U.S. Department
of Transportation
**Federal Railroad
Administration**

# Evaluation and Service Testing of Prototype Empty/Load Brake Device to Reduce Wheel Spalling Due to Slide

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**13. ABSTRACT**

The Transportation Technology Center, Inc. and New York Air Brake evaluated a prototype three-step graduated empty and load (E/L) brake device to reduce wheel spalling due to wheel slide on intermodal double-stack railcars. Analysis of the results showed an increase in the rate of wheel spalling on the test wheelsets compared to a control group of wheelsets. There is no logical reason why the three-step graduated E/L device would cause more wheel slides than a conventional E/L device, possibly indicating that other factors influenced the test results. One test wheelset location produced two tread damaged wheelsets during the course of the test. Brake shoe force measurements during the initial inspection indicated poorly distributed brake shoe forces, although the wheelset position which developed tread damage twice during the test had lower than expected brake shoe forces. Brake shoe force measurements during the final inspection showed more evenly distributed forces. No other spalling developed on the test wheelsets. Two additional cars are currently equipped with graduated E/L brake devices to increase the sample size and hopefully produce a statistically meaningful result.

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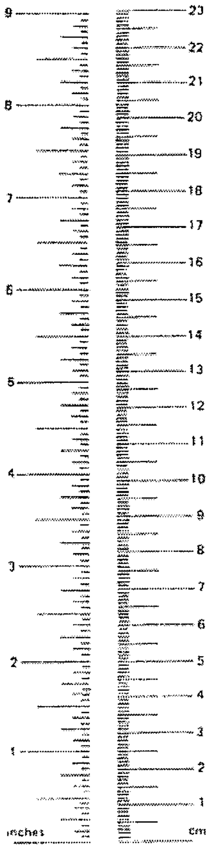
# METRIC CONVERSION FACTORS

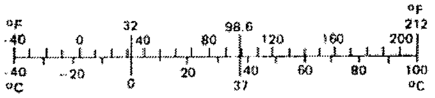
## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.50 | centimeters | cm |
| ft | feet | 30.00 | centimeters | cm |
| yd | yards | 0.90 | meters | m |
| mi | miles | 1.60 | kilometers | km |
| | | **AREA** | | |
| in$^2$ | square inches | 6.50 | square centimeters | cm$^2$ |
| ft$^2$ | square feet | 0.09 | square meters | m$^2$ |
| yd$^2$ | square yards | 0.80 | square meters | m$^2$ |
| mi$^2$ | square miles | 2.60 | square kilometers | km$^2$ |
| | acres | 0.40 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28.00 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.90 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5.00 | milliliters | ml |
| Tbsp | tablespoons | 15.00 | milliliters | ml |
| fl oz | fluid ounces | 30.00 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.80 | liters | l |
| ft$^3$ | cubic feet | 0.03 | cubic meters | m$^3$ |
| yd$^3$ | cubic yards | 0.76 | cubic meters | m$^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |



## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.40 | inches | in |
| m | meters | 3.30 | feet | ft |
| m | meters | 1.10 | yards | yd |
| km | kilometers | 0.60 | miles | mi |
| | | **AREA** | | |
| cm$^2$ | square centim. | 0.16 | square inches | in$^2$ |
| m$^2$ | square meters | 1.20 | square yards | yd$^2$ |
| km$^2$ | square kilom. | 0.40 | square miles | mi$^2$ |
| ha | hectares (10,000 m$^2$) | 2.50 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.10 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| m$^3$ | cubic meters | 36.00 | cubic feet | ft$^3$ |
| m$^3$ | cubic meters | 1.30 | cubic yards | yd$^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32 | Fahrenheit temperature | °F |



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* 1 in = 2.54 cm (exactly)

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# EXECUTIVE SUMMARY

The Federal Railroad Administration (FRA) contracted with the Transportation Technology Center, Inc. (TTCI) to conduct an evaluation of a prototype empty/load (E/L) brake device to reduce wheel spalling due to wheel slide on intermodal double-stack railcars. Analysis of the results showed an increase in the rate of wheel spalling on the test wheelsets compared to a control group of wheelsets. There is no logical reason why the three-step graduated E/L device would cause more wheel slides than a standard E/L device, possibly indicating that other factors influenced the test results.

When a wheel slides on a rail, an enormous amount of heat is generated in a small patch of wheel tread, producing very high temperatures that can transform a small amount of material into a brittle form of steel known as martensite. Cracks form around the martensite, and the transformed material eventually becomes dislodged from the wheel tread, creating a spall. Each time a wheel spall comes into contact with the rail, an impact load is produced that can damage the car, the lading, and the track structure.

A graduated E/L brake device has the potential to reduce wheel spalls in intermodal railcars by reducing the frequency of wheel slides by maintaining an appropriate brake ratio. Intermodal cars operate at many load levels due to the variable nature of the loads they carry. This reduces the effectiveness of a conventional E/L brake device in preventing wheel slides because undesirable high brake ratios can occur when the car carries a load that is significantly less than its maximum gross rail load but more than the transition level of the E/L brake device. A graduated three-step E/L brake device addresses this problem by providing a brake force level appropriate for a partial load in addition to empty and fully loaded brake force levels.

TTCI, New York Air Brake (NYAB) Corporation, and the test car owner installed prototype graduated E/L brake devices on trucks D and E of test cars A and B, both five-unit, double-stack well cars. The test team chose Trucks D and E because these are the only trucks that are not equipped with handbrakes. Car movement before releasing handbrakes can cause wheel slides and spalls and could add confusion to the results when evaluating the performance of the graduated E/L brake devices.

TTCI and NYAB performed inspections on five occasions for each test car to monitor the condition of the wheels and ensure proper functioning of the brake system. In addition to the typical inspection procedure, a complete single car test, according to AAR Standard S-486, was performed and brake shoe forces were measured during the initial inspection and final inspection.

TTCI observed spalling on one wheelset approximately 14 months after the start of the test. The wheelset was replaced approximately 18 months after the start of the test due to high-impact wheel loads. The replacement wheelset also developed spalling within 8 months. Pneumatic brake tests performed before, during, and after the test period showed nothing unusual. Brake shoe force measurements during the initial inspection indicated poorly distributed brake shoe forces in one of the test trucks, although the

wheelset position, which developed tread damage twice during the test, had lower than expected brake shoe forces. Brake shoe force measurements during the final inspection showed more evenly distributed forces. TTCI observed no other spalling on the test wheelsets, although one other wheelset produced large dynamic wheel loads due to an out-of-round condition probably unrelated to wheel sliding.

Two additional cars are currently equipped with graduated E/L brake devices to increase the sample size and hopefully produce a statistically meaningful result.

## 1.0 Introduction and Objectives

The FRA contracted with TTCI to conduct Task Order 212: “Evaluation and Service Testing of Prototype Empty/Load Brake Device to Reduce Wheel Spalling Due to Slide.” TTCI, along with significant support from NYAB and the test car owner, executed this task with the goal of quantifying the performance of a three-step graduated E/L brake device in reducing wheel spalling on intermodal double-stack railcars. A spall is the material void left in a wheel tread as a result of a metallurgical change in the wheel steel. When a wheel slides on a rail, an enormous amount of heat is generated in a small patch of wheel tread, producing very high temperatures. When the wheel stops sliding, the hot patch cools quickly. This rapid heating and cooling of the wheel can transform a small amount of material into a brittle form of steel known as martensite. Cracks form around the martensite, and it eventually becomes dislodged from the wheel tread, creating a spall. Each time a wheel spall comes into contact with the rail, an impact load is produced that can damage the car, the lading, and the track structure.

A graduated E/L brake device has the potential to reduce wheel spalls in intermodal railcars by reducing the frequency of wheel slides. Wheel slides can occur when the retarding force acting on a wheelset from the brake shoes is larger than the wheel/rail adhesion, calculated as the product of normal force and wheel/rail coefficient of friction. One way to control wheel slides is to maintain an appropriate relationship between car weight and brake force, known as brake ratio. Many types of railcars operate at two predetermined load levels: (1) tare weight of the car, when it is empty and (2) maximum gross rail load, when the car is loaded. This binary load condition enables the effective use of conventional two-step E/L brake devices, which act to reduce the brake force when the car is empty, thereby providing appropriate brake ratios to minimize wheel slides. Intermodal cars, however, operate at many load levels due to the variable nature of the loads they carry. This reduces the effectiveness of a conventional E/L brake device in preventing wheel slides because undesirable high brake ratios can occur when the car carries a load that is significantly less than its maximum gross rail load but more than the transition level of the E/L brake device. A graduated three-step E/L brake device addresses this problem by providing a brake force level appropriate for a partial load, in addition to empty and fully loaded brake force levels.

There is a network of wheel impact load detectors (WILD) installed throughout North America to measure the impact loads of wheels as they travel on their normal revenue service routes. WILDs report three force values per wheel: average load, impact load, and dynamic load. The average load is similar to a static wheel weight. The impact load is the maximum load measured while the wheel is in the sensitive zone of the WILD site. The dynamic load is the difference between the impact load and the average load and is especially useful for assessing the wheel tread condition of cars that do not carry consistent loads, such as the double-stack cars used in this test.

## 2.0 Procedures

### 2.1 Test Car Setup

TTCI, NYAB, and the test car owner installed prototype graduated E/L brake devices on trucks D and E of test cars A and B, both five-unit, double-stack well cars. The test team chose trucks D and E because these are the only trucks that are not equipped with handbrakes. Car movement before releasing handbrakes can cause wheel slides and spalls and could add confusion to the results when evaluating the performance of the graduated E/L brake devices. Wheelsets in positions 5, 6, 7, and 8 were replaced at the start of the test so that there would be no existing tread damage. Figure 1 shows the nomenclature associated with these cars and the location of the graduated E/L brake devices.

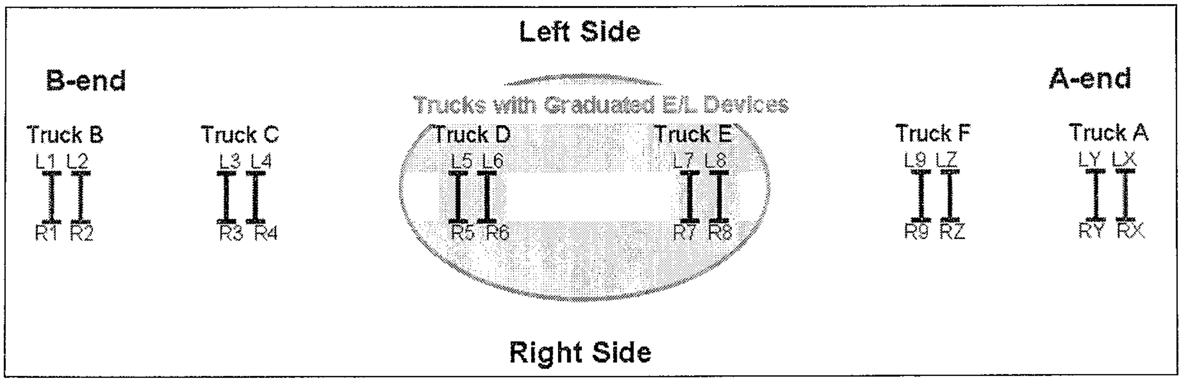


**Figure 1. Nomenclature and Location of Graduated Empty Load Devices**

As Figure 2 shows, each prototype graduated E/L brake device consists of two conventional E/L brake devices plumbed in series. This was done to minimize the development cost of the device by using off-the-shelf components. If the prototype graduated E/L brake devices are successful, an integrated graduated E/L brake device could be developed to provide the same functionality as the prototype but with a simplified installation. In order to fit the prototype components in the space available, each side frame of trucks D and E was equipped with a single conventional E/L brake device, as Figure 3 shows.

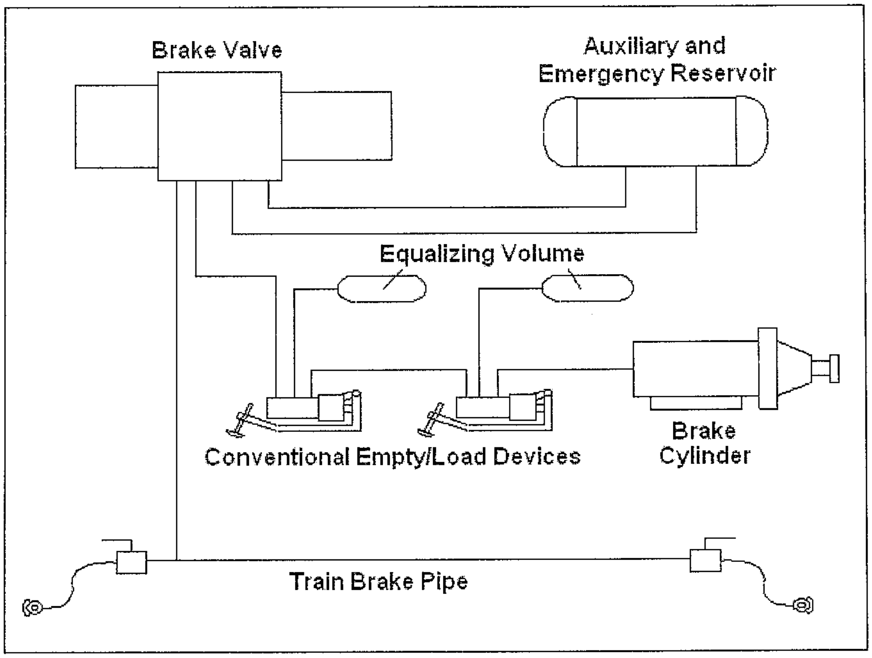


**Figure 2. Schematic Diagram Showing a Prototype Graduated E/L Brake Device**

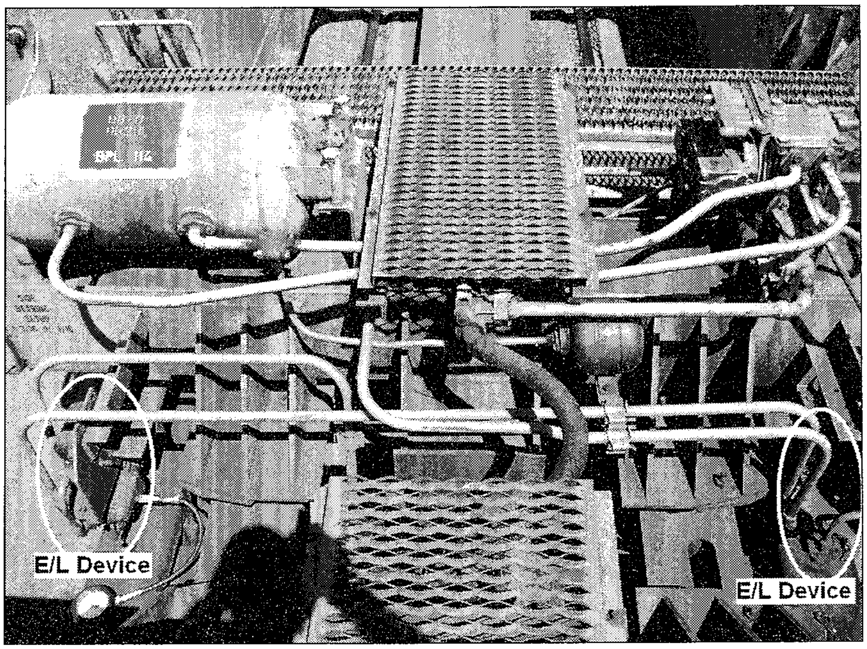


**Figure 3. Overhead View of a Truck Equipped with a Prototype Graduated E/L Brake Device**

The test team configured the graduated E/L brake devices to provide changes in brake force at 20 and 50 percent of car loading. Figure 4 shows the brake ratios as a function of car lading percentage for conventional E/L and graduated E/L brake devices.

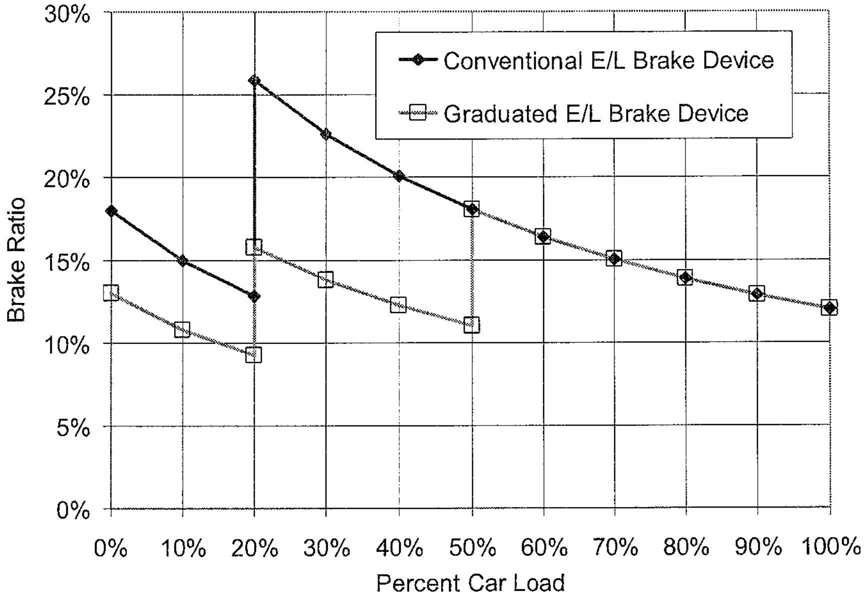


**Figure 4. Theoretical Brake Ratio Chart**

## 2.2 Inspection Procedures

TTCI performed inspections on five occasions for each test car between July 2003 and January 2007 to monitor the condition of the wheels and ensure proper functioning of the brake system. Although inspections were originally intended to be conducted every six months, the time between inspections was sometimes longer due to unpredictable routing and high demand for the cars. Table 1 describes some relevant details pertaining to the inspections.

**Table 1. Details Regarding Inspections**

| | | Car | |
|---|---|---|---|
| | | A | B |
| Inspection No. | Date | July 2003 | July 2003 |
| 1 | Location | Hamburg, SC | Hamburg, SC |
| | Brake Cylinder Pressures Measured | Yes | Yes |
| | Brake Shoe Forces Measured | Yes | Yes |
| 2 | Date | April 2004 | October 2004 |
| | Location | Tacoma, WA | Los Angeles, CA |
| | Mileage Since Previous Inspection | 99,935 | 88,761 |
| | Brake Cylinder Pressures Measured | No | No |
| | Brake Shoe Forces Measured | No | No |
| 3 | Date | July 2005 | August 2005 |
| | Location | Los Angeles, CA | Joliet, IL |
| | Mileage Since Previous Inspection | 84,289 | 93,338 |
| | Brake Cylinder Pressures Measured | Yes | Yes |
| | Brake Shoe Forces Measured | No | No |
| 4 | Date | January 2006 | April 2006 |
| | Location | Baltimore, MD | Houston, TX |
| | Mileage Since Previous Inspection | 1,897 | 34,080 |
| | Brake Cylinder Pressures Measured | Yes | Yes |
| | Brake Shoe Forces Measured | No | No |
| 5 | Date | January 2007 | December 2006 |
| | Location | Pueblo, CO | Pueblo, CO |
| | Mileage Since Previous Inspection | 57,129 | 33,752 |
| | Brake Cylinder Pressures Measured | Yes | Yes |
| | Brake Shoe Forces Measured | No | Yes |

A typical inspection for this test consisted of the following:

- General inspection of the car and brake system for any unusual conditions
- Examination of the running surface of each wheel for shells, spalls, slid flats, crack bands, pitting, or other anomalies
- Measurement of the transverse profile of each wheel using a MiniProf™ from Greenwood Engineering
- Monitoring of each brake cylinder pressure after a full-service brake application with blocks inserted under the E/L brake device arms to force a fully loaded condition
- Monitoring of each brake cylinder pressure after a full-service brake application with blocks inserted under one of the two E/L brake device arms to force a partially loaded condition
- Monitoring of each brake cylinder pressure after a full-service brake application with each E/L brake device arm in the empty position

- Procedures to adjust the graduated E/L brake devices are as follows:
    - Loosen the lock nuts that secure the adjusting screw
    - Screw the adjusting screw all the way in
    - No set-block is required
    - Pull the sensor arm down as far as it will go and hold it
    - Unscrew the adjusting screw until it just touches the truck side frame
    - Measure the distance the adjusting screw extends below the lever
    - For the E/L brake device closest to the control valve (changeover at 20% of car load), screw the adjusting screw out 5/8 inch and secure using the lock nuts
    - For the E/L brake device closest to the brake cylinder (changeover at 50% of car load), screw the adjusting screw out 1/8 inch and secure using the lock nuts

In addition to the typical inspection procedure, the test team performed a complete single car test (S-486) on the air brake system during the initial inspection and final inspection. The team also measured brake shoe forces for all but the final inspection of test car A, which was deemed unnecessary due to the use of truck mounted brakes on the cars and the consistent results measured previously.

## 3.0 Results

This section describes the results of the inspections that were performed on the cars with the graduated E/L brake devices and a statistical analysis that was performed to assess the effectiveness of the graduated E/L brake devices in reducing wheel spalling. The condition of the brake system and wheels affected by the graduated E/L brake devices (D and E trucks) are of primary concern, therefore the focus of the results section will be on these components.

### 3.1 Inspection Results

### *3.1.1 Brake System Findings*

During the January 2006 inspection of test car A in Baltimore, MD, the test team discovered that the service portion of the D-unit brake valve was allowing the brake cylinder pressure to leak off. The effect of this would have been to slowly decrease the braking force on trucks D and E as a brake application was held for a length of time. The test team replaced the service portion after the inspection. The previous inspection of this car in July 2005 did not find any problem with the valve, so the issue was rectified with minimal effect on the test results. Aside from that, the test team found no significant problems with the D-unit brake systems of both test cars that would have affected the outcome of the test.

The test team made minor adjustments to the E/L actuating arm adjusting screws during each inspection. These adjustments were unlikely needed due to any fundamental changes in the car, such as the suspension or brake system, but rather due to minor differences in variables such as track surface, rotational position of the truck, and lateral displacement of the side frames relative to the bolster. The contact point of the actuating arm is near the centerline of the side frame where a casting ridge can create large vertical differences due to small lateral displacements. The changes made to the adjusting screws would have only minor consequences in the changeover loads required for each step of the graduated E/L brake devices.

The test team measured and recorded brake shoe forces during the initial and final inspections. They found poorly distributed forces in truck D of test car B during the initial inspection, but no other unusual conditions. Appendix A shows the results.

### *3.1.2 Wheel Condition Findings*

As stated in Section 1.0, Introduction and Objectives, WILD dynamic loads are especially useful for assessing the wheel tread condition of double-stack cars. Wheels with dynamic loads above 20 kips (thousand pounds) are generally considered to have some type of tread damage. The wheels with dynamic loads that exceeded 20 kips will be discussed here.

In wheel R8 of test car A, the test team found dynamic loads that repeatedly exceeded 20 kips beginning mid-2006 and lasting until the final inspection. In fact, the largest dynamic load recorded for this wheel was 39 kips on December 29, 2006. Repair records do not indicate that the wheelset was replaced at any time during the test, yet no tread damage was found at any circumferential location of this wheel during the final inspection conducted January 31, 2007. Wheel profile wear patterns also confirm that this wheel was not changed during the duration of the test. The radial runout of this wheel was measured to see if an out-of-round condition existed. The test team found that the radius decreased approximately 0.030 inch and returned to its nominal value within about a 4-inch circumferential zone. Tapping the tread with a hard object in this zone caused a hollow sound possibly indicating a subsurface crack. The application of an etching solution on the wheel tread produced no martensite. While the cause of the out-of-round condition on this wheel is not known, the lack of visually observable martensite suggests that it was not caused by a wheel slide event.

Wheelset position R6 of test car B developed large dynamic loads twice during test. The initial wheelset was removed for an AAR Why Made Code 65 (high impact wheel) January 31, 2005, with dynamic loads as high as 87 kips. The replacement wheelset was subsequently removed for an AAR Why Made Code 80 (scrape, dent, or gouge) on May 11, 2006, at which point the dynamic loads had reached 43 kips.

Figures 5, 6, and 7 all pertain to wheel position R6 of test car B. Figure 5 shows spalling 4 months before the first wheelset was removed. Figure 6 shows spalls developing on the second wheelset 8 months before it was removed. Figure 7 shows spalling on the same wheel just weeks before removal. Wheel slide events are the likely cause of the observed damage.

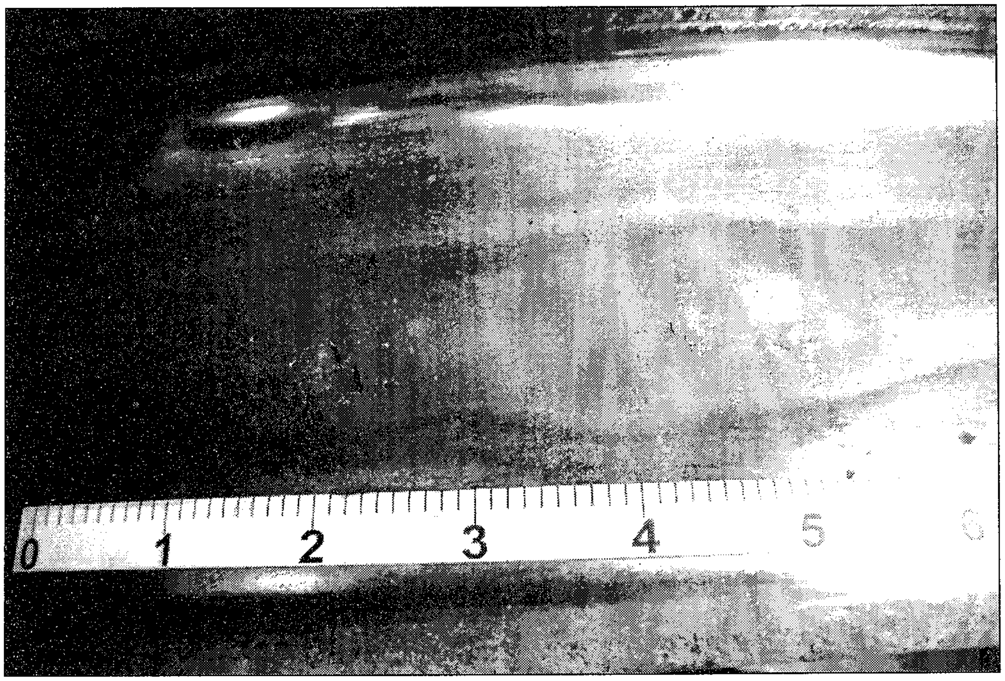


**Figure 5. Spall Discovered on Wheel R6 of Test Car B During the Inspection in Los Angeles, CA in October of 2004, before Wheelset Removal for High-Impact Loads in January 2005**

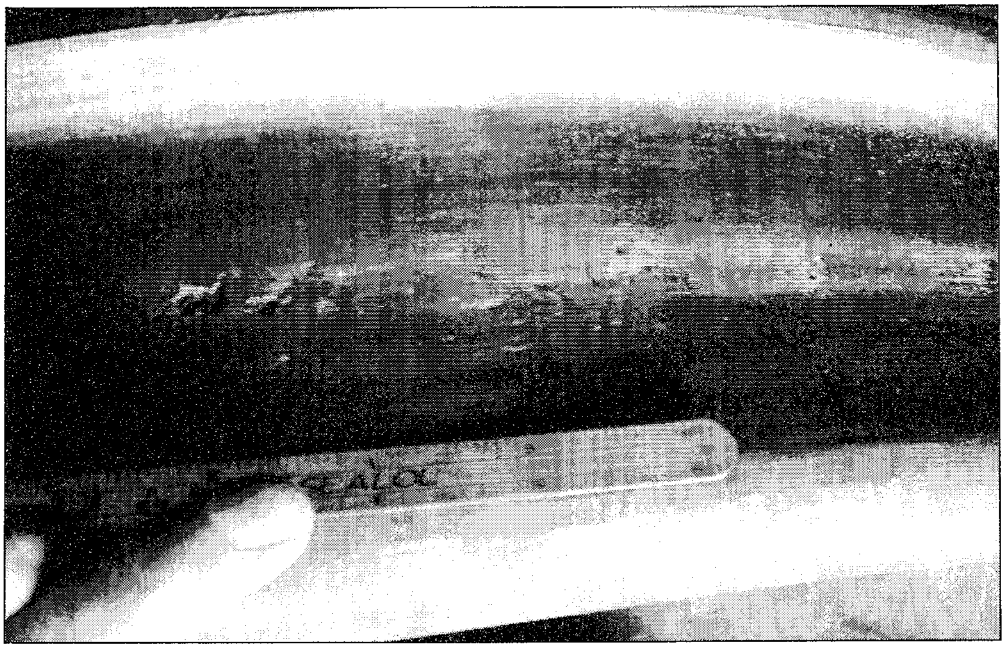


Figure 6. Small Pits and Spalls Observed at Many Circumferential Locations of Wheels R6 and L6 of Test Car B During August 30, 2005, Inspection, Joliet, IL

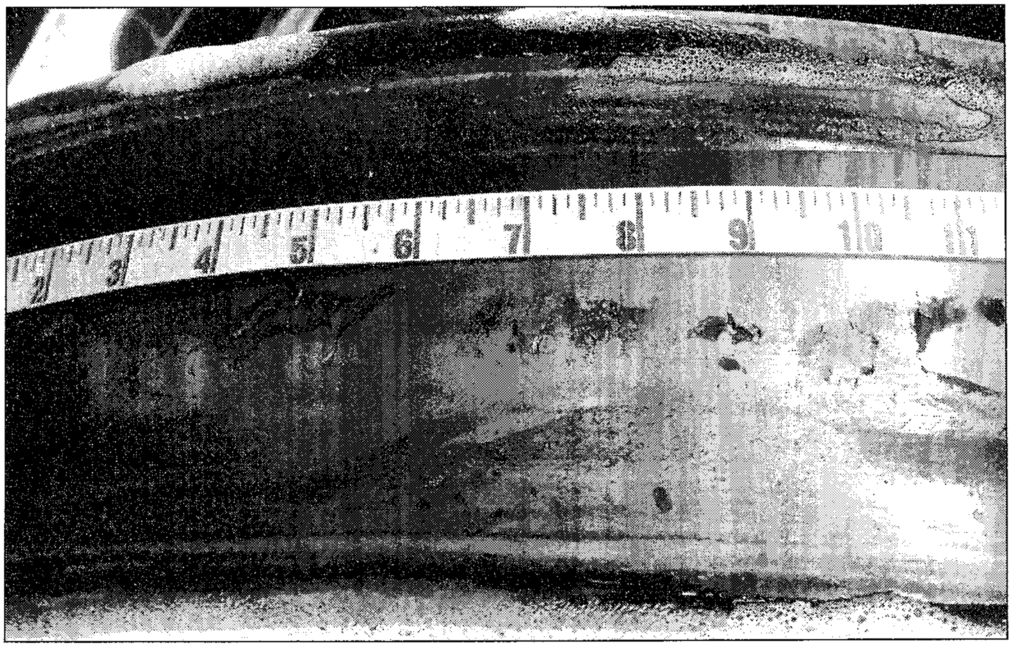


Figure 7. Large Spalls Evident at Many Circumferential Locations of Wheels R6 and L6 During April 18, 2006 Inspection, Houston, TX

## 3.2 Data Analysis

The test team performed a wheel life analysis to assess the effectiveness of the graduated E/L brake devices tested in this program. As stated previously, the prototype graduated E/L brake devices were installed on trucks D and E, which are the only trucks on the car not equipped with handbrakes. This was done to avoid any wheel tread damage that could have developed due to car movement with applied handbrakes. For this same reason, a comparison of the wheelsets in trucks D and E to the wheelsets in trucks A, B, C, and F would be unfair. Therefore, a control group consisting of wheelsets in trucks D and E of similar cars was chosen to compare against the test cars.

Table 2 describes relevant details of the car groups involved in the analysis. Mileage was similar between the groups at the start of the test. The test group accumulated fewer miles during the test than the control group. This may be due in part to the need to stop the cars periodically and have them moved to a safe track for the inspections.

**Table 2. Car Groups**

| Group | Number of Cars | Age of Wheelsets Known at Start of Test | Average Mileage During Test | Standard Deviation of Mileage During Test |
|---|---|---|---|---|
| Test | 2 | Yes | 276,089 | 5,539 |
| Control | 10 | Typically, yes (from maintenance records) | 306,402 | 23,936 |

In addition to evaluating the mileage accumulated during the test, it is important to consider the relative time and mileage spent at loading conditions sufficient to activate the each step of the prototype graduated E/L devices (between 20% and 50% of the gross rail load). Figure 8 shows that, based on average load (WILD sites) of the D and E trucks, the test cars and control cars were loaded in a similar manner during the test and the intermediate step of the prototype graduated E/L devices on the test cars should have been in use more than a quarter of the time the test cars passed WILD sites.

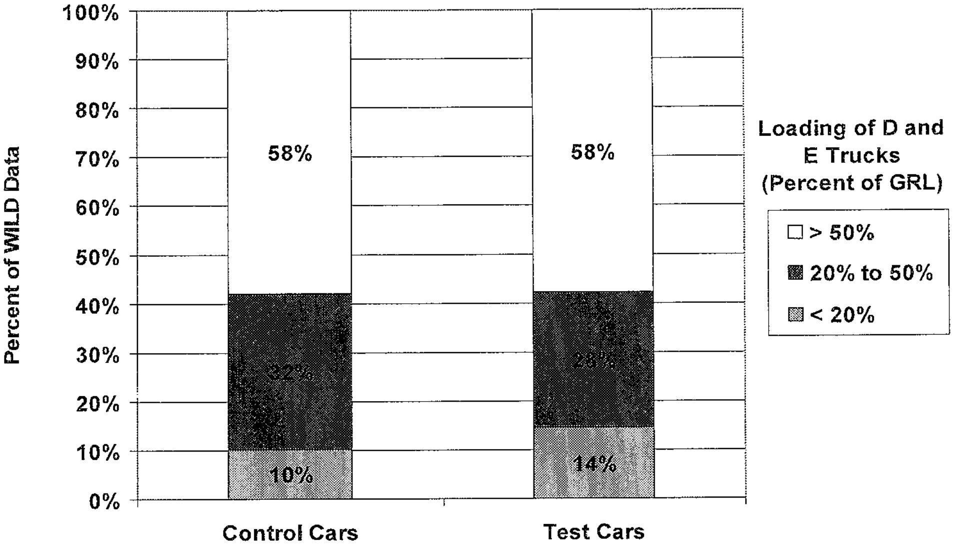


**Figure 8. Loading of Control Cars and Test Cars During Test**

The test team determined that the test duration window length was to be 1,132 days beginning July 30, 2003, after installation and testing of the graduated E/L brake devices, and ending September 4, 2006, when test car B arrived at the Transportation Technology Center, Pueblo, CO for its final inspection. Both test cars accumulated at least 272,172 miles during the test duration. Wheelset life comparisons were made on a time basis and on a mileage basis. Wheelsets from each group were divided into one of three categories according to the duration (or mileage) of service life and WILD dynamic wheel load:

1. Success: Wheelset did not exceed 20-kip dynamic load before a service life of at least 1,132 days (or 272,172 miles). Wheelsets that eventually exceeded 20-kip dynamic load after a service life longer than the test were categorized as successes.
2. Failure: Wheelset exceeded 20-kip dynamic load before a service life of at least 1,132 days (or 272,172 miles).
3. Undetermined: Wheelset met one of the following criteria:
    a. Wheelset did not exceed 20-kip dynamic load but had a service life shorter than 1,132 days (or 272,172 miles).
    b. Wheelset did not exceed 20-kip dynamic load, but the currently installed wheelset had been in service for less than 1,132 days (or 272,172 miles) at the time of the analysis.
    c. Wheelset with an unknown installation date was removed from service for any reason before a verifiable service life of at least 1,132 days (or 272,172 miles).

Table 3 describes the categorization of wheelsets from each group. The sample sizes are larger than the number of wheelset positions in trucks D and E per car times (4x) the number of cars due to wheelset change outs during the test.

**Table 3. Wheelset Categorization**

| Group | Basis for Wheelset Life | Wheelset Sample Size | Success | Percent Success | Failure | Percent Failure | Undetermined | Percent Undetermined |
|---|---|---|---|---|---|---|---|---|
| Test | Time | 13 | 3 | 23.1% | 3 | 23.1% | 7 | 53.8% |
| Test | Mileage | 13 | 3 | 23.1% | 3 | 23.1% | 7 | 53.8% |
| Control Group | Time | 85 | 40 | 47.1% | 7 | 8.2% | 38 | 44.7% |
| Control Group | Mileage | 85 | 41 | 48.2% | 8 | 9.4% | 36 | 42.4% |

Table 3 shows that the control group has a higher percent success and a lower percent failure than the test group whether the wheelset life is based on time or mileage. Wheel R8 of test car A was counted as one of the three failures of the test group based on WILD dynamic loads even though the wheel damage was probably not caused by a wheel slide event. This was deemed fair, since the wheel treads of the control group were not inspected for tread damage, but rather relied solely on WILD dynamic loads to make the assessment of success or failure. Had this wheel been considered a success rather than a failure, the control group would still have had a higher percent success and a lower percent failure than the test group.

The test team conducted this program to determine whether or not the prototype E/L device would improve wheelset life. If the test group had shown an improvement in wheelset life over the control group, an analysis would have been conducted to determine whether or not the improvement was statistically significant. Since no improvement was found, there was no need to conduct a statistical significance test.

There is no logical reason why the prototype E/L device would cause more wheel slides than a conventional E/L device. Brake shoe force measurements during the initial inspection indicated poorly distributed brake shoe forces among the wheels of truck D in test car B, although wheelset position 6, which developed tread damage twice during the test, had lower than expected brake shoe forces. Brake shoe force measurements during the final inspection showed more evenly distributed forces.

Normal operations in train service include some percentage of operations with very light brake pipe reductions less than 8 pounds per square inch (psi). Both the prototype and conventional E/L valves provide no reduction in brake force below this level, however, such light brake applications would not be expected to cause wheel sliding and spalling. At brake pipe pressure reductions greater than 8 psi, the prototype graduated E/L valves operate in a linear manner such that an incremental reduction in brake pipe pressure causes a corresponding increase in brake cylinder pressure. This design should provide the operator with maximum control of the brake force, and thus, aid in reducing wheel slides and spalling.

## 4.0 Conclusions/Observations

TTCI and NYBA conducted a test encompassing 3 1/2 years to quantify the performance of a three-step graduated E/L brake device in reducing wheel spalling on trucks D and E of two intermodal double-stack railcars. Analysis of the results showed an increase in the rate of wheel spalling on the test wheelsets compared to a control group of wheelsets. There is no logical reason why the three-step graduated E/L device would cause more wheel slides than a conventional E/L device, possibly indicating that other factors influenced the test results.

Spalling developed on one test wheelset approximately 14 months after the start of the test. The wheelset was replaced approximately 18 months after the start of the test due to high-impact wheel loads. The replacement wheelset also developed spalling within 8 months. Brake shoe force measurements during the initial inspection indicated poorly distributed brake shoe forces in one of the test trucks, although the wheelset position that developed tread damage twice during the test had lower than expected brake shoe forces. Brake shoe force measurements during the final inspection showed more evenly distributed forces. No other spalling developed on the test wheelsets, although one other wheelset produced large dynamic wheel loads due to an out-of-round condition probably unrelated to wheel sliding.

Two additional cars are currently equipped with graduated E/L brake devices to increase the sample size and hopefully produce a statistically meaningful result.

# Appendix A.

# Brake Shoe Force Readings

Car: Test Car A
Car Class: TW52BM
Light Weight: 195600
Gross Rail Load: 799000
Test Date: 07/23/03
Test Equipment: NYAB Sensotec
Test Equipment Calibration Date: 06/01/03
Test Performed At: Hamburg, SC
Control Valves: DB-60L, DB-60L, DB-60L
Empty/Load Type: 60% SC-1 on End Brake Systems, EL-60 on Intermediate Brake System (36% pressure and 60% pressure)
Brake Type: TMX High Lever Ratio. 9-1/4" Int. Trucks and 8" End Trucks
Hand Brake: Universal 4493-3 AAR-IP-93 Group O

| | | | Pneumatic Brakes | | | | | | | | | | | | | | Handbrake | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Minimum Application | | Full Service Application (100% Pressure) | | | | Full Service Application (60% Pressure) | | | | Full Service Application (36% Pressure) | | | | | | |
| Truck Location | Shoe Location | Piston Travel | Brake Cylinder Pressure | Untapped Force (Per Shoe) | Brake Cylinder Pressure | Tapped Force (Per Shoe) | Tapped Force (Per Truck) | Efficiency | Brake Cylinder Pressure | Tapped Force (Per Shoe) | Tapped Force (Per Truck) | Efficiency | Brake Cylinder Pressure | Tapped Force (Per Shoe) | Tapped Force (Per Truck) | Efficiency | HB Chain Force (Measured In Horizontal Chain) | Untapped Force (Per Shoe) | Untapped Force (Per Truck) |
| B | L1 | 1-3/4" | 9½ | 59 | 66 | 2909 | 12012 | 70.1% | 39 | 1798 | 7454 | 72.5% | | | | | 4475 | 6149 | 24330 |
| | R1 | | | 335 | | 3120 | | | | 1943 | | | | | | | | 6512 | |
| | L2 | | | 303 | | 2983 | | | | 1877 | | | | | | | | 6012 | |
| | R2 | | | 320 | | 3000 | | | | 1836 | | | | | | | | 5657 | |
| C | L3 | 2" | | 336 | | 4220 | 16697 | 72.9% | | 2649 | 10432 | 75.9% | | | | | | 7250 | 22000 |
| | R3 | | | 435 | | 4210 | | | | 2536 | | | | | | | | 4631 | |
| | L4 | | | 448 | | 4078 | | | | 2594 | | | | | | | | 4968 | |
| | R4 | | | 421 | | 4189 | | | | 2653 | | | | | | | | 5151 | |
| D | L5 | 1-3/4" | 9.7 | 343 | 63½ | 3762 | 14792 | 64.6% | 39 | 2274 | 8902 | 64.8% | 25½ | 1150 | 4877 | 54.3% | | | |
| | R5 | | | 293 | | 3660 | | | | 2228 | | | | 1376 | | | | | |
| | L6 | | | 300 | | 3510 | | | | 2158 | | | | 980 | | | | | |
| | R6 | | | 324 | | 3860 | | | | 2242 | | | | 1371 | | | | | |
| E | L7 | 1-3/4" | | 232 | | 4090 | 16167 | 70.6% | | 2294 | 9114 | 66.3% | | 1364 | 5633 | 62.7% | | | |
| | R7 | | | 244 | | 3989 | | | | 2185 | | | | 1371 | | | | | |
| | L8 | | | 348 | | 3975 | | | | 2360 | | | | 1432 | | | | | |
| | R8 | | | 155 | | 4113 | | | | 2275 | | | | 1466 | | | | | |
| F | L9 | 1-3/4" | 11 | 385 | 66 | 3956 | 16015 | 69.9% | 38.3 | 2280 | 9225 | 67.1% | | | | | 4475 | 6464 | 27420 |
| | R9 | | | 350 | | 3996 | | | | 2265 | | | | | | | | 6115 | |
| | LZ | | | 293 | | 4091 | | | | 2382 | | | | | | | | 6369 | |
| | RZ | | | 270 | | 3972 | | | | 2298 | | | | | | | | 8472 | |
| A | LY | 1-3/4" | | 463 | | 3528 | 14068 | 82.1% | | 1911 | 7509 | 73.0% | | | | | | 8477 | 26926 |
| | RY | | | 335 | | 3495 | | | | 1788 | | | | | | | | 5217 | |
| | LX | | | 408 | | 3495 | | | | 1886 | | | | | | | | 5190 | |
| | RX | | | 386 | | 3550 | | | | 1924 | | | | | | | | 8042 | |
| | | Totals | | 7786 | | 89751 | | | | 52636 | | | | 10510 | | | | 100676 | |

Car: Test Car B
Car Class: TW52BM
Light Weight: 195600
Gross Rail Load: 799000

Test Date: 07/29/03
Test Equipment: NYAB Sensotec
Test Equipment Calibration Date: 06/01/03
Test Performed At: Hamburg, SC

Control Valves: DB-60L, DB-60L, DB-60L
Empty/Load Type: 60% SC-1 on End Brake Systems, EL-60 on Intermediate Brake System (36% pressure and 60% pressure)
Brake Type: TMX High Lever Ratio. 9-1/4" Int. Trucks and 8" End Trucks
Hand Brake: E/N Peacock 33000 AAR-IP-93 Group O

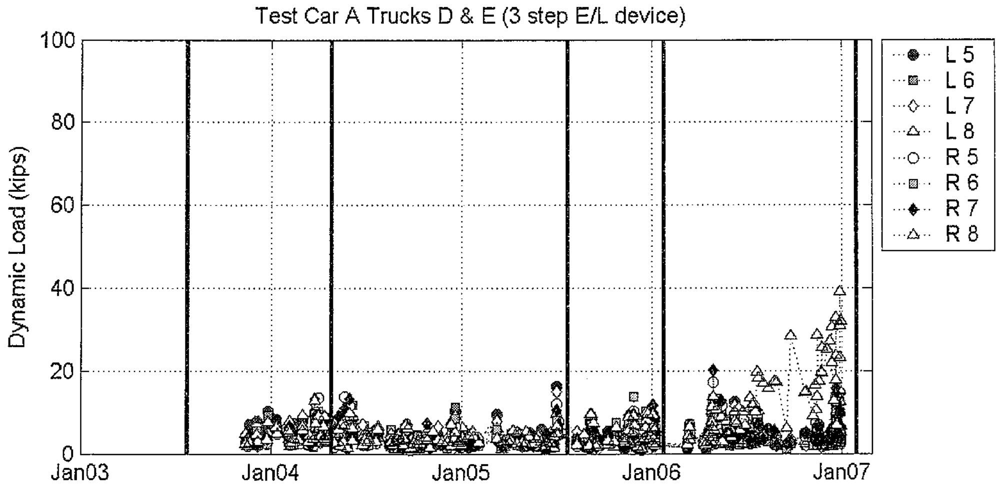
| | | | Pneumatic Brakes | | | | | | | | | | | | | | Handbrake | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Minimum Application | | Full Service Application (100% Pressure) | | | | Full Service Application (60% Pressure) | | | | Full Service Application (36% Pressure) | | | | | | |
| Truck Location | Shoe Location | Piston Travel | Brake Cylinder Pressure | Untapped Force (Per Shoe) | Brake Cylinder Pressure | Tapped Force (Per Shoe) | Tapped Force (Per Truck) | Efficiency | Brake Cylinder Pressure | Tapped Force (Per Shoe) | Tapped Force (Per Truck) | Efficiency | Brake Cylinder Pressure | Tapped Force (Per Shoe) | Tapped Force (Per Truck) | Efficiency | HB Chain Force (Measured In Horizontal Chain) | Untapped Force (Per Shoe) | Untapped Force (Per Truck) |
| B | L1 | 2" | 10 | 240 | 65 | 2988 | 12017 | 70.1% | 38½ | 1795 | 7465 | 72.6% | | | | | 4475 | 6418 | 21925 |
| | R1 | | | 333 | | 2966 | | | | 1943 | | | | | | | | 4910 | |
| | L2 | | | 310 | | 3052 | | | | 1868 | | | | | | | | 5215 | |
| | R2 | | | 252 | | 3011 | | | | 1859 | | | | | | | | 5382 | |
| C | L3 | 1-3/4" | | 330 | | 3876 | 16073 | 70.2% | | 2609 | 10309 | 75.0% | | | | | | 6110 | 20001 |
| | R3 | | | 439 | | 4174 | | | | 2531 | | | | | | | | 5281 | |
| | L4 | | | 451 | | 3927 | | | | 2556 | | | | | | | | 4230 | |
| | R4 | | | 418 | | 4096 | | | | 2613 | | | | | | | | 4380 | |
| D | L5 | 1-3/4" | 9 | 785 | 64 | 4080 | 16104 | 70.3% | 40 | 2550 | 9208 | 67.0% | 25½ | 1600 | 5475 | 60.9% | | | |
| | R5 | | | 251 | | 4026 | | | | 2123 | | | | 1571 | | | | | |
| | L6 | | | 60 | | 3925 | | | | 2080 | | | | 900 | | | | | |
| | R6 | | | 357 | | 4073 | | | | 2455 | | | | 1404 | | | | | |
| E | L7 | 2" | | 325 | | 3909 | 15737 | 68.7% | | 2459 | 10050 | 73.1% | | 1433 | 5830 | 64.9% | | | |
| | R7 | | | 293 | | 4048 | | | | 2475 | | | | 1490 | | | | | |
| | L8 | | | 292 | | 3843 | | | | 2600 | | | | 1481 | | | | | |
| | R8 | | | 222 | | 3937 | | | | 2516 | | | | 1426 | | | | | |
| F | L9 | 1-3/4" | 11.7 | 500 | 64½ | 3867 | 15601 | 68.1% | 38 | 2384 | 9401 | 68.4% | | | | | 4475 | 4310 | 19923 |
| | R9 | | | 512 | | 3950 | | | | 2376 | | | | | | | | 4369 | |
| | LZ | | | 551 | | 3907 | | | | 2355 | | | | | | | | 5135 | |
| | RZ | | | 533 | | 3877 | | | | 2286 | | | | | | | | 6109 | |
| A | LY | 1-3/4" | | 364 | | 2983 | 12049 | 70.3% | | 1845 | 7244 | 70.5% | | | | | | 5352 | 21649 |
| | RY | | | 335 | | 3046 | | | | 1834 | | | | | | | | 5180 | |
| | LX | | | 72 | | 2941 | | | | 1803 | | | | | | | | 4708 | |
| | RX | | | 267 | | 3079 | | | | 1762 | | | | | | | | 6409 | |
| | | Totals | | 8492 | | 87581 | | | | 53677 | | | | 11305 | | | | 83498 | |

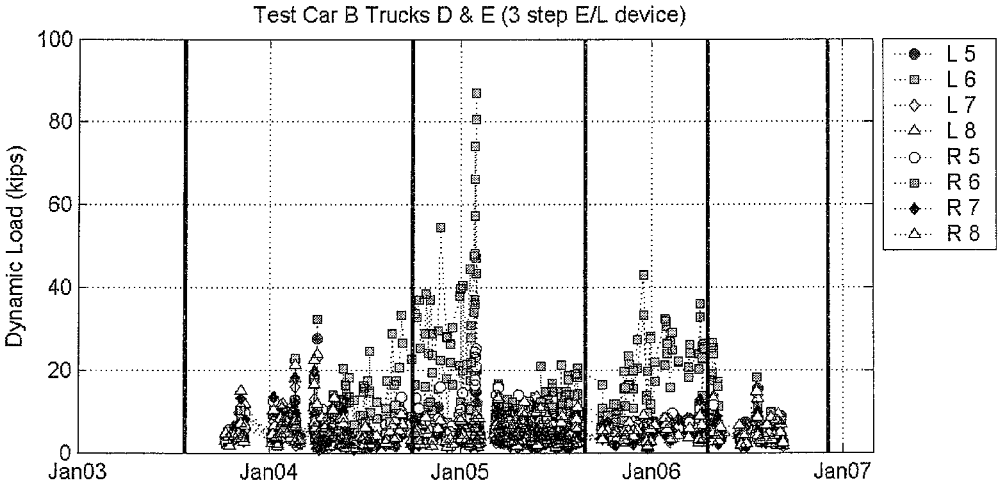
Car: Test Car B
Car Class: TW52BM
Light Weight: 195600
Gross Rail Load: 799000
Control Valves: ABDXL & DB-10, DB-60L, ABDXL & DB-10
Empty/Load Type: 60% SC-1 on End Brake Systems, EL-60 on Intermediate Brake System (36% pressure and 60% pressure)
Brake Type: TMX High Lever Ratio. 9-1/4" Int. Trucks and 8" End Trucks
Hand Brake: E/N Peacock 33000 AAR-IP-93 Group O

Test Date: 12/06/06
Test Equipment: NYAB Sens
Test Performed At: TTC

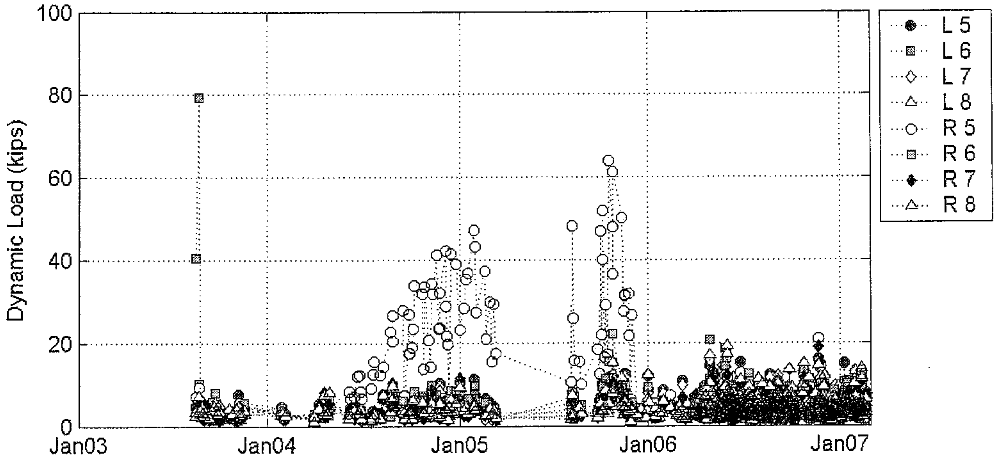
| | | Pneumatic Brakes | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Minimum Application | | Full Service Application (100% Pressure) | | | | Full Service Application (60% Pressure) | | | | Full Service Application (36% Pressure) | | | |
| Truck Location | Shoe Location | Brake Cylinder Pressure | Untapped Force (Per Shoe) | Brake Cylinder Pressure | Tapped Force (Per Shoe) | Tapped Force (Per Truck) | Efficiency | Brake Cylinder Pressure | Tapped Force (Per Shoe) | Tapped Force (Per Truck) | Efficiency | Brake Cylinder Pressure | Tapped Force (Per Shoe) | Tapped Force (Per Truck) | Efficiency |
| B | L1 | 8 | 103 | 64 1/4 | 2975 | 11706 | 69% | 37 | 1868 | 7355 | 76% | | | | |
| | R1 | | 116 | | 2988 | | | | 1864 | | | | | | |
| | L2 | | 167 | | 2817 | | | | 1802 | | | | | | |
| | R2 | | 203 | | 2926 | | | | 1821 | | | | | | |
| C | L3 | | 20 | | 4091 | 15606 | 69% | | 2571 | 9988 | 75.6% | | | | |
| | R3 | | 98 | | 4043 | | | | 2558 | | | | | | |
| | L4 | | 221 | | 3547 | | | | 2361 | | | | | | |
| | R4 | | 223 | | 3925 | | | | 2498 | | | | | | |
| D | L5 | 10 | 223 | 60 1/2 | 3957 | 16104 | 74.4% | 38 | 2532 | 9855 | 75.6% | 24 | 1486 | 5736 | 67.7% |
| | R5 | | 291 | | 3959 | | | | 2502 | | | | 1432 | | |
| | L6 | | 319 | | 3713 | | | | 2425 | | | | 1422 | | |
| | R6 | | 120 | | 3732 | | | | 2396 | | | | 1396 | | |
| E | L7 | | 272 | | 3919 | 16192 | 74.8% | | 2486 | 10188 | 78.2% | | 1591 | 6239 | 73.6% |
| | R7 | | 227 | | 4016 | | | | 2502 | | | | 1510 | | |
| | L8 | | 345 | | 4137 | | | | 2589 | | | | 1566 | | |
| | R8 | | 214 | | 4120 | | | | 2611 | | | | 1572 | | |
| F | L9 | 10 | 491 | 63 1/4 | 3693 | 15060 | 67.5% | 37 1/2 | 2416 | 9757 | 72.1% | | | | |
| | R9 | | 459 | | 3607 | | | | 2368 | | | | | | |
| | LZ | | 419 | | 3864 | | | | 2471 | | | | | | |
| | RZ | | 394 | | 3896 | | | | 2502 | | | | | | |
| A | LY | | 386 | | 3245 | 12665 | 75.8% | | 1960 | 7785 | 76.9% | | | | |
| | RY | | 344 | | 3119 | | | | 1952 | | | | | | |
| | LX | | 309 | | 3007 | | | | 1854 | | | | | | |
| | RX | | 339 | | 3294 | | | | 2019 | | | | | | |
| | Totals | | 6303 | | 86590 | | | | 54928 | | | | 46860 | | |
| | NBR | | | Loaded | 11% | | | 50% Loaded | 11% | | | Empty | 24% | | |

# Appendix B.
# WILD Dynamic Loads

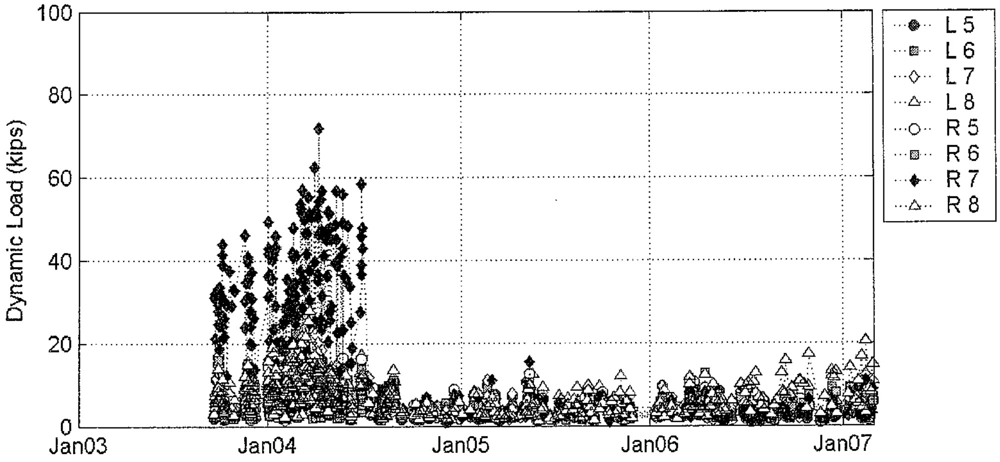

Test Car A Trucks D & E (3 step E/L device)


Test Car B Trucks D & E (3 step E/L device)

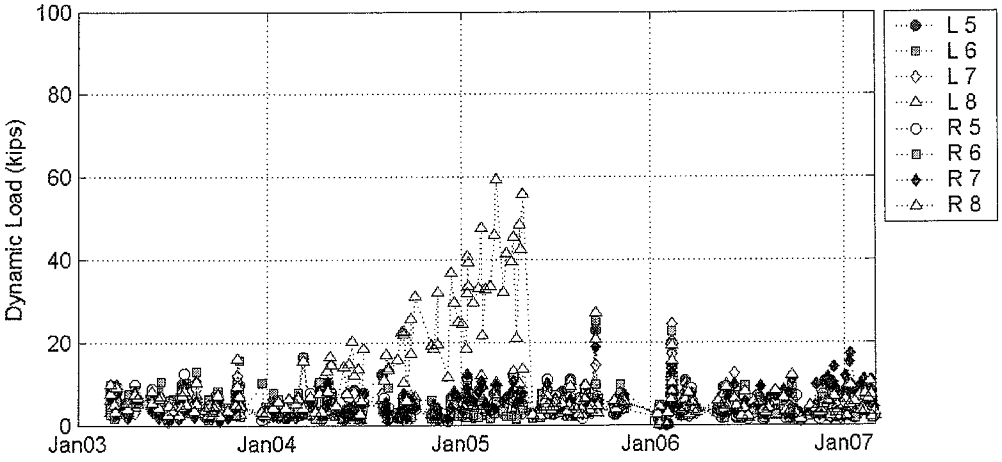
Note: Heavy black vertical lines indicate timing of test car inspections



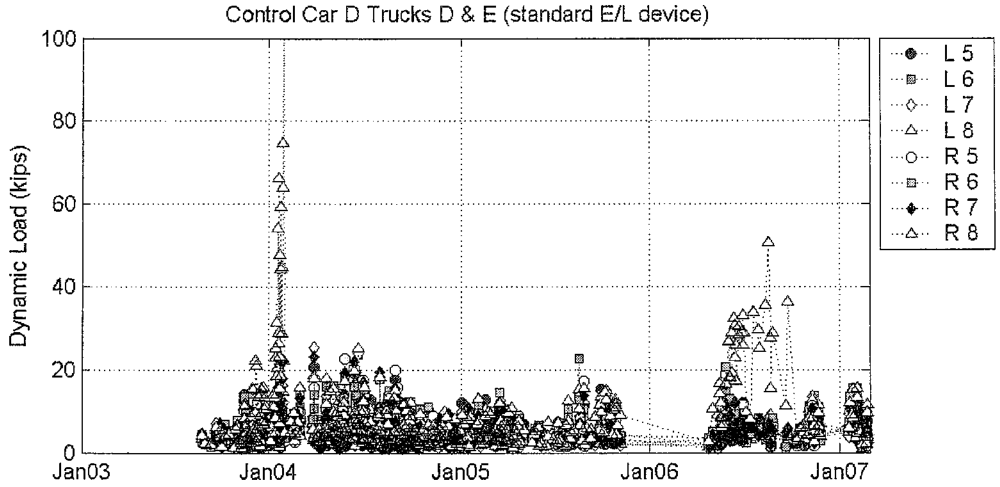
Control Car A Trucks D & E (standard E/L device)

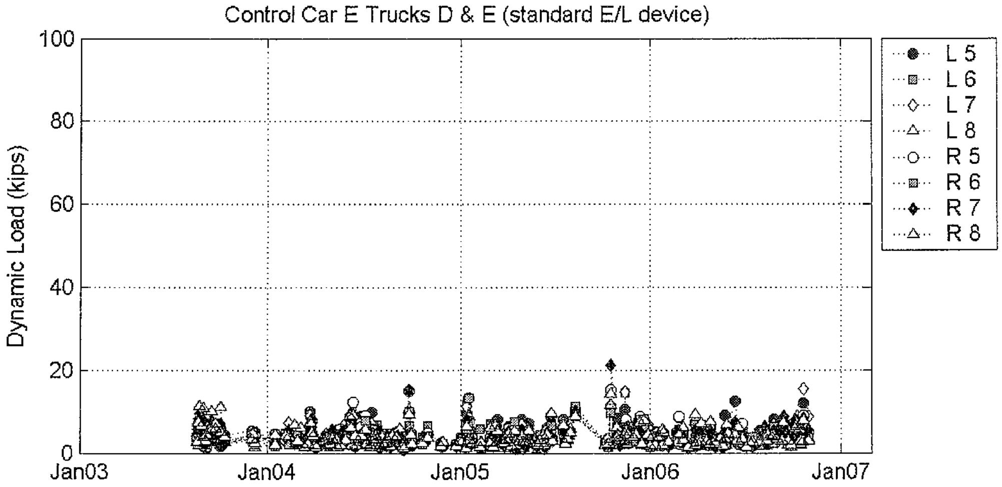


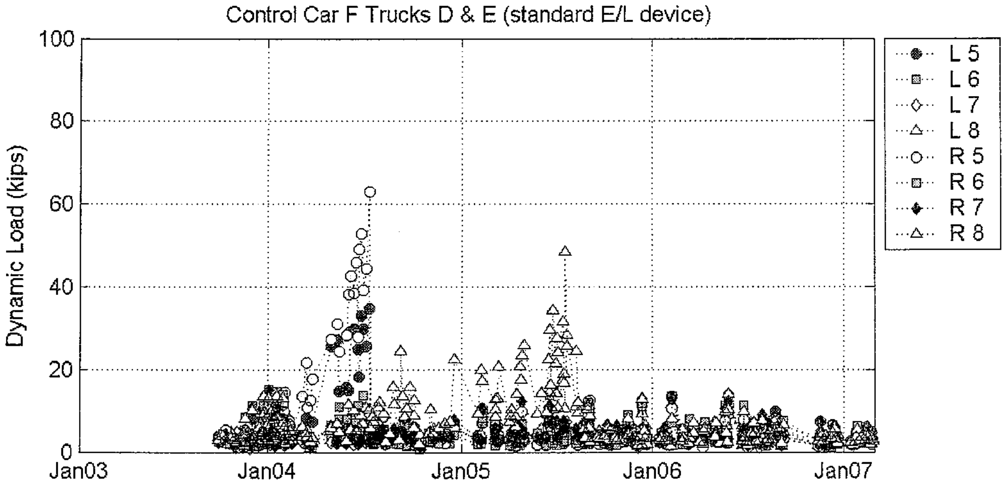
Control Car B Trucks D & E (standard E/L device)

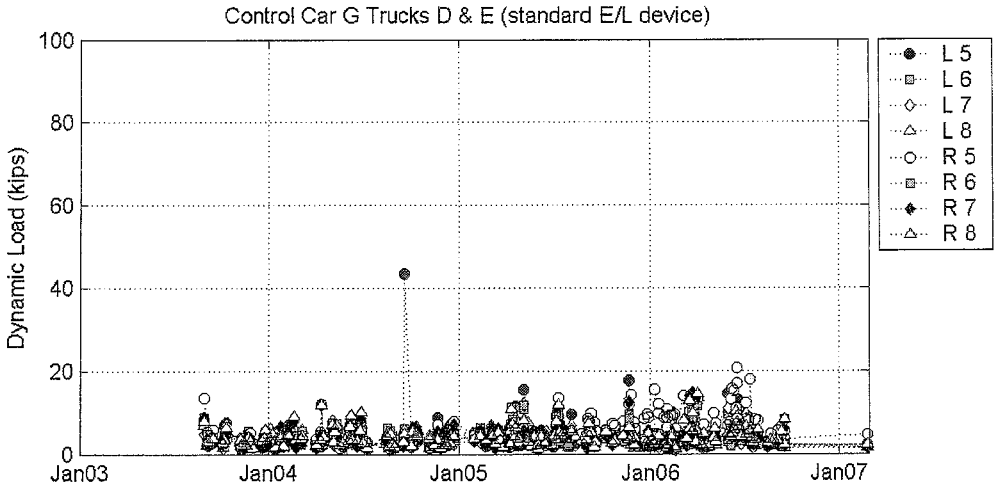


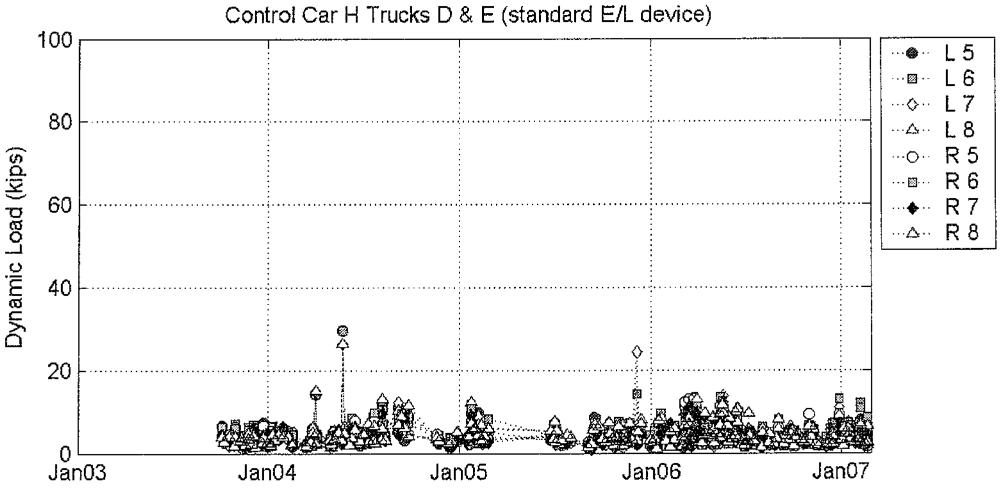
Control Car C Trucks D & E (standard E/L device)

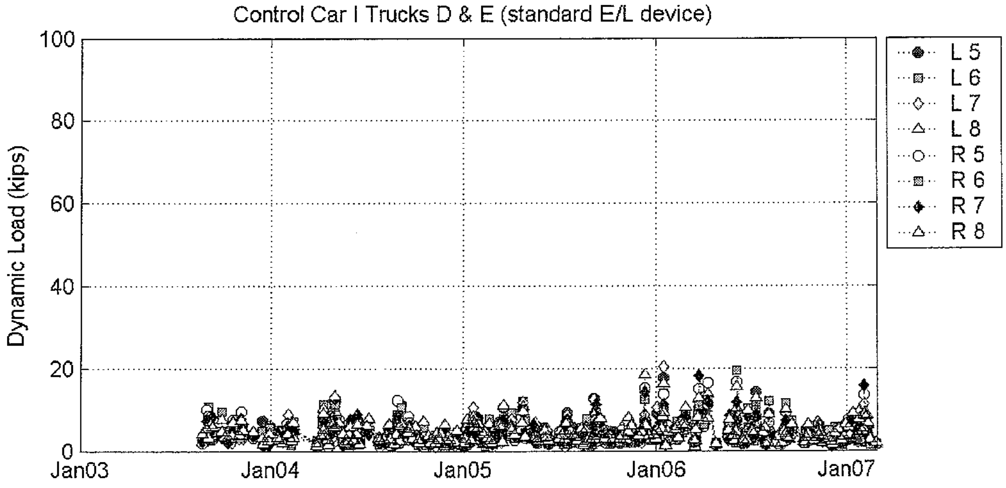

Control Car D Trucks D & E (standard E/L device)

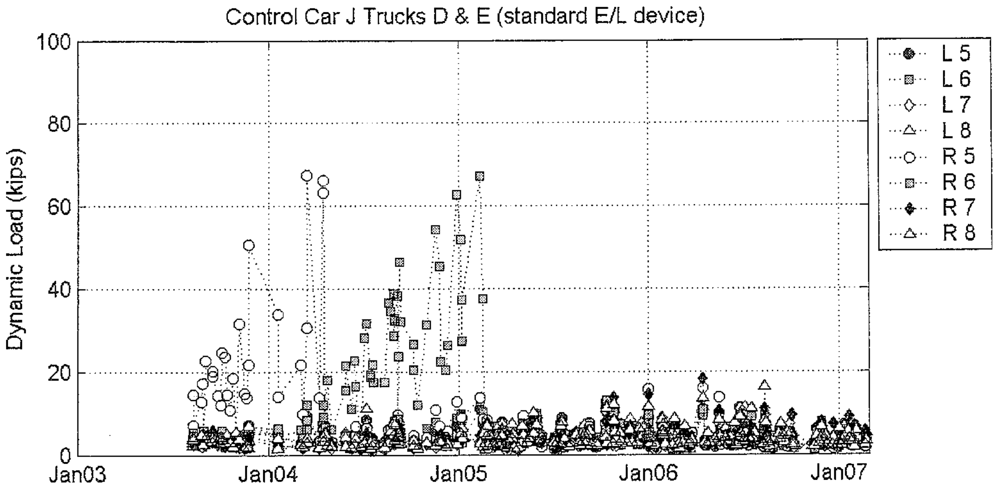

Control Car E Trucks D & E (standard E/L device)


Control Car F Trucks D & E (standard E/L device)


Control Car G Trucks D & E (standard E/L device)


Control Car H Trucks D & E (standard E/L device)


Control Car I Trucks D & E (standard E/L device)


Control Car J Trucks D & E (standard E/L device)
Dynamic Load (kips)
100
80
60
40
20
0
Jan03
Jan04
Jan05
Jan06
Jan07
L 5
L 6
L 7
L 8
R 5
R 6
R 7
R 8

# Acronyms

| | |
|---|---|
| E/L | empty/load (brake device) |
| FRA | Federal Railroad Administration |
| NYAB | New York Air Brake Corporation |
| TTCI | Transportation Technology Center, Inc. (the Company) |
| WILD | wheel impact load detector |