U.S. Department
of Transportation
Federal Railroad
Administration

SIDE BEARING CLEARANCE TESTING RESEARCH

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Final Report

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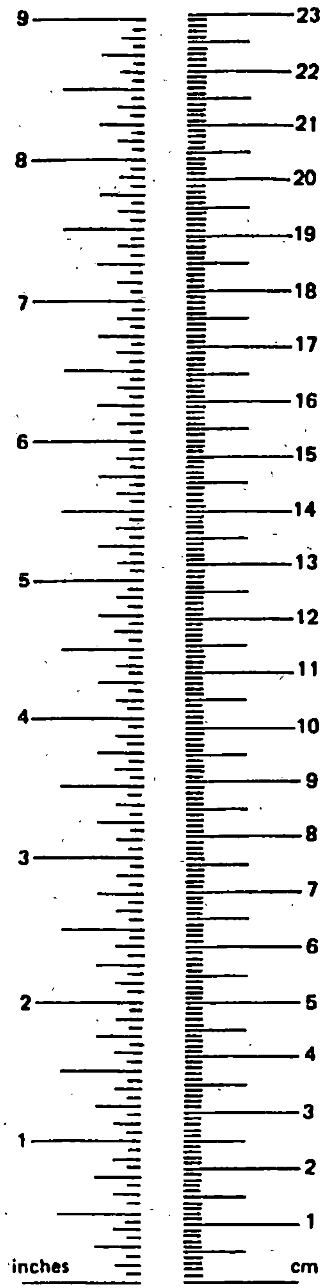
METRIC CONVERSION FACTORS

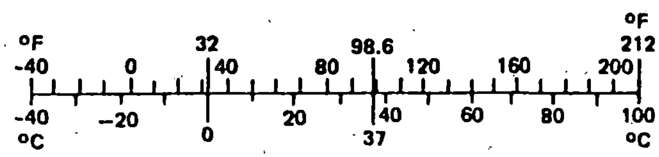
Approximate Conversions to Metric Measures

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



* 1 in. = 2.54 cm (exactly)

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16. Abstract

An investigation of the effects of variations in side bearing clearance on the vehicle dynamics of loaded freight cars with relatively high centers of gravity was conducted.

Data from the Vibration Test Unit (VTU) showed that increasing side bearing clearance significantly affected railcar roll responses. Jump response was exhibited. When testing on-track, the limitation in test zone length made it impossible to replicate the jump response shown during the VTU tests.

Results from the tests are as follows:

1. Compared to nominal gap clearance data, an increased gap produced significantly larger roll angles, at lower peak resonant frequency, over a wider range of frequencies.
2. Increased gap produced slightly less wheel unloading on the VTU. Due to safety considerations, it was not possible to test on-track at wheel-unloading conditions to determine which configuration was more severe.
3. Increased side bearing clearance allows more roll without involving suspension components.
4. On-track testing produced car body roll angles, displacement responses, and wheel loads which were similar in characteristic shape of amplitude level versus speed to the VTU test data, but not in amplitude and frequency. This is probably due to variances in the simulated VTU waveform.
5. It was found that slight changes in the input to the wheel/rail interface may cause major variations in dynamic response. This was most prevalent with the 3/4-inch roller side bearing gap clearance.

17. Key Words

VTU, On-track testing,Side bearing clearance, Jump response, Roll response

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EXECUTIVE SUMMARY

Side bearing clearance greatly influences a freight car's response to track twist during spiral negotiation -- increasing side bearing clearance decreases wheel unloading for a given amount of track twist. Thus, the potential for increased tolerance of track twist by increasing side bearing clearance was a motivator for this test. However, side bearing clearance also influences harmonic roll behavior, and there is concern about the possibility of increased roll response, wheel unloading, and rock-off tendency.

Of additional concern, describing-function analysis conducted by Volpe National Transportation Systems Center (VNTSC) indicated the potential for same track conditions and train operating speeds to produce different roll response depending upon whether the train is accelerating or decelerating.[1,2] This phenomenon is termed "jump response." It also has been encountered during previous VTU testing on boxcars.[3] Jump response occurs when the vibration frequency is decreased at a relatively uniform rate on a vehicle with a softening suspension system. It was anticipated that increasing side bearing clearance would amplify the effect of the roll suspension softening. Jump response was induced by the VTU with accelerating (sweep up) and decelerating (sweep down) sinusoidal waveform inputs.

Unfortunately, there is little supporting harmonic-roll test data available, and there has been contradicting model predictions as to whether increasing side bearing clearance improves or worsens harmonic roll behavior.

The Association of American Railroads, Transportation Test Center, Pueblo, Colorado, with support and direction from Federal Railroad Administration and VNTSC, conducted tests on the Vibration Test Unit (VTU) using a loaded freight car with a high center-of-gravity. The VTU was used to simulate a range of amplitudes of sinusoidally varying track cross level with a wavelength equal to the truck center spacing of the test vehicle. The simulated frequencies were varied to correspond to a range of test speeds of approximately 10 to 25 mph. The car was tested with constant-contact side bearings and conventional roller side bearings. When the car was equipped with the conventional roller side bearings, test runs were made with different side bearing to car body bolster gap clearances. Two truck sets were tested on the VTU.

The AAR also operated the car in two side bearing gap configurations on the Precision Test Track over the twist-and-roll test zone to correlate VTU and on-track car behavior.

It was evident from the VTU test data that increasing side bearing clearance significantly affected railcar roll responses. Jump response was exhibited. When testing on-track, the limitation in test zone length made it impossible to replicate the jump response shown during the VTU tests. If a research program were conducted to investigate the effect of side bearing clearance on roll response with only on-track testing, an error in conclusions could result unless a test zone of sufficient length and a variety of operating modes (increasing speed, decreasing speed) were developed.

Results from the tests show:

1. Compared to nominal gap clearance data, an increased gap produced significantly larger roll angles, at lower peak resonant frequency, over a wider range of frequencies.
2. Increased gap produced slightly less wheel unloading on the VTU. Due to safety considerations, it was not possible to test on-track at wheel-unloading conditions to determine which configuration was more severe.
3. Increased side bearing clearance allows more roll without involving suspension components.
4. On-track testing produced car body roll angles, displacement responses, and wheel loads which were similar in characteristic shape of amplitude level versus speed to the VTU test data, but not in amplitude and frequency. This is probably due to variances in the simulated VTU waveform.
5. It was found that slight changes in the input at the wheel/rail interface may cause major variations in dynamic response. This was most prevalent with the 3/4-inch roller side bearing gap clearance.

Differences in response between on-track tests and VTU tests are attributed in part to differences in input excitation and track modulus, which result in higher critical speeds, and to lack of realistic wheel/rail interaction forces, which result in altered vertical forces and unrealistic lateral forces (lateral dynamics). The inability of the VTU to accurately produce wheel/rail interaction forces and their ratios is a key problem. This criterion is extremely important for replicating many on-track certification procedures. Differences are also suspected to be attributed to lack of the random vibrations that are produced by wheel/rail dynamics, train handling, and other sources. These vibrations tend to reduce break-away friction in friction snubber elements. This was especially critical with higher-damped trucks.

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PREFACE AND ACKNOWLEDGEMENTS

This Federal Railroad Administration (FRA) sponsored research project was conducted at the Association of American Railroads (AAR) managed Transportation Test Center (TTC), Pueblo, Colorado, to investigate the effects of variations in side bearing clearance on the vehicle dynamics of loaded freight cars with relatively high centers-of-gravity. The project, Freight Car Tolerance -- Side Bearing Clearance Project, began in April, 1993. Concurrently, the AAR provided supplemental funding for the development of special instrumentation and equipment re-configuration required to successfully complete the project. A description of test preparation is found in the appendix.

Significant milestones, listed below, were met because of the dedication of many people. Key participants are being recognized for their involvement in the project.

SIGNIFICANT SEQUENTIAL MILESTONES

Significant milestones are sequentially arranged from the inception to the completion of this task order in the following table.

Significant Milestones

Project Milestone	Date Achieved
Contract award	4/14/93
Develop test procedures	5/93 - 6/93
AAR-funded test preparations: VTU instrumented load-measuring rail beam development, VTU translation	5/93 - 6/93
Test preparations: test car instrumentation setup, input development	6/93
Perform VTU tests	7/13/93 - 9/3/93
Setup for on-track tests	9/93
Perform on-track tests	10/13/93 - 10/15/93
Perform data analysis	8/93 - 12/93
Prepare report, data presentation	12/93 - 2/94

KEY PARTICIPANTS

Claire Orth and Tom Schultz of the FRA provided project management and technical guidance and were instrumental in the conduct of this test program. Dr. Herb Weinstock, David Tyrell, and Chris Dorsey of the Volpe National Transportation Systems Center also provided technical guidance and were instrumental in the conduct of this program.

The AAR employed a matrix project management organization to successfully meet the project objectives. The overall responsibility of managing the project resided with the Manager of Engineering Projects. The project required personnel from the Engineering, Instrumentation, and Operations departments at the TTC. Britto Rajkumar, Robert Florom, and David Cackovic, AAR/TTC, performed the project management tasks required for the successful conduct of the test program.

The key AAR/TTC participants in this project were:

<u>VTU Translation and Operation:</u>

Denzel Savage, Sr. RDL Technician
Tom Solano, RDL Technician
Claude Baggus, RDL Technician
Mike Sandoval, RDL Technician

<u>VTU and On-track Instrumentation and Operation:</u>

Wayne Cooksey, Electronic Systems Engineer

<u>VTU Instrumentation and Operation:</u>

Dave Johns, Sr. Instrumentation Technician

<u>On-track Testing:</u>

Kerry Hopkins, Sr. Engineer I
Steve Belport, Engineer
Ron Bidwell, Instrumentation Engineer
Mike Sudduth, Test Controller

1.0 INTRODUCTION

The Federal Railroad Administration (FRA) sponsored a research project with the Association of American Railroads (AAR) managed Transportation Test Center (TTC), Pueblo, Colorado, to investigate the effects of variations in side bearing clearance on the vehicle dynamics of loaded freight cars with relatively high centers of gravity (c.g.).

The AAR conducted tests on the Vibration Test Unit (VTU) using a loaded freight car with a high c.g. The VTU was used to simulate a range of amplitudes of sinusoidally varying track cross level with a wavelength equal to the truck center spacing of the test vehicle. The simulated frequencies were varied to correspond to a range of test speeds of approximately 10 to 25 mph. The car was tested with constant-contact side bearings and conventional roller side bearings. When the car was equipped with the conventional roller side bearings, test runs were made with different side bearing to car body bolster gap clearances. Two truck sets, the original "Truck 1" and the more highly damped "Truck 2" were tested on the VTU.

The AAR also operated the car in two side-bearing gap configurations on the Precision Test Track (PTT) over the twist-and-roll (T&R) test zone to correlate VTU and on-track car behavior.

1.1 BACKGROUND

Side bearing clearance greatly influences a freight car's response to track twist during spiral negotiation -- increasing side bearing clearance decreases wheel unloading for a given amount of track twist. Thus, the potential for increased tolerance of track twist by increasing side bearing clearance was a motivator for this test. However, side bearing clearance also influences harmonic roll behavior, and there is concern about increased roll response, wheel unloading, and rock-off tendency.

Of additional concern, function analysis conducted by VNTSC indicated the potential for same track conditions and train operating speeds to produce different roll response depending upon whether the train is accelerating or decelerating.[1,2] This phenomenon is termed "jump response." This has also been encountered during previous VTU testing on boxcars.[3] Jump response occurs when the vibration frequency is decreased at a relatively uniform rate on a vehicle with a softening suspension system. It was anticipated that increasing side bearing clearance would amplify the effect of the roll suspension softening. Jump response was induced by the VTU with accelerating (sweep up) and decelerating (sweep down) sinusoidal waveform inputs.

Unfortunately, there is little supporting harmonic-roll test data available, and there has been contradicting model predictions as to whether increasing side bearing clearance improves or worsens harmonic roll behavior.

Jump response was induced by the VTU with accelerating (sweep up) and decelerating (sweep down) sinusoidal waveform inputs. Figure 1 details jump response by comparing the results from the up and down sweeps which resulted from the prescribed VTU operations.

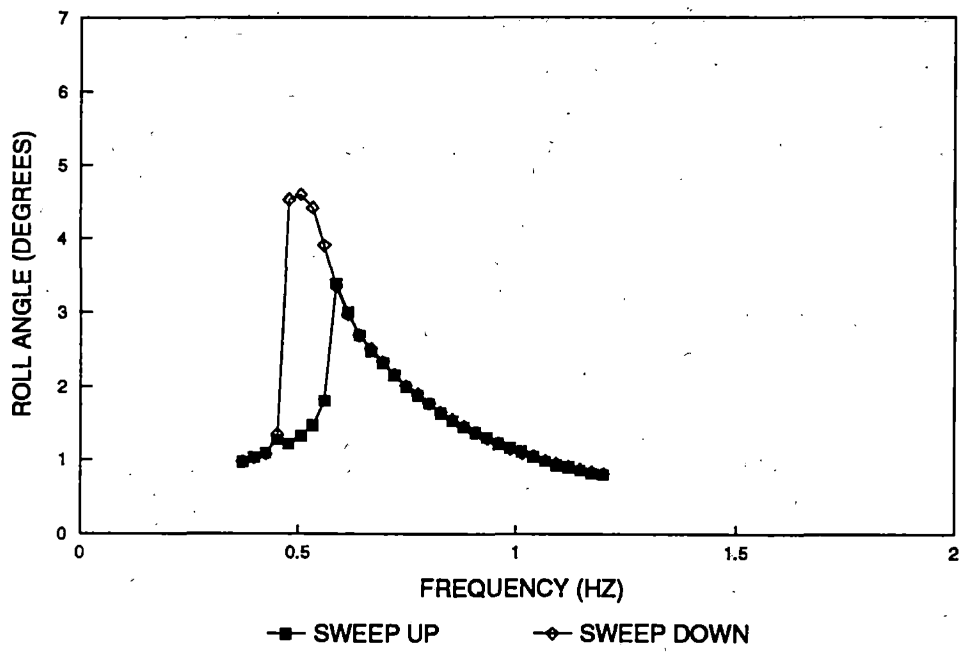


Figure 1. Example of Jump Response Phenomena in Car Body Roll

2.0 OBJECTIVE

The objective of this test was to determine experimentally the influence of side bearing clearance on the roll response of loaded freight cars through laboratory and on-track tests.

3.0 TEST CAR

Initially, it was planned to select and modify a test car to obtain a c.g. of 98.5 inches. However, the car selection process uncovered AAR102, a 100-ton capacity covered hopper car equipped with variable-damped Barber S-2-C trucks and 688B side bearing cages with rollers. The car is loaded to full capacity with a c.g. height of 93 inches above the railhead. The load was well-packed cement powder and did not shift during testing.

AAR102 has a history of testing dating back to when it was part of the Norfolk Southern Car Rocker Test Facility for testing trucks and snubbing devices. AAR102 is currently used by AAR/TTC for the conduct of testing described in AAR Specification M-965-86, "Special Devices to Control Stability of Freight Cars." After discussions with FRA and Volpe National Transportation Systems Center (VNTSC) personnel it was agreed that AAR102 would be used as the test car.

The AAR102 was tested with its own trucks (Truck 1) and with higher damped trucks (Truck 2).

3.1 TEST CAR STATISTICS

Test car statistics are given in Table 1.

Table 1. Test Car Statistics

Category	Item
Classification	Covered Hopper
Year Built	1971 (reconditioned in 1978)
Car number	AAR102
Capacity	200,000 lbs
Load limit	203,200 lbs
Light weight of car	59,800 lbs
Load tested	210,900 lbs
Weight on rail as tested	270,700 lbs
C.G. as tested	93"
Length between truck centers	40' 7"
Length of truck wheel base	70"
Truck 1	Barber S-2-C, 100-ton, variable-damped trucks (under damped for this application)
Truck 2	Barber S-2-C, 100-ton, variable-damped trucks with higher dampening
Side bearings as-received	Roller side bearings Stucki 688B cages
Spring Group	28 outer D-5, 28 inner D-5, 8 inner D-6
Draft Gear and couplers	M901E, standard type E

3.2 TEST CAR CHECKOUT

In addition to visual inspection, the test car was run over the twist-and-roll section of the PTT at 10 mph and carefully monitored to ensure that no response anomaly existed with the trucks supplied (Truck 1). Standard 1/4-inch side bearing gaps were tested.

3.3 TEST CAR MODIFICATIONS AND REPAIR

Initial inspection of AAR102 noted that the A- and B-end left side bearing pedestals and body bolsters were slightly damaged, probably the result of rocking out of the centerbowls during testing at the Norfolk Southern facility. This resulted in slightly bent A- and B-end left side bearing plates due to the unevenness of the plate support surface, as shown in Figure 2.

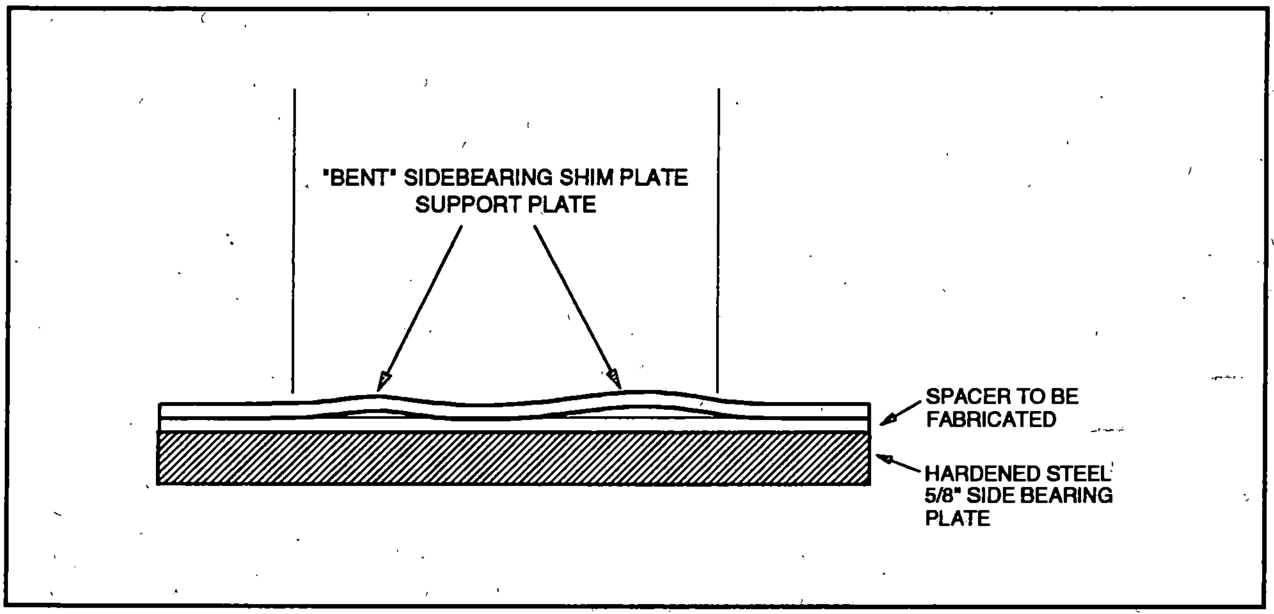


Figure 2. Uneven Side Bearing Plate Support Surface to Be Repaired

The test car's left-side side bearing shim supports were straightened to eliminate side bearing shim bending by heating the plates, then jacking a flat, hardened steel plate against the uneven surface. In addition, a product called "Liquid Steel," which hardens to a tough finish which can withstand shock loads, was used between the side bearing shims and support plate on the car body bolster to remove any remaining irregularities and ensure uniform shim support.

The final car configuration tested was documented with still photographs.

3.4 SIDE BEARING SHIMS

Side bearing shims were machined to allow the side bearing gap configurations listed in Table 2 to be tested.

Table 2. Side Bearing Gap Test Configurations

Side Bearing Type and Clearance
Roller, 1/4 inches (standard)
Roller, 0 inches
Roller, 1/2 inches
Roller, 3/4 inches
Constant Contact

The side bearing cage-bases had 1/4 to 1/2 inch removed to allow the maximum gap configurations to be tested. Figure 3 displays the locations used to determine the average gap. These measurements were used to ascertain the side bearing shim thickness required, as listed in Table 3.

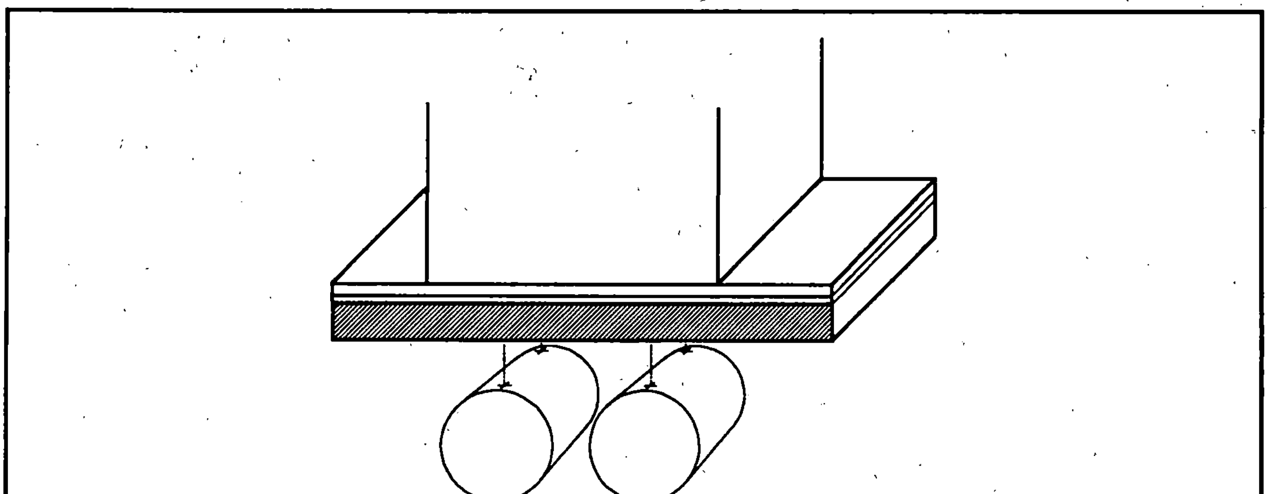


Figure 3. Locations Measured to Determine Side Bearing Shim Thickness

Table 3. Side Bearing Shims

Side Bearing Location	Avg. Beg. Gap	Side Bearing Gap[a] Configuration			
		1/4" Gap	3/4" Gap	1/2" Gap	0" Gap
		Required Shim Thickness			
BL	.731"	.481"	-0.019"[b]	.231"	.731"
BR	.738"	.488"	-0.012"[b]	.238"	.738"
AL	.924"	.674"	0.174"	.424"	.924"
AR	.791"	.541"	0.041"[b]	.291"	.791"

[a] Side bearing gaps will also be measured after shims are installed -- before and after each test configuration

[b] Error considered acceptable -- no shims required

The side bearing shims matched the geometry of the standard side bearing plates with the exception that the shims were slotted to allow easy installation and removal. Figure 4 shows the side bearing shim design.

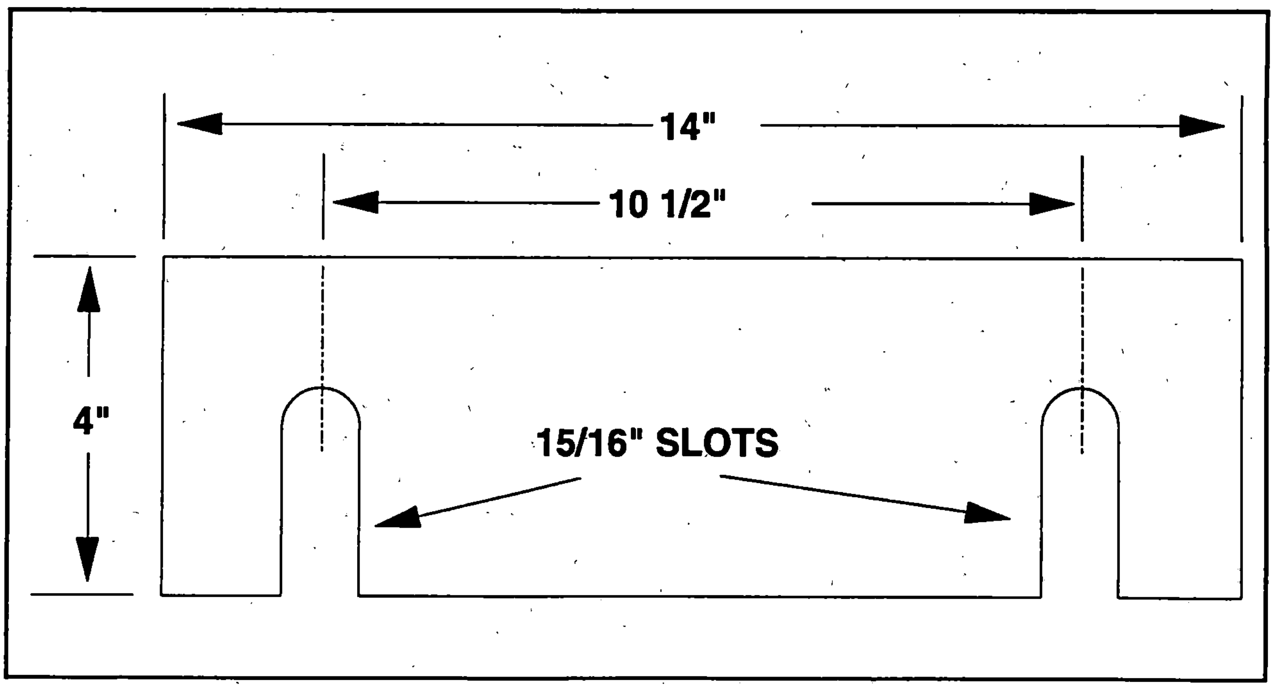


Figure 4. Side Bearing Shim Design

4.0 VTU TESTING

4.1 VTU TEST PROCEDURES

The VTU tests were performed from July 13 through September 3, 1993. Test procedures and results are described in the following sections.

4.1.1 VTU Test Instrumentation

4.1.1.1 Measurement Definitions

VTU Load-Measuring Instrumented Rail Beams

The VTU load-measuring instrumented rail beams are described in the appendix.

Roll Gyros

Two roll gyros were installed on both ends of the test car at the longitudinal c.g. center line to measure car body roll. They produce an output signal of roll rate that is subsequently integrated before recording by the data acquisition system. Figure 5 displays one of the gyros.

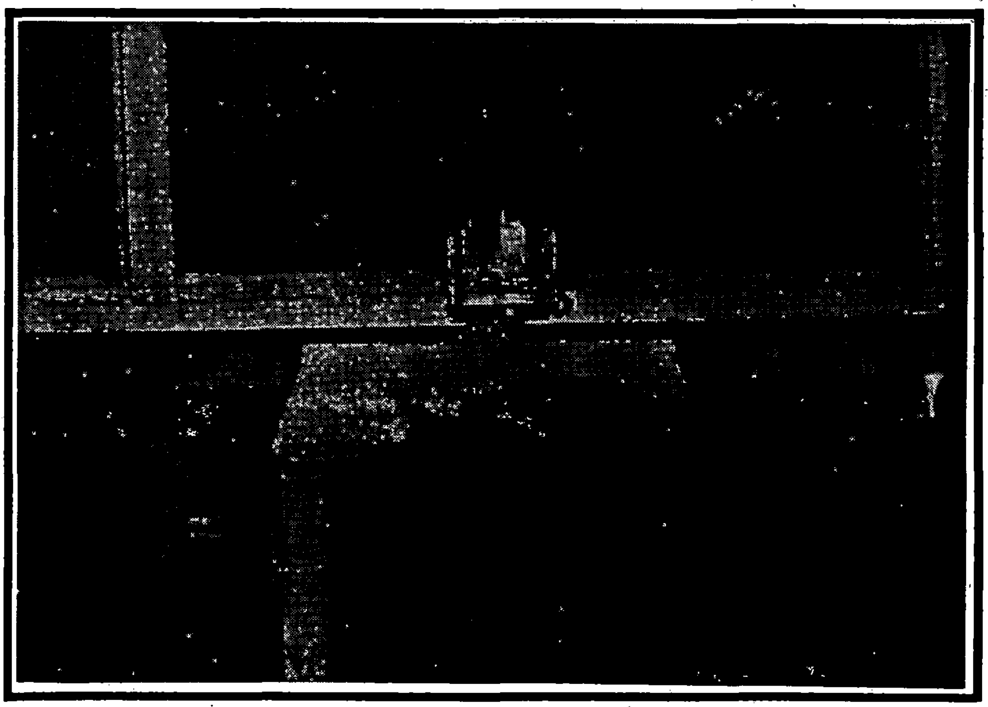


Figure 5. Roll Gyro

String Potentiometers

String potentiometers were installed across the spring nest on each of the four spring groups to measure the vertical displacement of the secondary suspension elements. String potentiometers were also installed between the car body and the truck bolster at each side bearing to measure dynamically the side bearing clearance.

4.1.1.2 VTU Test Measurement Summary

A summary of the measurements made during the VTU test is provided in Table 4. Figure 6 shows the measurement locations on the test car.

Table 4. VTU Test Measurement Summary

Meas. No.	Channel Name	Description
1	GYRB	B-End Car Body Roll Angle
2	GYRA	A-End Car Body Roll Angle
3	DZRB	B-End, Right Side Spring Nest Displacement
4	DZLB	B-End, Left Side Spring Nest Displacement
5	DZRA	A-End, Right Side Spring Nest Displacement
6	DZLA	A-End, Left Side Spring Nest Displacement
7	RSBB	B-End, Right Side Displacement Across Side Bearing
8	LSBB	B-End, Left Side Displacement Across Side Bearing
9	RSBA	A-End, Right Side Displacement Across Side Bearing
10	LSBA	A-End, Left Side Displacement Across Side Bearing
11	VF1R	B-End, Axle 1, Right Side Vertical Wheel Force
12	VF1L	B-End, Axle 1, Left Side Vertical Wheel Force
13	VF2R	B-End, Axle 2, Right Side Vertical Wheel Force
14	VF2L	B-End, Axle 2, Left Side Vertical Wheel Force
15	VF3R	A-End, Axle 3, Right Side Vertical Wheel Force
16	VF3L	A-End, Axle 3, Left Side Vertical Wheel Force
17	VF4R	A-End, Axle 4, Right Side Vertical Wheel Force
18	VF4L	A-End, Axle 4, Left Side Vertical Wheel Force

Note: Though not listed, lateral forces were also recorded.
VTU actuator control measurements (not listed) were also recorded to ensure proper control of excitation input signals into the test car.

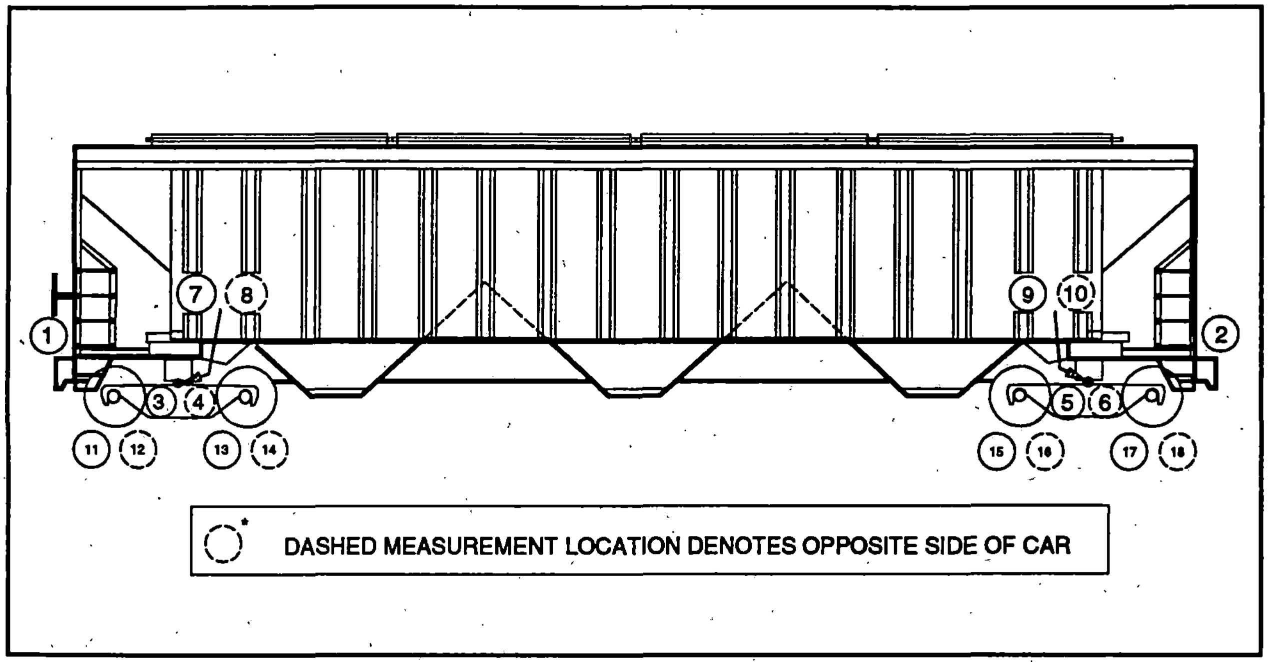


Figure 6. VTU Test Measurement Locations

4.1.1.3 VTU Test Data Acquisition

The Statement of Work called for VTU test data to be low-pass filtered at 5 Hz and sampled at 20 Hz. This would have been adequate for recording the low-frequency gross motions. However, 5- to 15-Hz information resulting from the action of the friction elements is often superimposed on the gross motion responses. In addition, the instrumented wheel sets used for on-track testing required a low-pass filter rate of 15 Hz with a sample rate of 150 samples-per-second. Since the on-track data was to be compared to the VTU rail-force data, it was decided to low-pass filter the VTU test data at 15 Hz, then record it digitally with a Hewlett-Packard 330 computer at a rate of 150 samples per second.

Four eight-channel strip-chart recorders were used to monitor up to 32 selected measurements. Still photography was used to document the instrumentation setup. Limited color video footage was also taken of at least four VTU runs using 1/2-inch VHS format video equipment.

4.1.1.4 VTU Test Measurement Daily Calibrations

Calibration of each test measurement was verified each test day. This was done with the HP data acquisition system checkout mode and through the use of shunt resistor calibrations and/or a brass cylinder of known circumference (string potentiometers only). The resulting data was logged for later retrieval, if required.

4.1.2 VTU Testing

4.1.2.1 Safety Considerations

Critical vertical wheel loads (unloading) and car body peak-to-peak roll angles (values greater than 6 degrees) were monitored on strip-chart recorders real-time throughout the testing. This, combined with visual observation of the VTU and test car, ensured the safe operation of the test.

4.1.2.2 VTU Test -- Inputs

The Statement of Work defined the inputs as sinusoidal waveforms phased to induce a pure roll response of the test car (i.e. the left side actuators were 180 degrees out-of-phase with the right side actuators). The Statement of Work also required the inputs to simulate speeds ranging from 10 to 25 mph and 25 to 10 mph. Low resolution speed steps (1 mph) and high resolution speed steps (0.1 mph) within the speed ranges were defined. Test input amplitudes were also clearly defined.

In the railroad environment, large roll responses usually are induced by staggered 39-foot rail sections. Therefore, "pure" roll can only be induced when a car's truck spacing is 39 feet. The test car's truck spacing was 40 foot, 7 inches; therefore, it could not be subjected to pure roll in normal railroad operations. Thus, using speed units of miles-per-hour for data presentation would not be entirely accurate for the VTU test data. For these reasons, the VTU test data is plotted as response versus frequency to reduce error and minimize confusion over the nature of the excitation.

Initially, an input development method was devised which involved the creation of files containing harmonic-roll input waveform data prior to testing. This method included a data reduction scheme which automated the determination and plotting of response for each individual speed step. This was accomplished before a pre-test meeting with Dr. Weinstock.

Waveforms

Inputs based on the sinusoidal waveform, shown in Figure 7, were used for testing. The mathematically-generated sinusoidal profile was applied only to the VTU vertical actuators and phased such that the car experienced pure rocking motions. Figure 7 also shows the transition and data zones, which were used in data reduction and analysis to eliminate transient response in the final data presented.

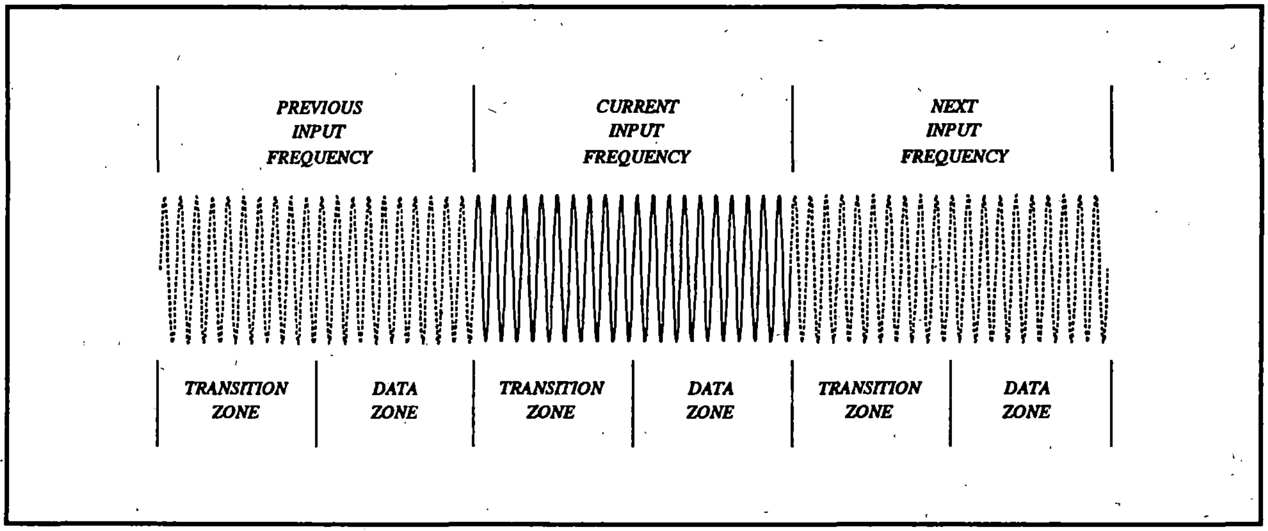


Figure 7. Sinusoidal Waveform

Low-Resolution Speed Step Definition

The FRA Statement of Work required 1 mph steps for low-resolution input speed steps, which corresponds to approximately 0.37607 Hz steps. The frequency steps for the low-resolution speed step inputs actually used were approximately 0.25 Hz.

High-Resolution Speed Step Definition

The FRA Statement of Work required 0.1 mph steps for high-resolution input speed steps, which corresponds to approximately 0.00376 Hz steps. The frequency steps for the low-resolution speed step inputs actually used were approximately 0.0035 Hz.

4.1.2.3 VTU Testing -- Side Bearing and Snubber Configurations

The Statement of Work defined 10 truck configurations to be tested on the VTU. Table 5 lists eight of them. Snubber-disabled test configurations 2, 4, 6, 8, and 10 were planned for Truck 1. However, excessive response during preliminary configuration 2 tests prevented further testing on the undamped truck configurations. Therefore, these tests were suspended. Configurations 11 and 12 were substituted to test the more highly damped Truck 2.

Table 5. Summary of the VTU Test Configurations

Configuration No.	Side Bearing Type	Side Bearing Clearance	Snubber Operation	Truck Type
1	Roller	1/4 inches	Enabled	Truck 1
2	Roller	1/4 inches	Disabled	Truck 1
3	Roller	0 inches	Enabled	Truck 1
5	Roller	1/2 inches	Enabled	Truck 1
7	Roller	3/4 inches	Enabled	Truck 1
9	Constant Contact	N/A	Enabled	Truck 1
11	Roller	1/4 inches	Enabled	Truck 2
12	Roller	3/4 inches	Enabled	Truck 2

4.1.2.4 Truck Break-in and Vertical Suspension Characterization

Quasi-static characterizations of the vertical suspension were performed on the VTU by slowly lifting each end of the car while measuring and recording all wheel vertical forces and spring deflections. Frequency response sweeps on the VTU in a pure bounce mode at an input amplitude of 0.5 inches were also run. X-Y plots at resonance were developed for these runs to determine test truck stiffness and damping characteristics. Table 6 lists the quasi-static and dynamic (bounce) truck characterization tests conducted on the VTU.

Table 6. Vertical Suspension Characterization Tests

Run No.	Start Freq.	End Freq.	Delta Freq.	P-P Act. Amp.	Comment
010	0.7	4	.2	1/2"	Configuration 1 bounce truck characterization.
011					Configuration 1 quasi-static truck characterization -- lift and lower car with crane.
030					Configuration 5 quasi-static truck characterization -- lift and lower car with crane.
063	.2	4	.2	1/2"	Configuration 3 bounce truck characterization. Repeat at end of tests with snubbers per Dave Tyrell's directions.
064					Configuration 3 quasi-static truck characterization -- lift and lower car with crane.
065	0.2	4	.2	1/2"	Configuration 2 bounce truck characterization. Too severe. Aborted at 2.6 Hz.
066	0.2	4	.2	1/4"	Configuration 2 bounce truck characterization. Too severe. Aborted at 2.4 Hz.
076	.2	4.0	.2	1/4"	Configuration 11 bounce truck characterization.
083	.4	4.2	.2	1/2"	Configuration 11 bounce truck characterization.
084	.2	4.8	.2	1/2"	Configuration 11 bounce truck characterization.
088					Configuration 12 static truck characterization.
089	.2	4.8	.2	1/2"	Configuration 12 bounce truck characterization.

4.1.2.5 VTU Testing -- Operations

The VTU tests with the inputs and configurations described above were conducted from July 13 through September 3, 1993. Strip charts were maintained and documented, including each speed change in the test speed sweeps. After preliminary checkout runs were conducted, the VTU tests were performed as follows:

1. Start test day instrumentation calibration checkouts.
2. Perform quasi-static and dynamic (bounce) suspension characterization tests.
3. Perform low- and high-resolution speed step sweep runs.

Table 7 lists the successful VTU test runs to evaluate roll response -- runs not included in the log include checkout runs, initial runs to determine the range of amplitudes to be tested, runs with errors, and runs with equipment failures.

Table 7. VTU Test Run Log

Run No.	Start Freq.	End Freq.	Delta Freq.	P-P Act. Amp.	Comment
Configuration 1 (Truck 1, 1/4" Side-bearing Clearance with Snubbers): This is the first configuration tested (July 13-14, 1993), and much trial and error was required until suitable input amplitudes were found.					
023	1.2	.373	.025	3/8"	First run in Run Log Summary Matrix (all runs in Run Log Summary Matrix are shaded).
024	.373	1.2	.025	3/8"	Paired with run 023.
025	.6	.704	.0035	3/8"	High resolution run. Need to go to slightly higher frequency.
026	.597	.726	.0035	13/32"	High resolution run. Held for bad actuator, ramp up and down several times within run.
Configuration 5 (Truck 1, 1/2" Side-bearing Clearance with Snubbers): This configuration was tested on July 14 and 15, 1993. Jump response was noted during ramp-down runs -- the ramp-down run seemed to produce a resonance that lasted through a wider frequency range than configuration 1. Again, 3rd and 4th solution responses were not found.					
028	.373	1.2	.025	13/32"	Paired with run 029.
029	1.2	.373	.025	13/32"	Paired with run 028.
031	1.2	.373	.025	3/8"	Paired with run 032.
032	.373	1.2	.025	3/8"	Paired with run 031.
033	.6223	.4573	.0035	13/32"	High resolution run. Sweep down from .6223 Hz to .4573 Hz, then back up to .5535 Hz to hold to set up for another HP data file (T101_RN034).
034	.5535	.5088	.0035	13/32"	High resolution run. Start at hold at .5535 Hz from previous run, sweep down to .4641 Hz, sweep up to .5123 Hz, then back down to .4573 Hz.

Table 7. VTU Test Run Log -- Continued

Run No.	Start Freq.	End Freq.	Delta Freq.	P-P Act. Amp.	Comment
Configuration 7 (Truck 1, 3/4" Side-bearing Clearance with Snubbers): This configuration was tested on July 15 and 16, 1993. Jump response was clearly noted during ramp-down runs, and it was obvious that the ramp-down runs produced a resonance that lasted through a wider frequency range than configuration 1. Again, 3rd and 4th solution responses were not found. Although the resonance lasted through a considerably wider range of frequencies in this configuration as compared to the nominal configuration 1 during ramp-down runs, an amplitude which caused wheel lift in configuration 1 did not cause the test car to near-wheel lift in this configuration.					
035	.373	1.2	.025	1/4"	Paired with run 036.
036	1.2	.373	.025	1/4"	Paired with run 035.
037	.3094	1.16	.025	3/8"	Paired with run 038.
038	1.16	.3094	.025	3/8"	Paired with run 037.
039	.3094	.7992	.025	13/32"	Paired with run 040. Run stopped at .7992 Hz due to pump problem -- data OK.
040	1.184	.22	.025	13/32"	Paired with run 039.
041	.599	.305	.0035	13/32"	High resolution run. Sweep down from .5993 Hz to .4078 Hz, back up to .422 Hz, down to .4078 Hz, up to .4433 Hz, down to .383 Hz, then to hold and stop at .4078 Hz to set up HP system for data run T101_RN042.
042	.5535	.5088	.0035	13/32"	High resolution run. Start at hold at .4078 Hz from previous run, sweep down to .3688 Hz, hold to repair actuator, up to .3759 Hz, hold to fix actuator -- disk off burst 1 on TO101_RN042 data file, start burst 2 and up to .5355 Hz, hold to fix actuator, disk off burst 2 on TO101_RN042 data file, start burst 3 and up to .5887 Hz, then down to .5284 Hz.
Configuration 9 (Truck 1, Resilient Constant Contact Side-bearings with Snubbers): This configuration was tested on July 22, 1993. Jump response was clearly noted during ramp-down runs, and it was obvious that the ramp-down runs produced a resonance that lasted through a wider frequency range than configuration 1. Again, 3rd and 4th solution responses were not found. This configuration looked similar to configuration 7 -- 3/4" side-bearing clearance with snubbers.					
045	.373	1.2	.025	1/4"	Paired with run 046.
046	1.2	.373	.025	1/4"	Paired with run 045.
047	.373	1.2	.025	3/8"	Paired with run 048.
048	1.2	.373	.025	3/8"	Paired with run 047.
049	.373	1.2	.025	13/32"	Paired with run 050.
050	1.2	.373	.025	13/32"	Paired with run 049.
051	.846	.4679	.0035	13/32"	High resolution run. Sweep down from .846 Hz to .4929 Hz, up to .5107 Hz, down to .4679 Hz, then up to .4822 Hz.
052	.5778	.7815	.0035	13/32"	High resolution run. Continuous sweep up.

Table 7. VTU Test Run Log -- Continued

Run No.	Start Freq.	End Freq.	Delta Freq.	P-P Act. Amp.	Comment
Configuration 3 (Truck 1, 0" Side-bearing Clearance with Snubbers): This configuration was tested on July 23, 1993 and August 30 - 31, 1993 (runs 74 - 75). Some very minor jump response was noted during ramp-down runs, and this was the only configuration with snubbers to suffer wheel lift with 13/32" and 3/8" P-P inputs. Again, 3rd and 4th solution responses were not found.					
055	.7826	1.565	.025	1/4"	Paired with run 056.
056	1.527	.75	.025	1/4"	Paired with run 055.
057	.75	1.527	.025	3/8"	Paired with run 058.
058	1.527	.75	.025	3/8"	Paired with run 057.
059	1.527	.75	.025	13/32"	Wheel lift at .8304 Hz.
062	.75	1.098	.025	3/8"	Repeat of run 057 to determine/investigate what happened on run 061. Seemed to have higher responses until .9107 Hz.
074	.85	1.254	.0035	1/4"	High resolution test, paired with run 075.
075	1.254	.85	.0035	1/4"	High resolution test, paired with run 074.
Configuration 2 (Truck 1, 1/4" Side-bearing Clearance without Snubbers): This configuration produced the highest bounce characterization test responses. Even after deducing the bounce input by 50 percent, the run could not be completed. Only two roll runs were conducted due to fear of damaging the wear plates. Roll inputs with only 1/16" P-P was required to produce significant response.					
067	.373	1.2	.025	1/16"	Paired with run 068. Very small input amplitude still resulted in significant response.
068	1.2	.373	.025	1/16"	Paired with run 067. Very small input amplitude still resulted in significant response.
Configuration 11 (Truck 2, 1/4" Side-bearing Clearance): Tests conducted September 1 and 2, 1993. This configuration was added after it was determined that Truck 1 undamped configurations 2, 4, 6, 8, and 10 could not be conducted for safety reasons.					
077	.373	1.2	.025	1/4"	Paired with run 078.
078	1.2	.373	.025	1/4"	Paired with run 077.
079	.373	1.2	.025	3/8"	Paired with run 080.
080	1.2	.373	.025	3/8"	Paired with run 079.
082	.373	1.2	.025	13/32"	Paired with run 085.
085	1.2	.373	.025	13/32"	Paired with run 082.
086	.6	1.004	.0035	13/32"	High resolution run. Paired with run 087.
087	1.004	.6	.0035	13/32"	High resolution run. Paired with run 086. Damaged A-end, right snubber and B-end, left snubber (noticed smoking).

Table 7. VTU Test Run Log -- Continued

Run No.	Start Freq.	End Freq.	Delta Freq.	P-P Act. Amp.	Comment
Configuration 12 (Truck 2, 3/4" Side-bearing Clearance): Tests conducted September 3, 1993. This configuration was added after it was determined that Truck 1 undamped configurations 2, 4, 6, 8, and 10 could not be conducted for safety reasons.					
090	.373	1.2	.025	13/32"	Paired with run 091.
091	1.2	.373	.025	13/32"	Paired with run 090.
092	.373	1.2	.025	3/8"	Paired with run 093.
093	1.2	.373	.025	3/8"	Paired with run 092.
094	.373	1.2	.025	1/4"	Paired with run 095.
095	1.2	.373	.025	1/4"	Paired with run 094.

4.1.2.6 Data Reduction and Analysis - VTU Tests

For the suspension characterization test runs, selected plots of wheel vertical load versus spring group vertical displacement were made. The data collected during the VTU roll-response tests was reduced to statistics for the last 10 cycles of each test frequency (test zone, after 10 transition settling cycles) in tabular form including mean, maximum, and minimum for each measurement at each speed. Data analysis included the generation of plots of amplitude versus frequency for car body roll angles, spring group vertical deflections, dynamic side bearing clearance, and vertical wheel loads. The high-resolution speed step tests have individual plots for each run, while data from the low-resolution speed step runs are combined for each sweep-up and sweep-down pair.

Table 8 lists the plots generated for each roll-response test configuration.

Table 8. Plots of VTU Test Data

Plot No.	Channel Name	Description
1	GYRB	B-End Car Body Roll Angle
2	GYRA	A-End Car Body Roll Angle
3	DZRB	B-End, Right Side Spring Nest Displacement
4	DZLB	B-End, Left Side Spring Nest Displacement
5	DZRA	A-End, Right Side Spring Nest Displacement
6	DZLA	A-End, Left Side Spring Nest Displacement
7	RSBB	B-End, Right Side Displacement Across Side Bearing
8	LSBB	B-End, Left Side Displacement Across Side Bearing
9	RSBA	A-End, Right Side Displacement Across Side Bearing
10	LSBA	A-End, Left Side Displacement Across Side Bearing
11	VF1R	B-End, Axle 1, Right Side Vertical Wheel Force
12	VF1L	B-End, Axle 1, Left Side Vertical Wheel Force
13	VF2R	B-End, Axle 2, Right Side Vertical Wheel Force
14	VF2L	B-End, Axle 2, Left Side Vertical Wheel Force
15	VF3R	A-End, Axle 3, Right Side Vertical Wheel Force
16	VF3L	A-End, Axle 3, Left Side Vertical Wheel Force
17	VF4R	A-End, Axle 4, Right Side Vertical Wheel Force
18	VF4L	A-End, Axle 4, Left Side Vertical Wheel Force

4.2 VTU TEST RESULTS

4.2.1 Vertical Suspension Characterization

The main purpose of the vertical suspension characterization tests was to ensure that the test trucks were consistent with typical well-worn trucks in normal revenue service and to provide suspension characteristic data for NUCARS modeling. Although both dynamic and quasi-static characterizations were run, the dynamic bounce characterization data was found to be more than sufficient for describing the test truck's vertical characteristics and is the only data presented here.

Although dynamic bounce characterization tests were conducted during test configurations 1, 3, 2, 11, and 12, the vertical characterizations were not side bearing gap configuration dependent. Figure 8 displays the initial characterization (run 10) for Truck 1, B-end, right side. It is clear that this truck is not highly damped; thus, Truck 1 configuration was representative of a well-worn truck.

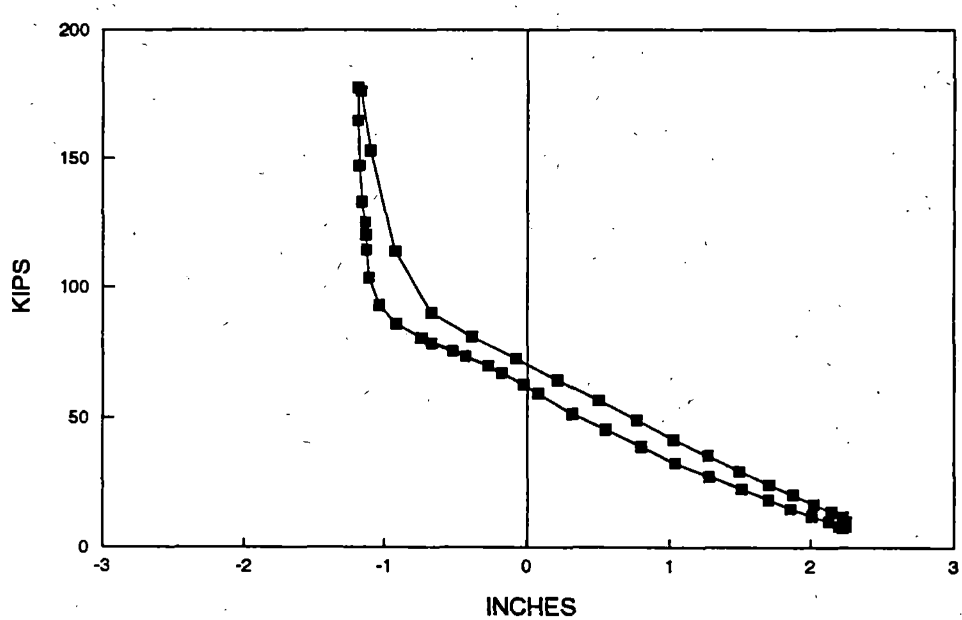


Figure 8. Truck 1 Vertical Suspension Characteristics, Run 10, B-end, Right Side

Figures 9 and 10 display the Truck 1, B-end, right side and A-end, left side dynamic vertical suspension characterization data obtained at the test's beginning (run 10) and at a point later on in the testing when questions arose about damping (run 63). The increased damping shown (A-end) in the configuration 3 data is the result of snubber surface galling. It is suspected that the VTU tests with high-resolution speed steps were the cause of the galling.

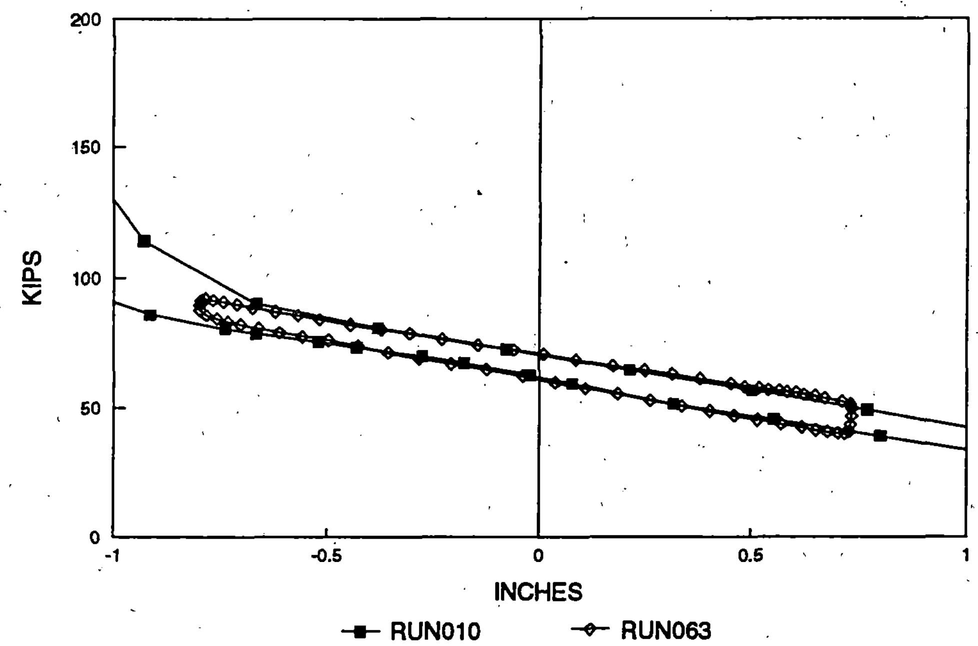


Figure 9. Expanded Vertical Suspension Characteristics, Runs 10 and 63, B-end, Right Side

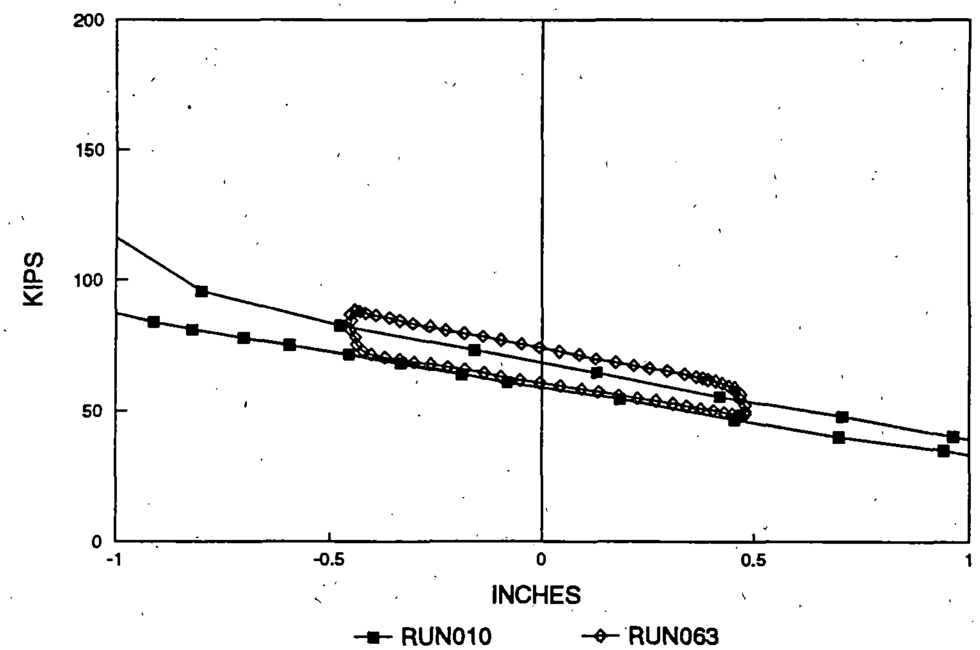


Figure 10. Expanded Vertical Suspension Characteristics, Runs 10 and 63, A-end, Left Side

Figure 11 compares the B-end, right side characteristics for the original truck (Truck 1, run 10) and for the second, much higher damped truck (Truck 2, run 84) which was tested after it was determined that the test configurations with snubbers disabled could not be safely run. This increased damping is clearly evident for Truck 2.

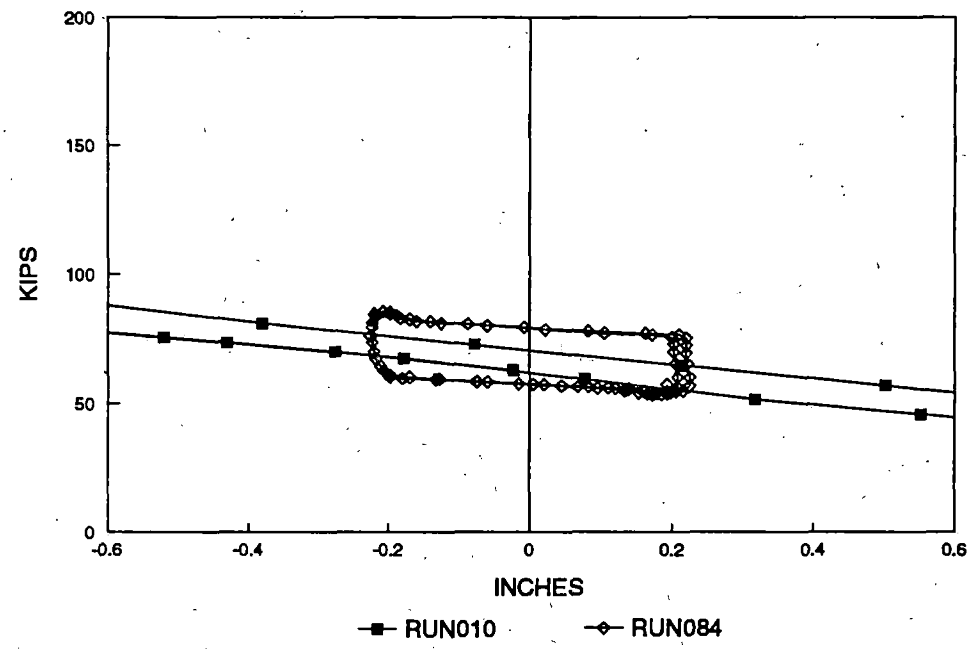


Figure 11. Expanded Vertical Suspension Characteristics, Trucks 1 and 2, Runs 10 and 84

4.2.2 VTU Roll-Response Tests

The plotted data from all of the roll response tests (540 plots) was transmitted separately to the FRA and to VNTSC. It was anticipated that low-resolution speed step inputs would map out the two-solution jump response phenomena, while high-resolution speed step inputs would be used to "hunt" for third and fourth solutions, which were predicted by VNTSC with a model that uses a describing function representation of the roll suspension characteristic. It was found during testing, however, that third and fourth solutions were unattainable. It was also found that plots of data from the low-resolution speed step tests were much clearer and more understandable. Thus, for the purpose of reporting the findings of the study in this report, data from the low-resolution speed step tests are used to present the findings.

Table 9 repeats the Table 5 list of the configurations tested, but sorted to list the data chronologically (test wise). Thus, test results will be presented in the following order: configurations 1, 5, 7, 9, 3, 2, 11, and 12.

Table 9. Repeat of Summary of the VTU Test Configurations

Configuration No.	Side Bearing Type	Side Bearing Clearance	Snubber Operation	Truck Type
1	Roller	1/4 inches	Enabled	Truck 1
5	Roller	1/2 inches	Enabled	Truck 1
7	Roller	3/4 inches	Enabled	Truck 1
9	Constant Contact	N/A	Enabled	Truck 1
3	Roller	0 inches	Enabled	Truck 1
2	Roller	1/4 inches	Disabled	Truck 1
11	Roller	1/4 inches	Enabled	Truck 2
12	Roller	3/4 inches	Enabled	Truck 2

4.2.2.1 Comparison of VTU-test Jump Response Phenomena

Car body roll response data is used to show whether or not each test configuration exhibited jump response. For each configuration, car body roll data from the test run with the highest input excitation is presented.

Figure 12 presents car body roll versus frequency data for Truck 1, configuration 1 (nominal), with 3/8-inch cross level VTU excitation inputs. It is clear from Figure 12 that jump response was not induced for configuration 1, nominal 1/4-inch side bearing clearance.

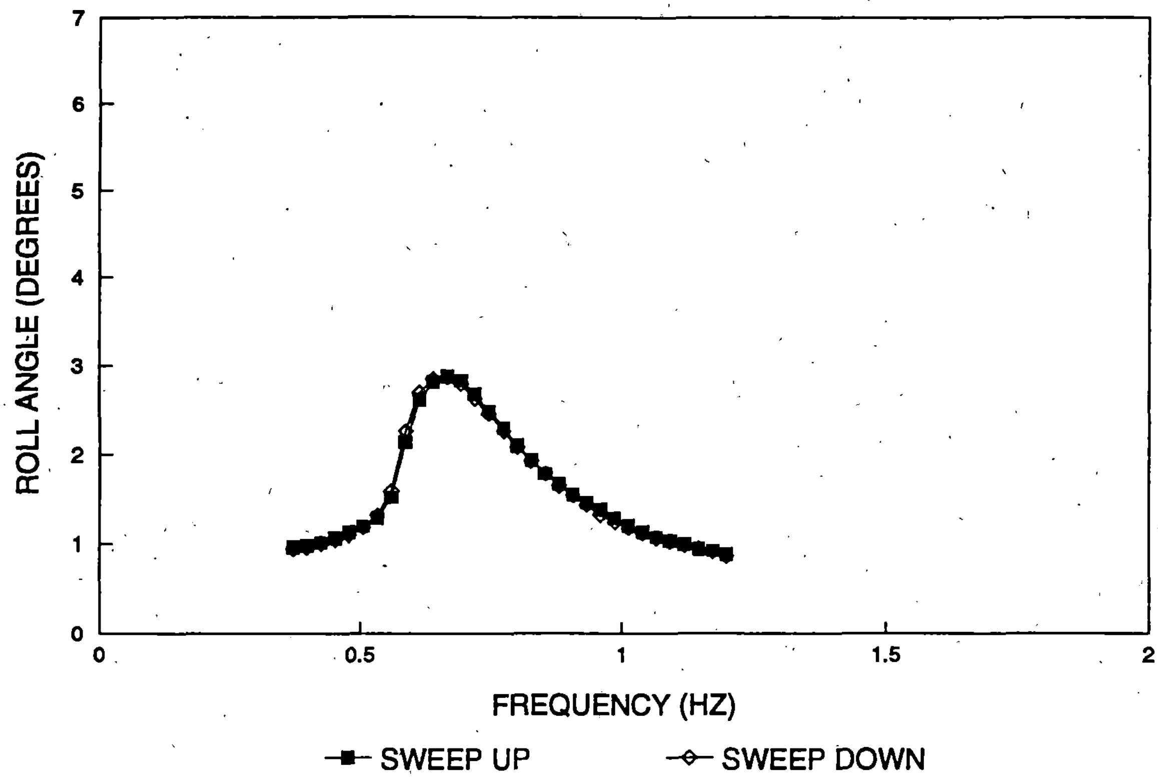


Figure 12. Nominal 1/4-inch Side Bearing Clearance VTU Test Results (Configuration 1) -- Truck 1, B-End Car Body Roll Angle Versus Frequency, 3/8" Peak-to-peak Cross Level VTU Excitation

Figures 13 through 20, car body roll response versus frequency for Truck 1 configurations 5, 7, 9, 3, and 2, and Truck 2 configurations 11 and 12, are presented below. In Figures 13 through 15, jump response was induced during ramp-down decelerating runs. Figure 14, 3/4-inch clearance (configuration 7), showed jump response at a greater degree than Figure 13, 1/2-inch clearance. Figure 15, constant contact side bearings (configuration 9), exhibited a response very similar to configuration 5. When jump response occurred, the resonance lasted through a wider frequency range and peaked at a lower frequency than the nominal side bearing clearance configuration. The displacement and vertical wheel load measurements showed similar results.

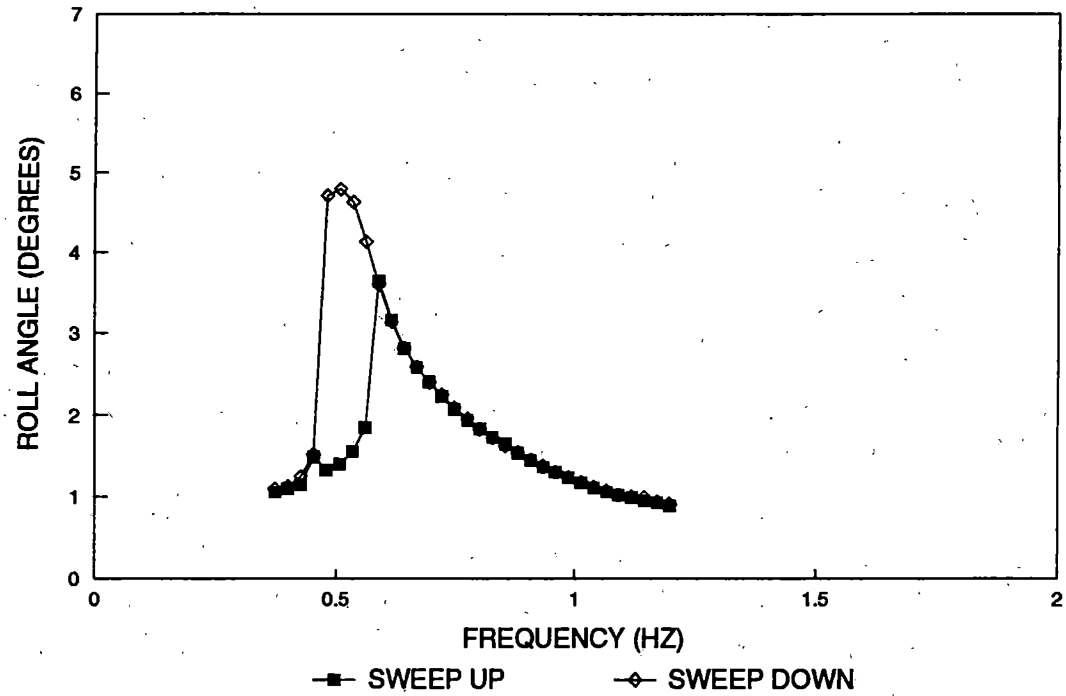


Figure 13. 1/2-inch Side Bearing Clearance VTU Test Results (Configuration 5) -- Truck 1, B-End Car Body Roll Angle Versus Frequency, 13/32" Peak-to-peak Cross Level VTU Excitation

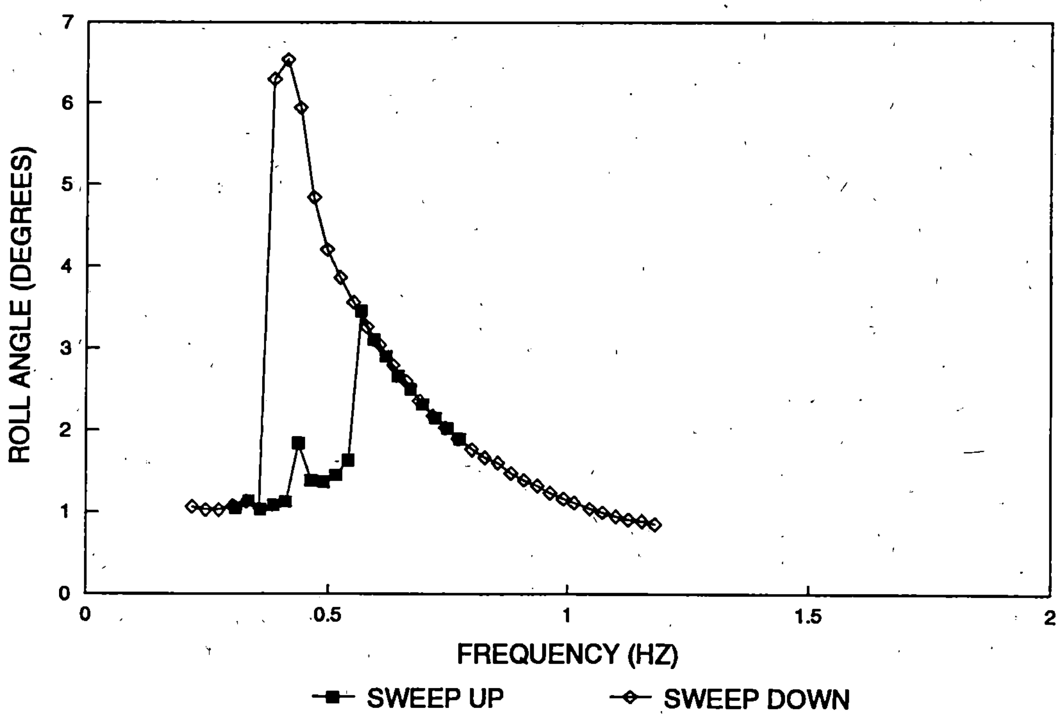


Figure 14. 3/4-inch Side Bearing Clearance VTU Test Results (Configuration 7) -- Truck 1, B-End Car Body Roll Angle Versus Frequency, 13/32" Peak-to-peak Cross Level VTU Excitation

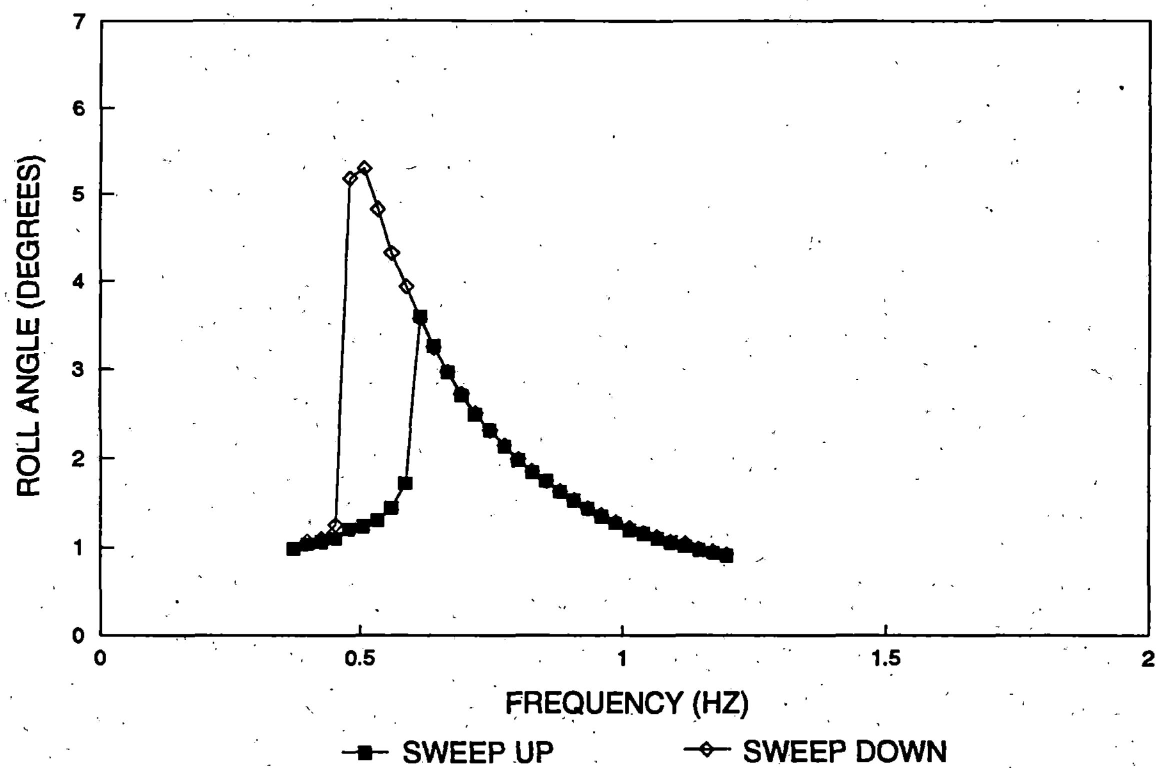


Figure 15. Constant Contact Side Bearing VTU Test Results (Configuration 9) -- Truck 1, B-End Car Body Roll Angle Versus Frequency, 13/32" Peak-to-peak Cross Level VTU Excitation

Figure 16 displays car body roll response versus frequency for Truck 1 configuration 3, zero side bearing clearance. The resonance peaked at a higher frequency than the nominal side bearing clearance configuration, and significant jump response did not occur.

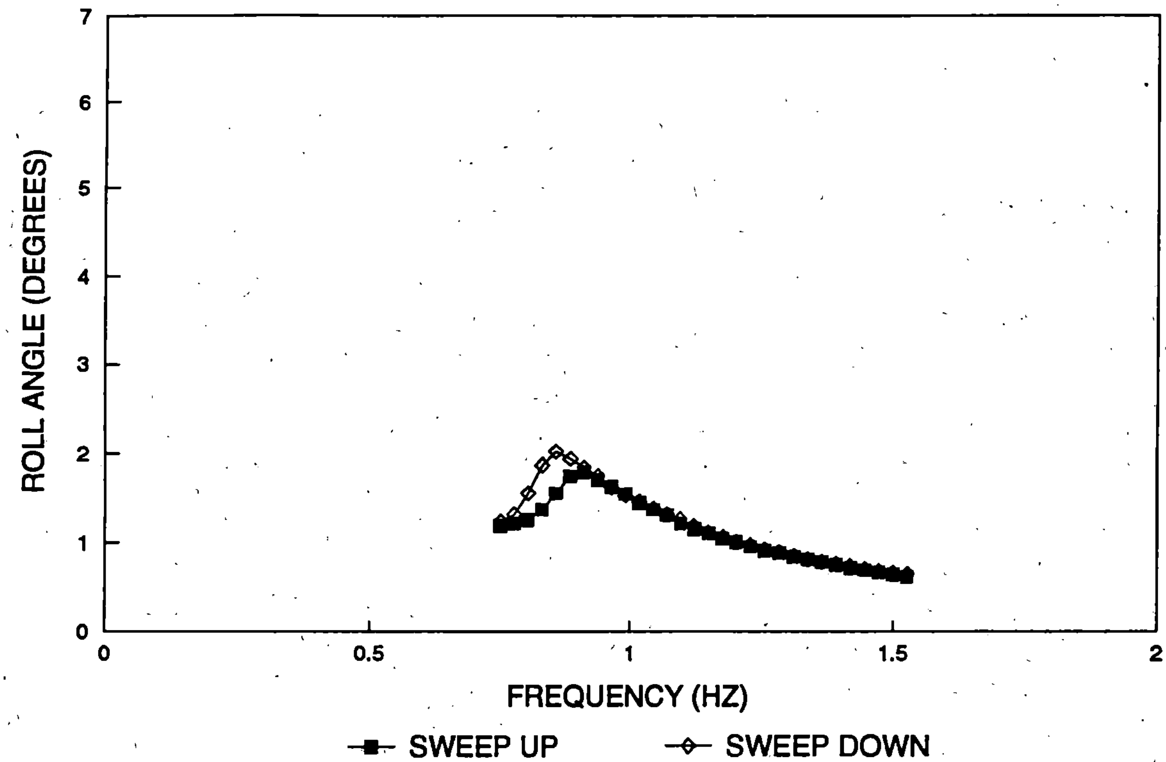


Figure 16. Zero Side Bearing Clearance VTU Test Results (Configuration 3) -- Truck 1, B-End Car Body Roll Angle Versus Frequency, 3/8" Peak-to-peak Cross Level VTU Excitation

Figure 17 displays car body roll response versus frequency for Truck 1 configuration 2, nominal side bearing clearance with snubbers disabled. This configuration and other snubber-disabled configurations were aborted due to safety issues and the potential of damaging the test truck wear plates.

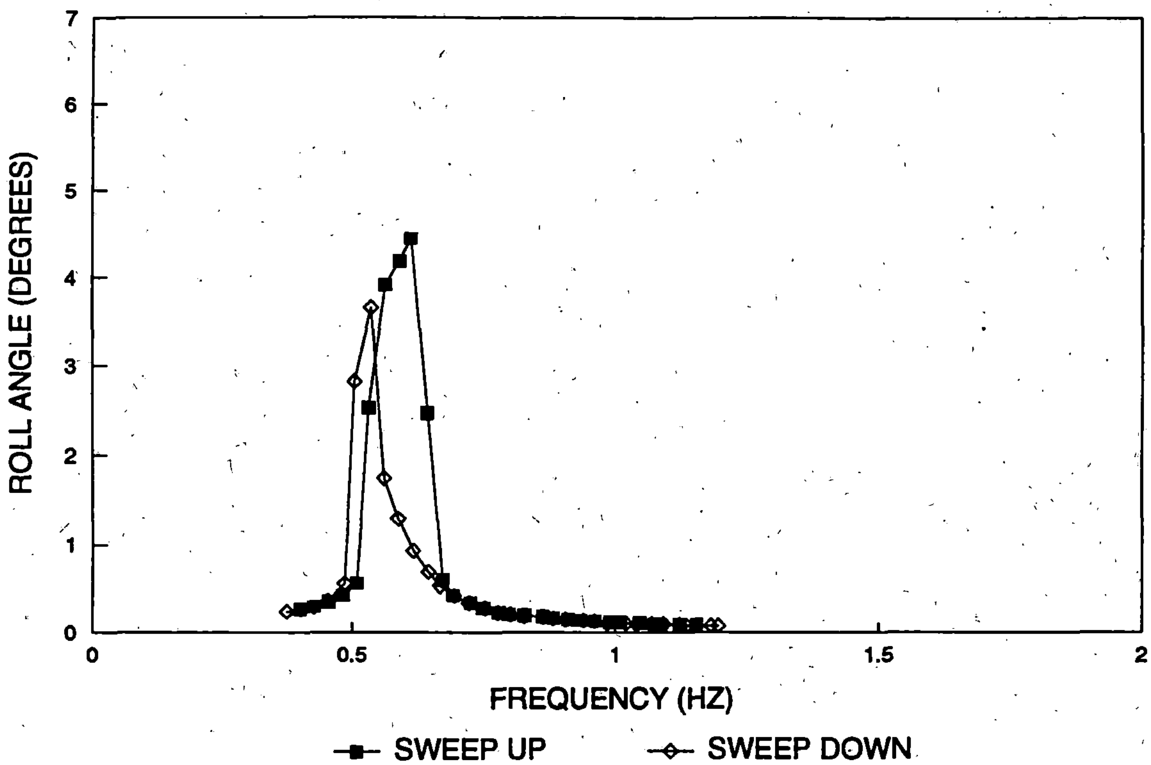


Figure 17. Nominal 1/4-inch Side Bearing Clearance VTU Test Results, Snubbers Disabled (Configuration 2) -- Truck 1, B-End Car Body Roll Angle Versus Frequency, 1/16" Peak-to-peak Cross Level VTU Excitation

Figures 18 and 19 display car body roll response versus frequency for Truck 2 configurations 11 and 12, nominal 1/4-inch side bearing clearance and 3/4-inch side bearing clearance. Figure 18 shows that the higher damped truck is similar to Truck 1 in the nominal side bearing clearance configuration -- jump response does not occur. Figure 19 shows jump response with two peaks, which was not expected. One possible explanation is that the damping was abnormal due to snubber galling. Figure 20 presents data for one of the few instances where a run was repeated. The variation in response, though it did not produce the result seen in Figure 19, is the effect of snubber galling on the suspension damping. It is suggested that the Truck 2 data, shown in Figure 19, is linked to suspension damping inconsistencies.

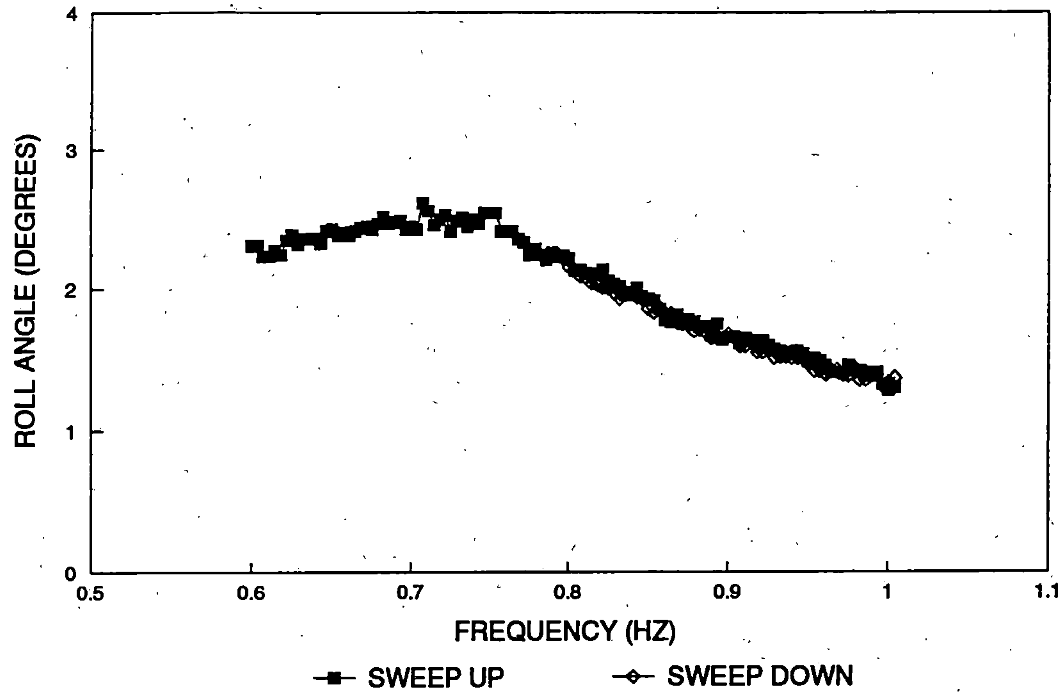


Figure 18. Nominal 1/4-inch Side Bearing Clearance VTU Test Results (Configuration 11) -- Truck 2, B-End Car Body Roll Angle Versus Frequency, 13/32" Peak-to-peak Cross Level VTU Excitation

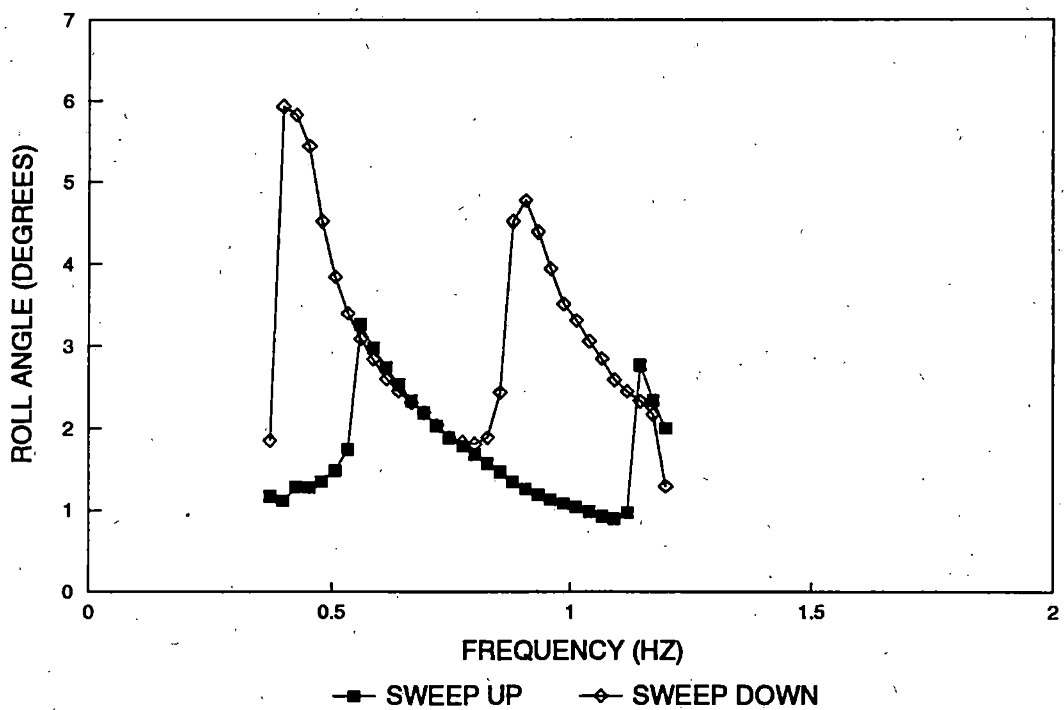


Figure 19. 3/4-inch Side Bearing Clearance VTU Test Results (Configuration 12) -- Truck 2, B-End Car Body Roll Angle Versus Frequency, 13/32" Peak-to-peak Cross Level VTU Excitation

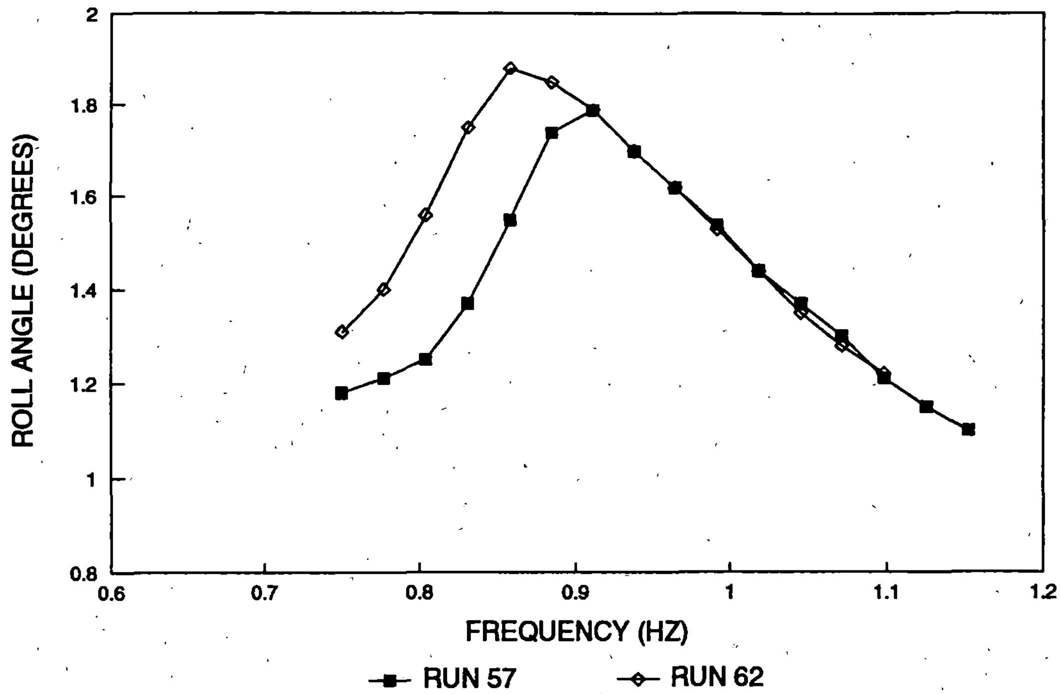


Figure 20. Zero Side Bearing Clearance VTU Test Results (Configuration 3) -- Truck 2, B-End Car Body Roll Angle Versus Frequency, 3/8" Peak-to-peak Cross Level VTU Excitation

4.2.2.2 Comparison of VTU-test Response Magnitudes

During VTU testing, it was found that varying side bearing clearance had a significant effect upon response magnitudes and frequencies. To emphasize the consequence of increased and decreased side bearing clearance upon dynamic response levels, configurations 1 (nominal), 7 (3/4-inch clearance), and 3 (zero clearance) are exhibited in Figures 21 through 24. Only decelerating data is shown.

Figure 21 compares car body roll angle response for VTU-test configurations 1, 7, and 3. The lower frequency, increased roll angle for the 3/4-inch side bearing gap clearance configuration is clearly evident.

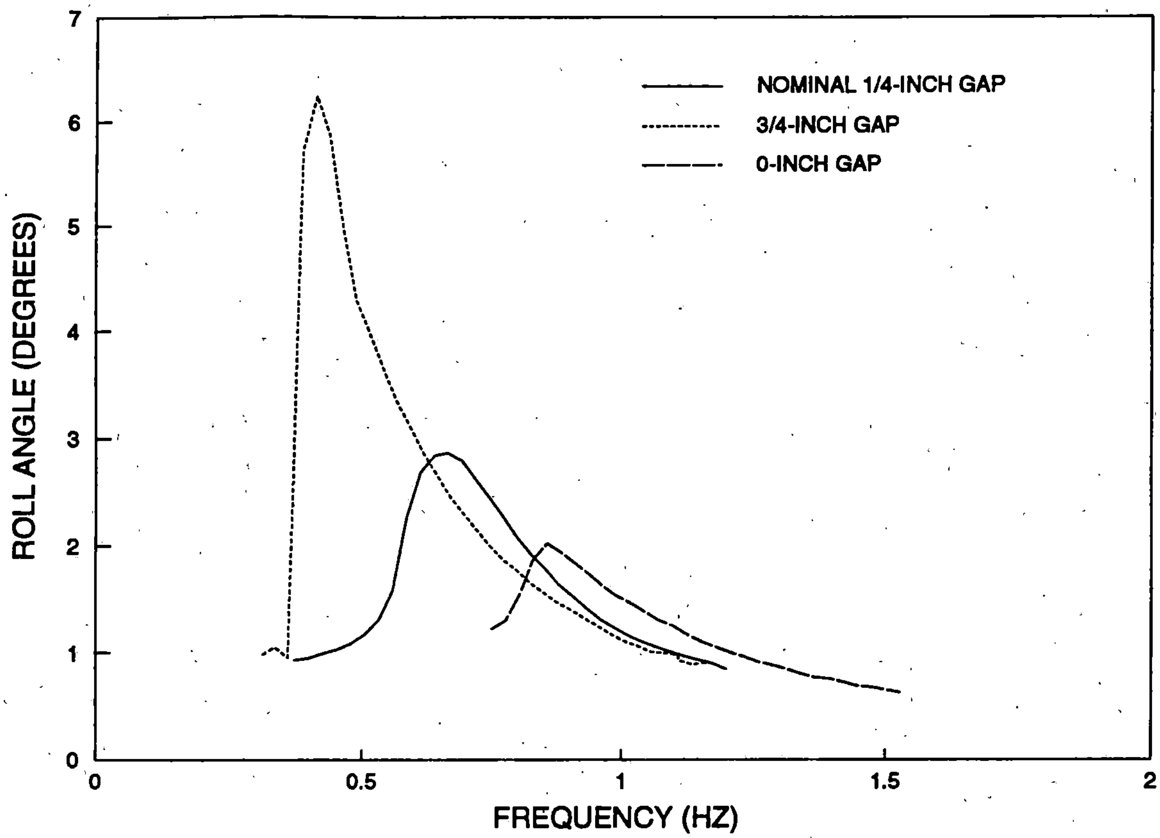


Figure 21. Comparison of Car Body Roll Response for Test Configurations 1 (nominal), 7 (3/4-inch clearance), and 3 (zero clearance)

Figure 22 compares spring nest displacement for VTU-test configurations 1, 7, and 3. The peak frequency for the increased side bearing gap clearance is evident. It is also apparent that less energy is absorbed through suspension elements in this configuration (less area under the curve).

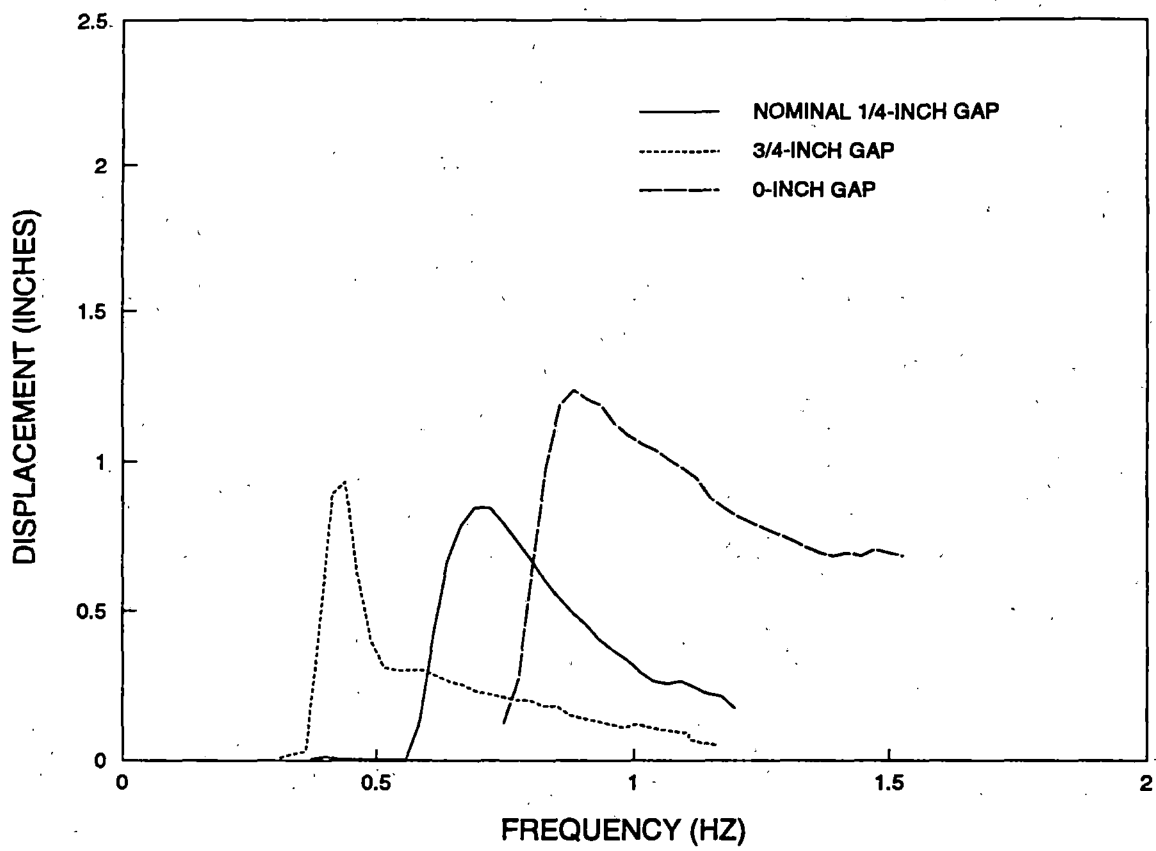


Figure 22. Comparison of Spring Nest Displacement for VTU-Test Configurations 1 (nominal), 7 (3/4-inch clearance), and 3 (zero clearance)

Figure 23 compares the displacement across the side bearing gap for VTU-test configurations 1, 7, and 3. Figure 24 compares wheel unloading for VTU-test configurations 1, 7, and 3. This example shows slightly more unloading with increased clearance, with the most unloading for configuration 3 zero clearance. On average, most other wheel locations showed slightly more unloading for the nominal clearance configuration over the 3/4-inch gap configuration.

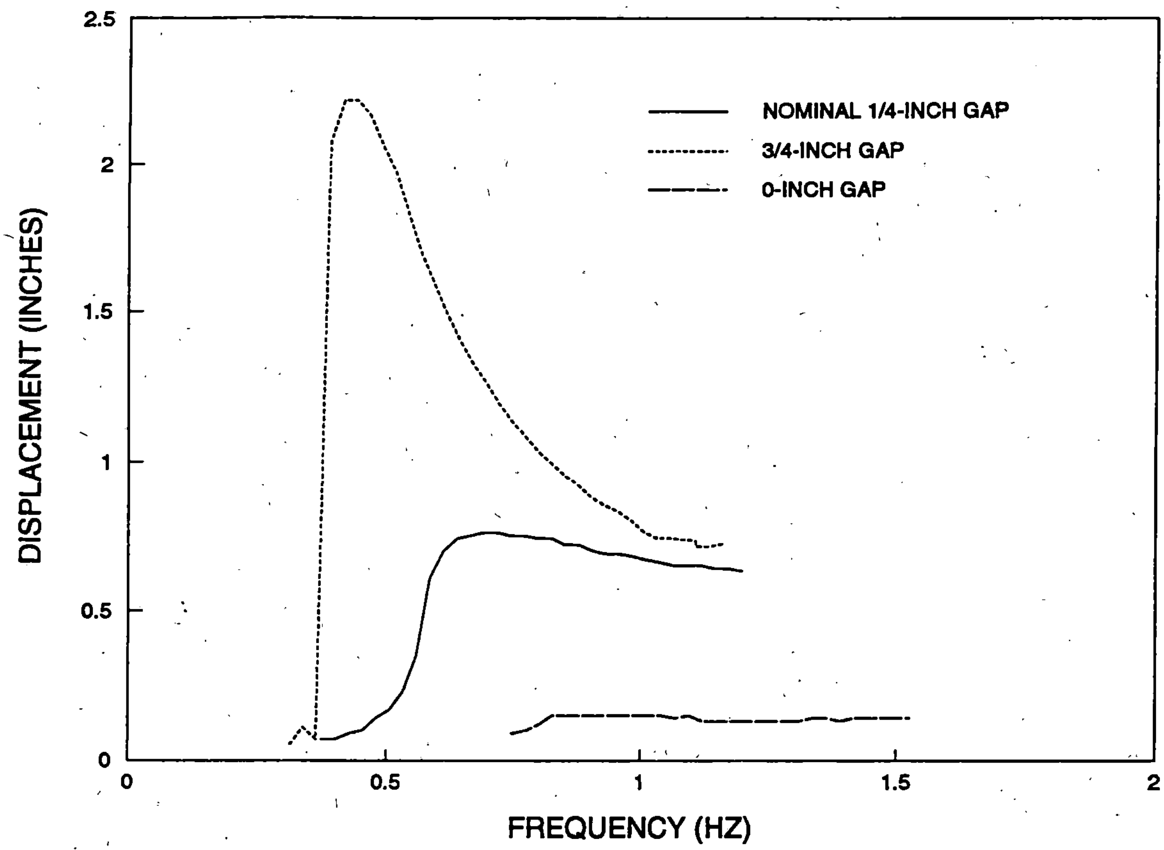


Figure 23. Comparison of Displacement Across Side Bearing Gaps for VTU-Test Configurations 1 (nominal), 7 (3/4-inch clearance), and 3 (zero clearance)

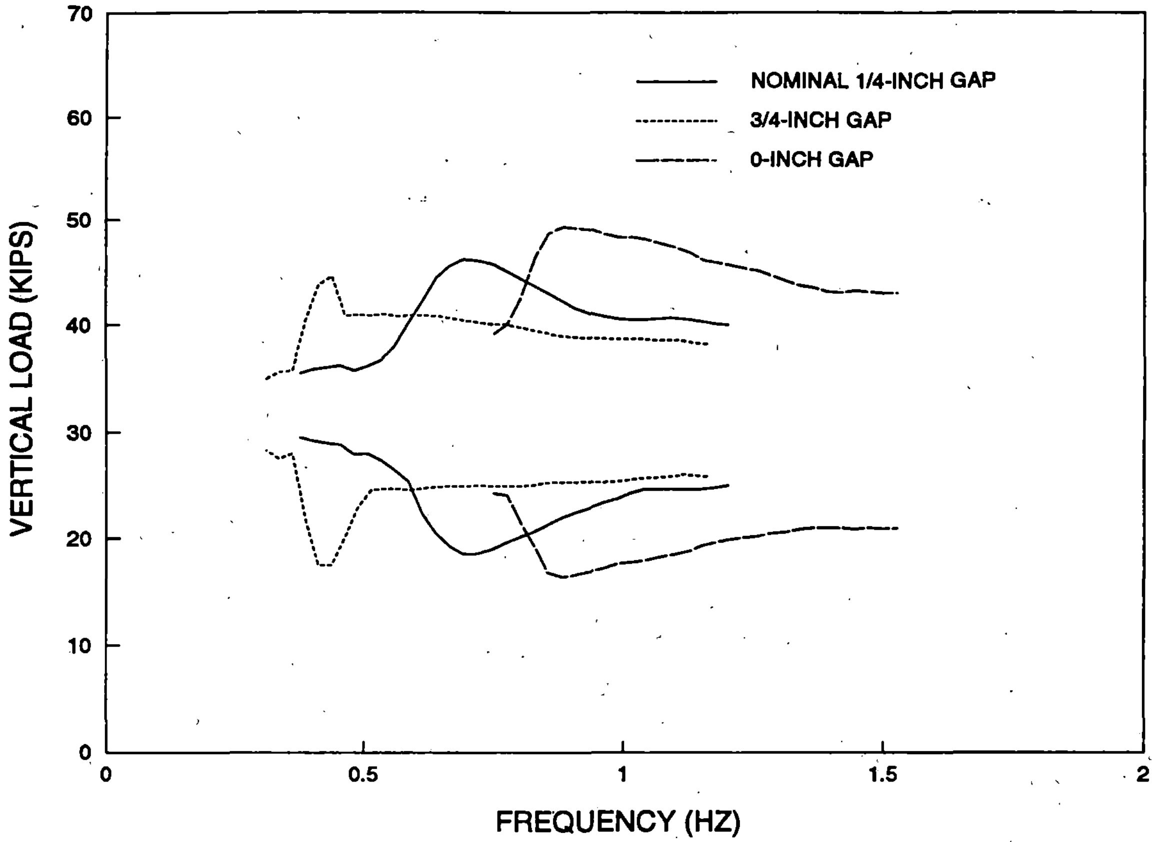


Figure 24. Comparison of Wheel Unloading for VTU-Test Configurations 1 (nominal), 7 (3/4-inch clearance), and 3 (zero clearance)

5.0 ON-TRACK TESTING

5.1 ON-TRACK TEST PROCEDURES

The following sections describe testing procedures.

5.1.1 On-track Test Instrumentation

5.1.1.1 Test Car Measurements

Many of the measurements recorded during the VTU test were recorded for the on-track test. Measurement of wheel/rail forces that had used load measuring rail beams on the VTU were made with load-measuring instrumented wheel sets in the lead position of each truck. The train speed was measured by a speed tachometer. Automatic location detectors were used to denote the test zone.

5.1.1.2 Test Measurement Summary

Table 10 summarizes the revised instrumentation list for the on-track tests.

Table 10. Revised Measurement Summary for On-track Test

Meas. No.	Channel Name	Description
1	TSPD	Train Speed
2	ALD	Automatic Location Detector
3	JVLA	B-End, Axle 1, Left Side Vertical Wheel Force
4	JLLA	B-End, Axle 1, Left Side Lateral Wheel Force
5	JLVA	B-End, Axle 1, Left Side L/V Ratio
6	JVLB	B-End, Axle 1, Right Side Vertical Wheel Force
7	JLLB	B-End, Axle 1, Right Side Lateral Wheel Force
8	JLVB	B-End, Axle 1, Right Side L/V Ratio
9	JTQA	B-End, Axle 1 Torque
10	KVLA	A-End, Axle 3, Left Side Vertical Wheel Force
11	KLLA	A-End, Axle 3, Left Side Lateral Wheel Force
12	KLVA	A-End, Axle 3, Left Side L/V Ratio
13	KVLB	A-End, Axle 3, Right Side Vertical Wheel Force
14	KLLB	A-End, Axle 3, Right Side Lateral Wheel Force
15	KLVB	A-End, Axle 3, Right Side L/V Ratio
16	KTQA	A-End, Axle 3 Torque
17-39		Instrumented Wheel Set Strain Gage Signals (Raw)
40	GYRA	A-End Car Body Roll Angle
41	GYRB	B-End Car Body Roll Angle
42	DZRA	A-End, Right Side Spring Nest Displacement
43	DZLA	A-End, Left Side Spring Nest Displacement
44	DZRB	B-End, Right Side Spring Nest Displacement
45	DZLB	B-End, Left Side Spring Nest Displacement
46	RSBA	A-End, Right Side Displacement Across Side Bearing
47	LSBA	A-End, Left Side Displacement Across Side Bearing
48	RSBB	B-End, Right Side Displacement Across Side Bearing
49	LSBB	B-End, Left Side Displacement Across Side Bearing
50	RWGA	A-End Car Body Roll Rate Gyro (Raw)
51	RWGB	B-End Car Body Roll Rate Gyro (Raw)

5.1.1.3 Data Acquisition Requirements

All measurements were collected digitally with a HP 330 computer at a frequency of 512 samples per second. The real-time processed wheel forces (measurements 3-16) were low-pass filtered at 15 Hz. The raw wheel set strain gage measurements were low-pass filtered at 200 Hz during the test, with the post-test processed forces filtered at 15 Hz. The remaining data channels were low-pass filtered at 30 Hz. Strip-chart recorders were used to monitor 16 data channels during the test.

The real-time wheel forces were used to ensure test safety. The real-time processors have known errors when calculating low vertical loads and loads with high lateral components. More accurate wheel forces are calculated when the raw signals are digitally processed.

Still photography was used to document the instrumentation setup. Limited color video footage was taken of at least four on-track runs using 1/2-inch VHS format video equipment.

5.1.2 <u>On-track Testing</u>

5.1.2.1 Safety Considerations

Railcars may have a violent dynamic response to the twist-and-roll test section. The TTC Test Engineer and Test Controller had final authority on the tests conducted to ensure safe completion of testing.

5.1.2.2 On-track Tests

Twist-and-roll tests were performed October 14-15, 1993, on the PTT. Test runs were made through the lower center roll resonance in 2 mph increments and discontinued after 30 mph. Some speeds were not attempted due to excessive roll and/or wheel lift. The accepted safety criteria for the twist and roll test are a maximum 6-degree peak-to-peak car body roll angle, and a 10 percent of static weight minimum vertical wheel load, and a maximum axle sum lateral to vertical force (L/V) ratio of 1.5.

Pitch and bounce test runs were made prior to twist and roll test series to ensure that the snubbers were not bound up and to characterize the trucks vertically on-track.

The twist and roll test section consists of 10 out-of-phase 39-foot wavelength perturbations with a 3/4-inch cross level every 19 1/2 feet. The pitch and bounce test section has the same 39-foot wavelength perturbations, but in-phase, so there is no cross level variation.

Test Car Conditions

The loaded covered hopper car (AAR 102) was tested with two roller side bearing setup clearances, 1/4 and 3/4 inches (configurations 1 and 7). These configurations were chosen based on the VTU test results. This car has 40-foot 7-inch truck centers, making it particularly susceptible to dynamic activity over the 39-foot track wavelength.

Test Summary

The test car exceeded established safety criteria for twist and roll. Wheel lift (zero vertical load) was measured by each instrumented wheel with both side bearing clearance configurations. Car body roll angles exceeded 6 degrees peak-to-peak in both configurations. Axle sum L/V ratios were greater than 1.5, but this was primarily due to wheel lift (low vertical loads).

Wheel lift was observed in the pitch and bounce test at 60 mph.

5.2 ON-TRACK TEST RESULTS

In general, the on-track test results did not clearly show significant improvement or degradation due to increased side bearing clearance. Car body roll angles increased, as would be expected with increased side bearing gap clearance. Wheel unloading performance was not greatly affected, as wheel lift occurred in both configurations tested.

5.2.1 Twist and Roll Test Results

5.2.1.1 Results for 1/4-Inch Side Bearing Clearance

The minimum vertical wheel load measured was zero percent of the static vertical load (wheel lift), occurring at 18 mph. The maximum car body roll angle was 6.8 degrees peak-to-peak at 18 mph.

Figures 25 and 26 show typical plots of minimum vertical wheel load versus speed for the 1/4-inch side bearing clearance configuration. This data shows a relatively smooth decrease then an increase in minimum wheel load with increasing speed, with lift noted at 18 mph. Due to the trend in the data, 17 mph was not attempted since it was believed to be more severe than at 15 or 18 mph. Figure 27 shows a representative time history of a vertical wheel load in the 18 mph run.

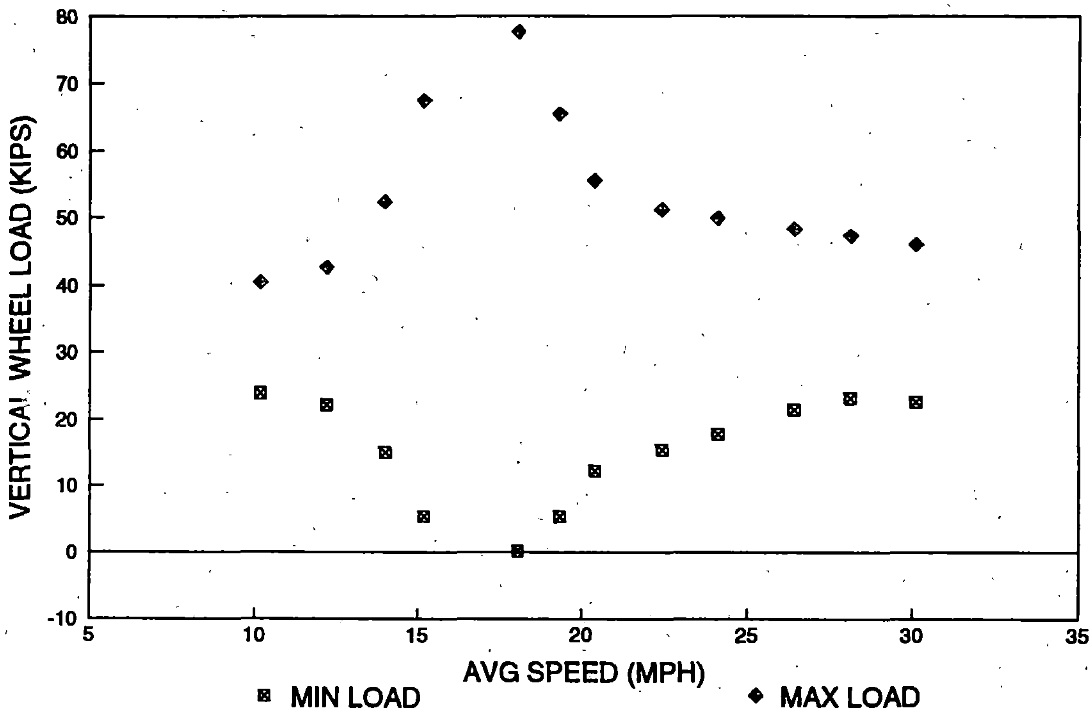


Figure 25. T&R Test Configuration 1, Axle 1 Left Wheel -- Min & Max Vertical Load Versus Speed

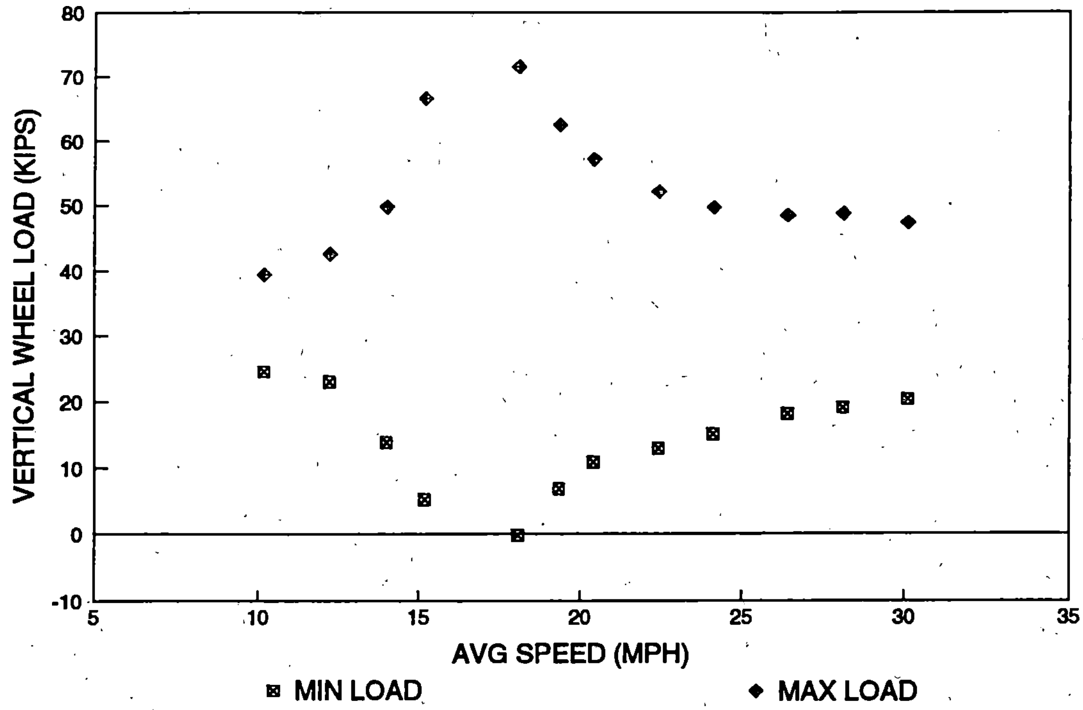


Figure 26. T&R Test Configuration 1, Axle 3 Left Wheel -- Min & Max Vertical Load Versus Speed

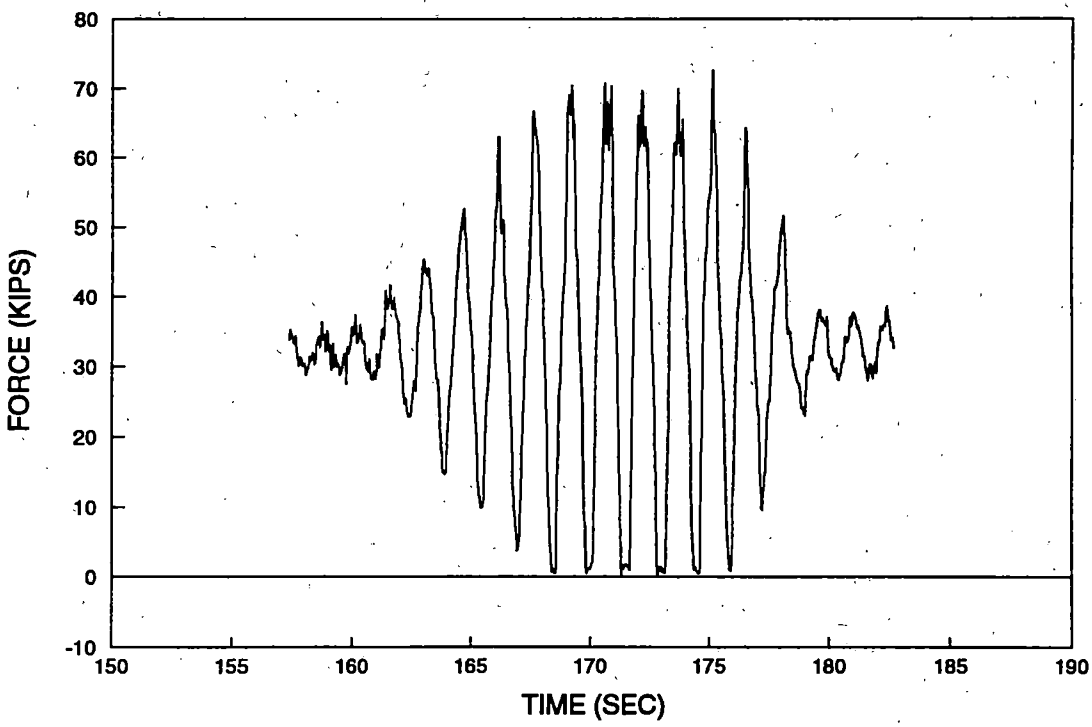


Figure 27. T&R Test Configuration 1, Axle 1 Right Wheel -- Vertical Wheel Force Time History Run 17

A plot of maximum peak-to-peak car body roll angles versus speed for the 1/4-inch side bearing clearance configuration is given in Figure 28. Figure 29 shows a time history of the car body roll angle for run 17.

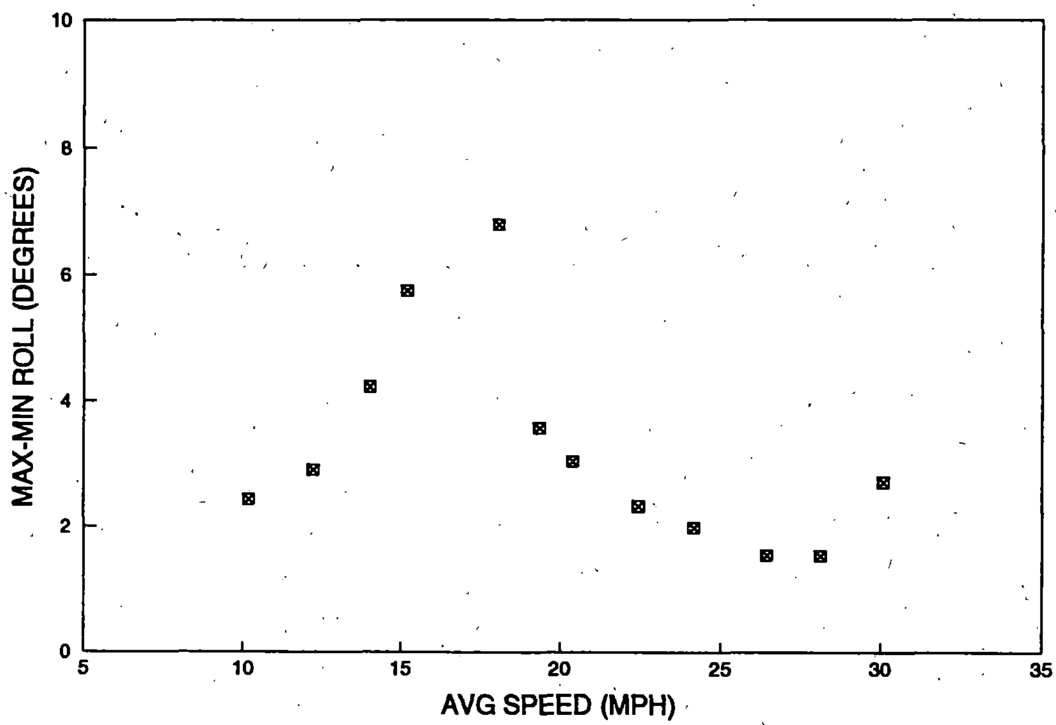


Figure 28. T&R Test Configuration 1, A-End Car Body Roll Angle Versus Speed

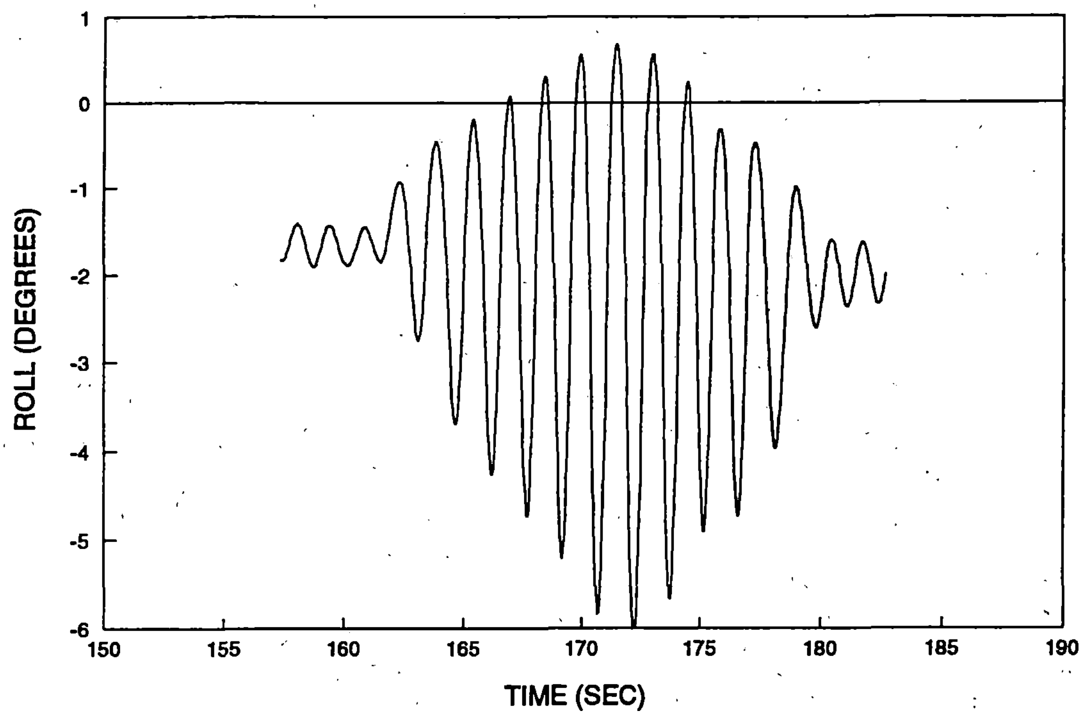


Figure 29. T&R Test Configuration 1, A-End Roll Gyro Time History

5.2.1.2 Results for 3/4-Inch Side Bearing Clearance

The minimum vertical wheel load measured was zero percent of the static vertical load (wheel lift), occurring at 12 and 12.5 mph. The maximum car body roll angle was 9.5 degrees peak-to-peak at 12.5 mph.

Figures 30 and 31 show typical plots of minimum vertical wheel load versus speed for the 3/4-inch side bearing clearance configuration. In contrast to the 1/4-inch clearance data, this data shows a sharp decrease then an increase in minimum wheel load with increasing speed, with lift noted at 12 and 12.5 mph. In fact, at 12 mph the minimum vertical wheel load was over 10 percent for the first six perturbations, then a slight track variation caused a dramatic increase in dynamic response for the rest of the run. Although this phenomenon is not jump response as observed during sweep down VTU testing, it does point out the sensitivity of a complex non-linear system to a slight change in input. Figures 32 and 33 contain time histories of a vertical wheel load in the 12- and 12.5-mph runs.

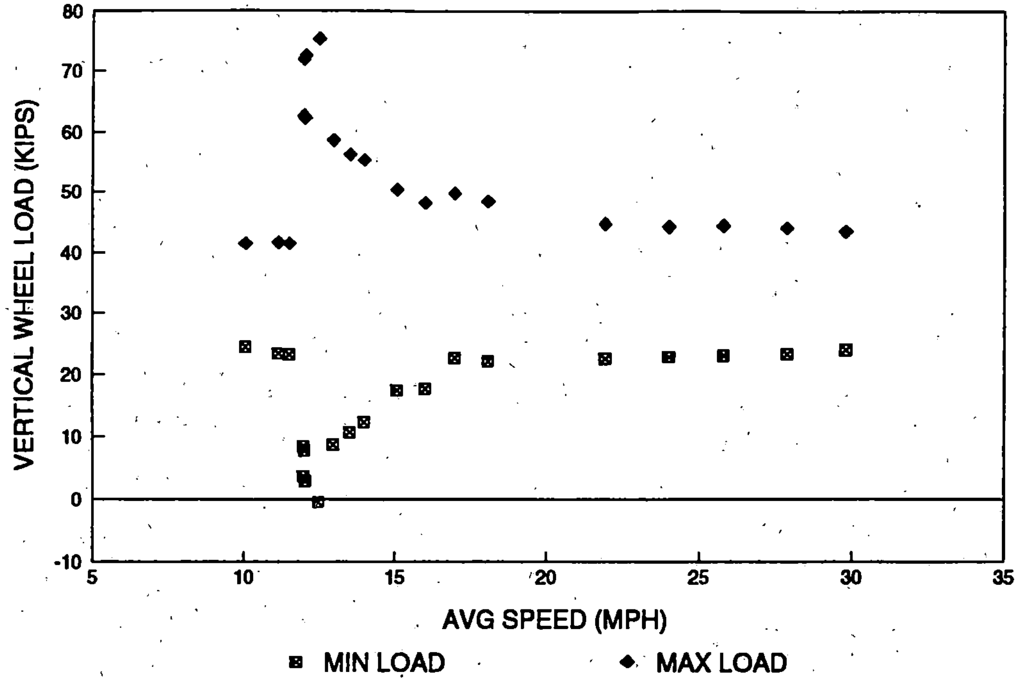


Figure 30. T&R Test Configuration 7, Axle 1 Left Wheel -- Min & Max Vertical Load Versus Speed

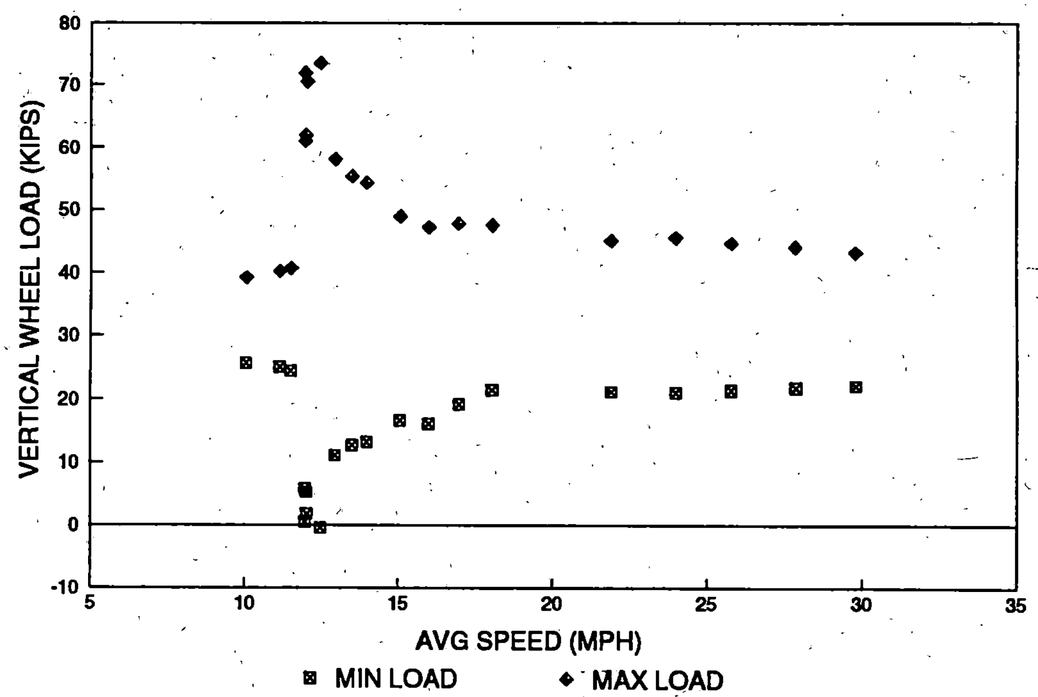


Figure 31. T&R Test Configuration 7, Axle 3 Left Wheel -- Min & Max Vertical Load Versus Speed

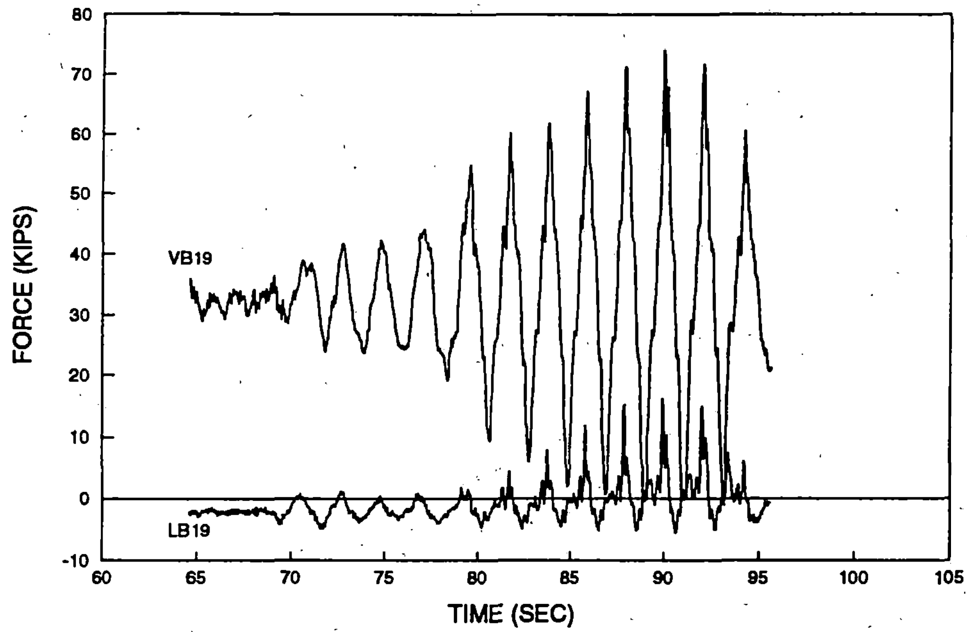


Figure 32. T&R Test Configuration 7, Axle 1 Right Wheel – Vertical & Lateral Wheel Force Time History Run 39

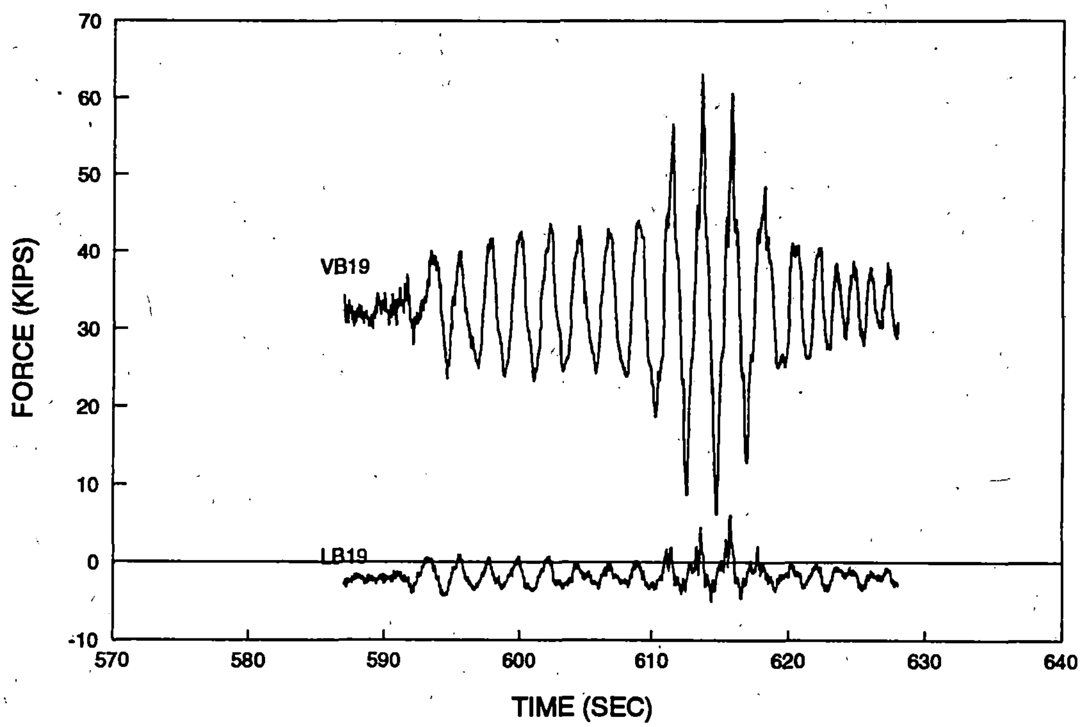


Figure 33. T&R Test Configuration 7, Axle 1 Right Wheel – Vertical & Lateral Wheel Force Time History Run 25

A plot of maximum peak-to-peak car body roll angles versus speed for the 3/4-inch side bearing clearance configuration is given in Figure 34. Time histories of the car body roll are shown in Figures 35 and 36.

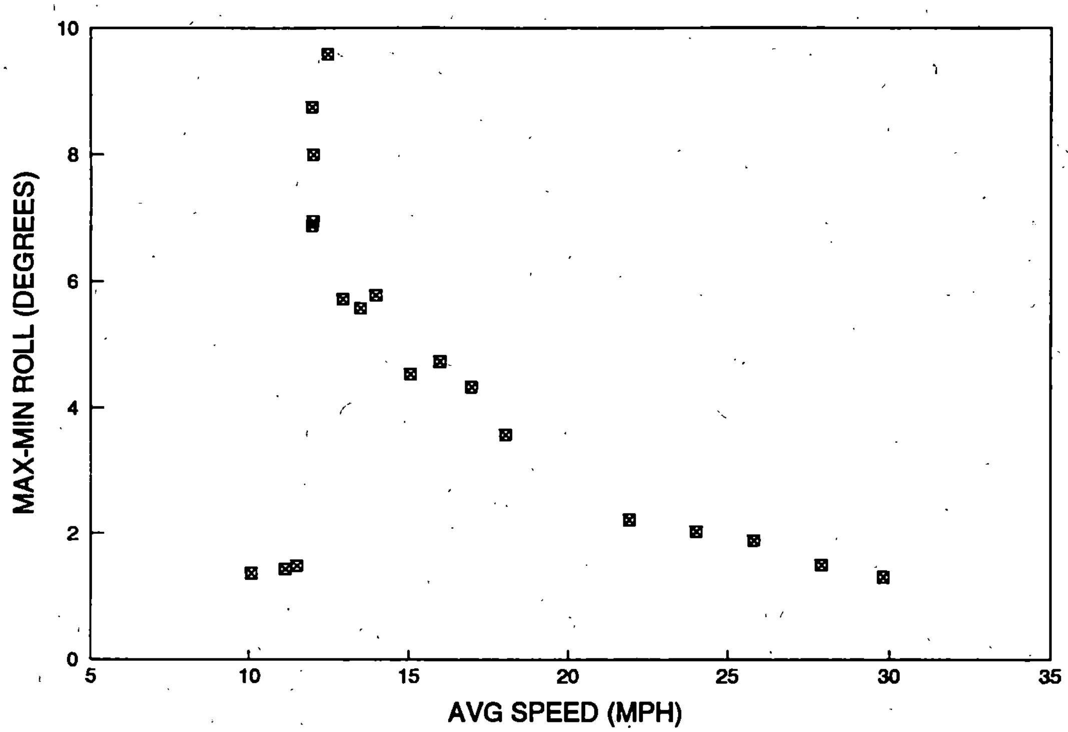


Figure 34. T&R Test Configuration 7, A-End Car Body Roll Angle Versus Speed

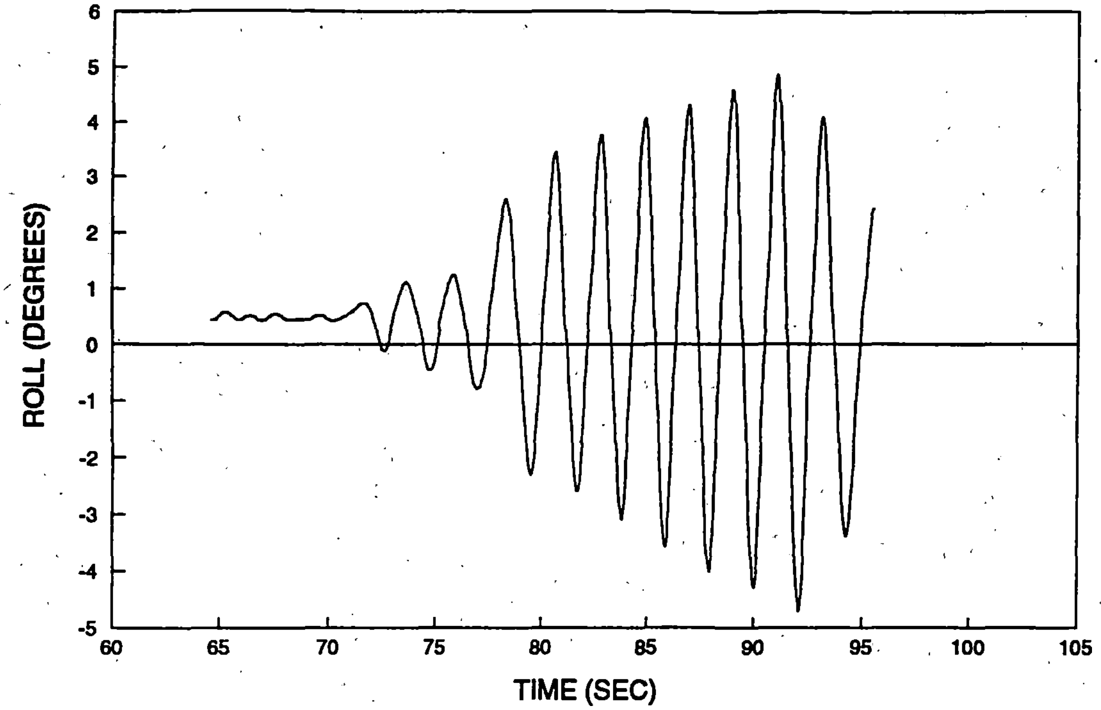


Figure 35. T&R Test Configuration 7, A-End Roll Gyro Time History Run 39

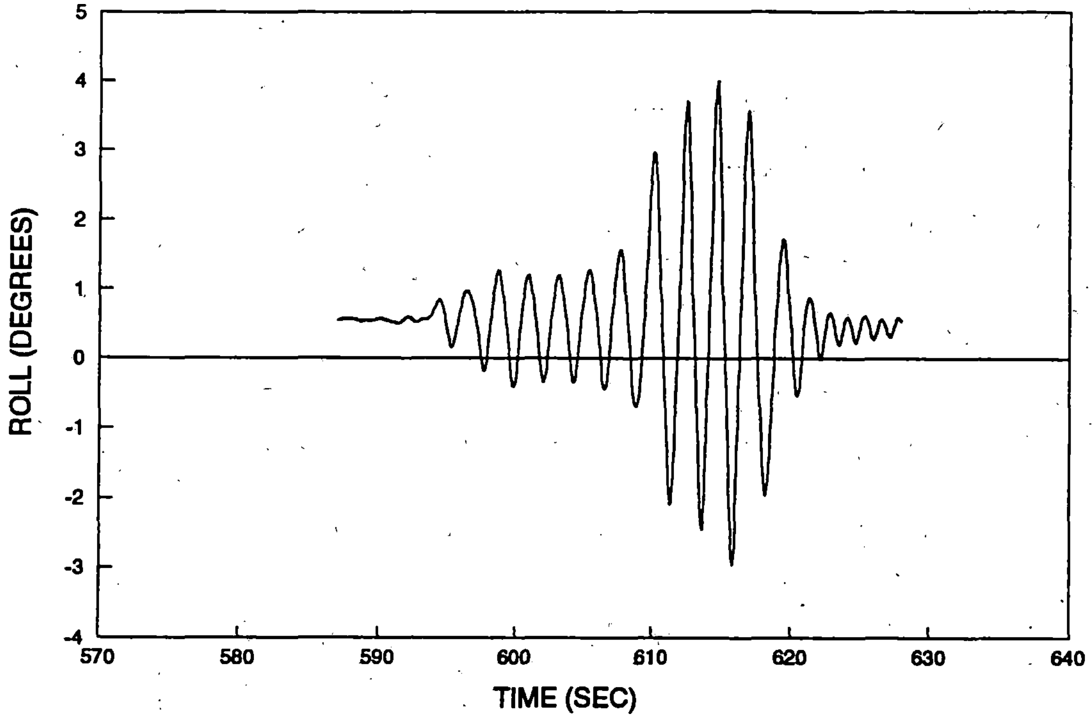


Figure 36. T&R Test Configuration 7, A-End Roll Gyro Time History Run 25

5.2.2 Pitch and Bounce Test Results

Wheel lift and vertical forces over 100 kips were monitored at 60 mph in the pitch and bounce test. Figure 37 shows an example plot of minimum and maximum wheel force versus speed for this test. Figure 38 is a time history of a vertical wheel force during the 60 mph test run.

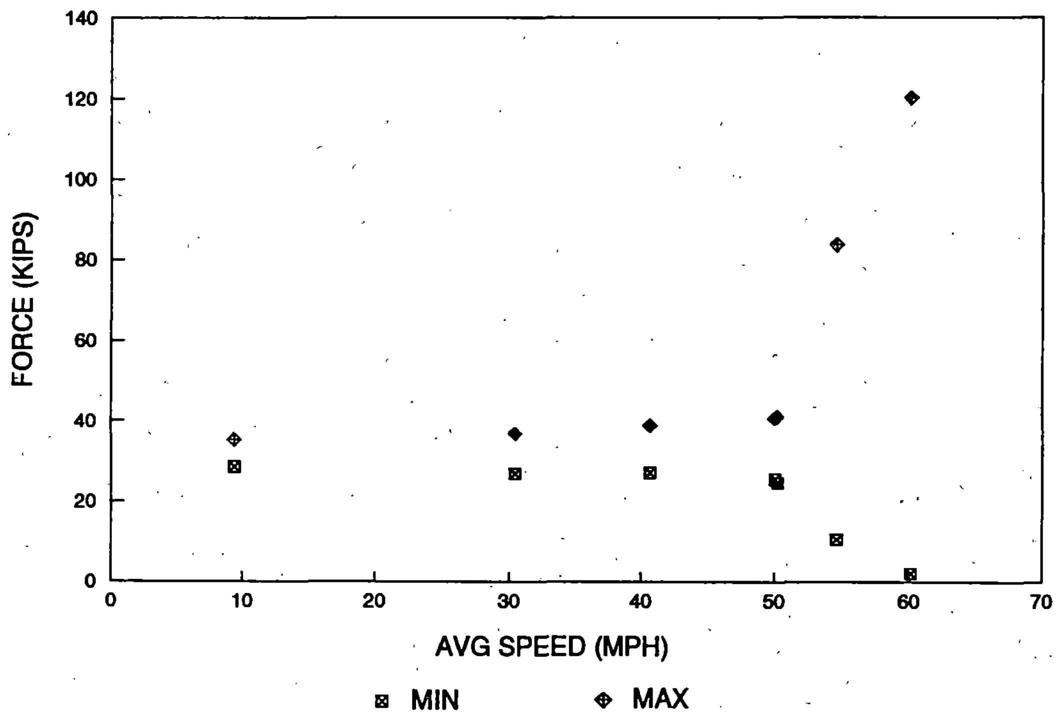


Figure 37. P&B Test Configuration 1, Axle 1 Right Wheel -- Min & Max Vertical Load Versus Speed

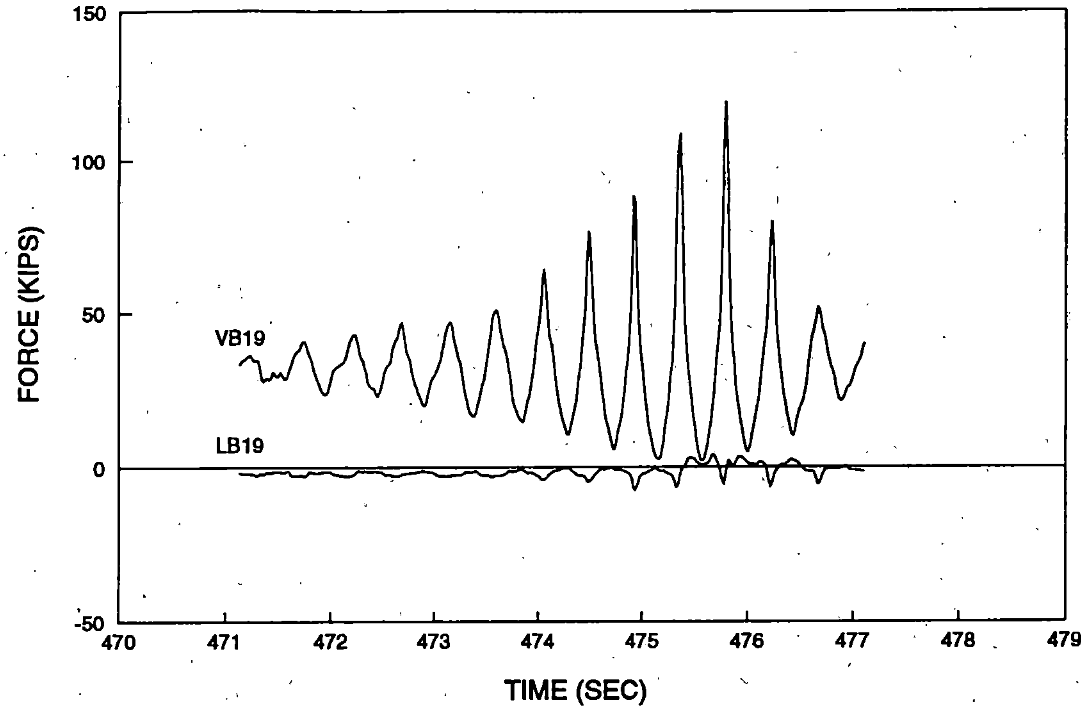


Figure 38. P&B Test Configuration 1, Axle 1 Right Wheel -- Vertical & Lateral Wheel Force Time History Run 5

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 VTU AND ON-TRACK TESTING

It was evident from the VTU test data that increasing side bearing clearance significantly affected railcar roll responses. Jump response was exhibited. When testing on-track, the limitation in test zone length made it impossible to replicate the jump response shown during the VTU tests. It is suggested that if a research program were initiated to investigate the effect of side bearing clearance on roll response with only on-track testing, it is possible an error in conclusions could result unless a test zone of sufficient length was developed.

Results of the tests show.

1. Compared to nominal gap clearance data, an increased gap produced significantly larger roll angles, at lower peak resonant frequency, over a wider range of frequencies.

2. Increased gap produced slightly less wheel unloading on the VTU. Due to safety considerations, it was not possible to test on-track at wheel-unloading conditions to determine which configuration was more severe.

3. Increased side bearing clearance allows more roll without involving suspension components.

4. On-track testing produced car body roll angles, displacement responses, and wheel loads which were similar in characteristic shape of amplitude level versus speed to the VTU test data, but not in amplitude and frequency. This is believed to be due to variances in the simulated VTU waveform.

5. It was found that slight changes in the input at the wheel/rail interface may cause major variations in dynamic response. This was most prevalent with the 3/4-inch roller side bearing gap clearance.

If the main purpose of the program was to show that the jump response phenomena would occur on the VTU, it was successful. If it is desired to use the test data from this program for adjusting policy, it is recommended that further examination of the test data provided, along with additional studies with the NUCARS model, and possibly more testing be done before decisions are made. The slight improvement of lessened wheel unloading may not be cause for change, especially when tempered with the increased car body roll responses encountered. In addition, not enough information about how other car types and/or suspension types might be affected is available.

6.2 COMMENTS ON VTU PERFORMANCE

The VTU was found to be an excellent tool for evaluating the effect of side bearing clearance. However, some limitations exist and should be stated here. Below are comments partially derived from conclusions which were reported for a proprietary test program and are repeated with permission. These comments are directed toward emphasizing the limitations of the VTU, and what could be done to improve the VTU capabilities for simulating on-track behavior. Improved VTU capability for replicating track conditions could be useful for evaluating the effect of increased side-bearing gap clearance under more realistic conditions. This would also be more cost effective than increasing the number of perturbations in the on-track test zone.

Differences in response between on-track tests and VTU tests are attributed in part to differences in input excitation and track modulus, which result in higher critical speeds, and to lack of realistic wheel/rail interaction forces, which result in altered vertical forces and unrealistic lateral forces (lateral dynamics). Wheel/rail interaction forces are not realistic on the VTU because of the lack of wheel to rail relative velocities that provide a major contribution to these forces when running on track or rollers. The inability of the VTU to accurately produce wheel/rail interaction forces and their ratios is a key problem -- this criterion is extremely important for replicating many on-track certification procedures. Differences are also attributed to lack of the random vibrations that are produced by wheel/rail dynamics, train handling, and other sources. These vibrations tend to reduce break-away friction in friction snubber elements. This was especially critical with higher-damped trucks.

It is suggested that additional testing be performed to investigate solutions to some of the VTU's limitations discussed above. Experimentation with superimposed random vibrations (dither) and lateral inputs that simulate the consequence of wheel/rail interaction forces could be done.

References

1. Lee, Harvey S. and Herbert Weinstock. "Influence of Variations in Side Bearing Clearances on the Roll Response of Rail Cars." U.S. Department of Transportation, Research and Special Programs Administration, Draft Report, April 1990.

2. Platin, B.E., et al. "Computational Methods to Predict Railcar Response to Track Cross-Level Variations." U.S. Department of Transportation, Federal Railroad Administration, Research & Development, Office of Rail Safety Research, Washington, D.C., September 1976. National Technical Information Service, Springfield, VA 22161, Report No. FRA-OR&D-76-293.

3. "Summary of Results of 70-ton Boxcar Testing." The MITRE Corporation, Metrek Division, McLean, VA 22102. January 1982. Draft WP-81W00713

APPENDIX

AAR-Funded Tasks

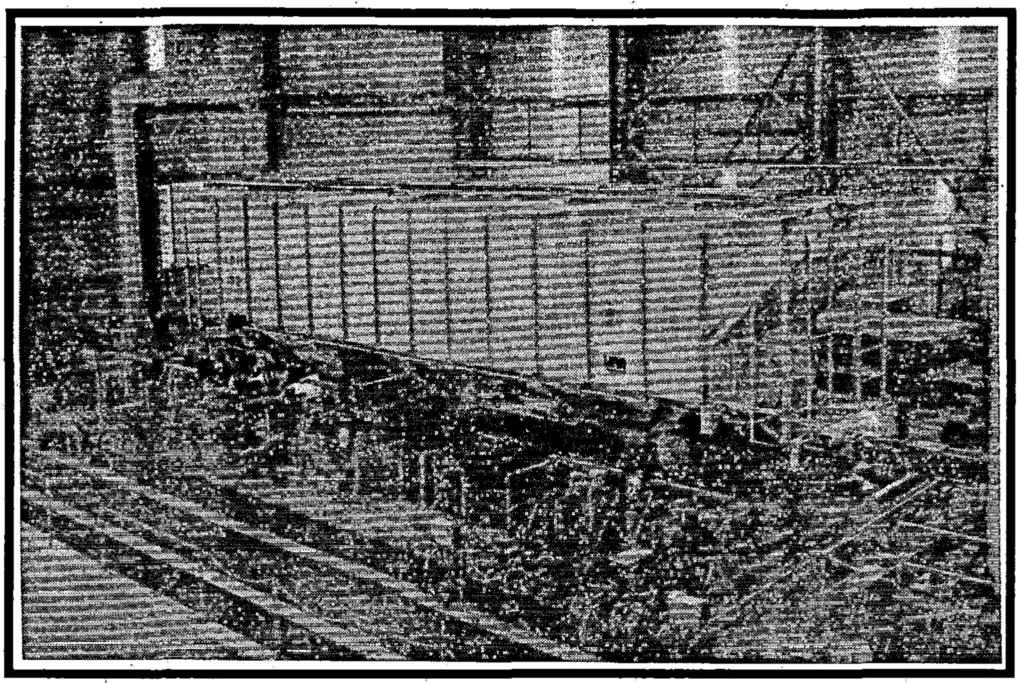
The Federal Railroad Administration awarded the Freight Car Tolerance -- Side Bearing Clearance Project to the Association of American Railroads (AAR) in April 1993. Concurrently, the AAR provided supplemental funding for the development of special instrumentation and equipment re-configuration required to successfully complete the project. A description of the preparation for this test follows:

VTU Description, Preparation

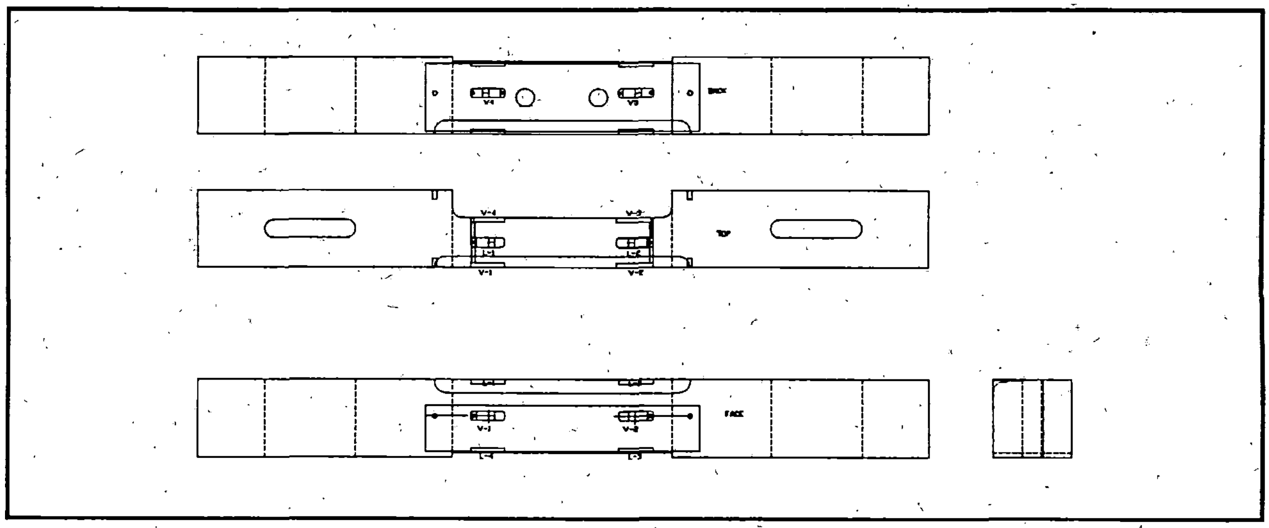
The Vibration Test Unit (VTU) is a vibration testing system designed and built for the purpose of testing railroad freight cars with controlled independent or combined vertical and lateral vibrations, thus creating the dynamic effects of perturbed track on a moving vehicle. The VTU is equipped with 12 hydraulic actuators which excite the test vehicle through its wheels. Eight of the actuators provide vertical inputs. Four act laterally at the wheel/rail level along the axis of each axle. The wheels of the test vehicle rest on load-measuring instrumented rail beams, which are supported by a system of hydrostatic bearings. These bearings allow a low-friction transmission of vertical and lateral excitation into the test vehicle by the hydraulic actuators.

A closed loop "servo-valve" feedback system is used to control the VTU's actuators with piston displacement and piston acceleration as feedback elements. Command-signal generation and data acquisition are accomplished with a DEC 11/23 computer.

The weight of the freight car is carried by the vertical actuators with a load limit of 40,000 pounds for each vertical actuator and 320,000 pounds for the total vehicle. The VTU, capable of accommodating railcars with truck spacing as long as 89 feet, was translated under AAR funding to allow testing of the test car with its 40-foot, 7-inch truck spacing.



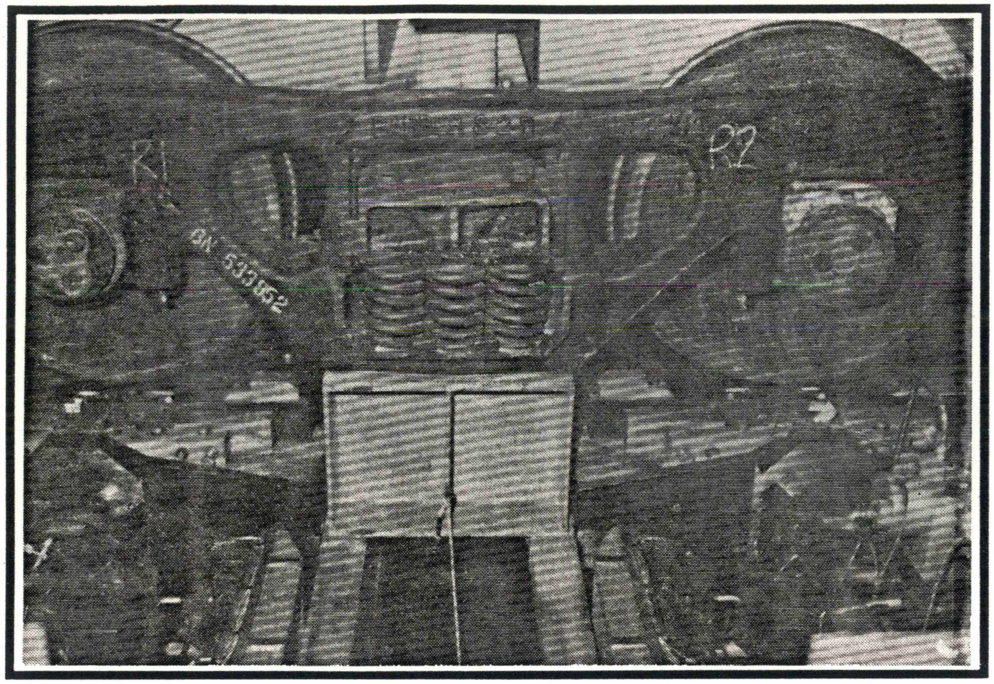
Test Car on VTU



Design for VTU Load Measuring Rail Beams

<u>Development of VTU Load-Measuring Instrumented Rail Beams</u>

Through funding supplied by the AAR, load-measuring instrumented rail beams were fabricated, calibrated, and installed on the actuator support bearings of the VTU. The beams were used to measure all eight vertical wheel forces during testing. Although not required by the Statement of Work for this program, the VTU rail beams were also configured to have the capability to measure lateral rail forces.



Test Truck and VTU Load Measuring Rail Beams

The accuracy of the load-measuring instrumented rail beams, founded on the worst beam calibration values, was approximately +/- 800 pounds based on a calibration range of 0 to 50,000 pounds and a test data recording range of 0 to 100,000 pounds. This shows notable improvement over load-measuring instrumented wheel set values of +/- 2,000 pounds (newer design wheel sets with considerably better accuracy were not available at the time of these tests). Even better resolution would be possible -- in future tests, to enhance lower wheel load level measurement accuracy (while sacrificing high level accuracy), the rail beam calibration values at and below the 25 percent of static wheel load levels could be used, and loads above the static load could be discarded. Thus, it is anticipated that the accuracy of the rail beams based on the worst beam could be reduced to a range of +/- 200 pounds at near wheel-lift condition.