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Parking Brake Tests on Air-Braked Heavy Truck and Tractors - Minimum Initial Service Brake Pressure

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16. Abstract This report examines the effects of initial treadle pressure and of compounding on parking brake holding capability. It documents the results of testing three Class 8 heavy vehicles including one straight truck and two tractors in parking brake performance tests. Federal Motor Vehicle Safety Standard (FMVSS) No. 121 requires that all air braked vehicles, except converter dollies, be equipped with sufficient parking brake capability.

Section 5.6 of FMVSS No. 121 specifies two options for testing the holding capability for the parking brakes of an air brake system: Section 5.6.1 Static Retardation Force or Section 5.6.2 Grade Holding. Both of these procedures were used to examine what the effect of varying the initial service brake application pressure prior to applying the parking brake (compounding) had on parking brake holding capability. Additional tests were performed, using these procedures, to study the effect brake anti-compounding systems had on the pin forces generated by the dual diaphragm brake chambers. FMVSS No. 121 does not include a statement on the use of an anti-compounding system during a parking brake test.

Static Retardation tests conducted at the tractor's compressor cut-out pressure produced results that were 25 to 36 percent higher than those for tests conducted with no initial treadle pressure. This significant increase in retardation force may not always be achievable during in-service use. For example, a leak or restriction in the service brake system could render that vehicle's system nearly or fully inoperable. As a result, the service brake system may supply little or no supplemental retardation force at the time of engaging the parking brake.

The grade holding test produces a binary result - pass or fail. Since the static retardation force is not measured, it is difficult to say how varying the initial treadle pressure effects results. None of the test conditions evaluated produced results that went from a non-passing to a passing result due to varying the initial treadle pressure.

The anti-compounding systems were found to be quite effective at limiting excessive forces and stresses exerted on the brake systems when the service brake and the parking brake were compounded.

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ACKNOWLEDGMENTS

The testing program documented in this report was a coordinated effort by the National Highway Traffic Safety Administration (NHTSA) Vehicle Research and Test Center (VRTC) and the Transportation Research Center Inc. (TRC) to examine the range of parking brake retardation forces resulting from compounding various initial treadle pressures, and to evaluate the effectiveness of anti-compounding devices, on recently built Class 8 heavy trucks and tractors.

The authors wish to recognize the outstanding support of our research colleagues, including Lead Driver and Vehicle Preparation Coordinator Lyle Heberling, Driver Bob Cahill, Instrumentation Specialist Don Thompson, Fixture and Adapter Fabricator Jim Preston, the Data Analysis Team including Tim Van Buskirk, Dave Dashner, and Kristen Huener, and additional technical support persons Jim Britell, Bryan O'Harra, Ed Parmer, Larry Armstrong, Kenn Campbell, Leslie Portwood, Chris Adams, Matt Hostetler, Jan Cooper, Judy Weiser, and Editor Dr. Riley Garrott.

Richard L. Hoover
J. Gavin Howe

Department of Transportation
National Highway Traffic Safety Administration
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TECHNICAL SUMMARY

Report Title: Parking Brake Tests on Air-Braked Heavy Truck and Tractors - Minimum Initial Service Brake Pressure	Date: October 2002
Report Author(s): Richard L. Hoover, Research Engineer - Transportation Research Center J. Gavin Howe, Research Scientist - Transportation Research Center	

On January 6, 1997, the Truck Manufacturers Association (TMA) submitted a petition to NHTSA requesting that the Federal Motor Vehicle Safety Standard (FMVSS) No. 121 be amended in several areas. The TMA, working with other industry representatives through a Society of Automotive Engineers (SAE) Task Force, reviewed in detail the requirements for a vehicle to comply with FMVSS No. 121. As a result of their effort, an SAE Recommended Practice "J1626, Braking, Stability, and Control Performance Test Procedures for Air-Brake-Equipped Trucks (rev APR96)" was developed to provide a process to verify vehicle compliance while minimizing test variability.

This study examines the effect of one of the TMA proposals on static retardation and grade holding test results. They have requested that when determining parking brake force in either the static retardation pull test (S5.6.1) or the grade holding test (S5.6.2), that a full service brake application be permitted prior to applying the parking brakes. This coincides with the SAE J1626 procedure for parking brake testing which specifies a full application of the service brakes, with the air reservoirs at tractor's compressor cut-out pressure, prior to applying the parking brake.

This report documents the results of testing air-braked Class 8 heavy vehicles including one straight truck and two tractors in parking brake performance tests. FMVSS No. 121 requires that all air-braked vehicles, except converter dollies, be equipped with sufficient parking brake capability to meet the requirements of either a static retardation force test or a grade holding test (the test selection is at the manufacturer's option). This test series did not sample buses.

Section 5.6 of FMVSS No. 121 specifies two options for testing the holding capability for the parking brakes of an air brake system: Section 5.6.1 Static Retardation Force or Section 5.6.2 Grade Holding. Both of these procedures were used to examine what the effect of varying the initial service brake application pressure prior to applying the parking brake (compounding) had on parking brake holding capability. The procedures were also used to study the effect of brake anti-compounding systems on the pin forces generated by the dual diaphragm brake chambers. Additional tests were also performed to examine the effects of brake anti-compounding.

All three test units met the FMVSS No. 121 requirements for the static retardation test procedure. The measured static retardation forces increased with increasing initial treadle pressure. Tests conducted at the tractor's compressor cut-out pressure produced results that were 25 to 36 percent higher than those for test conducted with no initial treadle pressure. This significant increase in retardation force may not always be achievable during in-service use. For example, a leak or restriction in the service brake system could render that vehicle's system nearly or fully inoperable. As a result, the service brake system may supply little or no supplemental retardation force at the time of engaging the parking brake.

Only two of three vehicles tested were able to meet the requirements for the grade holding part of the standard. Air-braked vehicles only have to pass either the static retardation or the grade holding test, and since all three vehicles passed the static retardation requirements, they were not required to pass the grade holding test.

The grade holding test produces a binary result - pass or fail. Since the static retardation force is not measured, it is difficult to say how varying the initial treadle pressure effects results. None of the test conditions evaluated produced results that went from a non-passing to a passing result due to varying the initial treadle pressure.

The last test procedure conducted was a combination of service brake and parking brake applications. This was a static test where no drawbar tension was applied. The tests were conducted over a wide range of initial treadle pressures and with the anti-compounding systems either activated or made inoperative (to simulate a vehicle with no anti-compounding). The anti-compounding systems were found to be quite effective at limiting excessive forces and stresses exerted on the brake systems when the service brake and the parking brake were compounded.

1.0 INTRODUCTION

The Federal Motor Vehicle Safety Standard (FMVSS) No. 121 [1] establishes performance and equipment requirements for vehicles equipped with air brake systems. It applies to trucks, tractors, buses, and trailers equipped with such systems. The purpose of this standard is to ensure safe braking performance under normal and emergency conditions.

On January 6, 1997, the Truck Manufacturers Association (TMA) submitted a petition [2] to NHTSA Safety Performance Standards requesting that the FMVSS No. 121 be amended in several areas.

1.1 Background

The TMA, working with other industry representatives through a Society of Automotive Engineers (SAE) Task Force, reviewed in detail the requirements for a vehicle to comply with FMVSS No. 121. As a result of their effort, a SAE Recommended Practice "J1626, Braking, Stability, and Control Performance Test Procedures for Air-Brake-Equipped Trucks (rev-APR96)" [3] was developed to provide a process to verify vehicle compliance while minimizing test variability.

This study examines the effect of the TMA proposal for minimum initial treadle pressure on static retardation and grade holding test results. They have requested that when determining parking brake force in either the static retardation pull test (S5.6.1) or the grade holding test (S5.6.2), a full service brake application be permitted prior to applying the parking brakes. This coincides with the SAE J1626 procedure for parking brake testing which specifies a full application of the service brakes, with the reservoirs at compressor cut-out pressure, prior to parking.

There is some concern that by allowing a full treadle brake application prior to setting the parking brake for a standards test, some vehicles may experience reduced grade holding ability at lower initial pressures in actual on-highway application. One example stems from the construction industry, where a truck may be stopped on a grade in the unloaded condition by a partial application of the brake treadle valve prior to the operator applying the parking brake. In this lightly loaded condition, the driver may not make a full treadle valve application since it would not be needed to stop the vehicle on the grade. Then, if such a vehicle were loaded (e.g. with dirt from a front-end loader or crane), there is some possibility that the vehicle could roll away.

In addition, there is some concern about the effect of full service brake applications, prior to engaging the parking brake, on the durability of brake components such as the brake chamber support brackets. The trend in recent years has been to reduce the mass of many truck components, and these components could suffer from deformation under high loading conditions imposed by compounding full service brakes and spring brakes. Another concern is the effect on foundation brake components when vehicles are parked with their brakes at high temperatures, because as the brake drums cool they would impose greater forces on the foundation brakes, which could lead to permanent deformation or fracture of some components.

1.2 Purpose of This Study

The Vehicle Research and Test Center (VRTC) of the National Highway Traffic Safety Administration (NHTSA) conducted a series of parking brake tests on three Class 8 vehicles. The goal of the testing was to identify the effect of different initial service brake pressures upon parking brake holding capability and to indicate how much strain was placed upon various brake components at these levels. Parameters studied included service brake pressure at the treadle valve, service and parking brake chamber pressures, and chamber pushrod forces (an array of chamber bracket displacements were added for the third test unit). Test procedures explored included the static retardation and grade holding tests outlined in the "Laboratory Test Procedure For FMVSS 121V (Vehicles) Air Brake Systems" [4].

1.3 Report and Experimental Overview

This study examined the parking brake capability of three Class 8 trucks and tractors, which represent typical units used today in commercial service. A description of each truck tested, which includes a 4x2 straight truck, a 6x4 tractor, and a 4x2 tractor, is given in Chapter 2.

Several preparations were made before testing the vehicles. First, they were inspected for brake condition and adjustment. The brakes on two of the in-use trucks were tested "as received", and the third (a new tractor) was run through a complete burnish before testing (Chapter 2). Next, instrumentation was installed to measure parameters including: line pressures, chamber pressures, pushrod stroke and force, and chamber movement (Chapter 3).

Static retardation and grade holding test procedures were performed on all three vehicles (Chapter 4). The static retardation tests were performed in accordance with FMVSS No. 121 Section 5.6.1. The grade holding tests were performed on a slope with a 20 percent grade (11.3 degrees). These tests were performed in accordance with FMVSS No. 121, Section 5.6.2. Additional tests were also performed and are discussed in Chapter 4.

Chapter 5, Parking Brake Results, details the findings of the tests performed. The first section covers the Static Retardation Tests, including the comparison of the forces measured by the two static friction measuring devices, the correlation between forward and rearward pulls, the mean and standard deviation of the forces, and a comparison to the requirement of FMVSS No. 121. The next section of the chapter covers the Grade Holding Test Results. All three vehicles were subjected to this test. In the last section are the results of the static No-Pull tests, where various combinations of initial treadle pressure and anti-compounding modes were combined to examine the net effect on pin force and stroke displacement without the added effects of drawbar pull or grade induced self-energization.

Chapter 6 concludes the report with a review of the vehicle brake performance, followed by a list of documentary references in Chapter 7.

2.0 TEST VEHICLE AND BRAKE SYSTEM DESCRIPTIONS AND CONDITIONING

Three Class 8 trucks/tractors were selected for the parking brake test series. The vehicles selected were representative of the trucks commonly driven on the highway today. The first two units were rented in-use vehicles, each with a year or more of service. The third unit was a new tractor with only two short road trips on its log. Each unit had antilock brakes (ABS) and was equipped with an anti-compounding device that limited the brake chamber force to no more than that produced by applying only the service brakes in the upper treadle pressure ranges.

2.1 Navistar 4x2 Dump Truck - Test Unit PB01

The first test unit was a 1997 Navistar 4900 straight truck (Figure 2.1) built in January, 1997. It has since been in service as a dump truck and snow plow, accumulating 13,508 miles. It had a 4x2 axle arrangement with a gross vehicle weight rating (GVWR) of 35,350 lbs. The truck was configured with a Galion model 408-U dump body with a capacity rating of 5.6-7.7 cubic yards. The wheelbase was 152 inches. The parking brake system consisted of MGM type 30-30 spring brake chambers (only on the drive axle) applying force to 6-inch Haldex automatic slack adjusters. The cam rotation was in the same direction as the wheels when traveling forward. The rear axle was rated 23,000 lbs and had a 31,000 lbs rated Vari-Rate ferrous spring suspension. The brakes were Rockwell Q-Plus type with R-301 linings. See Appendix A.1 for the full Vehicle Information Sheet - PB01.

Figure 2.1 - PB01 - Navistar 4x2 Dump Truck

2.2 Freightliner 6x4 Tractor - Test Unit PB02

The second test unit was a 1999 Freightliner Century Class tractor (Figure 2.2) built in late 1998. It has since been in service as a commercial rental tractor for over-the-road use, accumulating 41,644 miles. It had a 6x4 axle arrangement with a GVWR of 48,000 lbs. The wheelbase was 195 inches. The parking brake system consisted of MGM type 30-30 spring brake chambers (only on the rear-most drive axle) applying force to 5-inch Rockwell automatic slack adjusters.

The cam rotation was in the same direction as the wheel when traveling forward. The drive axles were rated 19,000 lbs (per axle) and had Firestone air springs on the suspension. The brakes were Rockwell Q-Plus type. See Appendix A.2 for the full Vehicle Information Sheet - PB02.

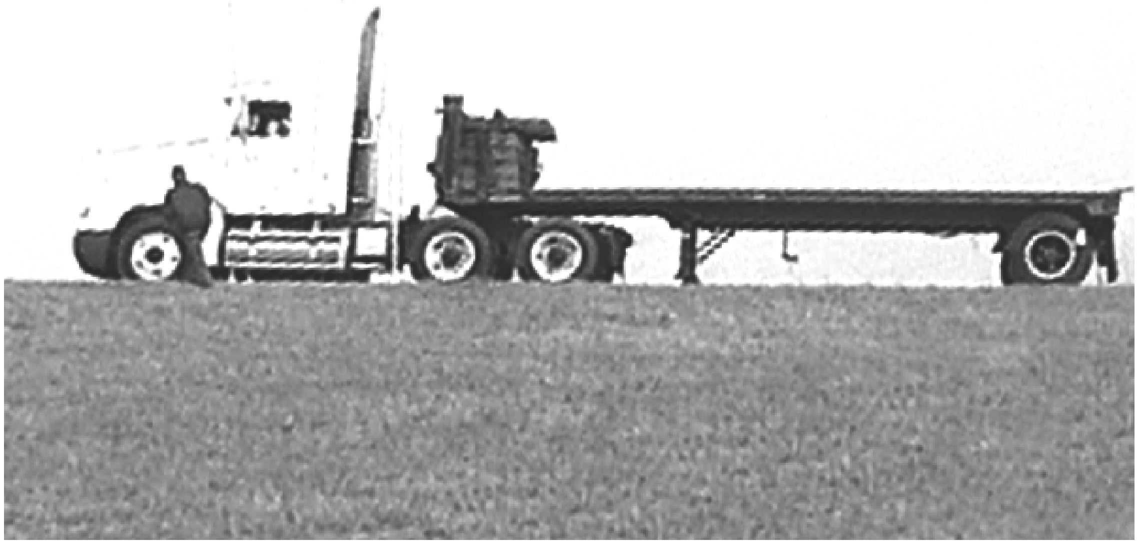

Figure 2.2 - PB02 - Freightliner 6x4 Tractor with Unbraked Control Trailer

2.3 Sterling 4x2 Tractor - Test Unit PB03

The third test unit was a 2000 Sterling A9513 tractor (Figure 2.3) built in August, 1999. Its service record only included two short road trips, each towing a lightly loaded flatbed trailer, and accumulating just 3,092 miles. It had a 4x2 axle arrangement with a GVWR of 34,700 lbs. The wheelbase was 148 inches. The parking brake system consisted of Maxibrake type 30-30 spring brake chambers (only on the drive axle) applying force to 6-inch Haldex automatic slack adjusters. The cam rotation was in the same direction as the wheels when traveling forward. The rear axle was rated 22,700 lbs and had a 23,000 lbs rated Hendrickson suspension with shock absorbers and Firestone air springs. The brakes were Rockwell Q-Plus type. See Appendix A.3 for the full Vehicle Information Sheet - PB03.

Figure 2.3 - PB03 - Sterling 4x2 Tractor

2.4 Brake Conditioning

The brakes on the two rental units (PB01 and PB02) were tested “as received”, as they both already had accumulated substantial milage. The brakes for these vehicles were checked for adjustment, but not given any additional brake conditioning (burnish snubs), as the primary goal of this program was to look at anti-compounding pressures and pushrod forces. The Sterling (PB03) was relatively new, so a full 500 snub conditioning series (specified in FMVSS No. 121, Section S6.1.8) was completed on the brakes before running the parking brake tests.

2.5 BM Roller Dynamometer Baseline Brake Force Measurement

A Hans Hermann BM BrakeTest Roller Dynamometer was used to measure both the service brake and the parking brake retardation forces produced by each test vehicle. This procedure was primarily done to verify that all of the brakes on the truck/tractor were in good working order. The Roller Dynamometer used two 24-hp (18-kW) electric motors to individually drive both wheels of the selected axle simultaneously at 1.55 mph (2.5 kph). While the driver applied an increasing force to the brake pedal to activate the brakes over the whole service range, a pedal force transducer or a treadle pressure transducer recorded the input effort, and load cells in the dynamometer measured the axle weight and the generated braking forces with respect to time. Plots were then generated to reflect the output brake force for the given input effort. The results of this testing are presented in Appendix B.

3.0 INSTRUMENTATION

The following pre-test preparations and instrumentation will be discussed in this chapter: Pressure Measurements, Temperature Measurements, Treadle Pedal and Parking Brake Control Movement, Chamber Stroke Displacement, Spring Chamber Bracket Movement, Clevis Pin Measurement, Baseline Brake Force Measurement, Draw-Bar Force Measurement, Data Acquisition System, Wheel Distance Travel, and Hunter Brake Plates.

3.1 Pressure Measurements

Multiple pressure lines were monitored to identify which brake system was active or quiescent, and to compare their inter-related timing sequences. A typical air brake system is depicted in Figure 3.1. The service brake pressure was monitored at the drive axle (primary) outlet port of the treadle valve by installing a full flow tee in the line, with a 150 psi pressure transducer mounted in the side port.

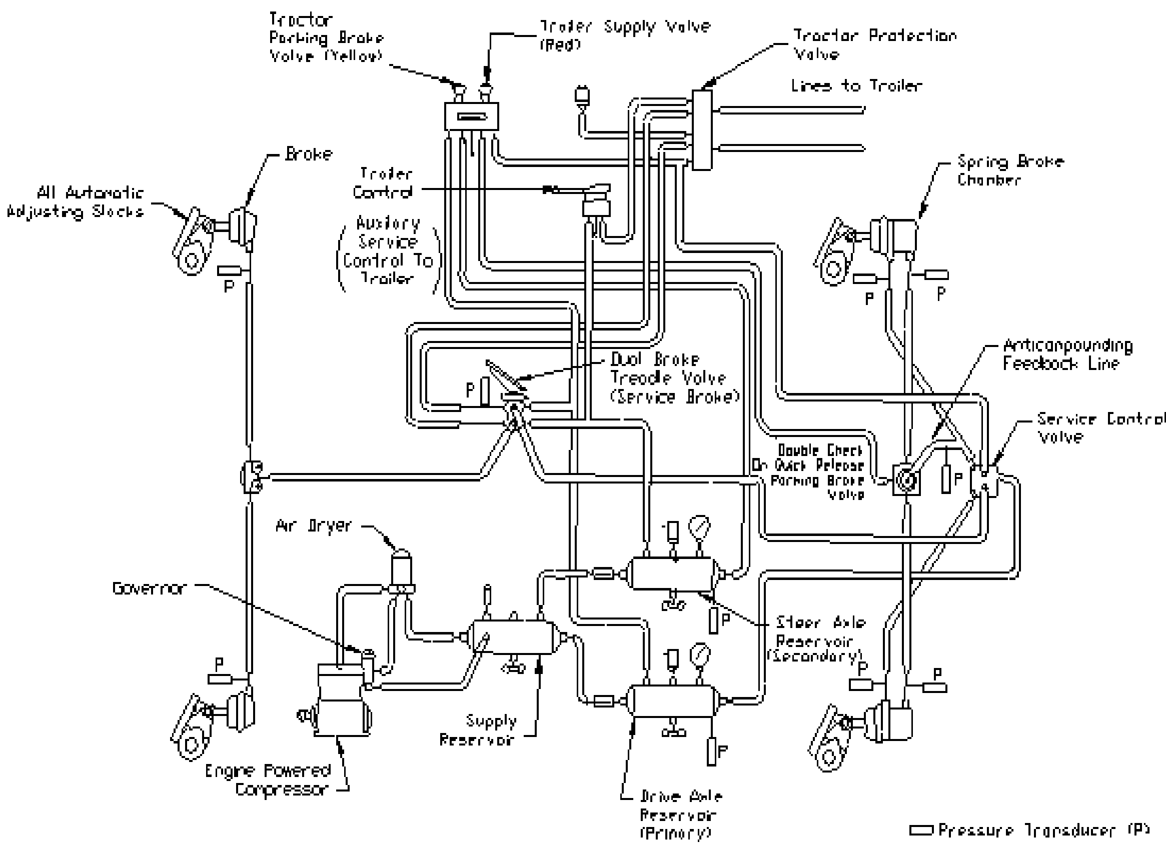

Figure 3.1 - 4x2 Tractor Airline Schematic with Pressure Transducers Added

Drawing does not show ABS modulator valves.

Drawing adapted through the courtesy of Honeywell Bendix.

Similar tee connectors and pressure transducers were installed at the inlet ports to each of the brake chambers. The steer axle chamber pressures and all of the drive axle chamber service pressures were monitored to verify that each of the service brakes were released at all times other than during a service brake application. The parking (emergency) brake chamber pressures were monitored to determine if the emergency application springs were being held off by residual line pressure, and to track application and release timing of the spring brakes.

Unit PB03 (the Sterling) was an in-house vehicle and several extra transducers were added that not only aided in the understanding of how the brakes were operating during this study, but for other planned research as well. Pressure transducers were added to both the drive axle (primary) and the steer axle (secondary) reservoirs to monitor the supply pressures for each "Initial Treadle Pressure" being applied before setting the parking brake. These pressure transducers doubled as "level of safety indicators" by also showing that enough air was maintained in the reservoirs for the service brake to be used to stop the truck from running away if the truck experienced a parking brake failure during a 20 percent grade holding test. A final pressure transducer was installed in a tee connector mounted in the anti-compounding balance (or feedback) line that led to the anti-compounding input port on the spring brake control valve. This transducer indicated when (and to what extent) the service control valve was supplying feedback pressure to the quick release valve.

A dial pressure gauge was installed at the treadle outlet port for all three vehicles. The driver read this gauge to determine what pedal effort was required to achieve the desired initial service brake pressure before applying the parking brake.

3.2 Temperature Measurements

The wheel temperatures were measured with a contact pyrometer for the two rental units (PB01 and PB02). On PB03, the brake linings were drilled and plugged with J-type thermocouples (FMVSS No. 121, Fig.2) before the brakes were burnished. The thermocouples were monitored with a ten channel Fluke #2166A Digital Thermometer.

An ambient temperature channel was later added for the PB03 testing. This was most critical during the grade holding tests, as the temperatures ran as low as 33 ºF (the FMVSS No. 121, Section S6.1.5, procedure specifies a valid test range of 32 to 100 ºF).

3.3 Treadle Pedal and Parking Brake Control Movement - Driver Inputs

The devices discussed in this section were only used on unit PB03. The FMVSS Standard No. 121, Section S5.3.3, identifies the beginning of brake event timing as "the first movement of the service brake control". A normally open, foot-activated, contact switch was installed on the top surface of the service brake treadle (foot pedal). The switch was pliable enough to close the contacts by the time the driver applied enough force to the foot pedal to begin moving the treadle valve, and resilient enough to release the contacts as soon as the driver lifted his foot from the pedal. This gave crisp timing marks in the data to identify whether, or not, the driver was pushing on the service brake control.

A proximity switch was used to measure the parking brake control activity. A micro-switch was installed adjacent to the tractor parking brake control knob. Pulling the knob to the position outward from the dash (apply parking brake position) closed the switch.

3.4 Chamber Stroke Displacement

The pushrod displacement (stroke) was measured on each spring brake chamber (Figure 3.2). A 4-inch linear potentiometer was mounted on the chamber mounting bracket parallel to the stroke of the chamber pushrod. It was attached at a right angle to the automatic slack adjuster with the measuring pin of the clevis pin transducer. The potentiometer indicated the relative displacement of the pushrod during each application of the parking brake or the service brake.

3.5 Spring Chamber Bracket Movement

Displacement potentiometers were installed on unit PB03 to measure the relative movement of the spring brake chambers and their mounting brackets during brake applications (Figure 3.2). Suitable brackets were fabricated (in the shape of an "L") from 2x2-inch and 1x1-inch angle iron to fit around the front of the spring brake chambers. The long side of the brackets were bolted to two of the protruding axle u-bolts. The base of the "L" brackets extended across the front of the chambers with a 1-inch clearance.

For each side of the tractor, a linear potentiometer was attached perpendicular to the long side of the "L" bracket at a point 13.25-inches from the centerline of the brake cam tube. The extension rod of the potentiometer was connected to a steel band fitted onto the spring cover of the chamber, to measure the lateral movement. A pull-string potentiometer was connected to the same pin on the chamber as the linear potentiometer. Its body was attached to the "L" base of the bracket, parallel to the longitudinal motion of the chamber pushrod, to measure the elongation of the bracket.

3.6 Clevis Pin Force Measurement

A new pair of dual axis, strain gaged, force pins (Figure 3.2) were acquired for this test series. They were rated at 3,000 lbs capacity for both the "x-axis" and the "y-axis", and were able to withstand overloads within a reasonable margin. The pins were properly sized and easily adapted to the clevis and slack adjuster combinations of the three vehicles being tested. The sensors were installed to measure the longitudinal "x" output force of the spring brake chamber and the small vertical "z" force caused by the inability of the chamber to rotate as the pushrod extends while attached to the rotating slack adjuster.

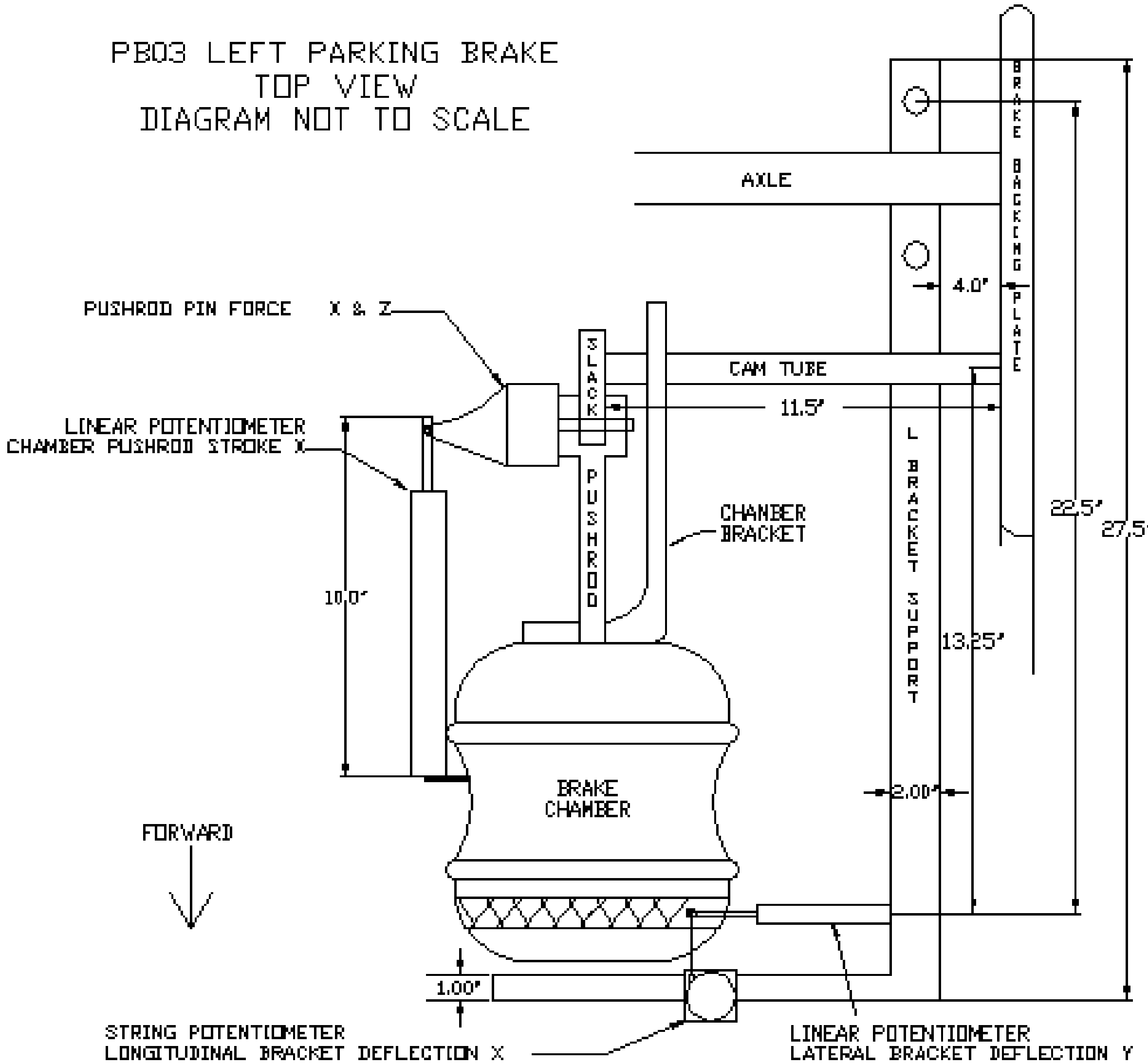

Figure 3.2 - Diagram of PB03 Left Wheel Parking Brake Instrumentation

3.7 Static Retardation Load Cell

A single in-line load cell was connected between the hydraulic ram and the tow chain to measure the draw force during the static retardation force tests. The load cell was rated at 25,000 lbs in tension.

3.8 Distance Traveled During Static Retardation Tests

Five different techniques were explored for measuring the distance traveled during the Static Retardation tests. Each technique showed both merits and deficiencies. The list includes: marking the tire, a wire pointer, a laser arrow, a 50-inch string potentiometer, and a cardboard disc fitted into one of the wheels. A brief description and some thoughts on the effectiveness of each device is given in Appendix C.

3.9 Data Acquisition and Reduction System

A basic Analog Data Acquisition System (ADAS) was installed in each of the three test vehicles. A complete list of the data channels connected to this system for each test vehicle is given in Table 3.1.

Table 3.1 – Data Channels for Parking Brake Anti-Compounding on Class 8 Trucks and Tractors.

	Vehicle	PB01 Navistar 4x2	PB02 Freightliner 6x4	PB03 Sterling 4x2
	Configuration	Dumptruck	Tractor	Tractor
Ch#	Channel Description	Fullscale Range	Fullscale Range	Fullscale Range
1	Treadle Pressure	0-150 psi	0-150 psi	0-150 psi
2	Steer Axle - Left Chamber Pressure	0-150 psi	0-150 psi	0-150 psi
3	Ambient Temperature			-148-+1436 degF
4	Steer Axle - Right Chamber Pressure	0-150 psi	0-150 psi	0-150 psi
5	Drive Axle - Left Service Pressure	0-150 psi	0-150 psi	0-150 psi
6	Drive Axle - Right Service Pressure	0-150 psi	0-150 psi	0-150 psi
7	Drive Axle - Left Parking Pressure	0-150 psi	0-150 psi	0-150 psi
8	Drive Axle - Right Parking Pressure	0-150 psi	0-150 psi	0-150 psi
9	Force Pin - Vertical Force - Left Chamber	-3000-+3000 lbs	-3000-+3000 lbs	-3500-+3500 lbs
10	Force Pin - Fore/Aft Force - Left Chamber	-3000-+3000 lbs	-3000-+3000 lbs	-3500-+3500 lbs
11	Force Pin - Vertical Force - Right Chamber	-3000-+3000 lbs	-3000-+3000 lbs	-3500-+3500 lbs
12	Force Pin - Fore/Aft Force - Right Chamber	-3000-+3000 lbs	-3000-+3000 lbs	-3500-+3500 lbs
13	Pushrod Displacement - Left Chamber	0-4 in	0-4 in	0-4 in
14	Pushrod Displacement - Right Chamber	0-4 in	0-4 in	0-4 in
15	Anti-compounding Balance Line Pressure			0-150 psi
16	Draw Distance			0-50 in
17	Draw Force - Load Cell	0-25000 lbs	0-25000 lbs	0-25000 lbs
18	Bracket Deflection - Longitudinal on Left			0-0.5 in
19	Bracket Deflection - Lateral on Left			0-1.0 in
20	Bracket Deflection - Longitudinal on Right			0-0.5 in
21	Bracket Deflection - Lateral on Right			0-1.0 in
22	Service Brake Pedal - Event – TimeS			0-9.95 volts
23	Parking Brake Handle - Event – TimeP			0-9.95 volts
24	Drive Axle Reservoir Pressure (primary)			0-150 psi
25	Steer Axle Reservoir Pressure (secondary)			0-150 psi
26	Intermediate Drive Axle-Left Service Press.		0-150 psi	
27	Intermediate Drive Axle-Left Service Press.		0-150 psi	
	Note 1) All transducer filters are 18 Hz, for a Sample rate of 100 Hz; event channels are not filtered			
	Note 2) Trigger on Keyboard			

The major components of the VRTC-designed ADAS were: a ruggedized portable Laversab PC-104 based computer (with an internally mounted digitizer, integral display, and keyboard), a signal conditioning breakout box, and interconnecting cables.

The PC controlled the acquisition of the data. The system functions were manipulated through "DIG815" data acquisition routines, written at VRTC. The PC controller was fitted with an Analog Devices RTI-815, 12-bit digitizer. The digitizer was configured to acquire analog data for up to thirty-two channels. Data were collected at a digitizing rate of 100 samples per second and were presented live on the screen during testing. The file length was adjusted for each type of test. The Grade Holding tests were recorded for 6 minutes and the Static Retardation tests for 1-1/2 minutes.

The breakout box (two were used on the Sterling) contained several types of subsystems. The first subsystem comprised the power switching and voltage regulation controls for the various components of the data system. These ensured that all components of the entire data acquisition system were referenced to the same groundplane. The second subsystem contained the signal conditioners. An Analog Devices 3B01, 16-channel backplane, framed the base for the signal conditioners. The 3B18 signal conditioners provided three essential functions: 1) a stable 10 volt DC excitation for the transducers requiring a power source, 2) adjustable gain, with a range from x1 to x1000, and 3) an adjustable frequency, 2-pole, low pass Butterworth filter set for 18 Hz. The ambient temperature signal was conditioned through an Analog Devices 3B47 amplifier. The 3B47 provided cold junction compensation, linearization, and magnetic isolation for the readings. The two event channels (service brake treadle and parking brake knob) were not filtered and had an open bandwidth of 20 kHz.

3.10 Hunter Plate Brake Tester - Brake Force Auxiliary Measurement

Another method used to measure the generated parking brake retardation forces was placing the truck on the Hunter Heavy Duty Plate Brake Tester. This brake tester was previously installed at VRTC for measuring the braking forces of heavy vehicles during the final moments of a service brake stop (an evaluation of this system was reported in NHTSA Report No. DOT HS 808 275 [5]). It functioned in this study as an auxiliary static retardation force measurement system. The Hunter system provided live axle weights and generated brake forces at each wheel during the Static Retardation tests. The peak coefficient of friction of the serrated steel lattice-grid surface was calculated as 0.78 for lug tires. (compared to 0.90 or higher for dry Portland Cement - FMVSS No. 121, section S5.6.2).

The vehicle was placed on the plates with the axle under test positioned just onto the far end of the rear plate, so the vehicle could be towed over the plates with the hydraulic ram assembly. Since the Hunter load and force transducers could not be directly interfaced to the ADAS, a video camera was used to capture the twice per second screen updates. After the test, the video data were scanned to determine the maximum braking forces generated for each segment of the total wheel revolution. The maximum of these peak values was logged as the maximum brake force for each direction of travel.

The brake forces measured by the Hunter Plate Brake Tester are compared to the Static Retardation tension load in Chapter 5 - Results. The readings from the Hunter plate were not used as the primary data because they were not time synched to the data system, they updated only twice a second, and the readings were averages of data collected for short time spans, rather than actual raw data points.

However, there were two significant benefits achieved with the Hunter Plate system. One was the convenience of live indication of the axle-to-axle weight transfer encountered during the Static Retardation tests. The live axle weight readings confirmed how much weight was actually transferred between the axles as the test vehicle was pulled toward the anchor vehicle. The second benefit was the ability to measure the difference between the left and right parking brake forces.

4.0 TEST PROCEDURES

Section 5.6 of FMVSS No. 121 specifies two options for testing the holding capability for the parking brakes of an air brake system: Section 5.6.1 Static Retardation Force or Section 5.6.2 Grade Holding. Both of these procedures were used to examine what the effect of varying the initial service brake application pressure prior to applying the parking brake had on parking brake holding capability. The procedures were also used to study the effect of brake anti-compounding systems on the pin forces generated by the dual diaphragm brake chambers. Additional tests were also performed to examine the effects of brake anti-compounding.

4.1 Static Retardation Test Procedure

The Static Retardation Test is one of two options specified in the FMVSS No. 121, Section 5.6 for testing Parking Brakes. The Office of Vehicle Safety Compliance (OVSC) "Laboratory Test Procedure TP121V-04" specifies fifteen steps for completing this test procedure:

1. Install pull device, load cell, and wheel rotation measuring device or method.
2. If parking brake chamber pressure was greater than 3 psi, install a pressure regulator and a method of supplying air at the recorded pressure to the parking brake chambers to be tested (none were required for these three test vehicles).
3. Position vehicle on level dry Portland cement concrete or equivalent surface in line with pull cable.
4. Connect pull cable and force measuring device so that cable is level within $\pm$ 5 degrees.
5. Mark circumference of tires on braked wheels at point of tire/ground contact and at 90 180, and 270 degrees from that point.
6. Disable parking brake chambers on axle(s) other than the axle being tested.
7. Throughout the sequence, warm brakes as necessary to achieve specified Initial Brake Temperature.
8. Place vehicle transmission in neutral.
9. Charge brake system reservoirs to compressor governor cut-out pressure.
10. Turn engine off.
11. Apply parking brakes.
12. Pull vehicle forward at a maximum rate of 4 ft/min until the wheel rotates 90 degrees. Release parking brakes.
13. Repeat steps (8) through (12) starting from 90, 180, and 270 degrees of wheel rotation.
14. Repeat (8) through (12) except pull the vehicle in the rearward direction.
15. Record peak pull force for each 90 degrees of wheel rotation.

The VRTC testing primarily followed the test procedure outlined above except where noted. The instrumentation used to conduct this testing was described in Chapter 3. Details for the Static Retardation test configuration, supply air for the parking brake system, Initial Brake Temperature, and anti-compounding status are given below. The test matrix for all the Static Retardation Tests is also presented.

4.1.1 Static Retardation Test Configuration

The static retardation test configuration is depicted in Figure 4.1. The main elements of the configuration are the anchor vehicle, a tensioning system, and a test vehicle. Two variations of the configuration were used. Most of the testing was performed with a hydraulic ram system. A smaller set of tests was performed using a cable winch system (PB03 was the only vehicle tested with the winch).

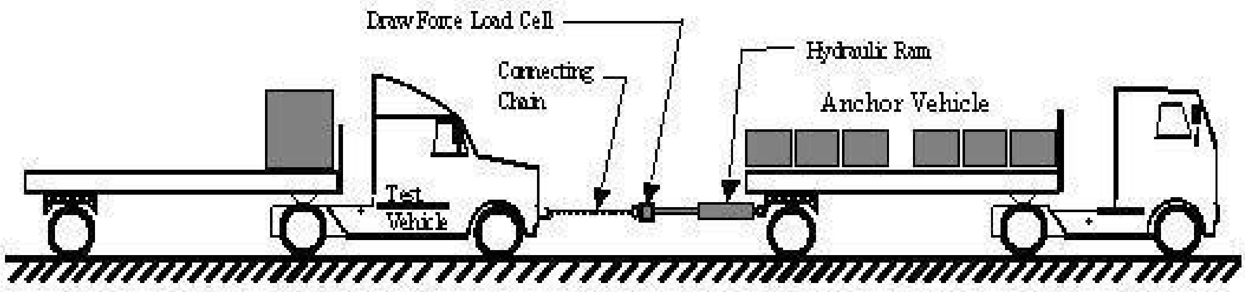

Figure 4.1 – Static Retardation Test Configuration Using A Hydraulic Ram

The anchor vehicle consisted of a two-axle tractor and single axle semi-trailer (2-S1) combination (Peterbilt COE tractor with a 27-foot Great Dane flatbed trailer) and a set of concrete blocks loaded on the trailer. The trailer was equipped with a high strength pintle hook on the rear. The pintle hook provided a fixed pulling height of 34 inches above the floor and a means to swivel the tensioning system. Six concrete blocks, each weighing 4,300 lbs, were chained onto the deck of the flatbed trailer for additional ballast. The total weight was 47,220 lbs. The parking brakes were set on both the tractor drive axle and the trailer axle to provide sufficient anchoring capability without bolting to the wall or floor. The trailer tires and the floor were marked to indicate if the combination moved. The anchor vehicle held fast for the entire set of tests.

The first test unit (PB01) was tested using a 24-inch stroke hydraulic ram. It was rated 20,000 lbs in retraction. With an effective cross-sectional area of 10.2 square inches, the measured retraction rate was almost 5 feet per minute. After allowing for droop during coupling, the effective pull distance under constant load ranged from 18 to19 inches. With one wheel revolution requiring 122 inches, this meant a total of 7 pulls were required to achieve just one revolution of the wheel. After reviewing the data from the first test series, it was determined that the draw rate was too fast (the OVSC - TP121V-04 specifies a maximum of 4 feet per minute) and the angular rotation was too short, so an alternate ram system was configured for the test units that followed.

The second and third test units (PB02 and PB03) were tested with a twin ram system. This revised pulling apparatus included twin 38-inch stroke rams, each with a cross-sectional area of 10 square inches. The resulting pull rate achieved was 3.1 feet per minute. This was slow enough to not generate much heat in the brakes. After allowing for droop during coupling, the new effective pull distance under constant load ranged from 30 to 31 inches, achieving the desired distance for the 90 degree wheel rotation.

The cylinder end of the ram was connected to the rear of the stationary trailer of the anchor vehicle at the pintle hook through a suitable swivel ring. This allowed the ram to swivel and rotate slightly to optimize the alignment during each pull. The load cell was connected to the end of the hydraulic ram with a straight coupling.

A 5-horsepower hydraulic pump supplied the fluid power to the hydraulic ram. It had a maximum flow rating of 3 gallons per minute at a sustained pressure of 2,000 psi. The pump system included filters, a flow control, and a manual 4-way, closed-center, control valve (for manual extension and retraction of the ram). It was connected to the hydraulic ram through a pair of 3/8-inch x 12-foot long high pressure hydraulic lines.

After the original three units were tested, a cable winch was used as an alternate pulling device for the Static Retardation tests. This system was used only for the third test unit (PB03). The 30,000 lbs winch was mounted on the front of a tandem axle straight truck fitted with a 5,000 gallon water tank (acting as the anchor vehicle for these tests). With its two axle parking brake system, this unit provided enough anchoring capability to withstand over 18,500 lbs of draw force without moving. The winch was connected to the load cell in place of the hydraulic ram used for the previous tests. The hydraulic motor of the winch was driven by a pump attached to the transmission power-take-off (PTO) of the water truck, and regulated through the positioning of a lever valve. One advantage of the cable winch was that it had an adjustable height pull point which minimized the vertical pull angle between the two vehicles.

The final link in the test configuration was the connecting chain. A full loop of 3/8-inch high grade welded steel binding chain (Figure 4.1) was connected between the in-line load cell on the ram and the test vehicle. When pulling from the front of the test vehicle, the loop was spread wide enough to grasp the two tow hooks. This helped to maintain a balanced pull. When pulling from the rear, the chain was looped around the pintle hook on the rear of the unbraked control trailer (for the two tractor test units PB02 and PB03).

4.1.2 Initial Brake Temperature

During the Static Retardation Tests, the OVSC - TP121V-04 indicates that throughout the test sequence the brakes should be warmed as necessary to achieve specified Initial Brake Temperature (IBT) (step 7). The IBT is defined in Section 10-A-8 as, “Brake temperature just prior to any parking brake test must be between 150 ºF and 200 ºF.” An end of test temperature is not specified.

The brakes were warmed for each of the Static Retardation tests. The vehicles were driven out-of-doors, where a few brake snubs were made to warm the brakes. Next, the vehicles were driven back into the building. For PB01 and PB02, the exterior surface temperature of the drums were measured with a pyrometer. The readings ranged from 190 to 220 ºF at the beginning of a series, and 140 to165 ºF by the end of the four pulls (7 pulls for PB01) required to fulfill the full wheel rotation test series. For PB03, the temperatures were monitored with thermocouples and the tests were only run while the initial brake temperatures were in the range of 150 to 200 ºF.

For the additional tests performed where only short pulls were made in rapid succession (discussed in Section 4.1.6), the temperatures ranged between room temperature and 180 ºF depending on the test unit. The temperature range for each individual test unit was relatively small (approximately ± 10 degrees from the mean temperature for each unit). For these tests, the effects of a range of initial pressures being applied were studied, while the brakes were at a fairly constant temperature for each test unit.

4.1.3 Brake Actuation Air Supply

The OVSC - TP121V-04 specifies that the brake system reservoirs be charged to compressor cut-out pressure, then the engine turned off before applying the parking brake (Steps 9 and 10). For some of the tests in this study, the engine compressor was cycled as prescribed in the OVSC - TP121V-04. For the others, as the alternative to running the engine compressor, a supplementary airline from the "shop air" supply was connected to the wet reservoir through a quick disconnect. The shop air supply pump cycled between 90 and 120 psi. This was sufficient for the tests, as they were not started when the pressure was below 100 psi (the shop air system was manually cycled to pump back up to 120 psi before continuing). The reliance upon the shop air did not adversely influence the testing, for the emphasis was on chamber pressure levels, not supply pressure; and on brake forces, not explicit timing (shop air pressure may recover faster than that from the engine compressor). Both the primary and the secondary reservoirs were monitored with pressure transducers on test unit PB03 to indicate this pressure supply activity.

4.1.4 Anti-Compounding Status

The status of the anti-compounding system was either active feedback (labeled as on), or disconnected (labeled as off). "On" represented a normal functioning system. "Off" was meant to represent either a brake system design without anti-compounding or a partially failed system. Both "on" and "off" conditions were tested using a series of short pulls that are described in the Section 4.1.6.

The active feedback used by the anti-compounding systems is generated by connecting the service control line (or one of its derivatives) to the anti-compounding port on the parking/emergency brake control valve with a "feedback" line. This feedback supplies a balance pressure to the parking brake system that "pumps up the spring brake chambers" to reduce the effort being applied by the emergency application springs. The net effect of the combined diaphragm and spring forces was expected to be limited to no more than the maximum force produced by using the service brake diaphragm alone. Anti-compounding systems are designed to minimize the occurrence of fatigue failures due to the bending of the chamber brackets, the shearing of clevis pins, the compression cracking of linings, and the stress cracking of drums. The feedback pressure was measured with a transducer installed though a tee connector added to the parking brake control valve.

To turn the anti-compounding system "Off", the air line providing the feedback was disconnected from the service control sourcing end. The source port was plugged so the service brake would operate normally. The free end of the airline was also plugged so the air pressure could still be measured at the anti-compounding inlet port to the parking brake control valve.

4.1.5 Static Retardation Test Matrix

There were two types of static retardation tests conducted: the standard test (described here) and an experimental test (described in Section 4.1.6).

The first type was a series as specified in the “Laboratory Test Procedure for FMVSS No. 121" [OVSC - TP121V-04] and is described in Section 4.1 of this report. These tests were performed on all three test vehicles. The test conditions for each series are given in Table 4.1. The Pull Direction, Initial Treadle Pressure, and Pulling Device are listed for each vehicle. The anti-compounding system was activated (on) during all of the tests conducted in this test series.

All three test units were tested using the hydraulic ram system. Additional tests were performed on unit PB03 using the winch system. All three test units were tested at 0 psi Initial Treadle Pressure with additional tests over a wide range of pressures being conducted on unit PB03.

As shown in Table 4.1, unit PB01 was not pulled in the rearward direction. Upon preparing for the pulls from the rear, this unit was found to have a very low pulling point, with respect to the anchor vehicle, thus creating a large incident angle. A special fixture would have been needed to connect this test unit to the anchor vehicle. Since the unit was only available for a limited period, this unit was not pulled from the rear.

Table 4.1 - Static Retardation Tests Conducted Using the Full Test Procedure

Test Unit	Pull Direction	Initial Treadle Pressure (psi)	Pulling Device
PB01	Forward	0	Hydraulic Ram
PB02	Forward	0	Hydraulic Ram
	Reverse	0	
PB03	Forward	0	Hydraulic Ram
	Forward	100	
	Forward	100	
	Reverse	100	
	Forward	0	Winch
	Reverse	0	
	Forward	40	
	Reverse	40	
	Forward	60	
	Reverse	60	
	Forward	80	
	Reverse	80	
	Forward	100	
	Reverse	100	
	Forward	120	
	Reverse	120	

4.1.6 Short Pull Test Procedures and Test Matrix

The second type of static retardation test was an experimental series initiated to study the effects of applying the initial treadle pressure at different levels and having the anti-compounding systems turned "on" or "off". Here, the draw-force system was configured to the standard setup, but the initial treadle pressure applied by the foot pedal was incremented on successive applications of the parking brake. The Initial Treadle Pressures ranged from 0 to 100 psi (specific range for each test unit is given in Table 4.2). The pulls were abbreviated so full tension was only applied for a few seconds (to obtain a constant pulling force measurement). Then this cycle was repeated at the next pressure level. The wheels only turned part of one revolution for each sequence of tests. The tests were performed in rapid succession to avoid brake cooling. The goal of this test sequence was not to find the maximum force for one whole revolution of the wheel, but rather to identify if there was a discernable difference in parking brake output as a result of having applied different service brake pressures (Initial Treadle Pressure) prior to applying the parking brake and to examine the effects of the anti-compounding system. The tests performed for each unit are given in Table 4.2. The anti-compounding condition (on or off), Pull Direction, and range of Initial Treadle Pressures is listed for each vehicle. The Initial Treadle Pressures listed in this table are approximate.

Table 4.2 - Static Retardation Short Pull Test Sequences

Test Unit	Anti-Com-pound	Pull Direction	Initial Treadle Pressure (psi)										
			0	10	20	30	40	50	60	70	80	90	100
PB01	Off	Forward	---	---	---	---	X	X	X	X	X	X	X
PB02	Off	Forward	X	X	X	X	X	X	X	X	X	X	X
		Reverse	X	X	X	X	X	X	X	X	X	X	X
	On	Forward	X	X	X	X	X	X	X	X	X	X	X
		Reverse	X	X	X	X	X	X	X	X	X	X	X

The first test series (PB01) was performed as a simulation of a grade test, where tension was maintained on the drawbar for a whole range of different treadle pressure applications. Once the treadle was applied for the first initial treadle pressure, the parking brake was applied, then tension applied. After the parking brake slipped for several seconds, the drawbar tension was *reduced* to where the vehicle stopped creeping forward. The treadle was re-applied, to the next incremental pressure step, and the parking brake cycled off and back on (all while maintaining tension on the drawbar). This draw sequence was repeated for the initial pressure range of 40 to 100 psi. Although the data looked similar to the values recorded for the *full pull* series, the repeatability of this procedure was questionable. Therefore, the grade simulation procedure (holding a constant drawbar tension to simulate gravity) was abandoned for the next vehicle.

For PB02, the short pull procedure was modified so the drawbar tension was released between each successive parking brake application cycle. Since this procedure was no longer a direct grade simulation, the range of initial treadle pressures was expanded to include all 10 psi increments from 0 to 100 psi. PB02 was pulled both forward and in reverse, with the anti-compounding turned on, and again with it turned off.

4.2 Grade Holding Test Procedures

The Grade Holding Test is the other option specified in the FMVSS No. 121, Section 5.6 for testing Parking Brakes. The laboratory test procedure [OVSC - TP121V-04] specifies thirteen steps for completing this test procedure:

1. Install device to measure vehicle movement on the grade.
2. If parking brake chamber pressure was greater than 3 psi, install a pressure regulator and a method of supplying air at the recorded pressure to the parking brake chambers to be tested (none were required for these three test vehicles).
3. Warm brakes, as necessary to achieve specified Initial Brake Temperature.
4. Charge brake system reservoirs to compressor governor cut-out pressure.
5. Ascend 20% grade of dry smooth Portland cement concrete or equivalent surface.
6. Apply and hold service brakes to minimum level necessary to hold vehicle stationary.
7. Place vehicle transmission in neutral.
8. Turn engine off.
9. Apply parking brakes.
10. Release service brakes.
11. Record initial movement of vehicle, if any, that takes place after release of service brakes until vehicle becomes stationary.
12. Record vehicle movement, if any, on grade after 5 minutes.
13. Repeat the test with the vehicle descending the grade.

The VRTC testing primarily followed the test procedures outlined above except where noted below. The instrumentation used to conduct this testing was described in Chapter 3. Details for the vehicle loading conditions, Initial Brake Temperature, the 20% brake slope, determination of minimum service brake holding pressure, and the engine running status are given below. The test matrix for the Grade Holding Tests is also presented.

4.2.1 Vehicle Loading Conditions

The FMVSS No. 121, Section S5.6.2 requires that each vehicle must be tested "both (a) When loaded to its GVWR, and (b) At its unloaded vehicle weight plus up to 500 lbs (including driver and the instrumentation)." For the empty tests, the weight of the driver, the data acquisition system, the transducers, and the hundreds of feet of cabling accounted for 350 lbs of the total weight listed as "empty weight" on the Vehicle Information Sheets in Appendix A.

Loading the vehicle to GVWR was accomplished by adding weights or connecting a control trailer to the vehicles. For the dump truck (PB01), several 4,300 lbs concrete blocks were chained into the bed and an auxiliary chain was wrapped between the lift bed and two points on the frame as a precaution to ensure that the load did not "dump" during the nose uphill test. For the tractors, a standard unbraked control trailer (as specified in FMVSS No 121, Section S6.1.1) was coupled. Steel plates were bolted and chained to the deck area above the kingpin to achieve the gross axle weight ratings specified by each tractor manufacturer. Concrete blocks could not be used as their lower density would have required a stack three feet higher than the front bulkhead of the trailer (which would have been hazardous to the driver) and would have exceeded the maximum 24-inch above the tractor fifth wheel ballast CG height requirement specified in the FMVSS No. 121, Section S6.1.10.2.

4.2.2 Initial Brake Temperatures

Step 3 of the test procedure states that the brakes should be warmed as necessary to achieve the Initial Brake Temperature. The lining temperatures were not directly monitored on PB01 or PB02. For PB03, lining thermocouples were installed to measure the initial temperatures. For all the test vehicles, the service brakes were applied five or six times to snub the speed from 40 to 20 miles per hour. The deceleration achieved was approximately 10 feet per second per second (~0.3 G). The driver's experience was that this effort would raise the brake temperatures into the 150 to 200 degree F range. The thermocouples on unit PB03 verified the correct temperature rise using this procedure. Between each successive test on the brake slope, the brakes were re-warmed by dragging them periodically while traversing the turn-around loop at the bottom of the hill.

4.2.3 Twenty Percent Brake Slope Description

A twenty percent (20%) sloped grade was used to test the parking brakes for all three test units (Figure 4.2). The main slope was an 81-foot long, concrete test pad with gradual tapers above and below the main slope. The surface was dry for each of the vehicle tests, with the exception of one test for unit PB03. At that time, there was a light dusting of winter road grit/salt on a slightly damp surface. Since the tires did not slide on the grit, the results were not affected by the debris being present.

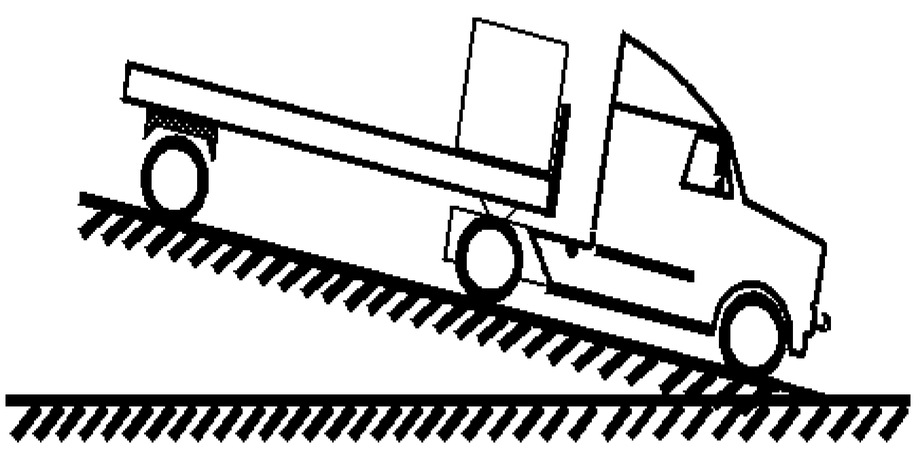

Figure 4.2 – Test Vehicle Holding on 20% Grade

4.2.4 Minimum Service Brake Holding Pressure Determination and Variation of Initial Service Brake Pressure

Step 6 of the test procedure says to apply and hold service brakes to minimum level necessary to hold vehicle stationary. This minimum level was determined by driving each unit onto the 20% grade, stopping it with the service brakes, and then the treadle pedal was modulated to reduce the service brake pressure to a level where the vehicle would just start to creep down the grade. This level set the lower limit for the initial treadle pressure (Section 5.6) for the Grade Holding tests conducted in this study.

The TMA has petitioned NHTSA to change this minimum level to the following specified in the SAE RP No. J360 [6] (Grade Parking Performance Test Procedure): "Apply and hold service brakes by using maximum treadle (pedal) travel with system at compressor cut-out pressure."
The FMVSS No. 121 indicates that the minimum cut-in pressure of the compressor regulator must be at or above 100 psi for trucks and tractors. The pressures selected for use in this study were the minimum pressure determined above and 40, 60, 80, and 100 psi.

4.2.5 Engines Running During Tests

To address two safety concerns prompted by the drivers and observers (1. The tractor drive axle tires sliding when tested in the bobtail condition, or 2. Parking brake failure), the engines were kept running during all tests on the 20% grade. The OVSC - TP121V-04 indicates that the engine must be turned off prior to applying the parking brakes (steps 8 and 9). Since this study used vehicles with unknown grade holding capabilities and which were loaded to various loading conditions, the engines were kept running.

Leaving the engines running ensured that the engine compressors would maintain the reservoir pressures at a level above the regulator cut-out pressure (required 100 psi minimum for trucks and tractors), enabling the service brakes to be applied at any moment the driver felt that the test unit was beginning to roll away. To ensure that leaving the engine running did not bias the test results, all of the service chambers and the parking brake chambers were monitored to make sure that their pressure had actually been vented down to zero psi during the grade holding tests. Another benefit from the engine running was having sufficient power to maintain normal air pressure for the vehicles with air-suspensions.

4.2.6 Grade Holding Test Matrix

The conditions tested for each test unit are summarized in Table 4.3. This table lists the loading condition, anti-compounding status (on or off), the slope direction, and range of Initial Treadle Pressures tested for each unit.

Table 4.3 - Grade Holding Tests Conducted for Each Test Unit

Test Unit	Loading Condition	Anti-Compounding	Slope Direction	Initial Treadle Pressure Range (psi)
PB01	GVWR	On	downhill	20 to 100
			uphill	20 to 60
		Off	downhill	40 to 100
			uphill	20 to 100
PB02	GVWR Using Loaded Trailer	On	downhill	100
			uphill	100
	Partially Loaded Trailer	On	downhill	100
			uphill	100
	Trailer Empty	On	downhill	100
			uphill	100
	Tractor Only	On	downhill	100
			uphill	100
PB03	GVWR Using Loaded Trailer	On	downhill	60 and 100
			uphill	60 and 100
	Tractor Only	On	downhill	60 and 100
			uphill	60 and 100

Both uphill and downhill tests were performed on all three test units with the anti-compounding On. Only unit PB01 was tested with the anti-compounding both On and Off. For PB02, several loading conditions were added in an attempt to get the 6x4 tractor to hold on the grade with parking brakes only on one drive axle. If a vehicle fails to hold on the grade, it must meet the requirements of the drawbar test.

4.3 Service and Parking Brake Application (No Pull) Test Procedures

A series of brake application tests were performed on each vehicle to examine the effects of brake anti-compounding. The brake application test procedures consisted of applying the service brake over a wide range of Initial Treadle Pressures and then applying the parking brake. Tests were conducted with and without the anti-compounding system being activated. The resulting pin forces and chamber strokes were measured for the parking brake equipped axle on each vehicle. The tests conducted on each unit are given in Table 4.4.

Table 4.4 - Brake Application Test Sequences

Test Unit	Anti-Compound	Initial Treadle Pressure (psi)										
		0	10	20	30	40	50	60	70	80	90	100
PB01	Off	X	X	X	X	X	X	X	X	X	X	X
	On	X	X	X	X	X	X	X	X	X	X	X
PB02	Off	X	---	---	---	---	---	X	---	X	---	X
	On	X	---	---	---	---	---	X	---	X	---	X
PB03	Off	X	---	X	---	X	---	X	---	X	---	---
	On	X	---	X	---	X	---	X	---	X	---	X

5.0 PARKING BRAKE RESULTS

This chapter presents results from the static retardation, grade holding, and combined service and parking brake (no pull) tests performed in this study.

5.1 Static Retardation Test Results

For "Static Retardation Tests", the FMVSS No. 121, Section S5.6.1, states that for a truck/tractor with two axles, the ratio of the static retardation force to the GAWR must be greater than 0.28 for any axle other than a front steer axle. PB01 and PB03 fell under this classification. PB01 had a 23,000 lbf GAWR, which yields a 6440 lbf minimum retardation force for the given 0.28 ratio. PB03 had a 22,700 lbf GAWR yielding a 6356 lbf minimum retardation. For a vehicle with more than two axles, the ratio of the total (sum of the individual parking brake axles) static retardation force to the GVWR must be greater than 0.14. PB02 fell under this classification. PB02 had a 48,000 lbf GVWR, which yields a 6720 lbf minimum retardation force for the given 0.14 ratio. The actual ratios achieved during this study will be presented later in Table 5.6.

For this study, two tests were conducted using the static retardation test fixtures. The first test was performed using the general guidelines of the OVSC "Vehicles - Air Brake Systems" TP121V-04. This test procedure requires that the vehicle must be pulled for a full wheel rotation. The second test was very similar to the full wheel rotation test except that the pull distance was very short. This second sequence was performed to examine the effects of Initial Treadle Pressure and anti-compounding status (Off or On) on test results. Details for these test procedures are given in Chapter 4 - Test Procedures.

5.1.1 Full Wheel Rotation Test Results

The Peak Static Retardation Force for each test unit is given in Tables 5.1 through 5.4. The peak value for each segment of wheel rotation is listed. Also listed in these tables are the Pull Direction, Initial Treadle Pressure, and Pull Device (when appropriate). The anti-compounding device was "On" for all the tests conducted with this test procedure. The Overall Peak Static Retardation Force is shown in bold. Mean and standard deviation values are also presented.

The Hunter Plate Brake Tester was used for auxiliary measurement of the parking brake forces. The Hunter System was too short to simultaneously measure all of the axles of the test unit (and the unbraked control trailer when used), therefore the readings do not include any residual forces (slight brake drag, bearing friction, etc.) from the other wheels as does the draw force load cell (except for when the other axle of the tandem rolled onto the plate for part of the test on PB02). The data from the Hunter Plate are also listed in Tables 5.1 through 5.4.

Table 5.1 presents the results for test unit PB01. Only one case was tested with this vehicle: forward pull with 0 psi Initial Treadle Pressure. This test was conducted with the hydraulic ram. The range of values over the course of the full wheel rotation was approximately 8800 to 10000 lbf. This variation may be attributable to the eccentricity and out-of-round conditions on the brake drums and, to a lesser extent, the tires. The percentage difference between the load cell and Hunter Plate measured peak forces for each segment of rotation are given at the bottom of the table. These two measuring methods produced very similar results for this test sequence, with percent difference values ranging from 0 to 2.2 percent. The Overall Peak Static Retardation value (shown in bold) for the load cell and the Hunter Plate data both occurred in the last segment of the wheel rotation. The mean and standard deviation values for the two measurement systems were very similar.

Table 5.1 - Peak Parking Brake Static Retardation Forces for Test Unit PB01 Full Wheel Rotation Tests

Measuring Device	Pull Direction	Initial Treadle Pressure (psi)	Peak Static Retardation Force for Each Pull Range (lbf)							Mean (lbf)	Std Dev (lbf)
			0-52 deg	52-104 deg	104-156 deg	156-208 deg	208-260 deg	260-312 deg	312-364 deg		
Load Cell	Forward	0	9155	8820	9200	9262	9359	9492	**10094**	9340	392
Hunter Plate	Forward	0	9013	8746	9186	9195	9355	9533	**9875**	9272	364
Percent Difference			1.6	0.8	0.2	0.7	0	0.4	2.2		

Table 5.2 contains the results for test unit PB02. Two cases were tested with this vehicle: forward and reverse pull with 0 psi Initial Treadle Pressure. These tests were conducted with the hydraulic ram. The range of drawbar load cell values for the forward pull test was approximately 7300 to 7700 lbf. For the reverse pull, the range was 6900 to 7300 lbf. All of the percent difference values for the forward pull test were less than 2.2 percent. One of the reverse pull tests had a higher percent difference value (4.1% for the 0 to 90 degree segment), but all of the other values were less than 2.4 percent. While the values were similar for the two force measuring systems, the Hunter Plate usually provided the lower values, as its measurement did not include residual forces generated by all of the other wheels. The Overall Peak Static Retardation forces for the forward pull tests occurred in the third segment of the wheel rotation for both measuring devices. The peak forces for the rearward pull tests occurred within one wheel rotation segment of each other.

Table 5.2 - Peak Parking Brake Static Retardation Forces for Test Unit PB02
Full Wheel Rotation Tests

Measuring Device	Pull Direction	Initial Treadle Pressure (psi)	Peak Static Retardation Force for Each Pull Range (lbf)				Mean (lbf)	Std Dev (lbf)
			0-90 deg	90-180 deg	180-270 deg	270-360 deg		
Load Cell	Forward	0	7316	7280	**7697**	7390	7421	190
	Reverse	0	7304	6850	**7341**	7230	7181	226
Hunter Plate	Forward	0	7164	7260	**7717**	7333	7369	242
	Reverse	0	7014	6727	7173	**7232**	7037	226
Percent Difference	Forward		2.1	0.3	-0.3	0.8	0.7	-24.4
	Reverse		4.1	1.8	2.3	0.0	2.0	0.0

The Peak Static Retardation Force values for test unit PB03 are presented in Tables 5.3 and 5.4. Table 5.3 contains the results from the load cell and Table 5.4 contains the results from the Hunter Plates. The first two test sequences listed in Table 5.3 are actually one test sequence. The first two pulls of this sequence were made with no Initial Treadle Pressure (ITP) application (0 psi), while the second two pulls were made at an ITP of 100 psi. The brakes were at room temperature for these four pulls and no Hunter Plate data was collected.

The remaining tests were conducted with the brakes pre-heated to the required IBT before beginning the drawbar pulls. Both the hydraulic ram and the winch system were used on unit PB03. These pulling systems are described in Chapter 4. A wide range of Initial Treadle Pressures were also tested with this unit. The effect of the pulling system and the effect of Initial Treadle Pressure on test results are examined in more detail, later in this section. These tables also have an additional heading for Service Brake Chamber Pressure. The bobtail proportioning valve was activated during some of these tests and therefore the pressure in the service brake chamber was sometimes much less than that for the treadle. The values presented are an average of those for the left and right side.

Table 5.3 - Peak Parking Brake Static Retardation Forces for Test Unit PB03
Full Wheel Rotation Tests - Load Cell Data

Pull Direction	Initial Treadle Pressure (psi)	Service Brake Chamber Pressure (psi)	Pull Device	Peak Static Retardation Force for Each Pull Range (lbf)				Mean (lbf)	Std Dev (lbf)
				0-90 deg	90-180 deg	180-270 deg	270-360 deg		
Forward at room temperature	0	-7.3	Ram	**10612**	9459	---	---	10036	815
	100	100		---	---	10600	11311	10956	503
Forward warm brakes	0	-7		8710	9557	9741	**9986**	9499	554
	100	101		11127	**11409**	10526	10931	10998	371
Reverse	100	103		**10366**	9213	9900	10219	9925	513
Forward	0	-8	Winch	7727	7650	7912	**8151**	7860	223
	40	14.6		**9785**	9220	9258	9475	9435	259
	60	20.4		**9894**	9709	9568	9640	9703	140
	80	83.9		11109	10638	**11300**	10416	10866	409
	100	105.7		10733	10642	**11050**	10842	10817	176
	111	107		10137	**11096**	11088	10866	10797	453
Reverse	0	-7.5	Winch	**7667**	7205	7578	7660	7528	219
	40	44.3		8586	8806	8638	**8983**	8753	180
	60	65.8		8715	8324	8554	**9049**	8661	305
	80	86.5		9315	9499	9388	**9556**	9440	108
	100	102.1		9874	**10042**	9755	9719	9848	146
	111	106.7		9221	9492	9289	**9623**	9406	185

Table 5.4 - Peak Parking Brake Static Retardation Forces for Test Unit PB03
Full Wheel Rotation Tests - Hunter Plate Data

Pull Direction	Initial Treadle Pressure (psi)	Service Brake Chamber Pressure (psi)	Pull Device	Peak Static Retardation Force for Each Pull Range (lbf)				Mean (lbf)	Std Dev (lbf)
				0-90 deg	90-180 deg	180-270 deg	270-360 deg		
Forward	0	-7	Ram	8600	9473	9672	**9957**	9426	585
	100	100		10778	**11140**	10484	11064	10867	299
Reverse	100	100		**10258**	9094	9856	9877	9771	488
Forward	0	-8	Winch	7626	7400	7460	**7738**	7556	154
	40	14.6		**9653**	9079	9146	9141	9255	267
	60	20.4		**9700**	9141	9395	9363	9400	230
	80	83.9		10572	10085	**11118**	10066	10460	497
	100	105.7		10427	10311	**10719**	10528	10496	173
	111	107		10624	10760	**10950**	10709	10761	138
Reverse	0	-7.5	Winch	7662	7476	7791	**7962**	7723	205
	40	44.3		8606	8770	9093	**9260**	8932	298
	60	65.8		8749	8488	8896	**9217**	8838	304
	80	86.5		9403	9527	9601	**9736**	9567	139
	100	102.1		9901	**10178**	10020	9919	10005	127
	111	106.7		**9987**	9657	9680	9747	9768	151

A couple of interesting things occurred during the testing with test unit PB03. The first was the creation of a vacuum in the service brake chamber when the parking brakes were applied and the other was the activation of the bobtail proportioning valve during testing. These phenomenons are depicted in Figures 5.1 and 5.2 respectively.

Figure 5.1 contains three subplots. The first subplot has three pressure traces as a function of time: parking brake, treadle, and service brake chamber 3 (drive axle, left side). The second subplot has the static retardation force and the third subplot has the chamber stroke, both as a function of time. As seen during this test, the treadle is not activated (stays at 0 psi) and at approximately -3 seconds, the parking brake is activated, the spring brake chamber goes from high to low pressure. At the same time, the pushrod moves outward, rarefying the air in the service brake chamber. This causes the service brake pressure to become negative, i.e., a partial vacuum is created with a magnitude of approximately 8 psi. It is not clear from the testing conducted in this study how this affects the static retardation test results. Clearly from the results presented in Tables 5.3 and 5.4, the 0 psi results produced the lowest static retardation force, and the results from the other tests suggest that static retardation force increases with increasing treadle pressure. This vacuum also occurred on test unit PB02, but at a much smaller level (approximately 1.5 psi).

Figure 5.2 presents data in a format similar to that of Figure 5.1, only the Initial Treadle Pressure was raised to 40 psi. The result here shows that no vacuum occurs in the service brake chamber. The effect of the bobtail proportioning is clearly evident by comparing the treadle and service chamber pressures for this test; the service brake chamber pressure is approximately half that applied by the treadle. The first subplot shows that anti-compounding is functioning as the parking brake pressure only drops to near the treadle pressure level when the parking brake is set.

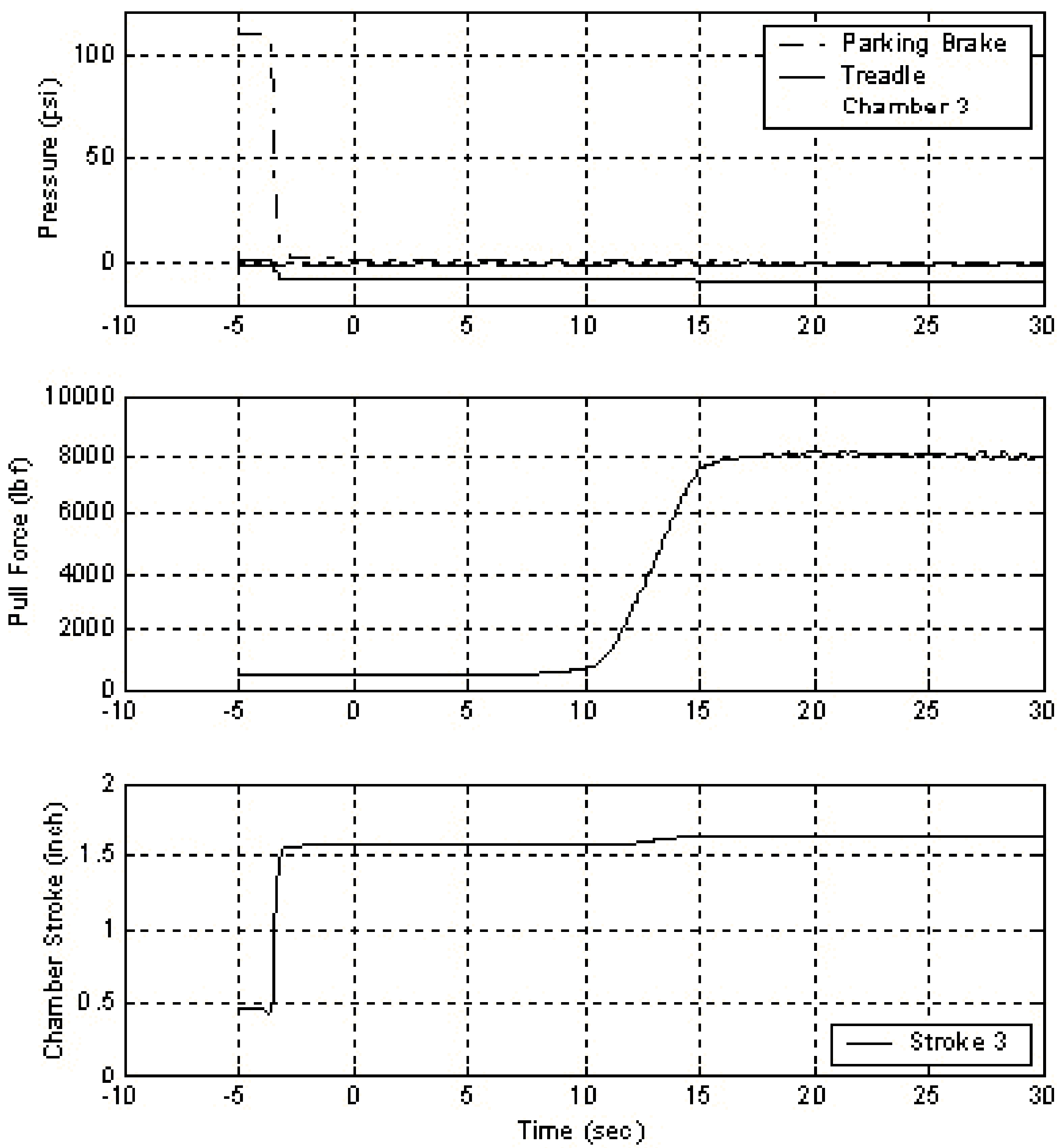

Figure 5.1 - Static Retardation Test Results for Unit PB03
No Initial Treadle Pressure (0 psi)

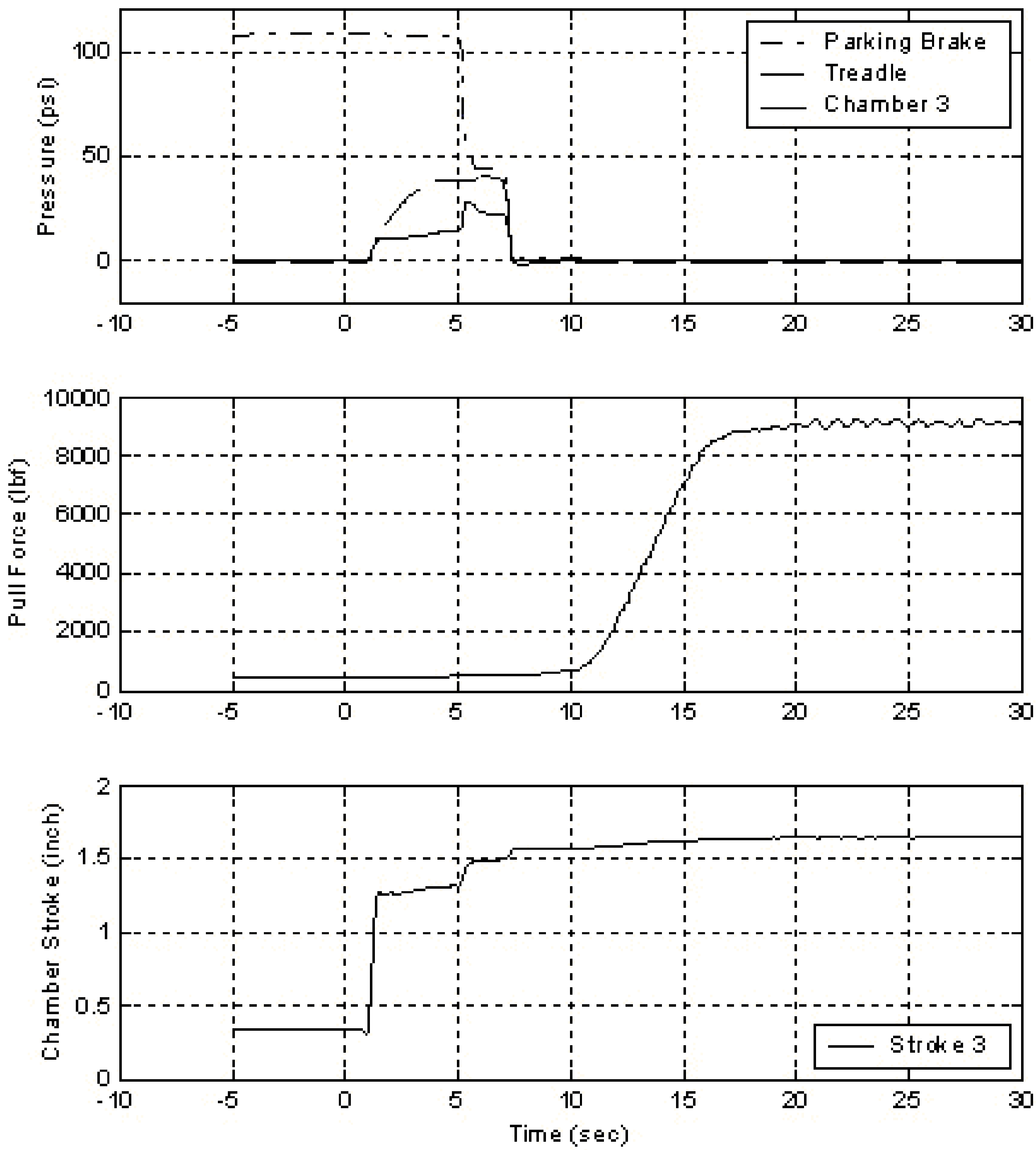

Figure 5.2 - Static Retardation Test Results for Unit PB03
40 psi Initial Treadle Pressure

For PB03, the Overall Peak Static Retardation Forces from the draw force load cell and from the Hunter Plate are compared in Table 5.5. The two systems appear to agree quite well for the measurement of the parking brake static retardation force. The maximum Percent Difference for all of the cases was 5.2 percent.

In Section 5.1, the target parking brake minimum-force-to-unit-weight ratios were established for the three test vehicles. These target ratios were compared to empirically derived ratios obtained from the study, and are presented in Table 5.6. For all test conditions, both measurement systems indicate that the parking brakes on each unit tested exceeded the minimum brake retardation requirement specified in FMVSS No. 121 for static drawbar tests, for their given axle configuration (PB01 and PB03 - two axles, PB02 - three axles).

Unit PB03 was tested in the forward and reverse directions with 100 psi Initial Treadle Pressure, and in the forward direction with 0 psi (no Initial Treadle Pressure), both with a hydraulic ram and with a winch system applying the pulling force. The Overall Peak Static Retardation Forces for these two application systems are examined in Table 5.7 (load cell data only). For the 100 psi tests, the two pulling systems gave results that were approximately 3.2 percent different from each other for both pulling directions. The 0 psi forward pull tests had a difference of over 20 percent.

Table 5.5 - Overall Peak Static Retardation Force Values

Test Unit	Pull Direction	Initial Treadle Pressure (psi)	Pull Device	Overall Peak Static Retardation Force (lbf)		
				Load Cell	Hunter Plate	% Diff
PB01	Forward	0	Ram	10094	9875	2.2
PB02	Forward	0	Ram	7697	7717	-0.3
	Reverse	0	Ram	7341	7232	1.5
PB03	Forward	0 cold	Ram	10612	---	---
		100 cold		11311	---	---
		0		9986	9957	0.3
		100		11409	11140	2.4
	Reverse	100		10366	10258	1.0
	Forward	0	Winch	8151	7738	5.2
		40		9785	9653	1.4
		60		9894	9700	2.0
		80		11300	11118	1.6
		100		11050	10719	3.0
		120		11096	10950	1.3
	Reverse	0	Winch	7667	7962	-3.8
		40		8983	9260	-3.0
		60		9049	9217	-1.8
		80		9556	9736	-1.9
		100		10042	10178	-1.3
		120		9623	9987	-3.7

Table 5.6 - Overall Peak Static Retardation Force/GAWR or GVWR Values

Test Unit	Pull Direction	Initial Treadle Pressure (psi)	Pull Device	Required Ratio (GAWR or GWVR)	Overall Peak Static Retardation Force/GAWR or GVWR (lbf/lbf)	
					Load Cell	Hunter Plate
PB01	Forward	0	Ram	GAWR (.28)	0.44	0.43
PB02	Forward	0	Ram	GVWR (.14)	0.16	0.16
	Reverse	0	Ram	GVWR (.14)	0.15	0.15
PB03	Forward	0 cold	Ram	GAWR (.28)	0.47	---
		100 cold		GAWR (.28)	0.50	---
		0		GAWR (.28)	0.44	0.44
		100		GAWR (.28)	0.50	0.49
	Reverse	100		GAWR (.28)	0.45	0.45
	Forward	0	Winch	GAWR (.28)	0.36	0.34
		40		GAWR (.28)	0.43	0.43
		60		GAWR (.28)	0.44	0.43
		80		GAWR (.28)	0.50	0.49
		100		GAWR (.28)	0.49	0.47
		120		GAWR (.28)	0.49	0.48
	Reverse	0	Winch	GAWR (.28)	0.34	0.35
		40		GAWR (.28)	0.40	0.41
		60		GAWR (.28)	0.40	0.41
		80		GAWR (.28)	0.42	0.43
		100		GAWR (.28)	0.44	0.45
		120		GAWR (.28)	0.42	0.44

Table 5.7 - Hydraulic Ram Versus Winch Overall Peak Retardation Force Comparison for Test Unit PB03

Pull Direction	Initial Treadle Pressure	Overall Peak Retardation Force (lbf)		Percent Difference (%)
		Hydraulic Ram	Winch	
Forward	100	11409	11050	3.2
Reverse		10366	10042	3.2
Forward	0	9986	8151	20.2

The differences between ram and winch tests include: 1. Ram tests were run in December after running vehicle outside to warm brakes, but cams and chambers may have been quite cold: 2. The test truck was new and only had a single 500 snub burnish performed on the brakes prior to the ram tests, while the winch tests were run late the following June after extensive FMVSS No. 121 type tests and the brakes were somewhat worn. There appears to be more variability in retardation force at 0 psi than at 100 psi ITP.

For unit PB03, there were additional tests conducted in both the forward and reverse directions over a full range of Initial Treadle Pressures using the winch pulling system (120 psi was the compressor cut-out pressure for this test unit). The Overall Peak Static Retardation Forces are plotted as a function of Initial Treadle Pressure in Figure 5.3 (values given in Tables 5.3 and 5.4). Both load cell and Hunter Plate data are presented. The two measurement systems gave very similar results. The Overall Peak Static Retardation forces show an increasing trend for pressures from 0 to 80 psi. The values tend to level out at higher pressures (≥ 80 psi). These results suggest that applying a full service brake application prior to applying the parking brake can give a large increase in the measured Overall Peak Retardation Force capabilities for the parking brake system even with anti-compounding.

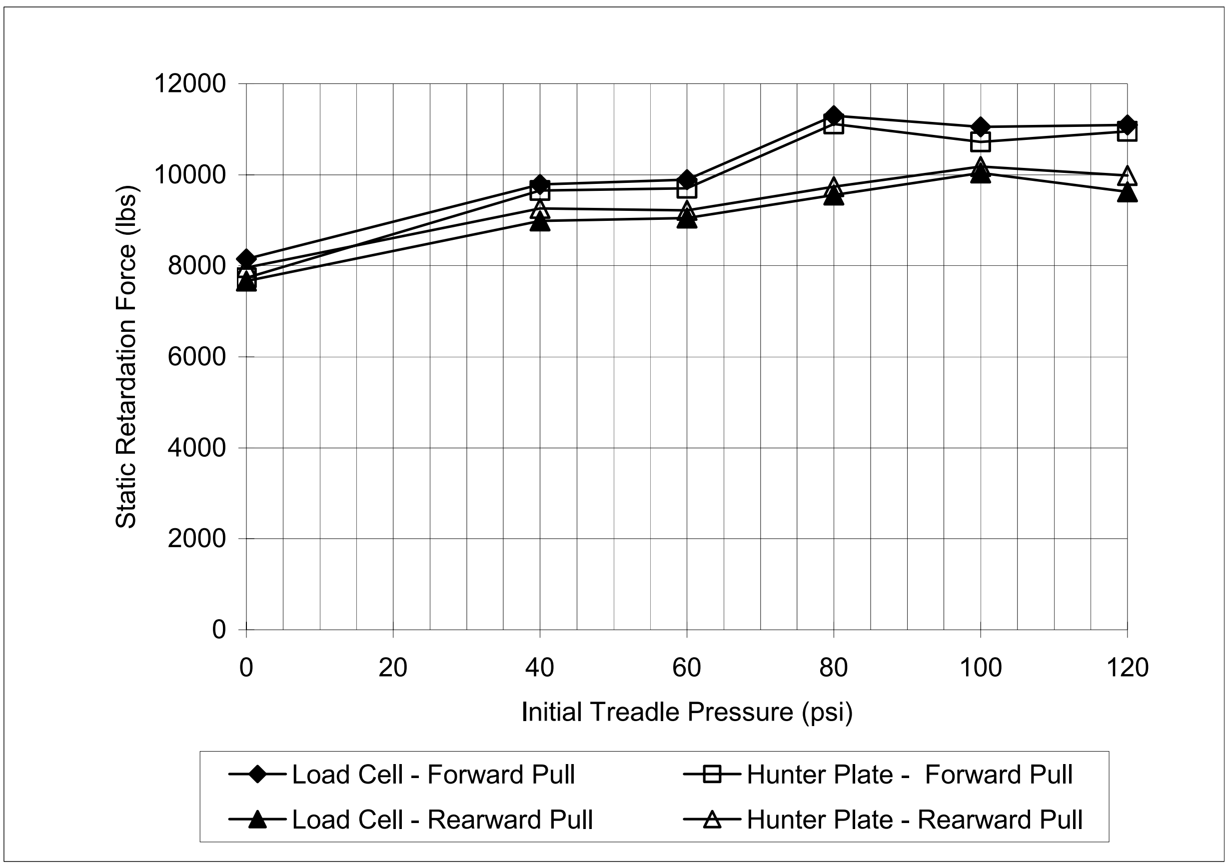

Figure 5.3 - Static Retardation Force as a Function of Initial Treadle Pressure - Full Wheel Rotation Results for Unit PB03 Using Winch System - Anti-Compounding "ON"

The 0 and 120 psi results for test unit PB03 are compared in Table 5.8 (load cell data). Both forward and reverse pull direction values are given. Providing a full service brake application prior to the initiation of the static retardation test sequence produced a 25 to 36 percent increase in the Overall Static Retardation Force versus having no service brake application.

Table 5.8 - Initial Treadle Pressure Effect On Overall Peak Retardation Force for Test Unit PB03 with Anti-Compounding "ON" - Winch Test Results

Pull Direction	Overall Peak Retardation Force (lbf)		Percent Increase (%)
	0 psi	120 psi	
Forward	8151	11096	36.1
Reverse	7667	9623	25.5

A comparison of forward versus reverse test results is given in Table 5.9. Test unit PB02 had only one Initial Treadle Pressure level evaluated. There was less than a 5 percent difference between the forward and reverse direction pulls for this test condition. Unit PB03 was evaluated over a wide range of pressures in both the forward and reverse direction. Regardless of the Initial Treadle Pressure or the Pull Device, the forward Overall Peak Static Retardation Force was always greater than that for the reverse direction. The Percent Difference ranged from 6 to almost 17 percent.

Table 5.9 - Forward Versus Reverse Pull Direction Effect on Overall Peak Static Retardation Force Values

Test Unit	Initial Treadle Pressure (psi)	Pull Device	Overall Peak Static Retardation Force (lbf)		
			Forward	Reverse	Percent Difference (%)
PB02	0	Ram	7697	7341	4.7
PB03	100	Ram	11409	10366	9.6
	0	Winch	8151	7667	6.1
	40		9785	8983	8.5
	60		9894	9049	8.9
	80		11300	9556	16.7
	100		11050	10042	9.6
	120		11096	9623	14.2

5.1.2 Short Pull Test Results

A series of short pull tests were conducted on test units PB01 and PB02 after completion of the full wheel rotation tests. These tests consisted of a very short pull after different levels of service brake pressure were applied prior to setting the parking brake.

The peak forces for each short pull test are given in Tables 5.10 and 5.11 (PB01 and PB02 respectively). PB01 was only pulled forward due to the low tow point on the rear of the truck. One series of short pulls was performed with the Initial Treadle Pressure ranging from 40 to 100 psi. All tests were run with the anti-compounding turned off (hose disconnected and plugged). The draw force load cell gave slightly higher values of brake force than the Hunter Plate for all Initial Treadle Pressures over 40 psi, but a little under at 40 psi. The correlation of the forces indicated that the two devices measured the force with less than a 2% difference for all ranges. With the anti-compounding turned off, the load cell forces increased 8.2% over the 40 to 100 psi range, and the Hunter Plate showed an increase of 6.0%.

Table 5.11 shows where PB02 was pulled (short pulls only) from the front and from the rear. This tractor was pulled 11 times in each direction with the anti-compounding turned on and 11 times with it turned off. The Initial Treadle Pressures ranged between 0 and 100 psi, in nominal 10 psi steps.

For this vehicle, with anti-compounding turned off, the load cell forces for the reverse pull were all higher than the forward pull forces. In the forward direction, the load cell forces correlated to the Hunter Plate with less than a 3% difference in values, but the reverse pulls ranged 8 to 15% difference. In each series, the retardation force increased significantly as the Initial Treadle Pressure was increased. For the load cell forces, the increase was 31% forward, and 28% reverse. For the Hunter Plate forces, the increase was 34% forward, while the reverse showed an increase of 5% (for the 0 to 20 psi range) before experiencing a problem with the video camera that was logging the Hunter data.

Table 5.10 - Short Pull Test Results - Unit PB01

Anti-Compound	Measurement Device	Pull Direction	Short Pull Maximum Pull (lbf)										
			0 psi	10 psi	20 psi	30 psi	40 psi	50 psi	60 psi	70 psi	80 psi	90 psi	100 psi
Off	Load Cell	Forward	---	---	---	---	8207	8476	8526	8587	8661	8771	8906
	Hunter Plate	Forward	---	---	---	---	8349	8399	8453	8506	8580	8687	8864
	Percent Difference %	Forward	---	---	---	---	-1.7	0.9	0.9	0.9	0.9	1.0	0.5

Table 5.11 - Short Pull Test Results - Unit PB02

Anti-Com-pound	Measurement Device	Pull Direction	Short Pull Maximum Force (lbf)										
			0 psi	10 psi	20 psi	30 psi	40 psi	50 psi	60 psi	70 psi	80 psi	90 psi	100 psi
Off	Load Cell	Forward	6727	6948	7046	7402	7611	7770	8126	8285	8653	9009	9206
		Reverse	7439	7585	8347	8788	9120	9193	9672	9721	9635	9954	9831
	Hunter Plate	Forward	6621	6834	6845	7298	7545	7758	8047	8228	8653	9002	9286
		Reverse	6857	6741	7243	---	---	---	---	---	---	---	---
	Percent Difference %	Forward	1.6	1.7	2.9	1.4	0.9	0.2	1.0	0.7	0.0	0.1	-0.9
		Reverse	8.1	11.8	14.2	---	---	---	---	---	---	---	---
On	Load Cell	Forward	6642	7071	6838	6985	7304	7414	6985	7488	7654	6985	8065
		Reverse	8396	8580	8801	8715	8715	8463	8604	8641	8715	8801	8641
	Hunter Plate	Forward	---	---	6809	6841	7233	7419	6842	7442	7675	6947	8119
		Reverse	8054	8055	7911	7849	7820	7793	7702	7829	8018	8390	8439
	Percent Difference %	Forward	---	---	0.4	2.1	1.0	-0.1	2.1	0.6	-0.3	0.5	-0.7
		Reverse	4.2	6.3	10.7	10.5	10.8	8.2	11.1	9.9	8.3	4.8	2.4

The same set of tests was repeated on PB02 with the anti-compounding turned back on (Table 5.11). Again, the load cell forces for the reverse pull were all higher than the forward pull forces. In the forward direction, the load cell forces correlated to the Hunter Plate with less than a 2.2% difference in values, but the reverse pulls ranged 2 to 11% difference (somewhat better than the anti-compounding-off mode). In each series, the retardation force increased significantly as the Initial Treadle Pressure was increased, but only about half as much as with the anti-compounding turned off. For the load cell forces, the increase was 19% forward, and 5% reverse. For the Hunter Plate forces, the increase was 18% forward, and again 5% reverse.

The peak forces from the forward short pull tests for unit PB01 are plotted as a function of Initial Treadle Pressure in Figure 5.4. Although the exact 10-psi pressure increments were not achieved (due to an erroneous driver's dial pressure gauge) actual pressure transducer readings were used for the plot. Both the load cell and Hunter Plate data are shown in this figure. The peak forces show a definite increasing trend over the range of Initial Treadle Pressures evaluated.

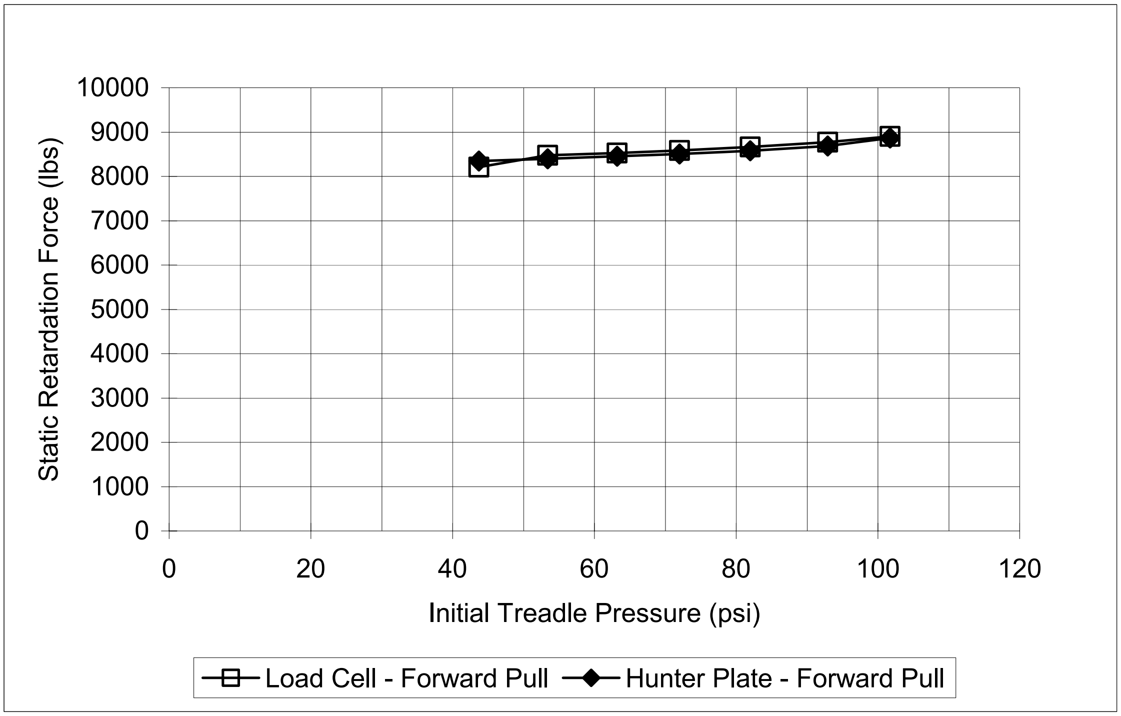

Figure 5.4 - Static Retardation Force as a Function of Initial Treadle Pressure Short Pull Test Results for Unit PB01 - Anti-Compounding "OFF"

Unit PB02 was tested with the anti-compounding system activated and with it disabled (on and off). This unit was pulled from both the front and the rear for both conditions. The peak static retardation forces are plotted as a function of Initial Treadle Pressure in Figures 5.5 and 5.6. Figure 5.5 contains the forward and rearward pulls for the tests with the anti-compounding system on, while Figure 5.6 contains the same data for the anti-compounding system off tests. Both load cell and Hunter Plate data are presented in these figures.

The peak static retardation forces from the rearward pulls for the anti-compounding system on tests (Figure 5.5) were relatively flat over the range of Initial Treadle Pressures tested. The forward pulls tended to increase slightly with increasing Initial Treadle Pressure, but there are some oscillations in the data.

The peak static retardation forces from both the forward and rearward pulls with the anti-compounding system off tests (Figure 5.6) have a more definite increasing trend with increasing Initial Treadle Pressure. The peak forces near the low end of the Initial Treadle Pressure range are similar to those found for the tests with the anti-compounding system on. The peak forces at the high end of the Initial Treadle Pressure range are somewhat higher for this series of tests with the anti-compounding system off than they were with the system on. These results suggest that the anti-compounding system does limit the upper bound of the peak static retardation force produced from higher treadle compounding pressures, but the critical output occurs in the region of low initial treadle pressure. Near zero psi treadle compounding pressures, the peak static retardation force obtained was at a minimum.

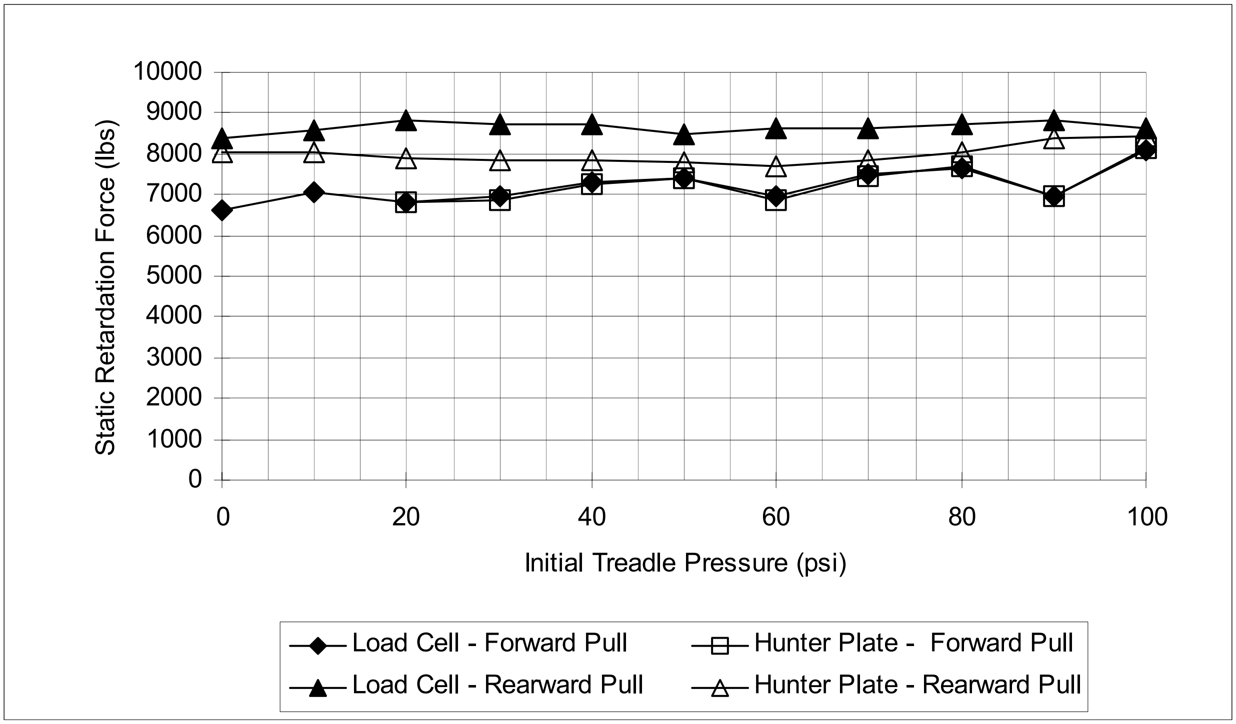

Figure 5.5 - Static Retardation Force as a Function of Initial Treadle Pressure Short Pull Test Results for Unit PB02 – Anti-Compounding "ON"

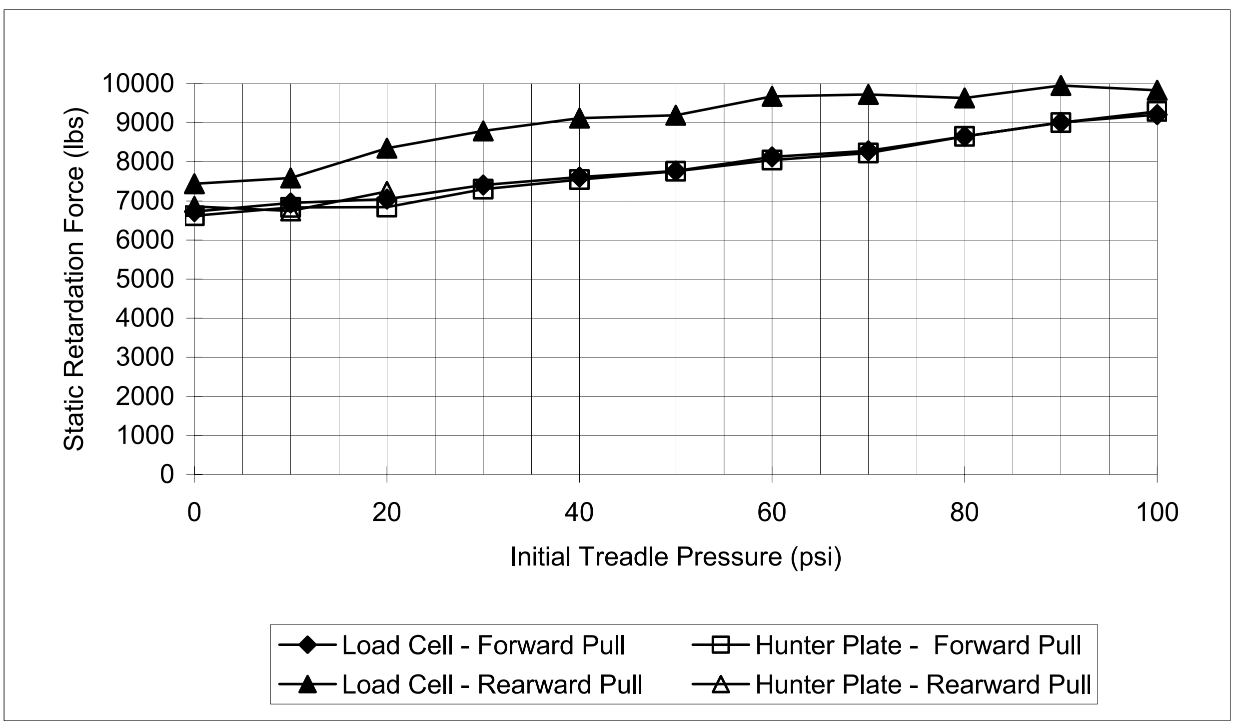

Figure 5.6 - Static Retardation Force as a Function of Initial Treadle Pressure Short Pull Test Results for Unit PB02 - Anti-Compounding "OFF"

5.2 Grade Holding Test Results

The parking brakes for all three test units were evaluated using the grade holding procedures given in Section 5.6.2 of the FMVSS 121. The test procedures are outlined in Chapter 4 of this report.

The parking brake on test unit PB01 (4x2 straight truck) was evaluated with Initial Treadle Pressure ranging from just high enough to barely hold the truck on the hill, up to 100 psi. Both downhill and uphill tests were conducted. Tests with and without the anti-compounding device engaged were also conducted. All of the tests were conducted at the GVWR. The OVSC "Vehicles - Air Brake Systems" TP121V-04 requires that the vehicle hold fast for 5 minutes.

The results of the grade holding tests for unit PB01 are listed in Table 5.12. Regardless of test condition (slope direction, anti-compounding status), all of the tests conducted above the minimum pressure required to hold the truck on the grade (approximately 22 psi), were able to meet the 5 minute holding period. For the tests conducted just above the minimum pressure required to hold the vehicle, the hold time was limited to two minutes primarily due to safety concerns about the *possibility* of the vehicle creeping and not due to the vehicle *actually* creeping.

Table 5.12 - Grade Holding Test Results for Unit PB01

Initial Treadle Pressure (psi)	Loading Condition	Slope Direction (front of truck pointing)	Anti-Compounding Status	Hold Time (sec)
101.9	GVWR	downhill	on	>300
81.7	GVWR	downhill	on	>300
61.5	GVWR	downhill	on	>300
43.2	GVWR	downhill	on	>300
22.8	GVWR	downhill	on	>120
61.0	GVWR	uphill	on	>300
41.5	GVWR	uphill	on	>300
26.7	GVWR	uphill	on	>120
96.7	GVWR	downhill	off	>300
60.4	GVWR	downhill	off	>300
41.1	GVWR	downhill	off	>300
99.3	GVWR	uphill	off	>300
60.1	GVWR	uphill	off	>300
41.3	GVWR	uphill	off	>300

Test unit PB02 was a 6x4 tractor. This test was run to confirm that this class of vehicle (a tractor with more than two axles) may need to use the alternative static retardation test procedure to measure the retardation force of its parking brake system. For this 20% grade series, an initial 100 psi Initial Treadle Pressure treadle application was made prior to each setting of the parking brake. Lower pressures were not evaluated due to the inability of the parking brakes to hold at higher pressures. Both uphill and downhill tests were conducted. Tests were conducted only with the anti-compounding activated (on).

A total of four different loading conditions were evaluated. It was initially intended that just the GVWR and lightly loaded (tractor only) conditions be tested, but other loading conditions were evaluated after it was determined that the parking brakes would not hold at GVWR.

The results for the grade holding tests for test unit PB02 are given in Table 5.13. The GVWR tests were conducted first. GVWR for this test unit was 48,000 lbs. The Gross Combination Weight (GCW) was 52,410 lbs (tractor GVWR plus 4500 lbs on the trailer axle). As shown in Table 5.13, this configuration would not hold on the slope in either the uphill or the downhill direction. The parking brakes would slip (not capable of holding the load) when the vehicle was either pointed up or down the hill. After the brakes did not hold under this condition, the hold time duration was limited to just two minutes for any tests where the brakes would hold. This was done primarily for safety concerns. After the GVWR tests, the load on the control trailer was reduced to give a GCW of 36,080 lbs (75% of GVWR). For this loading condition, the parking brakes held for two minutes with the front of the tractor facing up the hill, but the brakes still slipped with the tractor facing down the hill. The third condition tested was with the control trailer completely unloaded which gave a GCW of 25,590 lbs (53% of GVWR). Again, the parking brake held for two minutes with the front of the tractor facing up the hill, but the tires slipped on the concrete test surface when the tractor was facing down the hill. For the last test condition, the control trailer was disconnected and the tractor was tested "bobtail" without any additional loading (17,540 lbs). Again, the parking brakes held for the full two minutes with the front pointing up the hill, but the tires slid when pointing down the hill.

Table 5.13 - Grade Holding Test Results for Unit PB02

Initial Treadle Pressure (psi)	Loading Condition	Slope Direction (front of truck pointing)	Anti-Compounding Status	Hold Time (sec)	Holding Capability
100	GVWR plus control trailer	uphill	On	0	brakes slip
100		downhill	On	0	brakes slip
100	partially loaded control trailer	uphill	On	>120	held
100		downhill	On	0	brakes slip
100	empty control trailer	uphill	On	>120	held
100		downhill	On	0	tires slid
100	tractor only "bobtail"	uphill	On	>120	held
100		downhill	On	0	tires slid

Test unit PB03 (4x2 tractor) was tested at two loading conditions: GVWR plus control trailer and lightly loaded (tractor only). Both uphill and downhill tests were conducted. The anti-compounding was engaged for all of the grade holding tests conducted with this vehicle. Just two Initial Treadle Pressures were evaluated: 60 and 100 psi. The minimum Initial Treadle Pressure required to hold the test unit on the hill was also determined. This value ranged from 8 psi for the lightly loaded condition up 15 psi for the GVWR loading condition.

The results of the grade holding tests for test unit PB03 are given in Table 5.14. The parking brakes held fast (> 5 minutes) for each test condition evaluated.

Table 5.14 - Grade Holding Test Results for Unit PB03

Initial Treadle Pressure (psi)	Loading Condition	Slope Direction (front of truck pointing)	Anti-Compounding Status	Hold Time (sec)
100	GVWR plus control trailer	downhill	on	>300
100		downhill	on	>300
60		downhill	on	>300
100	GVWR plus control trailer	uphill	on	>300
60		uphill	on	>300
100	tractor only	downhill	on	>300
60		downhill	on	>300
100	tractor only	uphill	on	>300
60		uphill	on	>300

The grade holding test produces a binary result - either the parking brakes hold or they do not hold - and therefore it is difficult to determine what the affect of varying a test parameter (in this case Initial Treadle Pressure) is on results. The only way this can occur is if the test procedure goes from a pass to a non-pass result due to varying the test parameter. This did not occur during this test series. Test units PB01 and PB03 were able to hold on the hill regardless of the Initial Treadle Pressure applied (only a limited number of pressures were evaluated with PB03). Test unit PB02 generally could not hold on the hill (especially in the downhill condition) even at very high Initial Treadle Pressures, and therefore a range of pressures was not evaluated with this unit. Given this, it is difficult to draw any conclusions about the effect of a full service brake application versus a minimum grade holding service brake application. The results from the few test units evaluated suggest that applying a full treadle will not help a vehicle that cannot pass with a minimum brake application to pass with a full treadle application.

5.3 Combined Service and Parking Brake Application (No Pull) Test Results

The combined service and parking brake application test was conducted on all three vehicles. The first step in these tests was to apply the service brake. This was followed by setting the parking brake. The service brake was then released. The transitions from service brake only to service brake and parking brake combined and from service and parking brake combined to parking brake only are examined below for both anti-compounding on and anti-compounding off.

Test unit PB01 was evaluated over a range of 0 to 100 psi Initial Treadle Pressure in 10 psi increments. The anti-compounding off test results are presented in Figures 5.7 and 5.8. Figure 5.7 shows pin forces for the left side of the parking brake axle prior to and after the application of the parking brake over the entire range of pressures evaluated. This family of curves indicates that when compounding is allowed, the pin force component resulting from the parking (spring) brake application, directly adds to the pin force component generated by the initial service brake pressure. As the initial pressure is increased, the compounded pin force rises incrementally in direct proportion to the rise in pressure. The corresponding chamber stroke traces are shown in Figure 5.8. The stroke curves show a similar trend. Both of these figures show a definite increase in output when the parking brake and service brake are compounded.

Similar plots for the anti-compounding on tests are presented in Figures 5.9 and 5.10. These traces clearly show how the anti-compounding system limits the force on the pin and the corresponding chamber stroke. When the parking brake is applied with the initial treadle pressure at 0 psi, the pin force is limited to approximately 875 lbs and the chamber stroke is limited to approximately 1.1 inches. As the initial treadle pressure is incremented from 0 to 40 psi, the outputs are limited to the levels generated by the parking brake only. This is due to the anti-compounding feedback system supplying nearly the same pressure to both the service chamber and the parking brake chamber simultaneously, causing the parking brake spring tension to be reduced by a proportionate amount. At initial treadle pressures of 50 psi, and above, the pressure feedback to the parking brake diaphragm is large enough to completely eliminate the effect of the parking brake, leaving only the output generated by the treadle input.

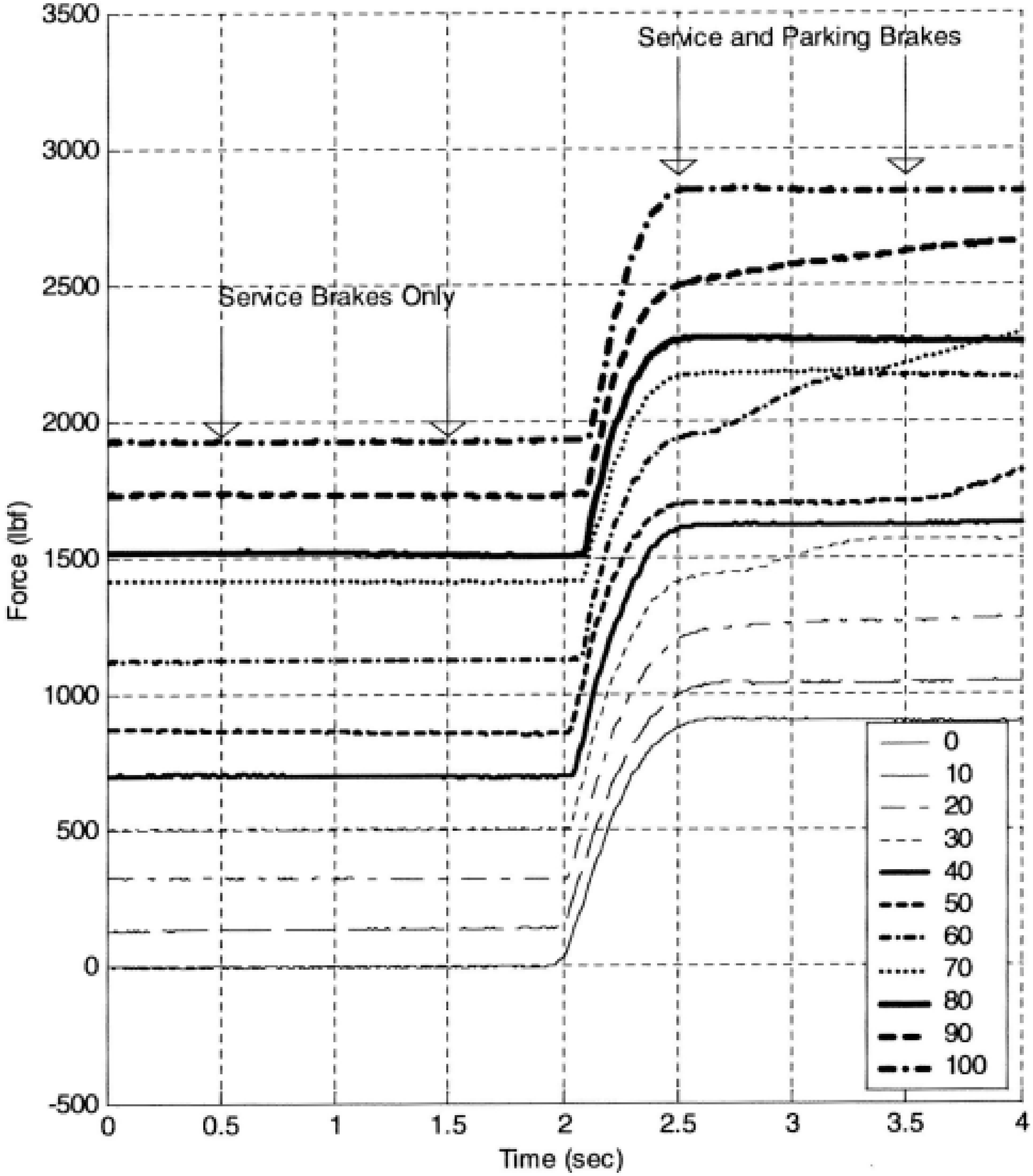

Figure 5.7 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB01 – Anti-Compounding "OFF"

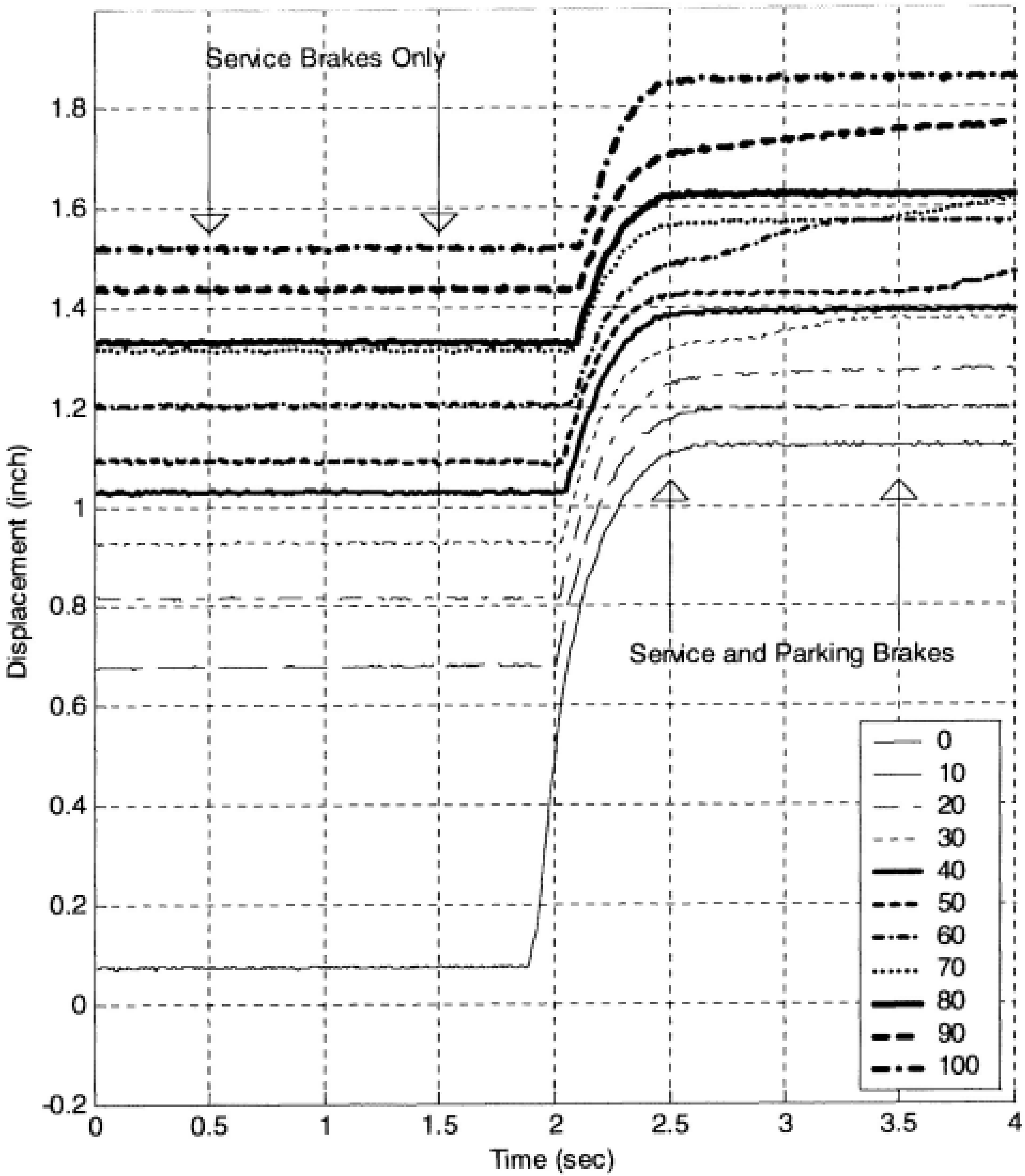

Figure 5.8 - Left Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB01 – Anti-Compounding "OFF"

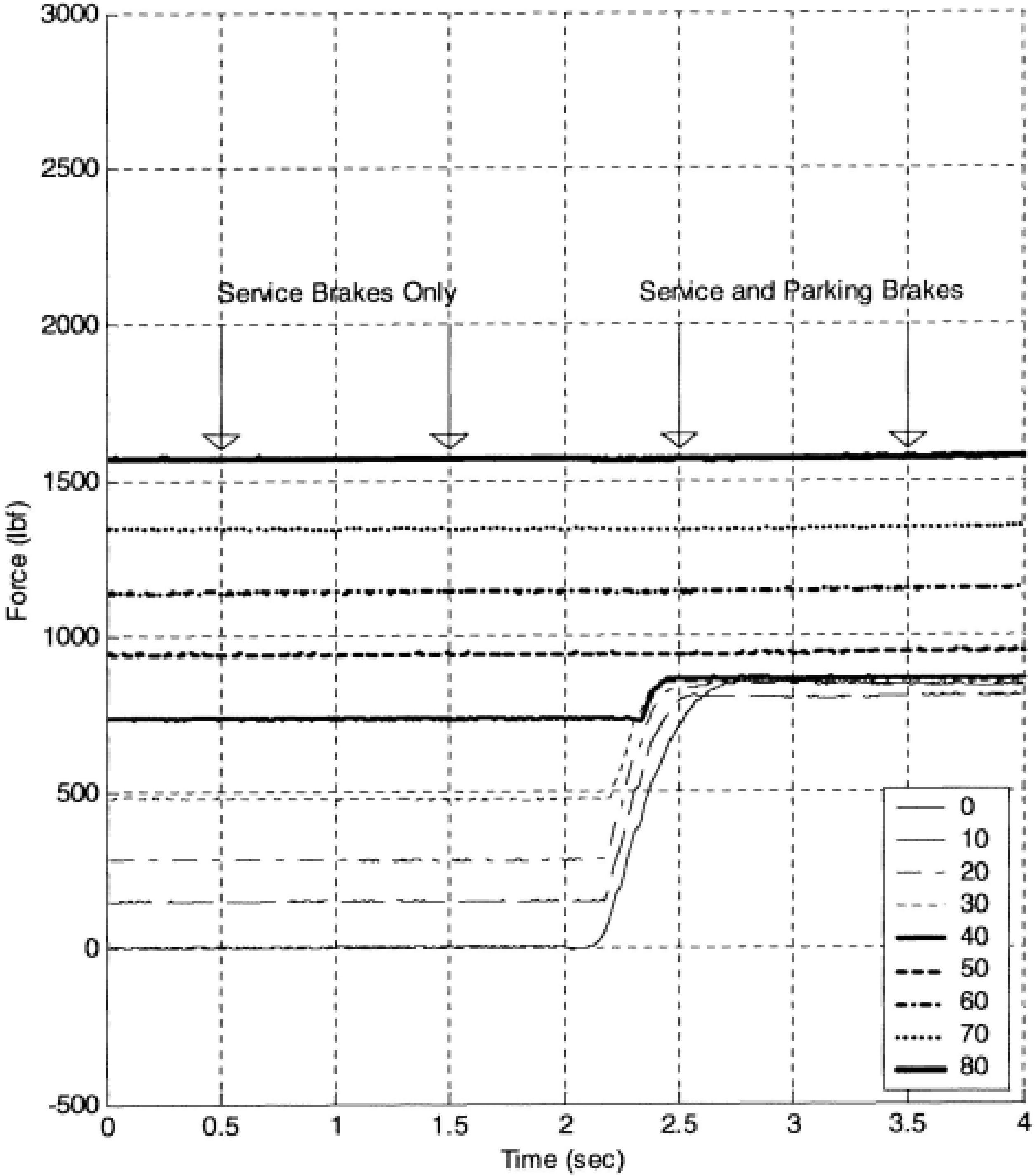

Figure 5.9 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests with Unit PB01 - Anti-Compounding "ON"

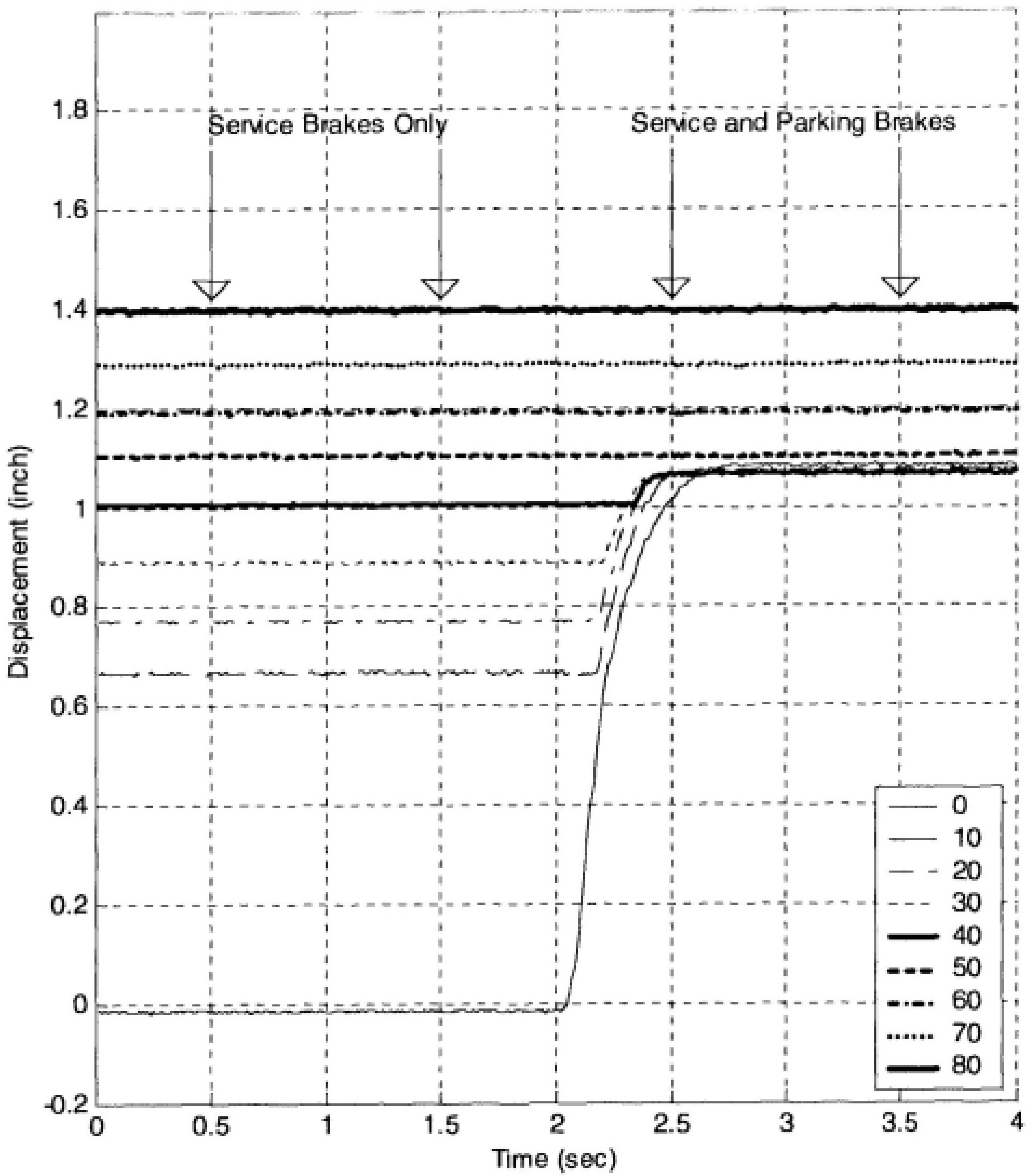

Figure 5.10 - Left Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB01 - Anti-Compounding "ON"

Test unit PB02 was also evaluated over a range of 0 to 100 psi Initial Treadle Pressures, but with fewer increments. The anti-compounding off test results for the right side of the parking brake axle are presented in Figures 5.11 and 5.12. Figure 5.11 shows pin forces prior to and after the application of the parking brake over the entire range of pressures evaluated. The corresponding chamber stroke traces are shown in Figure 5.12. As was the case for PB01, these figures show a definite increase for the forces applied on the pin and for the chamber stroke when the parking brake and service brake are compounded. The force pin transducer range was exceeded during this testing (at approximately 3000 lbf) and therefore the actual forces for some of the tests are greater than those presented in Figure 5.11.

Similar plots for the anti-compounding on tests for test unit PB02 are presented in Figures 5.13 and 5.14. These traces clearly show how the anti-compounding system limits the force on the pin and the corresponding chamber stroke. For all the initial treadle pressures evaluated (60 psi and greater), the pressure feedback to the parking brake is large enough to completely eliminate the effect of the parking brake, leaving only the output generated by the treadle input.

The left side pin forces and chamber deflections for the anti-compounding off tests for unit PB03 are presented in Figures 5.15 and 5.16. Test unit PB03 was evaluated over a range of 0 to 80 psi Initial Treadle Pressure. Figure 5.15 shows pin forces prior to and after the application of the parking brake over the entire range of pressures evaluated. The corresponding chamber stroke traces are shown in Figure 5.16. As was the case for the other test units, these figures show a definite increase for the forces applied on the pin and for the chamber stroke when the parking brake and service brake are applied simultaneously.

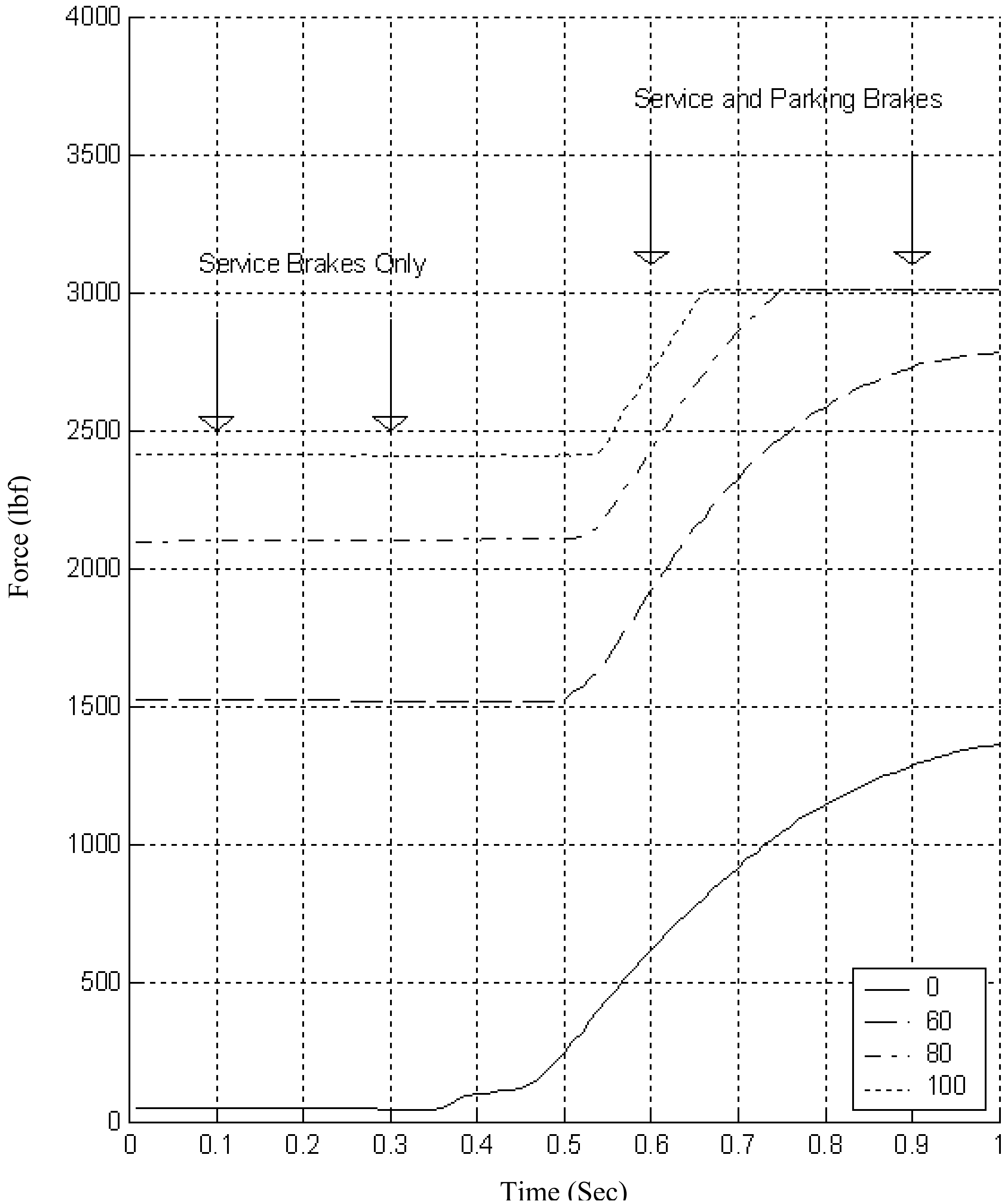

Figure 5.11 - Right Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB02 - Anti-Compounding "OFF"

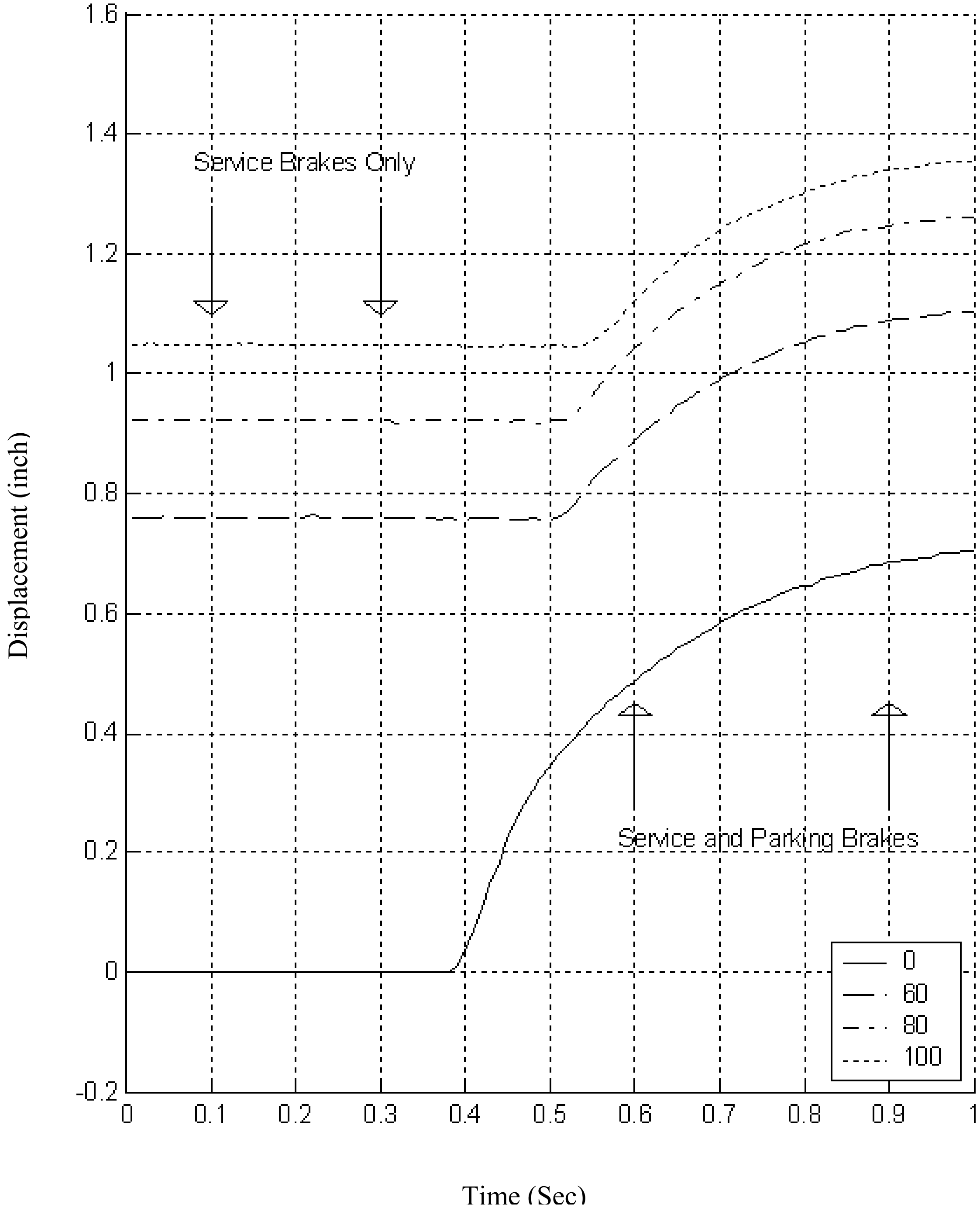

Figure 5.12 - Right Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB02 - Anti-Compounding "OFF"

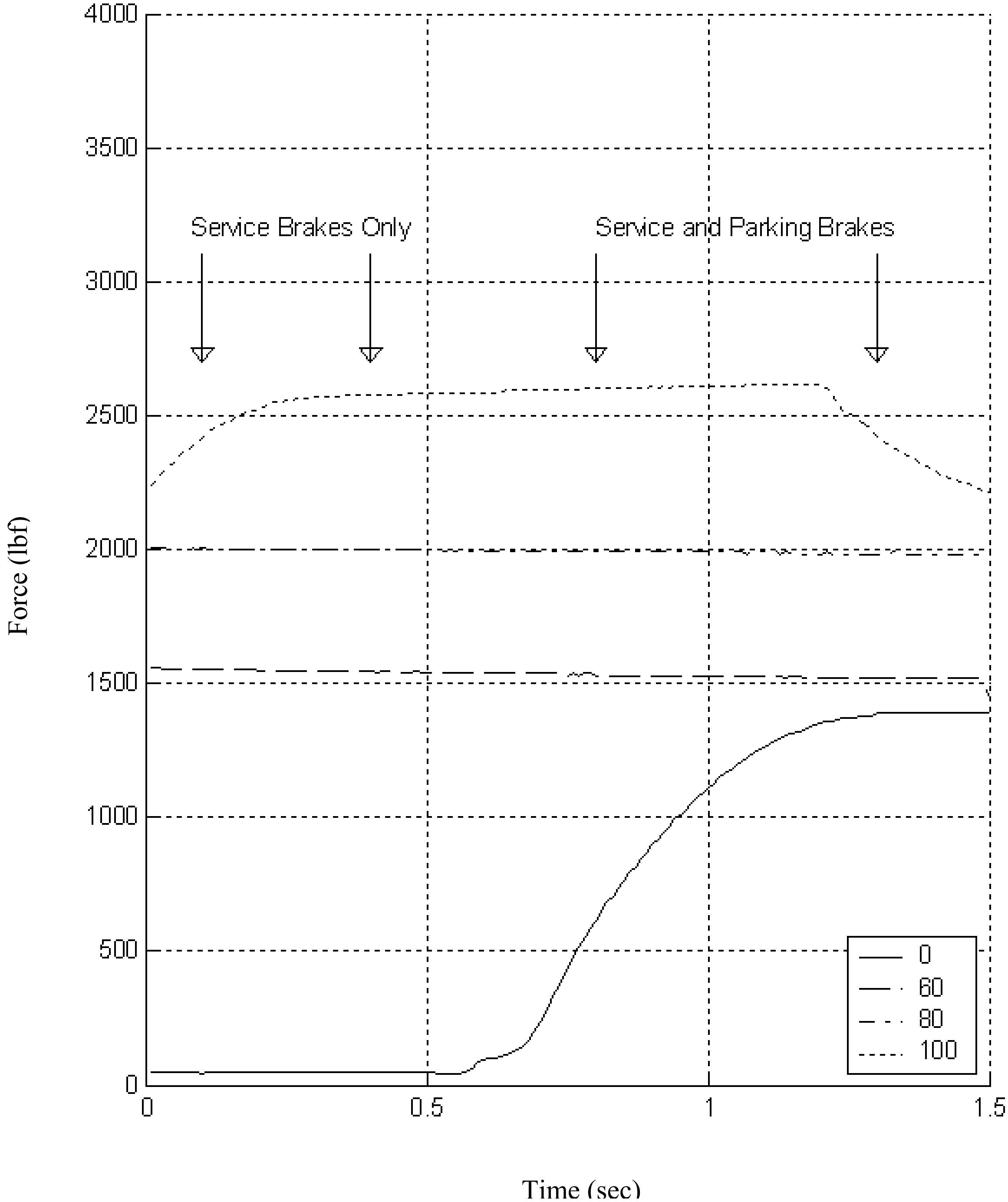

Figure 5.13 - Right Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB02 - Anti-Compounding "ON"

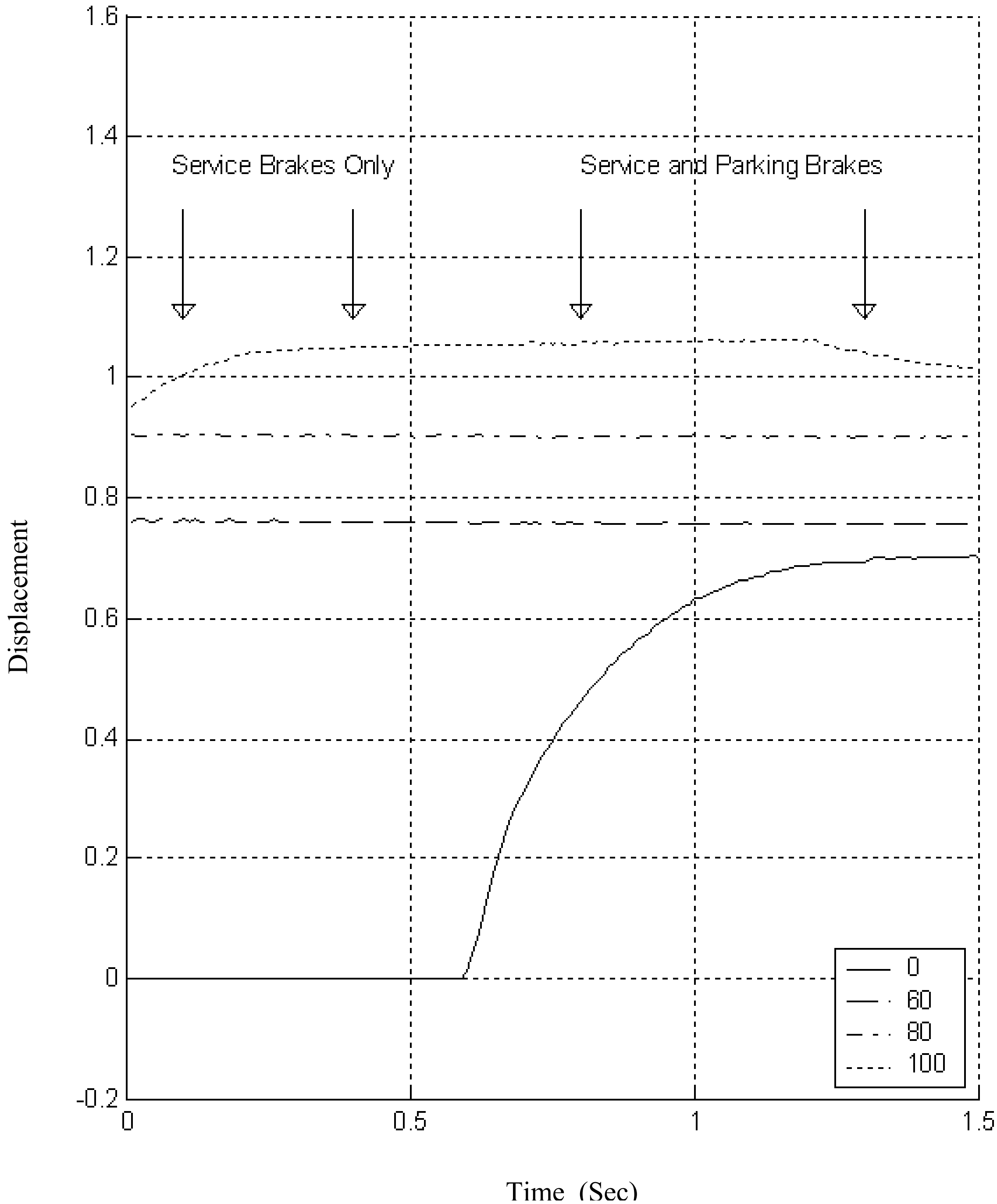

Figure 5.14 - Right Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB02 - Anti-Compounding "ON"

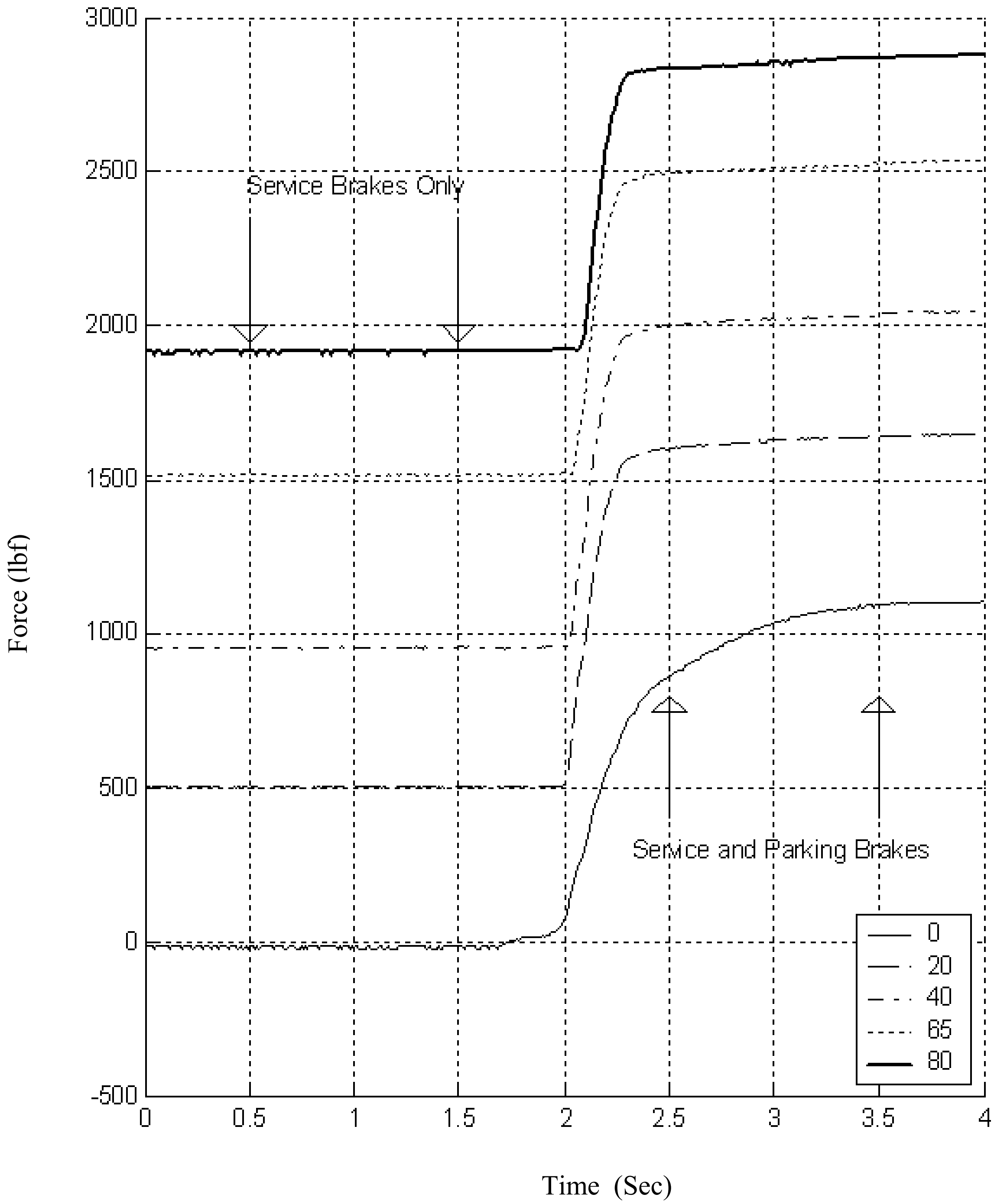

Figure 5.15 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB03 - Anti-Compounding "OFF"

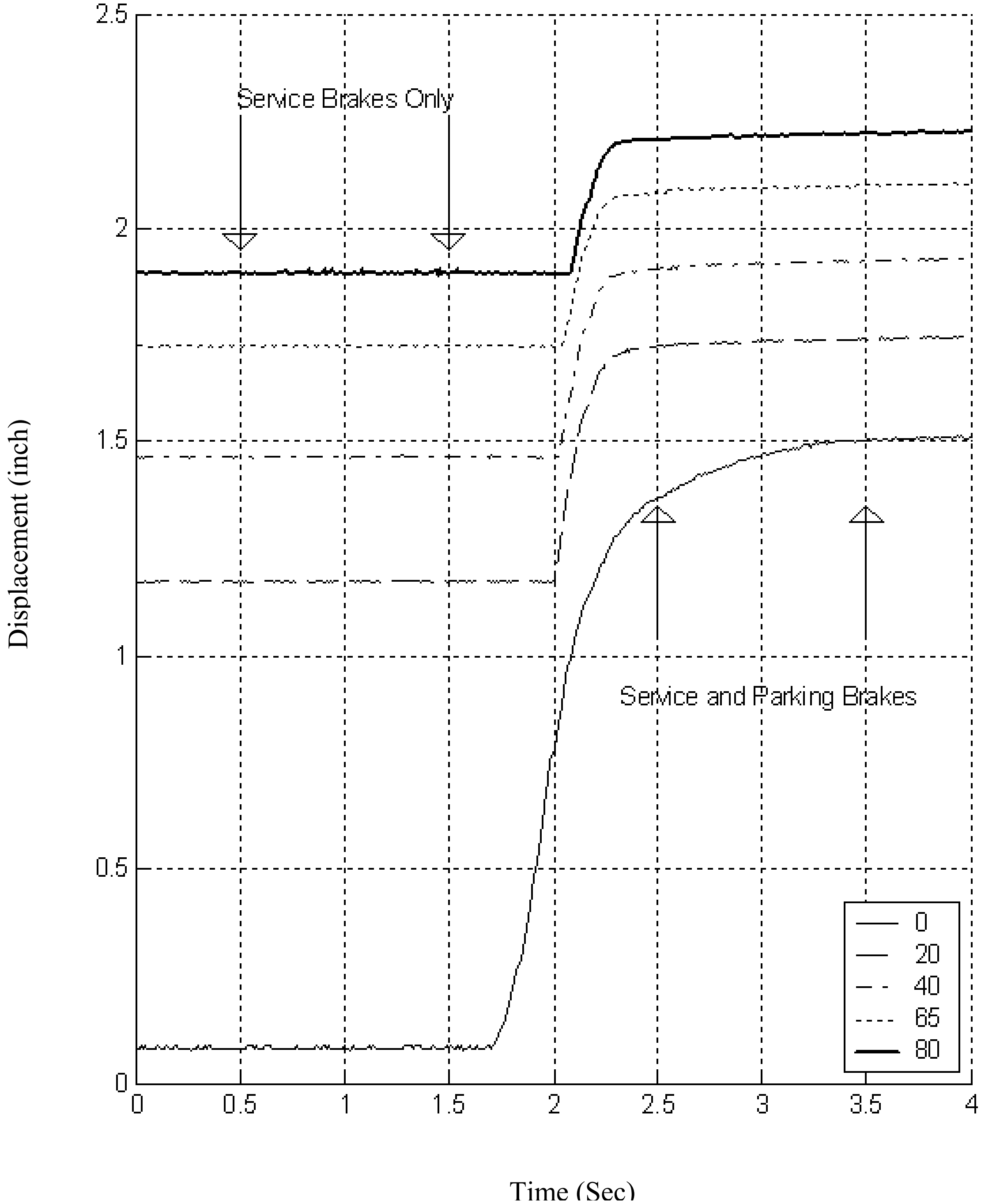

Figure 5.16 - Left Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB03 – Anti-Compounding "OFF"

Test unit PB03 had extra instrumentation on the brake chamber to measure the longitudinal and lateral deflection during service/parking brake applications. These traces are presented in Figures 5.17 and 5.18 respectively. For the lower Initial Treadle Pressures the longitudinal deflection shows the same increasing trend as for the pin force and chamber stroke measurements discussed previously, but it does not appear to be influenced at higher Initial Treadle Pressures. The authors believe this is more an artifact of the way the instrumentation was set up than it is actual measurements. It is believed that the higher Initial Treadle Pressure longitudinal measurement are reduced due to the large lateral deflections (Figure 5.18); in other words, the large lateral deflections inadvertently caused the longitudinal measurement to be reduced due to the orientation of the transducers. The traces in Figure 5.18 show the same increasing trend for lateral deflection that was seen for the pin forces and the chamber stroke measurements discussed previously.

Similar plots for the anti-compounding on tests for PB03 are presented in Figures 5.19 through 5.22. The traces in Figures 5.19 and 5.20 clearly show how the anti-compounding system limits the force on the pin and the corresponding chamber stroke. At initial treadle pressures of 60 psi, and above, the pressure feedback to the parking brake diaphragm is large enough to completely eliminate the effect of the parking brake, leaving only the output generated by the treadle input. For 40 psi and less the forces are limited to 1250 lbf, which is somewhat higher than the 0 psi force of 1000 lbf, but is still lower than that found for the systems without anti-compounding (Figure 5.15). The longitudinal deflection traces presented in Figure 5.21 are not that different than those presented for the anti-compounding test off tests presented in Figure 5.17. The major difference is the lack of a dip in the data when the parking braking is applied for the tests at higher initial treadle pressures. The lateral deflections traces presented in Figure 5.22 show the same trend as that seen for the pin forces and chamber stroke measurements in Figure 5.19 and 5.2

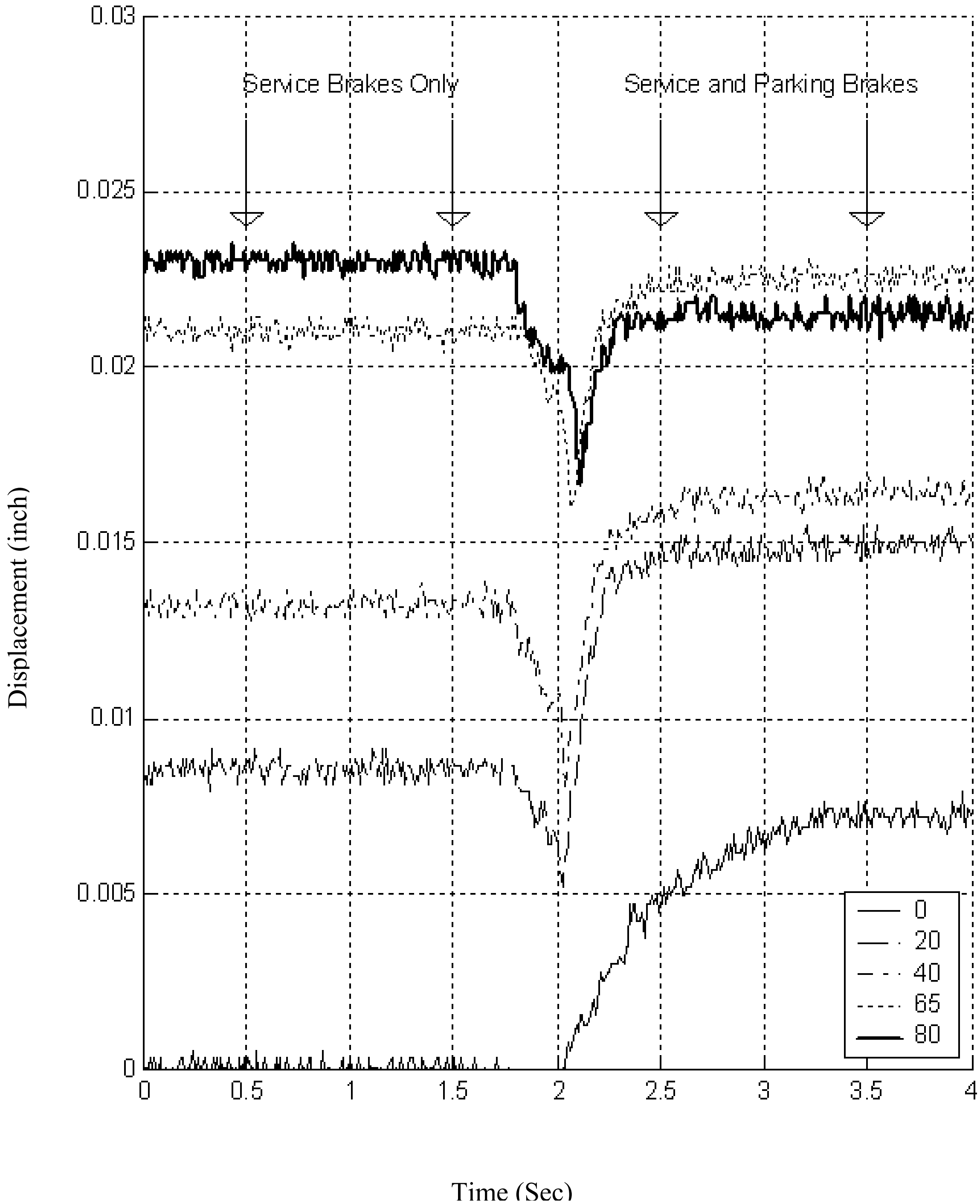

Figure 5.17 - Left Side Chamber Longitudinal Deflection for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB03 - Anti-Compounding "OFF"

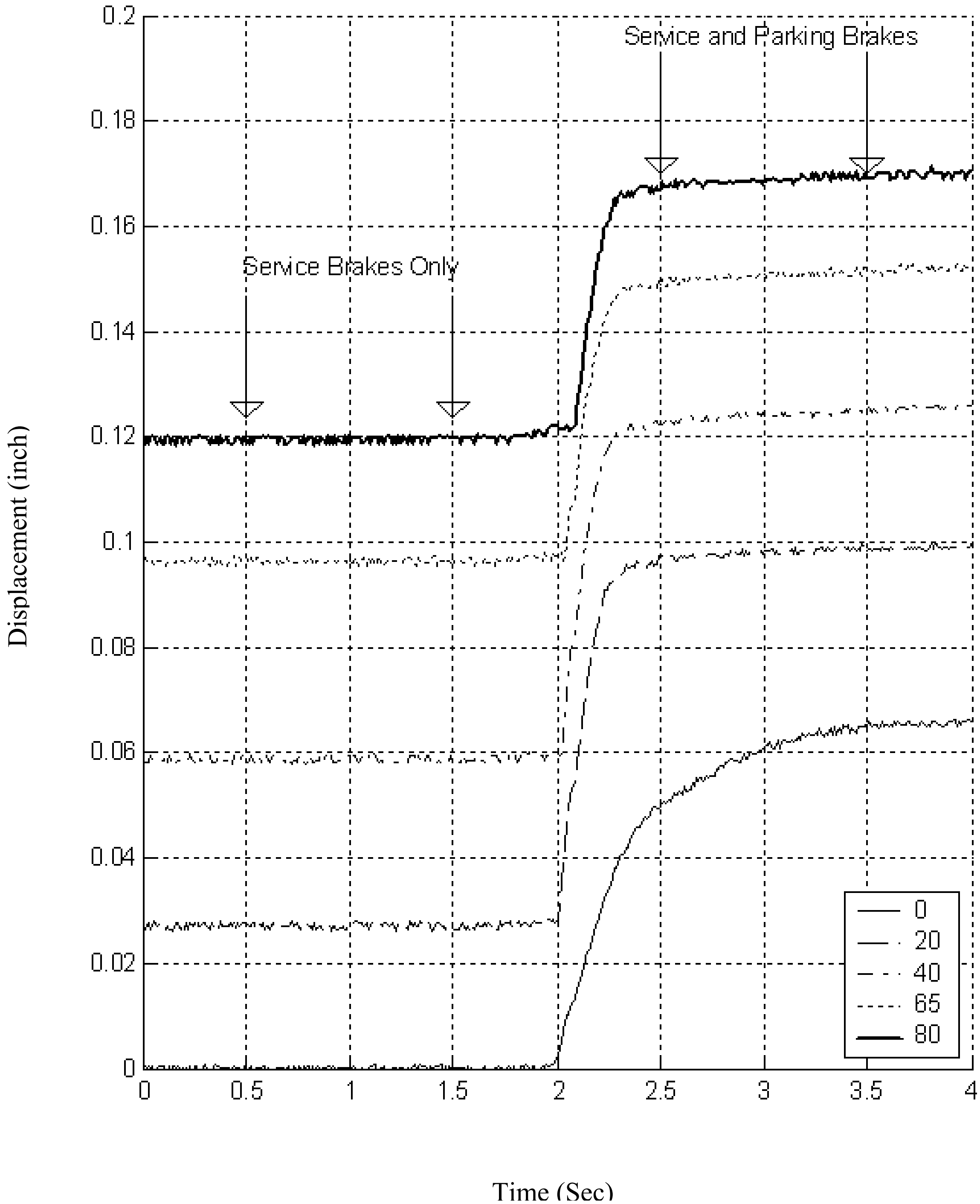

Figure 5.18 - Left Side Chamber Lateral Deflection for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB03 - Anti-Compounding "OFF"

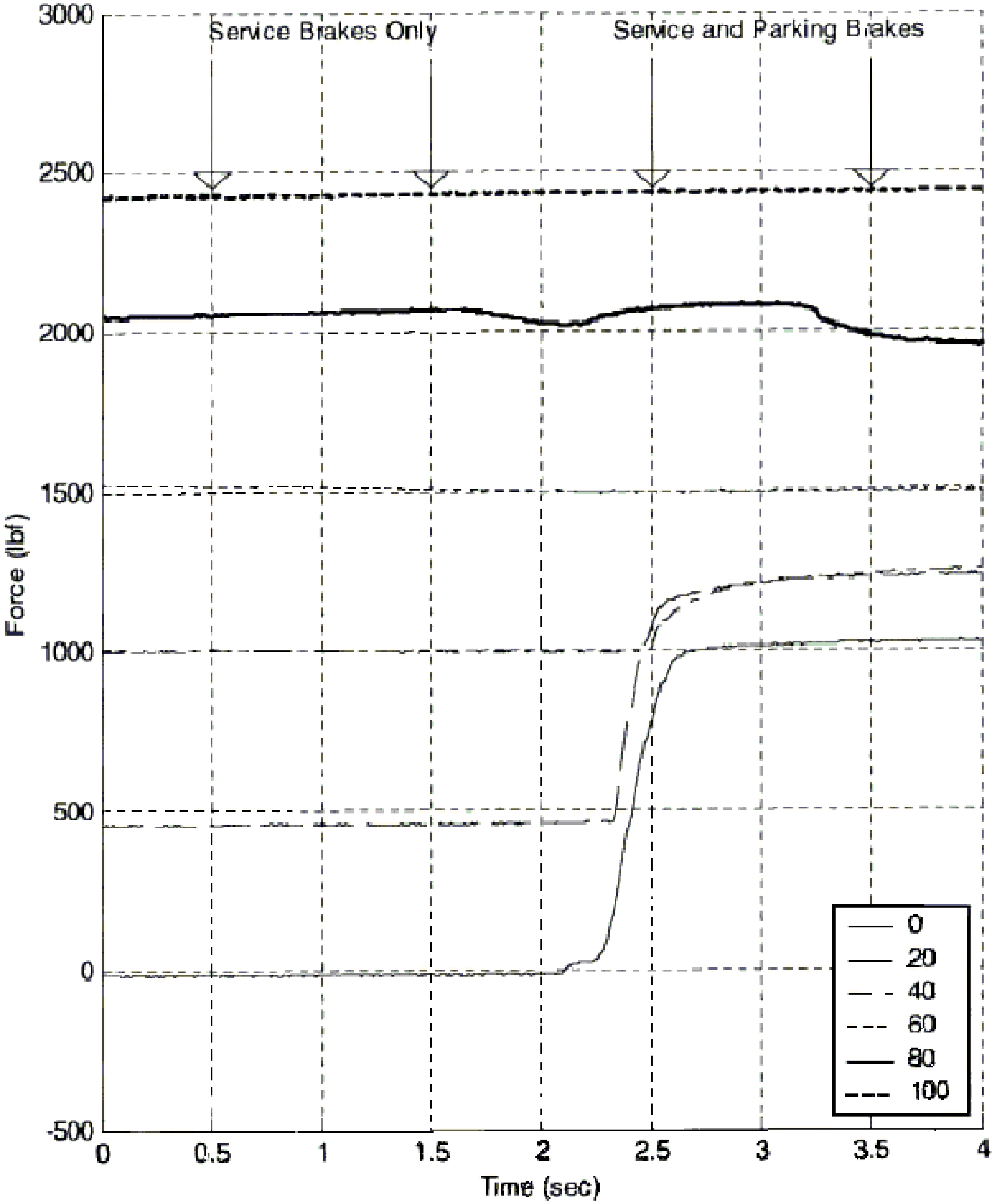

Figure 5.19 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB03 – Anti-Compounding "ON"

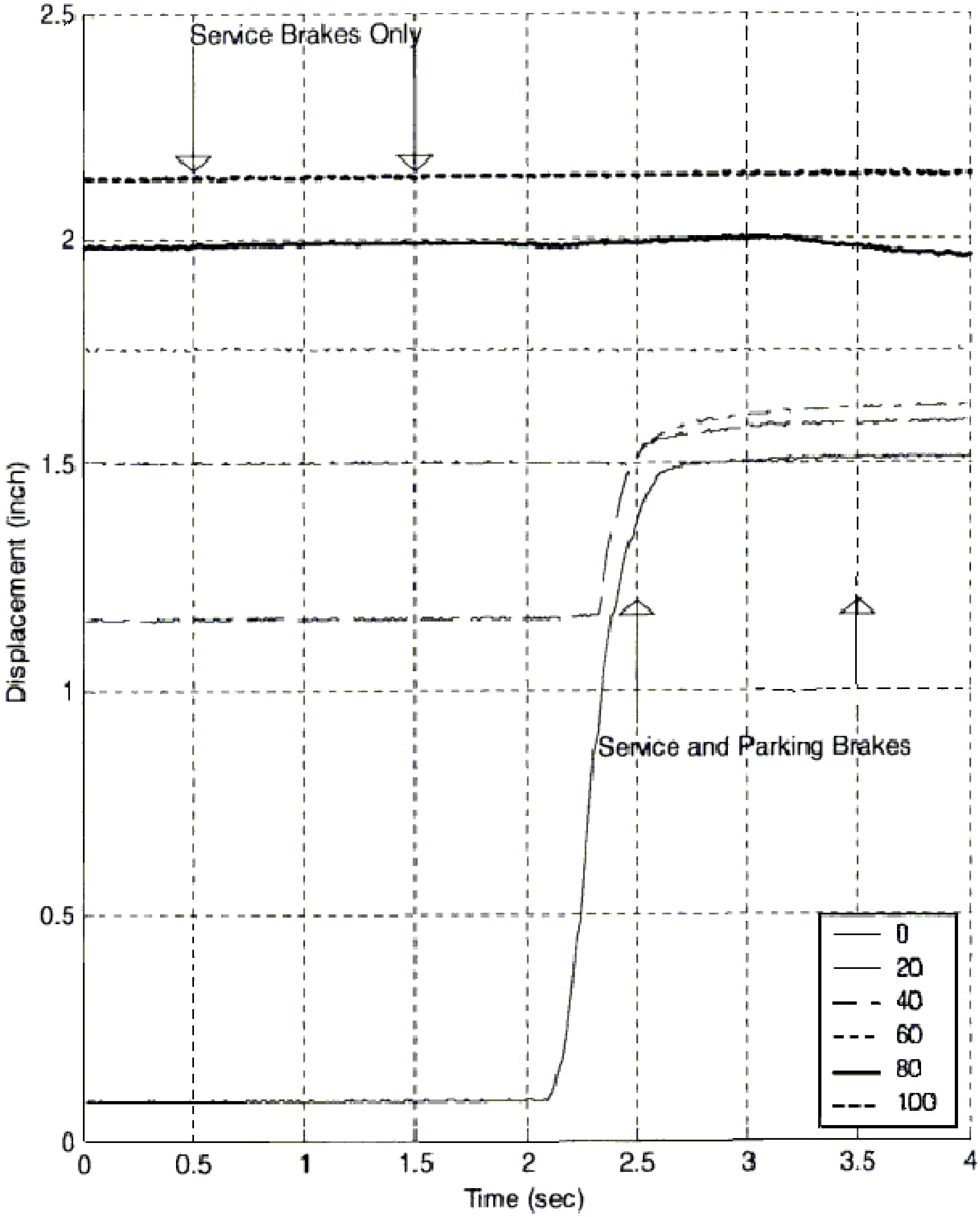

Figure 5.20 - Left Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB03 – Anti-Compounding "ON"

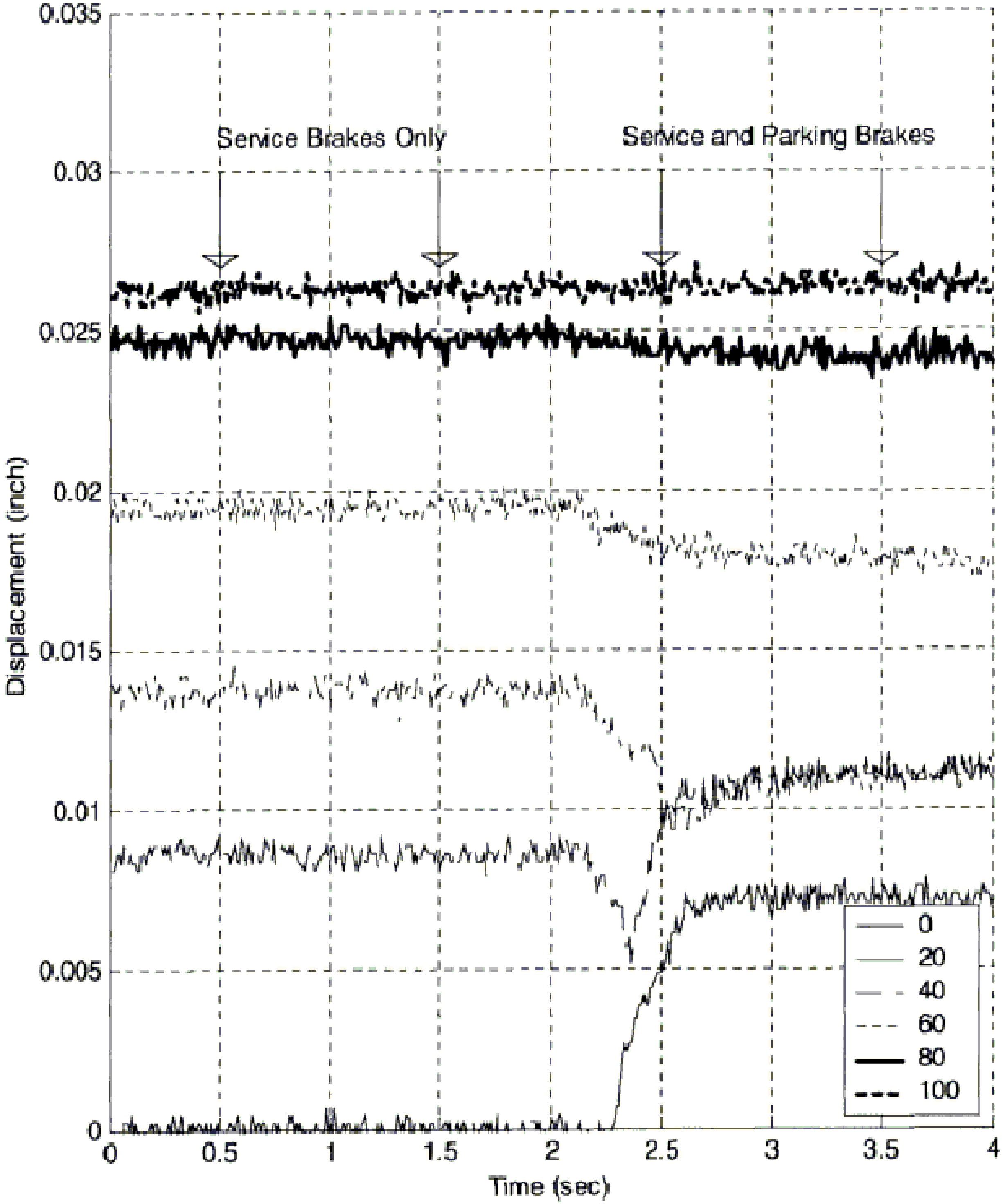

Figure 5.21 - Left Side Chamber Longitudinal Deflection for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB03 - Anti-Compounding "ON"

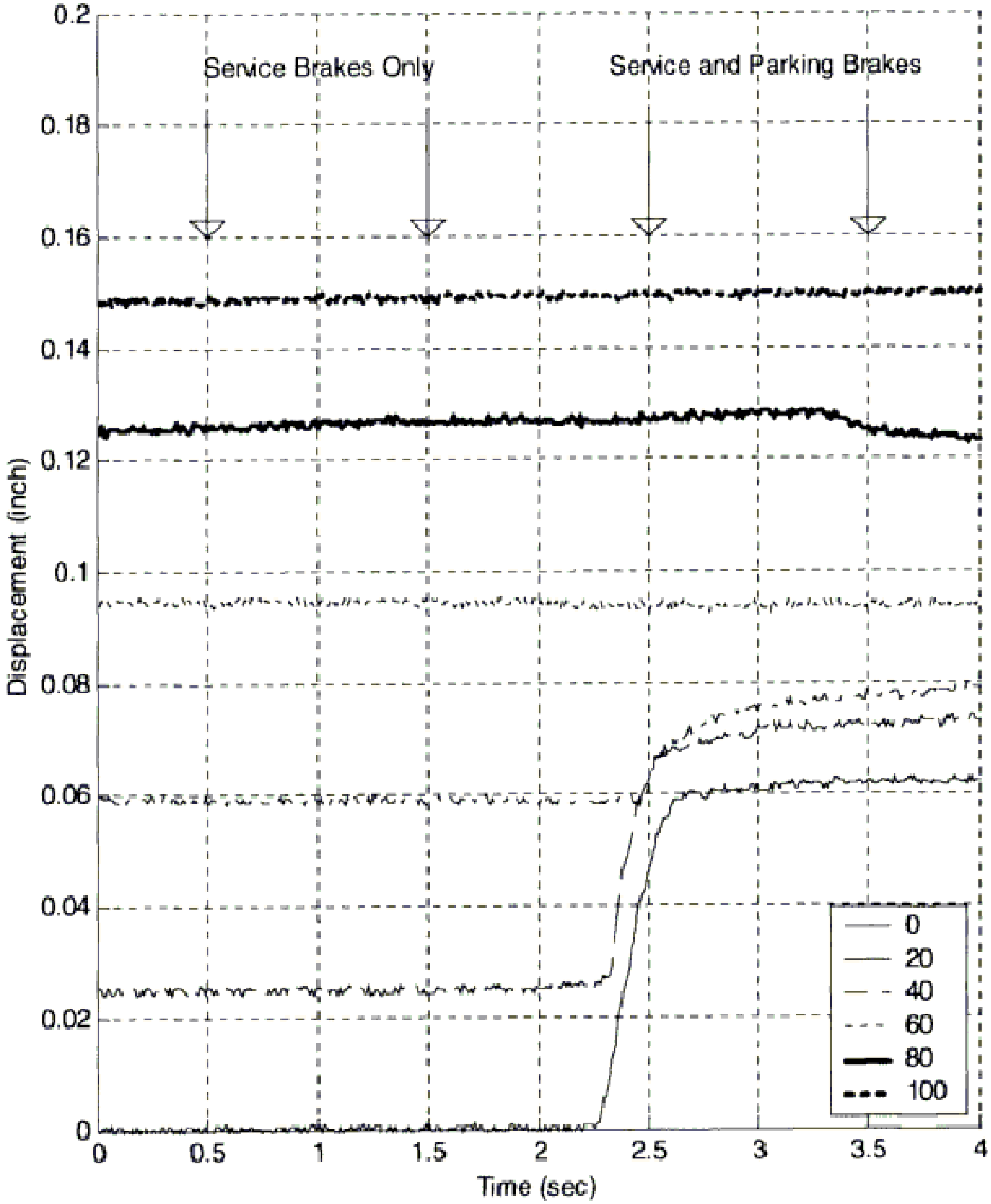

Figure 5.22 - Left Side Chamber Lateral Deflection for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB03 - Anti-Compounding "ON"

The figures given above depict the transition from service brake only to service and parking brake combined. Figures 5.23 through 5.26 show the transition from service and parking brake combined to parking brake only (i.e. releasing the service brake after the parking brake has been set). All four figures are for test unit PB01. Figures 5.23 and 5.24 show the left side pin force and chamber stroke for the anti-compounding off tests. Only the 50 to 80 psi Initial Treadle Pressure tests are shown because at 40 psi and less, the parking brake applies a greater force than the service brake (see Figure 5.9). The higher pressures are not included for clarity reasons. When the service brake is released, the pin force (Figure 5.23) drops to approximately 900 lbf and remains at this level. The chamber stroke (Figure 5.24) also drops to a level of approximately 1.15 to 1.18 inches and remains relatively flat.

The anti-compounding on results are presented in Figures 5.25 and 5.26. At the time of service brake release, the pin force (Figure 5.25) drops below the level seen when just the parking brake is engaged and then rises back up to a 900 lbf parking brake only level. It should be noted that the higher the Initial Treadle Pressure, the greater the dip in force. This dip lasts for only a short time, but there may be certain situations where it would allow the vehicle to creep slightly until the parking brakes are fully reinstated. A similar dip is seen for the chamber stroke (Figure 5.26). The tendency for this dip after releasing the service brake was seen for all three vehicles when the anti-compounding system was on.

In summary, the anti-compounding systems do a very good job of limiting excessive forces and deflections (and hence stresses) on the braking system. However, they may allow the vehicle to creep slightly when engaging the parking brake when an initial service brake application has been made prior to setting the parking brake.

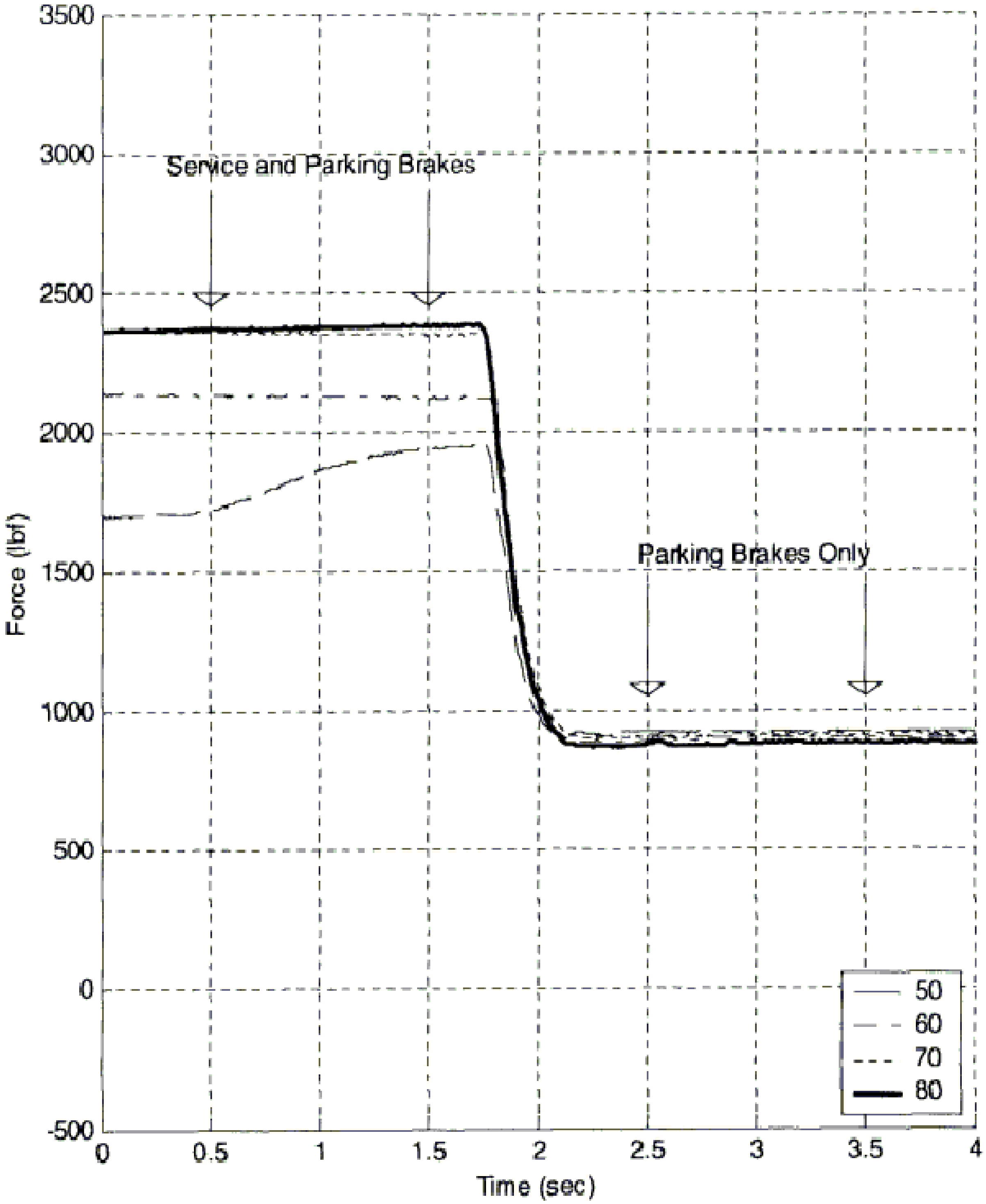

Figure 5.23 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB01 - Anti-Compounding "OFF" - Service Brake Release

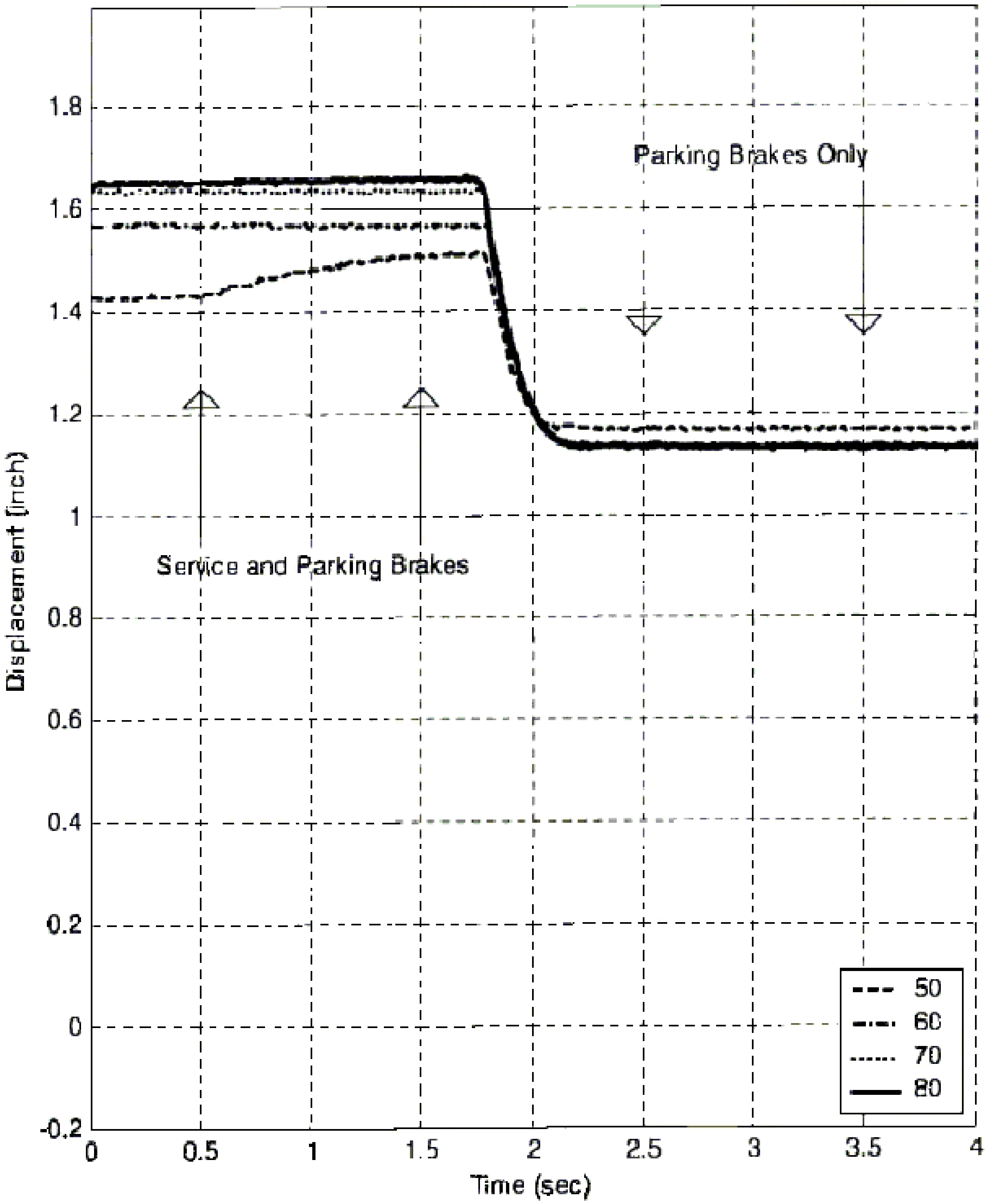

Figure 5.24 - Left Side Chamber Stroke for Combined Service and Parking Brake (NoPull) Tests Conducted with Unit PB01 - Anti-Compounding "OFF" - Service Brake Release

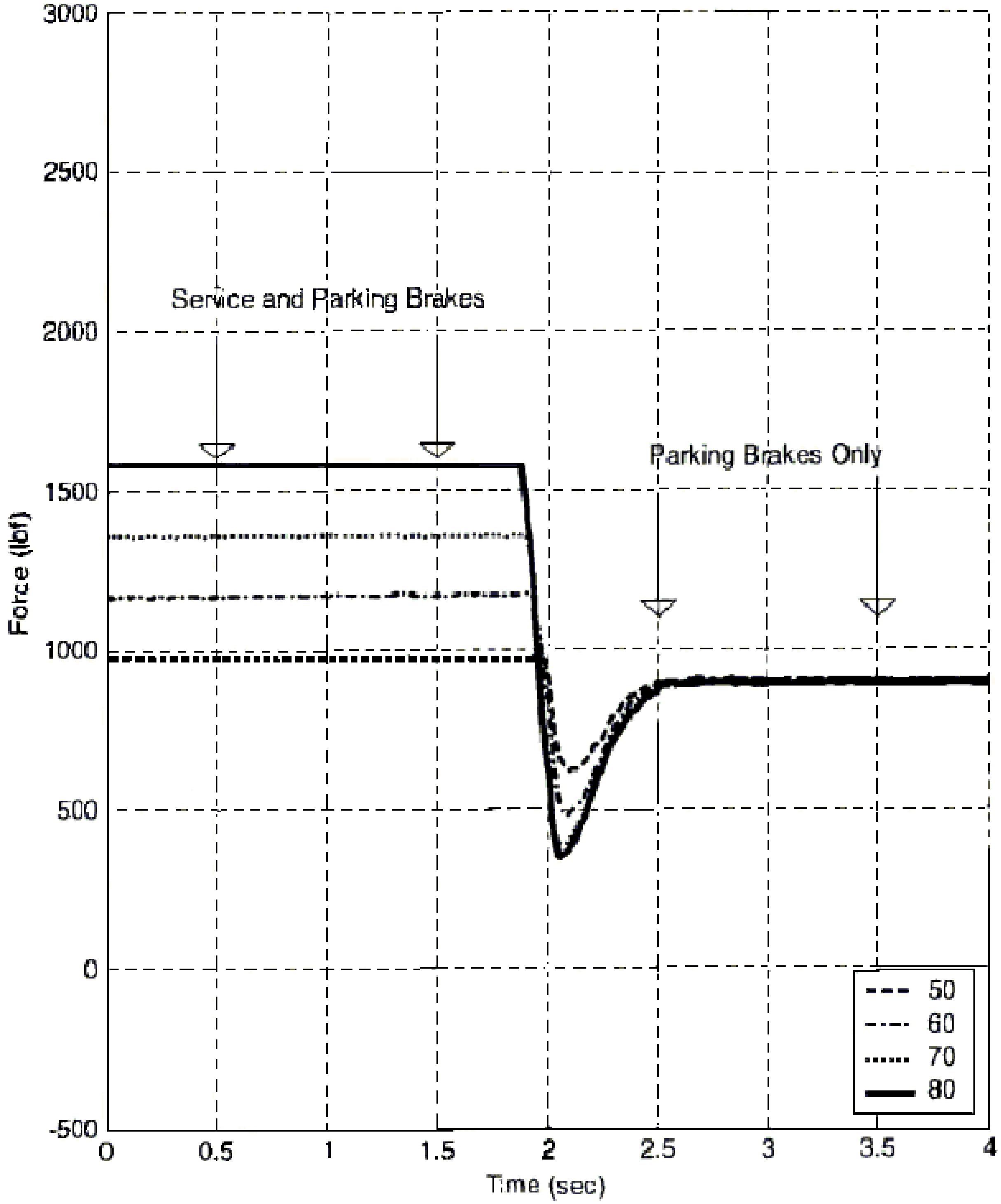

Figure 5.25 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB01 – Anti-Compounding "ON" – Service Brake Release

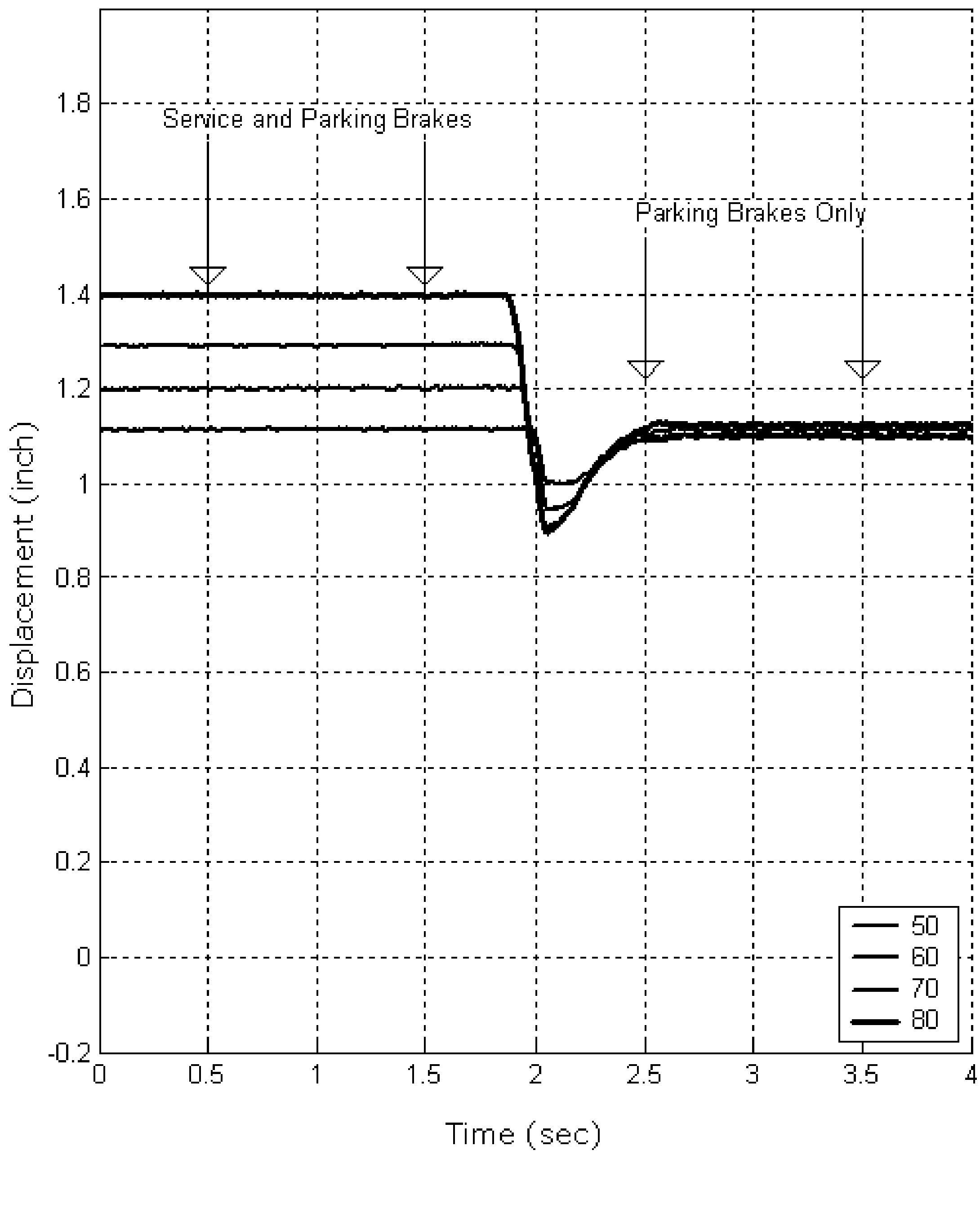

Figure 5.26 - Left Side Chamber Stroke for Combined Service and Parking Brake (NoPull) Tests Conducted with Unit PB01 - Anti-Compounding "ON" - Service Brake Release

6.0 CONCLUSIONS

FMVSS No. 121 establishes performance and equipment requirements for vehicles equipped with air brake systems. It applies to trucks, tractors, buses, and trailers equipped with such systems. The purpose of this standard is to ensure safe braking performance under normal and emergency conditions. On January 6, 1997, the Truck Manufacturers Association (TMA) submitted a petition to NHTSA requesting that FMVSS No. 121 be amended in several areas. This study examined the effect of one of the TMA proposals on static retardation and grade holding test results. They have requested that when determining parking brake force in either the static retardation pull test (S5.6.1) or the grade holding test (S5.6.2), a full service brake application be permitted prior to applying the parking brakes.

This study examined the parking brake capability of three Class 8 trucks and tractors, which represent typical units used today in commercial service. The test units were a 4x2 straight truck, a 6x4 tractor, and a 4x2 tractor. Steps were taken to assure that the brakes were in good working order and properly broken in.

Three basic types of tests were conducted in this study: static retardation pull tests, grade holding tests, and combined service and parking brake application tests without any pulling.

<u>S5.6.1 Static retardation pull test:</u>
There were two types of static retardation tests conducted: standard full wheel rotation (in quarter-turn increments) and short pulls. The conclusions from this testing are summarized as follows:

- All three test units met the FMVSS No. 121 requirements of S5.6.1.The measured static retardation forces increased with increasing initial treadle pressure. Tests conducted at the service brake cut-out pressure produced results that were 25 to 36 percent higher than those for tests conducted with no initial treadle pressure.

- A vacuum can be produced in the service brake chamber if the parking brake is applied without any initial treadle pressure being applied. This effect was more noticeable on the single drive axle tractor (PB03), and to a lesser extent on the tandem drive axle tractor (PB02) which had the spring brakes on only one axle. This effect was not noticed on the single drive axle straight truck (PB01).

- The Hunter Plate Brake Tester type of device is a good alternative for measuring the parking brake forces when conducting the static retardation tests.

S5.6.2 Grade holding tests: the vehicles must be held stationary on a 20 percent grade, facing upward and downward.

- Only two of the three test vehicles were able to meet the requirements of S5.6.2, the three axle tractor did not. These air-braked vehicles only have to pass either the static retardation or the grade holding tests. Since all three vehicles passed the static retardation requirements, they were not required to pass the grade holding test. However, the one failing result indicates that the grade test is more stringent.

- The grade holding test produces a binary result - pass or fail. No measurement of the static retardation force is found and therefore it is difficult to say how varying the initial treadle pressure affects results. None of the test conditions evaluated produced results that went from a non-passing to a passing result due to varying the initial treadle pressure.

Positive effects of anti-compounding systems:

The last test procedure conducted was a combination of service brake and parking brake applications (no pull). The tests were conducted over a wide range of initial treadle pressures and with the anti-compounding systems either activated or made inoperative (this condition simulates a vehicle with no anti-compounding). The anti-compounding systems (when configured for normal operation) were found to be quite effective at limiting the forces and stresses exerted on the brake systems to no more than that generated by the service brake system for treadle pressures above 60 psi.

7.0 REFERENCES

1. USDOT-NHTSA Federal Motor Vehicle Safety Standards (FMVSS) No.121 Air Brake Systems," 49 CFR 571.121 October 1, 1999.

2. Truck Manufacturers Association (TMA), "Reference: Petition For Rulemaking To Amend Federal Motor Vehicle Safety Standard 121, Air Brake Systems" requesting that the FMVSS No. 121 be amended in ten areas in reference to NHTSA Docket No. 96-050, petition dated January 6, 1997.

3. Society of Automotive Engineers (SAE) Recommended Practice "J1626, Braking, Stability, and Control Performance Test Procedures for Air-Brake-Equipped Trucks (rev APR96)".

4. USDOT-NHTSA Office of Vehicle Safety Compliance (OVSC) "Laboratory Test Procedure for FMVSS 121V (Vehicles) Air Brake Systems," Manual No. TP121V-04, June 4, 1999.

5. Flick, Mark A., "Evaluation of Hunter Heavy Duty Plate Brake Tester," Interim Final Report Number DOT HS 808 275, February, 1995.

6. Society of Automotive Engineers (SAE) Recommended Practice "J360, Truck and Bus Grade Parking Performance Test Procedure (Revised September, 1995).

APPENDIX A.1 VEHICLE INFORMATION SHEET - PB01

Vehicle: 1997 Navistar 4x2 Straight Truck
Test No.: 1999PB01 Test Date(s): Oct 1999 to Nov 1999
Test Facility and Location: Transportation Research Center, East Liberty, Ohio
Year, Make, and Model: 1997 Navistar 4900 DT466E 4x2 Straight Truck with Dump Body: Galion Dump Bodies, Inc., Model 408-U, Ser.No. 970438, Capacity: 5.6-7.7 yards And with DT 466E HEVI INT diesel 250hp/2300 rpm engine
VIN or Unit No.: 1HTSDAAR8VH474760 Odometer Reading: 13,508 miles (1116.8 hours)
GAWR , lb: 1st Axle 12,350 lb; 2nd Axle 23,000 lb GVWR 35,350 lb
Center of Gravity Height, in:

- •Truck, unladen (top of frame rail above ground): 40 in estimate
- •Truck, laden (top of frame rail above ground): NA
- •Ballast (above top of bed floor): 16.3 inches (block wt = 17,460 lb)

Wheelbase: 152 inches
Curb Weight Distribution, lb:
Unladen: 1st Axle: 8,260 lb; 2nd Axle: 9,020 lb; Total: 17,280 lb; CG: 79.3 in behind front axle
Laden (GVW): 1st Axle: 12,400 lb; 2nd Axle: 22,340 lb; Total: 34,740 lb; CG: 97.7 in behind front axle
Stopping Weight Laden: Same as GVW
Retarder(s) Type(s): None Aerodynamic Treatments: (Yes/No) (Attach Photo): None

AXLES:

Axle:	Type	Size	Make
1	I-140S	14,000 lb	International
2	RS23-160	23,000 lb	Meritor-Rockwell with locking differential

BRAKES:

Axle:	Type[1]	Size, in	Make	Lining (Edge Code)
1	Q-Plus	NA	Rockwell	R-301
2	Q-Plus	NA	Rockwell	R-301

BRAKE DRUM:

Axle:	Type[2]		Make	Dust Shields Installed?
1	Drum	16.5 x 5	NA	Yes
2	Drum	16.5 x 7	NA	Yes

ACTUATION DETAILS:

	Actuators		Slack Adjusters		
Axle:	Make	Type[3]	Length	Manufacturer	Cam Rotation[4]
1	MGM	T20	5-1/2 in	Haldex	Same
2	MGM	30-30	6 in	Haldex	Same

VEHICLE INFORMATION SHEET - PB01 (Continued)

Vehicle: 1997 Navistar 4x2 Straight Truck

TIRES: (All rated at 14 ply rating)

Axle:	Press (psi)	Size	Make	Model	Static Loaded Radius (in) Measured	Static Loaded Radius (in) DataBook
1 left	105	11.00R22.5	Goodyear	Unisteel G159A	19.1 in (9/32"deep)	19.4 in (19/32"deep)
1 right	105	11.00R22.5	Goodyear	Unisteel II	19.1 in (9/32"deep)	19.4 in (19/32"deep)
2	105	12.00R22.5	Goodyear	Unisteel G328	19.4 in (14/32"deep)	19.8 in (28/32"deep)

ABS: Manufacturer: WABCO Model: NA Configuration: 4S2M

FRONT SUSPENSION:

Type: Spring 14K# ; Make: International; Model: I-140S; Ross Power Steering - Model No. TAS-65

REAR SUSPENSION:

Type: 31K# Vari-Rate Springs; Make: Rockwell 23K# with locking differential; Model: RS23-160 (6.43 ratio); Tandem Axle Spread, (in): N/A Overall Width (SAE J693):

AIR SYSTEM: (Dual Air Brake System)

Compressor Capacity (cfm): Bendix TU-FLO 550; Cut-out (psi):______; Cut-in (psi):______;
Crack Pressure Ratings(psi)[5]:
1st Axle:________________ 2nd Axle:________________
3rd Axle: N/A Treadle Valve:
Bobtail Proportioning: 9 NA Front Axle Limiting:
Air Dryer: : Bendix AD-9 Air Compounding: Feedback limiter
Spring Brake Inversion Valve: 9 Number of Brakes Controlled:
Specifics Regarding Air Brake System Components:

AIR TANK VOLUMES (cu.in.):

Supply: NA Primary: NA Secondary: NA Auxiliary: NA Isolated From Service? 9

SPECIAL CONDITIONS:
Special conditions or equipment which might affect brake performance: Allison 6-Spd Automatic Transmission Model No. MD-3060/CR, with electronic throttle ctrl, cruise ctrl, road speed governor, and air conditioning.

[1] Cam, disc, wedge, etc.
[2] Cast or composite drum, vented or non-vented rotor, etc.
[3] Size and diaphragm or piston
[4] Same or opposite to forward wheel rotation
[5] Relative to rear axle(s) centerline (include sketch if necessary)

APPENDIX A.2 VEHICLE INFORMATION SHEET - PB02

Vehicle: 1999 Freightliner 6x4 Tractor
Test No.: 1999PB02 Test Date(s): Nov 19-22, 1999
Test Facility and Location: Transportation Research Center, East Liberty, Ohio
Year, Make, and Model: 1999 Freightliner Century Class 6x4 Tractor with Daycab
VIN or Unit No.: 1FUYDXYBXXPA73041 Odometer Reading: 41,644 miles
GAWR , lb: 1st Axle 12,000 lb 2nd Axle 19,000 lb 3rd Axle 19,000 lb GVWR 48,000 lb
Center of Gravity Height, in:

- •Tractor, unladen (top of 5th wheel above ground): 47.0 in (Bobtail)
- •Tractor, laden (top of 5th wheel above ground): 44.0 in (With unbraked trailer)
- •Ballast (above top of 5th wheel): 16.6 in. (60.6 inches above the ground)(block wt = 14,670 lb)

(Note: Weight of trailer not used for the above ballast CG height calculation)

Wheelbase: 195 inches Engine: Caterpillar C-14 diesel 340hp
Curb Weight Distribution, lb:
Unladen (bobtail): 1st Axle: 9,780 lb; Combined 2nd and 3rd Axles: 7,760 lb;
Total: 17,540 lb CG: 86.3 in behind front axle
Laden (GVW): 1st Axle: 11,220 lb; Combined 2nd and 3rd Axles: 36,770 lb;
Total: 47,990 lb CG: 149.4 in behind front axle
Stopping Weight Laden: Add unbraked trailer axle weight: 4,420 lb
Total Stopping Wt. Laden (GCWmeas.): 52,410 lb
Retarder(s) Type(s): NA; Aerodynamic Treatments: (Yes/No): Yes, air deflector on top of cab.

AXLES:

Axle:	Type	Size	Make
1	Meritor-Rockwell	12,000 lb	
2	Meritor-Rockwell	19,000 lb	
3	Meritor-Rockwell	19,000 lb	

BRAKES:

Axle:	Type[1]	Size, in	Make	Lining (Edge Code)
1	NA			
2	NA			
3	NA			NA

BRAKE DRUM:

Axle:	Type[2]		Make	Dust Shields Installed?
1	Drum	15 x 4 in		No
2	Drum	16.5 x 7 in		No
3	Drum	16.5 x 7 in		No

ACTUATION DETAILS:

	Actuators		Slack Adjusters		
Axle:	Make	Type[3]	Length	Manufacturer	Cam Rotation[4]
1	Midland	T20	5-1/2 in	Rockwell	Same
2	MGM	30	5 in	Rockwell	Same
3	MGM	30-30	5 in	Rockwell	Same

VEHICLE INFORMATION SHEET - PB02 (Continued)

Vehicle: 1999 Freightliner 6x4 Tractor

TIRES: (All rated 14-ply, load range G)

Axles:	Pressure (psi)	Size	Make	Model	Static Loaded Radius (in) Measured	DataBook
1	110	295/75R22.5	Bridgestone	R250	18.5 in (8/32"deep)	18.8 in (19/32"deep)
2	100	295/75R22.5	Bridgestone	M726	18.8 in (18/32"deep)	19.2 in (30/32"deep)
3	100	295/75R22.5	Bridgestone	M726	18.6 in (12/32"deep)	19.2 in (30/32"deep)

ABS: Manufacturer: Meritor Wabco Model: NA Configuration: 4S3M (side-to-side control on drives)
Sensors on both steer axle wheels and on both rear drive axle wheels (axle #3).
Modulators control steer axle, left drive axle pair, and right drive axle pair.

FRONT SUSPENSION:

Type: Leaf Spring Make: NA Model:

REAR SUSPENSION:

Type: Air Spring Make: Firestone Model:
Axle Spread: 102 in Overall Width (SAE J693):

AIR SYSTEM:

Compressor Capacity ccm(cfm): TuFlo 550 Cut-out kPa(psi): 120 psi; Cut-in kPa(psi): 100 psi
Crack Pressure Ratings(psi)[5]:
1st Axle: NA 2nd Axle: NA
3rd Axle: NA Treadle Valve: NA
Bobtail Proportioning: : Front Axle Limiting: NA
Air Dryer: : Air Compounding: anti-compounding sense line
Spring Brake Inversion Valve: : Number of Brakes Controlled: NA
Specifics Regarding Air Brake System Components: NA

AIR TANK VOLUMES (cu.in.):

Supply: NA Primary: NA Secondary: NA Auxiliary: NA Isolated From Service? 9

SPECIAL CONDITIONS:

Special conditions or equipment which might affect brake performance:
[1] Cam, disc, wedge, etc.
[2] Cast or composite drum, vented or non-vented rotor, etc.
[3] Size and diaphragm or piston
[4] Same or opposite to forward wheel rotation
[5] Relative to rear axle(s) centerline (include sketch if necessary)

APPENDIX A.3 VEHICLE INFORMATION SHEET - PB03

Vehicle: 2000 Sterling 4x2 Tractor (NEW)
Test No.: 1999PB03 Test Date(s): Dec 1999 to Jun 2001
Test Facility and Location: Transportation Research Center, East Liberty, Ohio
Year, Make, and Model: 2000 Sterling A9513 4900 4x2 Tractor with Daycab
VIN or Unit No.: 2FWWHEDB4YAG36385 Built: 8/99 Odometer Reading: 3092 miles
GAWR , lb: 1st Axle 12,000 lb 2nd Axle 22,700 lb 3rd Axle NA GVWR 34,700 lb
Center of Gravity Height, in:

- Tractor, unladen (top of 5th wheel above ground): 44.5 in (Bobtail)
- Tractor, laden (top of 5th wheel above ground): 44.3 in (With unbraked trailer)
- Ballast (above top of 5th wheel): 17.3 inches (61.6 inch above the ground) (block wt = 14,670 lb)

(Note: Weight of trailer not used for the above ballast CG height calculation)

Wheelbase: 148 inches
Curb Weight Distribution, lb:
Unladen (bobtail): 1st Axle: 9,180 lb 2nd Axle: 5,360 lb Total: 14,540 lb CG: 54.6 in behind front axle
Laden (at GVW): 1st Axle: 10,740 lb 2nd Axle: 21,620 lb Total: 32,360 lb CG: 98.9 in behind front axle
Stopping Weight Laden: Add unbraked trailer axle weight: 4,740 lb; Total Stopping Wt. Laden: 37,100 lb
Retarder(s) Type(s): None
Aerodynamic Treatments: (Yes/No) (Attach Photo): Yes, air deflector on top of cab.

AXLES:

Axle:	Type	Size	Make
1	RFS12143ANN1	12,000 lb	Meritor-Rockwell
2	RS23160NFNN980	22,700 lb	Meritor-Rockwell

BRAKES:

Axle:	Type[1]	Size, in	Make	Lining (Edge Code)
1	Q-Plus			
2	Q_Plus			

BRAKE DRUM:

Axle:	Type[2]	Make	Dust Shields Installed?
1	Drum 15 x 4 in		No
2	Drum 16.5 x 7 in		No

ACTUATION DETAILS:

	Actuators		Slack Adjusters		
Axles:	Make	Type[3]	Length	Manufacturer	Cam Rotation[4]
1	Midland	T20	5-1/2 in	Haldex	Same
2	Maxibrake	30-30	6 in	Haldex	Same

VEHICLE INFORMATION SHEET - PB03 (Continued)

Vehicle: 2000 Sterling 4x2 Tractor (NEW)

TIRES: (All tires are load range G)

Axles:	Pressure (psi)	Size	Make	Model	Static Loaded Radius (in) Measured	Static Loaded Radius (in) DataBook
1	110	295/75R22.5	Goodyear	Unisteel G159	18.7 in (18/32"deep)	18.7 in (18/32"deep)
2	100	295/75R22.5	Goodyear	Unisteel G167A	19.0 in (25/32"deep)	19.0 in (26/32"deep)

ABS: Manufacturer: Allied Signal Bendix Model: 4-wheel ABS with ATC Configuration: 4S4M

FRONT SUSPENSION:

Type: Leaf Spring (with shocks) Make: ______ Model: MFS12143ANN1
S10-12998-000 AVF9915B214 99215 -make date

REAR SUSPENSION:

Type: Single Axle, Air Spring (with shocks) Make: Hendrickson Model: HAS-23-Q23000 lb capacity
Axle Spread: N/A Overall Width (SAE J693):

AIR SYSTEM:

Compressor Capacity ccm(cfm): ______ Cut-out kPa(psi): 125 psi Cut-in kPa(psi): 100-105 psi
Crack Pressure Ratings(psi)[5]:
1st Axle: NA 2nd Axle: NA
3rd Axle: NA Treadle Valve: NA
Bobtail Proportioning: : ______ Front Axle Limiting: :
Air Dryer: : ______ Air Compounding: : anti-compounding sense line
Spring Brake Inversion Valve: : Number of Brakes Controlled: 2
Specifics Regarding Air Brake System Components: NA

AIR TANK VOLUMES (cu.in.):

Supply: NA Primary: NA Secondary: NA Auxiliary: NA Isolated From Service? 9

SPECIAL CONDITIONS:

Special conditions or equipment which might affect brake performance: New Tractor PB tested with ram drawbar (after 500 snub burnish); PB retested with Winch after full FMVSS No. 121 ABS series and several road trips.

1 Cam, disc, wedge, etc.
2 Cast or composite drum, vented or non-vented rotor, etc.
3 Size and diaphragm or piston
4 Same or opposite to forward wheel rotation
5 Relative to rear axle(s) centerline (include sketch if necessary)

APPENDIX B - BM ROLLER DYNAMOMETER BRAKE EFFECTIVENESS

A BM Autoteknik Roller Dynamometer was used to measure the baseline effectiveness of the service and parking brakes for each test vehicle. The system measured the axle weight and retardation (braking) force generated by each wheel, one axle at a time, and compared it to the treadle input pressure.

From previous tests, this machine has shown negligible difference in output between drum brakes tested at room temperature and ones that are slightly warmed. For this series, the drum brakes for all three test vehicles were warmed by performing a few snubs before running the roller dynamometer tests.

For the service brake test, the vehicle was loaded to GVWR, driven onto the rollers, and tested one axle at a time. The rollers were started and the system measured the rolling friction. The rolling friction value was automatically subtracted from subsequent measurements so only brake retardation forces were logged. Then, the driver slowly applied a treadle input until the brakes reached their maximum braking force. The test was repeated three times for each axle.

Individual wheel service brake forces were compared to the treadle applied control air pressure. Graphs of the generated braking forces vs. the respective inputs are located in Figures B.1 to B.3.

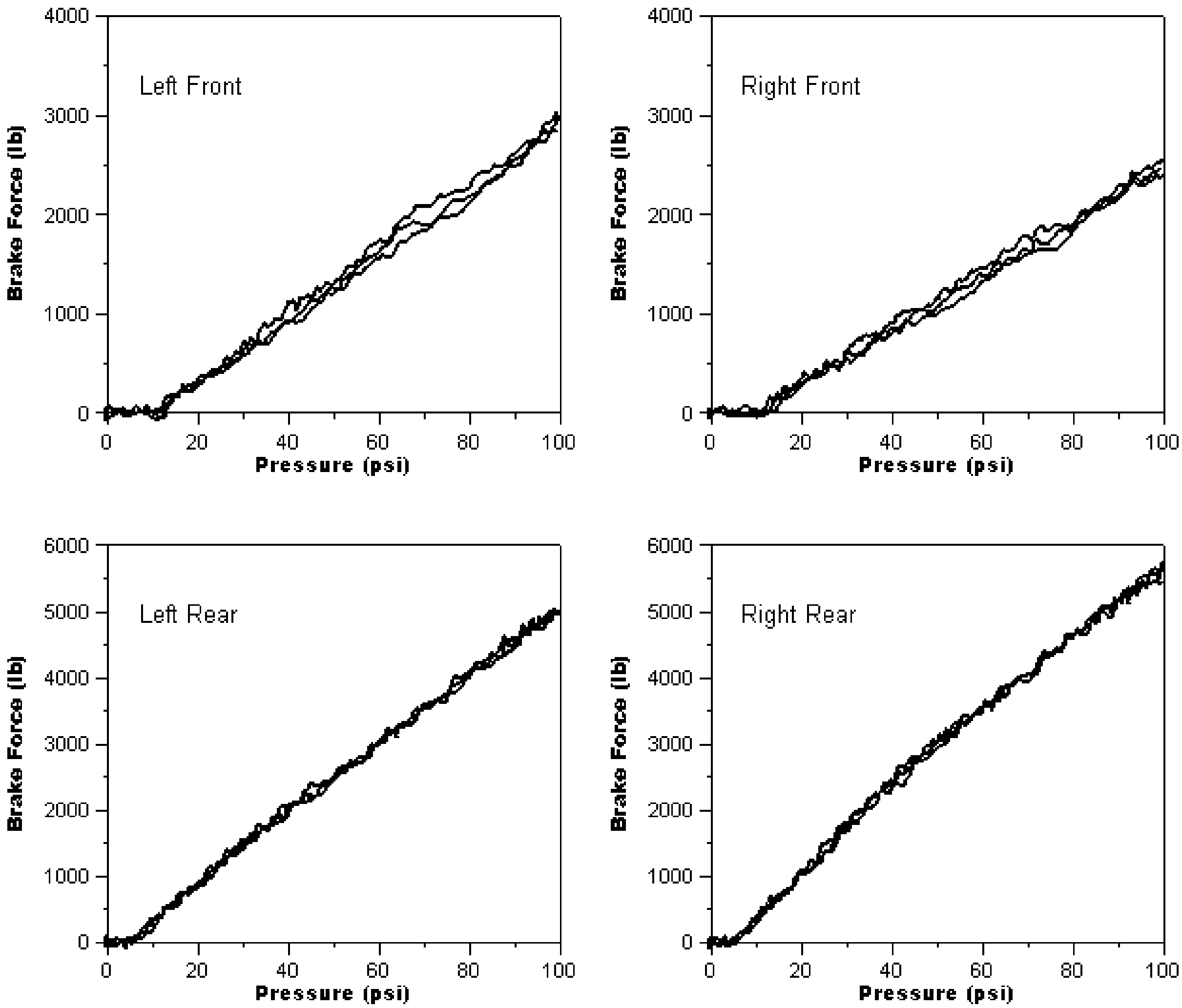

Figure B.1 – PB01 - Navistar 4x2 Dump Truck: Roller Dynamometer Service Brake Force vs. Treadle Pressure Plots

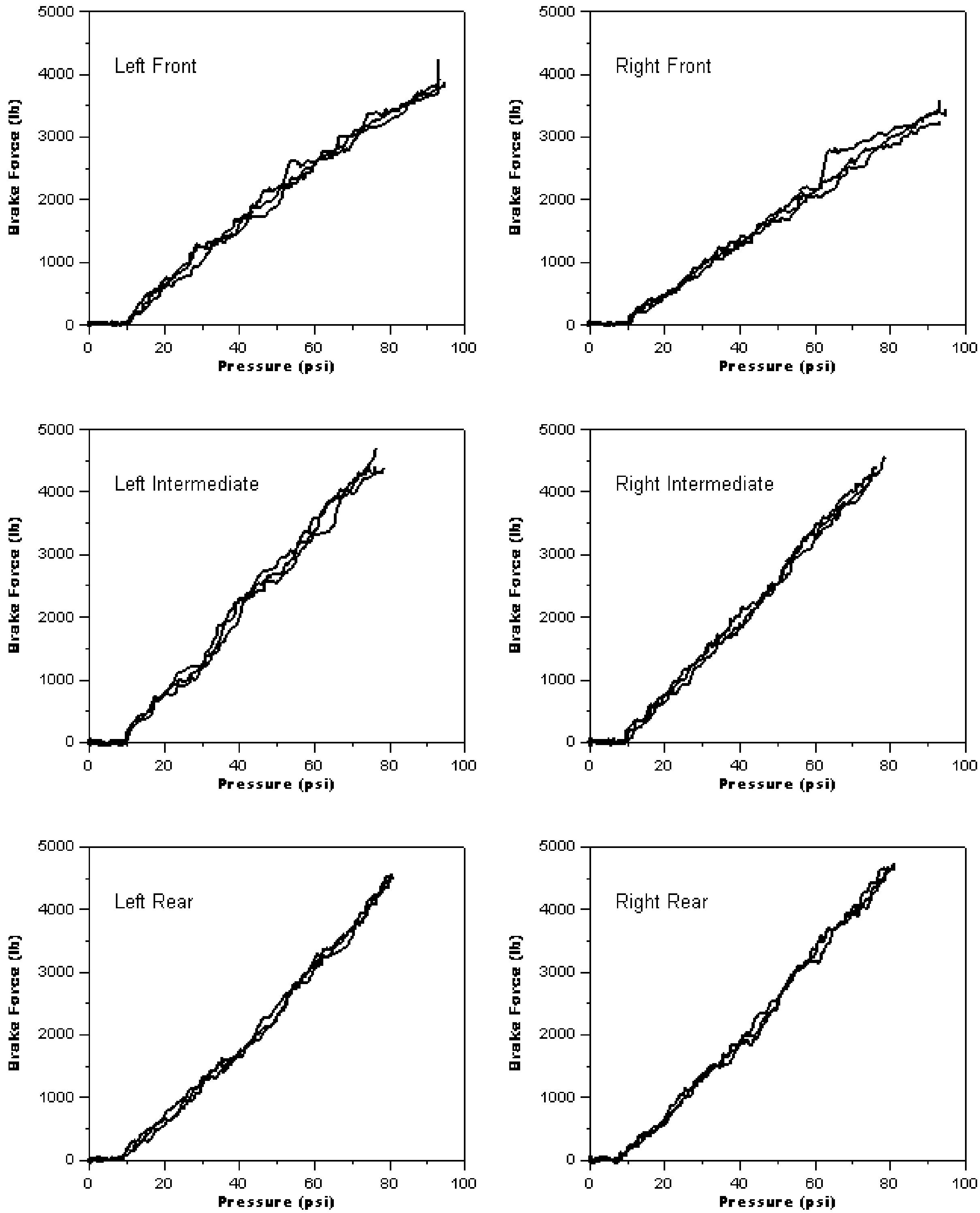

Figure B.2 - PB02 - Freightliner 6x4 Tractor: Roller Dynamometer Service Brake Force Vs. Treadle Pressure Plots

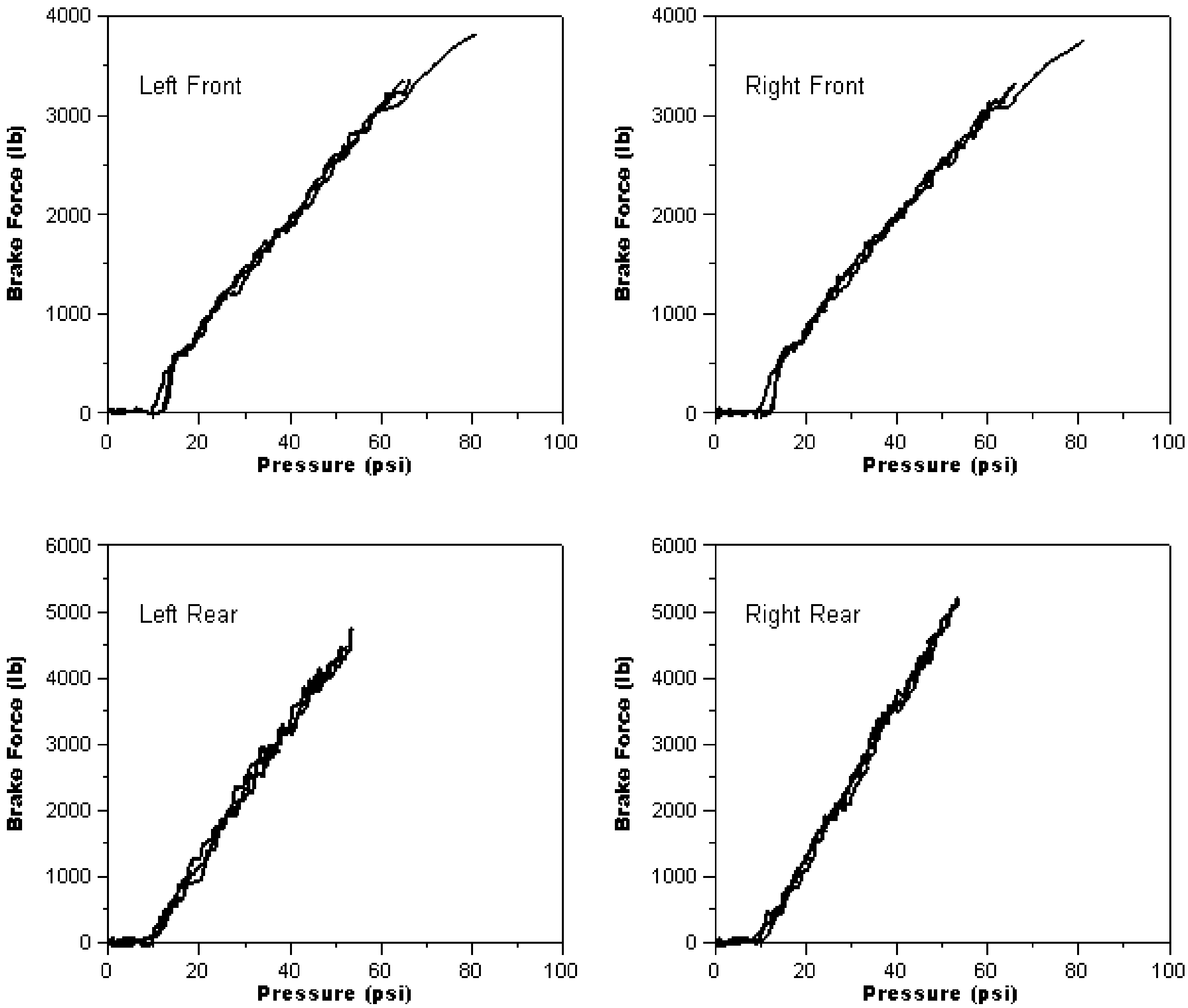

Figure B.3 - PB03 - Sterling 4x2 Tractor: Roller Dynamometer Service Brake Force vs. Treadle Pressure Plots

A second function of the roller dynamometer was to check the output of the parking brake system. Each test unit was loaded to GVWR, then driven onto the dynamometer so the parking brake equipped axle was situated on the roller. The rollers were started, each turning at 1.55 mph (2.5 kph). The driver applied the parking brake by pulling the yellow “parking brake” control handle on the dash, thus venting the spring brake chambers. The anti-compounding device was “on” when performing this test, but probably was not engaged since the initial service brake pressure was zero. All of these tests were performed with the wheels rolling as though being driven in the forward direction. The dynamometer’s data acquisition system recorded the time history of the parking brake application. This test was repeated three times. The results of the peak retardation forces are presented in Table B.1. The results given in this table are for the combined left and right sides of the axle being tested. The forces in bold represent the maximum values recorded for each vehicle.

Table B.1 -- Peak Parking Brake Retardation Forces - BM Roller Dynamometer

Vehicle	Test #1 (lbs)	Test #2 (lbs)	Test #3 (lbs)	Mean (lbs)	Std Dev (lbs)
PB01 - Navistar	**6375**	6036	6148	6186	173
PB02 - Freightliner	**6383**	6377	6264	6341	67
PB03 - Sterling	**8257**	7836	7847	7980	240

Full time history plots of the all of the parking brake applications are given in Figure B.4. This figure shows that the balance for the parking brakes is reasonable for all three vehicles, although the right side force for unit PB01 (Navistar) was somewhat higher than it was for the left side. The first row is for PB01 (Navistar). The second row is for PB02 (Freightliner). The third row is for PB03 (Sterling).

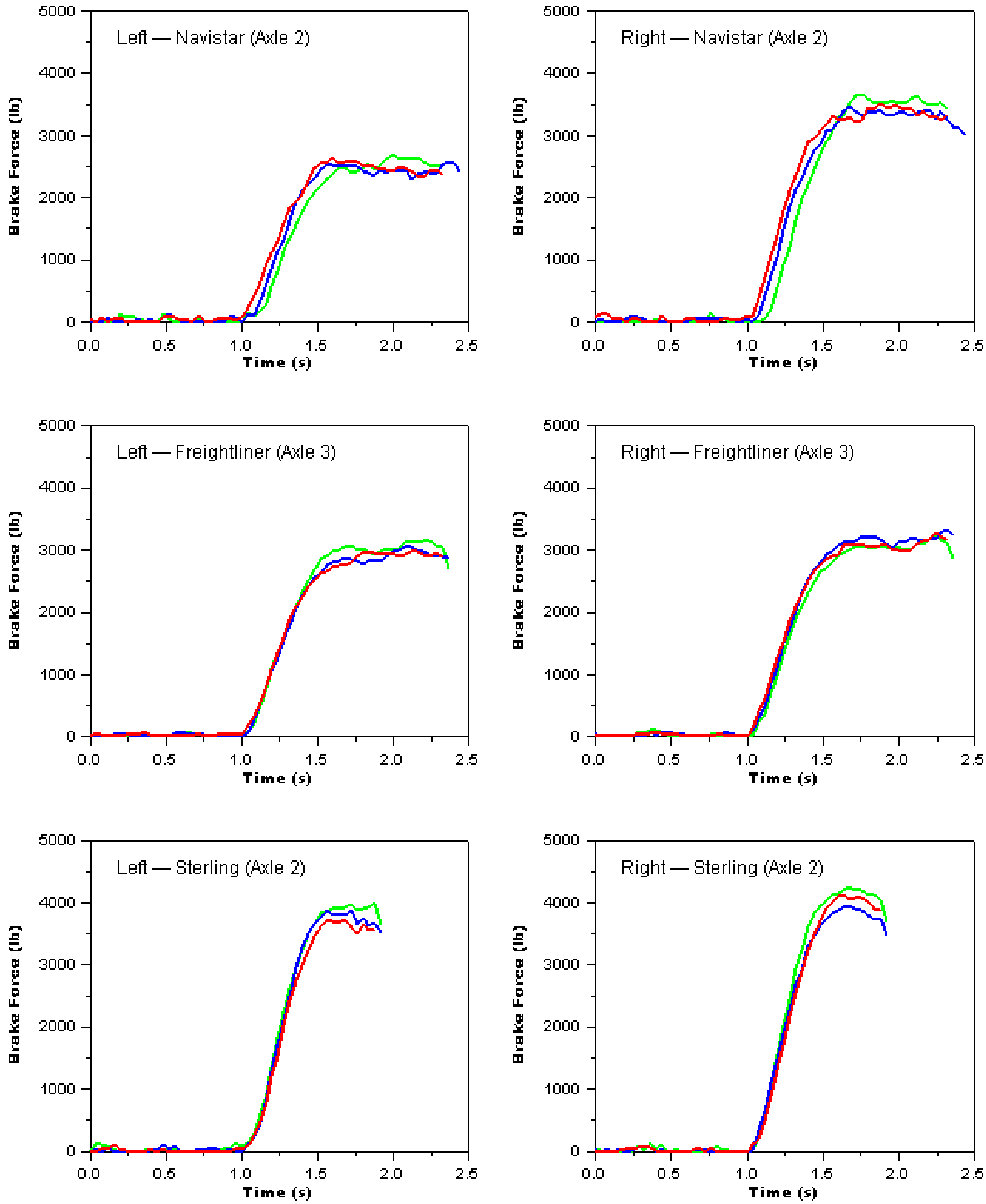

Figure B.4 - Roller Dynamometer Tests Parking Brake Application Force vs. Time

APPENDIX C - METHODS FOR MEASURING THE DISTANCE TRAVELED DURING STATIC RETARDATION TESTS

Five different techniques were explored for measuring the distance traveled during the Static Retardation tests (drawbar pulls). Each technique showed both merits and deficiencies. The list includes: marking the tire, a wire pointer, a laser arrow, a 50-inch string potentiometer, and a cardboard disc fitted into one of the wheels. A brief description and some thoughts on the effectiveness of each device are given below.

"Marking the tire" has been recognized by most standards as the easiest way to identify if the tire rolls or slides once the parking brake has been applied (FMVSS No. TP121V-04, Section 10-H-5 and SAE RP No. J1729, Section 6.6). The marks can be applied with chalk, crayon, or other marker after the vehicle is positioned and ready for the first of the four required pulls. The marks are spaced at 90 degree increments around the tire.

Some of the advantages of "marking the tires" include:

- that they can be observed from a safe distance during the test.
- they are easy to record on video.

The disadvantages are:

- this technique is poor for identifying small increments in initial creep distance (if the observer blinked or glanced away during the release of the service brake they may not have seen any obvious movement from the initial position).
- the need to measure the circumference of the tire and measure off equal spacing, or the need for an indexing fixture to mark the tire at the appropriate 90 degree increments.
- the marks are usually tedious to remove when testing is finished.
- the marks will be mis-positioned if the brakes cool too much during the first few rotations and the truck is moved to reheat the brakes.
- there is no way in real time to verify a constant draw rate.

This technique was only used on the first truck (PB01).

"A wire pointer" was easy to use. A long, stiff wire was attached to two of the test units (PB01 and PB02) as a moving pointer. The starting and stopping points were marked on a piece of paper taped to the floor, and measured for incremental distances equivalent to 1/4th of the tire circumference.

Some of the advantages of this system were:

- it was accurate for small creep distances (simulated grade tests)
- a layout fixture was not required as in the previous procedure.
- the distance the vehicle traveled during the pull was precise, as new start and stop points are established for each pull (therefore moving the vehicle to reheat the brakes had no effect on the measured distance).

However, there were several drawbacks:

- there is no indication as to which arc of the wheel rotation was to be tested next.
- the wire pointer was susceptible to being bent while technicians were working around the vehicle.
- the observer was required to stay in the vicinity of the vehicle during the test cycles and special precautions were taken to ensure their safety.
- it was hard to remove the marks from the floor before the paper was added.
- there was no way in real time to verify a constant draw rate.

A “laser arrow” is somewhat similar to the wire pointer, except it is not vulnerable to being bent while working around the truck. For the third test unit (PB03), the observer simply turned on the laser arrow, placed a starting mark on a piece of paper that was taped to the floor, waited for the truck to be drawn ahead, and then marked the end point for each pull. The laser arrow has many of the disadvantages of the wire pointer including not knowing which arc of the wheel rotation is to be tested next and that there is no way in real time to verify if the draw rate was constant.

The fourth technique used a “50-inch string potentiometer”. The string-pot directly measured the displacement of the hydraulic ram (for units PB02 and PB03). The data was collected real-time with the other tractor braking parameters, so this technique provided a valid time-displacement value once the system was drawn tight. It showed that the ram pulled at a constant rate. Its data was cross correlated with the data from the other channels in an x-y format. This showed that the string-pot accurately measured small incremental changes in creep distance (for simulated grade tests or brake cycling under load).

The string-pot was attached to the ram, instead of the directly between the test vehicle and the anchor vehicle. This allowed the ram system to be set up quickly and it minimized the number of items to be re-tensioned between each pull. The length of the wire string could be minimized. The cable from the string-pot did not interfere with the Connecting Chain.

Some tests were performed with a winch system instead of the hydraulic ram. For this configuration, the displacement string-pot (used for draw rate) was affixed to a manually-positioned pedestal stationed between the tow unit and the test vehicle.

The drawbacks of using the string-pot included that the string pot needed to be fairly well aligned with the vehicle motion to be accurate and it wasn’t able to identify which arc of the wheel rotation was to be tested next if the truck was moved to re-warm the brakes.

The fifth device used was the disc method. A cardboard disc was cut to fit into the rim of one of the wheels on the test axle. The disc was pre-marked with two perpendicular lines that crossed at the center of the wheel. After the brakes were warmed, the vehicle was positioned on the Hunter Plate ready for the first pull, and the disc popped into place on the test wheel. One of the lines was marked “#1" to indicate the starting point, and aligned vertically downward, pointing at the floor. A small index mark was also placed on the sidewall of the tire so the disc could be realigned to the same wheel position if the disc required removal to re-warm the brakes.

As the vehicle was moved forward, the disc rotated. The test was paused every 1/4 turn (each time the next line pointed at the floor) for release and re-application of the parking brake. This method provided the quickest determination of the required quarter wheel turn increments, but lacked an actual rate of travel speed. Therefore, the string-pot was used with the disc for optimum speed and accuracy.

APPENDIX D - ORIGINAL TEST PLAN

<u>Compounding Tests on Class 8 Straight Trucks and Tractors with S-Cam Drum Brakes and Spring Brake Chambers</u>

I. Acquire test vehicle - must have air brakes with anti-compounding feature on spring (parking/emergency) brake.

II. Inspect brakes - check condition of linings, drums, and other brake components; check stroke setting.

III. Inspect tires - Check overall condition of tire; measure both tread depth and air pressure.

IV. Add instrumentation to test vehicle.

A. Data Acquisition Controller.

B. Signal Conditioning Rack.

C. Transducers.

1. Each service brake line pressure at each chamber inlet port.
2. Each spring brake supply line pressure at each spring chamber inlet port.
3. Treadle control pressure (that connects to the primary brake system).
4. Two-axis chamber pushrod force pins (both sides of an axle at one time) installed at the connection to the slack adjusters. (For multiple axle spring brake vehicles, the test will be repeated for each spring brake axle).
5. Pushrod displacement - on each spring brake chamber being tested with a force pin.
6. Chamber mounting bracket deflection - on each spring brake chamber being tested with a force pin.
7. Vehicle movement - a minimum of 1/4 wheel rotation or 31.4 inches (initial tests will be limited to 24 inches of maximum travel due to the length of the hydraulic ram being used for the static tests.
8. Draw Force - 25k# load cell mounted on a full-swivel eye bracket at the pulling end of the test vehicle.

V. Load Vehicle to GVWR as specified on the vehicle placard installed by the manufacturer.

A. For straight trucks, ballast the vehicle to GVWR (or add a load frame for bare frame trucks, then add ballast weights.

B. For tractors, attach a standard unbraked control trailer (as specified in FMVSS 121) and front load the trailer so the tractor is loaded to GVWR and so the trailer axle is loaded to 4500 pounds.

VI. Condition brakes.

A. If the brakes are in good condition and been in service for some time, run 100 snub burnish stops from 40 mph down to 20 mph at a deceleration rate of 10 feet per second per second (0.3g), one mile apart, with the vehicle loaded to GVWR.

B. If the brakes are new, condition the brakes with a full 500 mile snub procedure as specified in FMVSS 121.

C. If the brakes are oily, greasy, or in poor condition, replace with OEM specified linings (and possibly new drums). Then follow step B) above for new brakes.

VII. Low Speed Dynamic Test on Brake Effectiveness - run three repetitions of the BM roller dynamometer on each axle when loaded to GAWR. Average results and record effectiveness of brakes.

III. Pressure vs. Brake Retardation Analysis - With vehicle loaded to GVWR (or unbraked trailer attached), attach draw bar to vehicle. Tension draw bar, then apply parking brake. Record draw bar force and spring brake air chamber pressures. Increase draw bar force until braked wheels begin to roll or tires slide (this procedure is a repeatable approach to adding more weight to a vehicle parked on a 20% slope). Identify air pressure where chamber springs begin to push enough to develop retardation torque, and draw bar force where brakes begin to slip and the wheels start to roll.

IX. Static Draw Bar Test - With vehicle loaded to GVWR (or unbraked trailer attached), attach draw bar assembly to the front of the vehicle and perform test series no.1.

X. Grade Holding Dynamic Test - With vehicle loaded to GVWR (or unbraked trailer attached), drive vehicle to 20% slope and perform test series no.2.

XI. Static Draw Bar Test - With vehicle loaded to LLVW, attach draw bar assembly to the front of the vehicle and perform test series no.1, only with ballast weight removed (or unbraked trailer detached).

XII. Grade Holding Dynamic Test - With vehicle loaded to LLVW, drive vehicle to 20% slope and perform test series no.2, only with ballast weight removed (or unbraked trailer detached).

Test Series No. 1 – Static Draw Bar Test

1. Attach draw bar to front of test vehicle. With all service brake lines at 0 psi, apply parking brake, then tension draw bar to 20 percent of the actual measured weight of the loaded vehicle (~0.2 x GVWR). Hold tension for five minutes. Record vehicle movement during the pull.

2. With the anti-compounding device functioning, repeat procedure of step one above, but at higher initial pressures of 20, 40, 60, 80, and 100 psi.

3. Repeat steps 1 and 2, but with the draw bar attached to the rear of the vehicle.

4. Disable the anti-compounding feature, and repeat steps 1, 2, & 3. Monitor the flexing of the chamber mounting bracket at 60 psi. If excessive flexing is observed, do not run 80 or 100 psi. If bracket flexing appears to be negligible, continue with the pressure increments, but continue to monitor the bracket flexing. Do not exert a pressure that is high enough to cause the bracket to yield or bend.

Test Series No. 2 – Dynamic 20% Grade Holding Test

1. With the vehicle loaded to GVWR (or the unbraked trailer attached), back the vehicle onto the 20% slope. Apply just enough service brake pressure to hold the vehicle stationary while the parking brake is being applied. Record time history of parking brake application. Hold parking brake on for 5 minutes with no vehicle movement. Record vehicle movement during the test.

2. With the anti-compounding device functioning, repeat step 1, only with higher initial pressures of 40, 60, 80, and 100 psi. Record vehicle movement during each 5 minute holding period.

3. Repeat steps 1 and 2, but with the vehicle pulled forward onto the 20% slope.

Disable the anti-compounding feature, and repeat steps 1, 2, & 3. Monitor the flexing of the chamber mounting bracket at 60 psi. If excessive flexing is observed, do not run 80 or 100 psi. If bracket appears to be flexing only a small amount, continue with the pressure increments, but continue to monitor the bracket flexing. Do not exert a pressure that is high enough to cause the bracket to yield or bend.

APPENDIX E - ALTERNATE TEXT DESCRIPTIONS OF FIGURES

Figure 2.1 - PB01 - Navistar 4x2 Dump Truck

This figure contains a picture of a Navistar dump truck. This vehicle has a single drive axle. Hydraulics for a snow plow are attached to the front of the vehicle. Three concrete ballast blocks line the bottom of the dumpster bed, with one stacked two high at the front end.

Figure 2.2 - PB02 - Freightliner 6x4 Tractor with Unbraked Control Trailer

This figure contains a picture of a Freightliner tractor with a flat-bed trailer attached. The tractor has two drive axles and the trailer has a single axle. A load frame and steel blocks sit at the front of the trailer bed. The ballast is secured with heavy bolts and chains.

Figure 2.3 - PB03 - Sterling 4x2 Tractor

This figure contains a picture of a Sterling tractor with a flat-bed trailer attached. Only the front portion of the trailer bed is visible. The tractor has a single drive axle and has an air foil on top of the cab. There is no ballast loaded onto the trailer.

Figure 3.1 - 4x2 Tractor Airline Schematic with Pressure Transducers Added

This figure depicts the brake system airlines for a 4x2 tractor. The brakes, including the brake chambers and slack adjusters, for the front and rear (drive) axle are clearly labeled, as are the supply, drive axle, and steer axle reservoirs; compressor, air dryer, treadle valve, tractor parking brake valve, tractor supply valve, tractor protection valve, anti-compounding feedback line, double check quick release parking brake valve, trailer control, and the service control valve. The airlines connecting these various components are clearly shown.

Figure 3.2 - Diagram of PB03 Left Wheel Parking Brake Instrumentation

The brake chamber, pushrod, slack adjuster, chamber bracket, and cam tube are shown in this figure. A pin force load cell is shown measuring the force that is developed as the pushrod is pushed out of the brake chamber. A linear potentiometer is shown that measures the pushrod displacement. An L-Bracket is also shown. Two potentiometers are connected to this L-Bracket. The other ends of the potentiometers are connected to the brake chamber and they are oriented to measure the longitudinal and lateral deflection of the brake chamber.

Figure 4.1 - Static Retardation Test Configuration Using A Hydraulic Ram

Two tractor-trailer combinations are depicted in this figure. The tractor-trailer combination on the left is labeled the test vehicle while the one on the right is labeled the anchor vehicle. The anchor vehicle has 6 concrete ballast blocks positioned on the deck of the flat-bed trailer. Three of the blocks are toward the rear of the trailer and the other three are at the front of the trailer, with a small gap between the two sets of blocks. The test vehicle has a single large block on the front of its flat-bed trailer (representing the same steel ballast that was specified in Figure 2.2). This block is approximately one and half times as wide and twice as tall as the blocks on the anchor vehicle.

Connecting the two vehicles is a chain and hydraulic ram "Drawbar" system. The hydraulic ram is attached to the rear pintle hook of the anchor vehicle trailer. Attached to the other end of the ram is a load cell that measures the force exerted by the ram. The other end of the load cell is connected to a chain which in turn is connected to the front of the tractor of the test vehicle at the tow hooks.

Figure 4.2 - Test Vehicle Holding On 20% Grade

This figure depicts the same tractor-trailer combination test vehicle, from Figure 4.1, only now it is sitting on a hill. The hill slopes downward 11.31 degrees from left to right. The front of the tractor is pointing down the hill. The vehicle is holding still with only the tractor parking brakes applied.

Figure 5.1 - Static Retardation Test Results for Unit PB03 - No Initial Treadle Pressure (0 psi)

This figure contains 3 sub-plots or panes. The top pane has the y-axis labeled "Pressure (psi)" and has a range of -25 to 125 psi. The middle pane has the y-axis labeled "Pull Force (lbf)" and has a range of 0 to 10,000 pounds-force. The bottom pane has the y-axis labeled "Chamber Stroke (inch)" and has a range of 0 to 2 inches. The x-axis for all three panes is "Time (sec)" and has a range of -10 to 30 seconds.

The top pane has three traces labeled "Parking Brake", "Treadle", and "Chamber 3". These traces are dashed-dot, dashed, and solid respectively. All three traces start at -5 seconds. The Parking Brake chamber pressure trace magnitude starts at approximately 110 psi (the parking brake is off) and remains at this level until approximately -3 seconds where it drops rapidly to 0 psi (as the square parking brake knob is pulled outward thus applying the parking brakes) and remains at this level for the duration of the time history. The Treadle trace starts at 0 psi and stays at this level for the entire time history (no treadle application was made prior to or during the parking brake application). The Chamber 3 trace starts at 0 psi and drops to -8 psi at -3 seconds (when the parking brake was applied) and remains at this level until the end of the time history (greater than 33 seconds).

The middle pane has a single trace that starts at -5 seconds and has a magnitude of approximately 500 pounds-force (the initial tension on the draw chain when first connected). It remains at this level until approximately 10 seconds where it starts to rise (more slowly at first) as the drawbar is pulled tight, reaching the upper knee of the curve at a level of 7,500 pounds-force at 15 seconds. The rate of rise then slows as the parking brake begins to creep and the trace reaches a maximum level of approximately 8,000 pounds-force at 17 seconds. It hovers around this level for the rest of the time history.

The bottom pane has a single trace labeled "Stroke 3". This trace starts at -5 seconds and 0.5 inch with all of the brakes off. At -3 seconds, the parking brake is applied, and the stroke trace rises rapidly to 1.55 inches. It remains at this level until approximately 10 seconds, where it starts to rise gradually as the drawbar is tensioned, reaching a value of 1.65 inches at 15 seconds. It remains at this level for the duration of the time history.

Figure 5.2 - Static Retardation Test Results for Unit PB03 - 40 psi Initial Treadle Pressure

This figure contains 3 sub-plots or panes, that are laid out the same as in the previous Figure 5.1. The top pane has the y-axis labeled "Pressure (psi)" and has a range of -25 to 125 psi. The middle pane has the y-axis labeled "Pull Force (lbf)" and has a range of 0 to 10,000 pounds-force. The bottom pane has the y-axis labeled "Chamber Stroke (inch)" and has a range of 0 to 2 inches. The x-axis for all three panes is "Time (sec)" and has a range of -10 to 30 seconds.

The top pane has three traces labeled "Parking Brake", "Treadle", and "Chamber 3". These traces are dashed-dot, dashed, and solid respectively. All three traces start at -5 seconds. The Parking Brake trace starts at approximately 110 psi (the parking brake is off) and remains at this level until approximately 5 seconds where it drops rapidly to 40-45 psi as the parking brake is applied. This trace hovers around this level until the service brake is released at 7 seconds, then it drops to 0 psi. It remains at this level for the duration of the time history. The Treadle trace starts at 0 psi and starts to rise at 1 second (when the foot treadle is applied) and reaches 40 psi at 4 seconds (this is the target treadle pressure level). It stays at this level until 7 seconds when the treadle is released, and it drops to 0 psi. It also remains at this level for the rest of the time history. The Chamber 3 trace starts at 0 psi and rises relatively rapidly to 10 psi at 1 second as the treadle is applied, then gradually rises to 15 psi at 5 seconds (limited by the bobtail proportioning valve). It then rises rapidly to 25 psi at 5.5 seconds when the parking brake is applied, then gradually droops to 20 psi. At 7 seconds, it then quickly drops to 0 psi as the service brake is released. It remains at this level for the rest of the time history.

The middle pane has a single trace that starts at -5 seconds and has a magnitude of approximately 400 pounds-force. It remains at this level until approximately 9 seconds where it starts to rise as the drawbar is tensioned, reaching 8,000 pounds-force at 16 seconds. The rate of rise then slows and the trace reaches 9,000 pounds-force at 18 seconds. It remains at this level (with minor oscillations) for the remainder of the time history.

The bottom pane has a single trace labeled "Stroke 3". This trace starts at -5 seconds and 0.35 inch. At 1 second it rises rapidly to 1.25 inches as the service brake is applied. It gradually rises to 1.35 inches at 5 seconds, then the parking brake is applied. The stroke increases rapidly to 1.5 inches at 5.5 seconds. It remains at this level until approximately 7 seconds where it rises slightly to 1.55 inches as the service brake is released, leaving just the parking brake applied. At 10 seconds, the stroke trace begins to rise gradually (as the drawbar is tensioned) reaching a value of 1.65 inches at 16 seconds. It remains near this level for the rest of the time history.

Figure 5.3 - Static Retardation Force as a Function of Initial Treadle Pressure - Full Wheel Rotation Results for Unit PB03 Using Winch System - Anti-Compounding "ON"

The static retardation force values for the test unit PB03 full-wheel rotation tests with the anti-compounding system on are plotted as a function of initial treadle pressure in this figure. The y-axis is labeled "Static Retardation Force (lbs)" and has a range of 0 to 12,000 pounds-force. The x-axis is labeled "Initial Treadle Pressure (psi)" and has a range of 0 to 120 psi. This graph has four traces. They are labeled as follows: solid diamond - Load Cell Forward Pull, solid triangle - Load Cell Rearward Pull, open square - Hunter Plate Forward Pull, and open triangle – Hunter

Plate Rearward Pull. A symbol is placed for each data point and a solid line connects the symbols for each symbol type, i.e. a solid line connects all the solid diamonds for the Load Cell Forward Pull data. Symbols for each type are plotted at 0, 40, 60, 80, 100, and 120 psi. All four traces have a generally increasing trend. All four traces start near 8,000 pounds-force. The forward pull traces rise to approximately 11,000 pounds-force while the rearward pull traces rise to approximately 10,000 pounds-force. The magnitudes for each data point are listed in Table 5.5.

Figure 5.4 - Static Retardation Force as a Function of Initial Treadle Pressure - Short Pull Test Results for Unit PB01 - Anti-Compounding "OFF"

The static retardation forces for the test unit PB01 short pull tests with the anti-compounding system off are plotted as a function of initial treadle pressure in this figure. The y-axis is labeled "Static Retardation Force (lbs)" and has a range of 0 to 10,000 pounds-force. The x-axis is labeled "Initial Treadle Pressure (psi)" and has a range of 0 to 120 psi. This graph has two traces. They are labeled as follows: open square - Load Cell Forward Pull, solid diamond - Hunter Plate Forward Pull. A symbol is placed for each data point and a solid line connects the symbols for each symbol type, i.e. a solid line connects all the open squares for the Load Cell Forward Pull data. Symbols for each type are plotted at approximately 40, 50, 60, 70, 80, 90, and 100 psi. Both traces have a generally increasing trend. They both start near 8,300 pounds-force and gradually rise to approximately 8,900 pounds-force. The magnitudes for each data point are listed in Table 5.10.

Figure 5.5 – Static Retardation Force as a Function of Initial Treadle Pressure - Short Pull Test Results for Unit PB02 - Anti-Compounding "ON"

The static retardation forces for the test unit PB02 short pull tests with the anti-compounding system on are plotted as a function of initial treadle pressure in this figure. The y-axis is labeled "Static Retardation Force (lbs)" and has a range of 0 to 10,000 pounds-force. The x-axis is labeled "Initial Treadle Pressure (psi)" and has a range of 0 to 100 psi. This graph has four traces. They are labeled as follows: solid diamond - Load Cell Forward Pull, solid triangle - Load Cell Rearward Pull, open square - Hunter Plate Forward Pull, and open triangle - Hunter Plate Rearward Pull. A symbol is placed for each data point and a solid line connects the symbols for each symbol type, i.e. a solid line connects all the solid diamonds for the Load Cell Forward Pull data. Symbols for each type are plotted at 0 to 100 psi in 10 psi increments (there is no open square data at 0 and 10 psi). The solid diamond data starts near 6,600 pounds-force and rises to 8,000. The open square data starts near 6,800 (20 psi is first point) and rises to 8,000 pounds-force following a similar trend to the solid diamond data. The solid triangle data falls within a narrow band of approximately 8,400 to 8,800 pounds-force. The open triangle data falls within a narrow band of approximately 7,700 to 8,400 pounds-force. The magnitudes for each data point are listed in Table 5.11.

Figure 5.6 – Static Retardation Force as a Function of Initial Treadle Pressure - Short Pull Test Results for Unit PB02 - Anti-Compounding "OFF"

The static retardation forces for the test unit PB02 short pull tests with the anti-compounding system off are plotted as a function of initial treadle pressure in this figure. The y-axis is labeled

"Static Retardation Force (lbs)" and has a range of 0 to 10,000 pounds-force. The x-axis is labeled "Initial Treadle Pressure (psi)" and has a range of 0 to 100 psi. This graph has four traces. They are labeled as follows: solid diamond - Load Cell Forward Pull, solid triangle - Load Cell Rearward Pull, open square - Hunter Plate Forward Pull, and open triangle - Hunter Plate Rearward Pull. A symbol is placed for each data point and a solid line connects the symbols for each symbol type, i.e. a solid line connects all the solid diamonds for the Load Cell Forward Pull data. Symbols for each type are plotted at 0 to 100 psi in 10 psi increments (there is no open triangle data for 30 psi and higher). All four traces have a generally increasing trend. The solid diamond data starts near 6,700 pounds-force and rises to 9,200. The open square data has a similar trend to the solid diamond data. The solid triangle data starts near 7,400 and rises to 10,000 pounds-force. The open triangle data has a similar trend as the solid diamond and open square data for its 3 data points (0, 10, and 20 psi). The magnitudes for each data point are listed in Table 5.11.

Figure 5.7 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO1 - Anti-Compounding "OFF"

The left side pin forces for the test unit PB01 "no pull" tests with the anti-compounding system off are plotted as a function of time in this figure. The y-axis is labeled "Force (lbf)" and has a range of -500 to 3,500 pounds-force. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 11 traces are plotted and the legend labels them from 0 to 100 in increments of 10. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." All of the traces have the same basic shape. They start at one level and then start to increase to another level starting near 2 seconds. They generally plateau at another level that is approximately 900 pounds-force higher than the original level between 2.5 and 2.7 seconds. Most of the traces stay at this plateau level, but a few tend to increase somewhat after the plateau. The initial values for the traces range from 0 pounds-force for the 0 psi test up to 1,900 pounds-force for the 100 psi test. The other traces are fairly evenly spaced between these two values. The plateaus range from 900 pounds-force for the 0 psi test and up to 2,800 pounds-force for the 100 psi test.

Figure 5.8 - Left Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO1 - Anti-Compounding "OFF"

The left side chamber strokes for the test unit PB01 "no pull" tests with the anti-compounding system off are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of -0.2 to 2 inches. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 11 traces are plotted and the legend labels them from 0 to 100 in increments of 10. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." All of the traces have the same basic shape. They start at one level and then start to increase to another level starting at 2 seconds. They generally plateau at another level near 2.5 to 2.6 seconds. Most of the traces stay at this plateau level, but a few tend to increase somewhat after the plateau. The initial values for the traces range from 0.08 inch for the 0 psi test up to 1.52 inches for the 100 psi test. The other traces are fairly evenly spaced between these two values. The plateaus range from 1.15 inches for the 0 psi test and up to 1.85 inches for the 100 psi test. The difference between the initial level and the plateau level values decreases with increasing initial treadle pressure.

Figure 5.9 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO1 - Anti-Compounding "ON"

The left side pin forces for the test unit PB01 "no pull" tests with the anti-compounding system on are plotted as a function of time in this figure. The y-axis is labeled "Force (lbf)" and has a range of -500 to 3,000 pounds-force. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 9 traces are plotted and the legend labels them from 0 to 80 in increments of 10. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." The 0 to 40 psi traces have the same basic shape. They start at one level and then start to increase to another level starting near 2.2 seconds. They all plateau at approximately 800 pounds-force with the 40 psi test reaching this value relatively quickly (2.4 seconds) and the 0 psi test reaching it more slowly (2.7 seconds). The 10, 20, and 30 psi tests fall between these values. The start value for the 0 psi test is 0 pounds-force and is 750 pounds-force for the 40 psi test. The 10, 20, and 30 psi tests fall between these two values. The 50 to 80 psi traces are all flat lines with values ranging from approximately 900 pounds-force for the 50 psi test up to 1,600 pounds-force for the 80 psi test.

Figure 5.10 - Left Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO1 - Anti-Compounding "ON"

The left side chamber strokes for the test unit PB01 "no pull" tests with the anti-compounding system on are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of -0.2 to 2 inches. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 9 traces are plotted and the legend labels them from 0 to 80 in increments of 10. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." The 0 to 40 psi traces have the same basic shape. They start at one level and then start to increase to another level starting near 2.1 to 2.4 seconds. They all plateau at approximately 1.08 inches with the 40 psi test reaching this value relatively quickly (2.4 seconds) and the 0 psi test reaching it more slowly (2.6 seconds). The 10, 20, and 30 psi tests fall between these values. The start values for the 0, 10, 20, 30, and 40 psi test are -0.01, 0.66, 0.77, 0.88, and 1 inch respectively. The 50 to 80 psi traces are all flat lines with values ranging from approximately 1.1 inches for the 50 psi test up to 1.4 inches for the 80 psi test.

Figure 5.11 - Right Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO2 - Anti-Compounding "OFF"

The right side pin forces for the test unit PB02 "no pull" tests with the anti-compounding system off are plotted as a function of time in this figure. The y-axis is labeled "Force (lbf)" and has a range of 0 to 4,000 pounds-force. The x-axis is labeled "Time (sec)" and has a range of 0 to 1 second. A total of 4 traces are plotted and the legend labels are 0, 60, 80, and 100. These values are the initial treadle pressures in psi. From 0 to 0.5 seconds the traces are labeled "Service Brakes Only" and above 0.5 second they are labeled "Service and Parking Brakes." All of the traces have the same basic shape. They start at one level and then start to increase to another level starting at approximately 0.5 seconds. The 0 psi trace begins at 50 pounds-force and starts to rise at 0.4 second, reaching a plateau of approximately 1,350 pounds-force at 1 second. The 60 psi trace begins slightly below 1,500 pounds-force and starts to increase at 0.5 second, reaching a plateau of 2,750 pounds-force at 1 second. The 80 psi trace begins at 2,100 pounds-force and starts to increase at 0.5 second, reaching a plateau of 3,000 pounds-force at 0.74 second. The 100 psi trace begins at 2,400 pounds-force and starts to increase at 0.55 second, reaching a plateau of 3,000 pounds-force at 0.66 second.

Figure 5.12 - Right Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO2 - Anti-Compounding "OFF"

The right side strokes for the test unit PB02 "no pull" tests with the anti-compounding system off are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of -0.2 to 1.6 inches. The x-axis is labeled "Time (sec)" and has a range of 0 to 1 second. A total of 4 traces are plotted and the legend labels are 0, 60, 80, and 100. These values are the initial treadle pressures in psi. From 0 to 0.5 second the traces are labeled "Service Brakes Only" and above 0.5 second they are labeled "Service and Parking Brakes." All of the traces have the same basic shape. They start at one level and then start to increase to another level starting at approximately 0.5 second. The 0 psi trace begins at 0 inch and starts to rise at 0.4 second, reaching a plateau of approximately 0.7 inch at 1 second. The 60 psi trace begins near 0.77 inch and starts to increase at 0.5 second, reaching a plateau of 1.25 inches at 0.95 second. The 80 psi trace begins near 0.93 inch and starts to increase at 0.5 second, reaching a plateau of 1.25 inches at 1 second. The 100 psi trace begins at 1.05 inches and starts to increase at 0.55 second, reaching a plateau of 1.35 inches at 1 second.

Figure 5.13 - Right Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO2 - Anti-Compounding "ON"

The right side pin forces for the test unit PB02 "no pull" tests with the anti-compounding system on are plotted as a function of time in this figure. The y-axis is labeled "Force (lbf)" and has a range of 0 to 4,000 pounds-force. The x-axis is labeled "Time (sec)" and has a range of 0 to 1.5 seconds. A total of 4 traces are plotted and the legend labels are 0, 60, 80, and 100. These values are the initial treadle pressures in psi. From 0 to 0.5 second the traces are labeled "Service Brakes Only" and above 0.5 second they are labeled "Service and Parking Brakes." The 0 psi trace begins at 50 pounds-force and starts to rise at 0.6 second, reaching a plateau of approximately 1,400 pounds-force at 1.3 seconds. The 60 and 80 psi traces are fairly flat and have values of approximately 1,500 and 2,000 pounds force respectively. The 100 psi trace begins at 2,200 pounds-force and immediately starts to rise reaching a plateau of 2,600 pounds-force at 0.3 seconds. It stays near this level until 1.2 seconds where it begins to drop (more rapidly at first) reaching 2,250 pounds-force at 1.5 seconds.

Figure 5.14 - Right Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO2 - Anti-Compounding "ON"

The right side chamber strokes for the test unit PB02 "no pull" tests with the anti-compounding system on are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of -0.2 to 1.6 inches. The x-axis is labeled "Time (sec)" and has a range of 0 to 1.5 seconds. A total of 4 traces are plotted and the legend labels are 0, 60, 80, and 100. These values are the initial treadle pressures in psi. From 0 to 0.5 second the traces are labeled "Service Brakes Only" and above 0.5 second they are labeled "Service and Parking Brakes." The 0 psi trace begins at 0 inch and starts to rise at 0.6 second, reaching a plateau of approximately 0.7 inch at 1.3 seconds. The 60 and 80 psi traces are fairly flat and have values of approximately 0.77 and 0.9 inch respectively. The 100 psi trace begins at 0.93 inch and immediately starts to rise reaching a plateau of 1.05 inches at 0.3 second. It stays near this level until 1.2 seconds where it begins to drop slowly reaching 1 inch at 1.5 seconds.

Figure 5.15 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO3 - Anti-Compounding "OFF"

The left side pin forces for the test unit PB03 "no pull" tests with the anti-compounding system off are plotted as a function of time in this figure. The y-axis is labeled "Force (lbf)" and has a range of -500 to 3,000 pounds-force. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 5 traces are plotted and the legend labels are 0, 20, 40, 65, and 80. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." All of the traces have the same basic shape. They start at one level and then start to increase to another level starting at approximately 2 seconds. The initial values for these traces are 0, 500, 950, 1,500, and 1,900 pounds-force respectively. The plateau values are 1,100, 1,650, 2,000, 2,500, and 2,800 pounds-force respectively. The 0 psi trace does not reach a plateau until 3.5 seconds while the other traces reach plateaus by 2.8 seconds.

Figure 5.16 - Left Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO3 - Anti-Compounding "OFF"

The left side chamber strokes for the test unit PB03 "no pull" tests with the anti-compounding system off are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of 0 to 2.5 inches. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 5 traces are plotted and the legend labels are 0, 20, 40, 65, and 80. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." All of the traces have the same basic shape. They start at one level and then start to increase to another level starting at approximately 2 seconds. The initial values for these traces are 0.1, 1.2, 1.45, 1.75, and 1.9 inches respectively. The plateau values are 1.5, 1.75, 1.9, 2.1, and 2.2 inches. The 0 psi trace does not reach a plateau until 3.5 seconds while the other traces reach plateaus by 2.8 seconds.

Figure 5.17 - Left Side Chamber Longitudinal Deflection for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO3 - Anti-Compounding "OFF"

The left side chamber longitudinal deflections for the test unit PB03 "no pull" tests with the anti-compounding system off are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of 0 to 0.03 inch. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 5 traces are plotted and the legend labels are 0, 20, 40, 65, and 80. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." The 0 psi trace begins at 0 inch and stays at this level until 2 seconds where it starts to rise reaching a plateau of 0.0075 inch at 3.4 seconds. The other trace have a different shape. They start at one level, then have a dip in value near 2 seconds, before rising to another value. The 20 psi trace begins at 0.0085 inch and stays at this level until 1.75 seconds where it starts to dip reaching 0.005 inch at 2 seconds. It then rises to 0.015 inch at 2.5 seconds and remains at this level. The 40 psi test starts at 0.0135 inch, dips down to 0.008 inch, and rises back up to 0.016 inch. The 65 psi test starts at 0.021 inch, dips down to 0.016 inch, and rises back up to 0.0225 inch. The 80 psi test starts at 0.023 inch, dips down to 0.017 inch, and rises back up to 0.0215 inch.

Figure 5.18 - Left Side Chamber Lateral Deflection for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO3 - Anti-Compounding "OFF"

The left side chamber lateral deflections for the test unit PB03 "no pull" tests with the anti-compounding system off are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of 0 to 0.2 inch. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 5 traces are plotted and the legend labels are 0, 20, 40, 65, and 80. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." All of the traces have the same basic shape. They begin at one level and then start to increase to another level near 2 seconds. The initial values for these traces are 0, 0.028, 0.059, 0.096, and 0.12 inch respectively. The plateau values are 0.065, 0.099, 0.125, 0.152, and 0.169. The 0 psi trace does not reach a plateau until 3.5 seconds while the other traces reach plateaus by 2.6 seconds.

Figure 5.19 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO3 - Anti-Compounding "ON"

The left side pin forces for the test unit PB03 "no pull" tests with the anti-compounding system on are plotted as a function of time in this figure. The y-axis is labeled "Force (lbf)" and has a range of -500 to 3,000 pounds-force. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 6 traces are plotted and the legend labels them from 0 to 100 in increments of 20. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." The 0, 20, and 40 psi traces have the same basic shape. They begin at one level and then start to increase to another level at approximately 2.3 seconds. They generally plateau at another level by 2.7 seconds. The initial values for the traces are 0, 475, and 1,000 pounds-force respectively. The plateau values are 1,000 pounds-force for the 0 psi test and 1,200 for the 20 and 40 psi tests. The 60, 80, and 100 psi trace are essentially flat lines (the 80 psi test has some slight waviness to its shape). The force level for these traces are 1,500, 2,050, and 2,400 pounds-force respectively.

Figure 5.20 - Left Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO3 - Anti-Compounding "ON"

The left side chamber strokes for the test unit PB03 "no pull" tests with the anti-compounding system on are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of 0 to 2.5 inches. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 6 traces are plotted and the legend labels them from 0 to 100 in increments of 20. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." The 0, 20, and 40 psi traces have the same basic shape. They begin at one level and then start to increase to another level starting at approximately 2.3 seconds. They generally plateau at another level by 2.7 seconds. The initial values for the traces are 0.1, 1.15, and 1.5 inches respectively. The plateau values are 1.5, 1.6, and 1.625 inches. The 60, 80, and 100 psi traces are essentially flat lines (the 80 psi test has some slight waviness to its shape). The stroke values for these traces are 1.75, 2, and 2.15 inches respectively.

Figure 5.21 - Left Side Chamber Longitudinal Deflection for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO3 - Anti-Compounding "ON"

The left side chamber longitudinal deflections for the test unit PB03 "no pull" tests with the anti-compounding system on are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of 0 to 0.035 inch. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 6 traces are plotted and the legend labels them from 0 to 100 in increments of 20. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled "Service and Parking Brakes." The 0 psi trace starts at 0 inch, begins to rise at 2.3 seconds, and plateaus at 0.0075 inch at 2.7 second. It remains at this level for the duration of the time history. The 20 psi trace begins at 0.0085 inch, starts to dip at 2.15 seconds reaching a low of 0.005 at 2.4 seconds, and then rises to 0.011 by 2.8 seconds and remains at this level for the duration of the time history. The 40 psi trace starts at 0.014 inch, begins to dip at 2.15 seconds reaching a low of 0.0095 at 2.55 seconds, and then rises to 0.011 by 2.8 seconds and remains at this level for the duration of the time history. The 60 psi trace starts at 0.0195 inch and it stays at this level until 2.1 seconds. It then begins to lower (more slowly at first) and reaches 0.018 inch by 2.5 seconds. It slowly decreases from this level reaching 0.0175 inch at 4 seconds. The 80 and 100 psi tests are relatively flat and have values of 0.025 and 0.026 inch respectively.

Figure 5.22 - Left Side Chamber Lateral Deflection for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO3 - Anti-Compounding "ON"

The left side chamber lateral deflections for the test unit PB03 "no pull" tests with the anti-compounding system on are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of 0 to 0.2 inch. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 6 traces are plotted and the legend labels them from 0 to 100 in increments of 20. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service Brakes Only" and above 2 seconds they are labeled

"Service and Parking Brakes." The 0, 20, and 40 psi traces have the same basic shape. They begin at one level and then start to increase to another level starting at approximately 2.3 seconds. They generally plateau at another level by 2.7 seconds. The initial values for the traces are 0, 0.025, and 0.06 inch respectively. The plateau values are 0.06, 0.07 and 0.075 inch. The 60, 80, and 100 psi traces are essentially flat lines (the 80 psi test has some slight waviness to its shape). The lateral deflection values for these traces are 0.095, 0.125, and 0.15 inch respectively.

Figure 5.23 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO1 - Anti-Compounding "OFF" - Service Brake Release

The left side pin forces for the test unit PB01 "no pull" tests with the anti-compounding system off are plotted as a function of time in this figure. The y-axis is labeled "Force (lbf)" and has a range of -500 to 3,500 pounds-force. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 4 traces are plotted and the legend labels them from 50 to 80 in increments of 10. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service and Parking Brakes" and above 2 seconds they are labeled "Parking Brakes Only." The traces have the same basic shape of beginning at one level, then starting to lower to another level at 1.75 seconds, and then reaching a plateau of 900 pounds-force at 2.1 seconds. The one exception to this is the 50 psi trace which begins at 1,700 pounds-force before starting to rise at 0.5 second reaching 1,950 pounds-force at 1.75 seconds. It then starts to decrease down to the plateau of 900 pounds-force. The 60 psi trace has an initial value of 2,150 pounds-force while the 70 and 80 psi traces have an initial value of 2,350.

Figure 5.24 - Left Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO1 - Anti-Compounding "OFF" - Service Brake Release

The left side chamber strokes for the test unit PB01 "no pull" tests with the anti-compounding system off are plotted as a function of time in this figure. The y-axis is labeled "Displacement (inch)" and has a range of -0.2 to 2 inches. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 4 traces are plotted and the legend labels them from 50 to 80 in increments of 10. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled "Service and Parking Brakes" and above 2 seconds they are labeled "Parking Brakes Only." The traces have the same basic shape of beginning at one level, then starting to lower to another level at 1.75 seconds, and then reaching a plateau of 1.15 inches. The one exception to this is the 50 psi trace which begins at 1.43 inches before starting to rise at 0.5 second reaching 1.5 inches at 1.75 seconds. It then starts to decrease down to the plateau of 1.18 inches. The 60, 70, and 80 psi traces have initial values of 1.58, 1.62, and 1.63 inches respectively.

Figure 5.25 - Left Side Pin Forces for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PBO1 - Anti-Compounding "ON" - Service Brake Release

The left side pin forces for the test unit PB01 "no pull" tests with the anti-compounding system on are plotted as a function of time in this figure. The y-axis is labeled "Force (lbf)" and has a range of -500 to 3,000 pounds-force. The x-axis is labeled "Time (sec)" and has a range of 0 to 4 seconds. A total of 4 traces are plotted and the legend labels them from 50 to 80 in increments of

10. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled “Service and Parking Brakes” and above 2 seconds they are labeled “Parking Brakes Only.” The traces all have the same basic shape of starting at one level, dipping down to a low value at 2.1 seconds, and then rising to a plateau of 900 pounds-force at 2.6 seconds. The 50, 60, 70 and 80 psi traces have initial values of 975, 1,175, 1,325, and 1,600 pounds-force respectively. The 50 psi trace starts to dip down at 2 seconds reaching a low of 650 pounds-force at 2.1 seconds before rising to the plateau of 900 pounds-force. The 60 psi trace starts to dip down at 1.95 seconds reaching a low of 500 pounds-force at 2.1 seconds. The 70 psi trace starts to dip down at 1.9 seconds reaching a low of 400 pounds-force at 2.1 seconds. The 80 psi trace starts to dip down at 1.85 seconds reaching a low of 375 pounds-force at 2.1 seconds.

Figure 5.26 - Left Side Chamber Stroke for Combined Service and Parking Brake (No Pull) Tests Conducted with Unit PB01 - Anti-Compounding “ON” - Service Brake Release

The left side chamber strokes for the test unit PB01 “no pull” tests with the anti-compounding system on are plotted as a function of time in this figure. The y-axis is labeled “Displacement (inch)” and has a range of -0.2 to 2 inches. The x-axis is labeled “Time (sec)” and has a range of 0 to 4 seconds. A total of 4 traces are plotted and the legend labels them from 50 to 80 in increments of 10. These values are the initial treadle pressures in psi. From 0 to 2 seconds the traces are labeled “Service and Parking Brakes” and above 2 seconds they are labeled “Parking Brakes Only.” The traces all have the same basic shape of beginning at one level, dipping down to a low value at 2.1 seconds, and then rising to a plateau of 1.1 to 1.12 inches at 2.6 seconds. The 50, 60, 70 and 80 psi traces have initial values of 1.13, 1.2, 1.28, and 1.4 inches respectively. The 50 psi trace starts to dip down at 2 seconds reaching a low of 1 inch at 2.1 seconds before rising to the plateau of 1.1 inches. The 60 psi trace starts to dip down at 1.95 seconds reaching a low of 0.95 inch at 2.1 seconds before rising to a plateau of 1.1 inches. The 70 psi trace starts to dip down at 1.9 seconds reaching a low of 0.9 inch at 2.1 seconds before rising to a plateau of 1.12 inches. The 80 psi trace starts to dip down at 1.85 seconds reaching a low of 0.9 inch at 2.1 seconds before rising to a plateau of 1.12 inches.

Figure B.1 – PB01 - Navistar 4x2 Dump Truck: Roller Dynamometer, Service Brake Force vs. Treadle Pressure Plots

This figure contains 4 sub-plots or panes. The 4 panes are laid out to match the location of the wheels on the straight truck, therefore the labels are (first row) Left Front and Right Front, and (second row) Left Rear and Right Rear, respectively. All 4 panes have the y-axis labeled “Brake Force (lb)”. The 2 upper front (steer) wheel panes have “y-ranges” of 0 to 4,000 pounds-force. The 2 lower rear (drive) wheel panes have “y-ranges” of 0 to 6,000 pounds-force. The x-axis for each pane is labeled “Pressure (psi)” and has a range of 0 to 100 psi.

The Left Front pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 12 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 100 psi, where the brake force achieves a maximum level of approximately 3,000 pounds-force.

*The Right Front pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 12 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 100 psi, where the brake force achieves a maximum level of approximately 2,500 pounds-force.

The Left Rear pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 6 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 100 psi, where the brake force achieves a maximum level of approximately 5,000 pounds-force.

The Right Rear pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 6 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 100 psi, where the brake force achieves a maximum level of approximately 5,600 pounds-force.

Figure B.2 – PB02 - Freightliner 6x4 Tractor: Roller Dynamometer, Service Brake Force vs. Treadle Pressure Plots

This figure contains 6 sub-plots or panes. The 6 panes are laid out in a two column by three row matrix to match the location of the wheels on the 6x4 tractor, therefore the labels are (first row) Left Front and Right Front, (second row) Left Intermediate and Right Intermediate, and (third row) Left Rear and Right Rear, respectively. All 6 panes have the y-axis labeled "Brake Force (lb)" and have "y-ranges" of 0 to 5,000 pounds-force. All 6 panes have the x-axis labeled "Pressure (psi)" and have ranges of 0 to 100 psi.

The Left Front pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 11 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 95 psi, where the brake force achieves a maximum level of approximately 3,900 pounds-force.

The Right Front pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 11 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 95 psi, where the brake force achieves a maximum level of approximately 3,500 pounds-force.

The Left Intermediate pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 10 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 77 psi, where the brake force achieves a maximum level of approximately 4,400 pounds-force.

The Right Intermediate pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 10 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 78 psi, where the brake force achieves a maximum level of approximately 4,500 pounds-force.

The Left Rear pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 8 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 80 psi, where the brake force achieves a maximum level of approximately 4,600 pounds-force.

The Right Rear pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 8 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 81 psi, where the brake force achieves a maximum level of approximately 4,800 pounds-force.

Figure B.3 – PB03 - Sterling 4x2 Tractor: Roller Dynamometer, Service Brake Force vs. Treadle Pressure Plots

This figure contains 4 sub-plots or panes. The 4 panes are laid out to match the location of the wheels on the 4x2 tractor, therefore the labels are (first row) Left Front and Right Front, and (second row) Left Rear and Right Rear, respectively. All 4 panes have the y-axis labeled “Brake Force (lb)”. The 2 upper front (steer) wheel panes have “y-ranges” of 0 to 4,000 pounds-force. The 2 lower rear (drive) wheel panes have “y-ranges” of 0 to 6,000 pounds-force. The x-axis for each pane is labeled “Pressure (psi)” and has a range of 0 to 100 psi.

The Left Front pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 11 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 66 psi, where the brake force achieves a maximum level of approximately 3,400 pounds-force. One trace did continue higher on the same slope to approximately 3,800 pounds force at a final pressure of approximately 80 psi.

The Right Front pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 11 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 66 psi, where the brake force achieves a maximum level of approximately 3,300 pounds-force. One trace did continue higher on the same slope to approximately 3,700 pounds force at a final pressure of approximately 80 psi.

The Left Rear pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 9 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 54 psi, where the brake force achieves a maximum level of approximately 4,600 pounds-force.

The Right Rear pane has three traces superimposed showing the repetitions in the test. The three traces fairly well match. The traces start at 0 pounds-force for an input of 0 psi. As the treadle pressure is increased the brake force remains at zero until approximately 9 psi, where the curve breaks upward with generated brake force. The slope rise is constant until the maximum applied pressure reaches 54 psi, where the brake force achieves a maximum level of approximately 5,200 pounds-force.

Figure B.4 - Roller Dynamometer Tests - Parking Brake Application Force vs. Time

This figure contains 6 sub-plots or panes. The 6 panes are laid out in a two column by three row matrix. The first row panes are labeled “Left - Navistar (Axle 2)” and “Right - Navistar (Axle 2)”, where the axle number indicates the axle where the parking brake was installed. The second row panes are labeled “Left - Freightliner (Axle 3)” and “Right - Freightliner (Axle 3)”. The third row panes are labeled “Left - Sterling (Axle 2)” and “Right - Sterling (Axle 2)”, respectively. All 6 panes have the y-axis labeled “Brake Force (lb)” and have “y-ranges” of 0 to 5,000 pounds-force. All 6 panes have the x-axis labeled “Time (s)” and have ranges of 0 to 2.5 seconds.

The Left - Navistar (Axle 2) pane has three traces superimposed showing the repetitions of the parking brake test. The three traces fairly well match. With the roller dynamometer running and the rolling friction tare value zeroed out, the traces start at 0 pounds-force at time equal to 0 seconds. At 1 second, the parking brake was applied and the brake force rapidly rose to a plateau of approximately 2,500 pounds-force at 1.5 seconds. This level was maintained until the rollers were stopped and the force drooped after 2.3 seconds.

The Right - Navistar (Axle 2) pane has three traces superimposed showing the repetitions of the parking brake test. The three traces fairly well match. With the roller dynamometer running and the rolling friction tare value zeroed out, the traces start at 0 pounds-force at time equal to 0 seconds. At 1.1 seconds, the parking brake was applied and the brake force rapidly rose to a plateau of approximately 3,500 pounds-force at 1.6 seconds. This level was maintained until the rollers were stopped and the force drooped after 2.3 seconds.

The Left - Freightliner (Axle 3) pane has three traces superimposed showing the repetitions of the parking brake test. The three traces fairly well match. With the roller dynamometer running and the rolling friction tare value zeroed out, the traces start at 0 pounds-force at time equal to 0 seconds. At 1.05 seconds, the parking brake was applied and the brake force rapidly rose to a plateau of approximately 3,000 pounds-force at 1.6 seconds. This level was maintained until the rollers were stopped and the force drooped after 2.3 seconds.

The Right - Freightliner (Axle 3) pane has three traces superimposed showing the repetitions of the parking brake test. The three traces fairly well match. With the roller dynamometer running and the rolling friction tare value zeroed out, the traces start at 0 pounds-force at time equal to 0 seconds. At 1.05 seconds, the parking brake was applied and the brake force rapidly rose to a plateau of approximately 3,200 pounds-force at 1.6 seconds. This level was maintained until the rollers were stopped and the force drooped after 2.3 seconds.

The Left - Sterling (Axle 2) pane has three traces superimposed showing the repetitions of the parking brake test. The three traces fairly well match. With the roller dynamometer running and the rolling friction tare value zeroed out, the traces start at 0 pounds-force at time equal to 0 seconds. At 1 second, the parking brake was applied and the brake force rapidly rose to a plateau of approximately 3,900 pounds-force at 1.6 seconds. This level was maintained until the rollers were stopped and the force drooped after 1.9 seconds.

The Right - Sterling (Axle 2) pane has three traces superimposed showing the repetitions of the parking brake test. The three traces fairly well match. With the roller dynamometer running and the rolling friction tare value zeroed out, the traces start at 0 pounds-force at time equal to 0 seconds. At 1.1 seconds, the parking brake was applied and the brake force rapidly rose to a plateau of approximately 4,100 pounds-force at 1.6 seconds. This level was maintained until the rollers were stopped and the force drooped after 1.9 seconds.

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