U.S. Department
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Federal Railroad
Administration

Office of Research,
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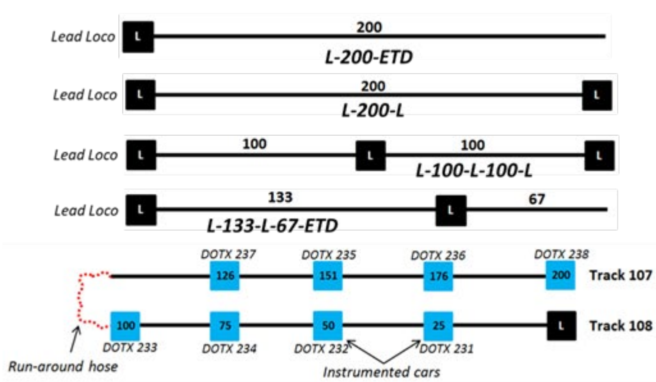
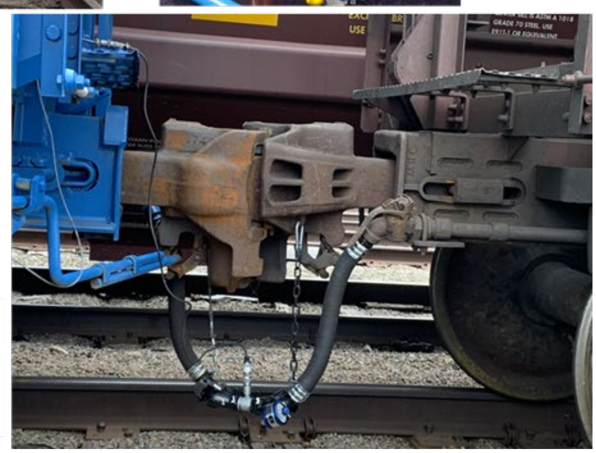
Washington, DC 20590

Very Long Trains – Phase III Stationary Train Tests





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14. ABSTRACT

In Phase III of this research, FRA sponsored Sharma & Associates, Inc. (SA), with significant assistance from Burlington Northern Santa Fe (BNSF) Railway, to conduct a series of tests to evaluate air brake system performance on a stationary train consisting of 200 cars in BNSF's railroad yard at Staples, MN. This phase of research was conducted between July 18 and July 28, 2022. In this phase, the research team developed a test plan describing the scope and test procedure in consultation with the TRC. The test train consisted of 192 hopper grain cars and up to 3 locomotives provided by BNSF, as well as 8 instrumented box cars owned by FRA. BNSF also provided other support for the test, including engineers to provide locomotive input, reconfigurations of the cars/locomotives as needed, and space in their yard for the tests.

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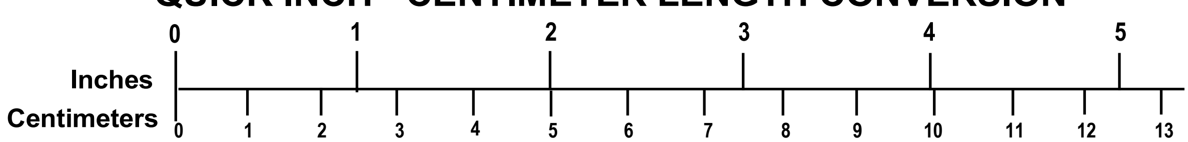
METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC			METRIC TO ENGLISH		
LENGTH (APPROXIMATE)			**LENGTH** (APPROXIMATE)		
1 inch (in)	=	2.5 centimeters (cm)	1 millimeter (mm)	=	0.04 inch (in)
1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
1 yard (yd)	=	0.9 meter (m)	1 meter (m)	=	3.3 feet (ft)
1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)
AREA (APPROXIMATE)			**AREA** (APPROXIMATE)		
1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)	1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)	1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)	10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			
MASS - WEIGHT (APPROXIMATE)			**MASS - WEIGHT** (APPROXIMATE)		
1 ounce (oz)	=	28 grams (gm)	1 gram (gm)	=	0.036 ounce (oz)
1 pound (lb)	=	0.45 kilogram (kg)	1 kilogram (kg)	=	2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)	1 tonne (t)	=	1,000 kilograms (kg)
				=	1.1 short tons
VOLUME (APPROXIMATE)			**VOLUME** (APPROXIMATE)		
1 teaspoon (tsp)	=	5 milliliters (ml)	1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	=	15 milliliters (ml)	1 liter (l)	=	2.1 pints (pt)
1 fluid ounce (fl oz)	=	30 milliliters (ml)	1 liter (l)	=	1.06 quarts (qt)
1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
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 meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)			**TEMPERATURE** (EXACT)		
[(x-32)(5/9)] °F	=	y °C	[(9/5) y + 32] °C	=	x °F

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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Contents

Illustrations

Tables

Executive Summary

The operation of long trains (termed Very Long Trains or VLTs for purposes of this report) is governed by the railroad's air brake and train handling instructions, as well as the education, training, and supervision of operating crews. 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 VLT 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 Phase III of this research, FRA sponsored Sharma & Associates, Inc. (SA), with significant assistance from Burlington Northern Santa Fe (BNSF) Railway, to conduct a series of tests to evaluate air brake system performance on a stationary train consisting of 200 cars in BNSF's railroad yard at Staples, MN. This phase of research was conducted between July 18 and July 28, 2022.

In this phase, the research team developed a test plan describing the scope and test procedure in consultation with the TRC. The test train consisted of 192 hopper grain cars and up to 3 locomotives provided by BNSF, as well as 8 instrumented box cars owned by FRA. BNSF also provided other support for the test, including engineers to provide locomotive input, reconfigurations of the cars/locomotives as needed, and space in their yard for the tests.

The tests were conducted to quantify the impact of leakage conditions and various air brake applications on brake signal propagation rate, brake pipe (BP) pressure reduction, and brake cylinder (BC) pressure buildup on a VLT (200-car train). These tests were conducted on both a conventional Head End (HE) power only train and on several Distributed Power (DP) train configurations.

The results of the stationary train tests helped corroborate key findings from the Phase II air brake rack tests for the HE train configuration. In addition, the stationary train tests helped to quantify the benefits of using a DP configuration over a HE configuration in VLT operations. The test data showed that brake signal propagation rates were faster, and release and recharge times were quicker, for the DP trains with shorter BP lengths between air sources. DP trains, with shorter lengths between air sources, also achieved better braking capability, as indicated by higher BC pressures and shorter BC pressure build-up times.

Analysis of the test results confirmed that an air brake application in the HE train configuration had a slower response and achieved slightly lower BC pressures compared to a similar length DP train. The longer recharge times in the HE configuration required longer wait periods in cycle braking (i.e., false gradient) situations to avoid potential unintended brake release. However, unintended release did not occur during the false gradient tests when the second application was sufficiently deeper than the first.

1. Introduction

In Phase III of this research, FRA sponsored Sharma & Associates, Inc. (SA), with significant assistance from Burlington Northern Santa Fe (BNSF) Railway, to conduct a series of tests to evaluate air brake system performance on a stationary train consisting of 200 cars in BNSF's railroad yard at Staples, MN. This phase of research was conducted between July 18 and July 28, 2022.

1.1 Background

While there are no federal or state statutes governing train length, 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 this phase, the research team developed a test plan describing the scope and test procedure in consultation with the TRC. The test train consisted of 192 hopper grain cars and up to 3 locomotives provided by BNSF, as well as 8 instrumented box cars owned by FRA. BNSF also provided other support for the test, including engineers to provide locomotive input, reconfigurations of the cars/locomotives as needed, and space in their yard for the tests.

1.2 Objectives

The objective of this effort was to understand the air brake system behavior in longer trains by evaluating braking system performance through a series of air brake tests on a stationary train. These tests represented train air braking operations, such as service and emergency stopping, as well as release and recharge operations. The braking performance was evaluated under various leakage conditions, train configurations, brake application, and release protocols. The tests also included several abnormal conditions not permitted under current railroad operating rules, but which might occur in service due to anomalies or en-route failures of air brake components or distributed power systems.

1.3 Overall Approach

1.3.1 Test Equipment

A test train was set up with 200 cars at the BNSF Yard in Staples, MN. The train consisted of 192 hopper grain cars and up to 3 locomotives provided by BNSF, as well as 8 instrumented box cars owned by FRA. The length of brake pipe (BP) in each grain car was 63 feet. All but five of the grain cars were empty and equipped with empty/load valves. UMLER records indicated that the cars at locations 33 (CAIX 540046), 64 (BNSF 431145), 135 (CAIX 540019), 150 (NOKL 852448) and 195 (CEFX 398856) did not have empty/load valves. The air brake systems of the cars were generally in a good state of maintenance. The cars had a mix of Wabtec and NYAB control valves with the following breakdown:

- Service portion: Wabtec (107), NYAB (92), Unidentified (1)
- Emergency portion: Wabtec (112), NYAB (86), Unidentified (2)

The eight instrumented box cars were loaded with ballast to a gross weight of 110 tons. These cars were not equipped with empty/load valves. The total BP length of the HE train was about 12,680 ft, including a 100 ft runaround hose between cars 100 and 101. The three BNSF locomotives used in the tests were 4400 HP AC locomotives (1 ES44SAC and 2 ES44C4) equipped with Locotrol® XA Distributed Power (LXA DP). Part of the test train stationed in the BNSF yard is shown in Figure 1.

Figure 1. Part of Test Train

1.3.2 Test Configurations

Five different train configurations, including two HE and three DP trains were tested (see Figure 2). In the configurations without a rear locomotive, the last car was equipped with an End of Train Device (ETD). The location of each locomotive is indicated by "L" in the figure. The number above the line indicates the number of cars in the train. For example, train configuration

L-100-L-100-L indicates a DP train with one lead and two remote locomotives and 100 cars between two consecutive locomotives.

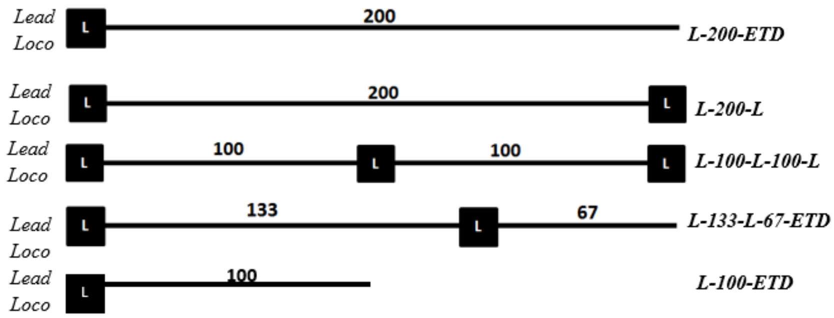

Figure 2. Test Train Configurations

The locations of the eight instrumented cars in the train are shown in Figure 3. Figure 4 shows the inside of instrumented car DOTX 234 (Car #75 in the test train).

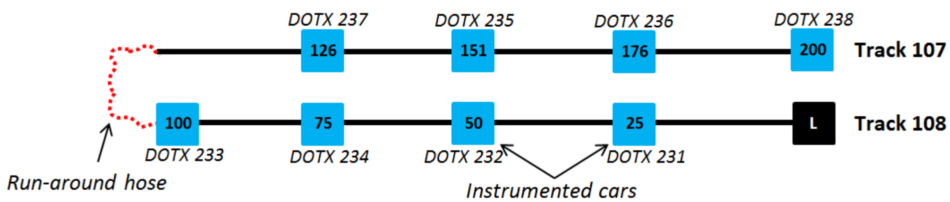

Figure 3. Location of Instrumented Cars

Figure 4. Inside of Instrumented Car DOTX 234

1.3.3 Data Collection

Eight cars were instrumented appropriately to monitor and record pressures in the BP, brake cylinder (BC), Auxiliary Reservoir (AR), and Emergency Reservoir (ER) as a function of time. The pressures were recorded using the SOMAT data acquisition system and fed into a laptop computer. The setup of the SOMAT eDAQLite device inside the instrumented car is shown in Figure 5.

Figure 5. eDAQLite Device Setup

The pressure tap and transducer setup for BP measurement in one of the test cars is shown in Figure 6.

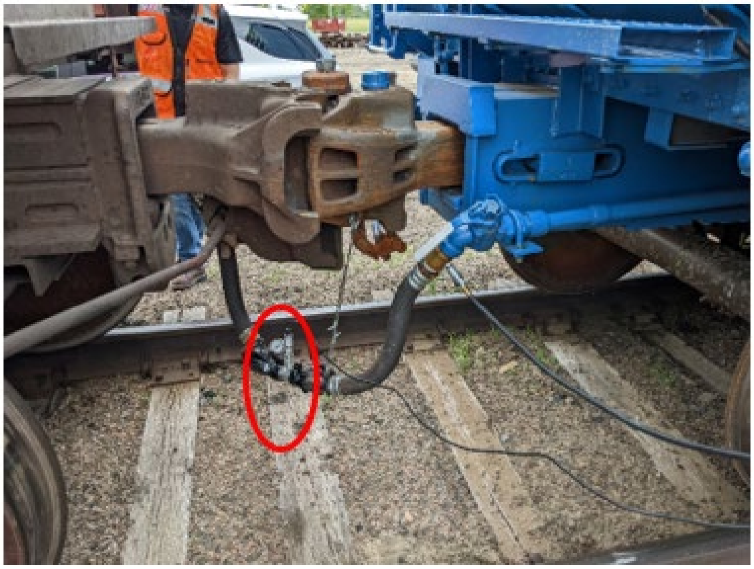

Figure 6. BP Pressure Measurement on Test Car

The BC pressures were collected at the eight instrumented cars. Figure 7 shows the pressure tap set up to collect the BC data in one of the test cars. The BC pressures from the seven instrumented cars were used to compute a train average BC pressure. During the test, the instrumented car DOTX 233 at location 100 was observed to have a service leakage issue, therefore the data from this car was not included in calculating the average BC pressure and average BC buildup time. Train average BC pressure build-up (a function of time) provides an index to compare the stopping ability of various train configurations.

The main factors that can influence the development of train average BC pressure, and consequently the train's stopping ability, are:

- Brake signal propagation time to rear of train

- BC build-up time at rear of train
- BP gradient (i.e., the difference in BP pressure between the first locomotive at the HE and the last car)
- Recharge time

Figure 7. BC Pressure Measurement on Test Car

Braking in a train with false gradient due to insufficient recharge may lead to reduced braking capability due to unintended brake release. False gradient refers to the condition during recharge in which the BP gradient is temporarily larger than it is under the steady state (i.e., fully charged) condition. An unintended release of brakes can occur under certain conditions of false gradient combined with a brake application using an insufficiently heavy BP reduction.

The team recorded the pressures in the AR and ER of the eight instrumented cars. Figure 8 shows the pressure transducers connected to the AR and ER in one of the instrumented cars.

Figure 8. AR and ER Pressure Measurement in Test Car

The tests were carried out for various leakage configurations, including natural leakage in the train (i.e., no added leakage) and concentrated leakage induced in selected cars to produce total train air flow of approximately 60 Standard Cubic Feet per Minute (SCFM), 90 SCFM, 140 SCFM (DP with 2 locomotives) and 160 SCFM (DP with 3 locomotives). The air flow rates in the range of 140 to 160 SCFM are referred to as "limiting" flow. The added leakage ports were distributed at 18 different locations in the train, including 8 instrumented FRA cars and 10 grain cars. The leakage ports were located at car numbers 20, 25, 30, 45, 50, 55, 70, 75, 80, 95, 100, 105, 125, 145, 150, 175, 180, and 200 in the train. The amount of leakage at each location varied depending on the train configuration and total air flow specified for the various leakage scenarios. Figure 9 shows the setup for a leakage port in one of the FRA cars. The flow meter, indicating the local relative leakage rate. was used to help adjust and balance the overall leakage distribution throughout the train.

Figure 9. Leakage Port in Test Car

The collected air brake system data was used to compute the performance parameters listed below:

- Application propagation time: Time from brake application command to the worst-case car's Brake Cylinder Pressure (BCP) rising above 0.5 psi.
  In Phase II, it was defined as the time interval from the first car BCP reaching 0.5 psi to the last car BCP rising above 0.5 psi.

- Release propagation time: Time from release command to the worst car's BCP beginning to exhaust to atmosphere.
  In Phase II, it was defined as time interval between the brake handle moving to release position and the initial air venting from the retainer of the last car.
- Release time: Time from release command to the worst car's BCP dropping below 3 psi.
  In Phase II, it was defined as time from the initial BP pressure increase at the locomotive to the last car's BCP dropping below 3 psi.
- Recharge time: Time from release command to the worst car's AR recharged to within 2 psi of its fully charged value prior to brake application.
  In Phase II, it was defined as time from the initial BP pressure increase at the locomotive to the last car's AR recharged to within 2 psi of its fully charged value prior to brake application.
- BC Pressure: Final BC pressure, average of seven instrumented cars[1].
  In Phase II, the BC pressures from the first car, car at one quarter point, car at middle of train, car at three quarter point, and the last car were averaged.
- BC Buildup Time: The average, over seven instrumented cars[2], of the times from the brake application command to each car's BCP building up to 90 percent of its final value (except for minimum application, in which case timings were based on BCP reaching 12 psi).
  In Phase II, it was the average, over five instrumented cars (first car, car at one quarter point, car at middle of train, car at three quarter point, and the last car), of the times from the initial BP pressure decrease at the locomotive to each car's BCP building up to 90 percent of its final value (except for minimum application, in which case timings were based on BCP reaching 12 psi).

Clock times for initiating brake application or release events were interpreted using the brake command data from the locomotive event recorder. Event termination times were based on data from the instrumented car with the longest response time (i.e., the "worst car"). In a DP train with remote consist at the rear, the "worst car" will be between locomotive consists.

1.4 Scope

The stationary train tests were designed to study the impact of leakage conditions and various air brake applications on HE and DP configurations for the 200-car train.

The following leakage conditions were considered in the tests:

- Nominal – amount of leakage existing naturally in the train, defined by the state of the cars in the test train
- Marginal – maximum allowable leakage as per current FRA regulations (e.g., 60 SCFM (HE configuration) or 90 SCFM per train (DP configuration) and gradient/sag less than 15 psi)

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[1] During the test, car # DOTX 233 (100th car in the consist) was observed to have a leakage issue in the AR; the data from this car was not used in the average BC pressure and average BC build up time calculations.

- Rare/extreme conditions – leakage induced in the instrumented cars beyond the marginal leakage to create 15 psi gradient (HE configuration) or 15 psi sag (DP configuration)

The scope included performance evaluation of the air brake system in HE and various DP configurations in various operating scenarios including stepped brake applications and applications with false gradients.

The scenarios also included some tests for conditions where equipment, systems, or communications might be malfunctioning. Such abnormal conditions are not permitted under current railroad operating rules, but may occur in service due to en-route failures of air brake components or distributed power systems. Specific failure modes included were Communication Loss Idle Down (CLID) due to DP communication failures, and transmission issues during emergency brake application. The objective of the CLID test was to determine whether CLID might be compromised at high leakage conditions for the different train configurations. The objective of this testing was not to evaluate the likelihood of communication loss (Comm Loss) on a locomotive; rather, to see if a 20 psi brake application from the lead locomotive would result in the remote locomotives initiating the CLID procedure after a Comm Loss condition is created by turning off the radio on the remote DP locomotive.

1.5 Organization of the Report

This report is structured as follows:

Section 2 describes the test cases.

Section 3 discusses the data from test results.

Section 4 summarizes the results of this study.

2. Test Cases

The research team conducted a series of more than 120 tests using the train configurations discussed in Section 1.3.2, various BP leakage conditions, and various air brake applications (see Table 1). The table is color coded to indicate the date each test was completed. The tests were conducted in the BNSF yard at Staples, MN, between July 18 and 28, 2022. The tests included straight and stepped brake applications, cycle braking, false gradients, and several additional tests. The measurements from each test were used to calculate the parameters, including brake signal propagation time, release and recharge times, as well as BC build up times, as explained in Section 1.3.3.

Table 1. Stationary Train Test Matrix and Schedule

Train Configuration		HE: L-200-ETD			DP: L-200-L				DP: L-100-L-100-L					DP: L-100-L-67-ETD					HE: L-100-ETD
Leakage		Min. Leak	60 SCFM	60 SCFM, 10,000 ft	Min. Leak	60 SCFM	90 SCFM	Limiting Flow	Min. Leak	60 SCFM	90 SCFM	Limiting Flow	Limiting Flow, mid-DP cut out	Min. Leak	60 SCFM	90 SCFM	Limiting Flow	Limiting Flow, ETD Comm Loss	60 SCFM
Straight Applications	Minimum application, release, recharge	1	1			1	1	1			1	1				1	1		
	10 psi BP reduction, release, recharge				1	1	1	1	2	2	1	1	1	2	1	1	1		
	15 psi BP reduction, release, recharge	1	1	2															2
	Full Service (FS), release, recharge	2	1	2	1	1	1	1			1	1			1	1	1		
	Emergency, release, recharge	2	1		2	2	1	1			1	1				2		2	
	Emergency propagation with 15% of valves cut out	1	1			2	1	1				1					1		
Stepped Application	Min. to 10 psi	2	2			2	1	1			2	1			2	1	1		2
	10 psi to 15 psi					2	1	1			2	1			2	1	1		
	15 psi to 17 psi					2	1	1			2	1	1			1	1		
	17 psi to FS							2									2		
	FS to Emergency?							2									2		
False Gradient, 20# release	-2 psi		1																
	-3 psi		1			1	1	1			1	1				1	1		
	-4 psi							C			C	C				C	C		
	-5 psi											2							
	BNSF -4 psi					2	2	2			2	2				2			
CLID	20 psi						1	1			1	1	1			2	2		
Trainline Emergency w/ valves cutout			1				1	1			1	1	1						
Segment Charging			1									1							
Cycle Braking			1				1									1			

1 - High priority test

2 - Lower priority test

C – Contingent test (decision to perform test depends on outcome of a previous test)

Yellow	Completed Day - 1, Monday 7-18-22
Green	Completed Day - 2, Tuesday 7-19-22
Medium blue	Completed Day - 3, Wednesday 7-20-22
Orange	Completed Day - 4, Thursday 7-21-22
Light green	Completed Day - 5, Friday 7-22-22
Light yellow	Completed Day - 6, Saturday 7-23-22
Light blue	Completed Day - 7, Sunday 7-24-22
Rose	Completed Day - 8, Monday 7-25-22
Bright blue	Completed Day - 9, Tuesday 7-26-22
Peach	Completed Day - 10, Wednesday 7-27-22
Magenta	Completed Day - 11, Thursday 7-28-22

2.1 Straight Brake Application, Release, and Recharge Cycles

Straight brake applications consisted of minimum application with BP reduction of 6 to 8 psi, as well as BP reductions of 10 and 15 psi. In addition, tests to simulate a Full Service (FS) application (i.e., BP reduction of 26 psi), Emergency application and Emergency propagation with 15 percent of the valves cut out (worst case scenario) were also performed. For each test, the brake application was held for 10 minutes or until the air flow stabilized, then the BCs were completely released and BP, AR, and ER were recharged to within 2 psi of the original pressure prior to the brake application.

2.2 Segment Charging Test

The intent of this effort was to monitor the effects of assembling a longer train from smaller segments that have met flow and gradient limits, with the assembled train subject only to a Class III brake test, and leaving the yard when at least 60 psi is detected at the last car. To assess the brake performance of cars under the “segment charging” conditions, three different tests were conducted:

- 1 test on HE-200-ETD with 60 SCFM leakage
- 2 tests on HE-200-ETD with natural leakage

The test procedure consisted of the following steps:

- Two blocks of cars (1-100 and 101-200) were parked overnight, with no air in the BP (Emergency). The segments were fully charged prior to Emergency.
- In the morning, the lead locomotive was coupled to the first block (1-100) followed by coupling to the second block. Train charging began.
- A 20-psi brake application was made once the ETD reached 60 psi.
- Brake performance was recorded.

2.3 Cycle Braking

This test emulated speed control events on a downgrade, wherein the engineer might make increasing brake applications, with intermediate releases. The tests were performed to identify both unintended releases and brakes staying applied long after a release had been commanded. These sequences are not common practice and would typically be considered a violation of railroad air brake and train handling rules.

The cycle braking tests were conducted for the following train configurations and leakage conditions:

- HE-200-ETD (60 SCFM)
- L-200-L (90 SCFM)
- L-133-L-67-ETD (90 SCFM)

Two cycle intervals were used:

- 60 second cycle interval (i.e., recharge time) between applications (for both HE & DP)
- 30 second cycle interval between applications (only for DP)

The following brake cycling sequence was used:

- Minimum brake application, wait for the brake to set
- Brake release, wait for 30/60 seconds

- 10 psi reduction, wait for the brake to set
- Brake release, wait for 30/60 seconds
- 15 psi reduction, wait for the brake to set
- Brake release and recharge

2.4 False Gradient

As previously explained in Section 1.3.3, false gradient is the difference between the actual BP pressure and the targeted BP pressure. An unintended release of brakes may occur when the BP pressure at the rear of the train increases (as the pressure maintaining feature recovers the lower BP pressure) above AR due to insufficient recharge of the system. To simulate false gradient scenarios, a release was made after a 15 psi brake application. The release was followed by an 8 psi minimum application with a partial recharge. Three levels of false gradients (-2 psi, -3 psi and -4 psi) were simulated by monitoring the BP and AR pressures at the rear of the car for the HE and DP configurations, as noted in the test matrix (Table 1). In addition, several tests were performed using the BNSF methodology (identified in the test matrix as "BNSF -4psi"), where the first brake application was followed by a deeper second application.

2.5 Train Line Emergency with Multiple Cut-out Valves

To assess the impact of cars with malfunctioning emergency valves during Train Line Emergency (TLE) incidents, several tests were performed for the HE and DP configurations and high leakage cases. Emergency was initiated with a hose separation at Car 50 in the test train. The brake valves of 11 cars in a row were cut out on either side of Car 50 (Cars 29-40 & 60-71) to simulate a sequence of cars with bad valves. The ensuing brake performance was recorded.

2.6 Stepped Brake Applications

The stepped application test started with a minimum application and continued to other intermediate BP reductions for the specific train configuration and leakage conditions. The tests were extended to FS and Emergency applications in the limiting flow case for the DP configurations L-200-L and L-133-L-67-ETD, as noted in Table 1.

2.7 Communication Loss Idle Down (CLID)

CLID relies on the BP to propagate a signal to the DP remote consist(s) when radio communication is interrupted between the locomotives in a DP configuration. It is possible that in a train with increased flow, the relay (i.e., wave) signal could be compromised after a communication loss. The varying conditions of BP length and its state of charge due to leakage and false gradient will affect CLID propagation.

The intent of this testing was not to evaluate the likelihood of CommLoss on a locomotive, but . assuming CommLoss has occurred by turning off the radio on the trailing locomotives, to see if a brake application of 20 psi from the lead locomotive would result in the remote locomotives initiating the CLID protocol. When the remotes sense the BP pressure drop, they cut out the feed valves and initiate the CLID protocol when in traction mode. This protocol while in a state of CommLoss allows the remote to step the throttle to Idle at 3 seconds per notch and cut out the brake valve as preventive actions to reduce any in-train forces. Instead of traction, if the locomotives are in Dynamic Brake (DB), the DB level will be maintained.

3. Discussion of Test Results

The event recorder data from the locomotives and the data retrieved from SOMAT for each test were used for data analysis. Event recorder data was downloaded from the locomotives daily and each time the train configuration was changed on a given day. The data in the event recorder downloads was provided at 1 second intervals.

3.1 Data Synchronization

As a first step, data synchronization was performed between locomotives and the test cars. The event recorder clocks of the DP locomotives were synchronized with the lead locomotive as shown in Figure 10, as they had different local times. The event recorder data for the example in the figure was downloaded from the DP train L-100-L-100-L on July 22, 2022, and was for the "limiting" flow case.

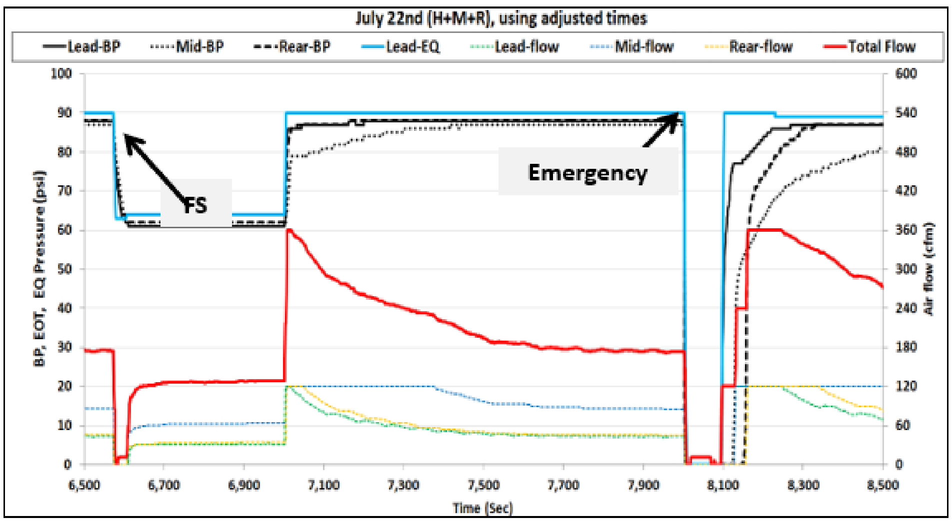


Figure 10. Locomotive Data Synchronization

For the HE configuration test cases, data synchronization between locomotive event recorder data and test car data was performed using emergency applications as a benchmark. The actual length between lead locomotive and Car 25 was 1,575 feet. The air signal travels through the BP at approximately 1000 ft/s. Therefore, the time from the first BP pressure drop in the locomotive to the time of the first BP pressure drop in Car 25 should be around 1.6 seconds. An example case for manual data synchronization using the BP pressures from an emergency application in the HE configuration with natural leakage is shown in Figure 11.

For DP cases, the following procedure was used for data synchronization between locomotives using emergency applications and reverser positions as benchmarks.

- The GPS time from the test cars was synchronized with the mid or rear locomotive event recorder time (mid/rear locomotives had the same time as GPS).
- To check the accuracy of this process, the BP pressures in Car 200 and the rear locomotive were monitored after an emergency application in the DP train configurations L-200-L and L-100-L-100-L.

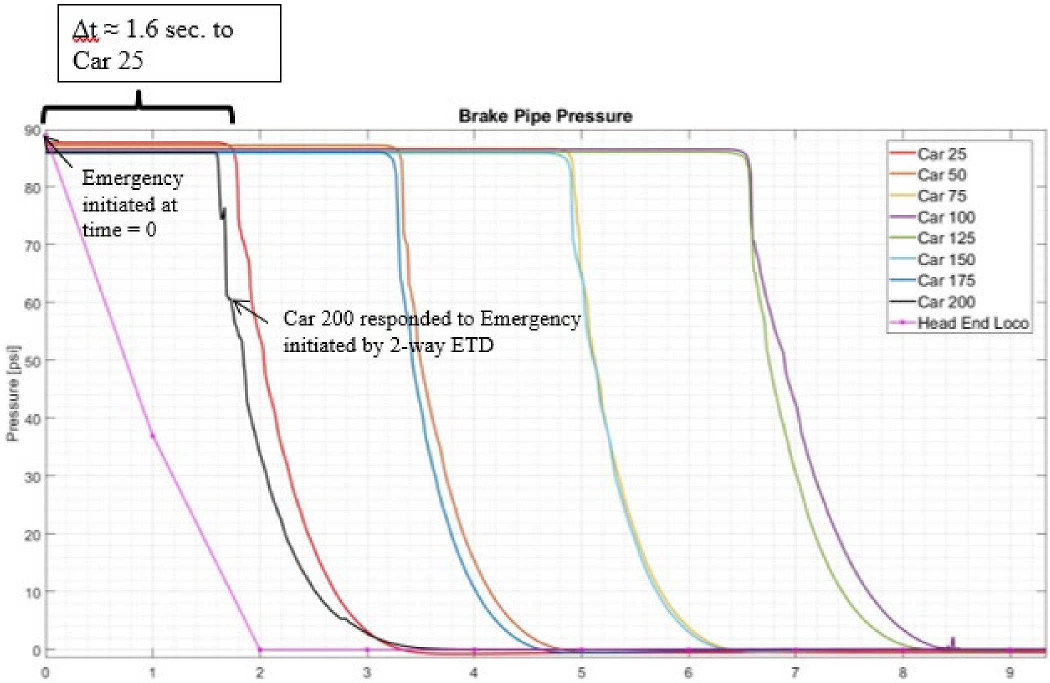


Figure 11. BP Pressure, L-200-ETD, Emergency Application

3.2 Comparison of Phase II and Phase III Tests in HE Configuration

In Phase II, researchers conducted a series of air brake rack tests with maximum train length configuration of 200 50-foot cars. The total length of BP for the 200-car train was 10,000 ft. A mix of ABDX and DB 60 control valves were used in the rack tests (a 2-way ETD device was not used). The specified leakage configurations were generated by applying leakage chokes at various locations throughout the test rack. For example, three different sized leakage chokes were provided at 55 different locations to develop 60 SCFM in the 200-car configuration. The team detailed the leakage choke setup for the minimum 60 SCFM and limiting air flow conditions in the VLT Phase II air brake rack test report [1].

In Phase III, researchers conducted stationary train tests in the BNSF rail yard with 200 cars. The total BP length was around 12,600 ft. The last car in the HE train configuration was provided with a 2-way ETD. As discussed in Section 1.4, the leakage was adjusted using ports at 18 different locations.

The comparison between Phase II and Phase III tests were limited to the conventional (i.e., HE only) trains, as that was the only configuration tested in Phase II. While the trains were not identical between the two phases (e.g., different train BP lengths, BP length per car, leakage distributions, etc.), the intent of the comparison was to show that the system behavior was consistent across the two series of tests. Even though the comparison showed numerical differences in the results between the two phases, they could be explained by differences in the physical characteristics of the trains and test setups.

The air flow and BP pressure gradients are compared in Table 2 for HE train configurations between Phase II and Phase III tests. The air flow and BP pressure gradients are similar between the two cases. During the Phase III tests, the lead locomotive reported 0 SCFM for flow less than 20 SCFM.

Table 2. Flow and Gradient Comparison for 200 Car HE Train

HE Configuration with 200 cars		Actual Flow, SCFM	Gradient, psi
Natural	Phase II	10 (9.9)[2]	1 (0.6)
	Phase III	<20[3] (11.8)	1.2 (1.2)
60 SCFM	Phase II	59.5 (60.3)	12.4 (12.3)
	Phase III	58-60 (58.4)	10.5 (10.9)

3.3 Brake Application Propagation Time

The signal propagation times for the minimum 15 psi full service and emergency brake applications are compared for the Phase II and Phase III tests in Figure 12. The propagation times measured during Phase III were longer compared to the data from the air brake rack tests in Phase II for all the brake applications, except for the emergency application.

The difference in signal propagation times between Phase II and Phase III are explained by:

- Longer train length in Phase III
- Longer BP length per control valve for the test train in Phase III
- Effect of 2-way ETD in Phase III emergency brake tests

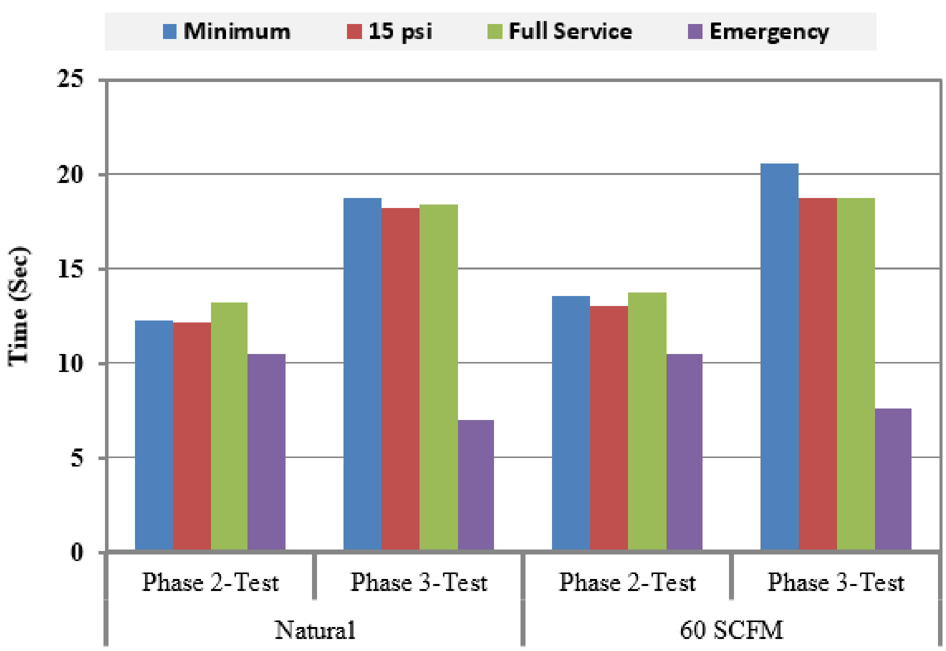


Figure 12. Brake Application Propagation Time

[2] Simulation values are in parentheses

[3] Lead locomotive reported 0 SCFM for flow < 20 SCFM in Phase III tests

For the FS brake application, signal propagation times in Phase III were 1.4 times longer than those of Phase II (see Figure 12).. The ratio of the BP length in the Phase III test (12,600 ft) to the BP length in the Phase II test (10,000 ft.) was 1.26. The longer overall BP length of the Phase III train compared to the Phase II test setup explains most of the longer propagation time.

Researchers simulated Phase II and Phase III tests using FRA's Train Energy and Dynamic Simulator (TEDS) software to confirm the contribution of longer train length and longer BP length per control valve. Table 2 compares the air flows and pressure gradients between the tests and simulations for both Phase II and Phase III.

Simulation runs were made for the following three cases:

- 200 cars at 50 ft BP length per control valve for a total BP length of 10,000 ft
- 252 cars at 50 ft BP length per control valve for a total BP length of 12,600 ft
- 200 cars at 63 ft BP length per control valve for a total BP length of 12,600 ft

Brake propagation times from the simulations for the FS brake application are plotted in Figure 13 for the 10 SCFM leakage condition. The simulation was able to reproduce the Phase II and Phase III test results in terms of the increase in propagation times based on the BP length between the brake valves. With the BP length per brake control valve at 50 ft, increasing the train length from 10,000 to 12,600 ft increased the propagation time by a factor of 1.27. For the 12,600 ft train with a BP length per control valve of 63 ft, the propagation time increased by a factor of 1.4.

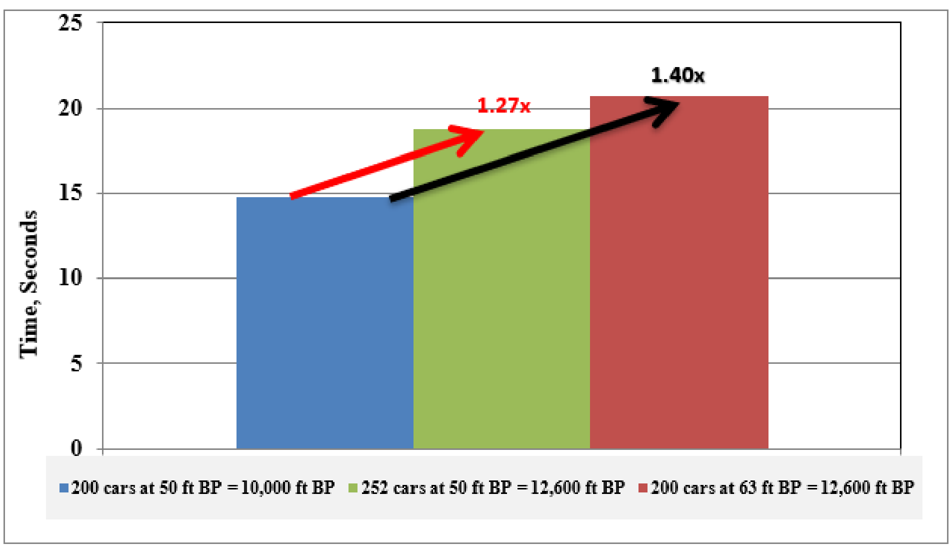


Figure 13. FS Brake Propagation Time from TEDS (10 SCFM)

3.3.1 Brake Cylinder Pressure

The BC pressures from data on the seven instrumented cars (Car #s 25, 50, 75, 125, 150, 175, and 200) were averaged and are shown for various leakage conditions and brake applications in Figure 14. For the natural leakage condition, the average BC pressure in Phase III was slightly lower compared to Phase II (i.e., 64.6 psi in Phase III vs. 66.5 psi in Phase II after a FS application).

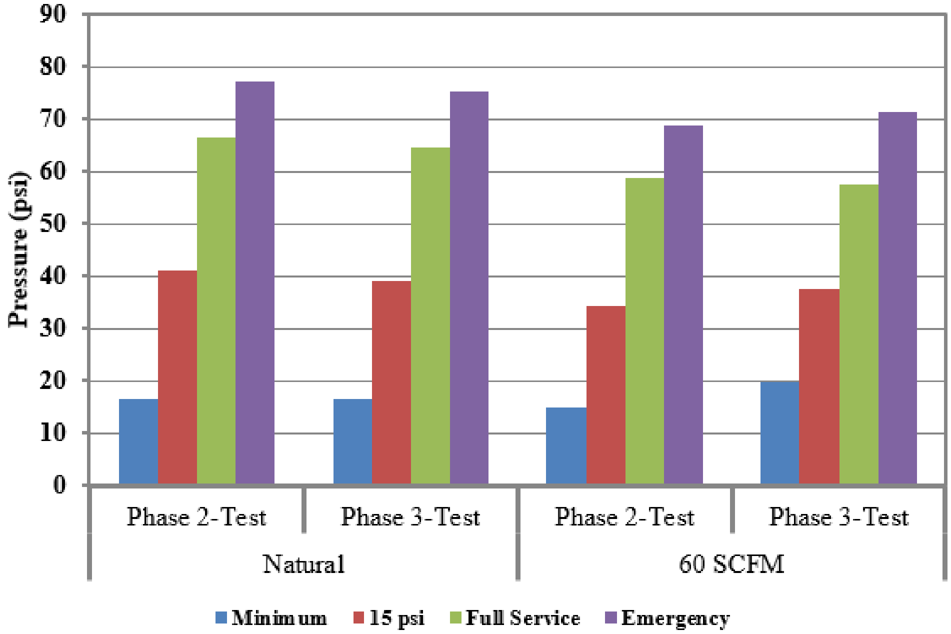


Figure 14. Comparison of Average BC Pressures

The BC pressure values were affected by the train length. The test train in Phase III had longer BP length and longer cars (63 ft of BP length per valve vs. 50 ft in Phase II) leading to slower BC pressure build up (see Figure 15) after FS application for the natural leakage condition. Another contributing factor was lower BP reduction in Phase III (26 psi) compared to Phase II (30 psi).

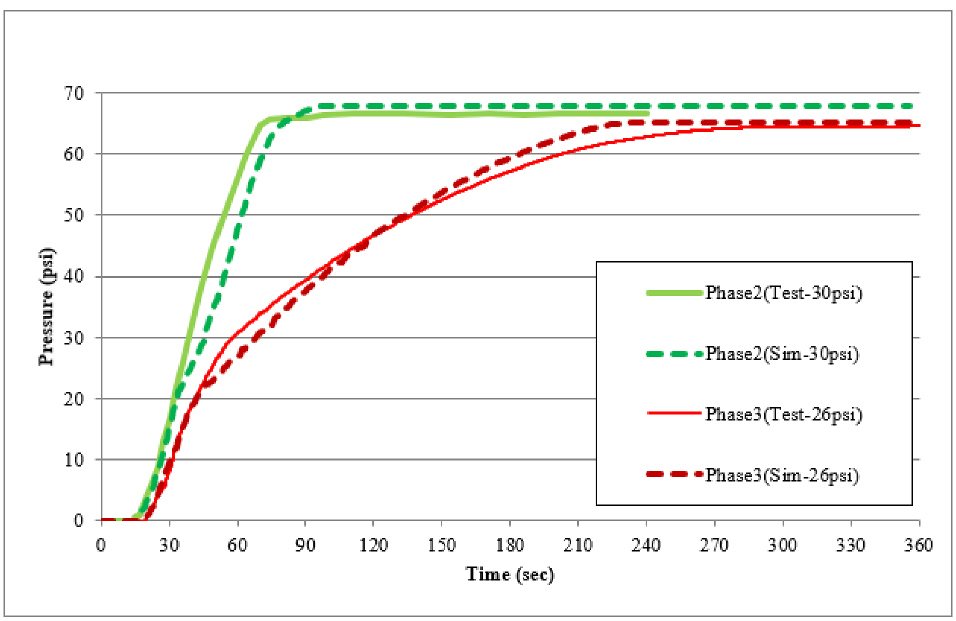


Figure 15. Average BC Buildup Time (FS, HE Train, Natural Leakage)

The average BC pressure buildup for the natural and 60 SCFM leakages are plotted in Figure 15 and Figure 16. The BC pressure buildup trends are similar for the two leakage conditions. For the

FS application, the higher leakage caused lower BC pressures in the case of 60 SCFM compared to the natural leakage condition, as noted from the plots in Figure 15 and Figure 16.

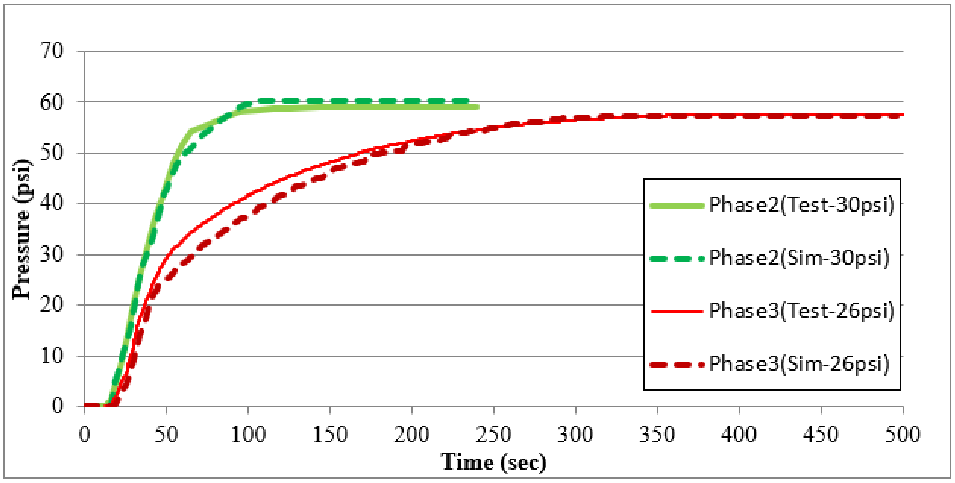


Figure 16. Average BC Buildup Time (FS, HE Train, 60 SCFM)

For the case of 15 psi brake application, build-up times for the cars located near the front end (Cars # 25, 50,75) were faster compared to those toward the rear of the train (Cars # 125, 150, 175, 200), as shown in Figure 17 and Figure 18. At any particular time, magnitude of difference in braking force throughout the train is an indication of the propensity for slack run-in and severity of buff coupler forces developed. Higher leakage, as shown in Figure 18, resulted in longer build-up times with greater variation of BCP through the train.

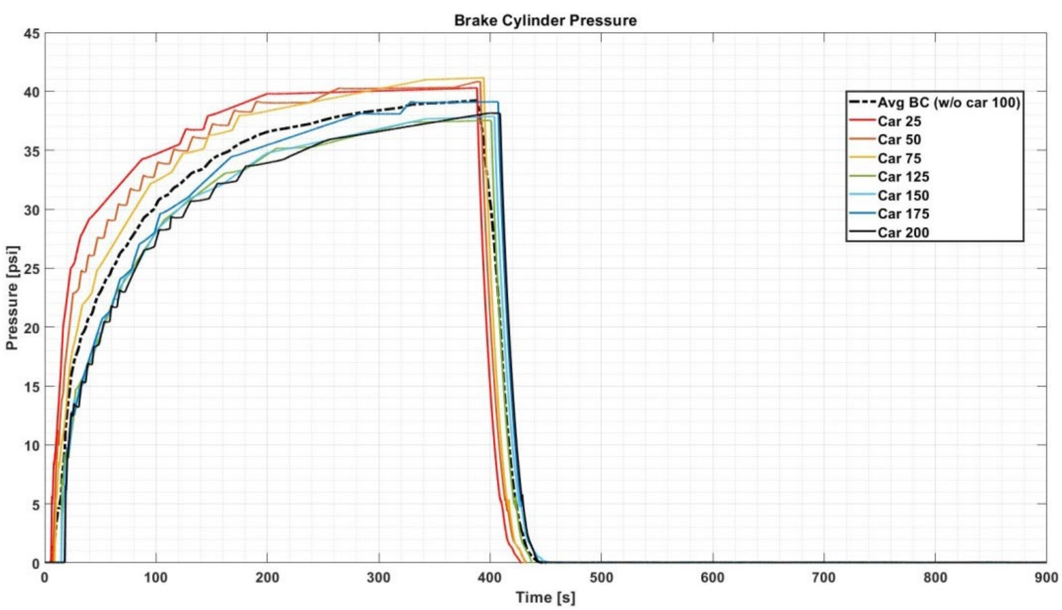


Figure 17. Buildup Time History, 15 psi Application, Natural Leakage

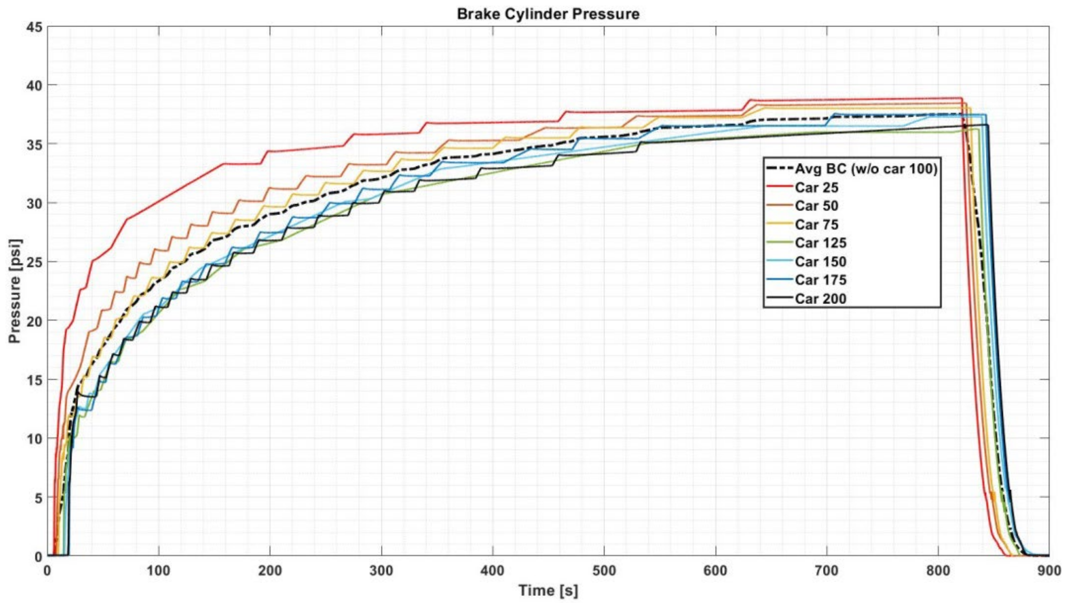


Figure 18. Buildup Time History, 15 psi Application, 60 SCFM

The characteristics of build-up time histories shown in Figure 19 and Figure 20 for the FS application are similar.

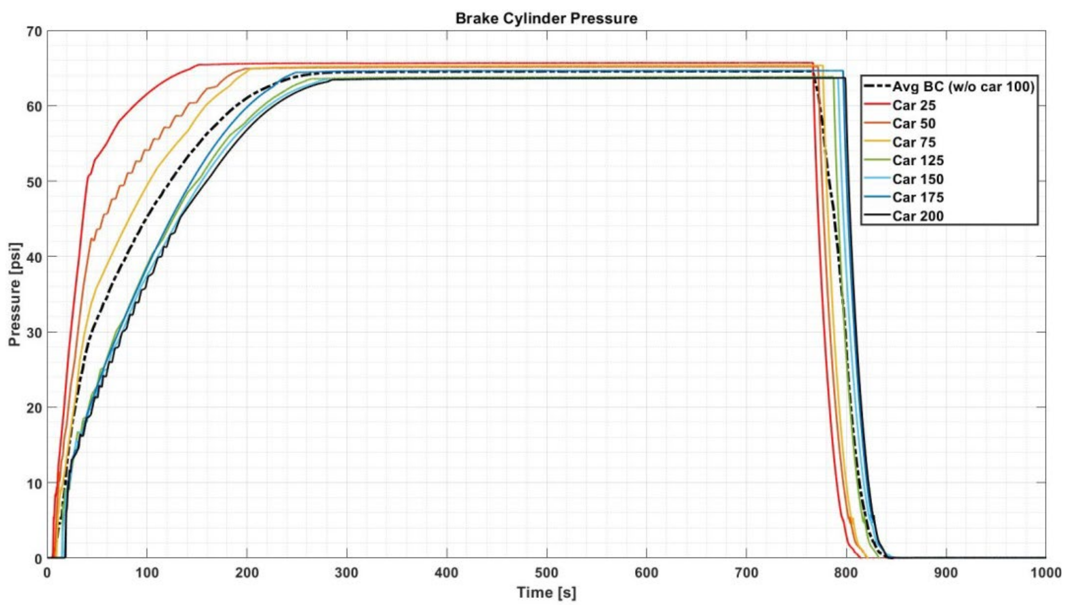


Figure 19. Buildup Time History, FS Application, Natural Leakage

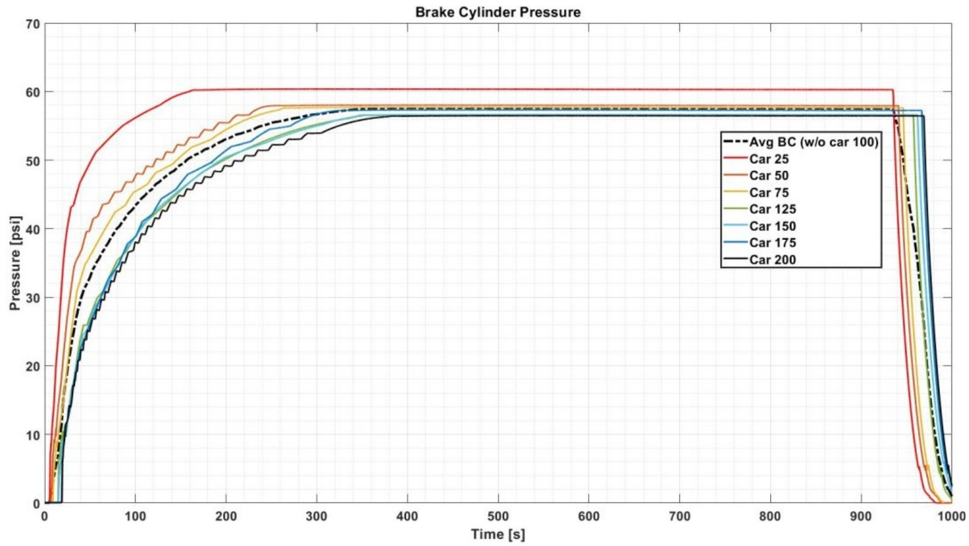


Figure 20. Buildup Time History, FS Application, 60 SCFM

3.3.2 Release and Recharge

Release time from brake handle movement to less than 3 psi BCP at the last car for Phase II and Phase III tests with 200 cars (HE-only) are shown in Figure 21. Since the Phase III train was longer than Phase II, release times were expected to increase for Phase III, due to longer release propagation times. This trend is generally apparent except for FS applications and release from emergency with high leakage. FS BP reduction for Phase II was 30 psi, whereas it was 26 psi for Phase III. Release propagation from 30 psi reduction takes longer than from 26 psi since an additional BP increase is required to initiate the release at each car. This extra release time for Phase II offsets the lower release time due to shorter BP length.

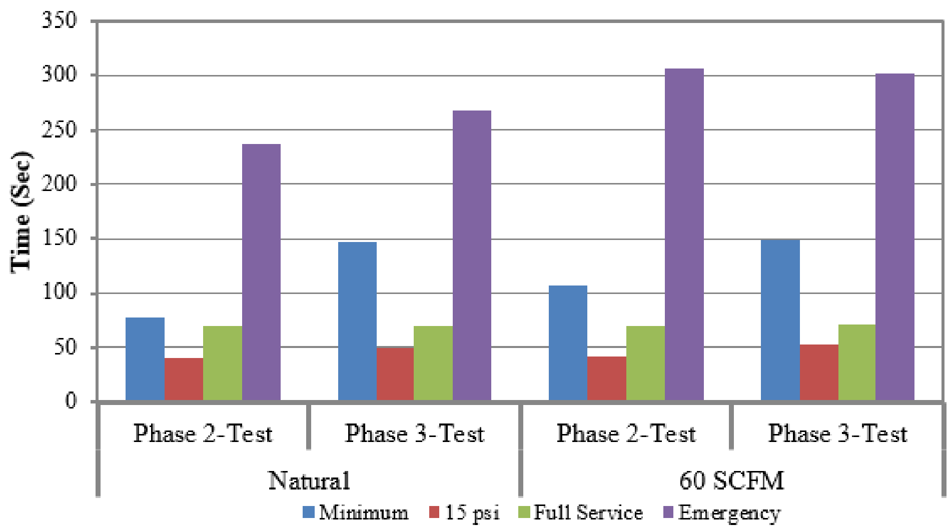
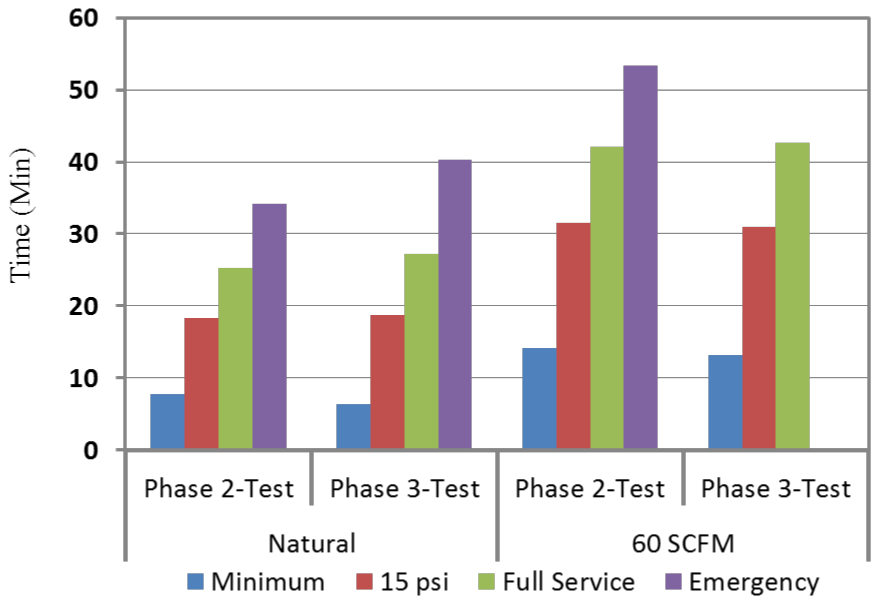


Figure 21. Release Time

Differences in release times from minimum application (between Phase II and Phase III tests) were much greater than release times from heavier brake applications. This reflects the sensitivity of release propagation rate to BP length for a minimum application. The service accelerated release feature might have some variability under minimum applications, especially with a long BP.

As shown in Figure 22, recharge times between Phase II and Phase III were similar for all application and leakage combinations (except for Emergency, which is unexplained). This similarity was expected because recharge time is driven primarily by the number of reservoirs to recharge, not the length of the BP. Data collection during the recharge from Emergency in Phase III testing of a 200-car train with high leakage was inadvertently terminated prematurely to start the next test. Consequently, the full recharge time for this test was not captured.



* *Recharge time of this test was not examined*

Figure 22. Recharge Time

3.4 Comparison of Performance Between HE and DP Configurations

This section provides a comparison between the brake system performances of an HE train (L-200-ETD) with a DP train with a locomotive in the rear end (L-200-L).

As shown in Figure 23, the propagation times of Minimum and FS applications are faster for the DP train. The propagation times for the emergency application are similar due to the 2-way ETD feature.

The average BC pressures displayed in Figure 24 show similar BC pressures for trains with similar gradients. For each configuration, average BC pressures are higher as the gradients are lower.

As seen from Figure 25, brake release times for the HE only configuration were longer compared to the DP train. For a given train configuration, the release times were similar for the different leakage setups tested, except in Emergency. The release times from a Minimum application are higher than those from an FS application because the accelerated service release feature does not consistently activate with less than a 10 psi BP reduction.

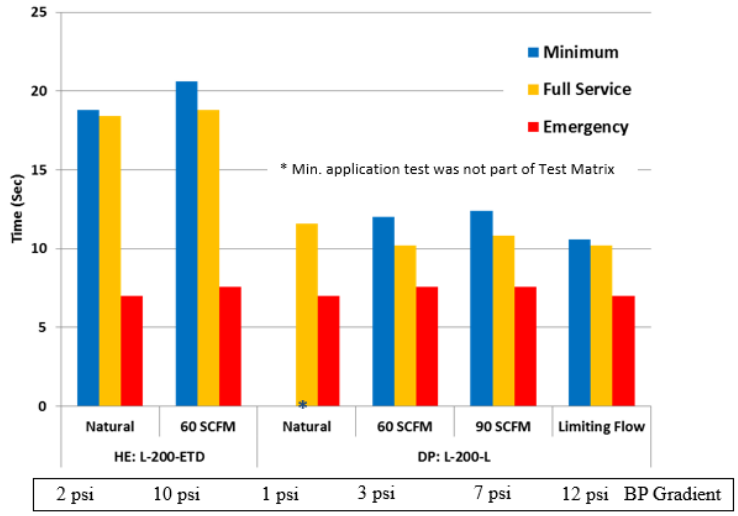


Figure 23. Application Propagation Time

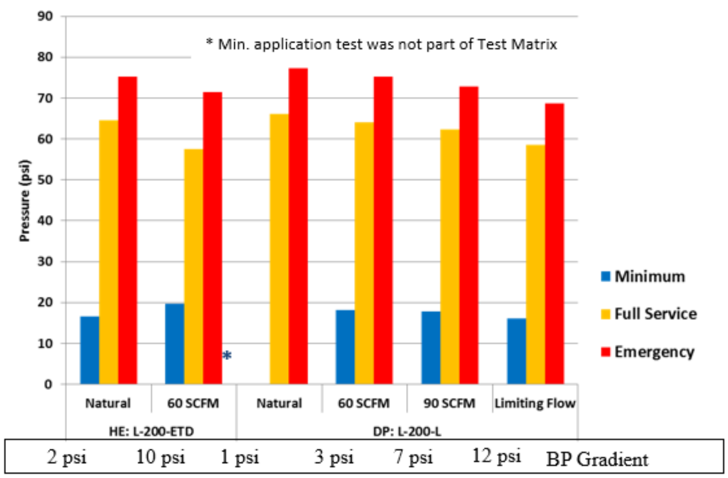


Figure 24. Average BC Pressures

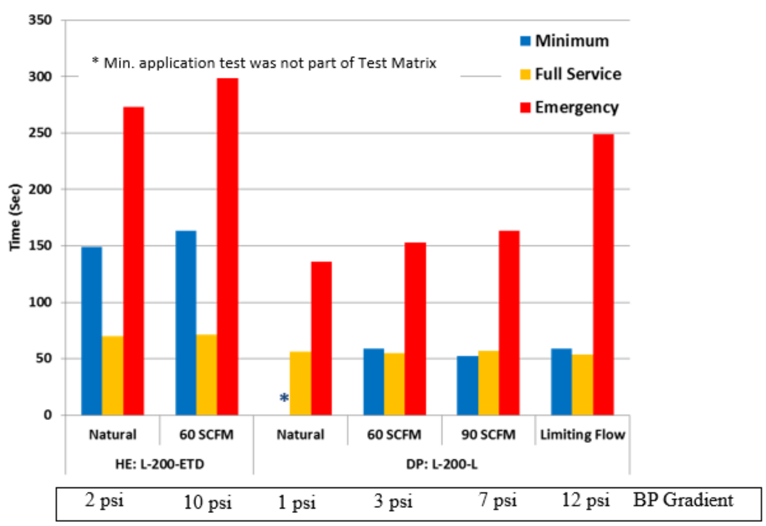


Figure 25. Release Times

Like the release times, the recharge times for the HE train were longer compared to the DP train. For a given train configuration, recharge times were longer for the higher leakage and gradient setups tested, as shown in Figure 26.

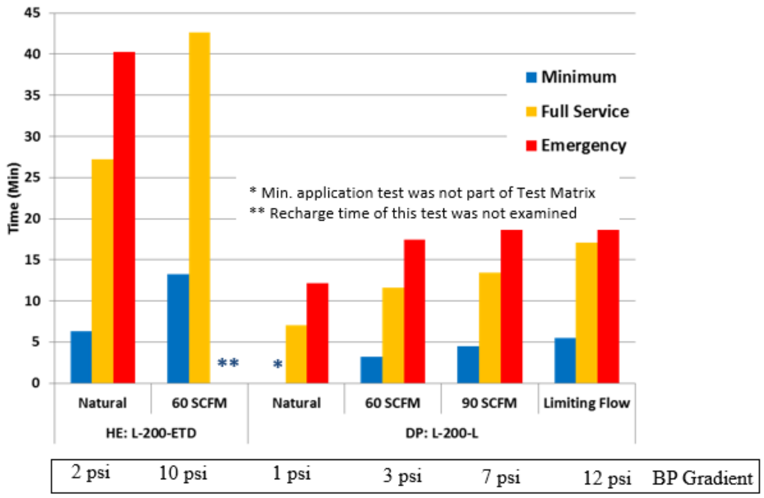


Figure 26. Recharge Times

3.5 FS Brake Performance in Various DP Train Configurations

The test matrix for three different DP configurations, with each configuration simulating three leakage values, is shown in Table 3. In addition to the DP configuration with the locomotive at the rear, there were two other DP configurations: the locomotive at two thirds of the full length and at the middle of the train. The leakage values in the table were target values. The actual leakages based on the flows from the locomotive event recorder were slightly different from the target leakages, depending on the state of the train in each test.

Table 3. DP Train Test Matrix

BP Gradient [psi] - FS			
Train	**60 SCFM**	**90 SCFM**	**Limiting Flow**
L-200-L	3.5	6.8	11.5
L-133-L-67-ETD	1.9	2.7	8.9
L-100-L-100-L	1.4	1.9	4.4

As shown in Figure 27, trains with smaller lengths between two air sources and consequently smaller gradients have faster propagation times.

Trains with smaller lengths between two air sources (i.e., smaller gradient) also have higher BCP and faster build up times, as seen in Figure 28 and Figure 29, respectively. For a given train configuration, BCP value is relatively lower as leakage increases.

Figure 30 shows faster release times for trains with shorter BP lengths between air sources, except for the L-133-L-67-ETD configuration under limiting flow. For a given configuration, release times are similar regardless of leakage values, except for the L-133-L-67-ETD configuration under limiting flow. The remote locomotive in the L-133-L-67-ETD configuration was feeding 133 cars, compared to only 100 cars for each locomotive in the L-200-L train. At the limiting flow rate, as seen from the hatched bar in the plot, the single remote unit in the L-133-L-67-ETD train was likely unable to meet the demand for air.

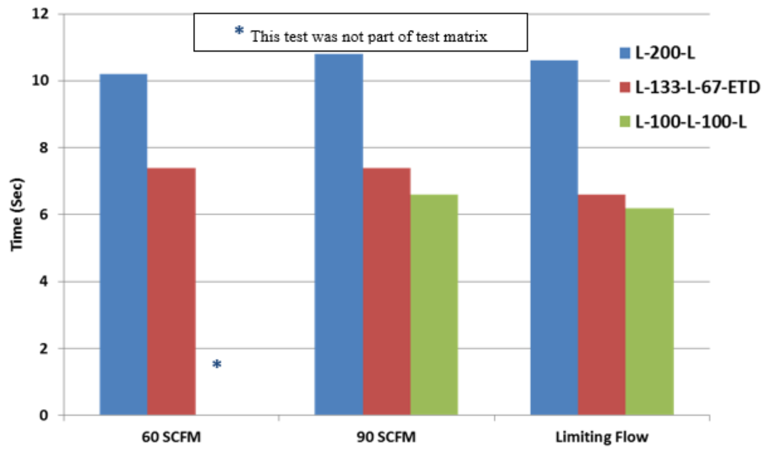


Figure 27. Propagation Time – FS Application

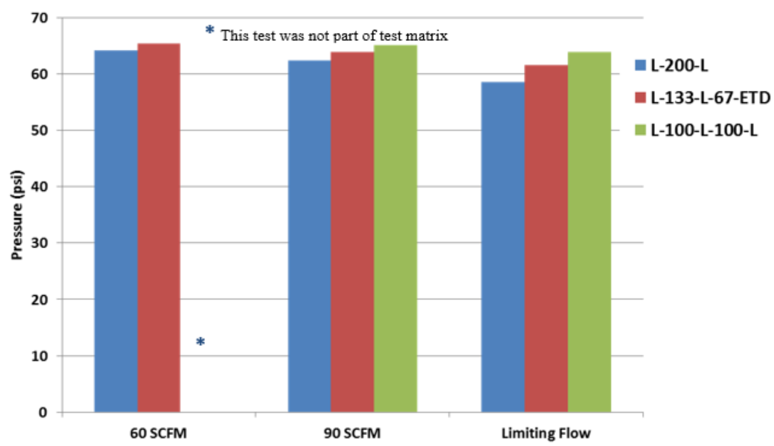


Figure 28. BC Pressure for FS Application

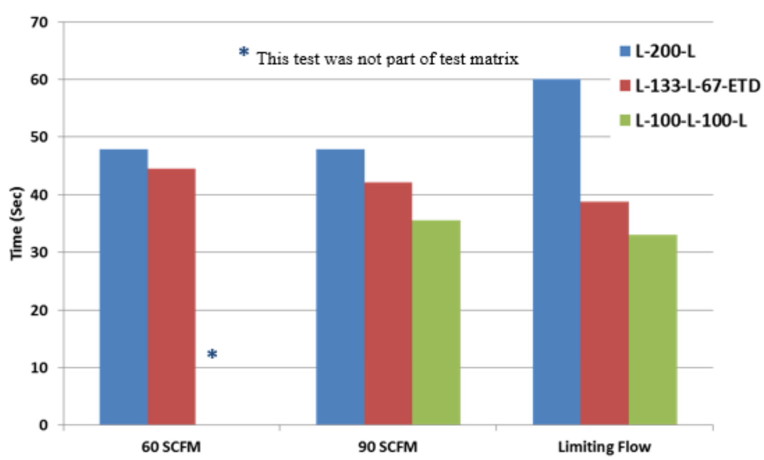


Figure 29. BC Buildup Time for FS Application

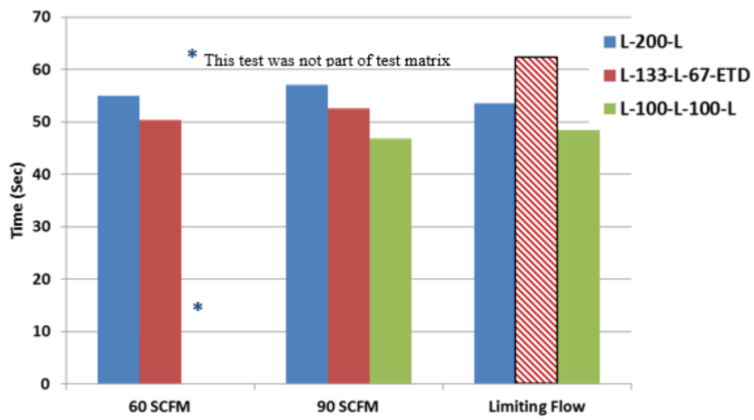


Figure 30. Release Times for FS Application

3.6 Segment Charging Tests

The research team monitored the effects of assembling a longer train from smaller segments that have met flow and gradient limits; the longer assembled train has only been subject to a Class III brake test, and leaves the yard when at least 60 psi of brake pipe pressure is detected at the last car.

In order to assess the brake performance of cars under this scenario, three different sets of tests were conducted on the HE configuration L-200-ETD train:

- 1 test with 60 SCFM leakage (on July 25, 2022)
- 2 tests with natural leakage (on July 26 and 28, 2022)

Two blocks of cars, comprising 100 cars each, were parked overnight after an emergency application with no air in the BP. The two segments were fully charged prior to the Emergency. In the morning, a locomotive was coupled to the first block (Cars # 1-100) and then to the second block (Cars # 101-200). The train began its charge. A 20-psi brake application was made once the ETD reached 60 psi and the brake performance of cars in the train was monitored.

The results from Test 1 are plotted in Figure 31. The plot shows that the train was still charging at 1200 seconds, when a 20 psi brake application was made. At this time, the BP pressure at Car #200 (the last car in the assembled train where the ETD was mounted) had just reached 60 psi. Shortly thereafter, at around 1410 seconds, the brakes were released on the instrumented cars (Cars # 100, 200 and 17), grain cars in the second half of the train.

An undercharge occurred in the cars in the rear of the train since the ARs did not have enough time to charge up to the same pressure as the BP at that car. Then, the control valve, sensing BP pressure to be higher than AR pressure, released the brakes in the rear of the train.

The second test performed on July 26 with natural leakage shows a similar behavior (see Figure 32). In this case, a total of 124 cars released including all the cars in the second half of the train and 23 cars in the first half. This included the five instrumented cars (from 75 to 200), the rest being the grain cars.

This test was repeated on July 28, and the results (plotted in Figure 33) are very similar. In this case, the brake released on a total of 102 cars including 97 grain cars from the second half of the train.

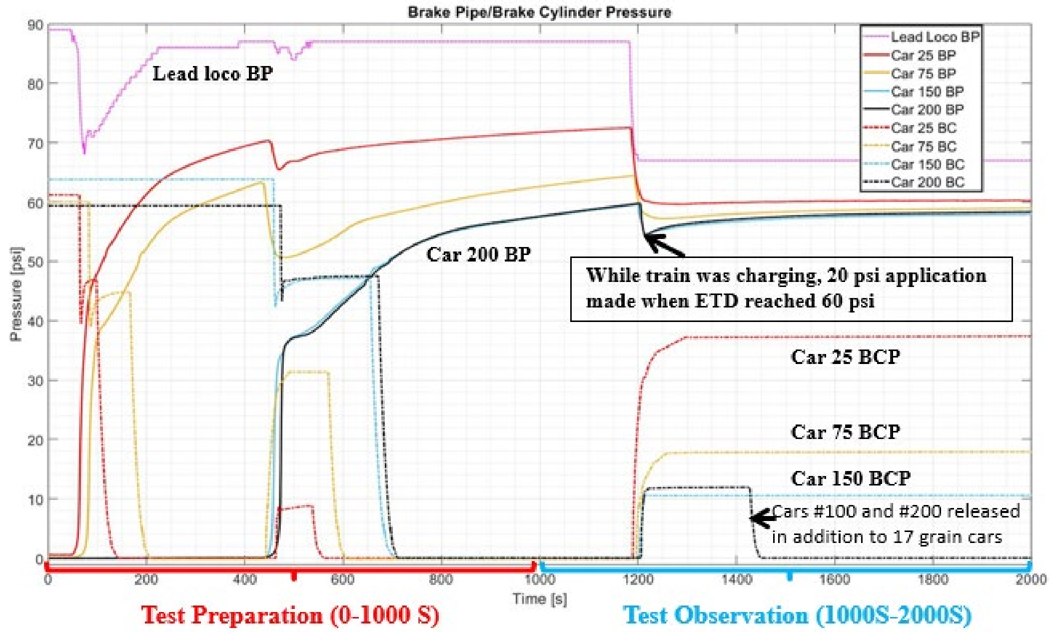


Figure 31. Test 1 on July 25, 2022 - 60 SCFM Leakage

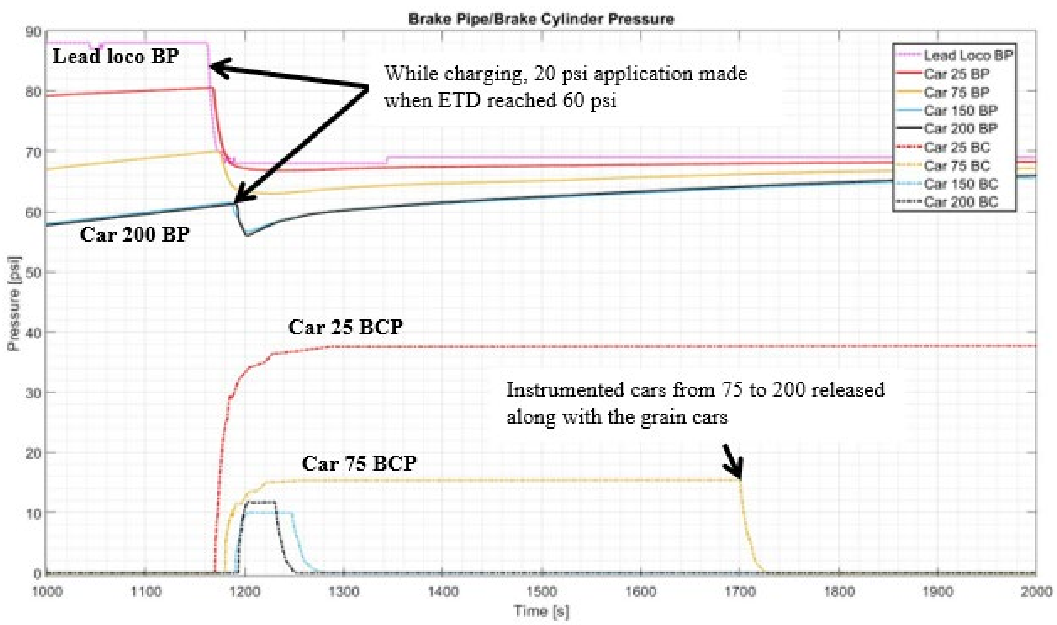


Figure 32. Test 2 on July 26, 2022 - Natural Leakage

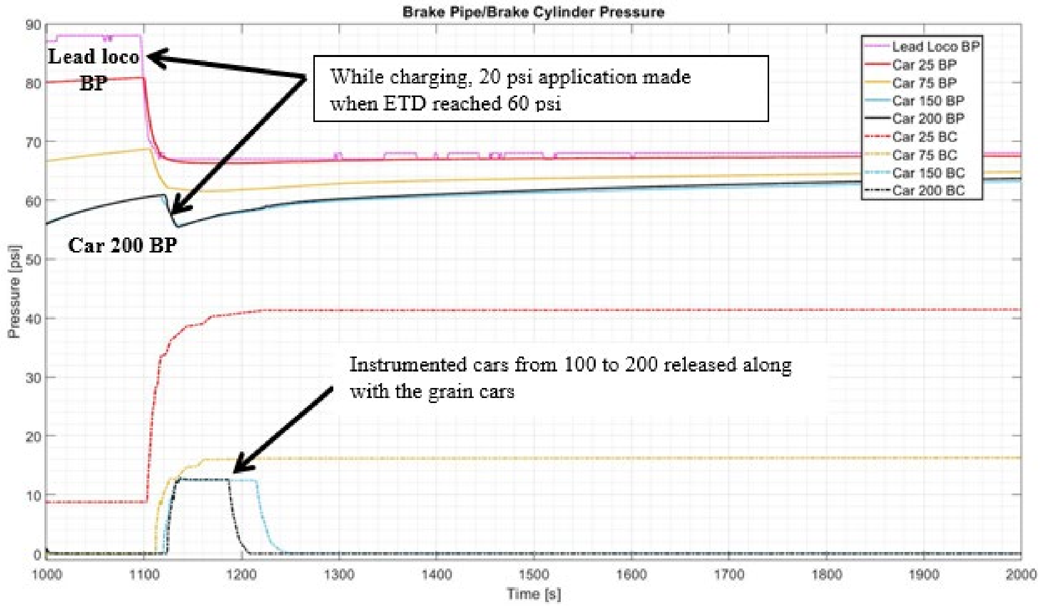


Figure 33. Test 3 on July 28, 2022 - Natural Leakage

3.7 Cycle Braking

Tests were conducted for both the HE only configuration (L-200-ETD) and the DP configurations (L-200-L and L-133-L-67-ETD) as discussed in Section 2.4. The leakages and cycle intervals simulated for the three configurations were:

- Leakage of 60 SCFM for HE-200-ETD
- Leakage of 90 SCFM for L-200-L and L-133-L-67-ETD
- 60 sec cycle interval (recharge time) between applications (for both HE and DP)
- 30 sec cycle interval (recharge time) between applications (only for DP)

For the HE configuration (shown in Figure 34), as the brakes were cycled, only Cars # 25 and 50 released and reapplied in response to the release and application. The brakes in the rest of the instrumented cars did not release during the test cycle. The brake release propagation time was 133 seconds for the HE configuration.

For the DP Configuration L-200-L (shown in Figure 35), all the instrumented cars released and reapplied for the 60 second cycle interval. When the cycle interval was reduced to 30 seconds for this configuration, only Cars # 25, 150, 175, and 200 released and reapplied.

Brakes on the rest of the instrumented cars did not release during the test cycle, as shown in Figure 36. The brake release propagation time was 39 seconds for the DP configuration.

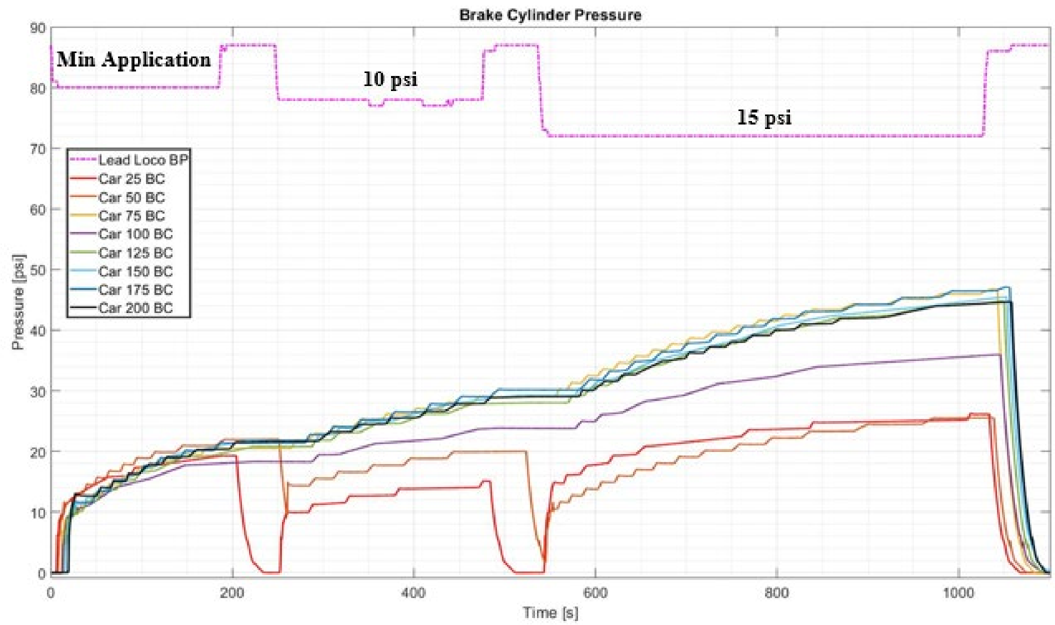


Figure 34. Cycle Braking on L-200-ETD, 60 SCFM, Cycle Interval 60 Sec.

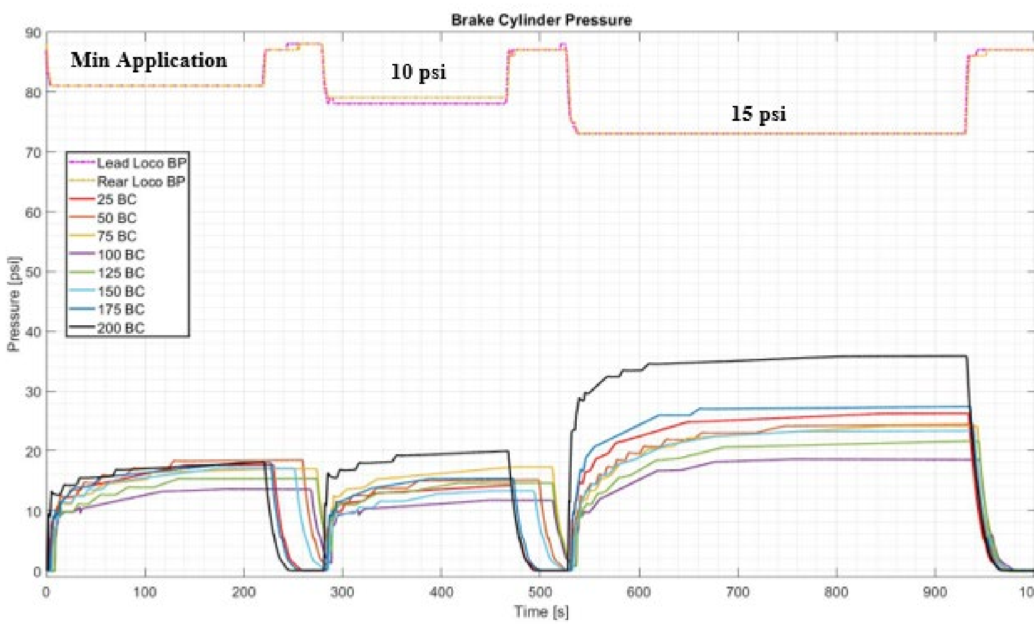


Figure 35. Cycle Braking on L-200-L, 90 SCFM, Cycle Interval 60 Sec.

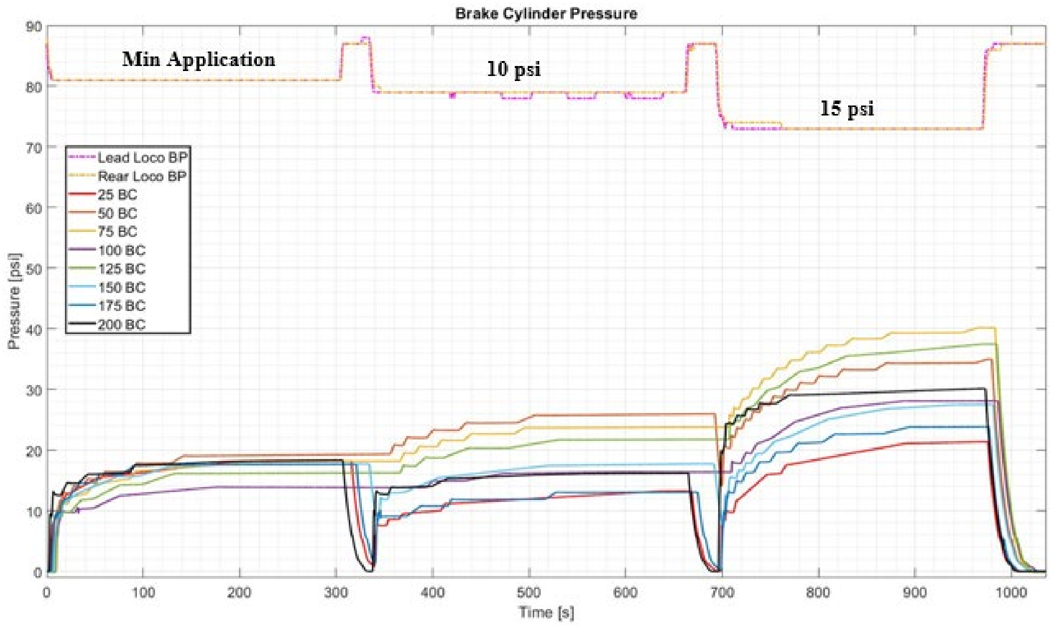


Figure 36. Cycle Braking on L-200-L, 90 SCFM, Cycle Interval 30 Sec.

3.8 False Gradients

Train brakes are fully charged when the BP, AR, and ER are all charged to the feed or regulating valve setting of the locomotive (i.e., 90 psi on freight trains). Due to leakage and other factors causing BP gradient, this full charge may not be possible at the rear of the train. Therefore, cars at the rear of the train may be charged to a lower pressure. If this pressure is within limits set by rules and the BP, AR, and ER are charged to that same pressure, this lower pressure condition at the rear of the train does not constitute an undercharge.

If a locomotive engineer makes a brake application and a running release of the brake and then follows with another reduction before the ARs have had time to recharge, there is a good possibility that some of the brakes will not apply from the second reduction, unless the second reduction is greater than the first. A false gradient is the difference between the actual BP pressure at the sag and the targeted BP pressure. An unintended release of brakes occurs when the BP pressure at the rear of the train increases (as the pressure maintaining feature recovers the lower BP pressure) above the AR due to insufficient recharge of the system.

Phase II brake rack tests indicated that unintended releases could occur during a subsequent application when the false gradients were 3 psi or higher. Tests were conducted in Phase III on a stationary train with the conventional train to validate these predictions using the brake racks in Phase II, as well as identify limiting conditions under the various DP setups in Phase III. The tests with false gradients evaluated a condition that would not be seen under normal operating practices. The intent of these tests was to identify the boundary conditions for unintentional release to occur.

As mentioned previously in Section 2.5, the test procedure consisted of recording the initial gradient, making a 15 psi[4] application, and allowing it to set. The brake was then released to

[4] A 20 psi application was used for the Phase II tests, but this variation would not have notably affected the results.

achieve different levels of gradients. The release was followed by a minimum brake application with a partial recharge. Three levels of false gradients (-2 psi, -3 psi and -4 psi) were simulated by monitoring the BP and AR pressures at the rear of the car for the HE and DP configurations. Additional tests were performed to evaluate performance using BNSF-specific operating practices, or "BNSF methodology tests." These tests required the second brake application to be at least 5 psi higher than the initial application to ensure that unintended releases did not occur.

Figure 37 plots the lead locomotive BP pressure and the BC pressures of the instrumented cars for the HE train configuration with 60 SCFM of air flow. The plot of BP pressure shows that after an initial 15 psi brake application and release, a minimum application was made to develop a false gradient of -3 psi. As the plot of BC pressures shows, the brakes on five of the instrumented cars were released unintentionally.

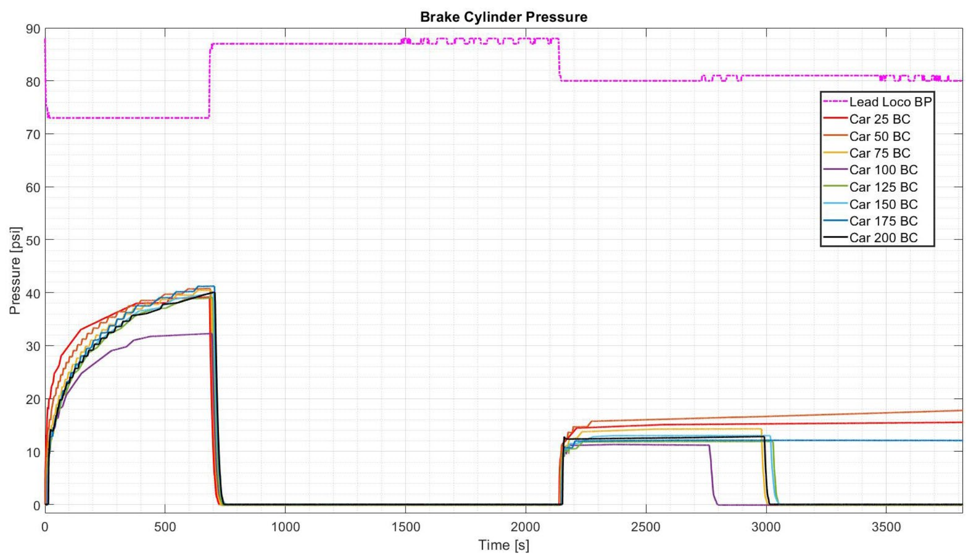


Figure 37. HE Train, False Gradient -3 psi, 60 SCFM

Table 4 provides a back to back comparison between Phase II and Phase III test results in terms of number of released cars for various levels of false gradients. The results show that unintended release situations can be avoided for the HE train configuration if the false gradient is less than 2 psi.

Table 4. Effect of False Gradients

	# of cars released (Phase 2)/ # of cars released (Phase 3)		
False Gradient (psi) →	**-2**	**-3**	**-4**
HE: L-200-ETD 60 SCFM	0/0	143/146	151/NA

Figure 38 plots the lead and rear locomotive BP pressures and the BC pressures of the instrumented cars for the DP train configuration with 60 SCFM of air flow. Following the BNSF methodology, after the initial 15 psi application and release, a 20 psi brake application was made when the BP of Car #100 reached within 4 psi of the fully recharged state. The plot shows that there were no unintentional brake releases and all the instrumented cars remained applied after the second brake application.

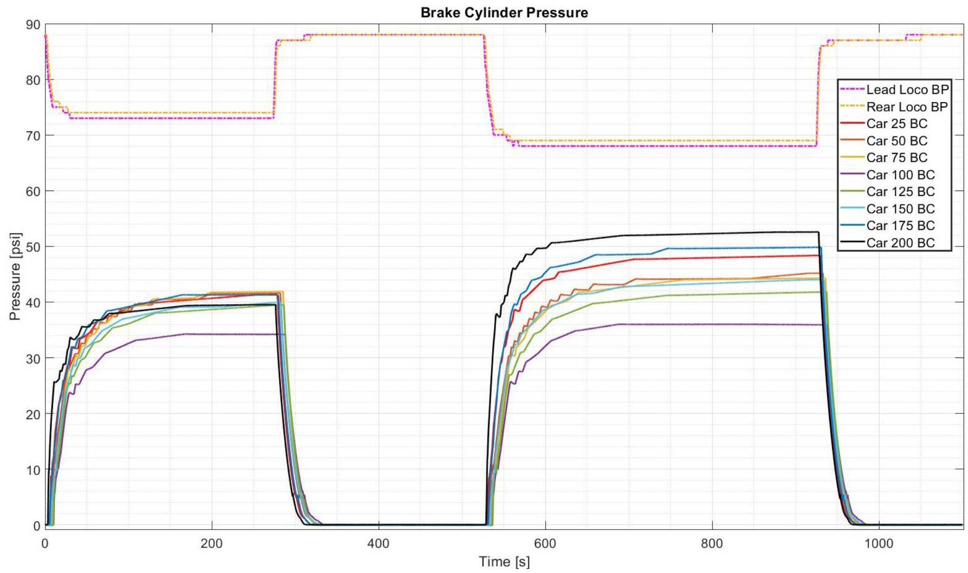


Figure 38. DP Train, False Gradient -4 psi, 60 SCFM (BNSF Methodology)

Table 5 summarizes the results for the various DP configurations and leakage values. Unintended brake releases were less likely under DP configurations, but could still occur under high leakage conditions. Unintended brake releases did not occur for the -2 psi false gradient for all the tested train configurations and leakage conditions. Unintended brake release also did not occur when the false gradient was -4 psi and the first brake application was followed by a deeper brake application, as per the BNSF methodology. Most Class 1 railroad operating practices require the second brake application to be at least 5 psi deeper than the first application to avoid unintended brake releases.

Table 5. Effect of False Gradients/Insufficient Recharge

False Gradient (psi)	**-3**	**-4**	**-4 (BNSF Methodology)**	**-5**
Train Configuration	Number of Grain Cars Released			
L-200-L (60 SCFM)	0	0	0	NA[5]
L-200-L (90 SCFM)	0	0	0	NA
L-200-L (140 SCFM)	0	74	0	NA
L-100-L-100-L (90 SCFM)	2	33	0	NA
L-100-L-100-L (160 SCFM)	0	6	0	111
L-133-L-67-ETD (90 SCFM)	0	0	0	NA
L-133-L-67-ETD (140 SCFM)	NA	0	NA	NA

3.9 Train-Line Emergency with Multiple Cut Out Valves

To assess the impact of cars with malfunctioning emergency valves during a train-line emergency (TLE) incident, several TLE tests were conducted for different train and leakage configurations based on the following setup:

- Train configuration was L-100-L-100-L with a high leakage condition with 160 SCFM of air flow

[5] Test not performed

- The Emergency was initiated with a hose separation at Car #50
- The brake valves of 11 cars in a row were cut out on either side of Car #50 (Cars # 29-40 and 60-71) to simulate a sequence of cars with bad valves

While cutting out a valve is not identical to a malfunctioning emergency portion on a valve, this approach was considered a reasonable surrogate, as the intent of the tests was to understand the effects of an emergency signal not propagating due to malfunctioning valves. The cut out valves emulate that condition. Figure 39 shows a schematic of the test setup to simulate the bad emergency valves on either side of the instrumented car (Car #50).

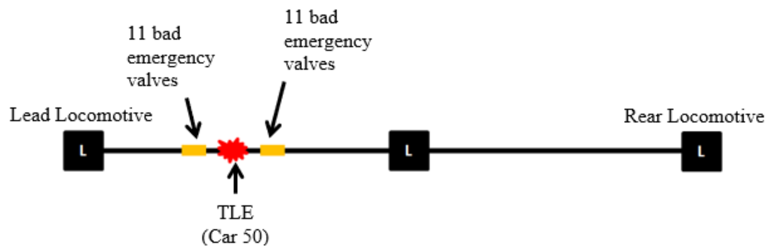


Figure 39. TLE on the Test Train

As seen from the top portion of Figure 40, the BP pressure drop on the lead and mid locomotives received the train line emergency signal as service application with the BP reduction in the range of 15 psi (lead locomotive) to 18 psi (middle locomotive). The BC pressure of Car #50 shows the emergency brake was applied on this car, and the rest of the instrumented cars (except for Car #200) experienced service brake application. The brake on Car #200 was never applied.

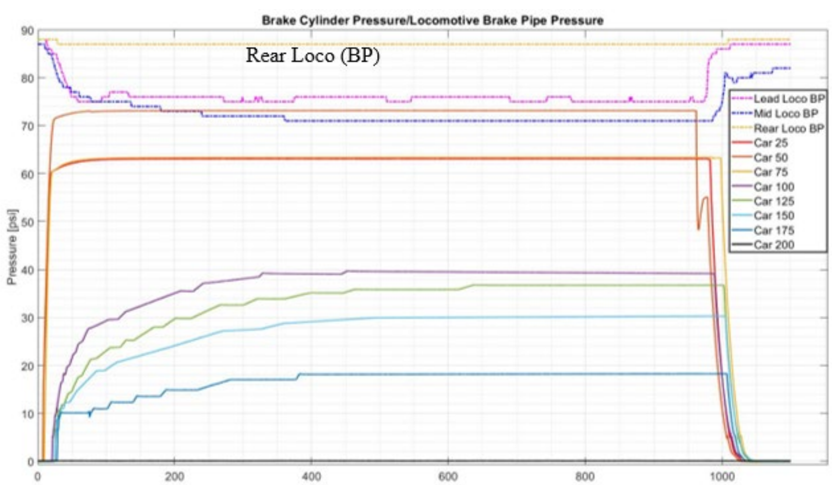


Figure 40. TLE with Bad Emergency Valves

The test showed that in a 200-car DP train with a high leakage condition, there is a possibility that TLE would not propagate through the train length if several cars have malfunctioning control valves.

3.10 Stepped Brake Applications

The following steps were performed to simulate the stepped application:

1. Apply the brakes with minimum BP reduction (~6 psi), wait for steady state
2. Increase BP reduction to 10 psi, allow system to stabilize

The BC pressure build up times for the HE and DP train configurations are shown in Figure 41. The plot shows the BC pressure buildup times for minimum brake application and for the subsequent minimum to 10 psi application. The BC pressure buildup times are faster for the DP trains with shorter BP length between air sources resulting in lower gradients/sag.

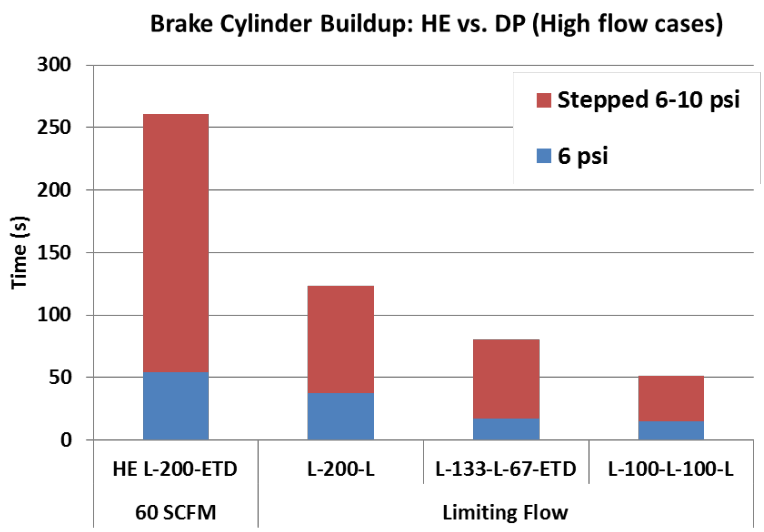


Figure 41. Brake Cylinder Buildup Time for Stepped Application

3.11 CLID Tests

The objective of this test was to determine whether CLID might be compromised under high leakage conditions and for the different configurations, and estimate the limiting leakage conditions. CLID tests were performed for the three DP configurations (L-200-L, L-100-L-100, and L-137-L-67-ETD) with high leakage conditions. In all the tests, the remote locomotives responded to the BP reduction as required by the CLID protocol.

4. Conclusions and Next Steps

The research team successfully completed the Phase III Stationary Train tests on a 200-car train in the railroad yard at Staples, MN, with support from BNSF. The test cases were performed both in HE and DP train configurations simulating various operating scenarios, as detailed in the TRC-approved test plan.

The results of the Phase III stationary train tests helped corroborate key findings from the Phase II air brake rack tests for the HE train configuration. In addition, the stationary train tests helped to quantify the advantages of using a DP over HE configuration in VLT operations. The test data showed that brake signal propagation, release, and recharge times were faster for the DP trains with smaller lengths between air sources. Also, DP trains with smaller lengths between two air sources achieved better braking capability with higher BC pressures and faster BC pressure build up times. The team found that the HE train configuration showed a slower response and achieved slightly reduced BC pressures after an air brake application. Longer recharge times in the HE configuration required a longer wait in cycle braking situations to avoid potential unintended brake release situations. An unintended release in the HE configuration did not occur with the false gradient when the first application was followed by a deeper second application.

Brake Application and BC Pressure Buildup

As expected, during brake application, signal propagation time was approximately proportional to the train length, and is almost double for the 200-car train compared to the 100-car train. This observation is valid across all leakage conditions and brake application conditions. Minimal impact was shown on train operation as long as the slower response and slightly reduced BC pressure in VLTs are noted and planned for during train operation.

Brake Performance of HE and DP Trains

Release and recharge times for the HE train was longer compared to the DP train. For a given train configuration, recharge times were longer for the higher leakage and gradient setups tested. Trains with smaller lengths between two air sources with smaller gradient have higher BCP and faster build up times.

Segment Charging Tests

Brake performance testing of the HE configuration train was performed with a longer train, assembled from two segments that met the flow and gradient limits individually. When a 20 psi brake application was made when at least 60 psi of BP pressure was detected at the last car, an undercharge occurred in the cars in the rear of the train since the ARs did not have enough time to charge up to the same pressure as the BP. The control valve, sensing BP pressure to be higher than the AR pressure, released the brakes in several cars in the rear of the train.

Cycle Braking Tests

In cycle braking tests for a train with the HE configuration, some of the cars did not release their brakes after the initial brake application for a cycle time interval of 60 seconds. In comparison, for the DP configuration with the same cycle time interval, all eight instrumented cars released and re-applied. When the cycle interval was reduced to 30 seconds for the DP configuration, half of the instrumented cars did not release their brakes during the test cycle. In a VLT, adequate time must be allowed for the brake system to completely charge and stabilize after a release before applying brakes again. The longer recharge times require a longer wait in cycle braking situations to avoid potential unintended brake release situations.

False Gradient

The results for the HE only cases were similar to the Phase II air brake rack results. In the case of brake application with a partial recharge (e.g., after a running release from a 20 psi application), there is a possibility for unintended release of brakes in some cars during a subsequent minimum BP reduction. The unintended brake release can be avoided if the false gradient is less than 2 psi.

Unintended releases were less likely under DP configurations, but could still occur under high leakage conditions. When railroad operating practices were followed, such as the BNSF methodology tested here, there were no unintentional releases.

Stepped Application

The BC pressure buildup times were faster for DP trains with shorter BP lengths between air sources, resulting in lower sag/gradients.

Next Steps

In the next phase of testing, the team will perform a moving train test on a unit grain train in revenue service operation in collaboration with a Class I railroad. In addition to the data collected in this test, coupler forces will be measured using instrumented couplers in the FRA box cars to understand the in-train forces during VLT operation.

References

1. Sharma & Associates, Inc. (2024). Very Long Trains – Phase II, Rack Tests Summary and Findings (Report No. Pending). Federal Railroad Administration.
2. Sharma & Associates, Inc. (2022). Very Long Trains – Phase III Stationary Train Test Plan.
3. Federal Railroad Administration, Department of Transportation. 49 CFR § 232 – BRAKE SYSTEM SAFETY STANDARDS FOR FREIGHT AND OTHER NON-PASSENGER TRAINS AND EQUIPMENT; END-OF-TRAIN DEVICES.

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
ER	Emergency Reservoir
ETD	End of Train Device
FEA	Finite Element Analysis
FRA	Federal Railroad Administration
FS	Full Service
HE	Head End
kips	kilo pounds
NYAB	New York Air Brakes
psi	pounds per square inch
SA	Sharma & Associates, Inc.
SCFM	Standard Cubic Feet per Minute
TRC	Test Review Committee
VLT	Very Long Train