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Very Long Trains – Phase IV Moving Train Tests

DOT/FRA/ORD-24/20

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13. ABSTRACT (Maximum 200 words)

In the final phase of this research project, a team from Sharma & Associates, Inc. conducted moving train tests on a 228-car, Distributed Power (DP) configured train consist traveling from Minot, ND, to Vancouver, WA, using a Burlington Northern and Santa Fe (BNSF) train and crew. This research was conducted in July of 2023. The team used a test train that was just over 14,000 ft long with a trailing tonnage of approximately 31,300 tons, traveling about 1300 miles over plains, mountains, and rolling terrain. Eight instrumented cars were interspersed throughout the train and collected data on train dynamics and brake system performance.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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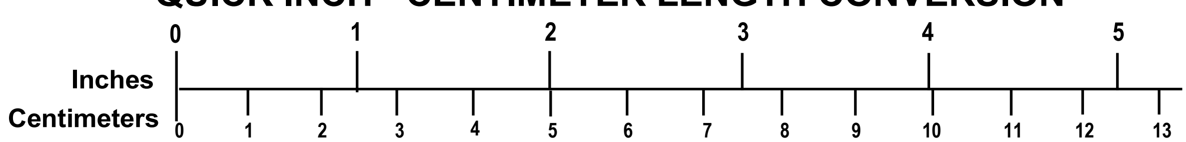
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

While there are no federal or state statutes governing train length, the Federal Railroad Administration (FRA) reviews and monitors train performance and accepted practices for long train (termed Very Long Train or VLT for purposes of this report) operations through tests and simulations to confirm the safe performance of the air brake system as well as resulting train dynamics. FRA initiated a multi-phase collaborative study of VLT operations steered by a Test Review Committee (TRC) comprised of FRA, Class I railroads, labor unions, and air brake equipment manufacturers, with a specific focus on brake system performance and train dynamics considerations.

In the final phase of this research project, a team from Sharma & Associates, Inc. conducted moving train tests on a 228-car, Distributed Power (DP) configured train consist traveling from Minot, ND, to Vancouver, WA, using a Burlington Northern and Santa Fe (BNSF) train and crew. This research was conducted in July of 2023. The team used a test train that was just over 14,000 ft long with a trailing tonnage of approximately 31,300 tons, traveling about 1300 miles over plains, mountains, and rolling terrain. Eight instrumented cars were interspersed throughout the train and collected data on train dynamics and brake system performance.

Prior work on this project included airbrake rack testing on trains comprising up to 200 cars, which documented brake system performance under a conventional (head-end only) locomotive configuration, as well as stationary train testing on a 200-car train, which documented brake system performance under head-end only and multiple DP configurations.

Researchers noted no unusual events (e.g., knuckle breaks) or notable instances of significant slack action or run-ins/run-outs at the lead locomotive during the test. Data from the instrumented cars were synchronized with data from the locomotive event recorders and analyzed to evaluate sections of interest, and the team selected a few critical events with relatively high in-train forces for more detailed review. Researchers identified multiple instances of elevated buff forces on the cars around the mid-locomotive consist when these cars traversed terrain with the front portion of the long train on an ascending grade and the rear portion of the train on a descending grade. In such scenarios, the front of the train slowed as it climbed the grade while the rear cars on the descending grade ran-in from behind, leading to high coupler forces on the middle cars at the bottom of the sag.

The research team assessed brake system performance based on data collected during emergency and full-service applications. The brake system performed as expected for a long train in a DP configuration.

Testing was conducted under relatively good conditions (e.g., a uniformly loaded unit train; DP consists in the front, mid, and rear; low leakage; no obvious malfunctioning equipment; generally good weather conditions). Researchers believe that changing these variables could reveal safety gaps, and the team recommends that such variables be studied through a combination of additional testing and simulations. Additional train testing using the instrumented box cars should include:

1. Testing of a unit train under cold weather conditions
2. Testing of a mixed manifest train
3. Conducting a test using an Eastern Railroad, as such tracks have a different mix of grades and curves

Recommended simulation effort should cover various non-ideal conditions, such as:

1. Extreme weather (e.g., hot/cold) performance of rolling stock
2. Malfunctioning equipment (e.g., brake valves, locomotive control systems, etc.)
3. Poor train makeup conditions (e.g., a mix of empty and loaded cars or cushioning units)
4. Non-ideal or complex train operations (e.g., false gradient operations, fencing, etc.)

Prior to undertaking additional simulation efforts, the research team recommends validating the simulation software to confirm and more thoroughly investigate factors contributing to the elevated coupler forces observed during the tests.

The research team also recommends additional analysis to quantify the fatigue performance of car structures and other mechanical components from the coupler forces measured during the tests. This analysis will allow better understanding of how running VLTs affects the expected durability of rolling stock mechanical components.

1. Introduction

In the final phase of a multi-phase research project, a team from Sharma & Associates, Inc. conducted moving train tests on a 228-car, Distributed Power (DP) configured train consist traveling from Minot, ND, to Vancouver, WA, using a Burlington Northern and Santa Fe (BNSF) train and crew. This research was conducted in July of 2023. The team used a test train that was just over 14,000 ft long with a trailing tonnage of approximately 31,300 tons, traveling about 1300 miles over plains, mountains, and rolling terrain. Eight instrumented cars were interspersed throughout the train and collected data on train dynamics and brake system performance. Prior work on this project included airbrake rack testing on trains comprising up to 200 cars, which documented brake system performance under a conventional (head-end only) locomotive configuration, as well as stationary train testing on a 200-car train, which documented brake system performance under head-end only and multiple DP configurations.

1.1 Background

While there are no federal or state statutes governing train length, the Federal Railroad Administration (FRA) reviews and monitors train performance and accepted practices for long train (termed Very Long Train or VLT for purposes of this report) operations through tests and simulations to confirm the safe performance of the air brake system as well as resulting train dynamics. FRA initiated a multi-phase collaborative study of VLT operations steered by a Test Review Committee (TRC) comprised of FRA, Class I railroads, labor unions, and air brake equipment manufacturers, with a specific focus on brake system performance and train dynamics considerations.

FRA sponsored a VLT study comprising four phases, in a logical sequence designed to gain maximum benefits as data and understanding of the system behavior became available after each phase. An overview of the scope of work for each of these phases is described below.

- Phase I: Investigate expected air brake performance of VLTs through modeling, using longitudinal train dynamics software capable of simulating air brake system and train dynamics, such as coupler forces and slack action due to train handling. This phase determined the need for further research; no publication was generated from this phase.
- Phase II: Conduct a series of air brake rack tests with up to 200 control valves and quantify the air brake performance of the VLT for Head End (HE) only train configuration.
- Phase III: Perform tests on a stationary VLT with 200+ cars, with both HE and Distributed Power (DP) configurations, to understand the impact of high leakage conditions at various air brake applications.
- Phase IV: Conduct tests on a moving train to capture dynamics resulting from braking operations and train handling.

In a prior phase of this work, researchers conducted a series of air brake rack tests with up to 200 airbrake control valves representing a 200-car train [1]. Subsequently, with the support of BNSF Railway, the research team performed stationary train tests on a 200-car train in the BNSF yard at Staples, MN, between July 18 and 28, 2022. The objective of the stationary train tests was to understand the impact of leakage conditions, and various air brake applications on five Head End (HE) and DP configurations. The research team issued a draft report summarizing the results of this research in 2023 [2].

The stationary train tests helped to quantify the advantages of using a DP configuration over an HE configuration; test data showed that brake signal propagation, release times, and recharge times were faster for the DP trains with shorter distances between air sources. Also, better braking capability with higher brake cylinder pressure and faster brake cylinder pressure build up times were achieved for DP trains due to shorter distances between two air sources. Analysis of the test results highlighted the need to account for the slower response and slightly reduced brake cylinder pressure in VLTs in a HE-only train configuration. Researchers found that longer recharge times in the HE configuration required longer waits in cycle braking situations to avoid potential unintended brake release situations. The team also found that unintended release in the HE configuration did not occur with the false gradient when the first application was followed by a deeper second application.

1.2 Objectives

The goal of this research was to better understand the dynamic performance of VLTs by collecting and analyzing in-train coupler forces, car accelerations, and brake system data during revenue service operation of a loaded unit train with 200 or more cars. These tests covered normal train handling operations under current railroad operating practices as well as specific test cases requested by the TRC for the territory in which the revenue service tests were conducted. The data from the research were analyzed to study the impact of VLT operations on in-train dynamics and brake system performance. The results of this effort will also be used to further validate the longitudinal train dynamics models.

1.3 Overall Approach

The team conducted a test run on a revenue service train that was at least 200 cars long, over a varied route that was at least 1,000 miles long, with eight instrumented box cars interspersed throughout the train to measure and document brake system and train dynamics performance. A test plan was prepared in consultation with the TRC describing the train, test route, instrumentation, and data collection requirements.

The test plan required instrumented couplers and accelerometers be installed on the eight DOTX box cars that were used in the previous stationary train tests. The proposed test train comprised 200 or more loaded grain hopper cars, and the instrumented DOTX cars were distributed along the length of the train. Data was collected during revenue service operation of the test train over a 1,300-mile route between Minot, ND, and Vancouver, WA.

1.4 Scope

The focus of the moving train test was to assess the performance of the air brake system and evaluate in-train dynamics of a VLT during revenue service operation. The data was collected over a 1,300-mile route, covering a mix of prairies, mountains, and rolling terrain. Locomotive engineer(s) operated the train using standard railroad operating practices.

1.5 Organization of the Report

This report is structured as follows:

Section 2 describes the testing, including instrumentation, data collection, and train operation details.

Section 3 analyzes the data from the instrumented cars for selected events where peak buff and draft coupler forces were recorded. The coupler data have been juxtaposed with the location, terrain, and event recorder data to understand the reasons for the high coupler forces.

Section 4 discusses air brake performance based on the data collected during full service and emergency brake applications on the stationary train.

Section 5 summarizes the results of the study.

Section 6 lists recommendations for future work.

Appendix A contains the detailed test plan.

Appendix B contains the complete train consist.

2. Test Description

2.1 Overview

VLT revenue service testing was conducted on the BNSF rail network. The test train consisted of 220 loaded hopper grain cars and eight instrumented DOTX box cars (Appendix B contains the train consist information). The train was operated using BNSF's ES44DC locomotives in a DP configuration. The train headed westward from BNSF's yard in Minot, ND, with two locomotives at the head end, three remote locomotives in the middle, and one locomotive at the rear end (2+3+1 configuration). The train was just over 14,000 ft. in length with a trailing tonnage of about 31,300 tons. A section of the train is shown in Figure 1. The revenue service train was headed west from Minot, ND, to Vancouver, WA, a route that was approximately 1,300 miles long and consisted of a mix of plains, rolling terrain, and mountains. Two pusher locomotives were added at Havre, MT, for operating the long, heavy train over mountainous terrain as it headed westward. A map of the route is shown in Figure 2.

Figure 1. Part of Test Train

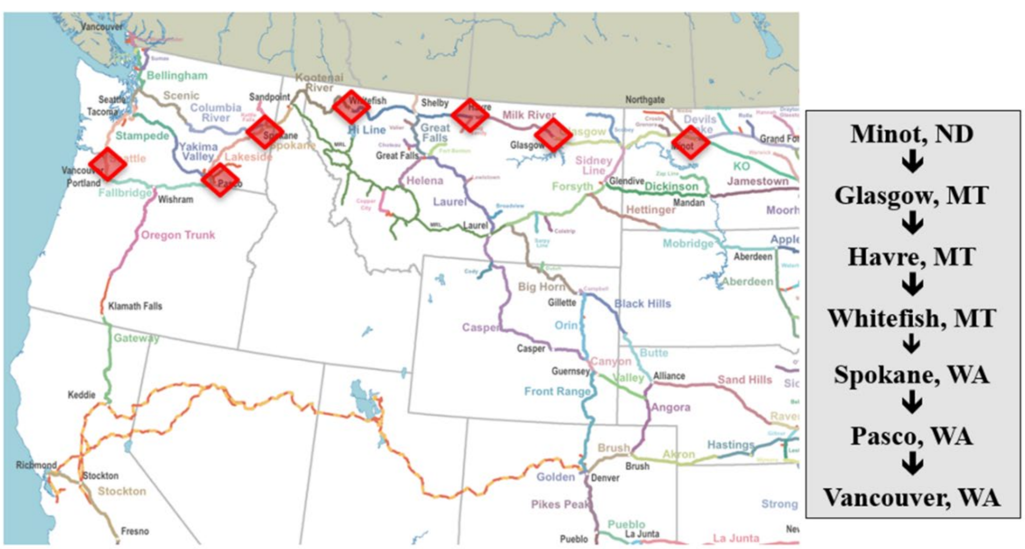

Figure 2. Test Route

2.2 Instrumentation and Data Collection

Eight ballasted box cars, instrumented appropriately to monitor and record pressures in the brake pipe (BP), brake cylinder (BC), Auxiliary Reservoir (AR), and Emergency Reservoir (ER) were used in the moving train test. These eight box cars had been used in the previous testing, as well.

A calibrated, instrumented coupler was installed at the front end of each of these cars to measure coupler forces. Figure 3 shows one of the instrumented couplers installed on a DOTX box car. An accelerometer was installed on the floor in the middle of each car to measure car acceleration in the moving train. In addition, each instrumented car had a Global Positioning System (GPS) antenna that recorded time, location in terms of latitude and longitude, and the car speed.

Figure 3. Instrumented Coupler Mounted on a DOTX Car

The instrumented cars in the test train are shown below in Figure 4, labeled by the car number (e.g., DOTX-238) and the vehicle location in the train (e.g., Vehicle #3). The eight cars were placed sequentially and strategically along the train. DOTX 238 was located directly behind the head end locomotives. The second and third instrumented cars were located at one third and two thirds points in the front section of the train with the fourth instrumented car (DOTX 235) ahead of the mid locomotive consist. The remaining four instrumented cars were arranged in a similar manner in the rear section of the train, behind the mid locomotive consist. There were no leakage ports added to induce leakage in the brake pipe; the test train was operated with natural leakage.

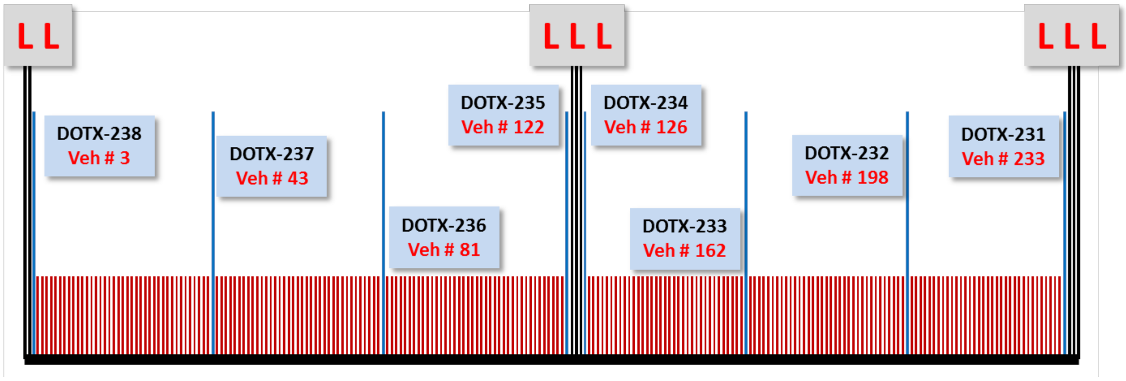

Figure 4. Train Make-up

The data from the instrumented cars were collected using a SOMAT eDAQLite system. The interior of an instrumented box car is shown in Figure 5 and the data collection device setup is shown in Figure 6. Additional details are provided in the test plan document in Appendix A. Instrumented car data were collected at 100 samples per second with a hardware cutoff frequency of 33.3 Hz.

Figure 5. Inside of Instrumented Box Car DOTX 234

Figure 6. eDAQLite Device Setup

Event Recorder data for the three consists was obtained from the railroad and is recorded at one sample per second. The team also obtained track charts for the entire test route.

2.3 Train Operation

The speed data from instrumented box car DOTX 238 is plotted in Figure 7 for the entire test run. Total trip time from Minot, ND, to Vancouver, WA, was approximately 58 hours at an average train speed just over 22 mph. The train was operated partially under Trip Optimizer (TO) and partially under manual modes. A Subject Matter Expert (SME) and an FRA representative were alternatively riding the lead locomotive in the test train during the 58-hour trip. There were no unusual events (e.g., a knuckle break, etc.) observed during the test. There weren't notable instances of significant slack action, run-ins/run-outs, etc. at the lead locomotive.

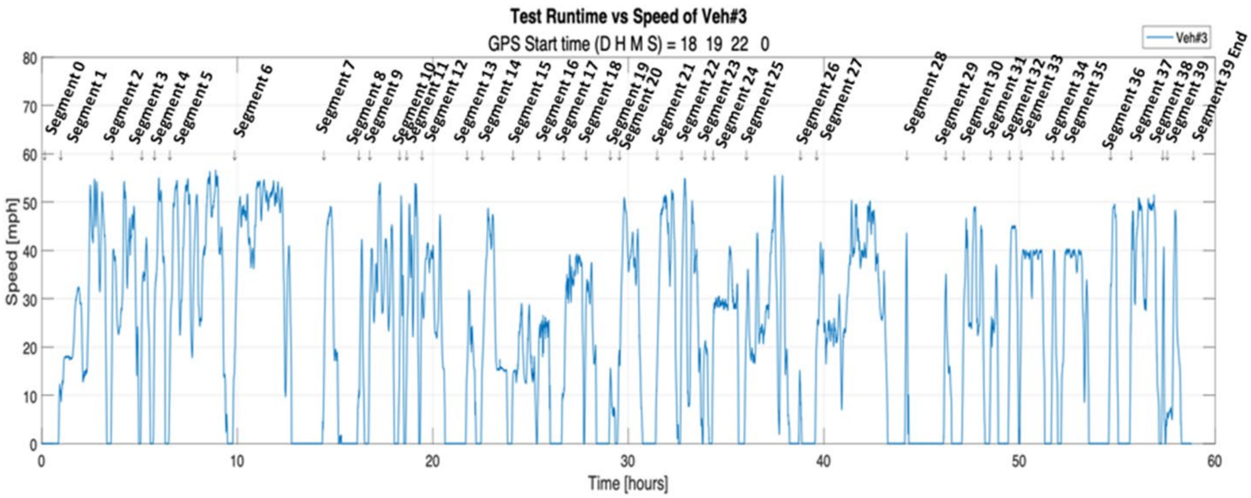

Figure 7. Speed data from DOTX 238

The train made several stops along the route, as indicated by instances of zero speed in the plot. For data analysis purposes, the test run was divided into 39 segments, each segment representing the train operation between two stops. The train was stopped either for railroad signal or crew change at the end of each segment.

Before the train left Minot, a stepped, full-service brake application was made on the stationary train to provide data for assessment of brake system performance. The brake application was initiated with a minimum brake application, followed by additional brake pipe reductions to 10 psi, 15 psi, and finally, 26 psi to achieve the full-service brake. The brake cylinder and brake pipe data collected from this test were used to assess the brake system performance, as described in Section 4.2 Once the train left Minot, the locomotive engineer used a combination of dynamic and air brakes as part of normal revenue service operation to control the train speed or bring the train to a stop. At the request of the test team, an emergency brake application was made when the train was stopped in Segment 5. The details of the data analysis are discussed in Section 4.1. In Segment 15, the test team asked the engineer to bring the train to a stop on a steep descending grade. At the end of the line, the locomotive engineer repeated the tests with full service and emergency brake applications on the stationary train in Vancouver, WA.

3. Data Analysis

In this section, some critical test scenarios are described and results of the data analysis presented, considering the terrain from the track charts and train handling input from the event recorder data.

3.1 Approach

BNSF provided the train consist data for the test train and the locomotive Event Recorder (ER) downloads from 1) BNSF 7733 in the lead consist, 2) BNSF 7754 in the mid consist, and 3) BNSF 7645 in the rear consist. Data synchronization first was performed between the locomotives and the test cars, and the SOMAT data from the eight instrumented cars were synchronized with the locomotive ER data.

The team reviewed the coupler force data from the instrumented DOTX cars to investigate run-in/run-out events. Run-in events create buff (i.e., compression) forces and run-out events create draft (i.e., tensile) forces at the couplers between any two cars in the train. Table 1 lists the values of peak buff and draft forces in kilo-pounds recorded in the instrumented cars in 16 instances at various locations on the test route (denoted by segment numbers) during the test run. In the following sections, seven scenarios from this list (five buff and two draft cases, highlighted in yellow) are discussed in more detail along with a test case where the train was brought to an intentional stop on a 1.8 percent descending grade.

Table 1. Peak Coupler Force (Unit in Kips)

DOTX Car #	Vehicle Location in Train	Buff Force		Draft Force	
		Kips	Segment #	Kips	Segment #
235	122	-406	14	393	16
234	126	-382	9	348	15
231	233	-376	14	374	28
233	162	-329	9	346	28
232	198	-322	9	370	28
236	81	-377	9	356	16
237	43	-318	9	314	38
238	3	-173	38	273	13

3.2 Maximum Buff Force on Vehicle 122 on Segment 14

The highest buff force of -406 kips was recorded on Vehicle 122 (DOTX 235) during Segment 14, located in the Hi-Line Subdivision of BNSF's Montana Division. The location of the car is shown on the map in Figure 8.

At the time of the peak force, the train was being operated in Manual mode (no Trip Optimizer), and was traveling at a speed of approximately 45 mph, with all the consists in Throttle Notch 8; there was no air brake application.

DOTX 235 was located just ahead of the mid-train locomotive consist, as noted in Figure 9. The train location at the time of the peak buff force occurrence is indicated by an orange line on the track chart in the figure. The front section of the train was on an ascending grade and the rear section was behind the Vehicle 122 on a descending grade. The peak buff force occurred when the car was at the bottom of the sag. The measured coupler forces for all the instrumented cars are plotted in Figure 10 for a duration of 15 seconds, along with speed, BP pressure, throttle position, and altitude data from Vehicle 3 (DOTX 238, as a proxy for the lead end of the train).

When the data including layout of the track, location of the train on the mountainous terrain, and train handling are considered together, it is likely that the front section of the train was slowing due to the ascending grade, and that the rear section of the train was speeding up due to the descending grade. Given the relative velocity between the front and rear train sections, Vehicle 122 at the bottom of the sag experienced the peak buff force because of the run-in from behind. The buff force on Vehicle 122 (DOTX 235) increased from around -155 kips before the run-in to -406 kips when the car was on the sag, an increase of around 250 kips.

Based on the time history of the coupler forces in the rear of the train, the first car to experience the buff force was Vehicle 162 (DOTX 233) located at the one third position behind the mid locomotive consist. The buff force from this car propagated in both directions through the train. The buff force on DOTX 234 (Vehicle 126, directly behind the mid locomotive) also increased from around -60 kips to -310 kips during the run in.

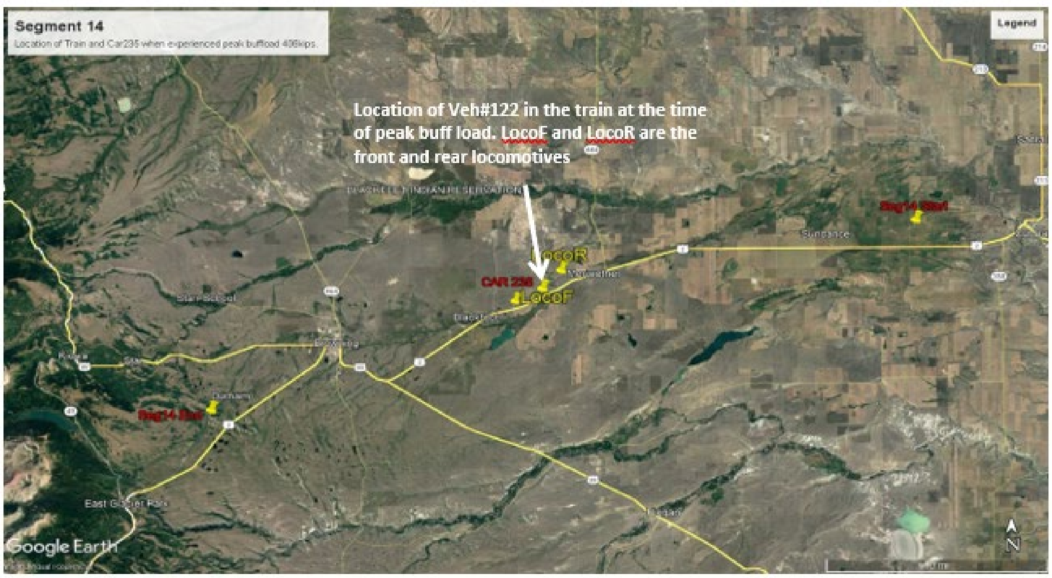

Figure 8. Train Location on Segment 14

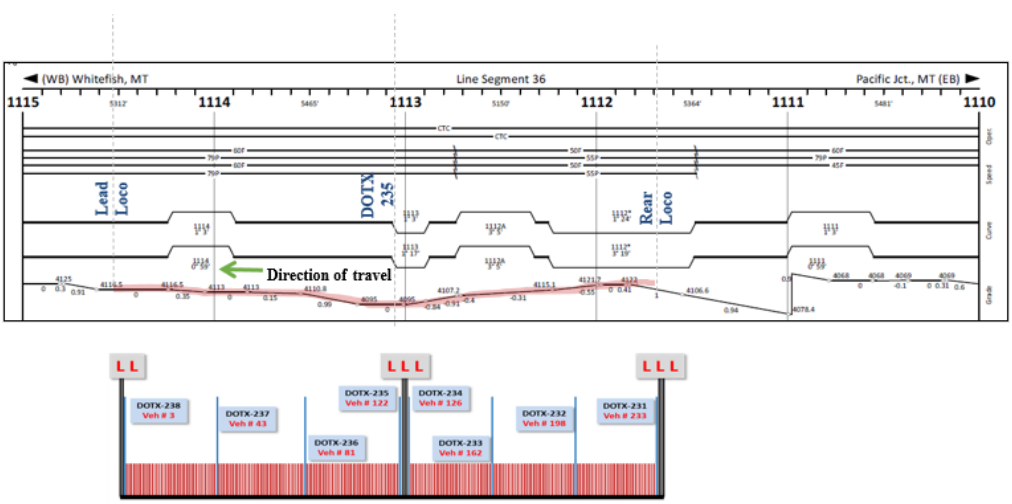

Figure 9. Vehicle 122 Location on Segment 14

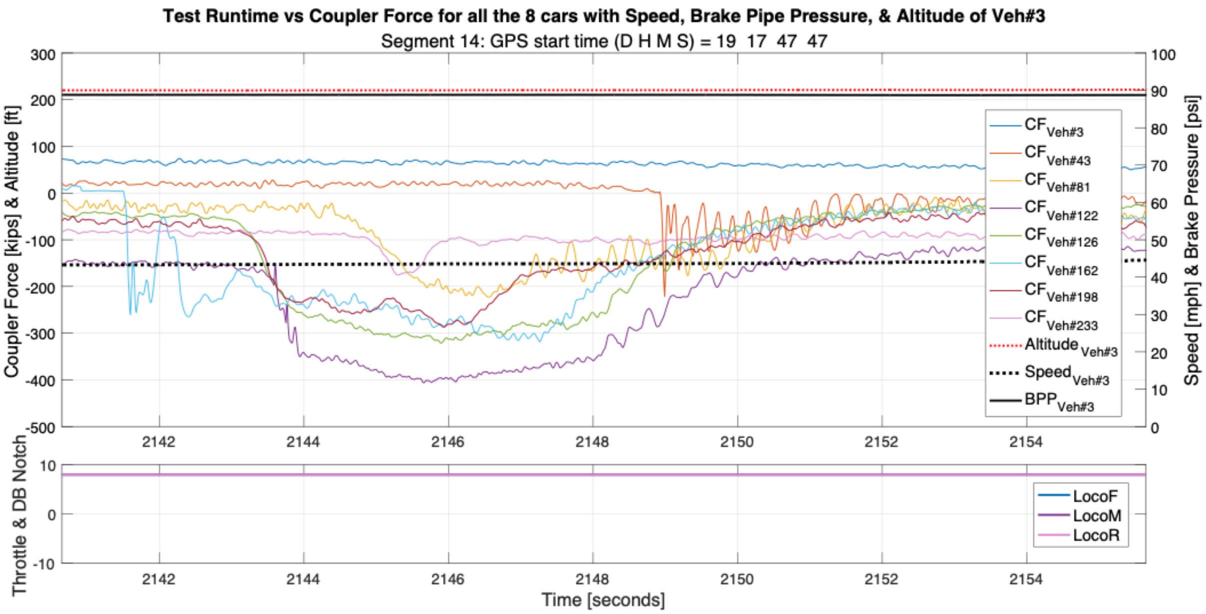

Figure 10. Coupler Forces from DOTX Box Cars on Segment 14

The buff force propagated further toward the front to Vehicle 43 (DOTX 237). As shown in Figure 10, the coupler force on the 43rd vehicle transitioned from near zero coupler force to a peak buff force of around -220 kips. As the wave-like effect of run-in from behind propagated toward the front of the train, the sudden transition from coasting to the bunched position caused the coupler force to oscillate for approximately 5 seconds. Measured coupler force oscillation is corroborated by the oscillations observed in the measured acceleration on the car, as shown in Figure 11.

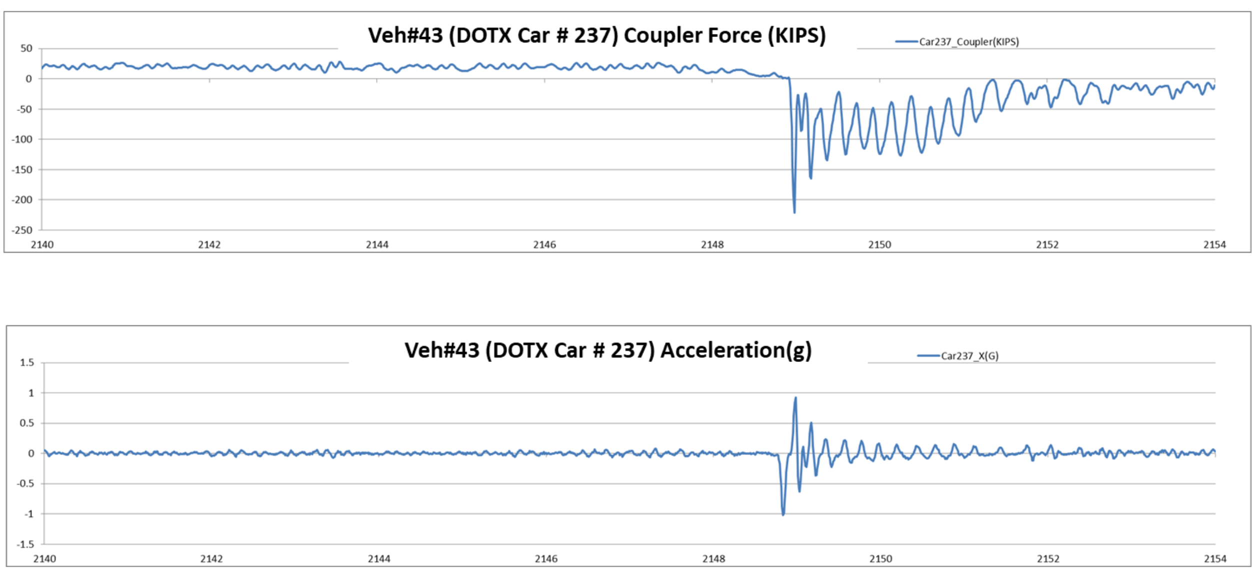

Figure 11. Coupler Force and Acceleration from Vehicle 43 on Segment 14

As expected, on Vehicle 3 (DOTX 238) directly behind the lead locomotive consist, the measured draft force was +60 kips as the front section of the train was being pulled on the ascending grade.

Overall, the measured coupler forces throughout the train were consistent with expectations for a train going through a sag.

3.3 Maximum Draft Force on Vehicle 122 on Segment 16

The highest draft force of 393 kips was also recorded on Vehicle 122 (DOTX 235). The location of the train on Segment 16 during this event is shown in Figure 12. The car was on level track (0 percent grade) as shown in Figure 13 and the train behind this car was on a descending 1 percent grade. The locomotives in all three consists were in Dynamic Brake (DB) with a minimum air brake application. The engineer was modulating the DB to maintain speed below 25 mph (track speed), as seen in Figure 14. At the time of the peak force, the DB on the mid-locomotive consist had just increased to DB7. The high draft force on Vehicle 122 is consistent with the terrain, the DB application, the rear portion of the train being 12 percent lighter in tonnage, and the train having more DB axles than the head end.

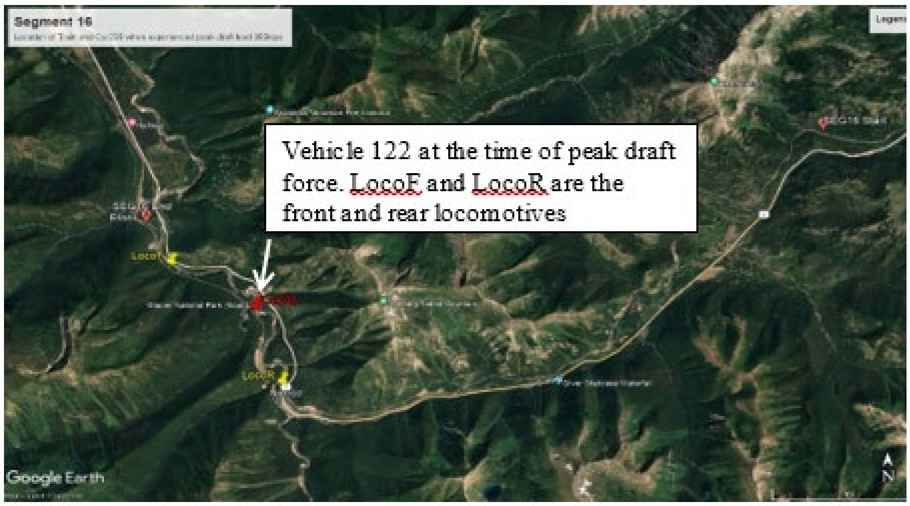

Figure 12. Train Location on Segment 16

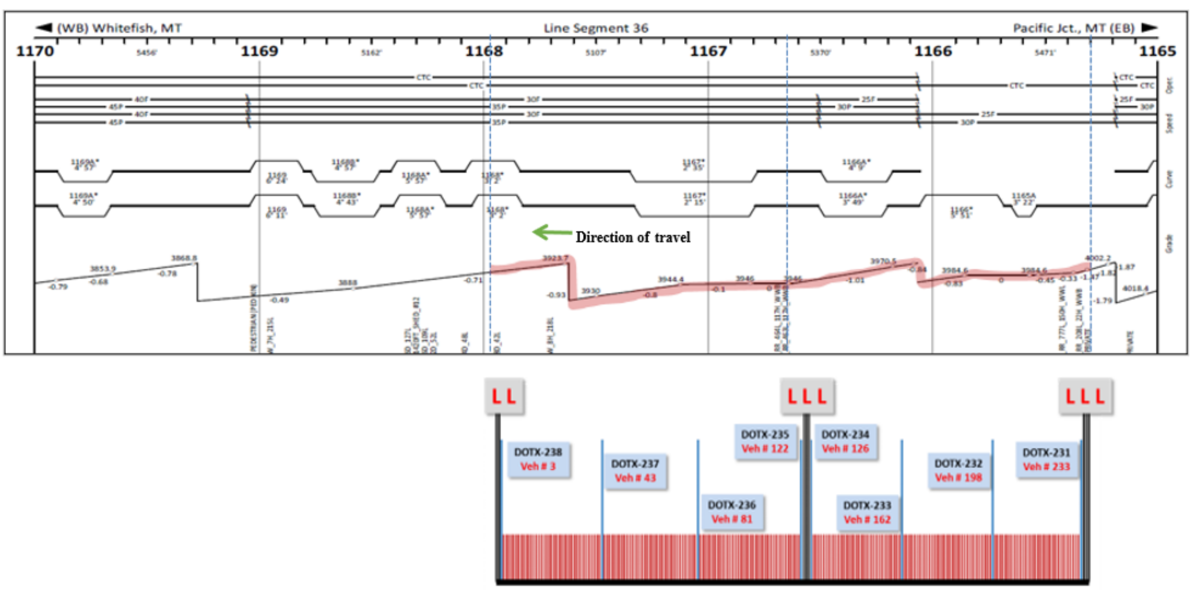

Figure 13. Vehicle 122 Location on Segment 16

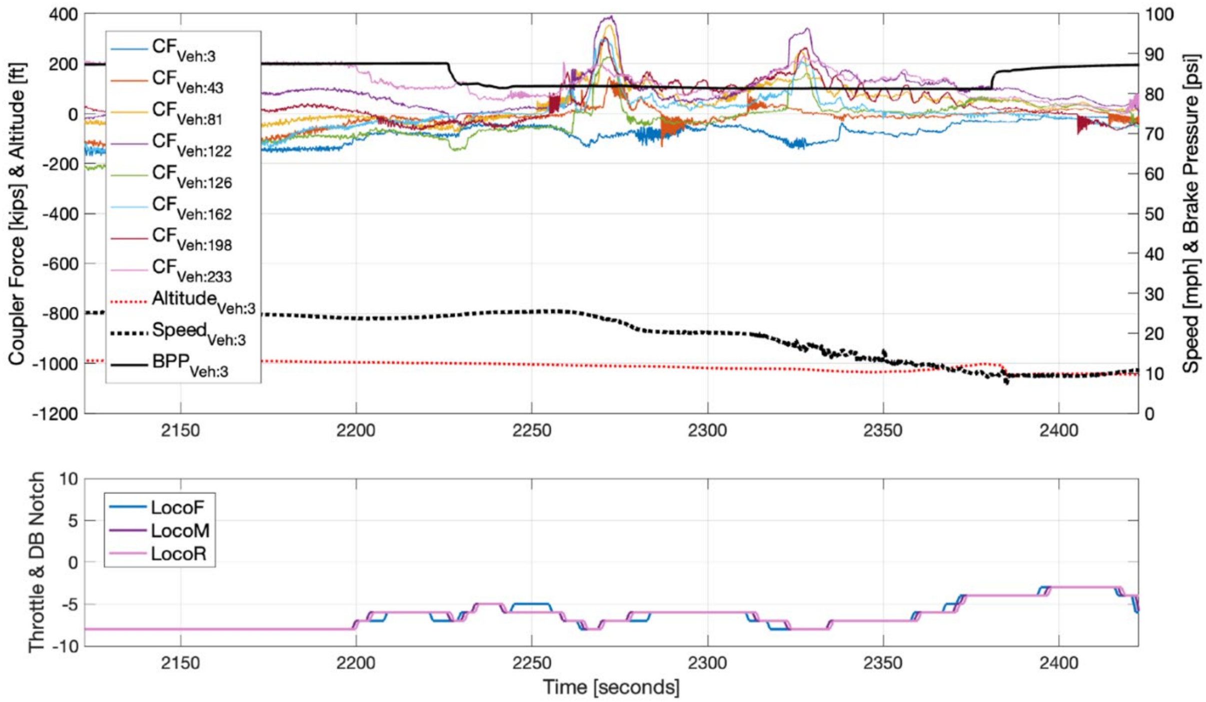

Figure 14. Coupler Forces from DOTX Box Cars on Segment 16

3.4 Maximum Buff Force on Vehicle 126 on Segment 9

Vehicle 126 (DOTX 234), located just behind the mid-locomotive consist, experienced its highest buff force of -382 kips on Segment 9. The location on the track chart is indicated in Figure 15. As shown in the figure, the car experienced the peak buff force when the front portion of the train was on an ascending grade and the rear portion on a descending grade; the car was at the bottom of the sag and was starting to travel uphill.

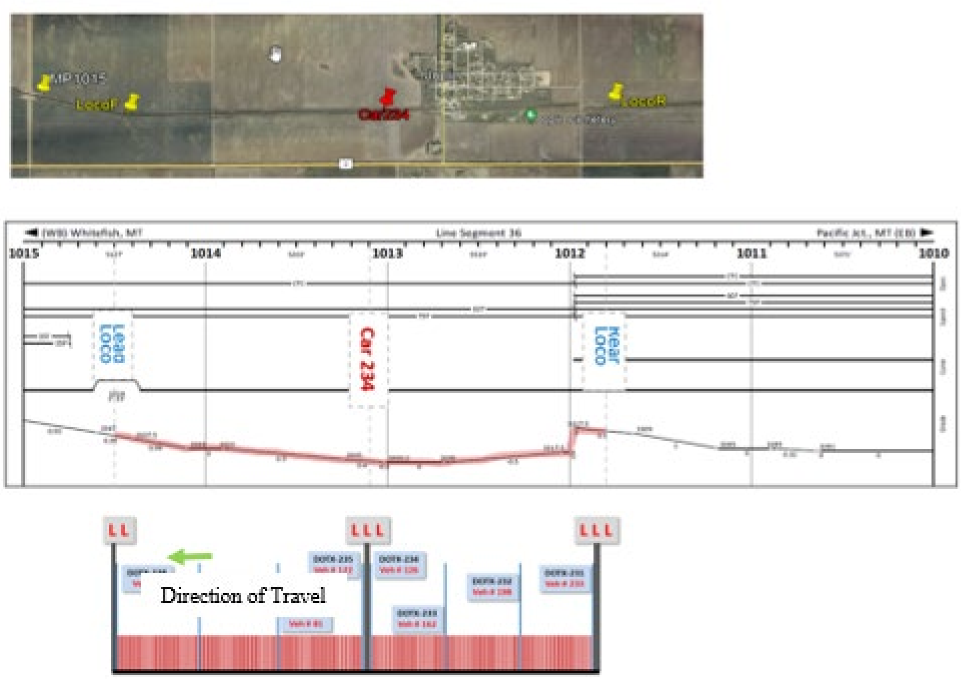

Figure 15. Vehicle 126 Location on Segment 9

Coupler forces for all the instrumented cars and throttle position for this event are plotted in Figure 16. The throttle positions in all three consists had been gradually reduced to Notch 2 in anticipation of the long downhill grade starting at MP 1016, and were synchronized by the time the peak force occurred on the car. The front portion of the train on the ascending grade was slowing in speed relative to the rear portion of the train on the descending grade, resulting in the rear of the train running into Vehicle 126.

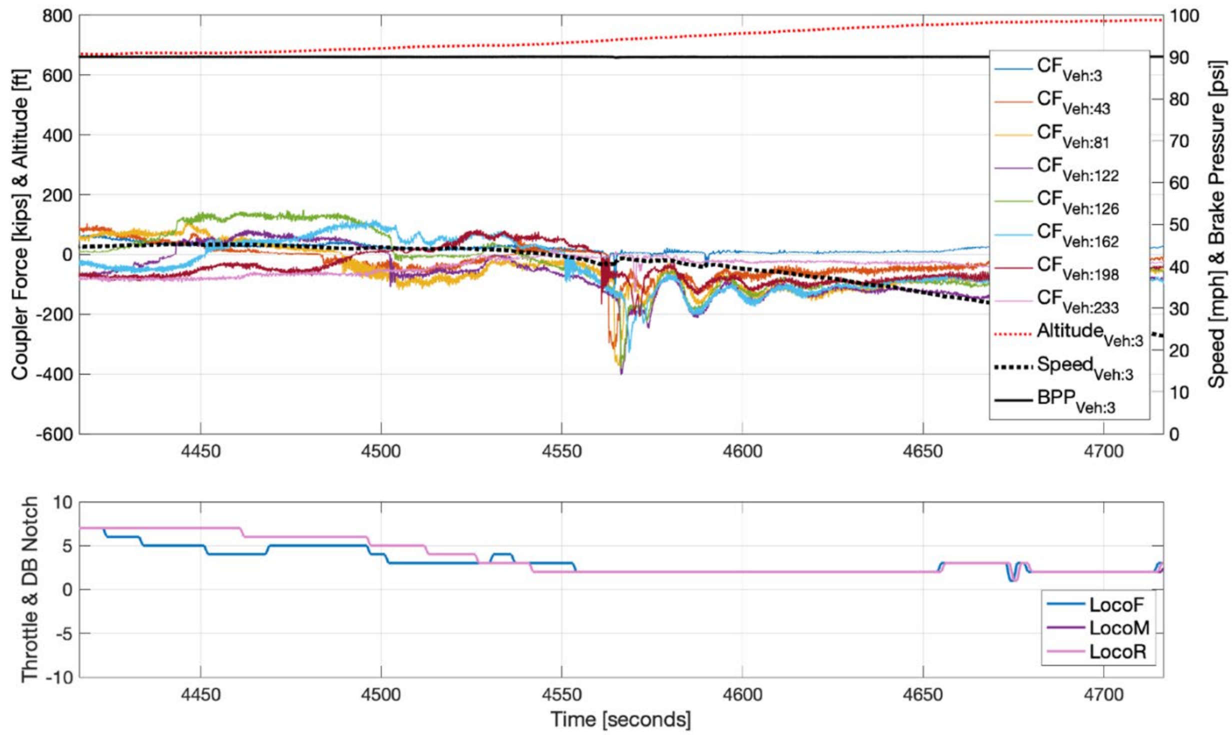

Figure 16. Coupler Forces from DOTX Box Cars on Segment 9

3.5 Maximum Buff Force on Vehicle 233 on Segment 14

Vehicle 233 (DOTX 231), the last instrumented car directly ahead of the rear locomotives, experienced a maximum buff load of -376 kips on Segment 14. The location of the car is indicated in Figure 17. The coupler forces for all the instrumented cars, BP pressure, speed, and throttle position for the rear locomotive are plotted in Figure 18. As the speed plot in the figure shows, the train had been stopped with throttle position at idle and was being held on a 1 percent grade with a BP reduction of 15 psi. As the engineer released the brakes and increased the throttle to start the train, the peak force occurred on Vehicle 233, with the throttle at Notch 8 and the speed increasing to around 8 mph.

The event recorder data indicated the tractive effort for the rear locomotive was 129 kips. The three rear locomotives were estimated to generate a total buff force of -387 kips (assuming all three locomotives generated the same level of tractive effort, or 129 kips x 3), which conforms well with the measured force of -376 kips on this car. The buff force on the car was relatively steady for nearly 2 minutes as the train was climbing up the 1 percent ascending grade.

Similarly, the tractive effort for the lead locomotive from ER data was 130 kips. The two lead locomotives were estimated to generate a total draft force of 260 kips on Vehicle 3 (DOTX 238), matching well with the measured force of 260 kips on this car.

ER data also listed the tractive effort on the mid locomotive as 128 kips. The difference in the measured coupler forces of 380 kips between Vehicle 122 (-240 kips on DOTX 235) and Vehicle 126 (140 kips on DOTX 234), which were on either side of the mid-locomotive consist, was consistent with the estimated total tractive force of 384 kips (128 kips x 3) from the three mid locomotives.

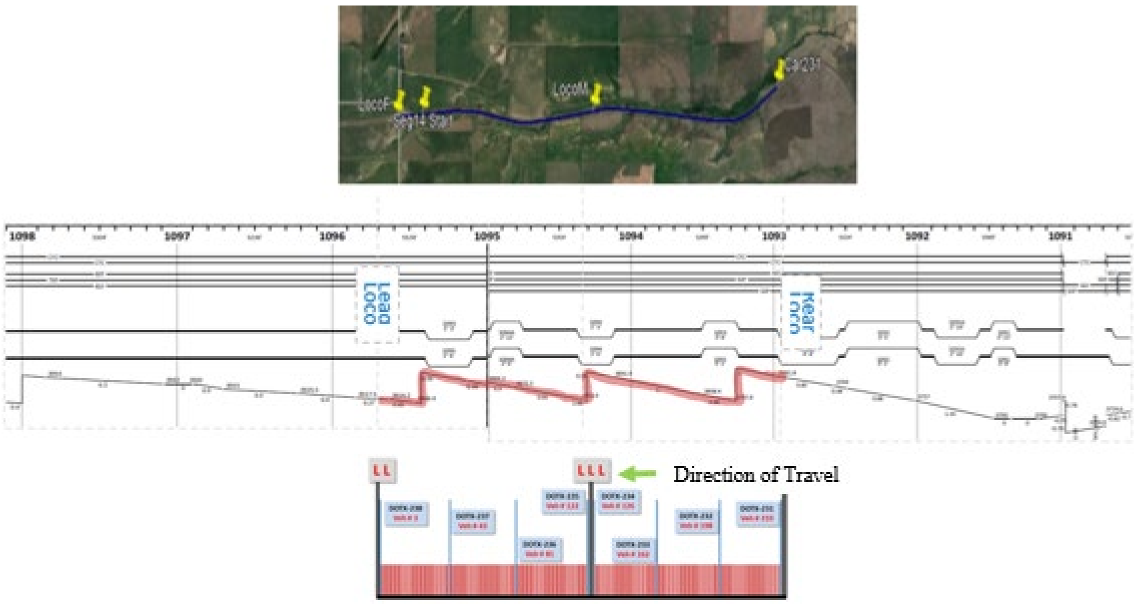

Figure 17. Vehicle #233 Location on Segment 14

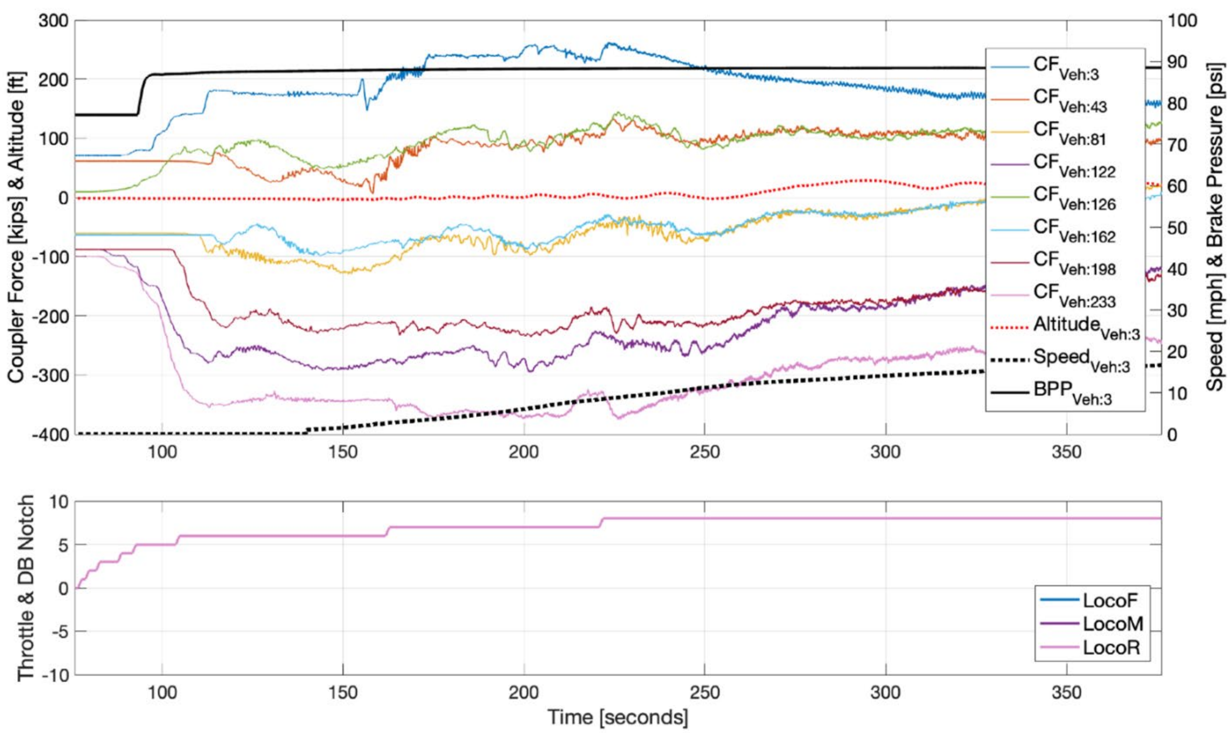

Figure 18. Coupler Forces from DOTX Box Cars on Segment 14

3.6 Maximum Buff Force on Vehicle 162 on Segment 9

A maximum buff force of -329 kips was recorded on Vehicle 162 (DOTX 233), at the one-third location in the rear section of the train on Segment 9. The location of the train at the time of maximum coupler force is shown in Figure 19. The rear portion of the train behind the car was on a descending grade of 0.5 percent, while the lead locomotive consist was pulling the front portion of the train on a 1 percent ascending grade. As shown in Figure 20, though the locomotive consists were initially not synchronized, all three consists were in Throttle Notch 2 position at the time of the peak force. The locomotive engineer was modulating the throttle to maintain track speed with the lead and rear sections of train on the ascending and descending grades, respectively. A few cars ahead of Vehicle 162 were on relatively level grade. As the throttle in the lead locomotive consist was shifted from Notch 3 to 2, the front section of the train slowed down. Given that the rear portion of the train behind DOTX 233 was still on the descending grade, the peak force on the car was caused by run-in of the train behind the car.

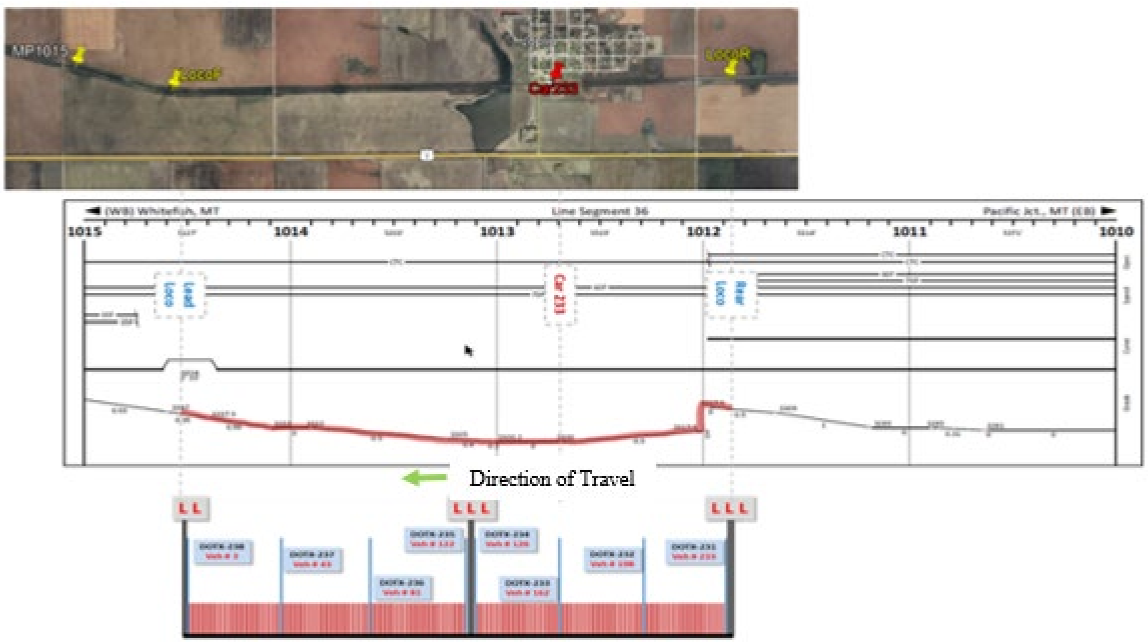

Figure 19. Vehicle #162 Location on Segment 9

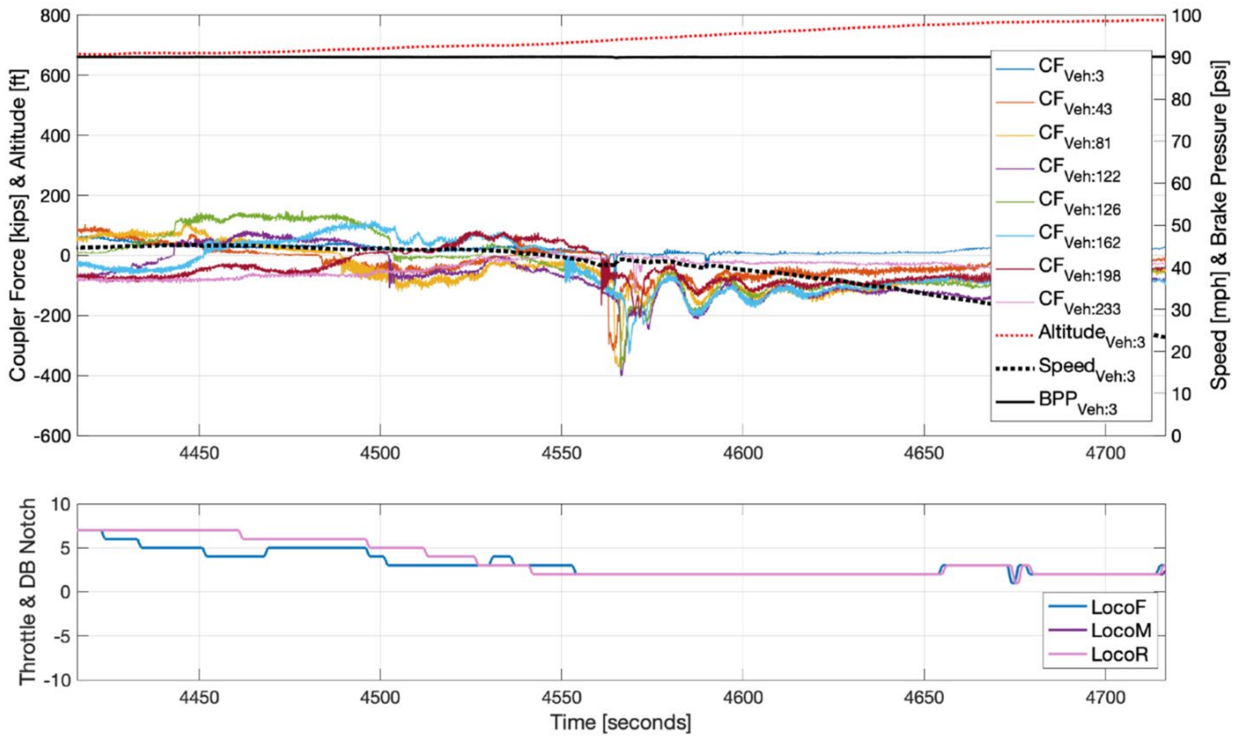

Figure 20. Coupler Forces from DOTX Box Cars on Segment 9

3.7 Maximum Buff Force on Vehicle 198 on Segment 9

A maximum buff force of -322 kips was recorded from the instrumented coupler in Vehicle 198 (DOTX 232), at the two-thirds location in the rear section of the train in Segment 9. The location of the train at the time of maximum buff coupler force is shown in Figure 21.

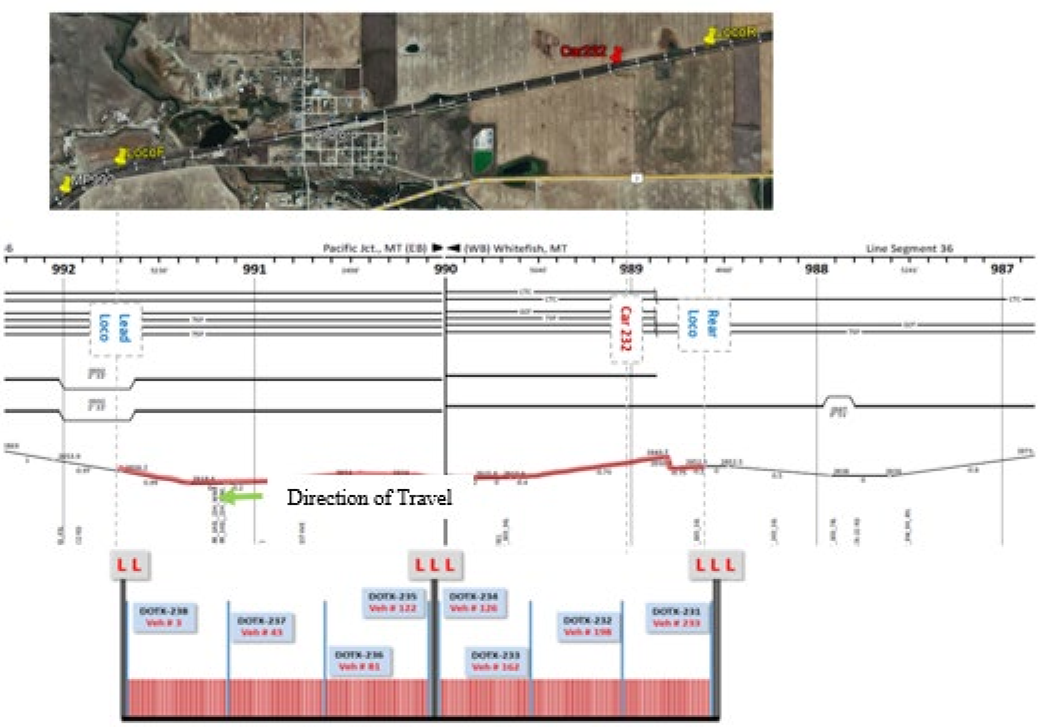

Figure 21. Vehicle 198 Location on Segment 9

At the time of the peak force, the car was on a 0.8 percent descending grade, the lead locomotive consist was pulling the front portion of the train on a 1 percent ascending grade, and the rear portion of the train was coming off an ascending grade and entering a descending grade. The three locomotive consists were not synchronized, with the lead in throttle Notch 6 and the mid and rear consists in Notch 2. As shown in Figure 22, the coupler force on Vehicle 198 was transitioning from draft to buff prior to the peak buff force event. The transition from a stretch position to bunched position was causing the coupler force to oscillate for about 5 seconds. The spike in the buff force was probably caused by the run-in event of the cars behind Vehicle 198 coming down the descending grade. Measured coupler force oscillation was corroborated by the oscillations observed in the measured acceleration, as shown in Figure 23.

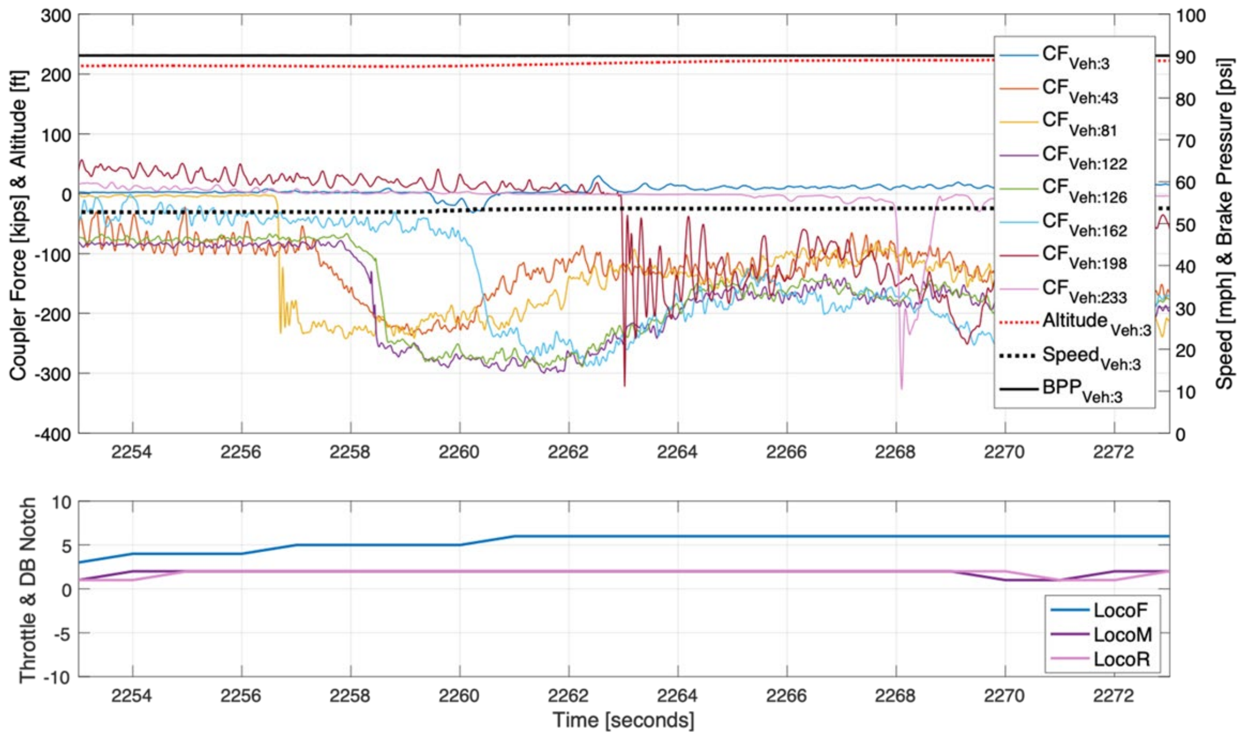

Figure 22. Draft to Buff Coupler Force Transition on Vehicle 198

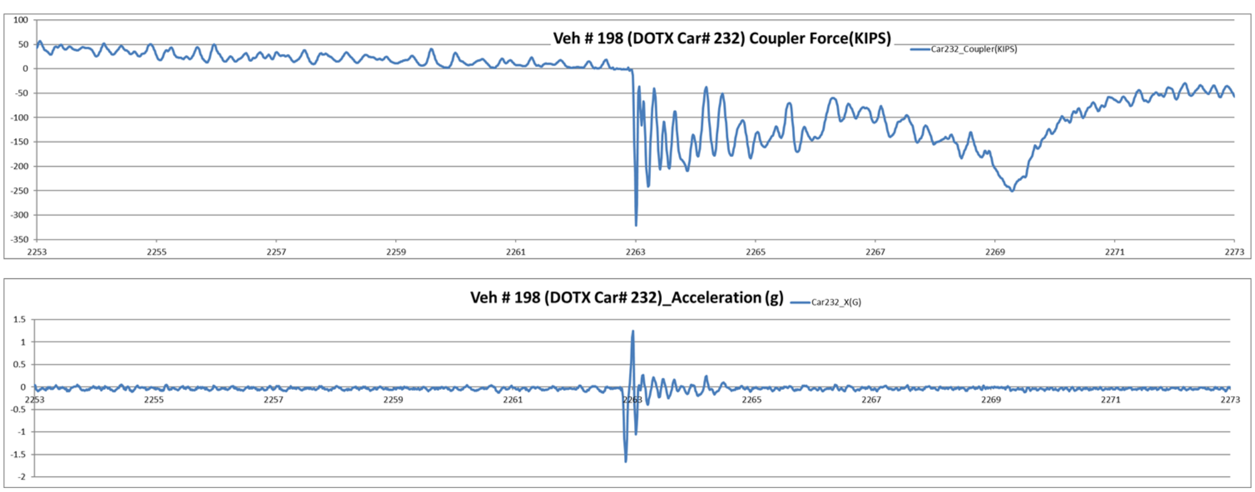

Figure 23. Coupler Force and Acceleration from Vehicle 198 on Segment 9

3.8 Maximum Draft Force on Vehicle 3 on Segment 13

A maximum draft force of 273 kips was recorded on Vehicle 3 (DOTX 238), the first car behind the lead locomotive consist. The location of the train at the time of maximum draft coupler force is shown in Figure 24. The train had been stopped (i.e., held by an air brake application) and was starting up a 1 percent ascending grade. As the locomotive engineer released the air brake and gradually increased the throttle (Figure 25), the coupler force on Vehicle 3 increased, peaking at 273 kips as the throttle position was moved to Notch 8. The event recorder in the lead locomotive recorded 141 kips of tractive effort. Assuming that the other locomotive is similar, the two locomotives in the lead consist could be expected to generate a total tractive effort of 282 kips, consistent with the measured coupler force of 273 kips on Vehicle 3.

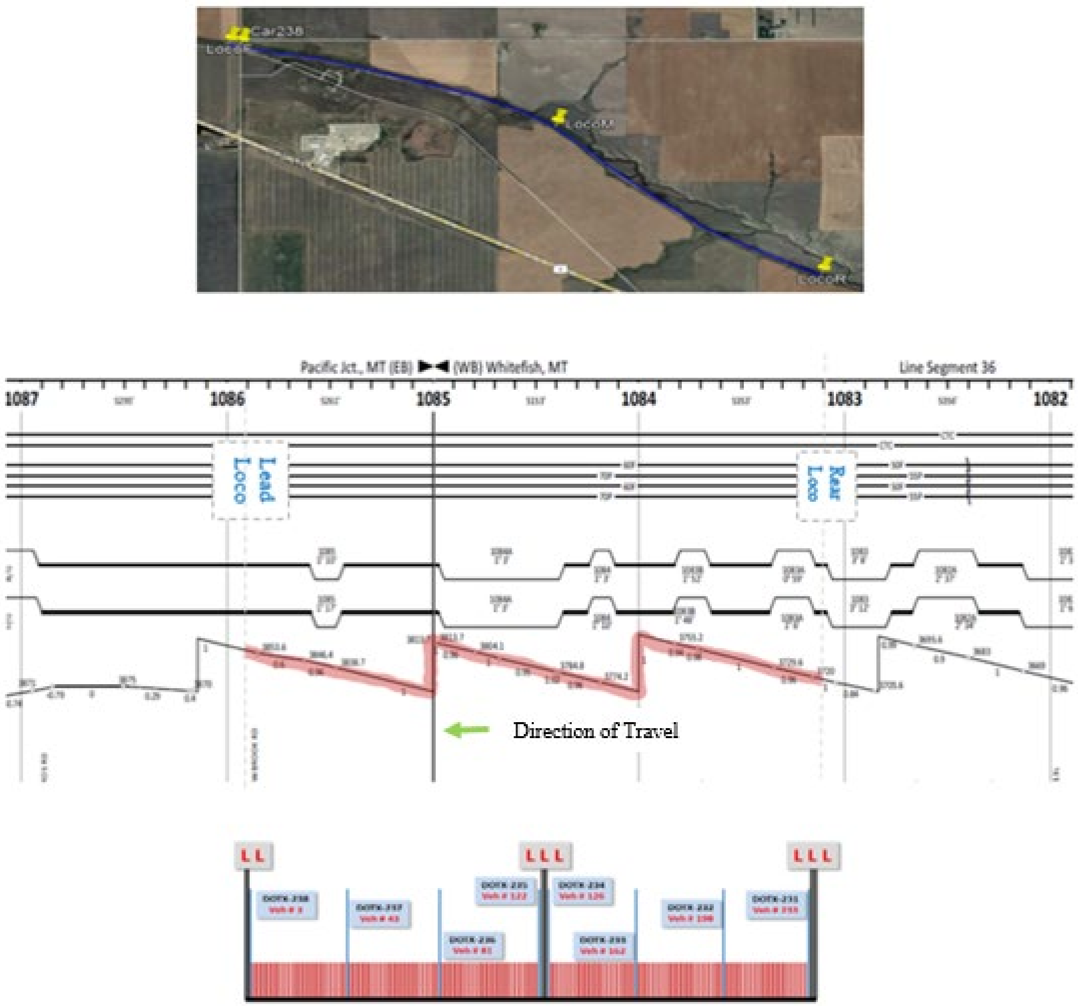

Figure 24. Vehicle 3 Location on Segment 13

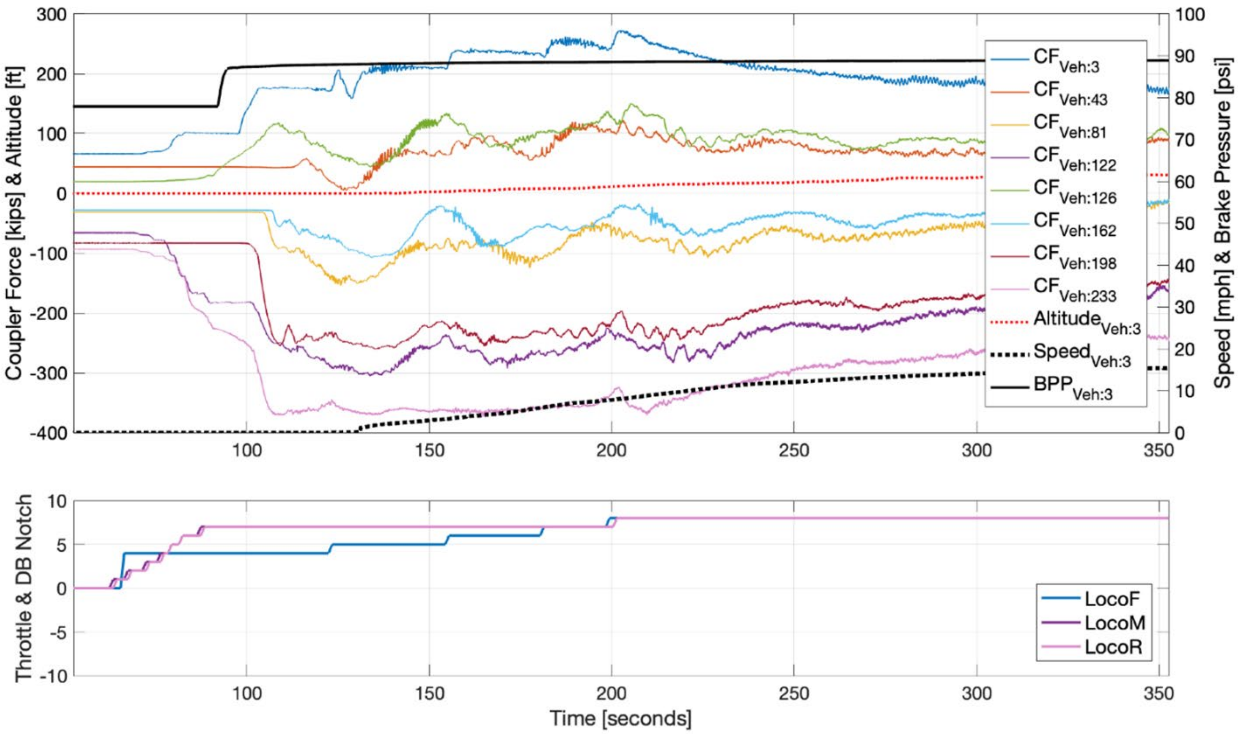

Figure 25. Coupler Forces from DOTX Box Cars on Segment 13

3.9 Stop on 1.8 Percent Descending Grade

The test plan called for an intentional stop of the VLT on a steep descending grade to quantify the in-train forces on the instrumented cars. The location of Vehicles 3 and 122 (DOTX 238 and DOTX 235) which experienced maximum buff and draft forces, respectively, during the event are shown in Figure 26 and Figure 27. As shown in Figure 28, in anticipation of the stop, the locomotive engineer made a 10-psi air brake application when the train speed was approximately 15 mph. The train was then stopped on the descending grade by progressively increasing the DB from idle to DB8. The maximum buff coupler force of -145 kips on Vehicle 3 occurred when the train had slowed to 12 mph and the lead consist was in DB8. The braking effort from the ER was 73 kips per locomotive, consistent with the maximum buff force measured on the third vehicle.

A maximum draft force of 270 kips was measured on Vehicle 122 when the locomotives were in DB7 and the train speed was 16 mph. The braking effort recorded in the mid locomotive BNSF 7754 at the time was 53 kips[1]. Assuming all three locomotives in the consist generated the same effort, the total braking effort from the consist would be 159 kips. The measured draft force on Vehicle 126 just behind the locomotive was 126 kips. Total force directly behind Vehicle 122 was therefore 285 kips, which matches reasonably well with the measured coupler force of 270 kips on Vehicle 122.

Stopping distance from the application of the air brake was 2.7 miles, and from the application of the dynamic brake was 1.3 miles, as shown in Figure 29.

[1] The effect of the dynamic brake from the two lead locomotives on the last vehicle (Vehicle 122, DOTX 235) in the front section of the train was expected to be minimal.

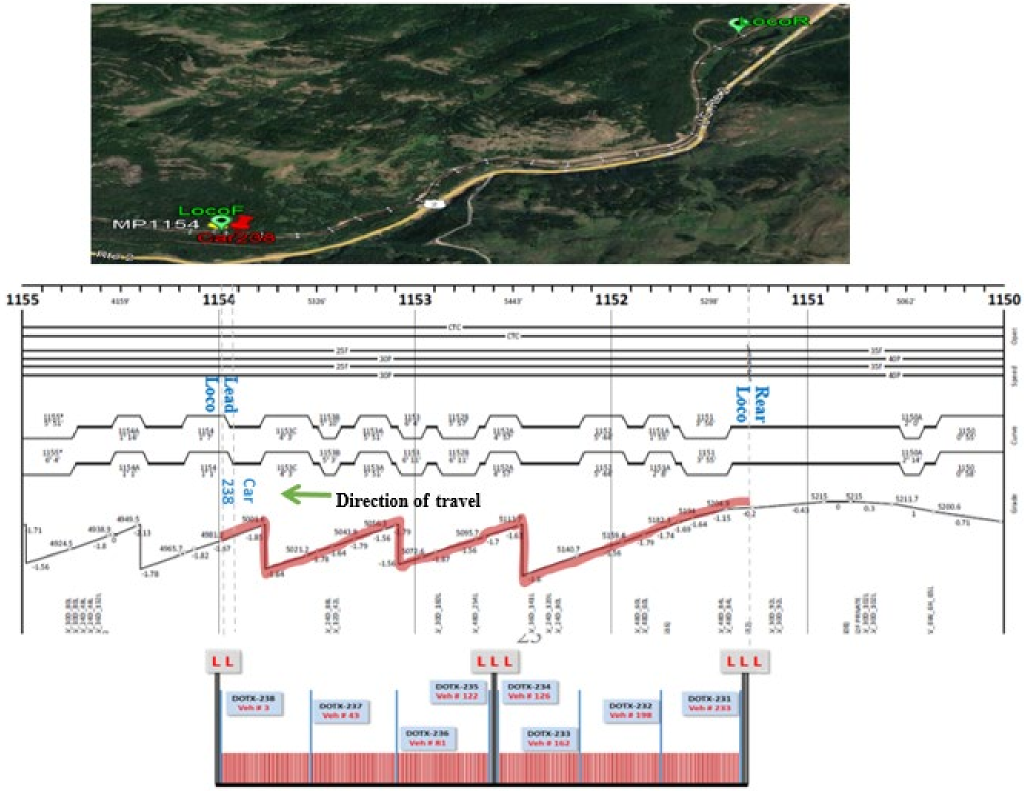

Figure 26. Location of Vehicle 3 at the Time of Peak Buff Force During Braking Event

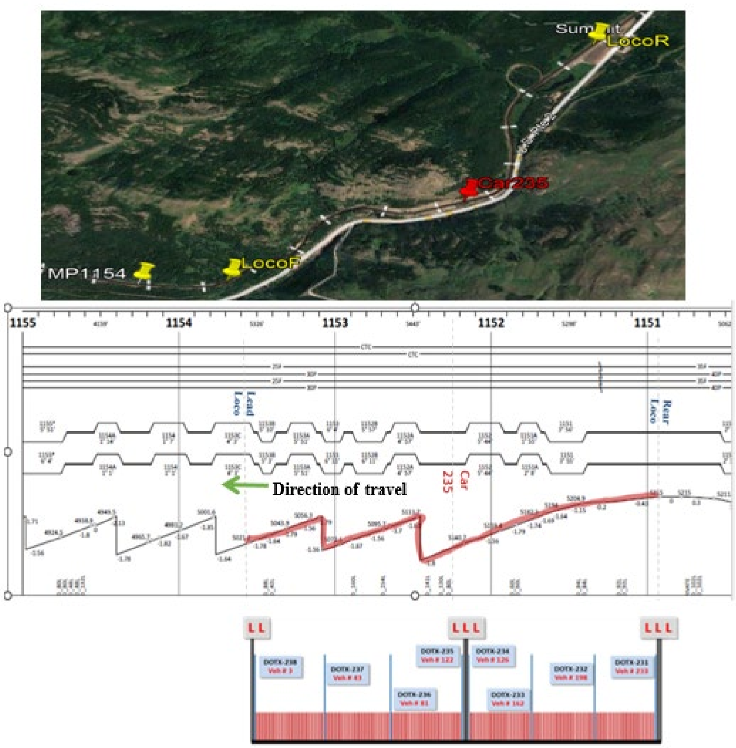

Figure 27. Location of Vehicle 122 at the Time of Peak Draft Force During Braking Event

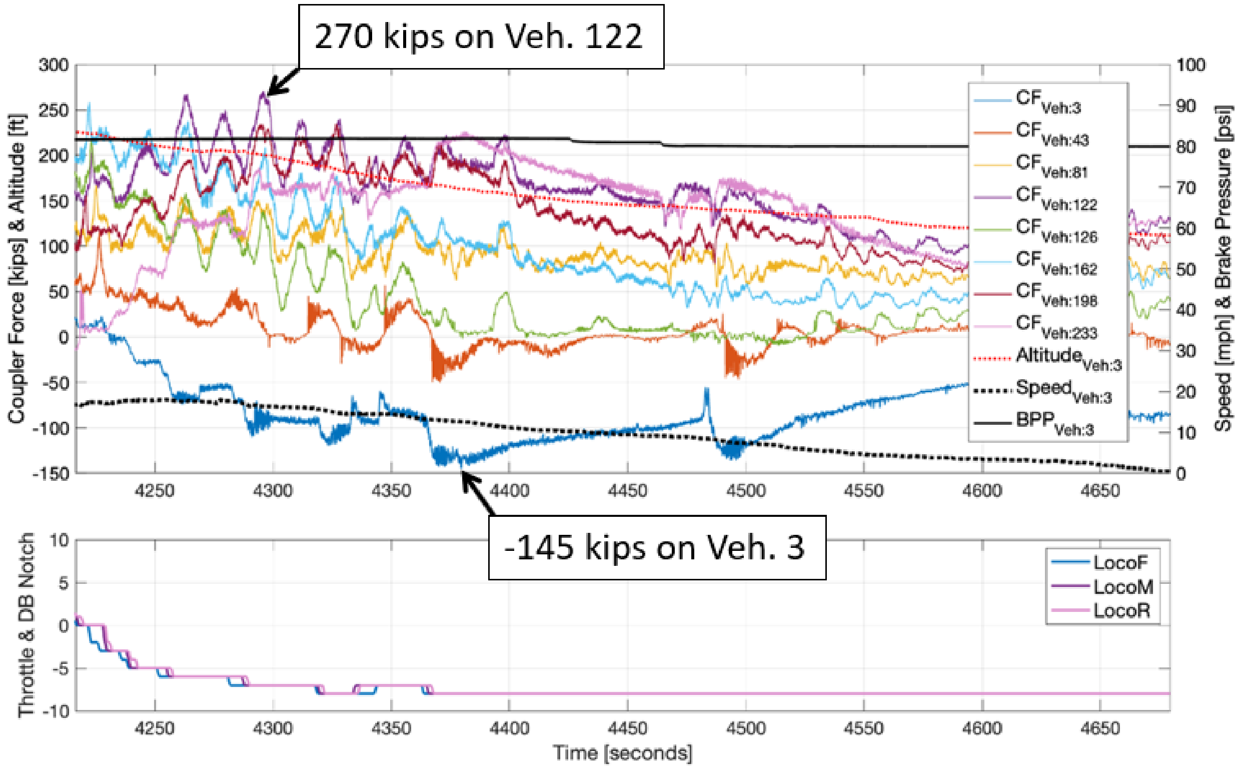

Figure 28. Coupler Forces on DOTX Box Cars During Stop on 1.8 Percent Grade

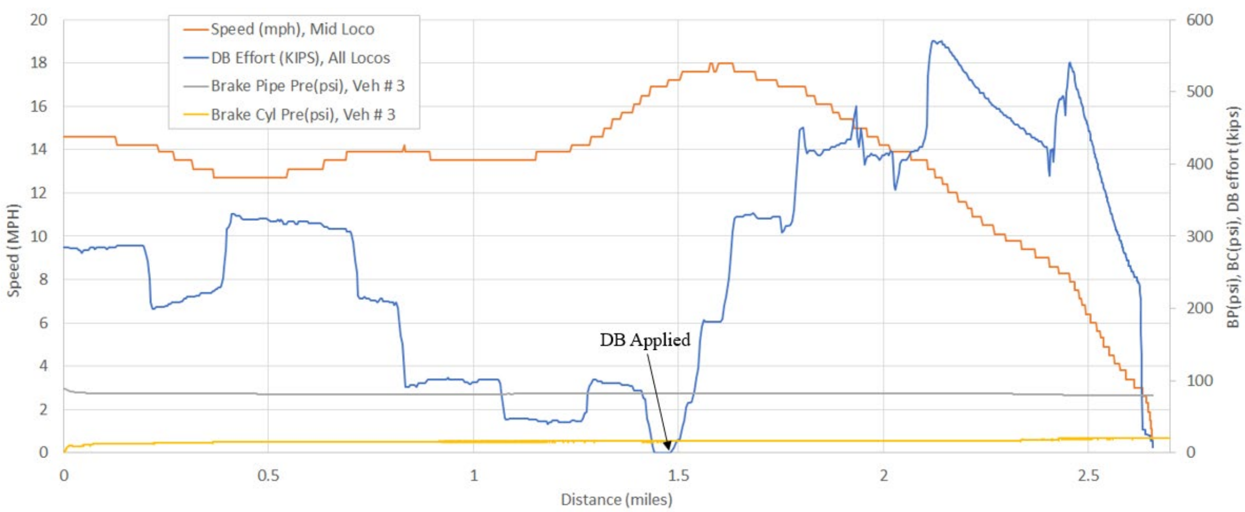

Figure 29. Stopping Distance

4. Air Brake Performance

The research team assessed the air brake performance on the stationary train before the train left Minot, ND, and again after the train reached its destination in Vancouver, WA. Both emergency brake and service brake applications were made to ensure normal response of the brake system.

4.1 Emergency Brake Application

An emergency brake application was made on the stationary train during a routine stop enroute (Segment 5 in Figure 7). The BP pressures from the three locomotives and the instrumented DOTX box cars are plotted in Figure 30. The cars next to the DP locomotives (Vehicles 122, 124, and 233) responded 2.5 seconds after the car next to the lead locomotive (Vehicle 3) due to a radio delay (i.e., processing the command at the transmission and receiving end). The locomotive data, reported at 1 sample/second, shows a slightly longer lag time between the lead and remote DP consists. The emergency propagation between cars was consistent with an emergency propagation time of 1000 feet/second.

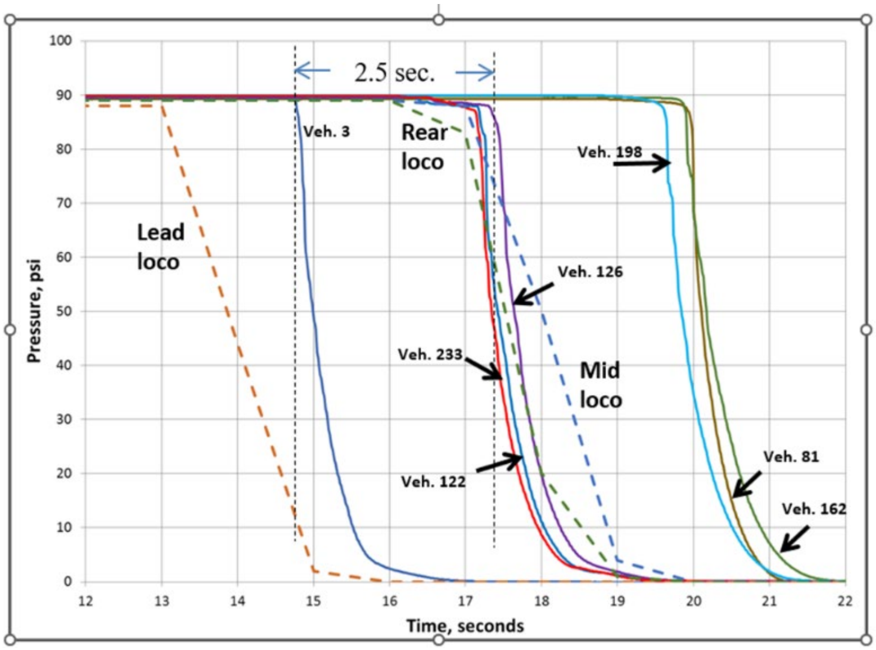

Figure 30. BP Pressure after Emergency Brake Application, Stationary Train

As seen in Figure 31, the measured BC pressures after emergency brake application in a stationary train were in the expected range of 75-77 psi. The BC pressure build up time was in the range of 12-15 seconds. Response time to the emergency brake application for DOTX 238 behind the lead locomotive (Vehicle 3) was 2 seconds. The cars next to the remote DP locomotives (Vehicles 233, 126, and 122) and Vehicle 43 responded 2.5 seconds later. The remaining three cars (Vehicles 81, 162, and 198) responded 2.5 seconds after the signal reached the DP locomotives.

The emergency brake application test was repeated on the stationary train after the train reached its destination in Vancouver, WA. The results plotted in Figure 32 are very similar to the earlier test.

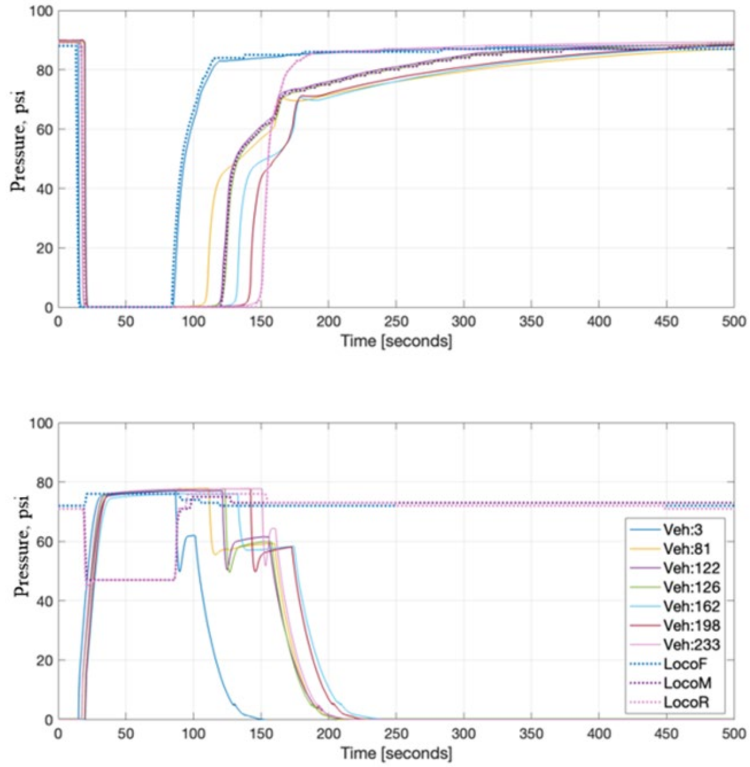

Figure 31. BP and BC Pressures after Emergency Brake, Stationary Train (Routine Stop)

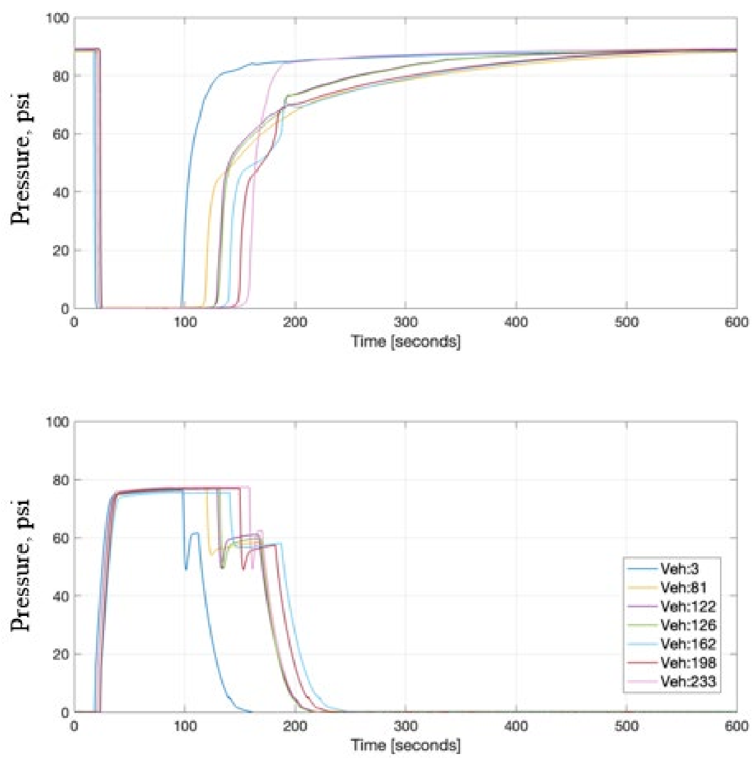

Figure 32. BP and BC Pressures Emergency Brake, Stationary Train (Vancouver, WA)

4.2 Stepped Brake Application

Figure 33 plots the measured values of BP and BC pressures as the locomotive engineer applied the brakes in steps from minimum to full service when the train was parked in Minot Yard. In each of the instrumented cars, the BC pressure values were appropriate for BP reduction. The pneumatic propagation rate in service brake application was about 700 feet/second. The test was repeated after the train reached its destination in the yard at Vancouver, WA. The BP and BC pressures, shown in Figure 34, were very similar to the earlier test in the yard at Minot, ND.

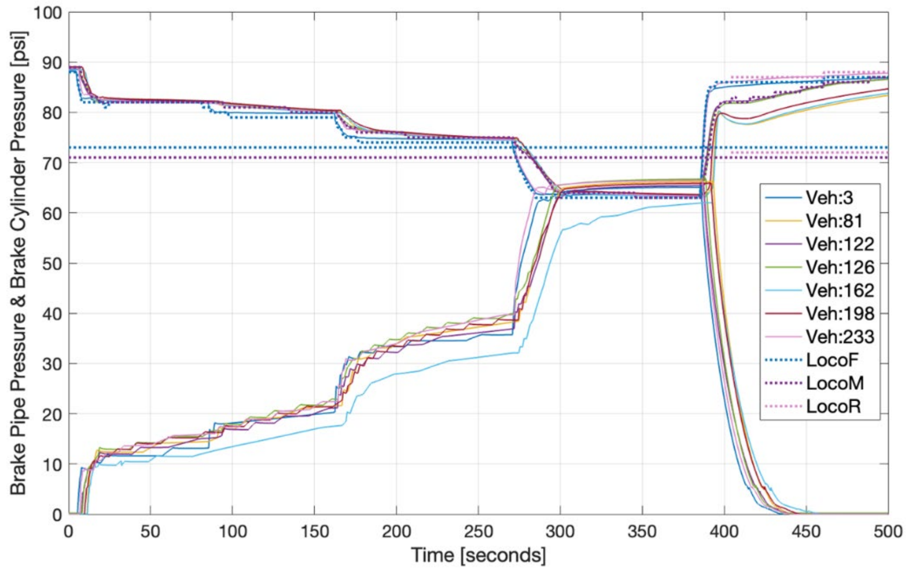

Figure 33. Stepped Application to Full Service & Release (Yard at Minot, ND)

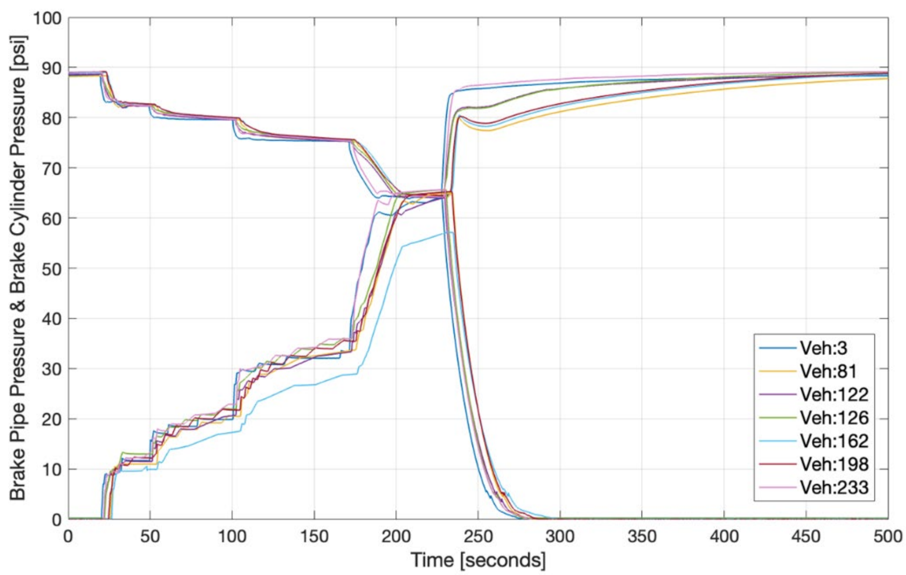

Figure 34. Stepped Application to Full Service & Release (Yard at Vancouver, WA)

5. Summary

Moving Train tests were completed successfully on a 228-car, DP train traveling from Minot, ND, to Vancouver, WA, using a BNSF train and crew. The test train was just over 14,000 ft. in length with a trailing tonnage of about 31,300 tons, and covered about 1300 miles, traversing plains, mountains, and rolling terrain. The eight instrumented cars that were interspersed throughout the train collected data on train dynamics and brake system performance to add to the industry's understanding of VLT performance.

There were no unusual events (e.g., knuckle breaks) observed during the test. Also, there were no notable instances of significant slack action or run-ins/run-outs at the lead locomotive.

The data from the instrumented cars were synchronized with data from the locomotive ERs and analyzed to identify sections of interest, and a few critical events with relatively high in-train forces were selected for more detailed review. Based on the analysis of the test data, there were multiple instances of elevated buff forces on the cars around the mid-locomotive consist when these cars traversed terrain with the front portion of the train on an ascending grade and the rear portion of the train on a descending grade. In such scenarios, the front of the train slowed as it climbed the grade while the rear cars on the descending grade ran-in from behind, leading to high coupler forces in the middle cars at the bottom of the sag.

Brake system performance was assessed based on the data collected during emergency and full-service applications when the train was stationary. The brake system performed as expected for a VLT in a DP configuration.

6. Recommendations for Future Work

Testing was conducted under relatively good conditions (e.g., a uniformly loaded unit train; DP consists in the front, mid, and rear; low leakage; no obvious malfunctioning equipment; and generally good weather conditions). It is likely that changing these parameters could reveal safety gaps that the railroad industry should consider as it develops and updates operating practices under such conditions.

The research team recommends that such variables be studied through a combination of additional testing and simulations. Additional train testing using the instrumented box cars should include:

1. Testing of a unit train under cold weather conditions
2. Testing of a mixed manifest train
3. Conducting a test with an Eastern Railroad, as railroads in this area have a different mix of grades and curves

The recommended simulation effort should cover various non-ideal conditions, such as:

1. Extreme weather (i.e., hot/cold) performance of rolling stock
2. Malfunctioning equipment, such as brake valves, locomotive control systems, etc.
3. Poor train makeup conditions, such as a mix of empty and loaded cars or cushioning units
4. Non-ideal or complex train operations such as false gradient operations, fencing, etc.

Prior to undertaking a simulation effort, the research team recommends validating the simulation software to confirm and more thoroughly investigate factors contributing to the elevated coupler forces observed during the tests.

Further, the research team recommends additional analysis to quantify the fatigue performance of car structures and other mechanical components from the coupler forces measured during the tests. This analysis will provide a better understanding of the effect of running VLTs on the expected durability of rolling stock mechanical components.

7. References

1. Sharma & Associates, Inc. (2021). Very Long Trains (VLTs) –Rack Tests, Summary, and Findings (Report No. xxxx). Federal Railroad Administration.
2. Sharma & Associates, Inc. (2023) VLT – Stationary Train Tests, Summary, and Findings (Report No. xxxx). Federal Railroad Administration.
3. Sharma & Associates, Inc. (2020). Train Energy and Dynamics Simulator (TEDS) Revenue Service Validation: Volume I Unit Train (Report No. DOT/FRA/ORD-20/24). Federal Railroad Administration.
4. Sharma & Associates, Inc. (2020). Train Energy and Dynamics Simulator (TEDS) Revenue Service Validation: Volume II Mixed Manifest Train with Distributed Power (Report No. DOT/FRA/ORD-20/26). Federal Railroad Administration.
5. Department of Transportation (2001). CFR Title 29, Subtitle B, Part 232 – Brake System Safety Standards for Freight and Other Non-Passenger Trains and Equipment.

Appendix A.
Test Plan

INTRODUCTION

1.1 Background

This document outlines the test plan for evaluation of in-train dynamics and air brake performance of a revenue service train with 200 or more cars in a Distributed Power (DP) configuration. This test effort is the final phase of a larger program researching the braking and train dynamics performance of Very Long Trains (VLTs) in North American freight railroad service. A prior phase of the effort, which was completed in 2022, addressed air brake performance on a 200 car stationary train in two conventional Head-End (HE) and three DP configurations. The following train configurations were tested in that research:

- HE with 200 cars (L-200-ETD) having an active End-of-Train Device (ETD)
- HE with 100 cars (L-100-ETD)
- DP configuration with 2 air sources (L-200-L), including a remote locomotive at the rear
- DP configuration having two air sources with an ETD in the rear of the train (L-133-L-67-ETD)
- DP configuration with 3 air sources (L-100-L-100-L).

During prior tests, eight instrumented cars were used to monitor and record Brake Pipe (BP), Brake Cylinder (BC), Auxiliary Reservoir (AR), and Emergency Reservoir (ER) pressures as a function of time.

The prior test report documented braking performance under various leakage conditions for the above train configurations, using various brake application and release protocols. The scenarios also included a few tests that simulated equipment, systems, or communication malfunction.

Some of the issues addressed by these earlier tests included:

1. How well did DP address brake performance concerns, such as those identified in prior VLT rack tests, including:
    - Stepped brake applications
    - False gradients
2. Performance evaluation at high leakage conditions and quantification of performance losses at limiting leakage levels
3. How did the brake system perform when the communication failure occurred? Specific failure modes considered included Communication Loss Idle Down (CLID) due to DP communication failures, and failure of pneumatic transmission during emergency brake application.

The VLT research plan calls for a test using a revenue service train with 200 or more cars in DP configuration as part of this final phase of the project. This document lays out the objective, scope, test scenarios, and the procedure for the testing.

1.2 Objectives

The goal of the Phase IV revenue service test is to better understand dynamic performance of VLTs by collecting and analyzing in-train coupler forces, car accelerations, and brake system data during revenue service operation of a loaded unit grain train with 200 or more cars. These tests will cover normal train handling operations under current railroad operating practices as well as specific test cases requested by the TRC for the territory where the revenue service tests will be conducted. The data from the test will be analyzed to study the impact of VLT operations on in-train dynamics and the brake system performance. The results of this effort will also be used to further validate the longitudinal train dynamics models.

2. TEST EQUIPMENT

2.1 Train Consist

The test train will consist of approximately 230 covered hopper grain cars and 8 instrumented box cars in a DP configuration with locomotives at the head end, middle, and rear of the train, including a similar number of cars in the front and rear portions of the train. The locomotives shall be equipped with Positive Train Control (PTC). The use of PTC-equipped locomotives assures that the Event Recorder (ER) downloads are synchronized between locomotives in the test train. The loaded test train will travel approximately one thousand miles from Minot, ND, to Tacoma, WA, encountering a mix of prairie and mountainous terrain. The train is expected to return to Minot, ND, after the grain is unloaded in Tacoma, WA, as either a single long train or as two shorter trains. There are no formal plans to collect data on the eastbound trip.

As part of the pre-test tasks, the railroad is requested to share the following data ahead of the revenue service test, so researchers can develop appropriate scenarios and conduct simulations.

- Track charts for the proposed westbound and return routes
- Time Tables for the proposed westbound and return routes
- ER downloads from a train (or trains) similar to the proposed test trains traveling on the proposed routes

2.2 Instrumentation

For the westbound train, eight instrumented cars will be located along the length of the train as described below:

- One instrumented car will be located as the first car behind the head-end consist
- One car each will be located on either side of the mid locomotive consist
- One instrumented car will be located as the last car, just ahead of the rear locomotive consist
- The remaining four instrumented cars will be evenly spaced along the train, with two cars in the front section and two in the rear section of the train

The above configuration is suggested because it is desirable to have an instrumented car next to each locomotive consist for ease of synchronizing the event recorders from the locomotives with the instrumented car data.

Each of the test cars will be equipped with a standalone SOMAT data acquisition system. Each of the SOMAT systems will be powered by an independent 12 volt battery. Two test engineers plan to either ride the test train or follow the train closely, by road, to ensure proper functioning of the instrumentation equipment, collection of the data, and download of the data enroute, if necessary. If the test engineers are allowed in the cab, they will also keep notes during the test and record any relevant information that may assist with the performance of an accurate simulation and the comparison of its results to the test data.

The same instrumented cars used in prior stationary train tests will be used in this revenue service test. Each of these cars will be instrumented with:

- One dynamometer coupler to measure the longitudinal forces being transferred through the coupler
- Four pressure transducers to measure the BP pressure, BC pressure, AR pressure, and ER pressure (Figure 35 and Figure 36 show examples of pressure transducers that were set up to collect and record BP and BC pressures, respectively, during prior stationary train tests)
- Accelerometer to measure the car body longitudinal acceleration
- GPS module to locate the car position, as well as determine its speed

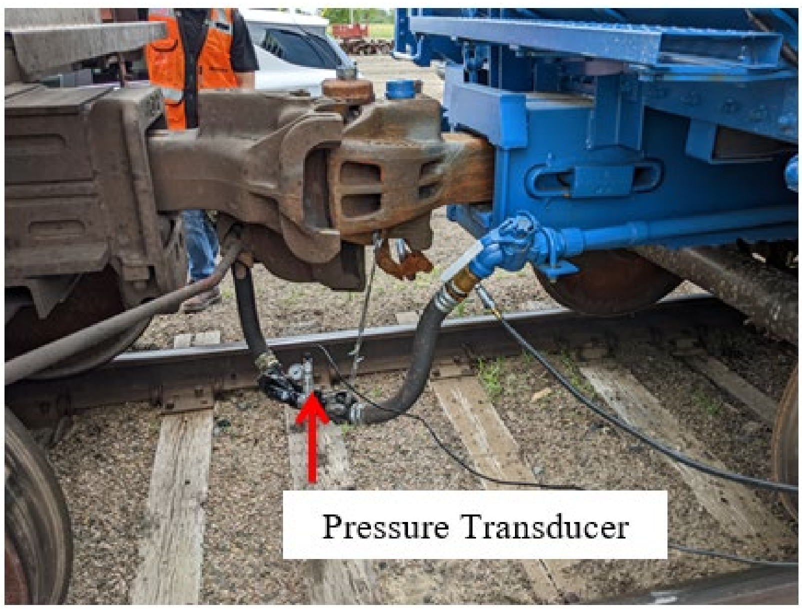

Figure 35. BP Pressure Measurement in the Instrumented Car

Figure 36. BC Pressure Measurement in the Instrumented Car

The instrumented cars will be switched into the test train at Minot, ND. The eight data acquisition units will be time synchronized, so that brake signal propagation rates and brake release and recharge time intervals can be captured. ER data will be downloaded from the locomotives in the test train at the end of each trip (westbound and eastbound). Time-based signals will be synchronized between the test cars and the locomotives using the PTC time data from the event recorder downloads.

2.3 Data Collection

2.3.1. BP, BC, and AR Pressures

Data will be collected at eight car locations, spaced throughout the train. Data will be collected during normal train handling; a few special braking scenarios, including full service application, will be requested during the testing.

2.3.2. Air Flow Data

The leakage in the test train will be characterized by the measured air flow rates at each of the locomotive consists when the brake system is fully charged and at steady state. No additional leakage will be intentionally added to the revenue service test trains (such as was done during the stationary train testing). The air flow (scfm) into the BP will be recorded in the controlling locomotive's ER at each consist. All locomotives used in the test should be able to record air flow between 0 and 20 scfm.

2.3.3. ER Download

The usual data from the event recorders shared during earlier tests should be shared for this test, as well. Refer to Appendix B for the required data from the ER. At a minimum, the following data shall be collected from the event recorder in each locomotive:

- Time
- Distance travelled

- Speed of locomotive
- BP pressure at the locomotive
- BC pressure at the locomotive
- Flow rates from the locomotive main reservoir into the BP
- Equalizing reservoir pressure
- Air brake handle position
- Bail off brakes
- Throttle position
- DB handle position
- Tractive (or DB) Effort
- GPS data from PTC channels
- Mile Post data
- ETD BP pressure and movement indication
- Reverser
- PCS
- EIE
- DP Mode
- DP RF Comm
- DP Rem A Valve, and DP Rem B Valve

2.3.4. Coupler Force and Carbody Acceleration

Dynamometer couplers installed in the instrumented cars will be used to measure the coupler forces. Solid-shank couplers, fitted with calibrated strain gauges, will help to capture peak coupler forces from slack run-ins and run-outs at the instrumented car locations in the 200+ car grain train. Accelerometers will be mounted on each test car, on the deck just above the center sill, to measure the carbody longitudinal acceleration due to slack action.

3. TEST CASES

3.1 Normal Operations

It is expected that a significant portion of the test will consist of normal, revenue service operations, during which the railroad will perform operations including starts, stops, and speed control manipulations under the locomotive engineer's control, over a variety of track conditions including tangent track, rolling terrain, and mountainous terrain.

Assuming the test train is powered by GE/Wabtec locomotives, it is also desired to conduct a portion of the test where the train is operating under Trip Optimizer (TO).

3.2 Requested Train Operations

In addition to the normal and TO operating conditions noted above, the following operations are requested:

- A defined stepped service application, preferably minimum service to 10 psi, to 15 psi, to full service application, in Minot, ND (before departure) and again in Tacoma, WA (upon arrival), which can be done while the train is stationary
- A defined emergency application in Minot, ND (before departure) and in Tacoma, WA (upon arrival), which can be done while the train is stationary
- If not included during normal operations, train stops as follows:
  - If possible, a service application without dynamic brake for selected stops, such as crew changes, which may be a split service application
  - Stop, or near stop, using only dynamic brake
- Over the course of the test, braking operations with:
  - only pneumatic application (if possible)
  - only dynamic brake application
  - both air and dynamic brakes
- Bring the westbound train to a stop on a ~1.8 percent descending grade using BNSF's normal practices for such a stop
- It is anticipated that the TRC might add elements to this list

4. ANALYSIS

Data collected in the revenue service train tests will be used to evaluate the train dynamics and braking system performance of the VLT. ER data will be gathered from all locomotives. The raw data from each of the SOMAT data collection systems will be downloaded with the data properly identified and tagged. The raw data will be post-processed with an appropriate filter, offset correction, etc.

For analysis of test data, specific sections of track will be selected along the test route consisting of a range of terrain (e.g., descending grade, ascending grade, combination of an ascending and descending grade, a crest, and an undulating terrain). The coupler forces from the instrumented couplers will be plotted for these sections to identify any locations where slack run-in or run-out occurred resulting in a spike in coupler forces, and the ER data will be analyzed to understand the reason for slack run-in or run-out. The carbody acceleration will be reviewed for the eight instrumented cars to understand the effect of the slack action.

In addition to the review of the recorded BC and BP pressures from the instrumented cars, stopping distance will be calculated from the ER, GPS, and speed data for appropriate train operation scenarios.

Appendix B.
Train Consist

Vehicle Position #	Vehicle ID	Type	Weight (Lbs.)	Gross Rail Load (Lbs.)	Length (Ft.)
1	**BNSF7733**	**Locomotive**	420,000	420,000	73.17
2	**CN2227**	**Locomotive**	420,000	420,000	73.17
3	**DOTX238**	**Instrumented Box Car**	160,000	220,000	55.25
4	BNSF495459	Covered Hopper	282,000	286,000	56.08
5	BNSF479237	Covered Hopper	282,000	286,000	60.08
6	NOKL852535	Covered Hopper	282,000	286,000	56.00
7	BNSF472330	Covered Hopper	282,000	286,000	60.08
8	BNSF489951	Covered Hopper	280,000	286,000	56.00
9	TILX521634	Covered Hopper	282,000	286,000	56.08
10	BNSF477418	Covered Hopper	282,000	286,000	56.08
11	BNSF489889	Covered Hopper	280,000	286,000	56.00
12	BNSF498555	Covered Hopper	282,000	286,000	55.67
13	BNSF473911	Covered Hopper	282,000	286,000	60.08
14	BNSF496188	Covered Hopper	282,000	286,000	56.08
15	BNSF482432	Covered Hopper	282,000	286,000	60.08
16	BNSF492096	Covered Hopper	282,000	286,000	56.08
17	BNSF480278	Covered Hopper	282,000	286,000	60.08
18	BNSF491247	Covered Hopper	284,000	286,000	56.00
19	BNSF491539	Covered Hopper	282,000	286,000	56.00
20	SOXX520808	Covered Hopper	280,000	286,000	56.00
21	BNSF478980	Covered Hopper	282,000	286,000	60.08
22	BNSF496052	Covered Hopper	282,000	286,000	56.08
23	BNSF487918	Covered Hopper	284,000	286,000	58.00
24	BNSF498029	Covered Hopper	284,000	286,000	56.00
25	BNSF472923	Covered Hopper	282,000	286,000	60.08
26	BNSF473740	Covered Hopper	282,000	286,000	60.08
27	BNSF495786	Covered Hopper	280,000	286,000	56.08
28	BNSF477260	Covered Hopper	282,000	286,000	56.08
29	WFRX447355	Covered Hopper	282,000	286,000	56.00
30	BNSF495506	Covered Hopper	282,000	286,000	56.08
31	BNSF476266	Covered Hopper	282,000	286,000	60.08
32	BNSF476714	Covered Hopper	282,000	286,000	60.08
33	WFRX447416	Covered Hopper	282,000	286,000	56.00
34	GACX75401	Covered Hopper	282,000	286,000	55.67
35	BNSF498639	Covered Hopper	282,000	286,000	55.67
36	BNSF488116	Covered Hopper	284,000	286,000	58.00
37	BNSF483013	Covered Hopper	282,000	286,000	60.08
38	BNSF485661	Covered Hopper	282,000	286,000	58.00
39	BNSF492223	Covered Hopper	282,000	286,000	56.08
40	BNSF482422	Covered Hopper	282,000	286,000	60.08

Vehicle Position #	Vehicle ID	Type	Weight (Lbs.)	Gross Rail Load (Lbs.)	Length (Ft.)
41	BNSF490402	Covered Hopper	280,000	286,000	56.00
42	FXE714032	Covered Hopper	282,000	286,000	56.00
43	**DOTX237**	**Instrumented Box Car**	160,000	220,000	55.25
44	BNSF478223	Covered Hopper	282,000	286,000	60.08
45	BNSF481209	Covered Hopper	282,000	286,000	60.08
46	BNSF488395	Covered Hopper	284,000	286,000	58.00
47	BNSF498141	Covered Hopper	284,000	286,000	56.00
48	AOK202037	Covered Hopper	280,000	286,000	56.00
49	BNSF482210	Covered Hopper	282,000	286,000	60.08
50	BNSF486869	Covered Hopper	282,000	286,000	58.00
51	BNSF488175	Covered Hopper	282,000	286,000	58.00
52	SOXX520862	Covered Hopper	280,000	286,000	56.00
53	BNSF478054	Covered Hopper	282,000	286,000	60.08
54	BNSF473411	Covered Hopper	282,000	286,000	60.08
55	BNSF482178	Covered Hopper	282,000	286,000	60.08
56	AOK202266	Covered Hopper	280,000	286,000	56.00
57	BNSF486644	Covered Hopper	282,000	286,000	58.00
58	BNSF483554	Covered Hopper	282,000	286,000	60.08
59	BNSF485262	Covered Hopper	282,000	286,000	58.00
60	BNSF481482	Covered Hopper	282,000	286,000	60.08
61	BNSF481768	Covered Hopper	282,000	286,000	60.08
62	BNSF482589	Covered Hopper	282,000	286,000	60.08
63	BNSF481452	Covered Hopper	282,000	286,000	60.08
64	BNSF485718	Covered Hopper	282,000	286,000	58.00
65	BNSF490530	Covered Hopper	282,000	286,000	56.00
66	NOKL852171	Covered Hopper	282,000	286,000	56.00
67	BNSF476155	Covered Hopper	282,000	286,000	60.08
68	BNSF481603	Covered Hopper	282,000	286,000	60.08
69	BNSF476827	Covered Hopper	282,000	286,000	60.08
70	BNSF483495	Covered Hopper	282,000	286,000	60.08
71	BNSF480378	Covered Hopper	282,000	286,000	60.08
72	BNSF482212	Covered Hopper	282,000	286,000	60.08
73	BNSF490133	Covered Hopper	280,000	286,000	56.00
74	BNSF489581	Covered Hopper	282,000	286,000	56.00
75	BNSF476519	Covered Hopper	282,000	286,000	60.08
76	BNSF498499	Covered Hopper	282,000	286,000	55.67
77	BNSF472107	Covered Hopper	282,000	286,000	60.08
78	COER309917	Covered Hopper	282,000	286,000	58.67
79	COER319896	Covered Hopper	282,000	286,000	60.17
80	BNSF483513	Covered Hopper	282,000	286,000	60.08
81	**DOTX236**	**Instrumented Box Car**	160,000	220,000	55.25
82	BNSF488320	Covered Hopper	284,000	286,000	58.00

Vehicle Position #	Vehicle ID	Type	Weight (Lbs.)	Gross Rail Load (Lbs.)	Length (Ft.)
83	BNSF472645	Covered Hopper	282,000	286,000	60.08
84	BNSF479367	Covered Hopper	282,000	286,000	60.08
85	WFRX447388	Covered Hopper	282,000	286,000	56.00
86	BNSF485438	Covered Hopper	282,000	286,000	58.00
87	BNSF483696	Covered Hopper	282,000	286,000	60.08
88	FXE713250	Covered Hopper	282,000	286,000	55.67
89	BNSF483039	Covered Hopper	282,000	286,000	60.08
90	BNSF480170	Covered Hopper	282,000	286,000	60.08
91	WRWK409042	Covered Hopper	280,000	286,000	56.00
92	BNSF483953	Covered Hopper	282,000	286,000	60.08
93	BNSF482293	Covered Hopper	282,000	286,000	60.08
94	BNSF486045	Covered Hopper	282,000	286,000	58.00
95	BNSF477784	Covered Hopper	282,000	286,000	56.08
96	BNSF436906	Covered Hopper	258,000	268,000	60.00
97	BNSF496066	Covered Hopper	282,000	286,000	56.08
98	BNSF480911	Covered Hopper	282,000	286,000	60.08
99	BNSF482146	Covered Hopper	282,000	286,000	60.08
100	BNSF480892	Covered Hopper	282,000	286,000	60.08
101	BNSF480544	Covered Hopper	282,000	286,000	60.08
102	BNSF479915	Covered Hopper	282,000	286,000	60.08
103	BNSF488198	Covered Hopper	282,000	286,000	58.00
104	NOKL447523	Covered Hopper	282,000	286,000	56.00
105	BNSF476126	Covered Hopper	282,000	286,000	60.08
106	BNSF490228	Covered Hopper	280,000	286,000	56.00
107	BNSF490382	Covered Hopper	282,000	286,000	56.00
108	NOKL447565	Covered Hopper	282,000	286,000	56.00
109	COER309711	Covered Hopper	282,000	286,000	58.67
110	COER311744	Covered Hopper	280,000	286,000	55.42
111	BNSF472843	Covered Hopper	282,000	286,000	60.08
112	BNSF477129	Covered Hopper	282,000	286,000	56.08
113	BNSF496763	Covered Hopper	282,000	286,000	56.00
114	BNSF486878	Covered Hopper	280,000	286,000	58.00
115	BNSF490388	Covered Hopper	280,000	286,000	56.00
116	WRWK409044	Covered Hopper	280,000	286,000	56.00
117	BNSF495340	Covered Hopper	282,000	286,000	55.67
118	BNSF480731	Covered Hopper	282,000	286,000	60.08
119	BNSF483422	Covered Hopper	282,000	286,000	60.08
120	BNSF474408	Covered Hopper	282,000	286,000	60.08
121	BNSF474103	Covered Hopper	282,000	286,000	60.08
122	**DOTX235**	**Instrumented Box Car**	160,000	220,000	55.25
123	**BNSF7754**	**Locomotive**	420,000	420,000	73.17
124	**BNSF7398**	**Locomotive**	420,000	420,000	73.17
125	**BNSF4073**	**Locomotive**	420,000	420,000	73.17

Vehicle Position #	Vehicle ID	Type	Weight (Lbs.)	Gross Rail Load (Lbs.)	Length (Ft.)
126	**DOTX234**	**Instrumented Box Car**	160,000	220,000	55.25
127	SHPX455203	Covered Hopper	270,000	286,000	60.17
128	BNGX31584	Covered Hopper	274,000	286,000	61.42
129	BNGX20217	Covered Hopper	280,000	286,000	70.00
130	FURX850869	Covered Hopper	270,000	286,000	58.00
131	CSYX12404	Covered Hopper	270,000	286,000	59.92
132	BNGX32172	Covered Hopper	276,000	286,000	61.42
133	BNGX32005	Covered Hopper	276,000	286,000	61.42
134	BNGX30458	Covered Hopper	268,000	286,000	61.42
135	SHPX455179	Covered Hopper	264,000	286,000	60.17
136	BNGX30001	Covered Hopper	268,000	286,000	61.42
137	BNGX30283	Covered Hopper	270,000	286,000	61.42
138	BNGX31909	Covered Hopper	274,000	286,000	64.42
139	BNGX31914	Covered Hopper	272,000	286,000	64.42
140	BNGX31184	Covered Hopper	270,000	286,000	61.42
141	BNGX31117	Covered Hopper	272,000	286,000	61.42
142	BNGX20376	Covered Hopper	282,000	286,000	70.00
143	BNGX32052	Covered Hopper	276,000	286,000	61.42
144	CAIX541008	Covered Hopper	274,000	286,000	56.67
145	BNGX31957	Covered Hopper	280,000	286,000	64.42
146	BNGX32194	Covered Hopper	278,000	286,000	61.42
147	BNGX31992	Covered Hopper	280,000	286,000	61.42
148	VTGX540048	Covered Hopper	274,000	286,000	56.33
149	BNGX31124	Covered Hopper	278,000	286,000	61.42
150	CAIX541012	Covered Hopper	274,000	286,000	56.67
151	BNGX30727	Covered Hopper	282,000	286,000	61.42
152	BNGX30532	Covered Hopper	276,000	286,000	61.42
153	BNGX30776	Covered Hopper	280,000	286,000	61.42
154	BNGX30686	Covered Hopper	278,000	286,000	61.42
155	BNGX20011	Covered Hopper	280,000	286,000	70.00
156	BNGX30830	Covered Hopper	278,000	286,000	61.42
157	BNGX31962	Covered Hopper	280,000	286,000	64.42
158	SHPX455113	Covered Hopper	272,000	286,000	60.17
159	BNGX31144	Covered Hopper	276,000	286,000	61.42
160	BNGX31695	Covered Hopper	278,000	286,000	61.42
161	VTGX540035	Covered Hopper	276,000	286,000	56.33
162	**DOTX233**	**Instrumented Box Car**	160,000	220,000	55.25
163	BNGX30642	Covered Hopper	278,000	286,000	61.42
164	BNGX31169	Covered Hopper	280,000	286,000	61.42
165	BNGX32232	Covered Hopper	282,000	286,000	61.42
166	VTGX540014	Covered Hopper	276,000	286,000	56.33
167	BNGX30332	Covered Hopper	276,000	286,000	61.42

Vehicle Position #	Vehicle ID	Type	Weight (Lbs.)	Gross Rail Load (Lbs.)	Length (Ft.)
168	BNGX20361	Covered Hopper	280,000	286,000	70.00
169	BNGX30075	Covered Hopper	270,000	286,000	61.42
170	BNGX30953	Covered Hopper	276,000	286,000	61.42
171	BNGX31154	Covered Hopper	276,000	286,000	61.42
172	BNGX31148	Covered Hopper	278,000	286,000	61.42
173	VTGX540055	Covered Hopper	280,000	286,000	56.33
174	BNGX31995	Covered Hopper	280,000	286,000	61.42
175	BNGX30318	Covered Hopper	276,000	286,000	61.42
176	BNGX30958	Covered Hopper	278,000	286,000	61.42
177	BNGX30062	Covered Hopper	272,000	286,000	61.42
178	BNGX30732	Covered Hopper	276,000	286,000	61.42
179	BNGX20267	Covered Hopper	286,000	286,000	70.00
180	BNGX32261	Covered Hopper	276,000	286,000	61.42
181	SHPX455160	Covered Hopper	272,000	286,000	60.17
182	CAIX541009	Covered Hopper	272,000	286,000	56.67
183	VTGX540065	Covered Hopper	280,000	286,000	56.33
184	BNGX30802	Covered Hopper	280,000	286,000	61.42
185	SHPX455141	Covered Hopper	270,000	286,000	60.17
186	BNGX31904	Covered Hopper	282,000	286,000	64.42
187	BNGX32165	Covered Hopper	280,000	286,000	61.42
188	BNGX31035	Covered Hopper	280,000	286,000	61.42
189	BNGX31990	Covered Hopper	280,000	286,000	64.42
190	BNGX31989	Covered Hopper	272,000	286,000	64.42
191	BNGX31944	Covered Hopper	276,000	286,000	64.42
192	BNGX30750	Covered Hopper	278,000	286,000	61.42
193	SHPX455059	Covered Hopper	268,000	286,000	60.17
194	BNGX31016	Covered Hopper	278,000	286,000	61.42
195	SHPX455135	Covered Hopper	268,000	286,000	60.17
196	SHPX455147	Covered Hopper	268,000	286,000	60.17
197	BNGX30839	Covered Hopper	274,000	286,000	61.42
198	**DOTX232**	**Instrumented Box Car**	160,000	220,000	55.25
199	BNGX30838	Covered Hopper	270,000	286,000	61.42
200	CAIX541072	Covered Hopper	268,000	286,000	56.67
201	CSYX12711	Covered Hopper	268,000	286,000	59.92
202	VTGX540040	Covered Hopper	268,000	286,000	56.33
203	VTGX540083	Covered Hopper	268,000	286,000	56.33
204	VTGX540034	Covered Hopper	270,000	286,000	56.33
205	BNGX32209	Covered Hopper	274,000	286,000	61.42
206	BNGX20073	Covered Hopper	284,000	286,000	70.00
207	BNGX30905	Covered Hopper	276,000	286,000	61.42
208	BNGX32206	Covered Hopper	274,000	286,000	61.42
209	BNGX31065	Covered Hopper	276,000	286,000	61.42
210	BNGX30884	Covered Hopper	274,000	286,000	61.42

Vehicle Position #	Vehicle ID	Type	Weight (Lbs.)	Gross Rail Load (Lbs.)	Length (Ft.)
211	SHPX455136	Covered Hopper	270,000	286,000	60.17
212	BNGX32153	Covered Hopper	278,000	286,000	61.42
213	BNGX30521	Covered Hopper	272,000	286,000	61.42
214	CAIX541052	Covered Hopper	272,000	286,000	56.67
215	BNGX31123	Covered Hopper	276,000	286,000	61.42
216	BNGX30743	Covered Hopper	280,000	286,000	61.42
217	BNGX20353	Covered Hopper	284,000	286,000	70.00
218	BNGX31102	Covered Hopper	272,000	286,000	61.42
219	BNGX20243	Covered Hopper	282,000	286,000	70.00
220	BNGX31935	Covered Hopper	272,000	286,000	64.42
221	BNGX20262	Covered Hopper	278,000	286,000	70.00
222	SHPX455149	Covered Hopper	266,000	286,000	60.17
223	SHPX454973	Covered Hopper	264,000	286,000	60.17
224	BNGX30415	Covered Hopper	270,000	286,000	61.42
225	BNGX32091	Covered Hopper	276,000	286,000	61.42
226	BNGX31013	Covered Hopper	276,000	286,000	61.42
227	BNGX31814	Covered Hopper	274,000	286,000	61.42
228	BNGX30274	Covered Hopper	274,000	286,000	61.42
229	SHPX455159	Covered Hopper	268,000	286,000	60.17
230	SHPX455146	Covered Hopper	264,000	286,000	60.17
231	CAIX541111	Covered Hopper	270,000	286,000	56.67
232	BNGX30869	Covered Hopper	274,000	286,000	61.42
233	**DOTX231**	**Instrumented Box Car**	160,000	220,000	55.25
234	**BNSF7645**	**Locomotive**	420,000	420,000	73.17
235	**BNSF7646**	**Locomotive**	422,000	420,000	73.17
236	**BNSF7647**	**Locomotive**	424,000	420,000	73.17

Abbreviations and Acronyms

ACRONYM	DEFINITION
AAR	Association of American Railroads
AR	Auxiliary Reservoir
BC	Brake Cylinder
BCP	Brake Cylinder Pressure
BNSF	Burlington Northern and Santa Fe
BP	Brake Pipe
BPP	Brake Pipe Pressure
CFR	Code of Federal Regulations
DB	Dynamic Brake
DOT	Department of Transportation
DP	Distributed Power
DP RF Comm	Distributed Power Unit Radio Frequency Communication
ER	Emergency Reservoir
FEA	Finite Element Analysis
FRA	Federal Railroad Administration
FS	Full Service
GIS	Geo Information Services
GPS	Global Positioning System
HE	Head End
kips	kilo pounds
PCS	Pneumatic Control Switch