Examining the Role of Wheel/Rail Interaction in a Derailment

Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

Transportation Safety Board of Canada (TSB)

Canada

TSB Mission

To advance transportation safety in the air, marine, rail and pipeline modes of transportation that are under federal jurisdiction

It is not the function of the Board to assign fault or determine civil or criminal liability.

TSB Mission accomplished by

- conducting independent investigations
- identifying safety deficiencies
- identifying causes and contributing factors
- making recommendations
- publishing reports

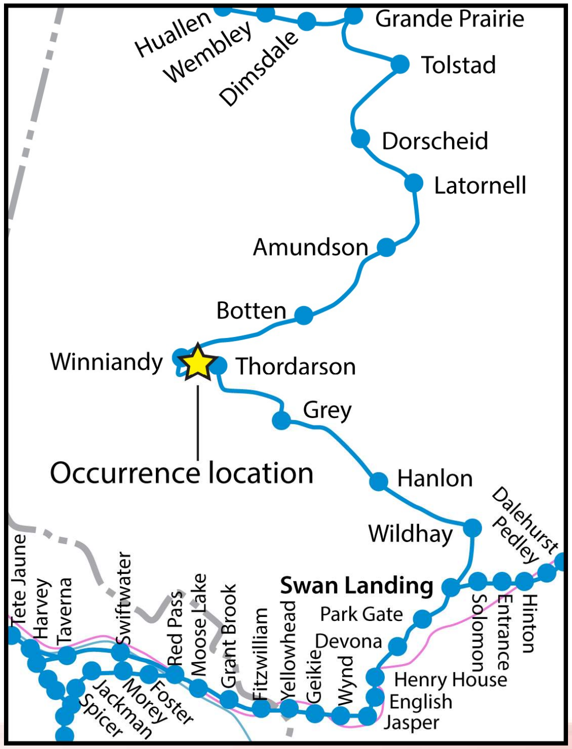
Wheel/Rail Derailments

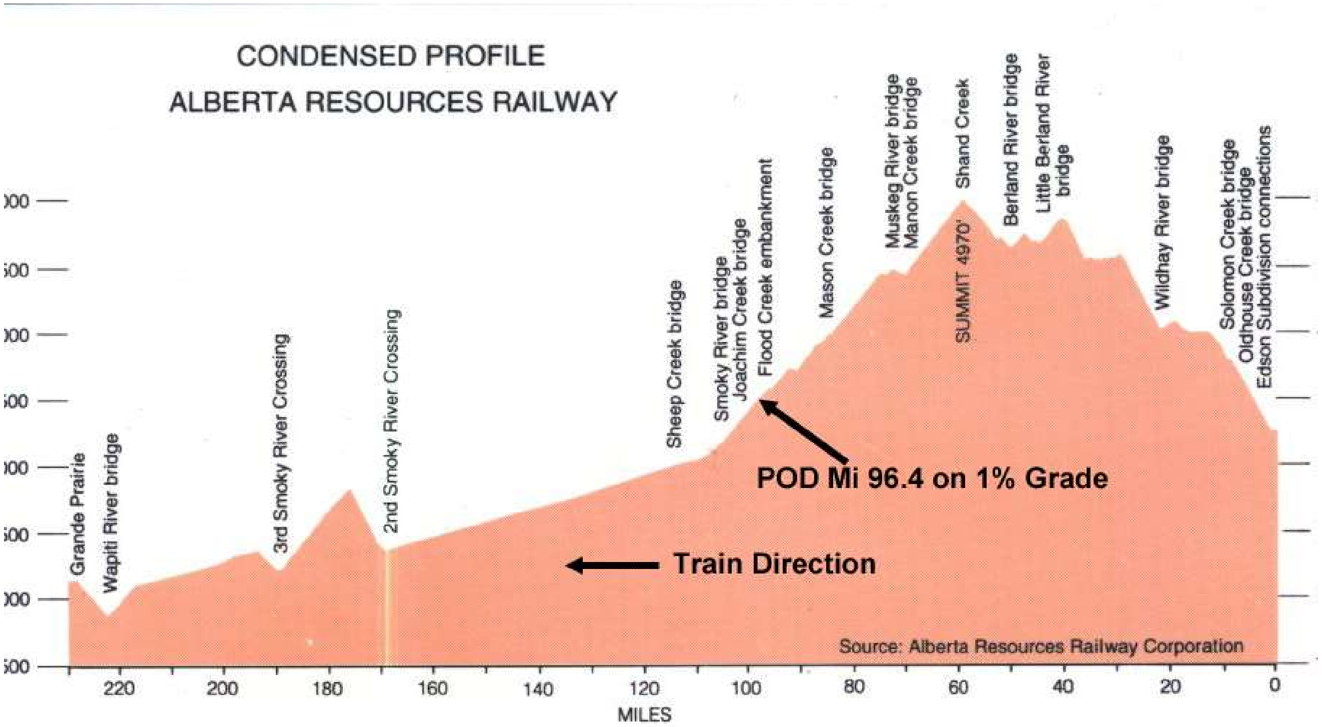
High lateral-force rail rollover, wheel climb or wheel drop in due to a combination of train speed, under-elevated curve, lowered L/V threshold due to 2-point contact or wheel profile, uneven or degraded rail fastener resistance to dynamic wide gauge

Grey, Alberta

Derailment of 28 hopper cars loaded with frac sand and two DP locomotives at Mile 96.4 Grande Cache Subdivision on 29 October 2016

Grey, Alberta





CONDENSED PROFILE
ALBERTA RESOURCES RAILWAY

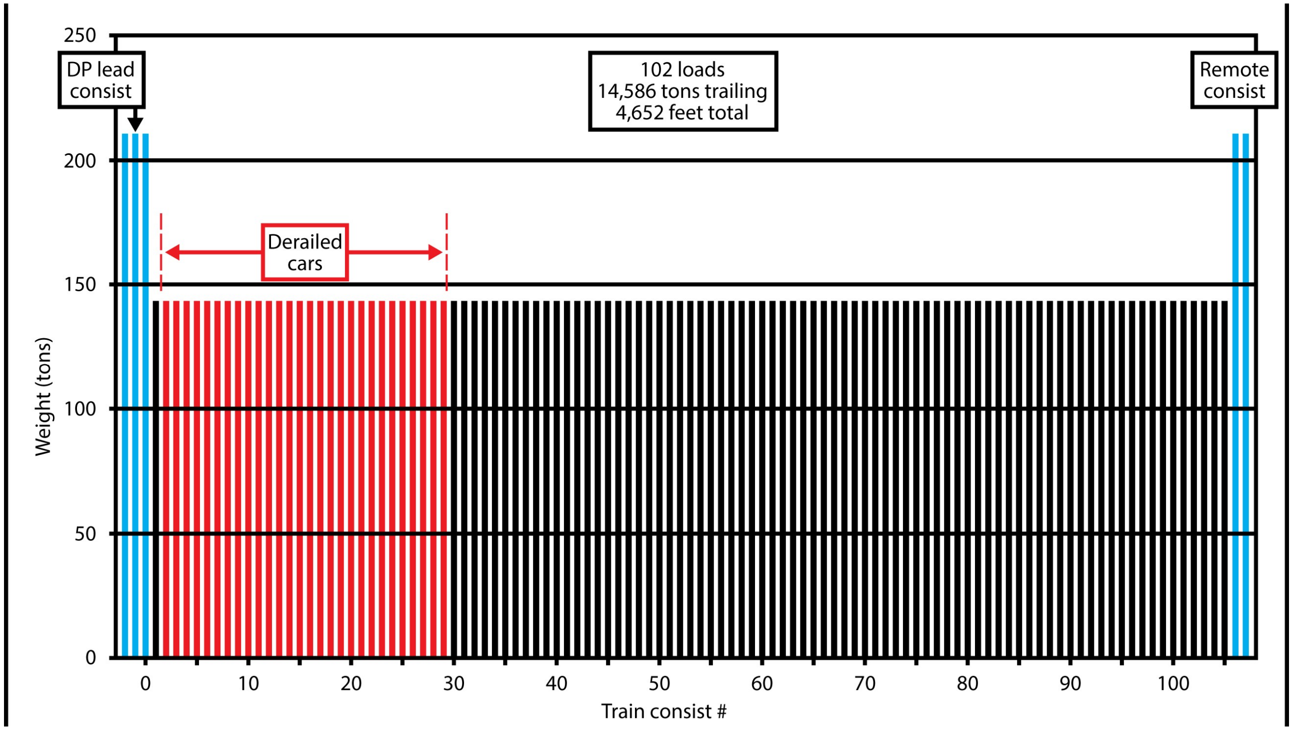
POD Mi 96.4 on 1% Grade

Train Direction

Source: Alberta Resources Railway Corporation

The Train

- DP train pulled by five GE ET44AC locomotives, 3 on the head-end and 2 positioned at the end of the train
- 102 loaded covered hopper cars, 14,586 tons and 4,652 feet long



Train A45851 length and tonnage profile

GE ET44AC Locomotive

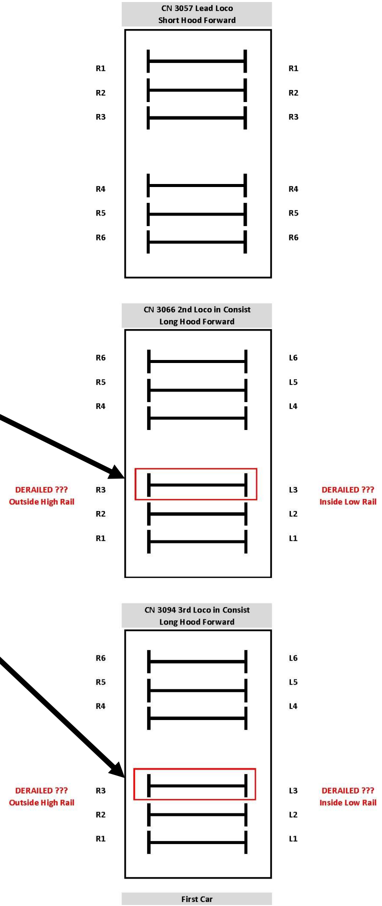
Emergency

- The train was descending a 1% grade through a 6° RH curve at 27 mph
- DB was in position DB5 on the lead locomotive
- DB was disabled on the 3rd head end locomotive
- Train brakes were not applied

Point of Derailment

- The first car behind the head end locomotives remained upright and did not derail
- The 2nd to the 29th car derailed

Leading wheel sets of trailing trucks of 2nd and 3rd locomotives (No. 4 axles in direction of travel) derailed. R3 wheels were derailed to the outside of the high rail and the L3 wheels were derailed to the inside of the low rail.



Derailment Investigation

- track maintenance practices
- curve superelevation
- rail wear and two point contact
- train handling, use of dynamic brake on DP powered heavy unit trains on mountain grades

Derailment Investigation

- Train dynamics analysis of in-train and transformed lateral forces
- Lateral-to-vertical (L/V) ratios

The Track

- Class 2 track posted maximum speed 25 mph
- 11.6 MGT in 2016
- Mix of HW and SW ties, 4 spikes/14” DS plate
- Fully anchored, crushed rock ballast

The Track

- 1991 Algoma 115lb CWR high rail, 2016 Evraz 115 lb CWR low rail
- Flange lubricators located at Mile 96.2 and 100.1

High Rail


115lb 1991 Algoma CWR
7mm head wear
8 mm flange wear

Plug Rail

- 34’ plug rail installed in high rail at POD months previously
- Both joints fully bolted at time of installation
- Both joints recovered intact

South plug rail joint

115lb 1991 Algoma Rail. Note missing bolts and wheel flange contact on top of gauge joint bar

Low Rail Replacement

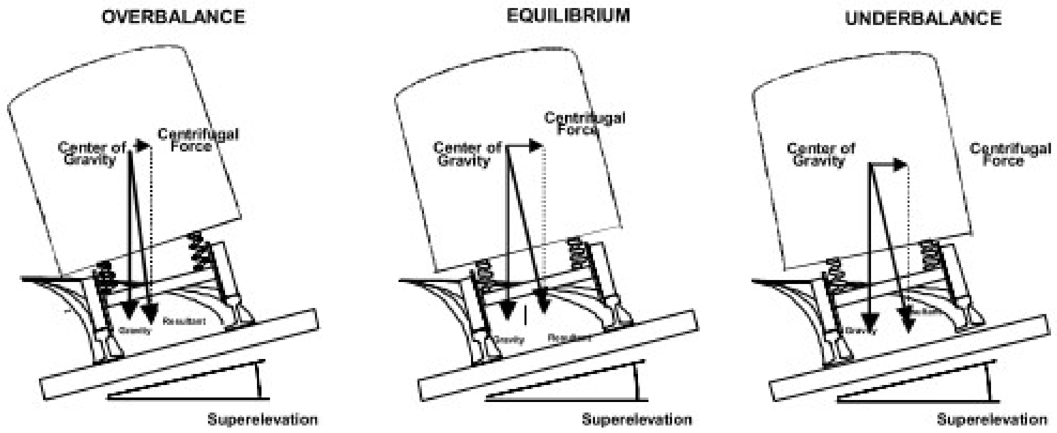
- tie installation in June 2016 and the low rail changed out in September 2016
- low rail securement strengthened due to increased spiking and gluing of the spike holes
- With new, full-height rail, the average superelevation on the curve was reduced by 0.42 inch to 0.99 inch

POD Curve

- The length of curve was 1762 feet.
- The curve extended from Mile 96.24 to Mile 96.57.
- The average degree of curvature was about 6 degrees (i.e., ranging from 5.94° to 6.06°).

POD Curve

- The superelevation ranged from 0.51 inches and 1.28 inches.
- The average superelevation was 0.99 inches.
- The design speed was 26.7 mph.
- The balanced superelevation was 2 ¾ inches.



$$V_{\max} = \sqrt{\frac{E_a + 3}{0.0007D}}$$

Amount of Underbalance

$V_{\max}$ = Maximum allowable operating speed (mph).

E_a = Average elevation of the outside rail (inches).

D = Degree of curvature (degrees).

Hopper Cars

42’ Frac Sand Covered Hopper

59’ Covered Grain Hopper

Short Covered Hopper Cars

For cars of the same weight, in some circumstances, shorter cars can exert higher forces on the rail in curves (i.e., unbalanced centrifugal L/V and/or transformed lateral forces when the cars are in jackknifed position under buff in-train forces) than longer cars

Short Covered Hopper Cars

The shorter distance between sets of trucks in short cars will bring the pressure bulbs produced by each set of trucks closer together and create a larger area of overlapping pressures and lateral forces

Length of car/truck center distance ratio

Car Number	Outside Length	Truck Center	Ratio	Load Limit	Volume
CP 601324	59	46	1.28	205,900	4550
CN 110092	59	46	1.28	222,800	4550
ALPX 628141	59	46’-3”	1.28	204,800	4550
CEFX 312560	42	28’-8”	1.46	232,800	3260
ALNX 396053	59	46	1.28	200,000	4550
CN 109410	59	46	1.28	224,100	4550
CN 109231	59	46	1.28	223,600	4550

Transformed Lateral Force

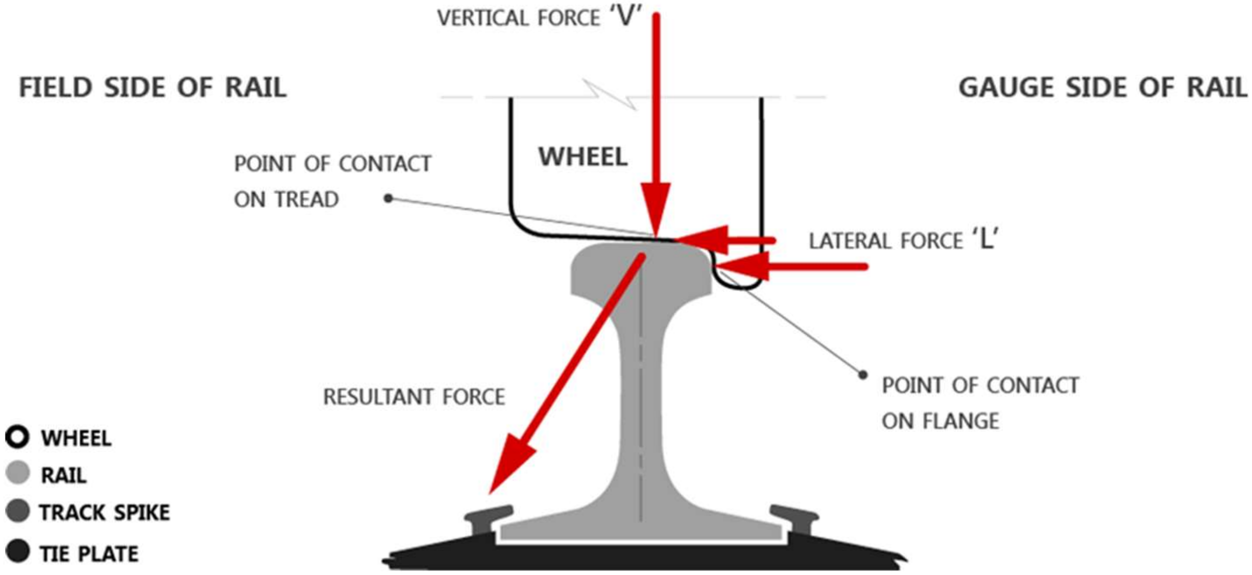
$$L_{tr} = L_{bar} * L_c / L_{tc}$$

Wheel/Rail Interface Forces

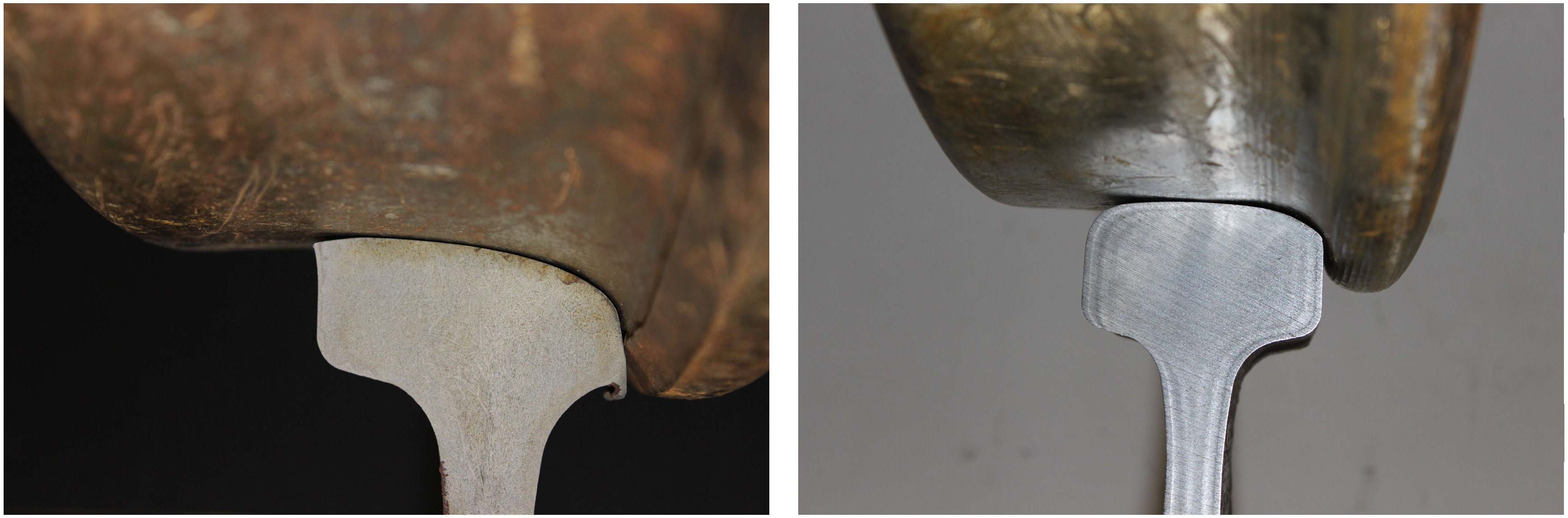
The lateral and vertical forces at the wheel/rail interface are a result of interaction between:

- track geometry
- vehicle dynamics
- wheel/rail profile

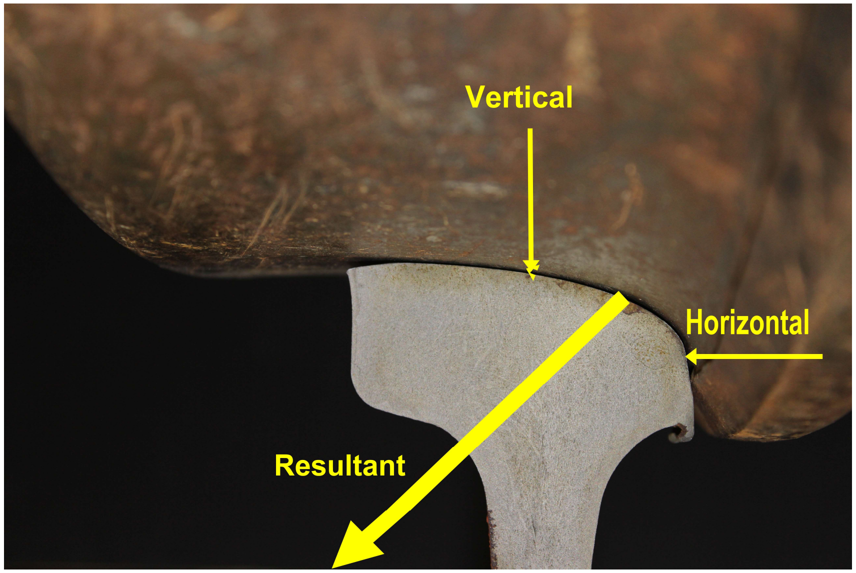
Wheel/Rail Interface Forces

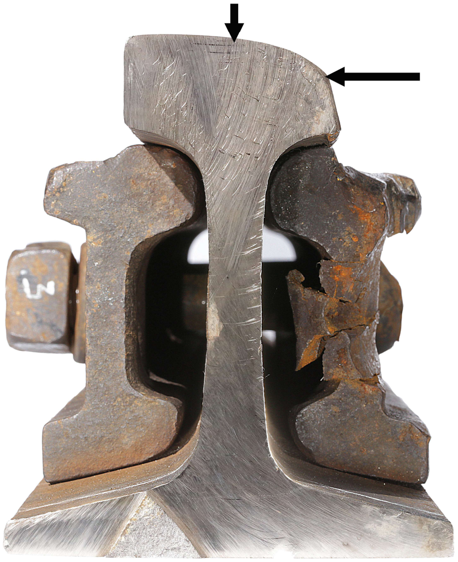


Worn vs New Rail Contact



Two Point Contact





Train Operations Simulator (TOS) and Quasi-static Lateral Train Stability (QLTS) Models

QLTS Simulation Results

- The locomotive/locomotive lateral force calculated was 12,066 pounds and 0.19 truckside L/V ratio.
- The lateral force for the locomotive/car combination was 12,247 pounds with 0.19 truckside L/V ratio

QLTS Simulation Results

- The lateral force for the car/car combination was 8,224 pounds with 0.18 truckside L/V ratio

TOS Simulation Results

- The maximum longitudinal in-train drawbar forces on the locomotives were below 100 kips when the locomotive derailed at 27 mph.
- These values were considered moderate and non-causative for well-supported and maintained track.

Train Energy and Dynamics Simulation (TEDS)

- in-train buff force between 85 kips and 115 kips (2 locos at DB5)
- Total lateral forces and L/V ratio = dynamic curving + unbalanced centrifugal + transformed lateral force

TEDS Results

- Total truckside L/V ratios were about 0.51 for the sand cars and 0.48 for the locomotives
- Lateral force at the leading outside wheel was approximately 22 kips for the sand cars and 26 kips for the locomotives.

Derailment Mechanism

- high rail in the 6° right-hand curve rolled over as the head end of the train travelled over the plug rail
- Underelevated curve resulted in higher lateral forces exerted on high rail

Derailment Mechanism

- 2-point contact at the wheel-rail interface likely occurred, resulting in a lower L/V derailment threshold
- dynamic brake resulted in a further increase in lateral forces on the high rail by the head-end locomotives

Increased Potential for High Rail Rollover

- Uneven fastener resistance between the high and low rail
- reduced superelevation after the low rail was replaced with a new full-height rail

Elastic Fasteners on high rail, spikes on low

TSB investigation reports R04T0161 and R11T0162, and TSB Railway Occurrence R06T0125

Rail Fastener Systems

Elastic Fastener

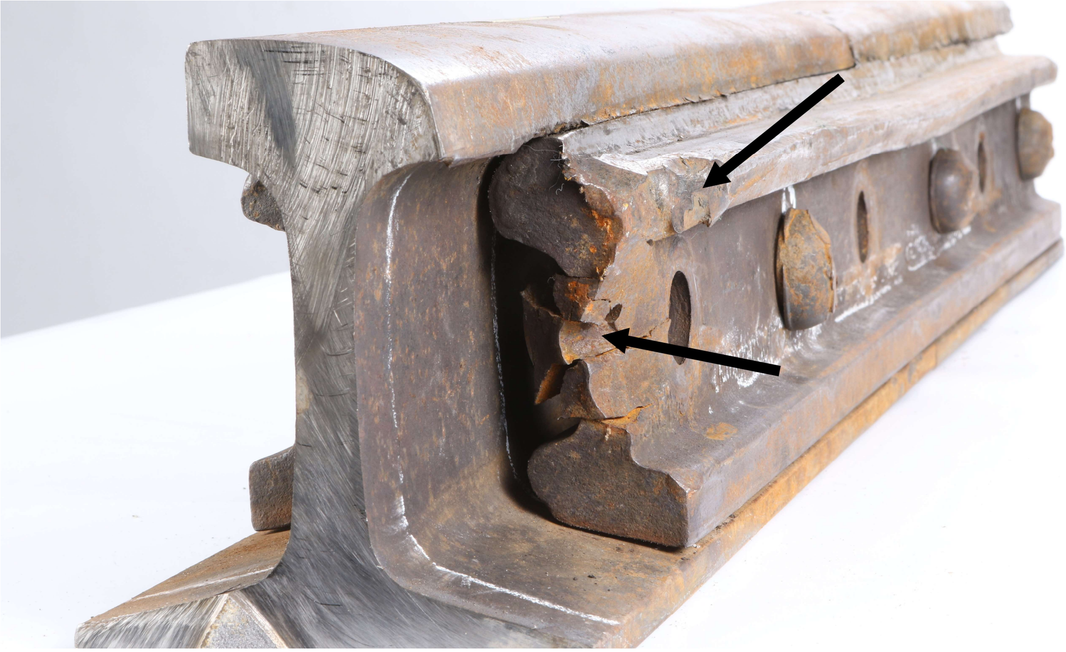
Spikes

Rail

- With the high rail close to its wear limits, wheel/rail contact was closer to the field side of the high rail, resulting in a lower lateral-to-vertical derailment threshold
- High rail likely rolled or canted out sufficiently to allow low rail wheels to drop in

Cause

High rail rolled over due to a combination of dynamic brake and train speed on the under-elevated curve, lowered L/V threshold due to 2-point contact on the worn high rail, and uneven high/low rail fastener resistance to dynamic gauge widening



South plug rail joint bar

Safety Action Taken

- Gauge restrain measuring
- Review of superelevation standard
- Mandatory use of air in combination with DB
- Increased Engine Service Office presence
- Increased track patrol frequency

QUESTIONS?

- Derailment reports available at:
- http://www.tsb.gc.ca/eng/rapports-reports/rail/index.asp