction of this specialized equipment into its operations. When this type of situation occurs, there is an increased likelihood that equipment will be marshalled into a train consist without appropriate restrictions, compromising safe railway operation.

Changes in Locomotive Dynamic Brake Displays

The lead locomotive (CN 2252) was brought into service with an updated operator console that displays dynamic braking as "tractive effort" (TE). However, at the time of this occurrence, CN's locomotive operating instructions and older locomotives referred to dynamic braking application and displayed dynamic braking in "amperage." The relationship between TE and amperage is not linear and can be misleading. For example, at 45 mph, amperage limits per locomotive (as set out in the *Locomotive Engineer Operating Manual*) are already exceeded when less than 50 per cent of the maximum TE is applied.

While locomotive engineers were provided training on the new locomotives in December 2006 as part of a one-day distributed power course, crews reported continuing difficulty understanding the relationship between TE and amperage. In instances where locomotive instrumentation displays dynamic braking effort in a manner inconsistent with operating instructions, there is an elevated risk that the locomotive engineer will apply an incorrect amount of dynamic braking effort to control the train during normal operations.

Overstress Failure of Herzog Locomotive Components During Derailment

Site examination and the TSB Engineering Laboratory analysis determined that the overstress brittle failure of the Herzog locomotive components did not cause the derailment. Inspection of the damage determined that the pedestal and the spring plank were both struck by an object in the same longitudinal plane. In addition, the shape of the impact mark on the spring plank indicates that the striking object, although not recovered, was likely the broken end of the north rail. The Herzog locomotive, HZGX175, was already derailed when the north rail broke. The end of the broken rail then struck and damaged the components on the leading truck of HZGX175. The spring plank was then driven into the bottom of the HZGX175's fuel tank, leading to the release of diesel fuel.

Canadian National Accident Investigation Directives, Policies, and Procedures

CN has a corporate process for accident reporting, investigation and analysis, and a separate process for tracking follow-up and corrective action. However, the focus on the rapid resumption of service can result in processes that are neither consistent nor thorough with respect to accident cause finding.

At Armstrong, CN identified the derailment as a high priority event and determined the cause to be a combination of train handling and marshalling; however, CN records do not provide root cause analysis as to what aspects of train handling or train marshalling contributed to the derailment. The operating crew was provided with coaching on train handling, but no action was taken on the marshalling of the Herzog machine. Therefore, despite a recent derailment under similar circumstances, the Herzog machine was allowed to be marshalled on train 363 without additional restrictions to address the equipment's behaviour under buff force conditions.

Findings as to Causes and Contributing Factors

1. The derailment occurred when excessive lateral forces acting on the trailing truck of car HZGX1750A caused the car to lift and derail to the low side as it entered a 1.19-degree curve. The lateral forces further caused the leading truck on the Herzog locomotive to push to the high side of the curve, roll the high rail, and drop in on the low side.

2. The excessive lateral forces were produced when longitudinal forces were translated through a non-standard coupler arrangement between HZGX1750A and the Herzog locomotive.

3. The placement of the Herzog machine directly behind train 363's locomotives, where in-train forces were the greatest, increased the magnitude of lateral forces translated laterally through the non-standard coupler arrangement.

4. The longitudinal forces were produced during a rapid and excessive application of dynamic brake, and exacerbated by the train's empties-before-loads configuration, causing a run-in of train slack at the head end of the train.

Findings as to Risk

1. In the absence of a requirement for testing non-standard couplers under buff force conditions before they are permitted to be used on a train, rolling stock with couplers that can generate lateral forces exceeding track constraining capabilities will continue to be placed in service without appropriate restrictions, increasing the risk of a derailment under normal buff force conditions.

2. When General Operating Instructions do not keep pace with the introduction of specialized equipment, such as the Herzog machine, there is an increased risk that this type of equipment will be marshalled into a train consist without appropriate restrictions, compromising safe railway operation.

3. In instances where locomotive instrumentation in the cab displays dynamic braking effort in a manner inconsistent with existing operating instructions, there is an elevated risk that a locomotive engineer will apply an incorrect amount of dynamic braking effort to control the train during normal operations.

Other Findings

1. The Herzog locomotive, HZGX175, was already derailed when the north rail broke. The end of the broken rail struck and damaged components on HZGX175's leading truck, and drove the spring plank into the bottom of its fuel tank, leading to the release of diesel fuel.

2. Despite a recent derailment under similar circumstances where Canadian National investigators were made aware of the unique coupler design of the Herzog machine, the machine was allowed to be marshalled in trains without additional restrictions.

Safety Action Taken

TSB Rail Safety Advisories and Rail Safety Information Letter

In August 2007, the TSB issued Rail Safety Information Letter (RSI) 14-07 and Rail Safety Advisories (RSA) 08-07 and 09-07.

- RSI 14-07 indicates that the Cobourg derailment occurred as train 363, an empties-before-loads configured train powered by three high-capacity dynamic brake (DB) locomotives, entered the 1.13-degree right-hand curve under full dynamic braking (that is, exceeding 900 amperes (A) per locomotive). The Canadian National (CN) *Locomotive Engineer Operating Manual* directs crews to limit the application of dynamic braking force to less than 500 A per locomotive when the head end is entering a turnout, crossover or curve for consists with three or more high-capacity DB locomotives. Excessive braking events on trains configured with empties before loads has been identified as a causal or contributing factor in a number of recent derailments.

- RSA 08-07 indicates that the Herzog equipment features a non-standard coupler design that permits a drawbar angle exceeding 30 degrees. Although this car was tested and determined to be compliant with Association of American Railroads (AAR) requirements (M-1001, paragraph 2.1.6), such coupler angles are known to accentuate lateral coupler forces during the run-in of train slack, even under moderate buff forces or on tangent track. The RSA identified that the Herzog equipment is considered potentially troublesome, and suggested that Transport Canada may wish to review the requirements for the analysis of potentially troublesome equipment to ensure that the associated risks are recognized and mitigated.

- RSA 09-07 indicates that, despite an unwritten CN operating practice that restricts the marshalling of more than 25 empty multi-level or flat cars at the head end of a train on the Kingston Subdivision, this train was marshalled with 45 empty multi-level cars at the head end, 21 of which derailed during this occurrence. The risks to safe railway operations presented by trains marshalled in a manner widely known to elevate in-train forces (for example, an empty-before-load configuration) should be understood and mitigated for that specific train. The RSA indicates that Transport Canada may wish to revisit CN's train marshalling practices on the Kingston Subdivision to determine whether these practices are consistent with safe railway operations and to intervene in whatever manner necessary to manage the risk for all trains.

Industry Safety Action

Following the derailment, CN took the following safety action:

- stopped handling the Herzog equipment in regular trains until specific handling instructions are developed by Herzog;
- ensured that the document providing information on dynamic braking effort measured in amperes versus tractive effort is provided to locomotive engineers as part of distributed power training; and
- issued a notice updating restrictions in the *Locomotive Engineering Operating Manual* to include a tractive effort limit in addition to the amperage limit.

Following the derailment, Herzog Contracting Corporation stencilled special handling instructions on all its multi-purpose machines (see Photo 8). The instructions indicate that this equipment should only be marshalled at the rear end of a train movement.

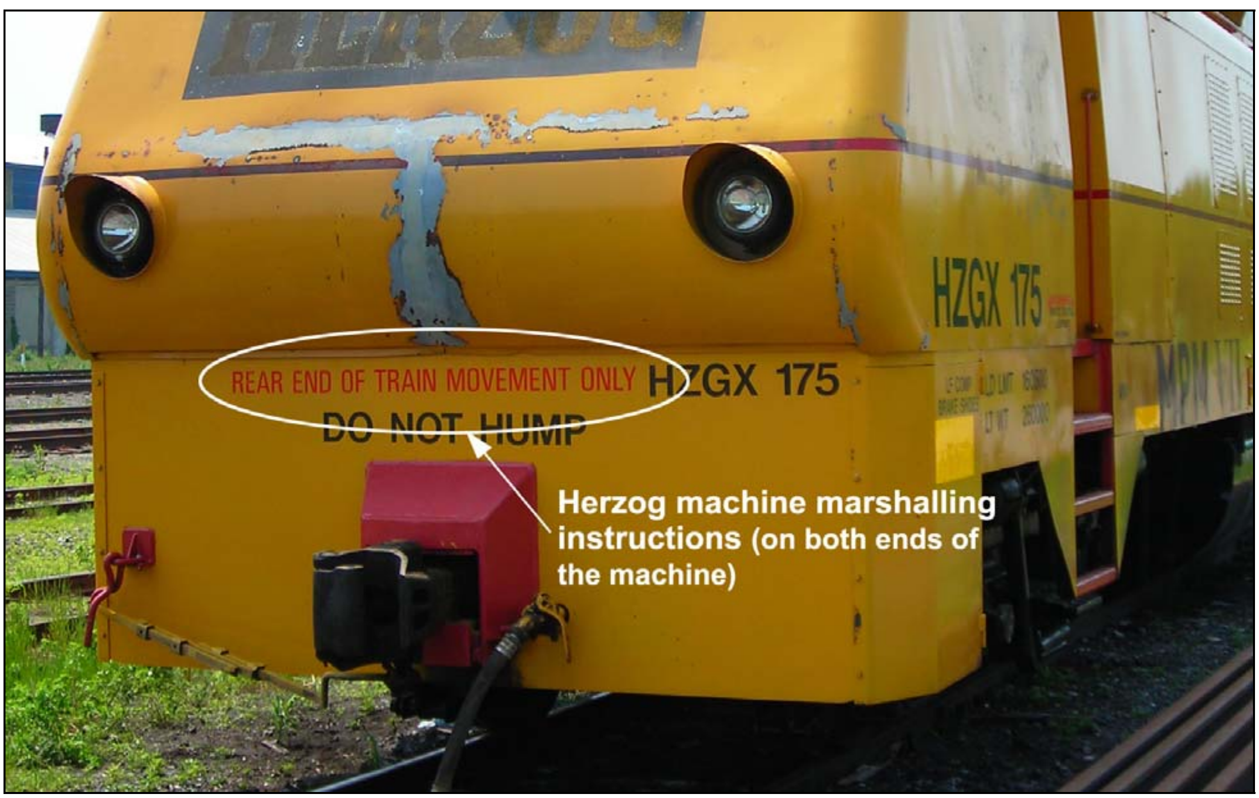

Photo 8. Herzog machine (locomotive HZGX175)

Regulator Safety Action

On 01 May 2007, Transport Canada Ontario Region met with CN senior managers to discuss recent main-track freight train derailments. CN confirmed with TC that it does not have internal instructions regarding trains marshalled in empties-before-loads configuration and indicated that it is working on a strategy to address its marshalling practices.

Transport Canada Ontario Region followed up and monitored CN's corrective actions during the months of June to August 2007. Transport Canada has verified that CN is no longer moving the Herzog equipment in revenue trains.

Safety Concerns

Buff Force Performance Standards for Rolling Stock

Since 2000, the Board has investigated three derailments (R07T0110, R05C0082 and R02C0050) involving rolling stock, which, while compliant with current AAR design standards, demonstrated behaviour during a buff force event that generated sufficient lateral coupler forces to cause a rail rollover or wheel lift derailment. While there are design standards to address car behaviour under draft forces, there are no similar performance standards for buff force events.

When cars are placed in trains without consideration for trailing tonnage, and then handled using DB and throttle as the primary means of train control, the generation of elevated in-train buff forces is inevitable. While these forces are normally insufficient to cause wheel lift or rail rollover in most rolling stock, these recent derailments demonstrate that elevated in-train buff forces can provoke derailment conditions when "potentially troublesome" cars are marshalled at the head end of a train.

Therefore, the Board remains concerned that, without buff force performance standards for rolling stock, cars with troublesome buff force behaviour will continue to be marshalled in trains without appropriate restrictions.

Train Marshalling and Tonnage Distribution

Although the Board is encouraged to learn that CN is working on a strategy to address its marshalling practices, train marshalling and tonnage distribution continues to be a causal or contributing factor in derailments.

For more than seven years, the Board has highlighted train marshalling as a significant rail safety issue. [10] In 2004, the Board recommended that "Transport Canada encourage 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"

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10 B. Tucker, "Trends In Transportation Safety – TSB Key Safety Issues," presented at the Canadian Transportation Research Forum, 02 November 2001

(Recommendation R04-01, issued April 2004). Transport Canada's response to this recommendation was assessed as fully satisfactory in 2005. However, it is becoming increasingly clear that encouragement to the railway industry may not sufficiently address this safety issue.

In 2006, the TSB raised the issue of tonnage distribution and train length in RSA 02/06, *Marshalling of Long Merchandise Trains on CN's Kingston Subdivision.* In response to this RSA, Transport Canada reported that CN had in place an unwritten company practice that requires trains carrying in excess of 25 empty multi-level cars in a block, or any block of 25 empty flat cars, to marshal the block of empty cars at the tail end of the train. Yet, this derailment demonstrates that unwritten practices were not reliably followed, tracked or validated.

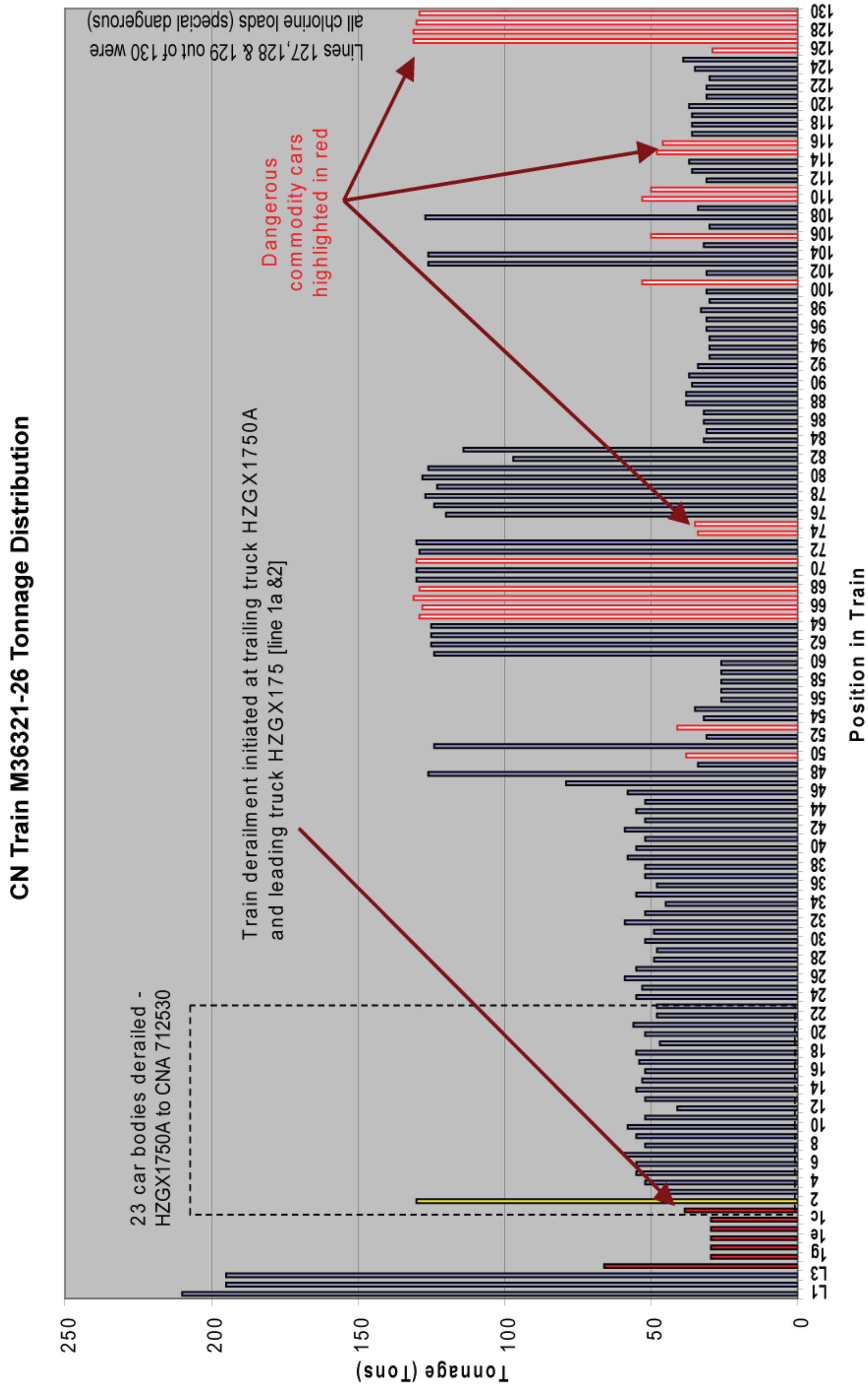
In 2007, in response to additional TSB railway safety communications on this issue (RSI 14-07, RSA 08-07, and RSA 09-07), Transport Canada reported that CN is working on a strategy to address tonnage distribution. However, despite regular meetings between Transport Canada and CN management on this issue, CN still does not have a train marshalling system that considers tonnage distribution.

Therefore, the Board remains concerned with the frequency of derailments caused or accentuated by in-train forces, especially in transportation corridors traversing densely populated areas.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 14 May 2008.

*Visit the Transportation Safety Board's Web site (**www.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 – Tonnage Profile for Train



Appendix B - TSB Engineering Laboratory Calculations of Lateral/Vertical Ratios on the Leading Truck of HZGX175 and the Trailing Truck of HZGX1750A Platform

Incorporating site measurements and train data, the TSB Engineering Laboratory conducted an analysis of lateral/vertical (L/V) ratios for the likely first equipment to derail (that is, HZGX1750A (empty gondola) and HZGX175 (the Herzog locomotive)). This equipment was connected by a non-standard coupler that permits a maximum drawbar angle exceeding 30 degrees. Based on site observations and the following calculations, it was determined that:

- In this derailment, in-train buff force was excessive, as defined by the operator for normal train operating conditions, and exceeded the sustainable limit of the Herzog unit. The large drawbar angle at the Herzog empty car transformed the in-train buff force into an excessive lateral force, which resulted in the derailment.

- The maximum measured deformed drawbar angle at car HZGX1750A was 37.3 degrees. At this angle, with a dynamic braking force of 135 000 pounds, the truck side L/V ratio for the trailing truck on HZGX1750A was as high as 5.93, more than seven times the derailment criteria and exceeding the rail rollover resistance. Even in the rebuilt even height case and the normal designed condition case, the truck side L/V ratio would still reach 4.51 and 3.10 respectively, resulting in rail rollover. The truck side L/V ratio for the leading truck on HZGX175, the Herzog locomotive, was in the range of 0.59 to 1.06.

- The L/V ratio for the trailing truck on HZGX1750A was large enough to enable the wheels to roll over and/or to lift to the low side. The trailing truck of HZGX1750A likely derailed first, releasing the constraint on the drawbar angle at the locomotive end, and permitting the drawbar angle to continue to enlarge until the transformed lateral force canted out and rolled the high rail, derailing HZGX175 almost simultaneously.

1. HZGX175 – Locomotive

   Light weight 260 000 pounds
   2 axle truck

2. HZGX1750A Platform

   Post-derailment measurement showed that HZGX1750A was connected to HZGX175 by a bar at ends with two spherical joints at different heights above rail top, which were designed to be at the same height.

Lead truck: articulated truck shared with Platform C
Trailing truck: 2 axle truck

Load limit	84 000 pounds
Light weight	77 180 pounds

(Entire HZGX750)

(Load limit	615 200 pounds)
(Light weight	505 000 pounds)

3. Measured Connection Jointed Bar

Joint-Joint Distance: 3 feet 11 inches (or 4 feet)

Joint at Locomotive End Height:	30 inches
Joint at Car End Height:	33 inches

Note: The heights are supposed to be the same. The measured height difference was likely due to a missing suspension assembly in the locomotive.

Longitudinal Height Difference Angle: 3.66 (3.58) degrees

Joint at Locomotive End:

Bar Thickness:	5 ¼ inches
House Width Inside:	10 ½ inches
House Width Edge:	10 5/8 inches
Joint to House Edge:	5 ¼ inches

Gap Between Bar and House Edge in Travel Direction:

Left:	2 ½ inches
Movable Angle:	28.4 degrees
Right:	2 7/8 inches
Movable angle:	33.2 degrees

Joint at Car End:

Bar Thickness:	5 ¼ inches
House Width Inside:	10 ½ inches
House Width Edge:	10 7/8 inches
Joint to House Edge:	5 ¼ inches

Gap Between Bar and House Edge in Travel Direction:

Left:	3 11/16 inches
Movable Angle:	44.6 degrees
Right:	1 15/16 inches
Movable Angle:	21.7 degrees

Note: The designed normal drawbar angle without deformation is approximately 30 degrees, the same as the movable angles at the articulated trucks.

4. Locomotive event recorder (LER) recorded buff force at the joint bar: 3 x 45 000 pounds = 135 000 pounds

5. After the derailment sequence, the drawbar was in the jackknifed position, and the drawbar was at the largest movable angle with the longitudinal centreline of the Herzog locomotive and the HZGX1750A platform. The calculation cases included the measured case, the rebuilt even height case, the normal designed case, and the smallest angle case. The coefficient of friction between the wheel tread and the rail top was assumed to be 0.4.

6. At the trailing truck of HZGX1750A

6.1 Measured Case:

V = ½ (77 180) – 135 000 sin (3.66) =	29 972 pounds
L = 135 000 sin (44.6) =	94 791 pounds
Truck L/V =	3.16
Truck side L/V = (L-f*V/2)/(V/2) =	5.93

6.2 Rebuilt Even Height Case
Drawbar at horizon level and at the largest lateral angle of 44.6 degrees

V = ½ (77 180) =	38 590 pounds
L = 135 000 sin (44.6) =	94 791 pounds
Truck L/V =	2.46
Truck side L/V = (L-f*V/2)/(V/2) =	4.51

6.3 Normal Design Case
Drawbar at horizon level and at the largest lateral angle of 30 degrees

V = ½ (77 180) =	38 590 pounds
L = 135 000 sin (30) =	67 500 pounds
Truck L/V =	1.75
Truck side L/V = (L-f*V/2)/(V/2) =	3.10

6.4 Smallest Angle Case
Drawbar at horizon level and at the smallest lateral angle of 21.7 degrees

V = ½ (77 180) =	38 590 pounds
L = 135 000 sin (21.7) =	49 916 pounds
Truck L/V =	1.29
Truck side L/V = (L-f*V/2)/(V/2) =	2.19

7. At the lead truck of the locomotive HZGX175

7.1 Measured Case:
Drawbar at horizontal angle of 3.66 degrees and the largest lateral angle of 33.2 degrees

Truck V = ½ (260 000) + 135 000 sin (3.66) = 138 618 pounds

Truck side V =	69 309 pounds
L = 135,000 sin (33.2) =	73 921 pounds
Truck L/V =	0.53
Truck Side L/V =	0.67

7.2 Rebuilt Even Height Case:
Drawbar at horizon level and at the largest lateral angle of 44.6 degrees

Truck V = ½ (260 000) =	130 000 pounds
Truck side V =	65 000 pounds
L = 135 000 sin (44.6) =	94 791 pounds
Truck L/V =	0.73
Truck Side L/V =	1.06

7.3 Normal Designed Case
Drawbar at horizon level and at the largest lateral angle of 30 degrees

Truck V = ½ (260 000) =	130 000 pounds
Truck side V =	65 000 pounds
L = 135 000 sin (30) =	67 500 pounds
Truck L/V =	0.52
Truck Side L/V =	0.64

7.4 Smallest Angle Case
Drawbar at horizon level and at the smallest lateral angle of 28.4 degrees

Truck V = ½ (260 000) =	130 000 pounds
Truck side V =	65 000 pounds
L = 135 000 sin (28.4) =	64 391 pounds
Truck L/V =	0.50
Truck Side L/V =	0.59