Train Operations Study
Port of Vancouver Connection Track

Final Report

Prepared for:

HDR Engineering, Inc.

Prepared by:

TÜV Rheinland Mobility
Rail Sciences Division

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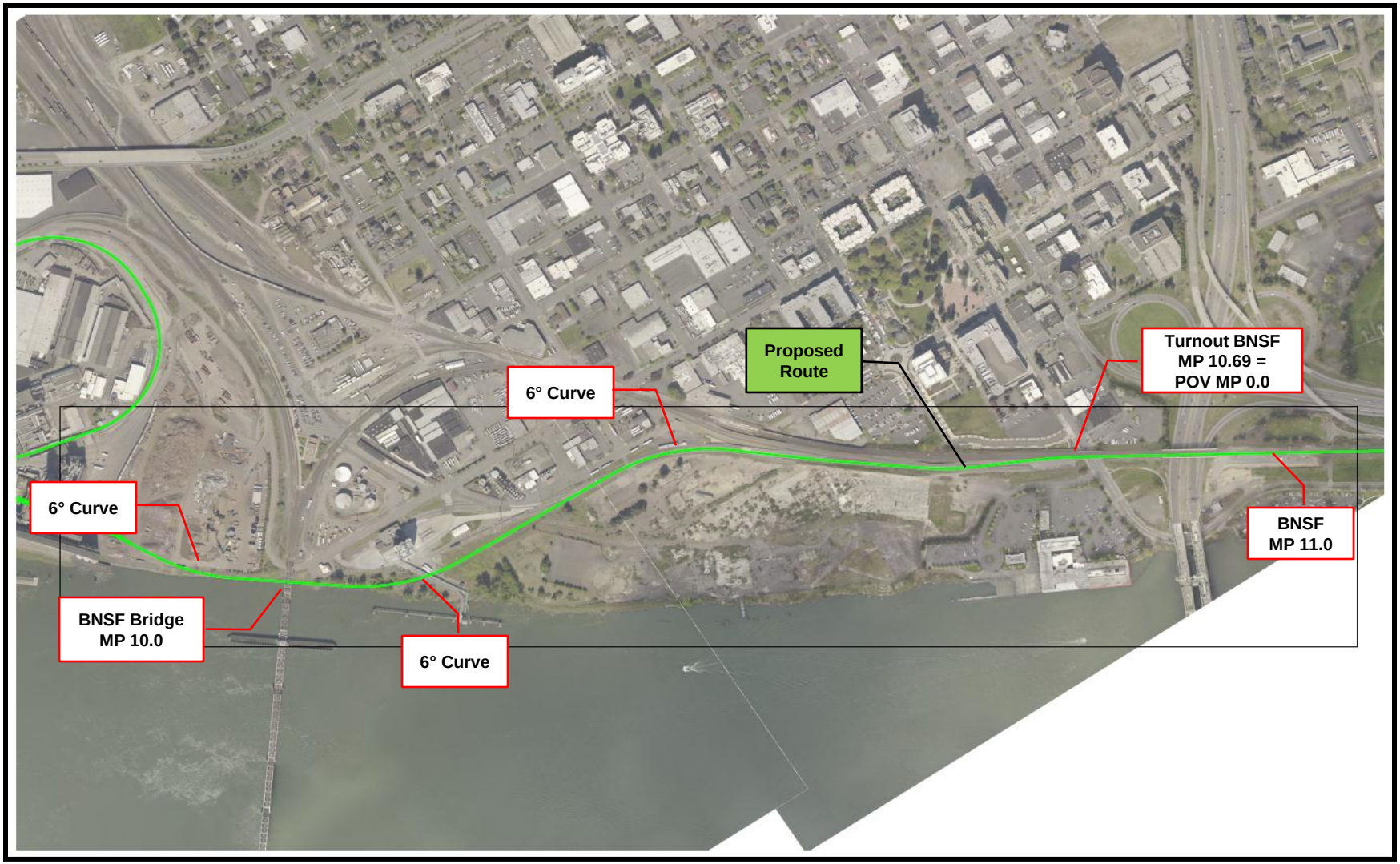
Introduction

- HDR Engineering, Inc. (HDR) requested that TÜV Rheinland Mobility Rail Sciences Division (TÜV-RSI) evaluate the derailment risk of the new rail connection track exiting BNSF Fallbridge Subdivision at MP 10.69 into the Port of Vancouver.
- HDR provided TÜV-RSI with track geometry data, operating speed limits, and the following train consist data:
  - **Grain**
    110 covered hopper cars [60 ft/car], 2 C44-9 lead locomotives, 1 rear C44-9 locomotive
    15,000 tons loaded weight, 3,500 tons empty weight, 6600 feet length of cars
  - **Oil**
    120 tank cars [63 ft/car], 3 C44-9 lead locomotives, 2 rear C44-9 locomotives
    18,000 tons loaded weight, 3,500 tons empty weight, 7564 feet length of cars
  - **Potash**
    170 covered hopper cars [47 ft/car], 2 AC4400 lead locomotives, 2 rear AC4400 locomotives
    24,310 tons loaded weight, 3,740 tons empty weight, 7,990 feet length of cars
- The following aerial photo illustrates the proposed connection route exiting the BNSF main track at MP.69 [POV MP 0.0], running adjacent to a proposed commercial waterfront construction site, and continuing under the BNSF Bridge at MP 10.0 [POV MP 0.75].

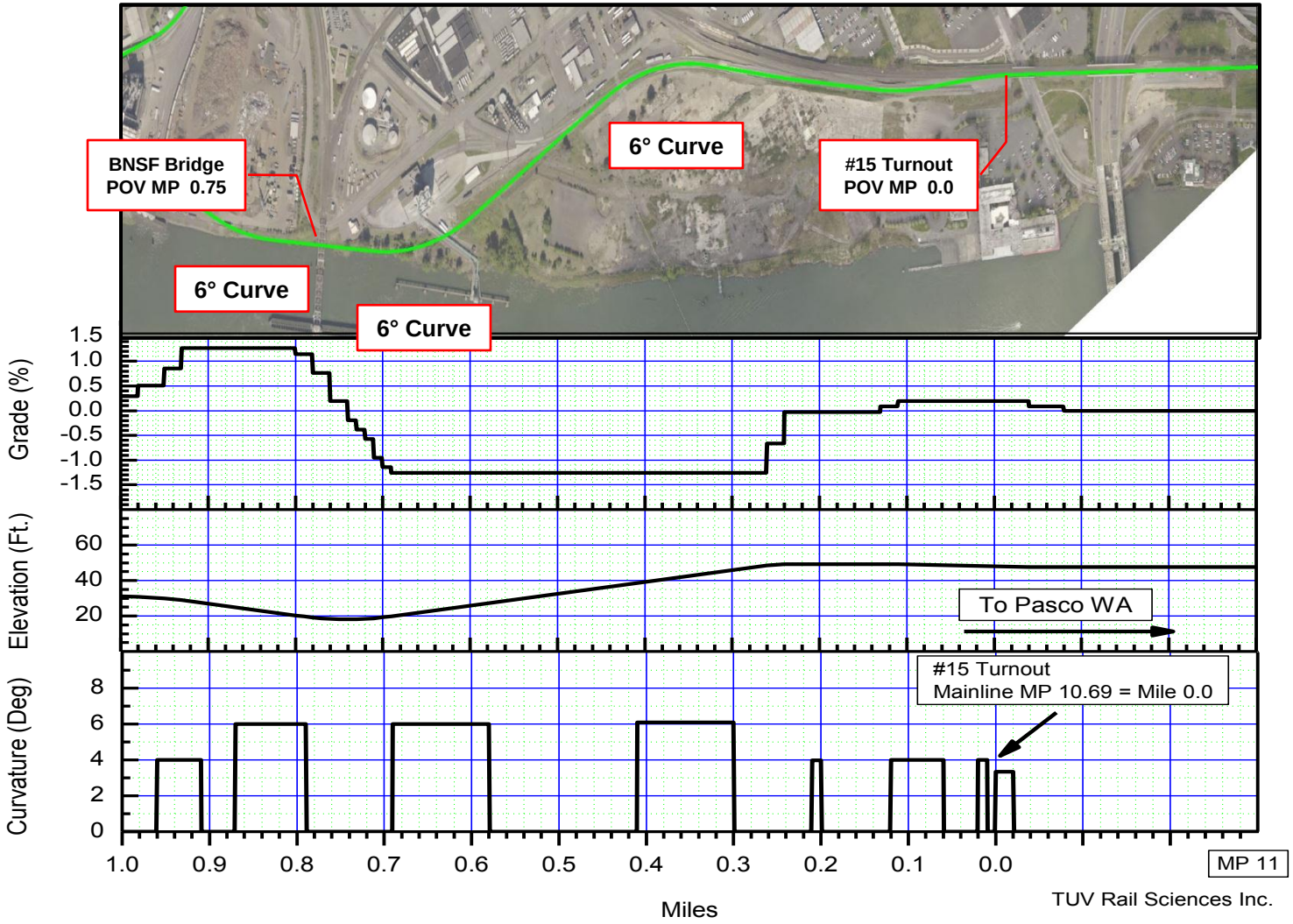
Port of Vancouver – Proposed Connection



Introduction

- The AAR Train Operations Simulator (TOS) was used to determine the longitudinal in-train forces and the DeltaRail VAMPIRE® rail vehicle dynamics package was used to determine the lateral forces and L/V ratios.
- The results of each analysis are described in two sections:
  - In-Train Force Analysis [TOS]
  - Vehicle Dynamics Simulation [VAMPIRE®]
- The following slide shows the proposed track data used in both analyses. The survey station data has been converted to mileage to match the simulation output later in the report. The power switch [#15 turnout] located at BNSF MP 10.69 [equivalent POV MP 0.0] was used as the basis (anchor point) for the POV mileposts.

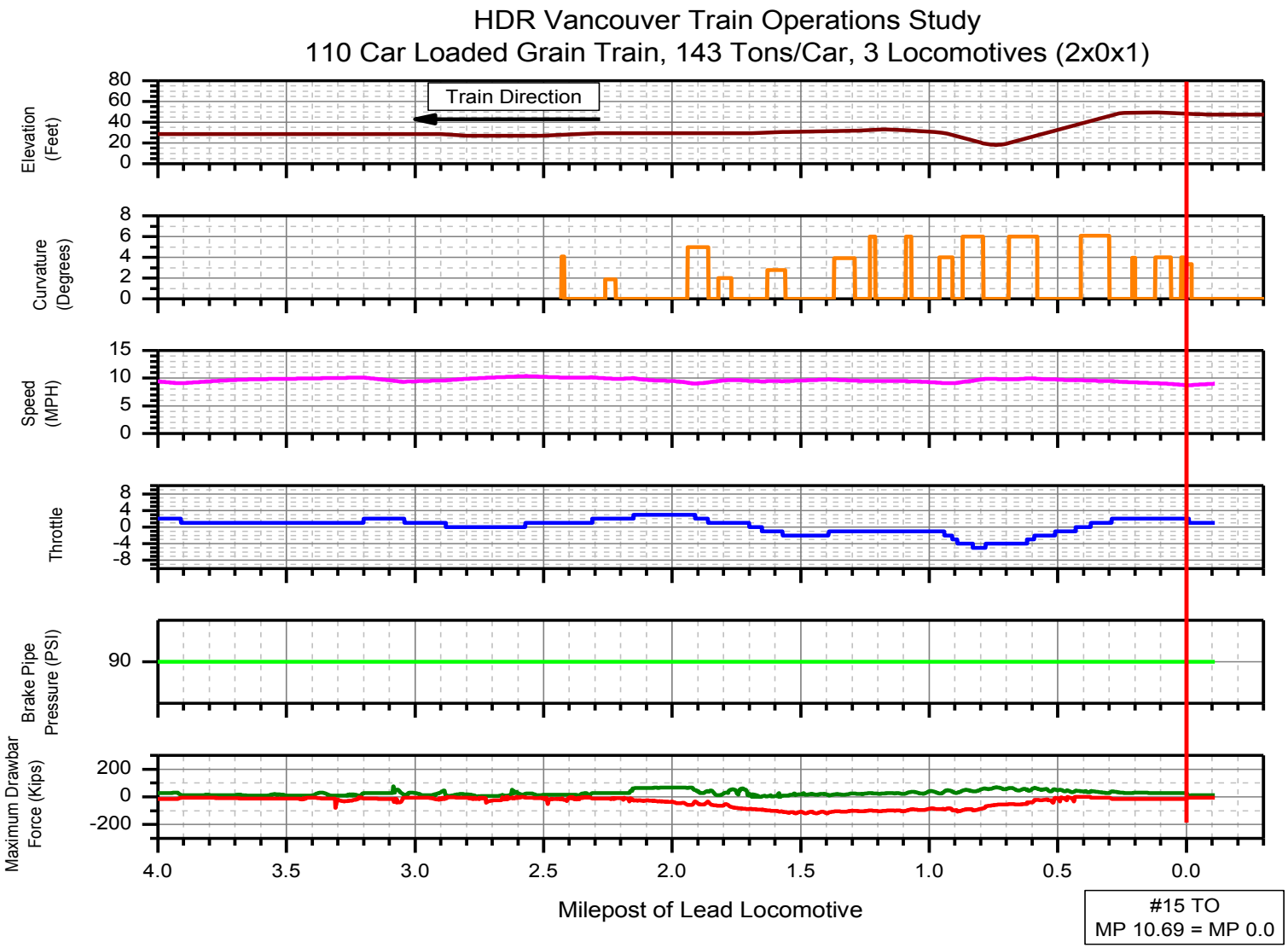
Port of Vancouver Connection Track Profile



In-Train Force Analysis

- The Train Operations Simulator (TOS) was used to determine the longitudinal in-train forces for the six (3 loaded and 3 empty) simulated consists.
- Initially over-the-road run-through simulations were conducted across the proposed route and through the connection track assuming a 10 MPH speed limit [no stops] using nominal train handling.
  - Throttle and dynamic brake modulation was used to handle the trains and maintain the speed limit.
  - Locomotives were taken off-line if they were not needed in empty-train service.
  - Drawbar forces on all cars in each train were extracted for each second of simulation.
  - The maximum draft and buff forces occurring anywhere in the train were compiled and analyzed.
- The following six slides (slides 7-12) show the simulation results for loaded and empty trains. Each plot shows the track geometry (elevation and curvature), speed, train handling, and maximum draft and buff forces.

In-Train Force Analysis



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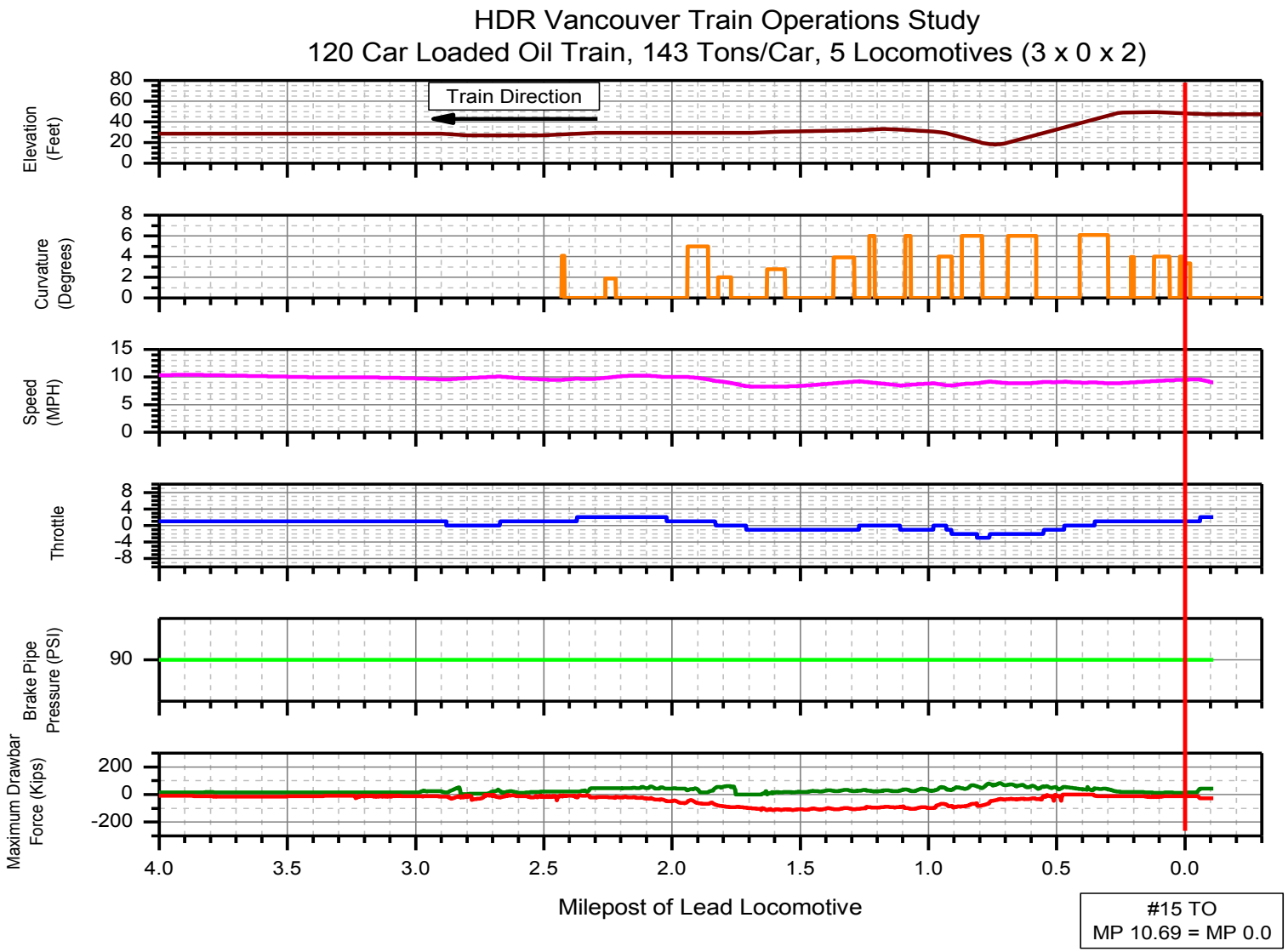
In-Train Force Analysis



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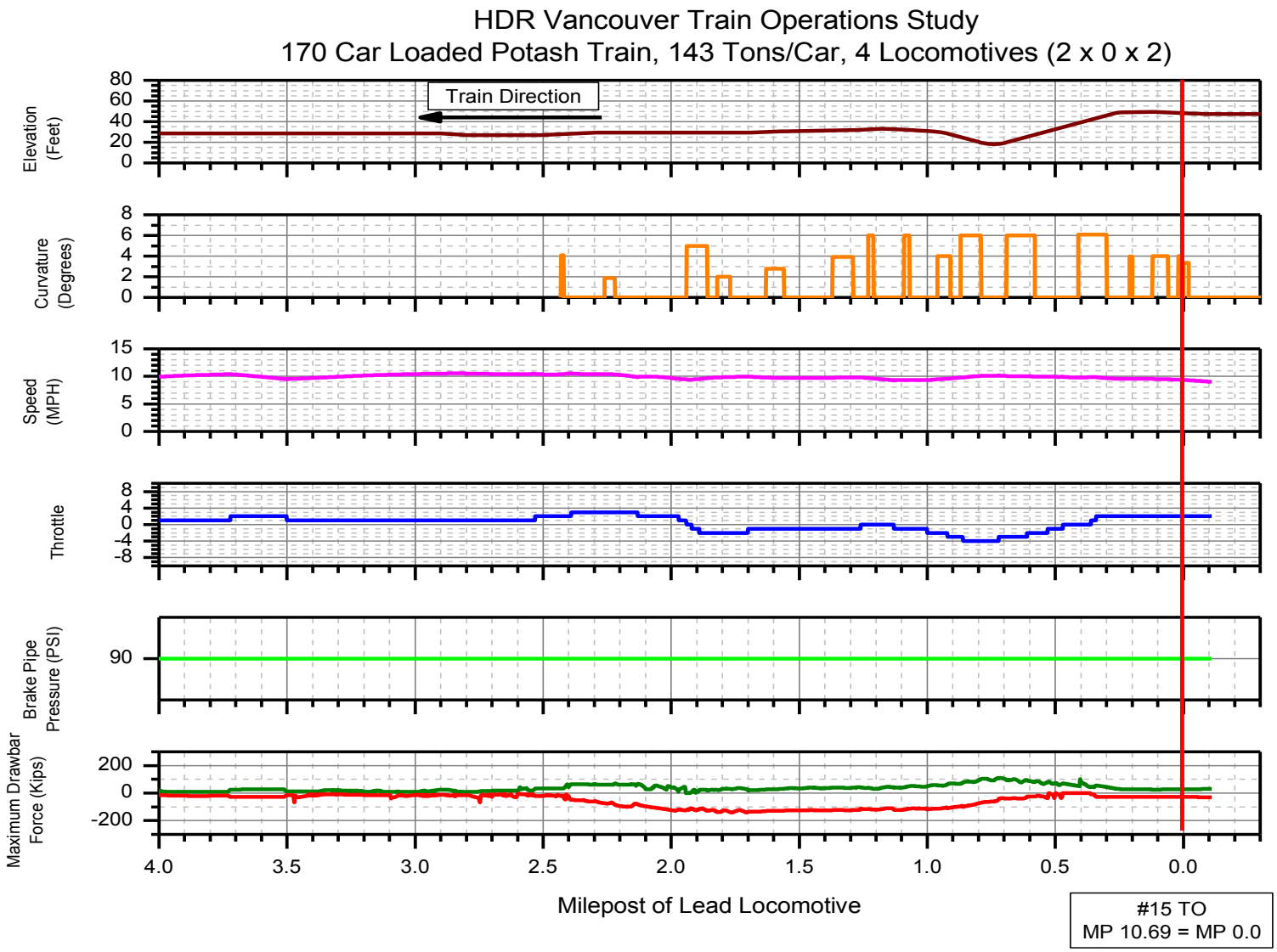
In-Train Force Analysis



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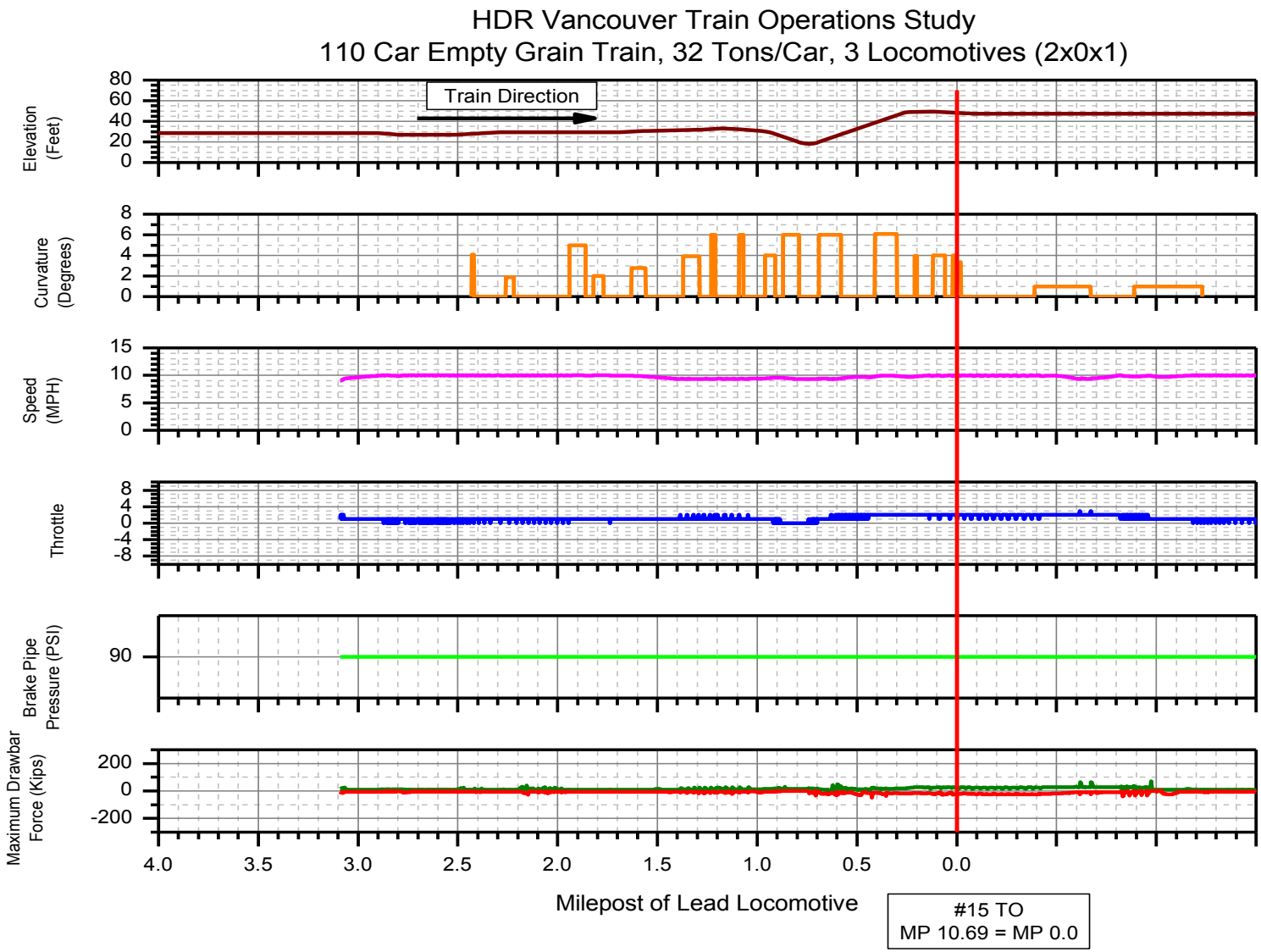
In-Train Force Analysis



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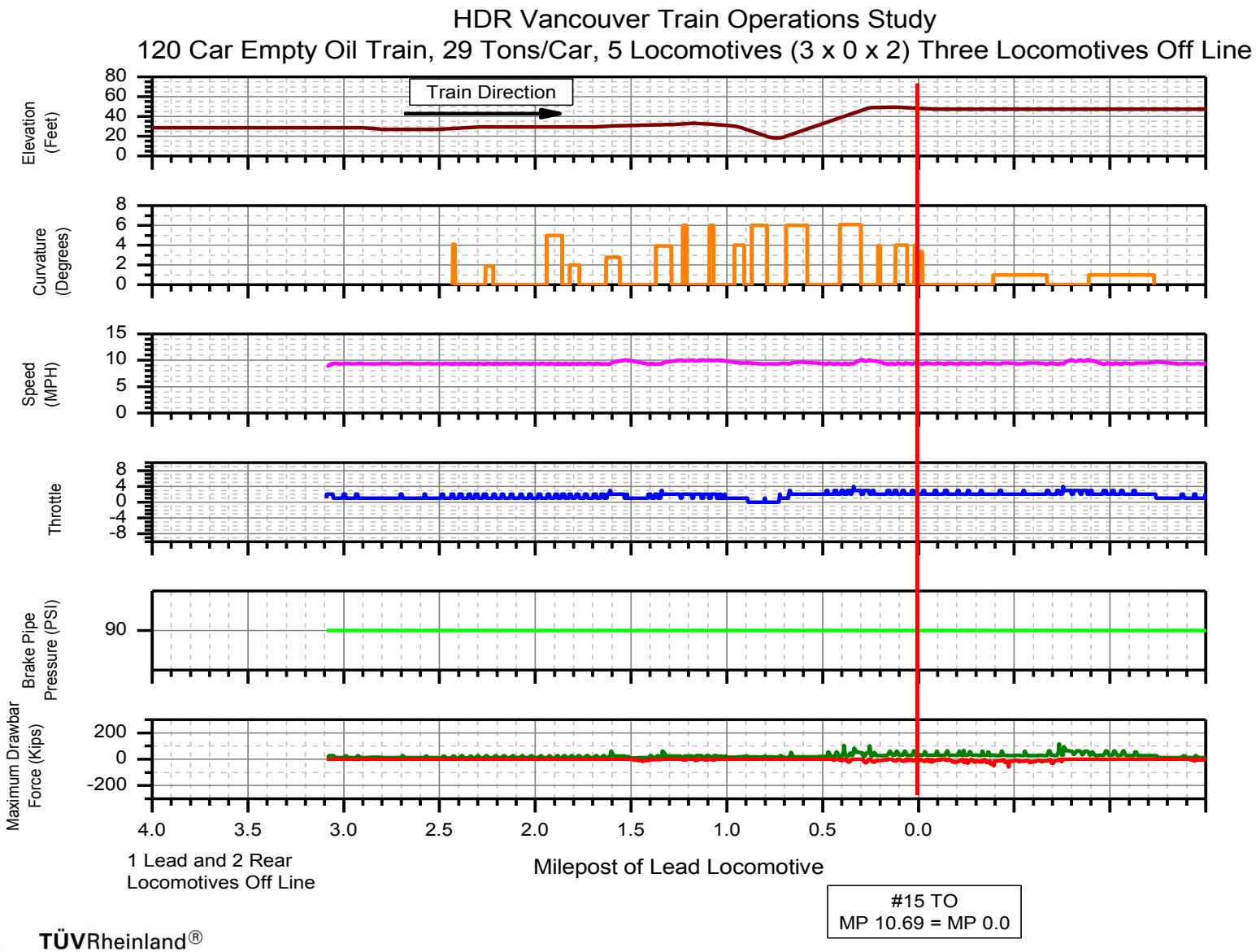
In-Train Force Analysis



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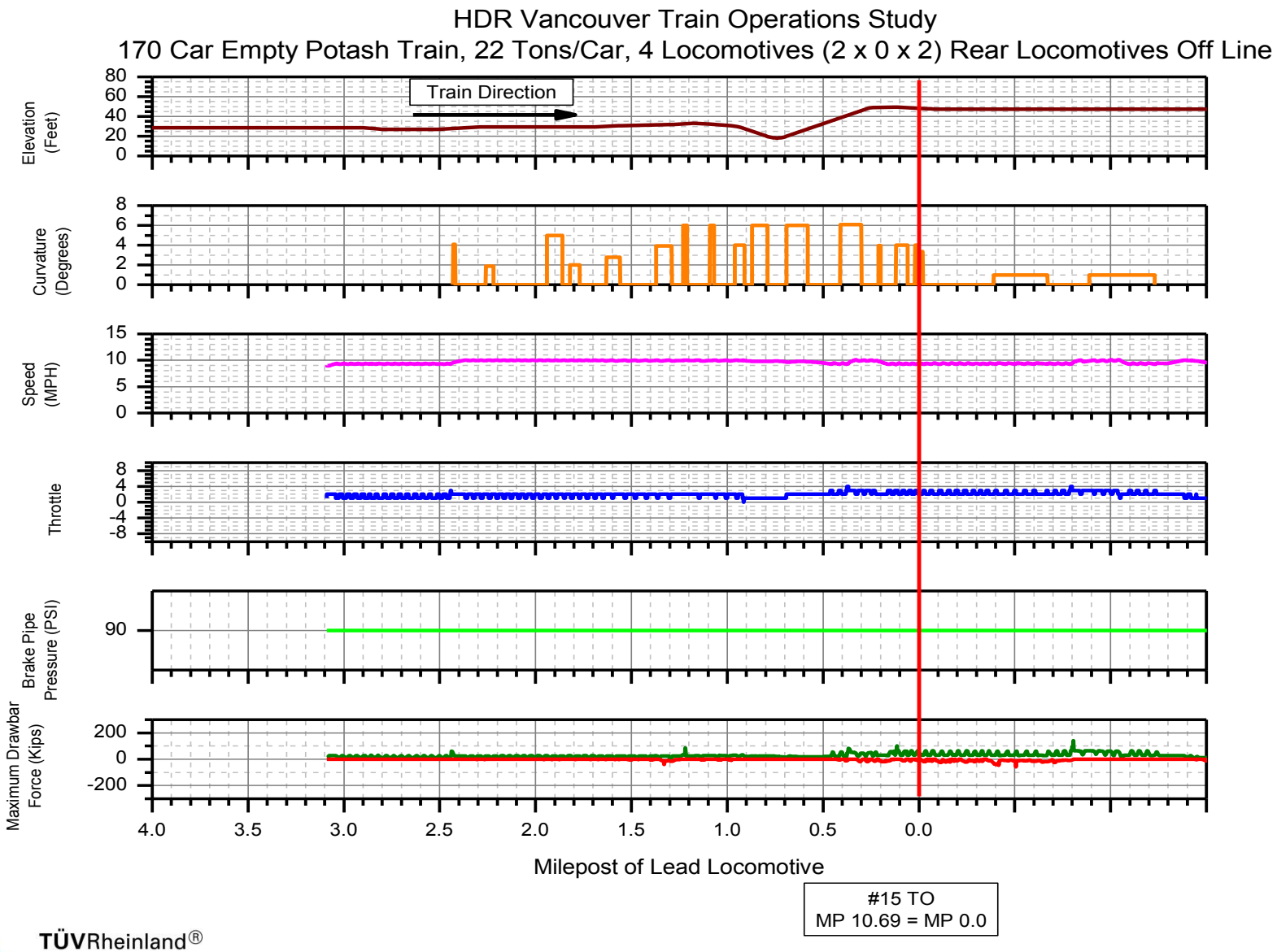
In-Train Force Analysis



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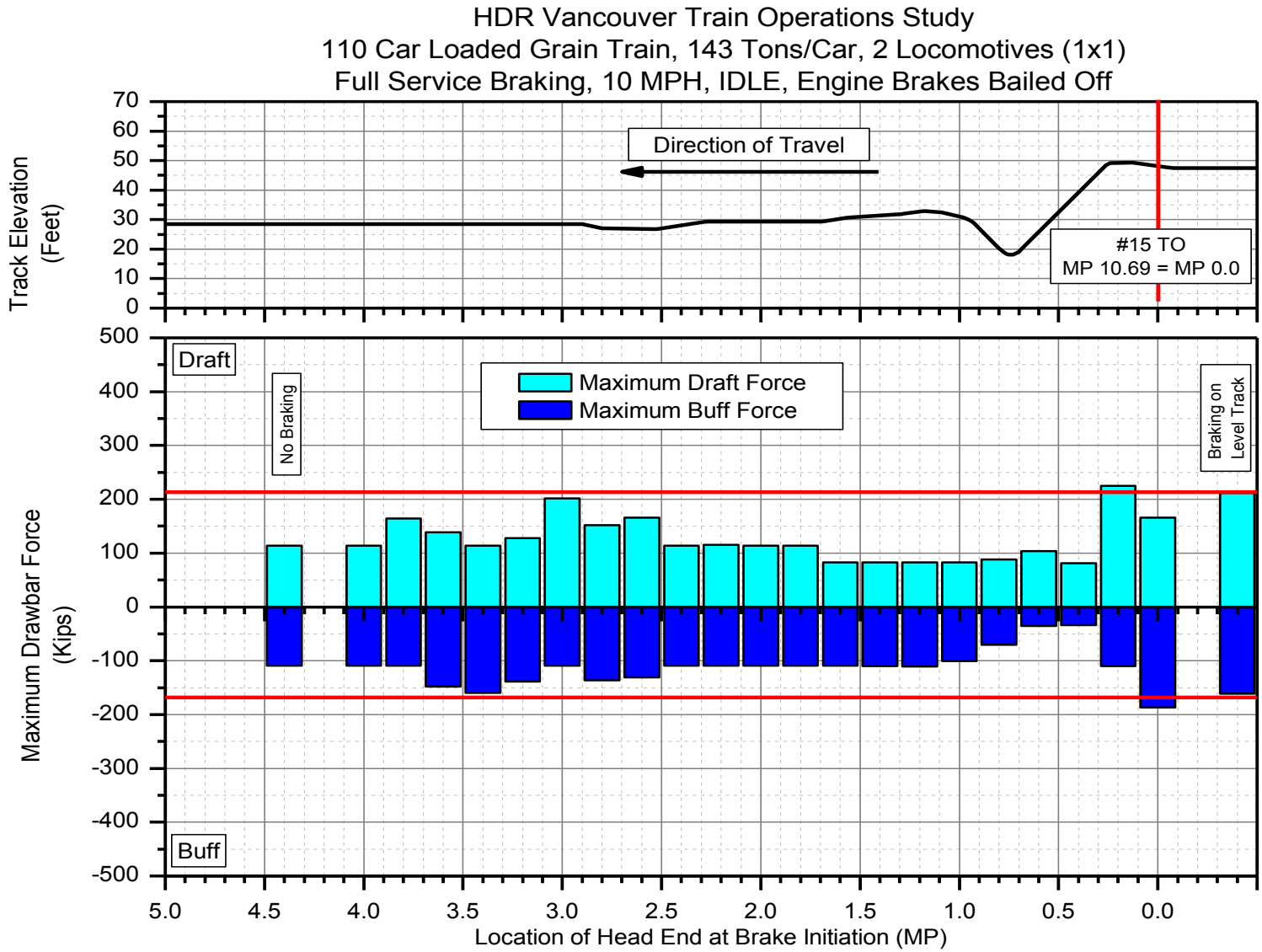
In-Train Force Analysis

- Next, a series of train stopping simulations were performed using loaded trains with nominal train handling (slides 7-9) approaching the track location where braking was initiated during:
  - Full service braking stops
  - Emergency braking stops
- Utilizing nominal train handling prior to the onset of braking normalized the train slack in a representative state to determine if train slack is a significant factor relevant to predicted in-train forces.
- Braking from 10 mph was initiated (at 0.2 mile intervals) over 8 miles encompassing the 3 miles of proposed connection track. Track was assumed to be level on each end of the provided track data.
- Two train braking scenarios were simulated:
  1. Full Service
     - Nominal train handling was employed up to the train braking location at which point full service braking was initiated, the throttle was immediately moved to IDLE from its current position, and the engine brakes were bailed off.
  2. Head-End Emergency
     - Nominal train handling was employed up to the train braking location at which point emergency braking was initiated form the lead locomotive, the throttle was immediately moved to IDLE from its current position, and the engine brakes were bailed off.

In-Train Force Analysis

- The maximum draft and buff forces are compared on slides 15-20.
- The red horizontal lines on the graphs show the force values determined by simulation on the lead-in [level tangent] track. This allows a direct comparison of forces predicted on the proposed connection track versus those generated on track that is level and tangent.

In-Train Force Analysis



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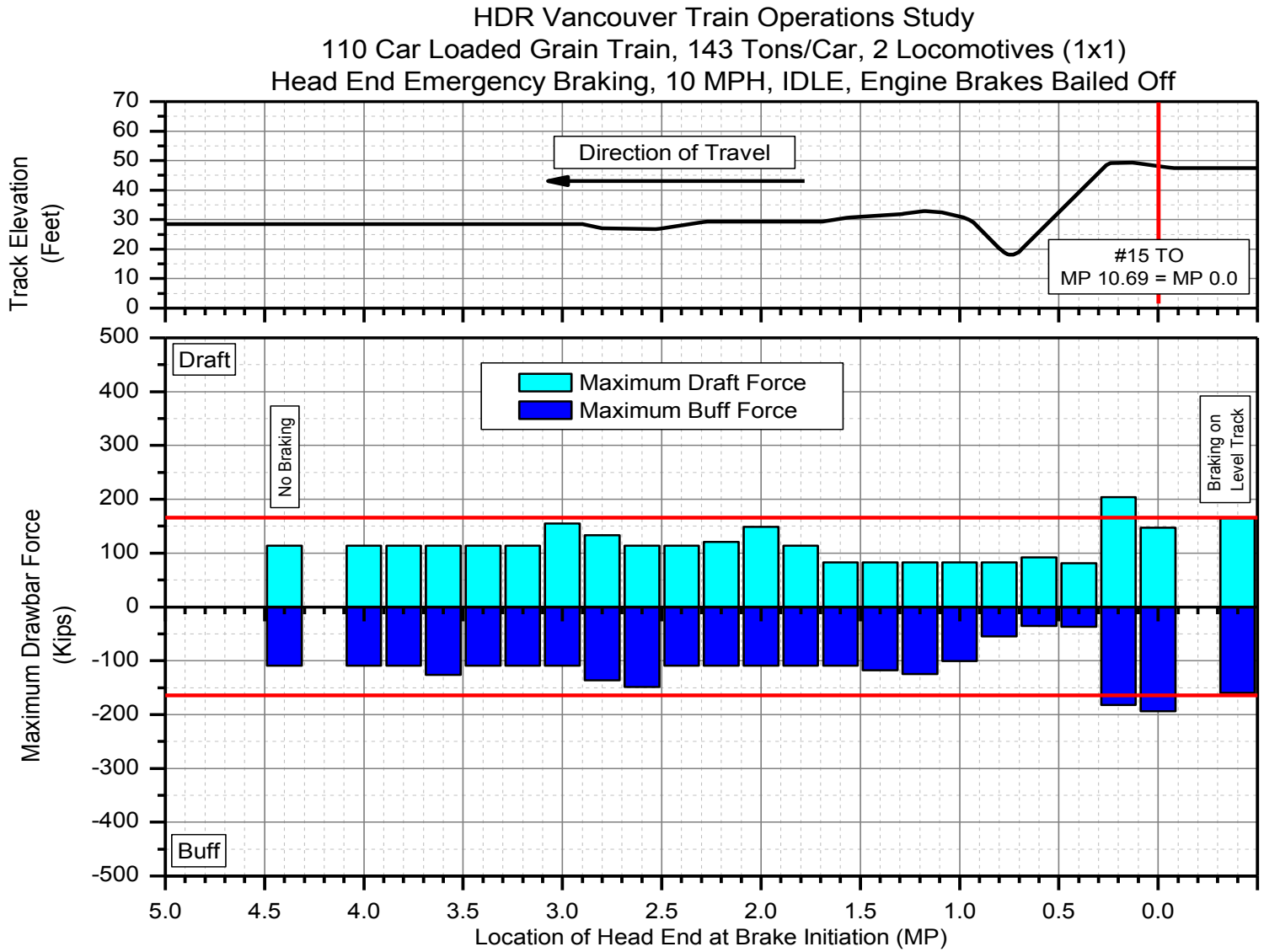
In-Train Force Analysis



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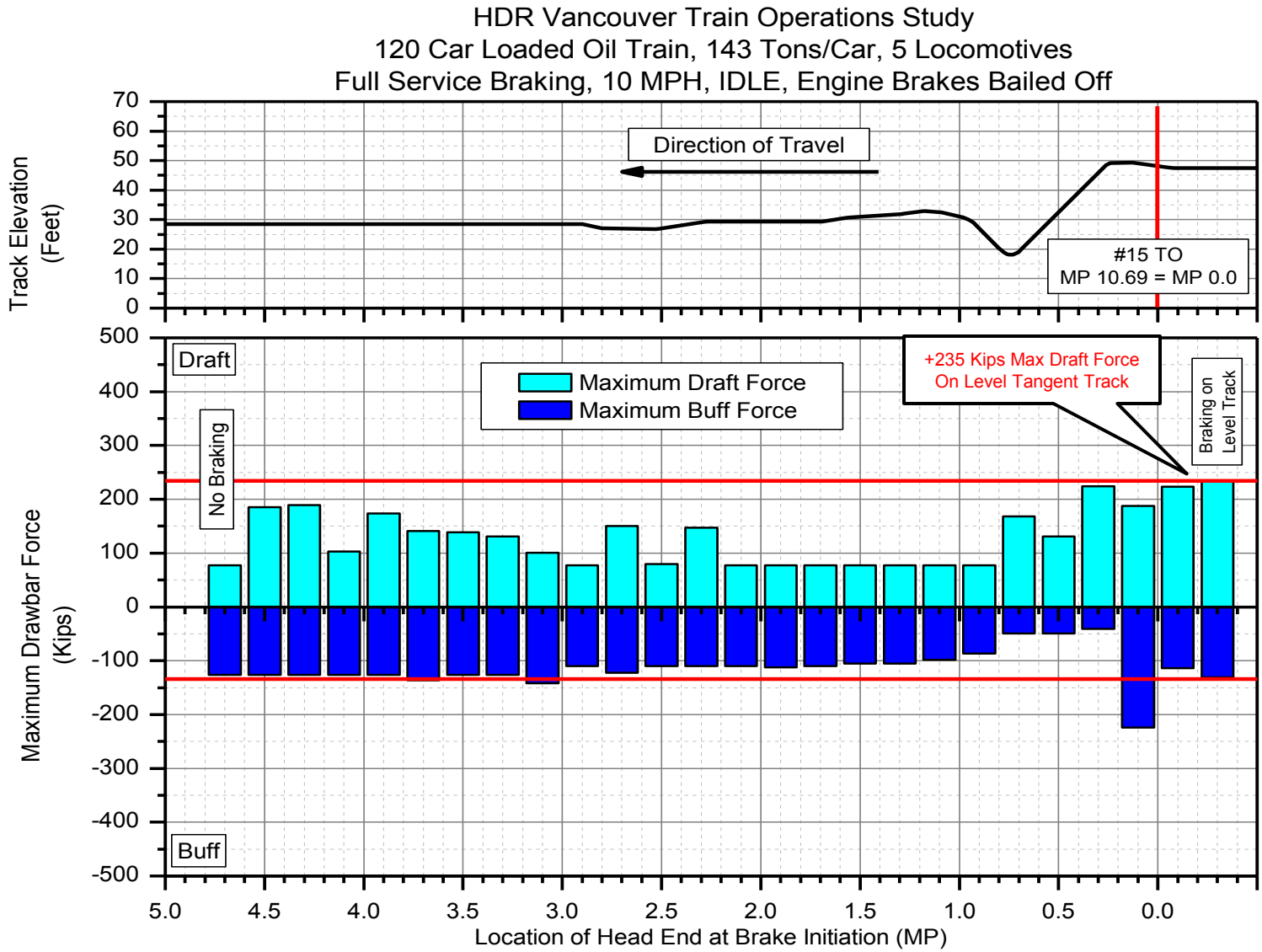
In-Train Force Analysis



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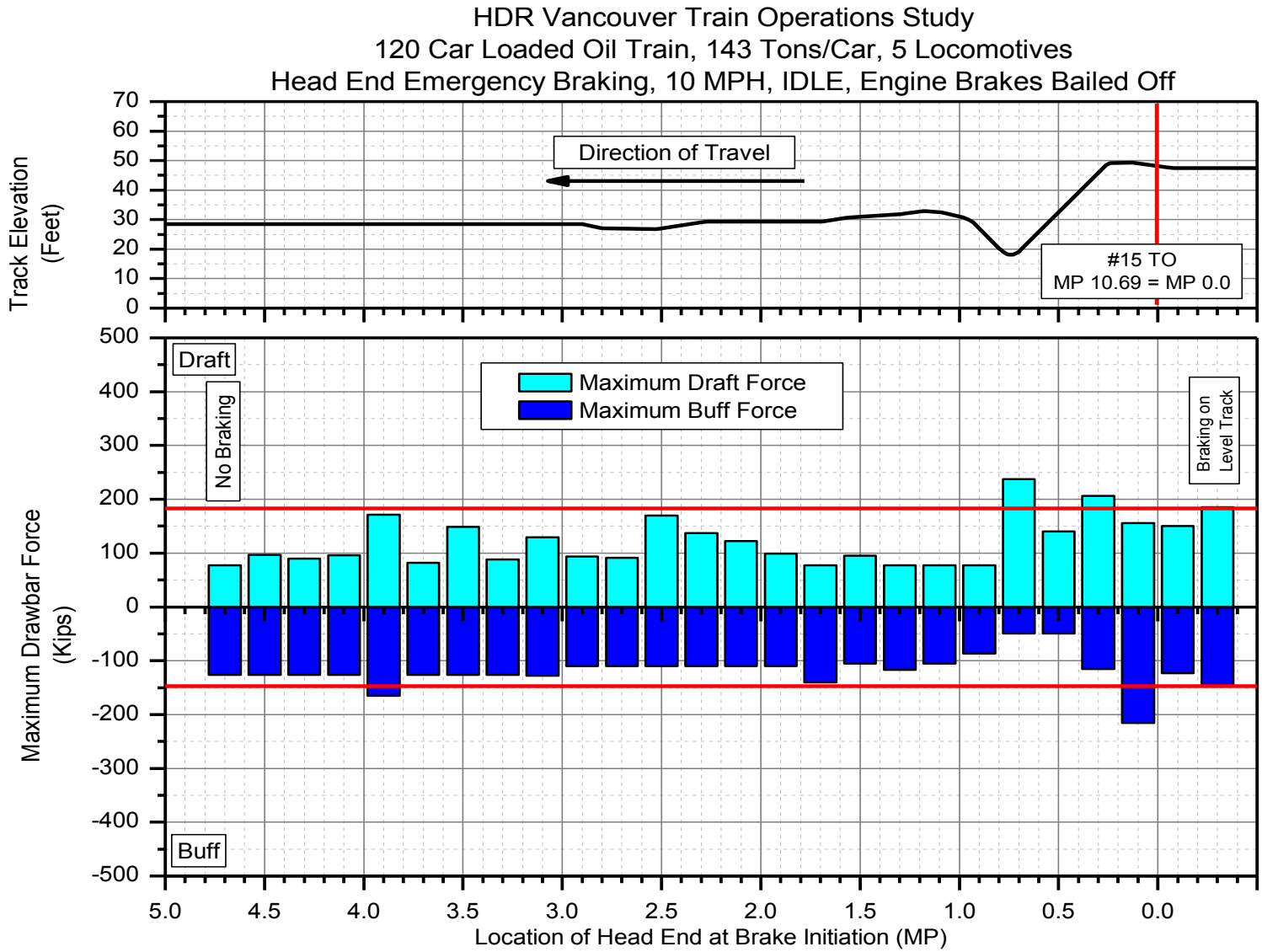
In-Train Force Analysis



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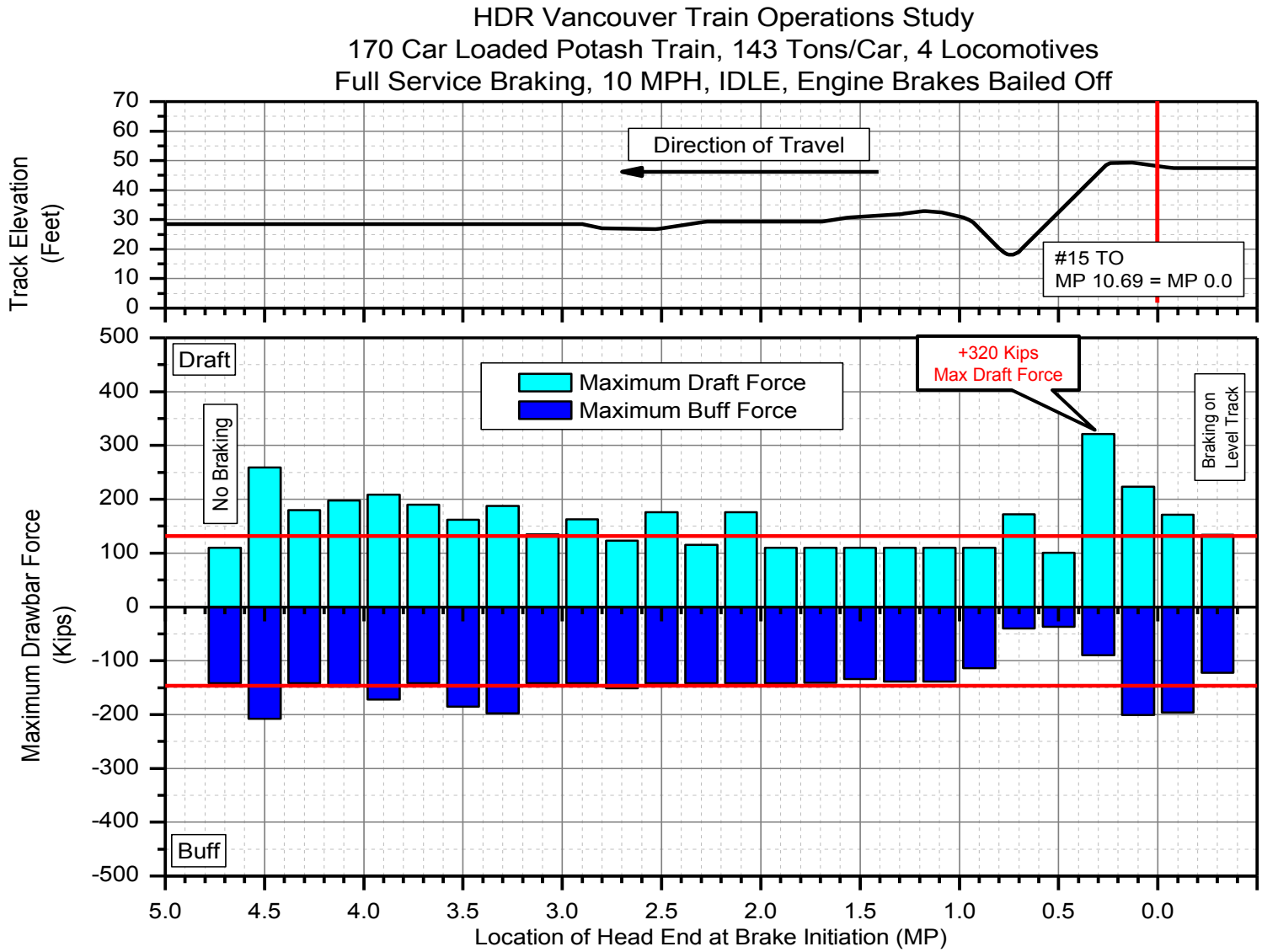
In-Train Force Analysis



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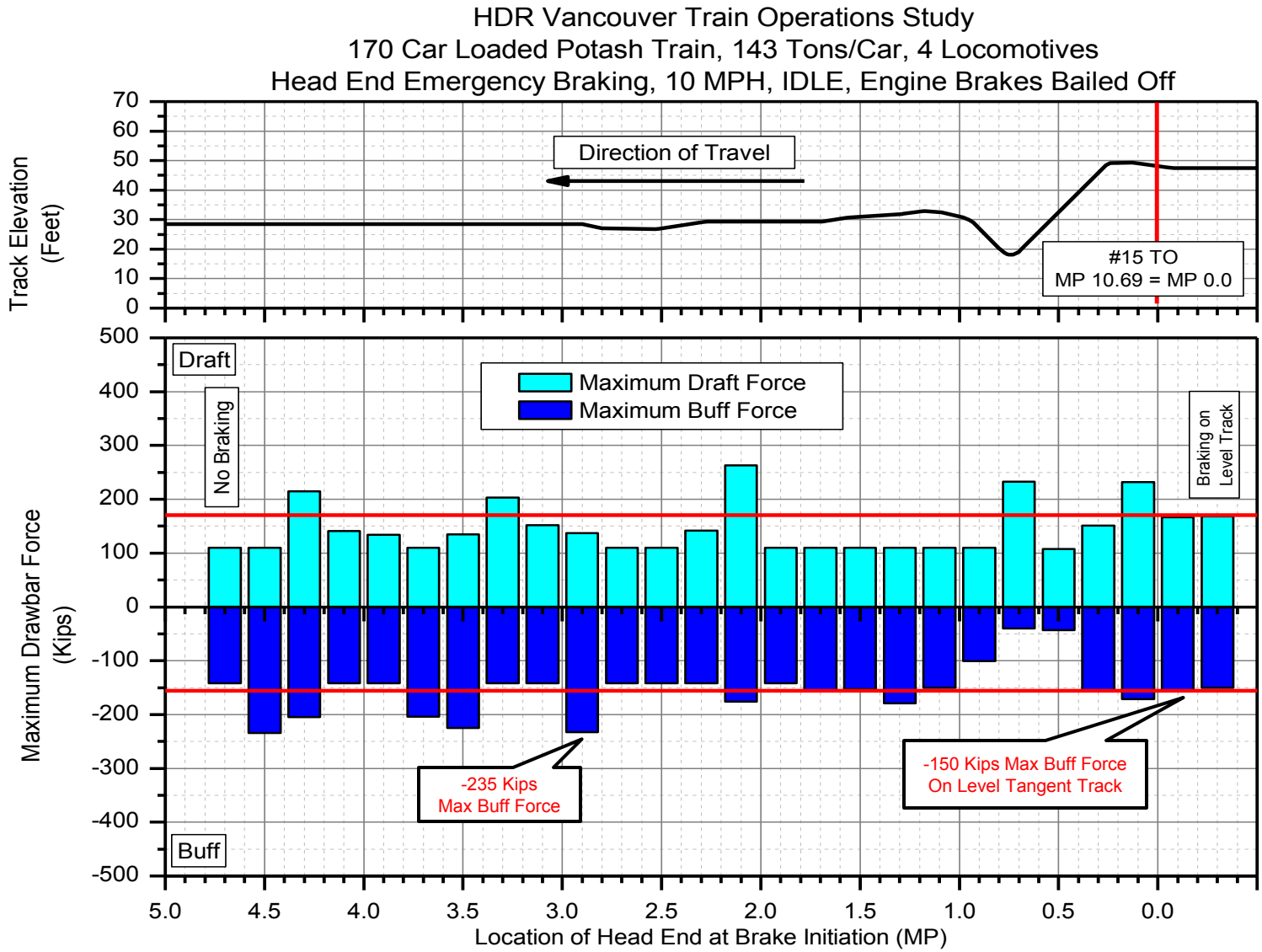
In-Train Force Analysis



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- The following table quantifies the maximum in-train longitudinal forces observed in all nominal and braking simulation scenarios above.

Table 1.0 Maximum Longitudinal Forces

Scenario			Maximum In-Train Longitudinal Forces (Kips)*									
Train	Consist		Nominal 10 MPH		Full Service Braking				Emergency Braking			
Type	Locomotives	Cars	Connection Track		Connection Track		Level Track		Connection Track		Level Track	
			Draft	Buff	Draft	Buff	Draft	Buff	Draft	Buff	Draft	Buff
Grain	C44-9 2x0x1	110 Covered Hoppers	115	-110	225	-185	225	-125	165	-140	150	-90
Fuel	C44-9 3x0x2	120 Tank Cars	75	-125	225	-225	235	-130	235	-215	185	-145
Potash	AC4400 2x0x2	170 Covered Hoppers	110	-140	320	-210	135	-120	265	-235	170	-150

* Note: Forces rounded to nearest multiple of 5.

In-Train Force Analysis Summary

- Longitudinal simulations using the TOS model show:
  - Moderate throttle and dynamic brake commands (RUN 5 through DYN 5) were sufficient to control train speed at 10 mph and operate through the proposed route.
  - All six trains simulated (3 loaded and 3 empty), using nominal train handling can move [with no stops] through the connection track without any adverse slack or steady-state forces. Maximum forces were predicted to be less than +115 kips draft and -140 kips buff for through-route operations.
  - These forces using nominal train handling on the proposed track are below the forces that would be generated in stops with the trains on level track and are considered low risk for derailment.
  - Even under full service and emergency braking conditions, worst-case maximum draft and buff forces did not exceed +320 kips and -235 kips buff, respectively. By comparison, emergency braking simulations on level track yielded lower worst case force maximums of +235 kips draft and -150 kips buff.
  - The worst case forces under full service and emergency braking on the proposed track have moderate potential to break a coupler [knuckle] in draft [train stretched] but low risk of derailing railcars in buff [train bunched] or draft.

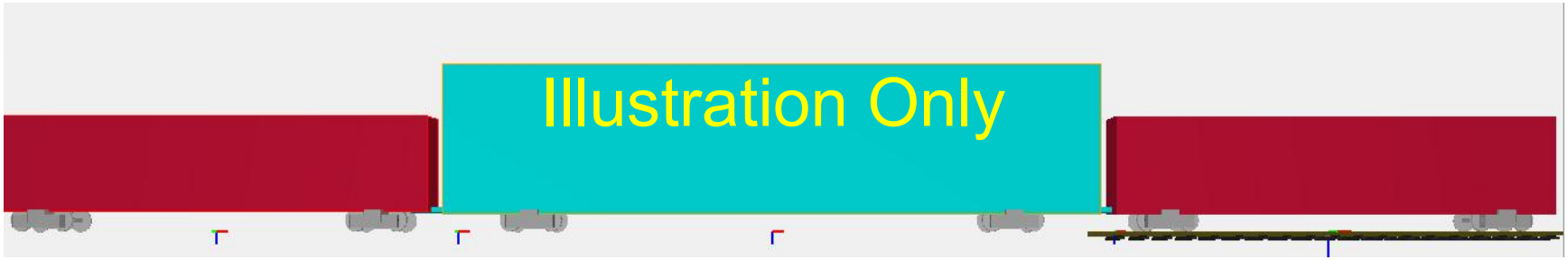
Vehicle Dynamics Simulation

- A vehicle dynamics simulation analysis was conducted using the VAMPIRE® computer simulation model to further:
  - Simulate effects of and inherent derailment risks associated with localized track anomalies.
  - Further assess if the in-train force levels predicted by TOS simulation are significant in conjunction with the presence of local track perturbations.
- Multicar vehicle models were used in order to take coupler angularity and in-train forces into account.
- All simulations were performed at 10 mph.
- Track models were created representing the as measured/designed track as well as models to include cross level dips of class 1 and 2 levels.
- The individual wheel L/V ratio, minimum percent vertical wheel load, axle sum L/V ratio and truck side L/V ratio (loaded vehicles only) were output from the simulations for the middle car of the 3-car sections as the indicator of derailment.

- Maximum buff and draft forces obtained from the longitudinal simulations for the loaded and unloaded vehicles were applied to the outside vehicles in the three car models to transmit the coupler forces at the appropriate magnitude and angle to the middle vehicle.
- This method allows the effects of the in-train forces to be included in the calculations of the derailment indicators.
- Outputs were compared with industry and AAR Chapter XI prescribed thresholds as indication of relative safe operations versus derailment.
- As reference, the following thresholds are traditionally utilized within the industry:
  - *Indicator of Wheel Climb Potential:*
    - » Common Industry Recommended L/V Threshold = 0.82
    - » AAR Chapter XI Standard Maximum L/V Threshold (for new car acceptance criteria) = 1.00
    - » AAR Chapter XI Standard Maximum Allowable Axle Sum L/V Ratio = 1.50
  - *Indicator of Wheel Lift Potential:*
    - » AAR Chapter XI Standard Minimum Allowable Percent Wheel Unloading = 10.0%
  - *Indicator of Potential to Shift the Rail Laterally or Roll the Rail:*
    - » AAR Chapter XI Standard Maximum Allowable Truck Side L/V Ratio = 0.60

Vehicle Dynamics Simulation

- Track models were created for the route in question in the following states:
  - As designed/measured based upon provided data.
  - With a class 1 cross level dip in a critical location.
  - With a class 2 cross level dip in a critical location.
- Vehicles were simulated to travel in both directions as appropriate to their loading condition.
- Critical locations [6° curves] were identified from initial simulations in both directions over the designed/measured track with the various vehicle models where derailment indicators from the simulations were at their relative maximums/minimums. See slide 28.
- Cross level dips of Class 1 and Class 2 levels were introduced at these critical locations and the simulations were repeated in order to investigate sensitivity to possible deviation from less than ideal geometry according to the track class. See slide 29.
- Vehicle dynamics simulation results for empty and loaded vehicles are presented on slides 30 – 36.



- Multi-car models of all vehicle types in both the loaded and unloaded states were used for the VAMPIRE simulations so that in-train forces calculated from the longitudinal simulations and coupler angularity could be included as the vehicles move over the route in question.
- As vehicles move through curves and over track geometry features, the forces being applied through the couplers will change directions along with the couplers.
- The angles that the couplers take, and the subsequent changing directions of action of their forces have a significant effect at the wheel/rail interface.
- The multi-car model is capable of taking this into account during simulation. The maximum forces calculated in the train handling simulations for the various vehicles and loading conditions were applied throughout the corresponding VAMPIRE simulations to obtain the most conservative results.

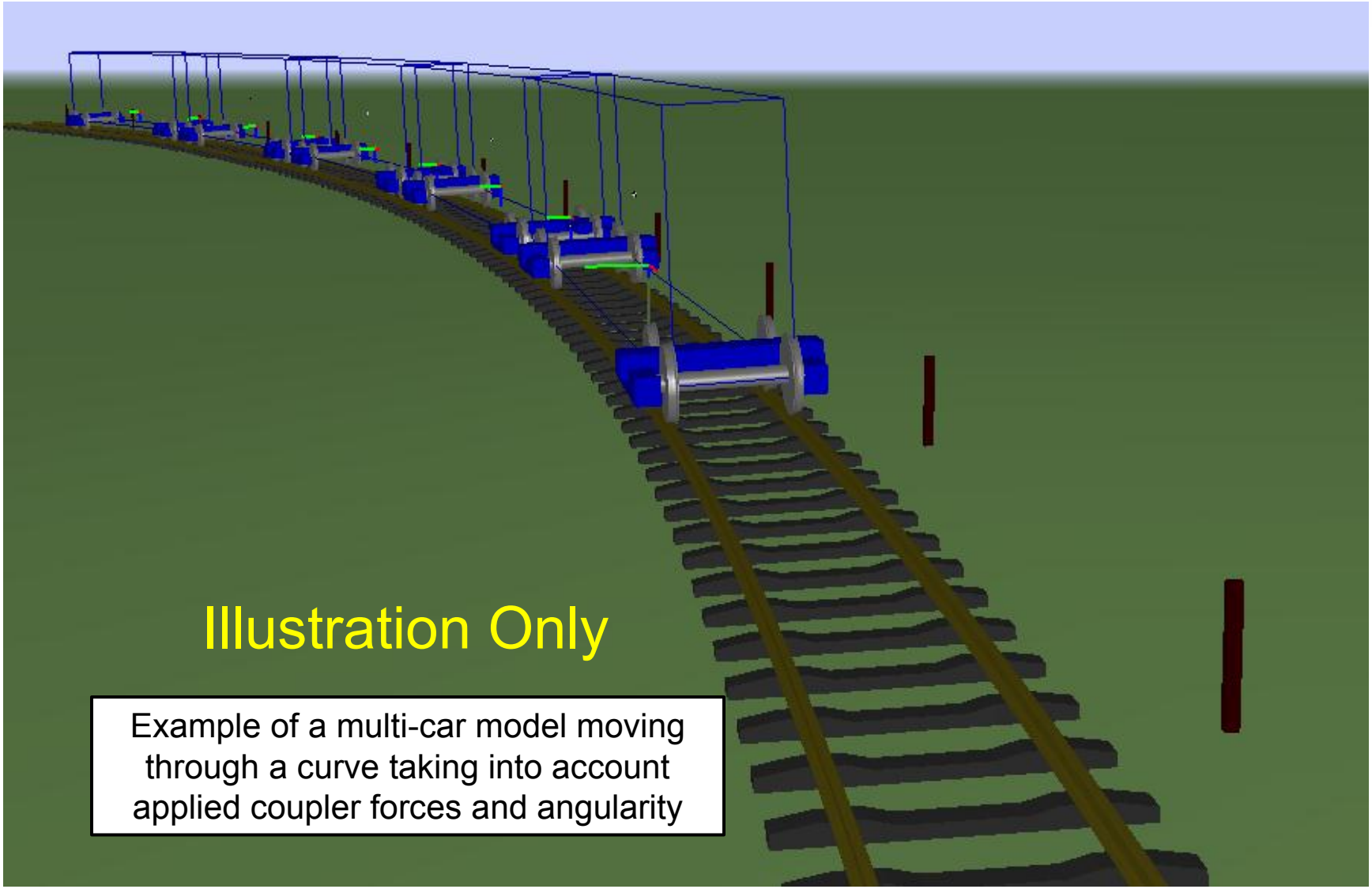
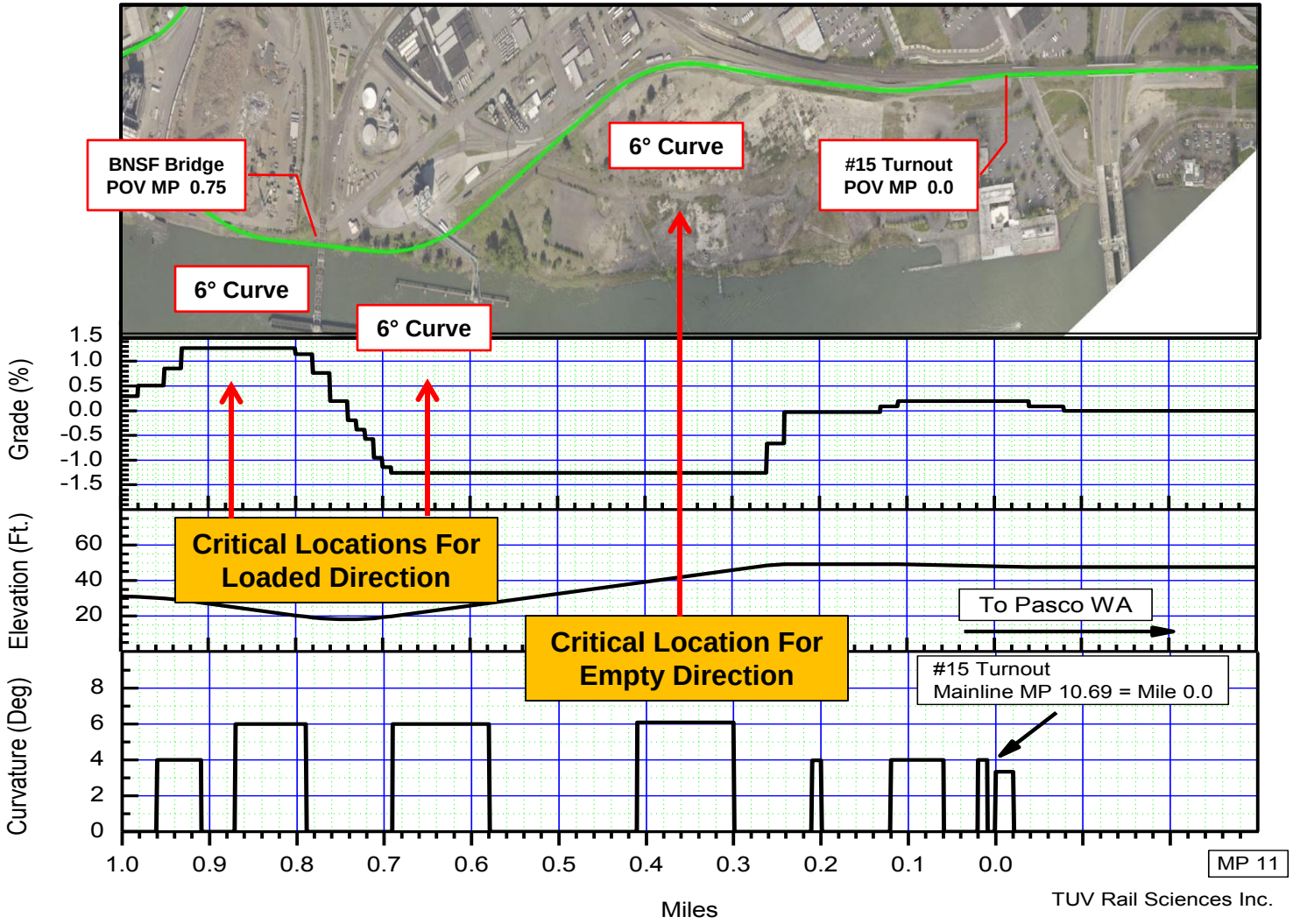


Illustration Only
Example of a multi-car model moving through a curve taking into account applied coupler forces and angularity

Port of Vancouver Connection Track Profile



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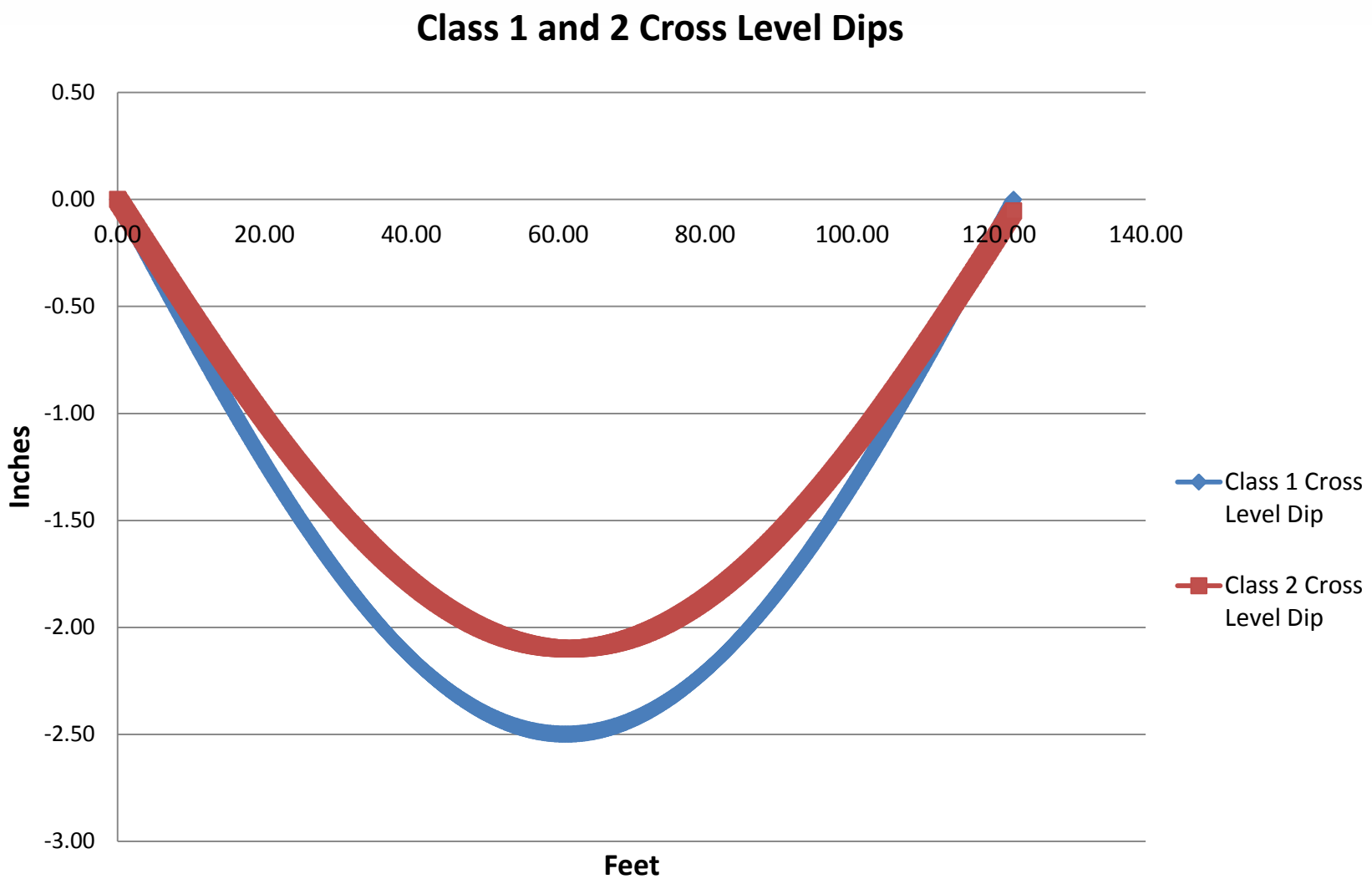

- Cross level dips inserted at critical locations indicated on previous slide.

Vehicle Dynamics Results – Empty Vehicles

Maximum Individual Wheel L/V Ratio				
Vehicle	In-Train Force	As Designed Track	Class 1 Cross Level Dip	Class 2 Cross Level Dip
Grain Car Empty	200 Kips Buff	0.54	0.73	0.71
	200 Kips Draft	0.36	0.35	0.35
	None	0.42	0.50	0.50
Potash Car Empty	200 Kips Buff	0.52	0.60	0.59
	200 Kips Draft	0.35	0.35	0.35
	None	0.43	0.41	0.42
Tanker Car Empty	200 Kips Buff	0.55	0.74	0.73
	200 Kips Draft	0.36	0.39	0.35
	None	0.43	0.56	0.54

- *Indicator of Wheel Climb Potential:*
  - Industry Recommended Maximum Allowable L/V Ratio = 0.82
  - AAR Chapter XI Standard Maximum Allowable L/V Ratio = 1.00

Vehicle Dynamics Results – Empty Vehicles

Minimum % Wheel Unloading				
Vehicle	In-Train Force	As Designed Track	Class 1 Cross Level Dip	Class 2 Cross Level Dip
Grain Car Empty	200 Kips Buff	65.62	31.69	34.08
	200 Kips Draft	73.06	41.06	43.53
	None	81.36	51.15	53.41
Potash Car Empty	200 Kips Buff	70.92	39.51	41.47
	200 Kips Draft	77.65	47.48	49.98
	None	83.54	52.02	55.11
Tanker Car Empty	200 Kips Buff	67.33	29.91	32.69
	200 Kips Draft	67.46	35.99	39.18
	None	80.35	50.73	52.21

- *Indicator of Wheel Lift Potential:*
  - AAR Chapter XI Standard Minimum Allowable Percent Wheel Unloading = 10.0%

Vehicle Dynamics Results – Empty Vehicles

Maximum Axle Sum L/V Ratio				
Vehicle	In-Train Force	As Designed Track	Class 1 Cross Level Dip	Class 2 Cross Level Dip
Grain Car Empty	200 Kips Buff	0.88	1.07	1.07
	200 Kips Draft	0.58	0.64	0.64
	None	0.76	0.84	0.84
Potash Car Empty	200 Kips Buff	0.86	0.96	0.95
	200 Kips Draft	0.57	0.63	0.61
	None	0.77	0.77	0.76
Tanker Car Empty	200 Kips Buff	0.89	1.09	1.09
	200 Kips Draft	0.62	0.69	0.69
	None	0.77	0.91	0.89

- *Indicator of Wheel Climb Potential:*
  - AAR Chapter XI Standard Maximum Allowable Axle Sum L/V Ratio = 1.50

Vehicle Dynamics Results – Loaded Vehicles

Maximum Individual Wheel L/V Ratio				
Vehicle	In-Train Force	As Designed Track	Class 1 Cross Level Dip	Class 2 Cross Level Dip
Grain Car Loaded	300 Kips Buff	0.44	0.58	0.56
	300 Kips Draft	0.34	0.50	0.48
	None	0.39	0.56	0.54
Potash Car Loaded	300 Kips Buff	0.43	0.59	0.57
	300 Kips Draft	0.34	0.52	0.50
	None	0.39	0.56	0.54
Tanker Car Loaded	300 Kips Buff	0.43	0.57	0.55
	300 Kips Draft	0.34	0.50	0.48
	None	0.39	0.54	0.53

- *Indicator of Wheel Climb Potential:*
  - Industry Recommended Maximum Allowable L/V Ratio = 0.82
  - AAR Chapter XI Standard Maximum Allowable L/V Ratio = 1.00

Vehicle Dynamics Results – Loaded Vehicles

Minimum % Wheel Unloading				
Vehicle	In-Train Force	As Designed Track	Class 1 Cross Level Dip	Class 2 Cross Level Dip
Grain Car Loaded	300 Kips Buff	82.58	55.75	58.35
	300 Kips Draft	90.30	66.23	69.22
	None	90.78	60.95	63.31
Potash Car Loaded	300 Kips Buff	86.29	58.83	61.01
	300 Kips Draft	91.89	67.13	69.83
	None	91.05	62.36	65.32
Tanker Car Loaded	300 Kips Buff	83.86	56.96	59.42
	300 Kips Draft	90.60	68.37	70.75
	None	90.87	62.09	64.75

- *Indicator of Wheel Lift Potential:*
  - AAR Chapter XI Standard Minimum Allowable Percent Wheel Unloading = 10.0%

Vehicle Dynamics Results – Loaded Vehicles

Maximum Axle Sum L/V Ratio				
Vehicle	In-Train Force	As Designed Track	Class 1 Cross Level Dip	Class 2 Cross Level Dip
Grain Car Loaded	300 Kips Buff	0.77	0.92	0.90
	300 Kips Draft	0.65	0.84	0.82
	None	0.73	0.89	0.87
Potash Car Loaded	300 Kips Buff	0.76	0.93	0.91
	300 Kips Draft	0.66	0.86	0.84
	None	0.72	0.90	0.88
Tanker Car Loaded	300 Kips Buff	0.76	0.91	0.89
	300 Kips Draft	0.67	0.84	0.82
	None	0.73	0.88	0.86

- *Indicator of Wheel Climb Potential:*
  - AAR Chapter XI Standard Maximum Allowable Axle Sum L/V Ratio = 1.50

Vehicle Dynamics Results – Loaded Vehicles

Maximum Truck Side L/V Ratio				
Vehicle	In-Train Force	As Designed Track	Class 1 Cross Level Dip	Class 2 Cross Level Dip
Grain Car Loaded	300 Kips Buff	0.31	0.37	0.36
	300 Kips Draft	0.30	0.28	0.27
	None	0.28	0.33	0.32
Potash Car Loaded	300 Kips Buff	0.31	0.37	0.37
	300 Kips Draft	0.31	0.31	0.30
	None	0.29	0.35	0.34
Tanker Car Loaded	300 Kips Buff	0.32	0.39	0.38
	300 Kips Draft	0.33	0.32	0.31
	None	0.30	0.36	0.35

- *Indicator of Potential to Shift the Rail Laterally or Roll the Rail:*
  - AAR Chapter XI Standard Maximum Allowable Truck Side L/V Ratio = 0.60

Vehicle Dynamics Results Summary

- VAMPIRE simulations indicate a low risk for derailment for the proposed operation assuming properly maintained track and railcars.
  - Maximum L/V ratio predicted under all conditions was 0.74 observed on the *empty* tank car. This result is below the recommended industry maximum of 0.82 and the AAR Chapter XI maximum allowable threshold of 1.00.
  - Minimum percent wheel unloading predicted under all conditions was 29.9% observed on the *empty* tank car. This is nearly three times greater than the AAR Chapter XI minimum allowable threshold of 10.0%.
  - Maximum axle sum L/V ratio predicted under all conditions was 1.09 observed on the *empty* tank car. This result is more than 25% below the AAR Chapter XI maximum allowable threshold of 1.50.
  - Maximum truck side L/V ratio predicted under all conditions was 0.39 observed on the *loaded* tank car. This is well below the AAR Chapter XI maximum allowable threshold of 0.60.

Conclusions and Recommendations

- TÜV-RSI concluded from the in-train force and vehicle dynamics analyses that the proposed operation and track configuration is acceptable with a low potential for derailment.
- TÜV-RSI recommends the following to further mitigate risk:
  - Construct the track structure with new concrete or wooden ties, premium fasteners, and continuously welded rail [136 – 141 pound] to maintain a robust and less dynamically varying track structure.
  - Perform [VERSE] rail neutral temperature measurements during track construction to properly set track neutral temperature. Periodically monitor track neutral temperature following construction.
  - Maintain track to a *minimum* Class 2 standard to reduce levels of allowable track deviation and the associated risks of local track perturbations over time.
  - Install a high guard rail frog on #15 turnout, MP 10.69, and double guard rail on the connection track between #15 turnout and the BNSF overhead bridge, POV MP 0.75, to lessen the potential of significant derailment and damage.
  - Maintain gage face lubrication in curves to encourage proper railcar steering, lessen curve binding, the potential for rail climb, and rail wear.
  - Periodically measure track geometry and perform vehicle dynamics simulations to ensure safety against derailment as the track changes over time.
  - BNSF remotely operate and monitor the connecting track turnouts between the BNSF main line and Port of Vancouver yard tracks to ensure a clear route for trains entering or exiting the Port.

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