PB 82 118647

U.S. Department of Transportation
Federal Railroad Administration

Truck Design Optimization Project: Phase II
Performance Specification for Type II Trucks

Office of Research and Development
Washington, D.C. 20590

FRA/ORD-81/36.1

August 1981

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

03 - Rail Vehicles & Components

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FRA/ORD-81/36-I		

4. Title and Subtitle	5. Report Date
TRUCK DESIGN OPTIMIZATION PROJECT (TDOP) PHASE II Performance Specification for Type II Freight Car Trucks.	August 1981
	6. Performing Organization Code
7. Author(s) P.V. RamaChandran and M.M. ElMadany	8. Performing Organization Report No. Wyle Report No. 81-28
9. Performing Organization Name and Address Wyle Laboratories Scientific Service of Systems Group 4620 Edison Avenue Colorado Springs, CO 80915	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DOT-FR-742-4277
12. Sponsoring Agency Name and Address Department of Transportation Federal Railroad Administration (FRA) Office of Research and Development Washington, DC 20590	13. Type of Report and Period Covered Technical Report Jan. 1979 - July 1981
	14. Sponsoring Agency Code FRA/RRD-11

15. Supplementary Notes Associated reports are the "Performance Characterization of Type I Trucks" (FRA/ORD-81/10) and the "Test Specification for Type II Trucks" (FRA/ORD-81/36-II). The performance test data tapes are available through NTIS (reference FRA/ORD-81/38-I through VII).

16. Abstract

One of the important goals of the Truck Design Optimization Project (TDOP) Phase II is to provide the railroad industry with a basis for performance specifications for the new generation (Type II) freight car trucks. This report sets forth such a quantitative basis as supported by available field test data. The quantified performance characterizations and recommended guideline specifications have been arrived at through field testing several representative Type II trucks, reducing and analyzing the field test data, and interpreting them in the light of physical reasoning. The performance characterizations and guideline specifications are provided in four distinct regimes of performance including lateral stability, trackability, steady-state curve negotiation, and ride quality.

17. Key Words	18. Distribution Statement
Type II trucks, performance regimes, performance characteristics, lateral stability, trackability, ride quality, steady state curve negotiation, TDOP Phase II, freight car truck performance	Document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	118	

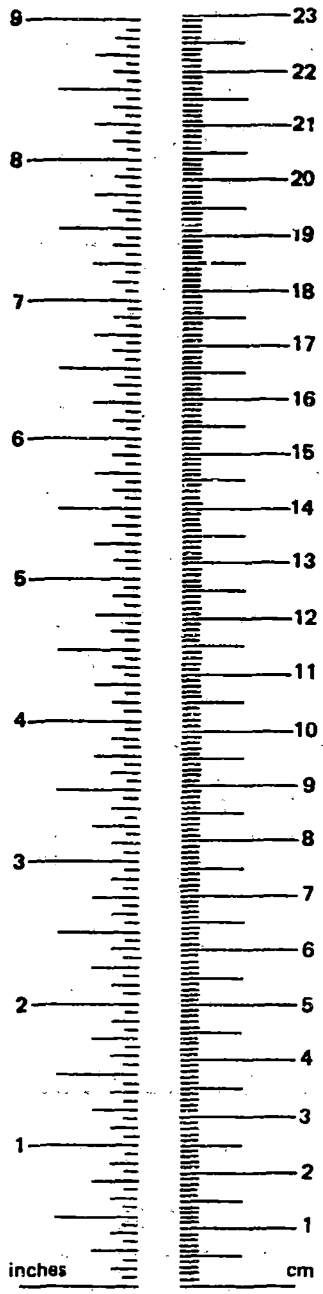
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

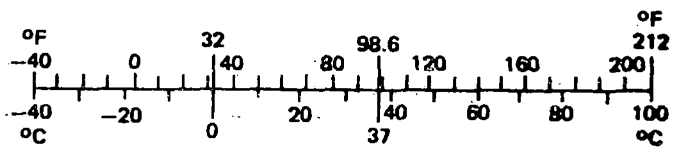
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	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

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	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	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

Under the Federal Railroad Administration (FRA) - sponsored Truck Design Optimization Project (TDOP) Phase II, a number of Type II (premium) freight car trucks have been evaluated on the basis of their performance under representative operating conditions. Seven trucks were selected and field tested to provide performance test data, which were analyzed to provide quantified measures of performance. These quantified performance levels were correlated with representative revenue service operating conditions and used in the characterization of truck performance. Characteristic performance levels were then interpreted in the light of both the performance levels associated with the standard, three-piece (Type I) trucks and the test variables associated with the Type II truck field test data. As a result, a set of preliminary performance specifications for the Type II trucks, applicable under a defined set of equipment variables and operating conditions, have been determined. Both the performance characterizations and the specifications are presented in this report.

The following general observations are made on the performance levels of the Type II trucks on the basis of the analysis and interpretation of field test data:

1. The radial trucks seem to achieve a measured degree of success in attaining their goal of reducing the levels of lateral forces at the wheel/rail interface in curved track, especially in track of moderate curvature (less than 5 degrees). There are obvious economic implications associated with such an improvement in performance levels in terms both of energy efficiency (fuel savings), and increased wheel and rail service life.

2. The greater lozenging stiffness incorporated in the rigid truck designs, in association with the other companion modifications such as primary suspension elements, reduced coupling between the trucks and the carbody and dampening mechanisms, allow these truck designs to achieve improvements in lateral stability performance levels.

3. Primary suspension trucks seem to result in reduced vertical dynamic loads and thus point to potential improvements in freight car truck design.

4. In general, no single Type II truck tested in the program seems to achieve significantly improved performance in all four performance regimes, i.e., lateral stability, trackability, steady state curve negotiation, and ride quality. The improved performance in specific performance regimes on the part of a given Type II truck can be related to specific design features which have desirable impact on performance in that regime. Improvement in performance in one regime is often attained at the cost of degraded performance in another. A thorough evaluation of the specific design features, as compared to evaluation of the truck itself, with a view toward maximizing the potential benefits while at the same time optimizing the trade-off in detrimental effects, should be considered in continuing efforts of the type undertaken in TDOP Phase II. The potential for combining the advantageous technological features into one future truck design cannot be ruled out. The framework for pursuing such an effort is contained in the experimental and analytic methodology developed and used in TDOP Phase II.

5. The classification of truck performance into distinct performance regimes and identification of performance indices typical of each regime is an important first step in a standardized methodology for truck evaluation. Detailed analytic procedures were used in reducing, analyzing and interpreting field test data and the results were then correlated to various service conditions resulting in a set of preliminary truck performance specifications.

ACKNOWLEDGMENT

The authors wish to express their gratitude and deep sense of appreciation for help and guidance received from various quarters during the effort reported in this document. The project was sponsored by the Federal Railroad Administration, guided by Messrs. N. Thomas Tsai, Philip Olekszyk and Arne Bang. Various railroad industry representatives on the TDOP Consultants Group provided incisive perspectives as well as consultative and guiding directions from the points of view of railroad operators, suppliers, equipment leasors, users and industry associations during the course of the project. Finally, members of the entire Wyle organization ranging from field test crew and computer analysts to editorial and mangement staff have tirelessly toiled to make these results possible. Our thanks to everyone who helped us in this effort.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1 - INTRODUCTION

The primary objective of the Truck Design Optimization Project (TDOP) Phase II was to define the engineering options available to the railroad industry in order to improve the efficiency and productivity of rail freight transportation. Results from experimental and theoretical investigations were applied, in consultation with the industry, to the development of guideline performance specifications for Type II freight car truck configurations. A Type II (premium) truck is defined as a special purpose truck which utilizes current wheel set and journal bearing assemblies, is compatible with existing air brake systems, and preserves car coupler height, while incorporating engineering innovations in the design of the suspension systems.

This report is a companion document to the "Performance Characterization of Type I Trucks" (Reference 1)*. In characterizing the performance of Type II trucks from the results derived from field test data, the methodology used is the same as that employed in the characterization of Type I trucks (defined as the standard, three-piece truck), with the exception that more emphasis was placed on the test data. The summary results from the field test data characterizing the performance of Type II trucks are described in Section 5. In translating the performance characteristics into a set of recommended guideline specifications for Type II trucks, the test results were interpreted and engineering judgment exercised in correlating factors such as the influence of expected component wear on performance and possible economic implications. The resulting guidelines form a set of recommended "performance specifications" for Type II freight car trucks.

As more information becomes available on such factors as wheel and rail wear, and truck component wear (from the wear data collection program in progress) as well as other sources, the recommended "specifications" published here may have to be further refined to reflect factual influences replacing the judgment factor. However, it is believed that the recommended guidelines presented in this report provide a framework to define a set of improved performance levels associated with design changes.

Another document in this series, the "Test Specification for Type II Trucks" (FRA/ORD-81/36-II), sets forth the guidelines within which test programs in the field and in the laboratory are to be conducted in order to provide the data necessary for the evaluation of freight car trucks, along the lines presented in this document.

*Numbers in parenthesis refer to references on page 84.

SECTION 2
CLASSIFICATION OF TRUCK PERFORMANCE

The task of evaluating Type II truck performance has been made more complex (as compared to Type I trucks) by the variations in design features incorporated in the Type II trucks. A principal objective of TDOP Phase II was to set up a framework within which relationships between the major design features and the performance characteristics of the Type II freight car truck configurations could be evaluated. With this objective in mind, and following the groundwork laid for a similar characterization of performance for Type I trucks (Reference 1), the overall performance of freight car trucks has been classified (Reference 2) to facilitate quantitative evaluation of performance.

PERFORMANCE REGIMES

Performance regimes are defined as sets of conditions associated with predominant features that distinguish one regime from another. The four distinct performance regimes are lateral stability, trackability, steady state curve negotiation, and ride quality. The set of these four performance regimes is considered to identify all aspects of truck behavior. Within each of these performance regimes, performance indices are identified. A performance index is defined as a measurable quantity typical of the performance regime associated with it. Characterization of performance is achieved by means of a range of performance indices quantified in each of the regimes, and associated with a set of specified operating conditions such as speed, track quality, and lading conditions.

Lateral Stability

The dynamic performance regime of lateral stability (hunting) is identified with the phenomenon of self-excited lateral and yaw oscillation of the truck and carbody occurring above what is termed as "critical speed." In dynamic terms, hunting represents an interplay between creep forces at the wheel/rail interface, the tendency of the elastic creep forces to react and stabilize the vehicle, inertial forces trying to amplify the oscillations, and the suspension damping tending to attenuate them. Economic and safety-related consequences of hunting arise from truck and component wear and the attendant detrimental effects on performance, impact forces between wheel and rail (possibly resulting in gauge widening and posing the danger of wheel fracture), and also the violent oscillations of the carbody during hunting leading to damage of the lading. Performance indices, or measurable physical quantities unambiguously associated with performance, identified within the lateral stability regime are:

- Critical speed (quantified in terms of root mean square lateral acceleration)
- Peak lateral acceleration

Trackability

The ability of a truck to maintain a safe range of vertical load distribution under a range of track conditions and the dynamic response of the vehicle to transient and periodic changes in these conditions are associated with the trackability performance regime. Subclasses of this performance regime and their associated performance indices are given below:

Performance Subregimes	Performance Indices
Harmonic Roll	- Critical Speed - Peak roll angle
Bounce	- Critical Speed - Peak vertical acceleration
Track Twist	- Wheel unloading index
Curve Entry/Exit	- Wheel unloading index

The wheel unloading index (WUI) is defined as follows:

$$\text{WUI} = 1 - W_L/W_H/3$$

where

W_L = vertical force on most lightly loaded wheel

W_H = sum of vertical forces on the three most heavily loaded wheels

This definition of the wheel unloading index, in practical terms, implies that the higher the value of the index, the worse the condition of load equalization. In other words, a value of unity for the WUI denotes wheel lift off and a value of zero, for the WUI, indicates equal distribution of vertical load among all four wheels.

The mode with the lowest natural frequency in freight cars is generally lower center roll in which lateral displacement of the center of gravity and roll about that center occur roughly in phase. Alternating vertical forces, most usually due to staggered rail joints, give rise to carbody oscillations called harmonic roll or rock-and-roll, in which the carbody pivots about centers successively farther offset from the geometric center of the truck: first, the edge of the centerplate, and finally the side bearings.

The lateral shift of the center of gravity compresses the springs on the one side until they are solid and in extreme cases the opposite wheels lift off the rail. Derailment is inevitable if any kinetic energy of roll rotation remains when the center of gravity of the body is vertically above the side bearing.

Harmonic roll is a low-speed phenomenon, occurring usually at speeds below 20 mph. The critical speed is determined by rail joint spacing, mass and mass distribution of the carbody (including height of center of gravity) and the characteristics of the suspension system, i.e., the spring rates. The main resistance to harmonic roll comes from friction snubbing.

At higher speeds, and thus higher frequencies, an important dynamic cause of wheel unloading is the phenomenon called bounce/pitch. When the carbody oscillates about a transverse horizontal axis, with the ends of the carbody rising and dropping out of phase; a vertical bounce motion may be superimposed. The natural frequencies are determined by the mass and mass moment of inertia in pitch of the carbody and by the suspension spring stiffness.

All trucks have some provision for accommodating vertical rail irregularities with a wave length of the order of magnitude of the axle spacing. This adjustment is intended to retain a safe vertical load on the four wheel-rail contact points when they no longer lie in a plane. The standard truck adjusts itself to such vertical rail irregularities by independent rotation of the side frames, while rigid trucks rely on the displacement allowed by the secondary suspension, or on torsionally flexible side frame connections. For all trucks, there is some limit of track twist beyond which vertical wheel loads may fall below a safe minimum, and the probability of derailment is increased.

In curve entry and exit sections of the track, the track curvature is constantly changing. The spiral entry and exit sections represent the transient zones between the tangent track and constant curvature track sections. Once again, the ability of the truck suspension system to maintain a safe range of vertical loads on all four wheels will determine the ability of the vehicle to traverse these transient track sections under stable conditions.

In operational terms, within all four of these subregimes of performance, the consequences are primarily safety related. This does not necessarily preclude other detrimental effects such as fretting damage to the suspension springs arising from extreme motions during harmonic roll, potential fracture mechanisms in components such as centerplates due to bounce motions, and damage to truck components from impact forces.

Steady Stage Curve Negotiation

As a train negotiates a constant curvature segment of track at more-or-less steady speed, horizontal forces at the contact planes between the wheels and the rails work to rotate and guide the vehicle around the curved track. Since most truck designs are limited in their ability to permit individual axles to align themselves radially in the curve, this results in the wheel flanges making contact with the rails. Therefore, the trucks rely on flange contact to provide guidance in curves. The consequences of these lateral forces are wheel and rail wear; resistance of the truck to forward motion resulting in increased demands on tractive power and therefore increased fuel consumption; and, in extreme cases, the tendency for wheels to climb the rails thus giving rise to the potential of derailment. With the desirability of flange-free curving, some of the improved truck designs have concentrated on improving truck kinematics to extend their performance to provide the maximum attainable radial alignment of axles in curved track and thus minimizing flange contact with rails.

The performance indices identified with this regime are:

- Average lateral force on leading outer wheel
- Average lateral-to-vertical force ratio (L/V ratio) on the leading outer wheel
- Average angle of attack

Ride Quality

Ride quality as a performance regime refers to the dynamic environment in the carbody and encompasses the capability of the truck suspension to attenuate the excitation arising from track irregularities. The characteristics of a truck to function as a mechanical filter in isolating the carbody from the disturbances induced by the track is of primary interest in this performance regime.

The principal performance index identified in this regime is transmissibility, defined here as the ratio of the rms value calculated from the response power spectral density within a specified frequency bandwidth to the rms value calculated from the track input power spectral density over a corresponding frequency bandwidth. Transmissibility can be quantified for vertical, lateral, and roll motions of the carbody, with the corresponding track input arising from track profile, alignment, and crosslevel. Additionally, the rms response over a wide band spectrum (0-20 Hz) has been identified as a supplementary index. This index reflects the level of energy content in the oscillatory motions of the carbody and provides a means for comparison of the ride quality of various vehicle configurations under equivalent conditions of operation.

Primary operational consideration in this performance regime is the possible damage to lading from poor ride quality.

SECTION 3
METHODOLOGY FOR DEVELOPMENT OF PERFORMANCE SPECIFICATIONS

Establishment of an analytic and experimental methodology for relating truck parameters to the economics-related performance indices defined in each of the performance regimes over the range of in-service train configurations, track conditions, equipment parameters, and speeds is a major engineering goal within TDOP Phase II. Applying this methodology, and in coordination with industry, guideline performance specifications were developed for the Type II trucks.

The major elements comprising the methodology for truck evaluation are:

- Field testing of selected trucks to obtain performance test data and the reduction and analysis of the field test data leading up to quantitative definition of performance
- Simulations utilizing credible mathematical models to augment and complement results from field test data
- Determination of wear and degradation of freight car trucks under revenue service conditions through a structured program of periodic measurement of various truck components including wheels
- Correlation of results from analysis of economic data on truck maintenance and operation from operating railroads with results from analysis of performance test data.
- Engineering interpretation of the results from the analysis of test data and formulation of recommended guideline specifications for the Type II trucks.

A block diagram indicating the flow of elements in the methodological scheme is shown in Figure 3-1.

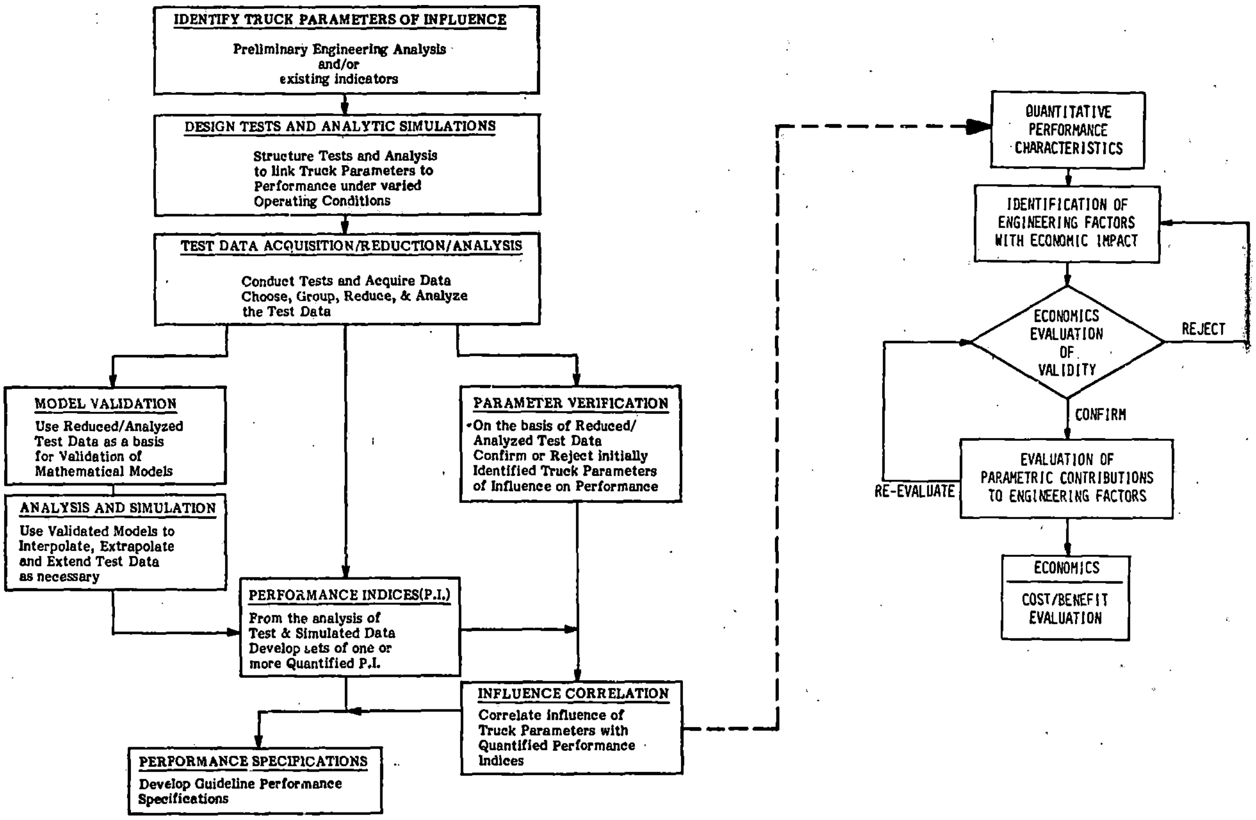


FIGURE 3-1. METHODOLOGY FOR TRUCK EVALUATION

SECTION 4 - EQUIPMENT TESTED

The characterizations of performance of Type II trucks required the selection of a sample of trucks that incorporated various, innovative design features. Some of these features may be identified as primary suspension systems, secondary suspension systems, rigid frame arrangements, and radial alignment of axles in curved track. A survey of the industry identified the various types of Type II trucks commerically available on the market. A set of clearly defined criteria for the selection of Type II trucks for testing was decided upon in consultation with the TDOP Consultants' Group, comprised of representatives from operating railroads and equipment suppliers. A systematic selection process based on this set of criteria was undertaken to ensure that the samples selected for testing would be representative of the state-of-the-art in truck design (Reference 3). The seven trucks selected for testing represent generic design innovations incorporated in Type II trucks commercially available in the market at the time. The selected trucks may be classified into these following groups:

- Primary suspension trucks featuring suspension elements at the axle bearing
- Secondary suspension trucks which leave the conventional suspension springs under the bolster ends intact, but feature other design innovations such as guidance of wheels/axles for radial alignment
- Trucks featuring primary + secondary suspension elements which utilize a combination of both types of suspensions elements

Alternately, the selected seven trucks may be grouped as follows:

- Radial (steering) trucks which provide the axles some freedom to align themselves radially in curved track
- Rigid trucks which incorporate a rigid bolster to sideframe connection resulting in increased lozenging stiffness
- Trucks with unconventional design which vary significantly from the standard design of a freight car truck consisting of a bolster and two sideframes with auxiliary suspension elements

All but one of the seven Type II trucks tested in TDOP Phase II were 100-ton trucks, with the remaining truck being a 70-ton truck. The carbodies used in conjuction with the test trucks during the field tests were a 100-ton open hopper car for the 100-ton trucks and a 70-ton open hopper car for the 70-ton truck. Details pertaining to instrumentation, test variables such as speed and lading conditions, and test procedures may be found in TDOP Phase II test documentation (Reference 4). A summary of the characteristic parameters relating to test trucks and carbodies is given in Tables 4-1 and 4-2 respectively.

Six of the trucks tested used the Canadian National (CN) profile wheels, shown in Figure 4-1. These wheels were new wheels obtained from the wheel manufacturer, produced to the CN production specifications. Although initial plans called for the use of new standard AAR 1:20 taper wheels and worn wheels derived from the AAR standard profiles, resource limitations within the project did not permit such a scope for field tests. The CN profile was selected as a compromise, in agreement with the TDOP consultants. The seventh truck which is a primary + secondary suspension truck used new AAR 1:20 taper wheel profiles.

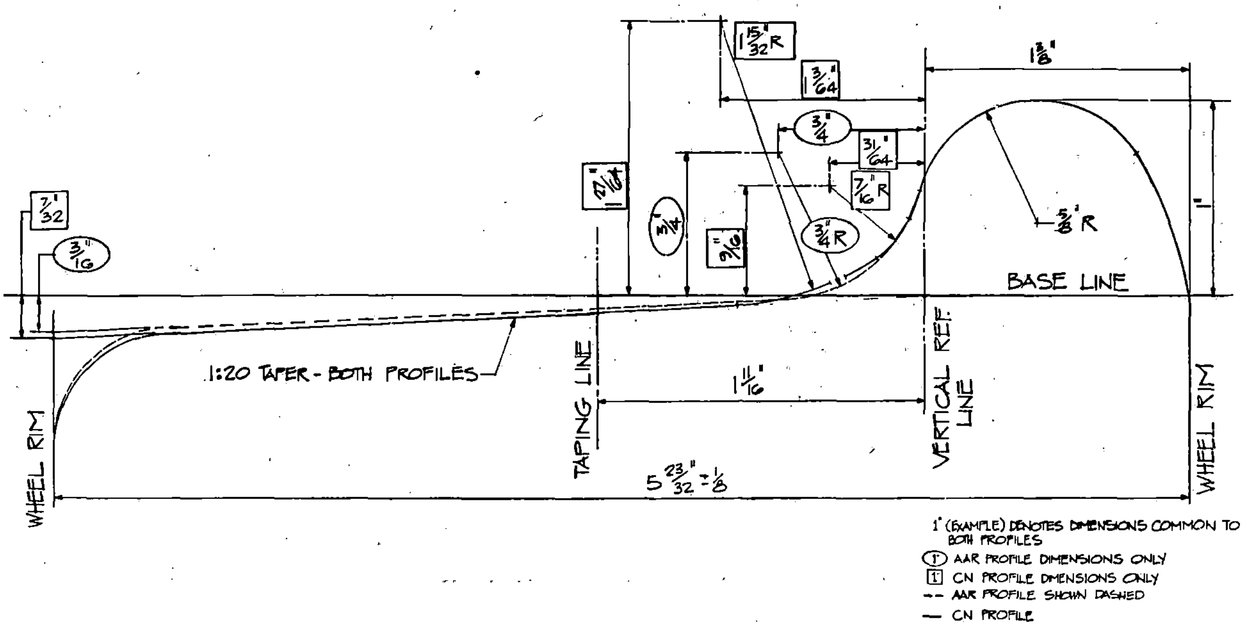


FIGURE 4-1. WHEEL PROFILE COMPARISON - CN PROFILE VS AAR STANDARD 1:20 PROFILE

TABLE 4-1. TRUCK CHARACTERISTICS

	Dresser DR-1**	National Swing Motion**	Barber-Scheffel**	Maxiride*	Devine-Scales*	ACF**	Alusuisse***
Wheel Base, in	70.00	72.00	75.00	72.44	70.00	70.00	-
Spring Group					-	-	-
In	6-D5	6-D6	7-D5	†			
Out	7-D5	6-D7	6-D5	†	-	-	-
Center Plate Diameter, in	16.00	16.00	16.00	14.00 (spherical)	16.00	16.00	13.625 (spherical)
Side Bearer Clearance, in	0.625	0.28	0.181	None	0.1875	Constant Contact	Constant Contact
Snubbing:	Load Dependent	Load Dependent	Load Dependent	Load Dependent (non standard)	Load Dependent	Hydraulic Dampers	Load Dependent (Leaf Spring Friction)
Weight, lb+	11,125	11,425	11,500	10,428	12,000	10,600	N/A
Wheel Diameter, ft	3.00	3.00	3.00	3.00	3.00	3.00	2.75

* Primary suspension trucks
** Secondary suspension trucks
*** Primary + secondary suspension trucks
† Vertical Spring rate (per car), lb/in
22,100 (empty)
161,100 (loaded)
\+ Best estimates on the basis of manufacturer's supplied information.

TABLE 4-2. CARBODY CHARACTERISTICS

	70-Ton Capacity* Open Hopper Car	100-Ton Capacity Open Hopper Car
Empty (light) weight, lb	44,700	67,300
Loaded weight, lb	167,900	237,000
Capacity, lb	154,000	196,000
Length over pulling face of coupler, ft	46.17	53.04
Truck centers, ft	33.67	40.5
Center of Gravity (above rail):		
Loaded, ft	5.85	7.17
Empty, ft	-	4.38

*Used only on Alusuisse truck testing.

SECTION 5 - PERFORMANCE CHARACTERIZATION

Test data acquired from field tests conducted in TDOP Phase II on the Type II trucks were analyzed through digital computers and software packages especially tailored to meet the data reduction requirements within the project. The computer outputs of data analyses were arranged in digital printout and plot formats to facilitate analysis and presentation of the results. Data pertaining to each performance regime were first examined for quality; then, the total time history in each of the tests was reviewed in the process of selecting appropriate windows on the data to be analyzed; finally, selected data were analyzed in keeping with specific engineering and analytic requirements for quantitative definition of performance characteristics. The results in each of the performance regimes included digital printouts allowing for statistical analysis, and various forms of plots defining functional relationships of performance characteristics with operational variables included in the test conditions. The methodology for data analysis in each of the performance regimes is included in the discussions in Section 5.2.

5.1 TEST DATA

One carset each of the selected Type II trucks were tested to generate the performance test data (Reference 4). Accelerometers, displacement transducers, force transducers, strain gages, instrumented couplers, and a specially developed package of eddy current transducers for the measurement of wheel/rail angle of attack comprised the package of instrumentation. However, field test data on the seven tested trucks varied in scope in many cases from truck to truck within each of the performance regimes due to the limitations on the deployment of instrumentation imposed by the design features of the trucks themselves. In particular, the deployment of the lateral/vertical force (L/V) measurement system and the angle of attack measurement system had to be left off some of the trucks. Five of the test trucks were instrumented for L/V measurements and six of the trucks were instrumented for angle of attack measurements. These variations in available field test data as well as any exception with regard to the usage of data are discussed in the following paragraphs organized by performance regimes (Reference 4). Table 5-1 shows the test matrix and the data available from the field tests. For the track geometry data, see Appendix B and References 5 and 6.

5.1.1 Lateral Stability Performance Test Data

Field test data for the lateral stability performance regime were acquired on all seven test trucks, from tests on mainline, bolted jointed rail (BJR) and were acquired on two trucks from tests using continuous welded rail (CWR). The test cars were run at test speeds ranging from 40 to 79 mph with dwells of approximately 60 seconds duration at 5 mph intervals within the test speed range. The tests were conducted with both empty and loaded test cars.

5.1.2 Trackability Performance Test Data

Performance test data for this regime were collected through separate test runs covering the subregimes. Data for harmonic roll were collected from test runs on branch line track, with empty and loaded test cars, for an operating speed range of 4 mph to 30 mph with dwells approximating 40 seconds in duration at 2 mph increments; the tests were then repeated at 2 mph decrements from 30 mph down to 4 mph. Although perturbed track following standards such as specified by the AAR would have provided more desirable test conditions for the simulation of performance within these subregimes, existing branch lines were chosen as a compromise to accommodate the scope of field testing within project resource allocations.

Data for use in the subregime of track twist were acquired from test runs on yard track at approximately 10 mph in the forward and reverse directions.

For the subregime of curve entry/exit, data were acquired during test runs in a test zone consisting of mainline jointed track, ranging in curvature from 1.1 to 6.2 degrees and ranging in equilibrium speeds from 34 to 48 mph. These were the same tests designed to collect data for use in the curve negotiation regime (see Section 5.1.3).

5.1.3 Curve Negotiation Performance Test Data

Test runs for the generation of performance test data relating to the curve negotiation performance regime, as well as the curve entry/exit subregime of the trackability performance regime were conducted over a test zone comprised of mainline jointed track. Profiles and other related information for the different curves included in this test zone are given in Figure 5.1.3-1. The tested zone consisted of track ranging in curvature from 1.1 to 6.2 degrees and associated equilibrium speeds ranging from 34 to 48 mph. Tests were conducted using carbodies in the empty and the loaded conditions for six of the test configurations, and only in the loaded condition for the remaining configuration. Three passes were made through the test zone for each condition, one at approximately 10 mph less than the nominal equilibrium speed, another at the nominal equilibrium speed, and a third at approximately 7 mph greater than the nominal equilibrium speed. All the curve negotiation test runs were made in the uphill direction. Auxiliary runs made in the downhill direction with controlled application of brakes have not been used in the characterization of curving performance of the trucks.

Test data acquired on the seven Type II trucks were not uniform, as indicated in Table 5-1, owing to the varying degrees of instrumentation deployed on them.

The instrumented wheelsets and bearing adapters for the measurement of lateral and vertical (L/V) forces and the eddy current sensors for the measurement of wheel/rail angle of attack were deployed on five of the test trucks. A sixth truck had the angle of attack transducers applied to it, but not the L/V measurement system. The remaining truck had neither the L/V nor the angle of attack measurement system applied to it. These variations on the level of instrumentation on the test trucks were made necessary by the complexities in the design features precluding uniform application of all transducers on all trucks. Specifically, the truck with the L/V measurement system but not the angle of attack measurement system was a secondary suspension, rigid truck; and the truck with neither the L/V nor the angle of attack measurement system was a truck which featured a combination of secondary and primary suspension elements.

TABLE 5-1. PHASE II TEST MATRIX

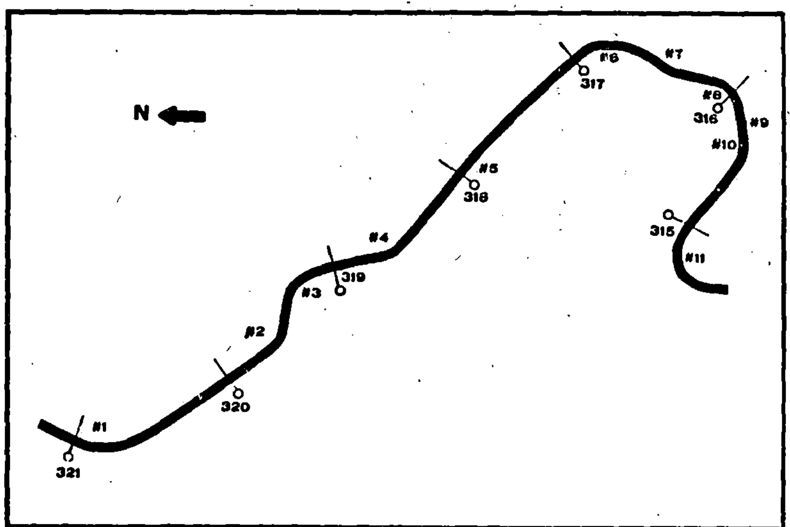
Truck	Carbody	Wheel Profile	Lading	Lateral Stability & Ride Quality		Trackability		Curve Negotiation
						Harmonic Roll	Track Twist	
				Class 4 BJR	Class 5 CWR	Class 2 BJR	Yard BJR	Class 4 BJR
Dresser DR-1	100-Ton Open Hopper Car	CN	E	•	•	•	•	•
			L	•		•	•	•
Barber-Scheffel	100-Ton Open Hopper Car	CN	E, L	•		•	•	•
Devine-Scales	100-Ton Open Hopper Car	CN	E, L	•		•	•	•
National Swing Motion	100-Ton Open Hopper Car	CN	E, L	•		•	•	•
Maxiride 100	100-Ton Open Hopper Car	CN	E	•	•	•	•	•
			L	•		•	•	•
ACF Fabricated	100-Ton Open Hopper Car	CN	E, L	•		•	*	o
Alusuisse	70-Ton Open Hopper Car	AAR 1:20 Taper	L	•		•	*	

Legend

- • Test Data Available
- o Curving Data Consisting of Angle of Attack; No L/V Forces
- * No Data Available on L/V Forces

E=Empty
L=Loaded

BJR=Bolted Jointed Rail
CWR=Continuous Welded Rail
CN=Canadian National Profile



Curve No.	Degree of Curve	Direction Curve	Length (ft.)	Super Elevation (in.)	Start MP	Stop MP	Equilibrium Speed
1	2.5	Left hand	2736	4.09	321.1	320.6	48.3
2	6.2	Left hand	1080	4.98	319.7	319.5	33.9
3	6.1	Right hand	1386	4.90	319.4	319.1	33.9
4	5.2	Left hand	1136	5.08	318.7	318.5	37.4
5	1.1	Right hand	934	1.41	318.0	317.8	42.8
6	3.0	Right hand	3118	3.32	317.1	316.5	39.8
7	5.1	Left hand	961	4.88	316.5	316.3	37.0
8	5.0	Right hand	2070	4.79	316.2	315.8	37.0
9	3.7	Left hand	492	3.72	315.8	315.7	37.9
10	6.2	Right hand	1037	4.94	315.7	315.5	33.7
11	6.1	Left hand	2420	4.92	315.0	314.6	34.1

FIGURE 5.1.3-1. CURVE PROFILES - TEST ZONE

The forces at the wheel/rail interface were measured using instrumented wheelsets. The instrumented wheelsets comprised of eight full-bridge strain gages at two locations, located symmetrically inboard of the wheels for the measurement of bending strains in the axle, and two strain gages at the middle of each axle to measure torque, which could be used to estimate longitudinal creep forces. The bearing adapters are also instrumented with strain gages for measurement of vertical forces. However, strain gaging the bearing adapters was not a feasible method of vertical force measurement in all cases. Where strain-gaged bearing adapters could not be used, displacements of the primary spring groups were measured to provide a means for the calculation of the vertical forces at the bearing adapter.

Using the strain gage measurements from the axles and the vertical forces obtained through the instrumented bearing adapter or the primary spring group displacements, lateral and vertical forces were calculated by means of the axle bending technique (Reference 7).

An angle of attack measurement system using eddy current sensing devices was developed expressly for the purposes of TDOP Phase II. It consisted of four eddy current transducers at each wheelset. Two of the transducers measured the side frame position relative to the wheel, and the other two measured the side frame position relative to the rail. Eliminating the common reference to the side frame between the two sets of measurements, and using the known distance between the two sensors in each pair, the angle of attack was calculated. The measurement systems were applied to the forward truck of the test car at the right side only. Thus, angle of attack data were available on two wheels at the forward truck, both situated on the right side of the car. In retrospect, it would have been advisable to provide angle of attack measurement instrumentation on both the left and the right sides of the trucks since vehicle dynamics seem to have had significant effects on the measurement system and caused considerable scatter in the data. This has limited the applicability of the angle of attack data for characterizing performance of the trucks. For this reason, the results from the angle of attack data are presented in Appendix A.

5.1.4 Ride Quality Performance Test Data

The data for use in the ride quality performance regime come from the same test runs which produced data for the lateral stability performance regime. These test runs consist of the high speed runs on mainline, tangent track. Lateral oscillations indicative of unstable phenomena were excluded from consideration in the ride quality regime.

In addition to the performance test data on the test cars, track geometry data were also collected during TDOP, Phase II (Reference 5,6). These data were necessary to quantify transmissibility.

5.2 DATA REDUCTION AND ANALYSIS

Reduction and analysis of the field test data acquired through TDOP Phase II field test program were undertaken in-house through the use of digital computers. An existing software package (Reference 8) was updated and modified to suit the requirements of data analysis within each of the performance regimes and to provide the results in digital printouts to facilitate statistical analysis of the data. The software also produced plots in various formats for presentation of the quantified performance indices as functions of appropriately correlated operating conditions. A discussion of some of the details involved in the data reduction and analysis is contained in the paragraphs below.

5.2.1 Analysis of Lateral Stability Performance Data

Performance test data on the lateral acceleration of the test vehicle were available at various locations. These included (a) the leading end (B-end), the trailing end (A-end), and the center of the carbody at the sill level; (b) the leading end (B-end), and the trailing end (A-end) of the carbody at the roof level; and (c) all axles of the two trucks (B-end and A-end, four axles) under the test car. Thus, a total of nine lateral acceleration measurement locations are represented in the data. Data at all these locations were studied in the process of evaluating performance in the lateral stability regime. The frequency range of analysis was 0-20 Hz. Indications of instability were identified from the data and the power spectra. The power spectra were scanned in the range of 0-5 Hz and the characteristic frequency of hunting was identified. Centered around this frequency, root mean square (rms) accelerations were calculated for a bandwidth of 1 Hz. The calculated rms values for lateral accelerations were then plotted as functions of operating speed.

The rms lateral accelerations calculated for the various locations on the test vehicle were compared for the purpose of arriving at an engineering judgment to choose the appropriate location to represent the characteristic performance of the test truck. This process resulted in the choice of the locations at the carbody sill level for this purpose. Comparative study of the wheelset acceleration data with the carbody data indicated that the carbody experienced higher amplitude of oscillations than the wheelset, especially with increasing speed. This was in keeping with the conventional wisdom that carbody hunting dominated lateral oscillatory motions of rail vehicles within the operational speed range up to the presently legal limit of 79 mph on American railroads. The accelerometers at the roof level of the carbody were used principally to determine the effects of such modes as twist and upper center roll on the lateral oscillations at the higher operating speeds.

The characteristics in the lateral stability regime are represented by the following parameters: (a) the maximum rms value of lateral oscillations associated with a characteristic hunting frequency in the spectrum of 0-5 Hz obtained from a comparative analysis of the results between the leading and trailing ends of the carbody at the sill level; and (b) the rms value of lateral oscillations associated with a characteristic hunting frequency in the spectrum of 0-5 Hz at the center of the carbody at the sill level; (c) the maximum of the peak value of lateral accelerations obtained from a comparative analysis of the results between the leading and trailing ends of the carbody at the sill level; and (d) the peak value of lateral acceleration at the carbody center/sill level. The latter parameter is presented since it was noticed that, for some of the Type II trucks, it reflected the maximum levels of lateral oscillations at the sill level. It is believed that this could result from a flexural mode interacting with the lateral and/or yaw mode of oscillation near the hunting frequency of approximately 3 Hz.

Typical results of an empty carbody operating on continuous welded rails are given in Figures 5.2.1-1 through 5.2.1-2. Analysis of the data has shown that there are differences in the response due to the differences in the nature of track excitation. The frequencies of the peaks and the corresponding amplitudes are different, with the response to the excitations arising from the jointed rail being higher than that arising from continuous welded rail. The harmonics of the rail joints are a major vibratory input to the system and they are strong enough to force the freight car system to vibrate at their frequencies, and not allow the mode shapes predicted by the eigenvalues of the system to be developed. On the other hand, the spectral response using continuous welded rail are dominated by several frequencies associated with the carbody modes. While a moderate amplitude intermittent hunting is experienced by the vehicle system operating on jointed rail, no evidence of hunting is noticed with the vehicle running on continuous welded rail.

5.2.2 Analysis of Trackability Performance Test Data

Analysis of data in the trackability regime fell under the subregimes of harmonic roll, track twist, and curve entry/exit. The test data for harmonic roll consisted of medium speed runs on a branch line. The data from the medium speed (4 mph to 30 mph) runs on the branch line were examined. However, no indications of harmonic roll could be discerned from the data. In other words, no quantifiable levels of roll motion were found in the data. Therefore, no quantified levels of performance are provided for this subregime.

In the other two subregimes, namely track twist and curve entry/exit, the wheel unloading index has been quantified. Data relating to the track twist subregime consisted of yard track tests and those relating to curve entry/exit consisted of the segments of curved zone test runs representing the entry and exit spirals associated with each of the curves in the test track. The quantified levels of the wheel unloading index for the track twist subregime are provided in tabulated format. For the curve entry/exit subregime, values of the wheel unloading index with associated probability of occurrence of 95% are plotted as functions of speed.

5.2.3 Analysis of Curve Negotiation Performance Test Data

Test data from field tests in the curved track zone were examined and the data collected over track segments of constant curvature identified for use in the curve negotiation regime. The test data consisted of wheel/rail force measurements through the instrumented wheelsets and bearing adapters, and the angle of attack measurements through the eddy current transducers.

Lateral forces and L/V ratios were calculated at all four wheel/rail interfaces on the leading truck of the test car. The lateral forces and L/V ratios at all four wheel/rail interfaces were subjected to comparative analysis, correlated with operational parameters such as speed as well as track curvature. On the basis of such an analysis, the forces and ratios at the leading outer wheel were confirmed to be larger than those at the other locations, especially at speeds near and above the equilibrium speeds.

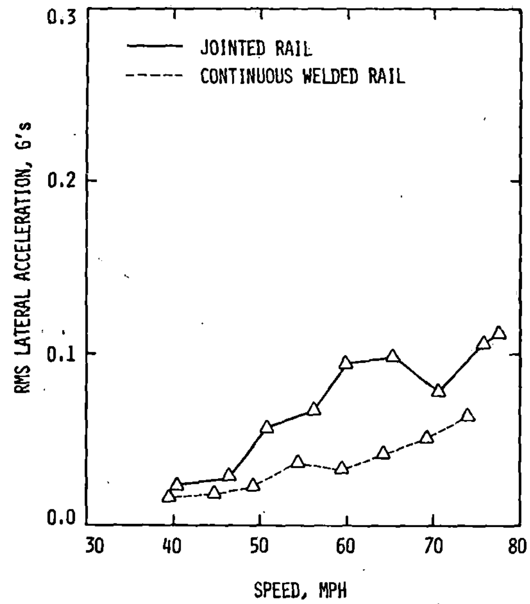


FIGURE 5.2.1-1. RMS LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED -EMPTY CARS

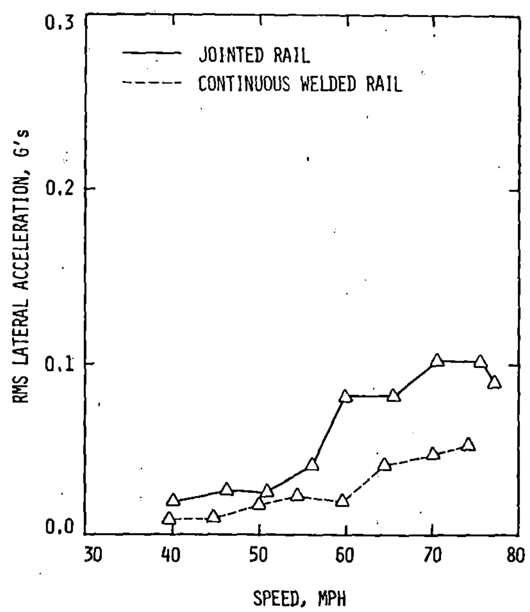


FIGURE 5.2.1-2. RMS LATERAL ACCELERATION AT LEADING AXLE/ LEADING TRUCK VERSUS SPEED - EMPTY CARS

The results of the calculations of the angle of attack of the Type II trucks are given in Appendix A.

5.2.4 Analysis of Ride Quality Performance Test Data

The high speed tangent track test runs were used in the analysis of ride quality performance. Since this body of data was the same as the one used for the analysis of lateral stability performance, the distinction between the two analyses should be made clear. Ride quality analysis confined itself to those parts in the body of high speed test data which excluded extreme phenomena such as unstable behavior characterizing hunting.

The requirement to quantify transmissibility as a performance index necessitated the concurrent analysis of track geometry data and test vehicle response data. The track geometry data (Appendix B) were acquired through an independent test run on the same track which was utilized for performance tests. Therefore, concurrent analysis of the two bodies of data imposed a few conditions such as the definite establishment of one-to-one correspondence between the two bodies of test data insofar as they ensured corresponding input/output relationships. In the already completed characterization of Type I truck performance (Reference 1), this was accomplished by merging the track geometry data base with the performance test data base and alignment of the two data bases relative to track location established. However, during the course of work on the Type II truck data, striking a compromise with available project resources did not allow for such an effort including merger of the two data bases and the spectral analyses required to quantify transmissibility. Consequently, the quantification of performance in this regime concentrated on the rms response over the wide band spectrum (0 - 20 Hz) as a performance index.

5.3 PERFORMANCE CHARACTERISTICS

As a result of the analysis of field test data on the performance of the seven Type II trucks, quantified levels of performance could be studied as functions of operational variables. Analysis of test data permitted quantification of the performance indices defined within each of the performance regimes. The performance characteristics presented in this section of the report represent the quantitative range of these indices as functions of operational variables such as speed and lading conditions. It is considered that these ranges of quantitative performance levels are typical to the extent that they may be expected to be repeatable under comparable test conditions.

In making any comparison with the performance levels associated with Type I trucks described in Reference 1, one cautionary note is important to keep in mind. That is, the Type II trucks were tested in conjunction with an open hopper car and the trucks used the CN profile wheels; whereas, the Type I trucks tested under TDOP Phase I were in conjunction with carbodies inclusive of boxcars and covered hopper cars, and the trucks used the AAR standard 1:20 taper profile wheels. Although the Type I trucks tested in TDOP Phase II were tested in conjunction with an open hopper car, the trucks did use the AAR standard 1:20 taper wheel profiles. One other cautionary remark is in order; namely, that the seventh Type II truck tested during TDOP, Phase II, which has been referred to as a "truck with unconventional design" or one featuring "primary + secondary suspension elements", was a 70-ton truck as compared to the other six Type II trucks which were all 100-ton trucks.

The results presented in the following subsections are organized by performance regimes and by the two forms of grouping (rigid and radial, etc.) discussed in Section 4.

All the figures presented in this section represent results from data on seven Type II trucks grouped into various categories. Each symbol on a given figure represents a data point referring to a specific Type II truck. An explanation of the symbols is given in Table 5.3-1.

5.3.1 Lateral Stability Performance Characteristics

Characteristic performance levels represented by quantified ranges of performance indices as functions of operating speed for this regime of lateral stability are shown in Figures 5.3.1-1 through 5.3.1-18. Figures 5.3.1-1 through 5.3.1-10 present the performance characteristics for the trucks classified into groups representing primary suspension trucks, secondary suspension trucks, and primary + secondary suspension truck. Figures 5.3.1-11 through 5.3.1-18 present the same information by grouping the trucks in an alternate manner, namely radial trucks, rigid trucks, and the truck with the unconventional design; the truck with the unconventional design is the same as the one represented by the primary + secondary suspension category. The rms and peak levels of lateral accelerations represented in these figures are obtained at the sill level of the carbody by choosing the maximum levels between the forward and rear ends of the carbody.

In the interest of presenting complete information from the test data, response levels at the center of the carbody at the sill level are presented in Figures 5.3.1-19 through 5.3.1-36; and response levels at the truck axle are presented in Figures 5.3.1-37 through 5.3.1-45. The spectrum of the characteristic frequencies of hunting as a function of speed for all the configurations tested is given in Figure 5.3.1-46.

A summary of the results is presented in Tables 5.3.1-1 through 5.3.1-4 on test configurations with empty cars and loaded cars, respectively. Since sustained hunting was observed in only relatively few cases, the analysis considered in some detail the intermittent hunting phenomenon. Even within the intermittent hunting, amplitudes of oscillations were carefully studied by arbitrarily grouping them in three categories, namely low amplitude (less than 0.5g), moderate amplitude (from 0.5 to 0.8 g), and high amplitude (larger than 0.8 g) of oscillations. Consideration of the results in this detail was deemed necessary in view of the requirement to establish guideline specifications for the classes of trucks tested.

5.3.2 Trackability Performance Characteristics

Quantification of performance characteristics in this performance regime covered the subregimes of harmonic roll, track twist, and curve entry/exit. Performance test data covering the harmonic roll subregime consisted of data from test runs on branch line, Class 2 track. Analysis of the test data indicated that the excitations arising from the track irregularities were not sufficient to cause the rock and roll phenomenon. This phenomenon is characterized by roll angles in the range of 3° to 5°. The test data, however, showed a moderate response with the roll angle being in the range of 0.5 to 1.0°. Therefore, no characterization of performance for the Type II trucks in this subregime is provided. The performance characteristics presented in this section cover only the two subregimes of track twist and curve entry/exit.

The performance index defined in the subregime of track twist (load equalization) is the wheel unloading index (WUI). From the definition (see Section 2), it may be seen that this index may vary from zero for a perfectly equalized truck to unity for a truck with one wheel completely unloaded. To provide some statistical significance associated with the quantitative values presented, the index presented is the 95th percentile; and the average value as well as the standard deviation of the index are given. The results presented represent the performance of trucks as they traverse a left hand, 16 degree curved yard track at an approximate speed of 10 mph. The superelevation of the curve was -0.26 inch. The results are given in Tables 5.3.2-1 and 5.3.2-2.

The data presented indicates a wide variation in performance between the various trucks tested. The empty cars, in general, experience higher values of wheel unloading index as compared with loaded cars. Although individual Type II trucks seem to attain improved load equalization levels, as a class, the group of vehicles tested cannot make such a claim.

The main response descriptor used in the subregime of curve entry/exit is the 95th percentile of the wheel unloading index, WUI95. In descriptive terms, the 95th percentile indicates that the value of the wheel unloading index given is likely to be exceeded only 5% of the time during a single passage through the spirals. The results are presented in Figures 5.3.2-1 thru 5.3.2-32.

5.3.3 Steady State Curve Negotiation Performance Characteristics

Results presented in this section cover five of the seven Type II trucks included for evaluation in TDOP, Phase II. The exceptions are the truck featuring primary + secondary suspension elements, which was not instrumented for measurement of the key parameters in this regime, namely lateral and vertical forces at the wheel/rail interface and wheel/rail angle of attack, and a rigid truck which was instrumented only to measure the angle of attack.

In the process of analyzing the field test data to quantify the performance indices, some unexpected behavioral trends were observed as they relate to the wheel/rail force measurements. A closer examination of these trends through various test runs as well as examination of coupler force data confirmed that the measured lateral forces tended to be asymmetric with respect to the sense of track curvature. In general, the lateral forces tended to be lower on right-hand curves as compared to left-hand curves. Although various hypotheses were formulated to explain the causes of this asymmetric trend, they remain to be verified. These hypotheses include relating the measurements to well defined wheel/rail contact geometry considerations which may uncover patterns of asymmetry themselves, and influence of truck "set" or "memory" as the truck travels from one curve to another, among others. A comparison of the lateral forces for the five Type II trucks as they behaved over right-hand curves and left-hand curves as two distinct groups are given in Figures 5.3.3-1 through 5.3.3-4. Figures 5.3.3-1 and 5.3.3-2 represent the results for the test configurations with empty cars and Figures 5.3.3-3 and 5.3.3-4 represent results for test configurations with loaded cars. On the basis of conservatism under the circumstances, the characterization of performance of the trucks was determined upon the higher level of forces, namely those obtained over the left-hand curves.

Lateral forces and L/V ratios at each of the four wheel/rail interfaces on the leading truck were examined for the three test speed conditions, namely below, at, and above equilibrium, or "balance" speeds. The algebraic means (average values) of the lateral forces were calculated for each curve over the length of track which could be considered "steady state" or "constant curvature" track. In plotting the characteristics, the absolute values of these algebraic averages were used.

Performance characteristics of the Type II trucks represented by quantified levels of performance indices, namely lateral force at the leading outer wheel, and L/V ratio at the leading outer wheel, organized into groups representing trucks with primary suspensions, trucks with secondary suspensions, radial trucks, and rigid trucks are presented in Figures 5.3.3-5 through 5.3.3-100. Figures 5.3.3-5 through 5.3.3-52 represent results covering the test configurations with empty carbodies, and Figures 5.3.3-53 through 5.3.3-100 represent results covering the test configurations with loaded carbodies.

The absolute average net lateral forces acting on the leading axle of the leading truck and the leading truck itself as a whole are presented in Figures 5.3.3-101 through 5.3.3-106 to provide a more comprehensive view of truck performance in curves.

The trucks featuring radial alignment features seem to accomplish their goal of attaining flange free curving in the shallower ranges of track curvature (up to 3.7 degrees), but in the zone with sharper track curvature (5 degrees and above) guidance around the track depends on flange contact. No definitively detrimental degradation in performance was discerned in the case of the rigid trucks relative to the baseline performance of Type I trucks. Of course, any comparative evaluation has to keep in perspective the differences in test conditions, especially as they relate to wheel profiles. It is recalled here that the Type I trucks were tested with AAR Standard 1:20 profile wheels, whereas the Type II trucks were tested with CN profile wheels. In general, the test data indicate that in all the cases the trailing axle tends to carry the higher net lateral forces for the conditions representing the below balance speed test runs, and the leading axle tends to carry the higher net lateral forces for the conditions representing the balance speed and the above balance speed test runs.

5.3.4 Ride Quality Performance Characteristics

As discussed in Section 5.2.4, only one of the two identified performance indices in this regime was quantified, namely the rms response over the wide band spectrum of 0-20 Hz. The index was analyzed for the vertical, lateral, and roll accelerations on the carbody. Accelerations were measured on both ends of the carbody and the quantitative characteristics presented in this section are the result of studying the vertical, lateral, and roll accelerations at both ends to choose the performance boundaries determined by the maximum levels.

Resulting characteristics of performance, represented by rms vertical, lateral, and roll accelerations in a 0-20 Hz frequency bandwidth, plotted as functions of operating speeds, are shown in Figures 5.3.4-1 thru 5.3.4-27. Figures 5.3.4-1 thru 5.3.4-9 illustrate the vertical response; 5.3.4-10 thru 5.3.4-18 illustrate the lateral response; and 5.3.4-19 thru 5.3.4-27 illustrate the roll response.

Considering vertical vibrations, trucks with primary suspensions indicate comparable acceleration environment between the empty and loaded conditions, with the rms acceleration levels tending to increase with increasing speeds. On the other hand, secondary suspension trucks indicated a pronounced difference between the empty and loaded carbody responses, with the empty car responses being the consistently higher levels. The truck with primary + secondary suspension elements featured in the design was tested only in the loaded condition, and the response levels for this configuration were bordering the lower bounds of performance levels for the whole class of Type II trucks.

In general, for the empty cars equipped with Type II trucks, the rate of increase of the amplitude of vertical oscillations with increasing vehicle speed is small; the response curves level off in the speed range of 40 to 60 mph. Above 60 mph, the rate of increase in the response levels of some trucks indicate possible resonance phenomena at high speeds or, perhaps, a high degree of coupling between the vertical and lateral motions of the vehicle system exciting coupled modes. An examination of the performance of the class of rigid trucks relative to the radial trucks indicate that, for the empty car test conditions, the responses for the radial trucks vary in a range so wide that they form the upper and lower bounds of performance for the whole group of Type II trucks; in the loaded condition, the response of the radial trucks also determines the upper bounds of performance for the whole group of Type II trucks tested.

In lateral motion, the responses of the primary suspension trucks with empty cars indicate levels higher than that for the secondary suspension trucks. In the loaded condition, the differences in the levels of acceleration responses were not significant. Empty cars generally indicated higher levels of lateral acceleration response as compared to loaded cars for the Type II trucks, as a group.

Generalization of performance for groups of Type II trucks in the case of roll motion proved to be difficult. Rather, individual trucks showed the ability of specific design features to influence roll motion. The ability of a given truck to provide the levels of damping required to control the motion was especially demonstrated in the results of the roll response levels.

TABLE 5.3-1. SYMBOL IDENTIFICATION FOR TYPE II TRUCKS

△	Dresser DR-1	Primary Suspension Trucks	○ ●
□	Barber-Scheffel	Secondary Suspension Trucks	△ □ ▲ ■
○	Devine-Scales	Primary + Secondary Suspension Trucks	◇
●	Maxiride 100		
▲	National Swing Motion	Radial Trucks	△ □ ○
■	ACF Fabricated	Rigid Trucks	● ■ ▲
◇	Alusuisse	Other Trucks	◇

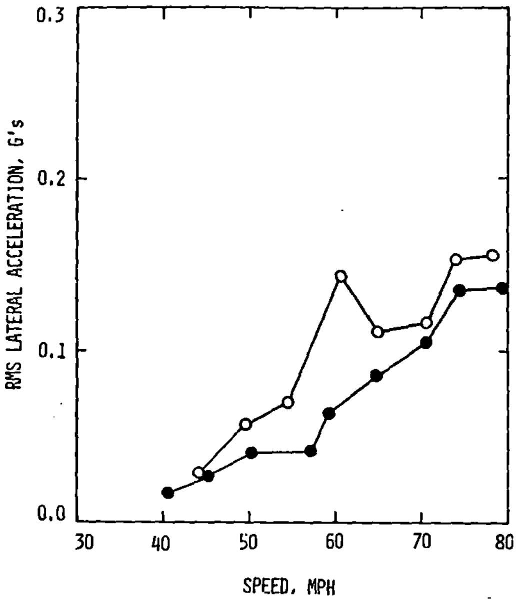


FIGURE 5.3.1-1 RMS LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/EMPTY CARS

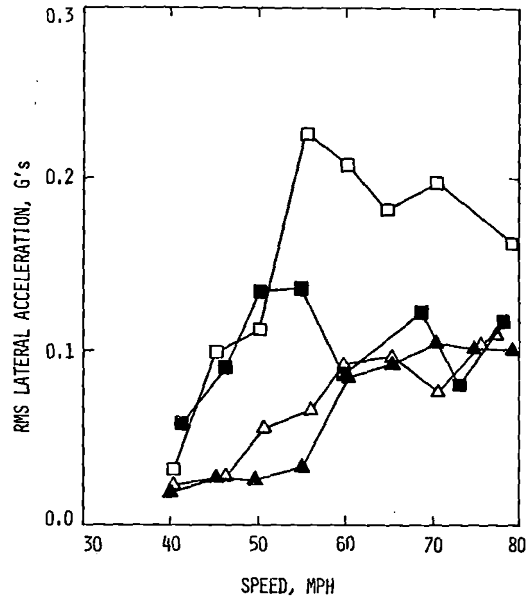


FIGURE 5.3.1-2 RMS LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/EMPTY CARS

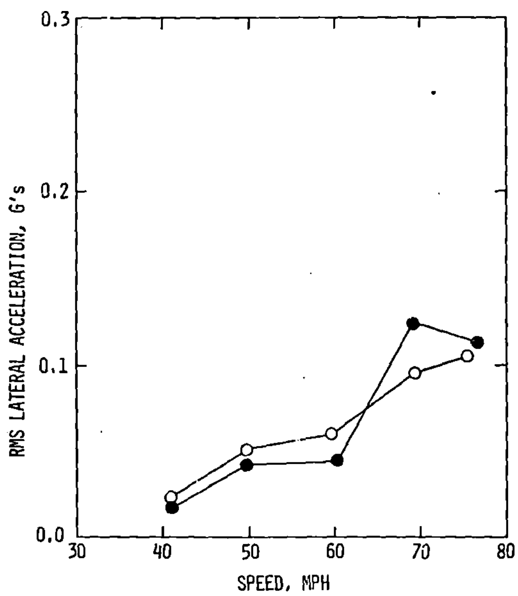


FIGURE 5.3.1-3 RMS LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/LOADED CARS

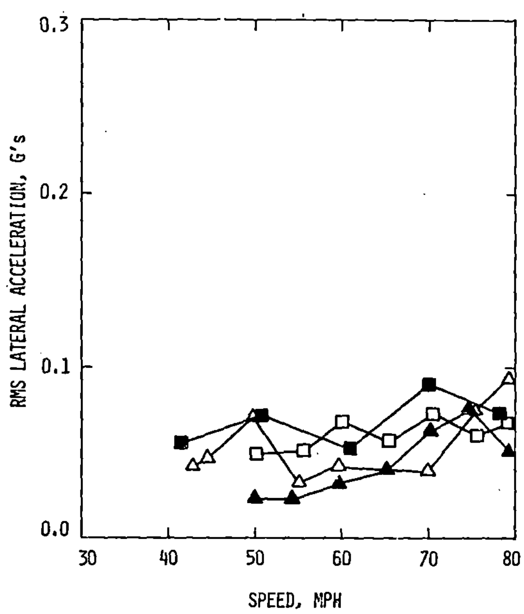


FIGURE 5.3.1-4 RMS LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/LOADED CARS

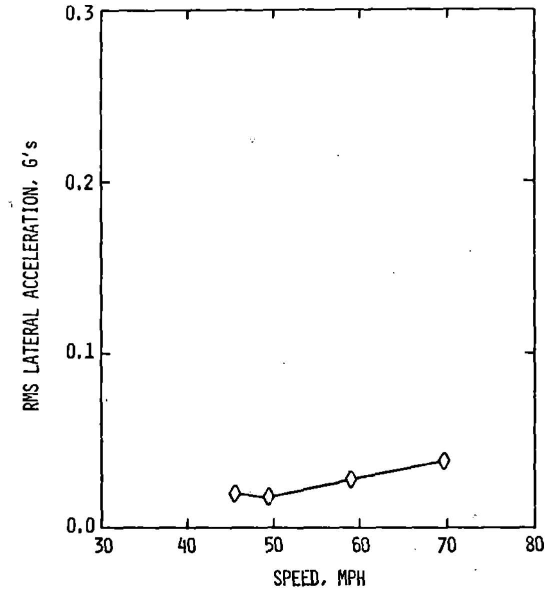


FIGURE 5.3.1-5 RMS LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - PRIMARY + SECONDARY SUSPENSION TRUCKS/LOADED CARS

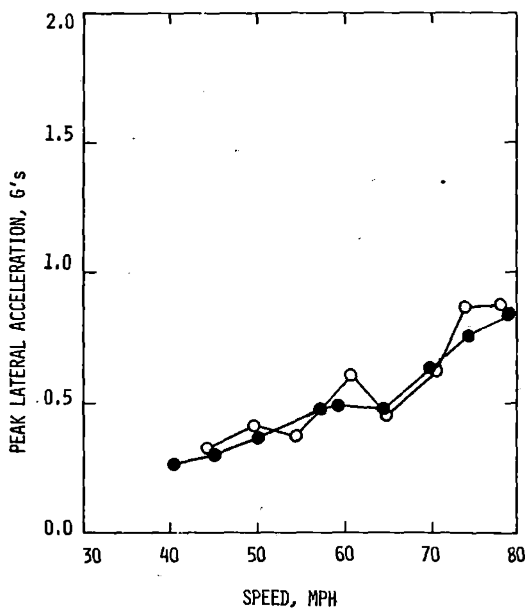


FIGURE 5.3.1-6 PEAK LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/EMPTY CARS

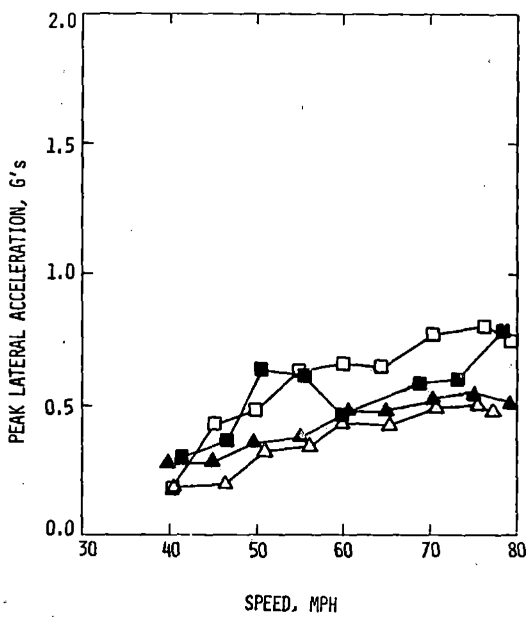


FIGURE 5.3.1-7 PEAK LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/EMPTY CARS

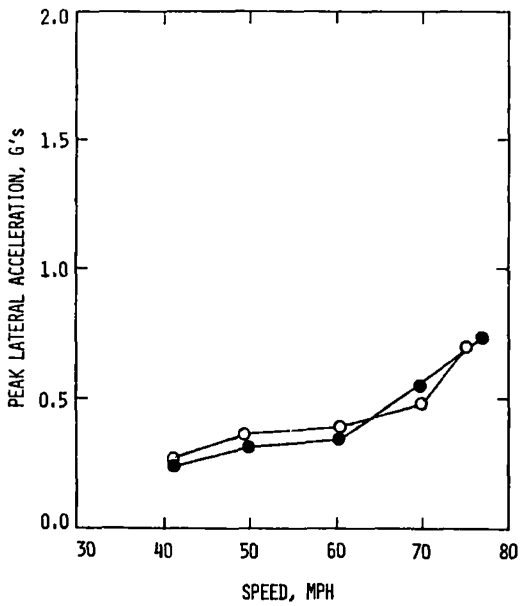


FIGURE 5.3.1-8 PEAK LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/LOADED CARS

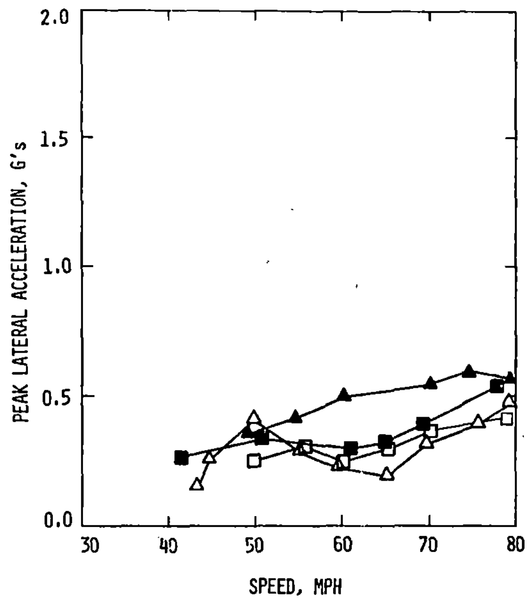


FIGURE 5.3.1-9 PEAK LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/LOADED CARS

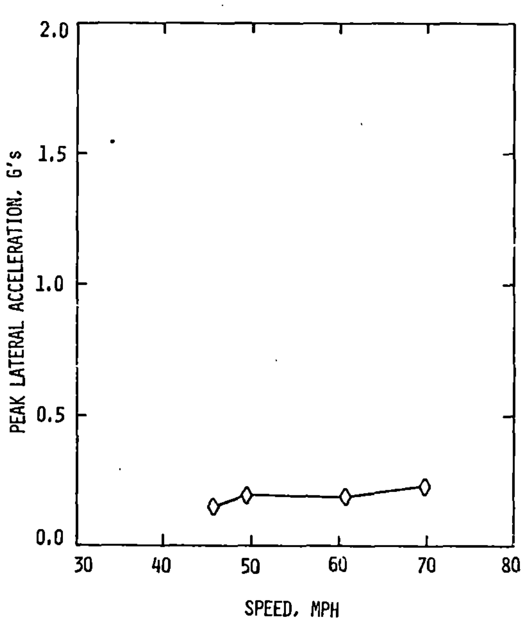


FIGURE 5.3.1-10 PEAK LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - PRIMARY + SECONDARY SUSPENSION TRUCKS/LOADED CARS

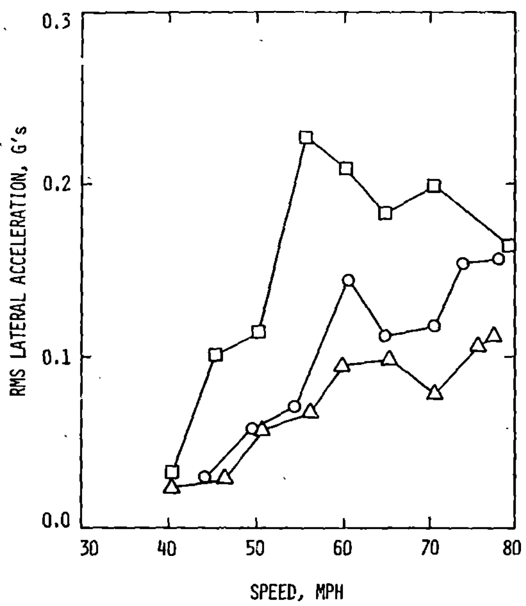


FIGURE 5.3.1-11 RMS LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - RADIAL TRUCKS/ EMPTY CARS

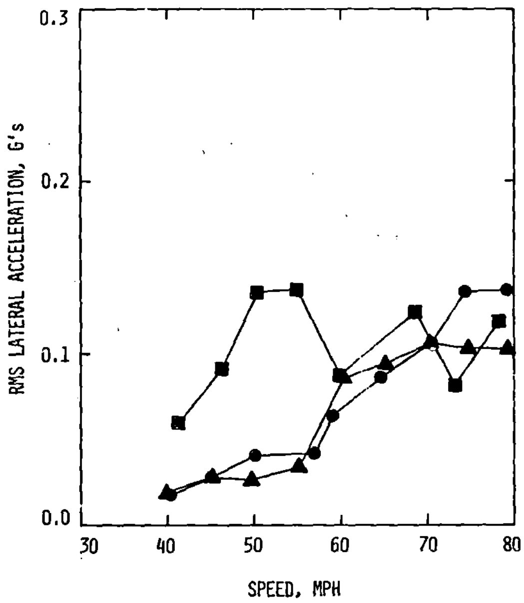


FIGURE 5.3.1-12 RMS LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - RIGID TRUCKS/ EMPTY CARS

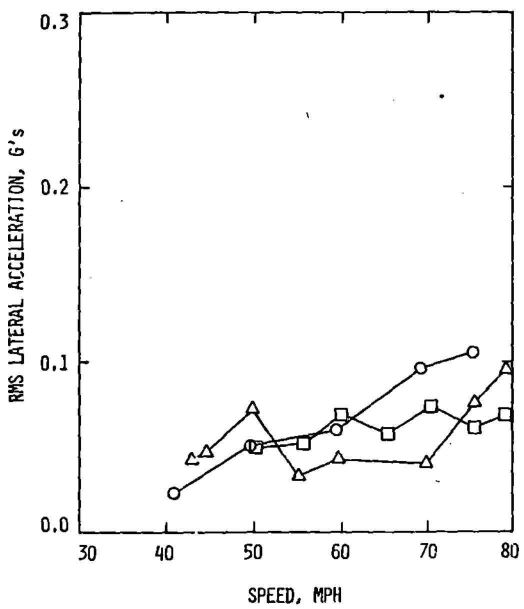


FIGURE 5.3.1-13 RMS LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - RADIAL TRUCKS/ LOADED CARS

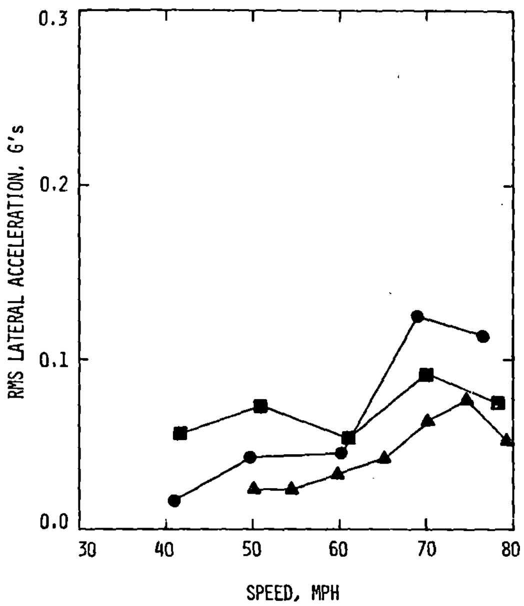


FIGURE 5.3.1-14 RMS LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - RIGID TRUCKS/ LOADED CARS

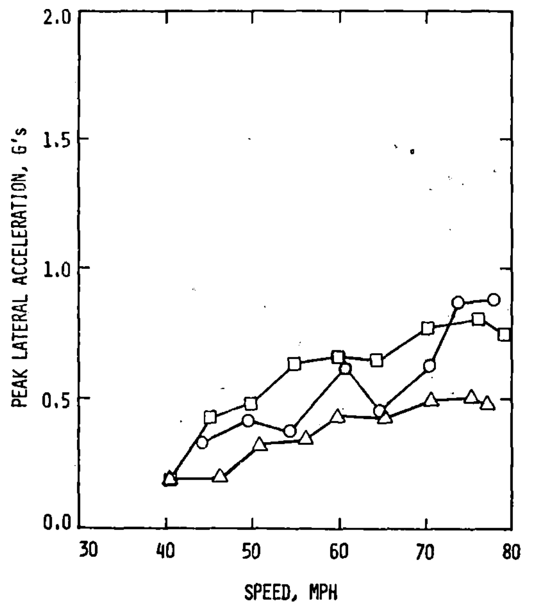


FIGURE 5.3.1-15 PEAK LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - RADIAL TRUCKS/ EMPTY CARS

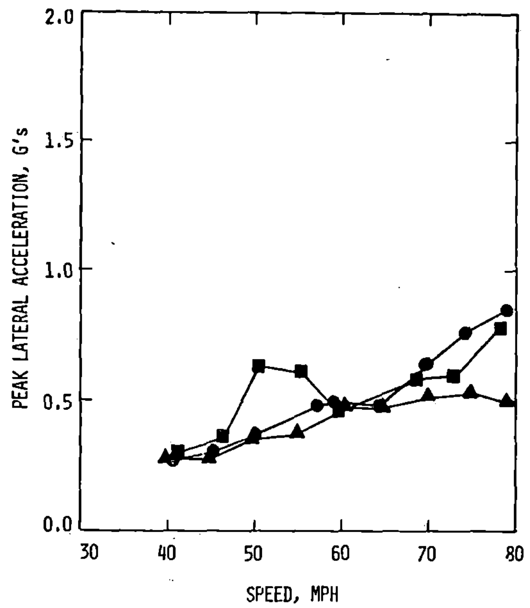


FIGURE 5.3.1-16 PEAK LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - RIGID TRUCKS/ EMPTY CARS

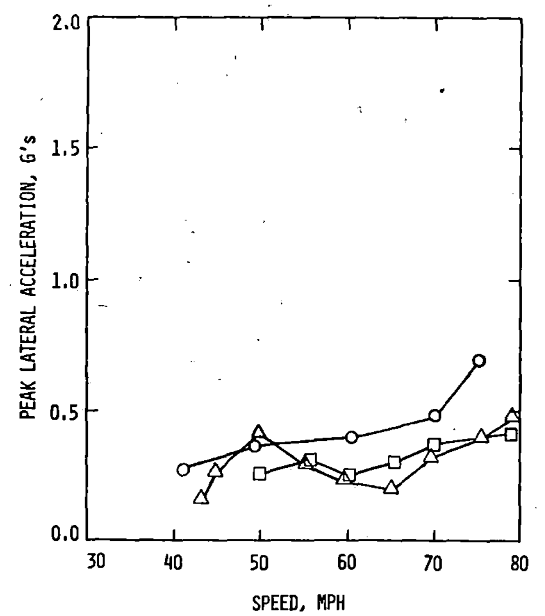


FIGURE 5.3.1-17 PEAK LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - RADIAL TRUCKS/ LOADED CARS

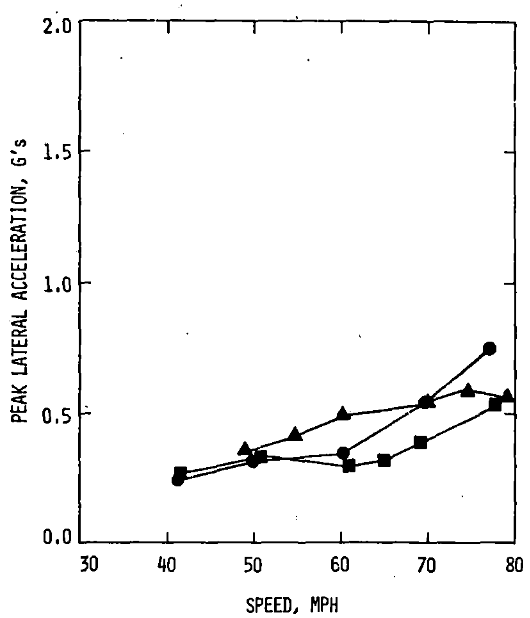


FIGURE 5.3.1-18 PEAK LATERAL ACCELERATION AT SILL LEVEL VERSUS SPEED - RIGID TRUCKS/ LOADED CARS

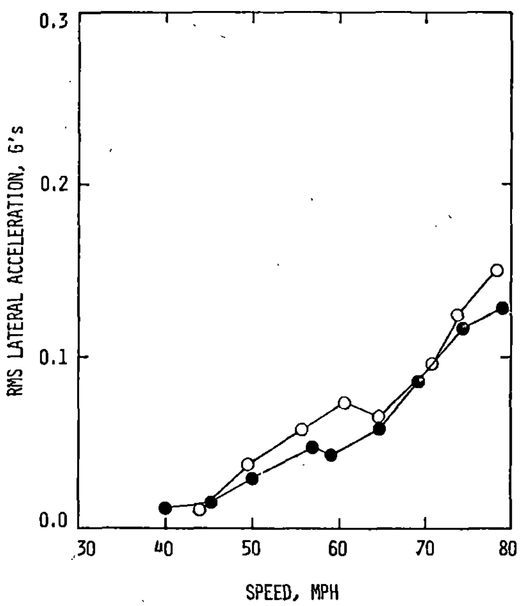


FIGURE 5.3.1-19 RMS LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/EMPTY CARS

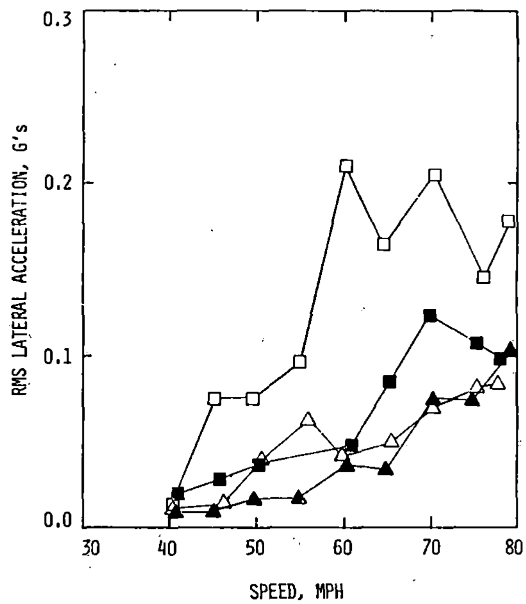


FIGURE 5.3.1-20 RMS LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/EMPTY CARS

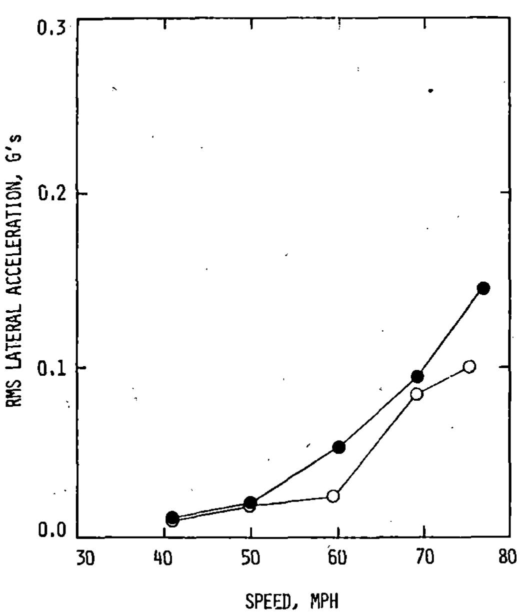


FIGURE 5.3.1-21 RMS LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/LOADED CARS

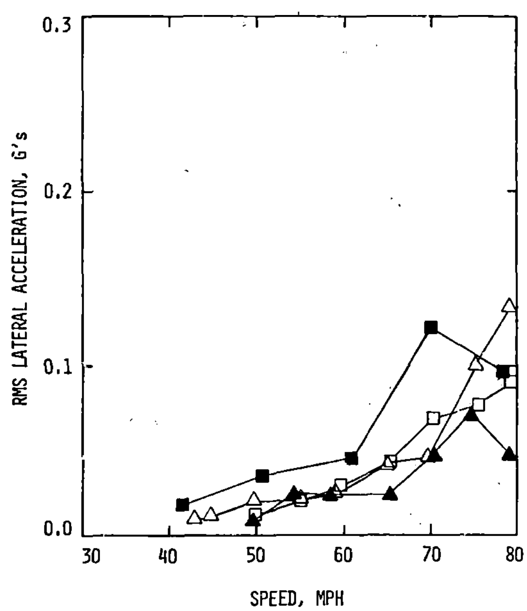


FIGURE 5.3.1-22 RMS LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/LOADED CARS

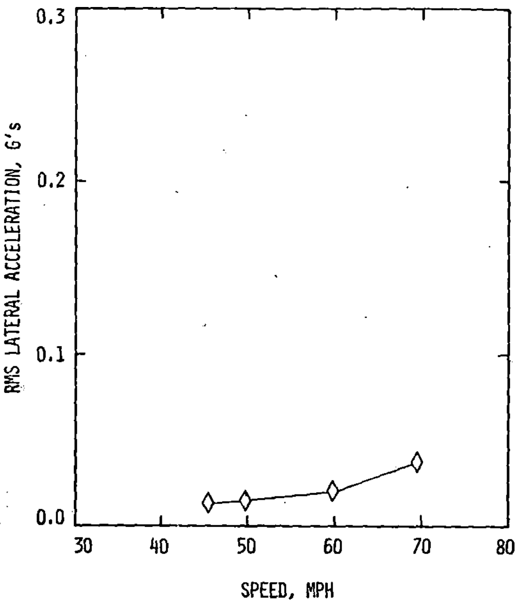


FIGURE 5.3.1-23 RMS LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - PRIMARY + SECONDARY SUSPENSION TRUCKS/LOADED CARS

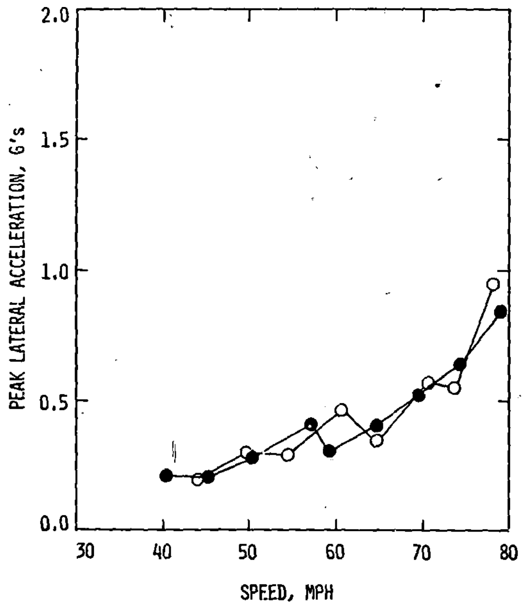


FIGURE 5.3.1-24 PEAK LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/EMPTY CARS

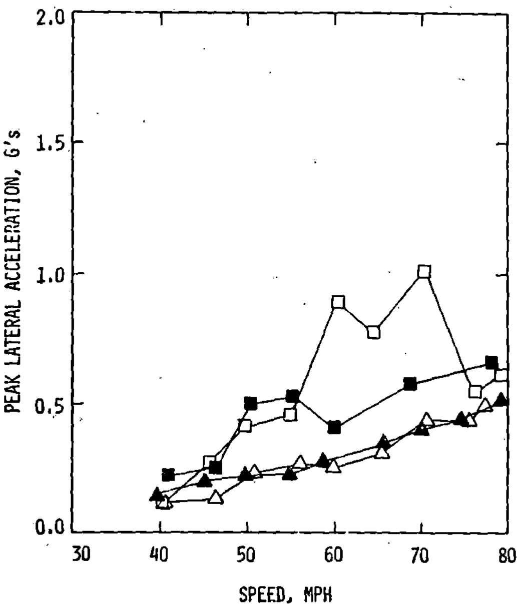


FIGURE 5.3.1-25 PEAK LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/EMPTY CARS

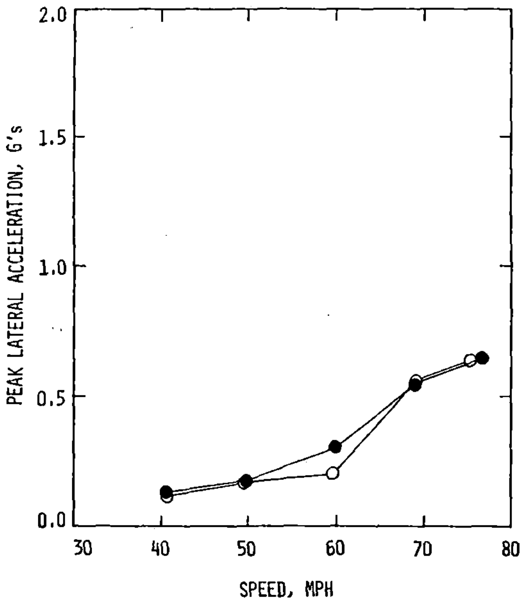


FIGURE 5.3.1-26 PEAK LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/LOADED CARS

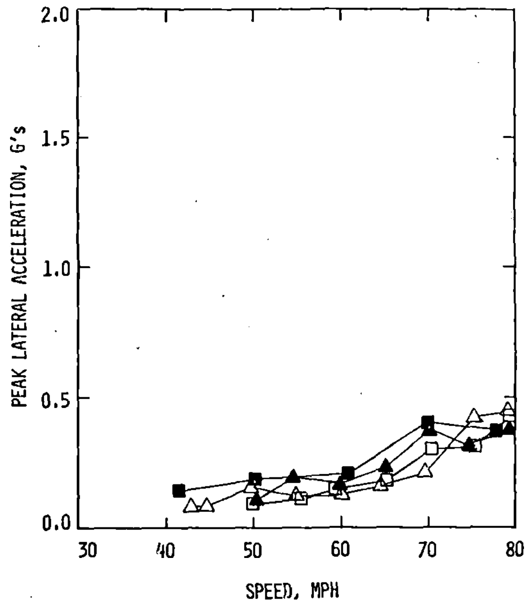


FIGURE 5.3.1-27 PEAK LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/LOADED CARS

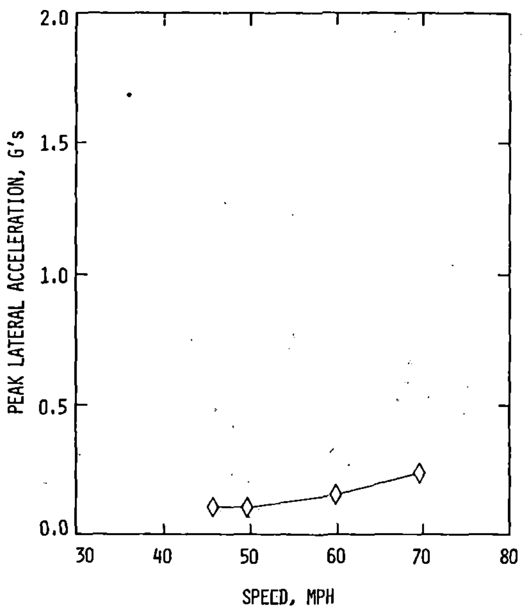


FIGURE 5.3.1-28 PEAK LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - PRIMARY + SECONDARY SUSPENSION TRUCKS/ LOADED CARS

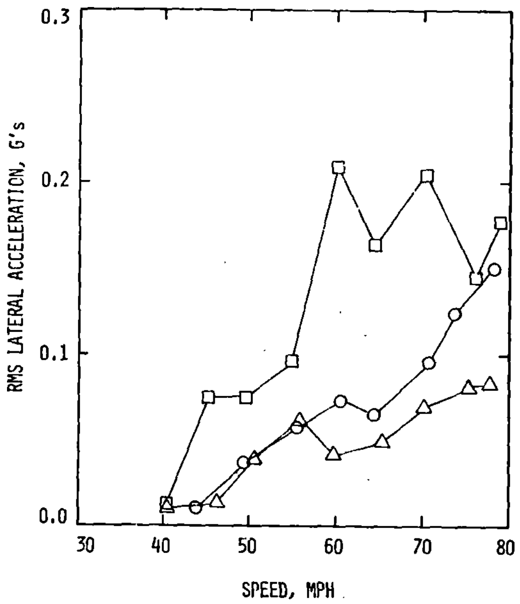


FIGURE 5.3.1-29 RMS LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - RADIAL TRUCKS/EMPTY CARS

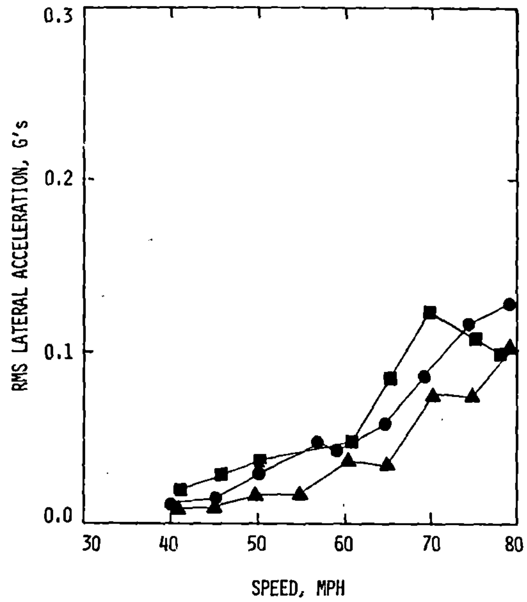


FIGURE 5.3.1-30 RMS LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - RIGID TRUCKS/EMPTY CARS

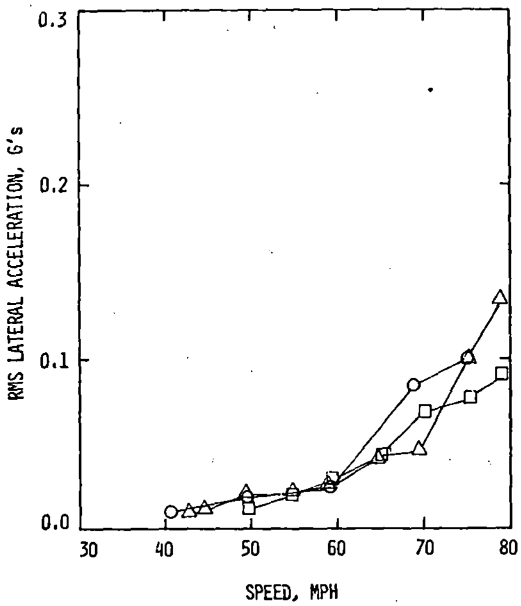


FIGURE 5.3.1-31 RMS LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - RADIAL TRUCKS/LOADED CARS

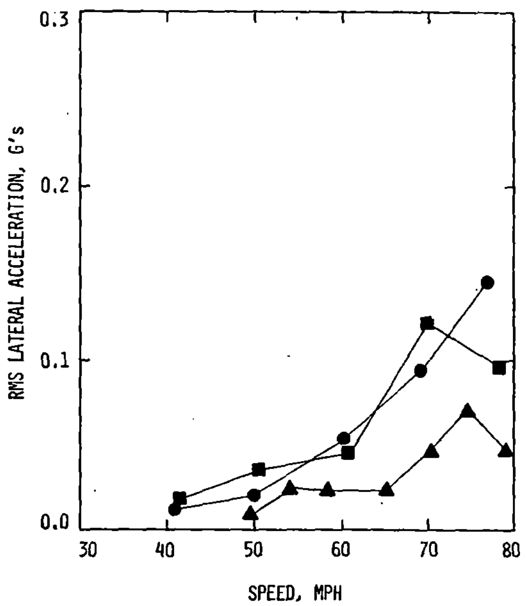


FIGURE 5.3.1-32 RMS LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - RIGID TRUCKS/LOADED CARS

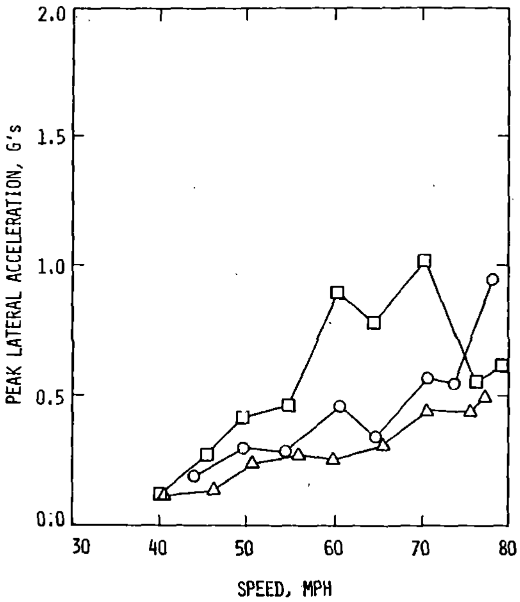


FIGURE 5.3.1-33 PEAK LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - RADIAL TRUCKS/EMPTY CARS

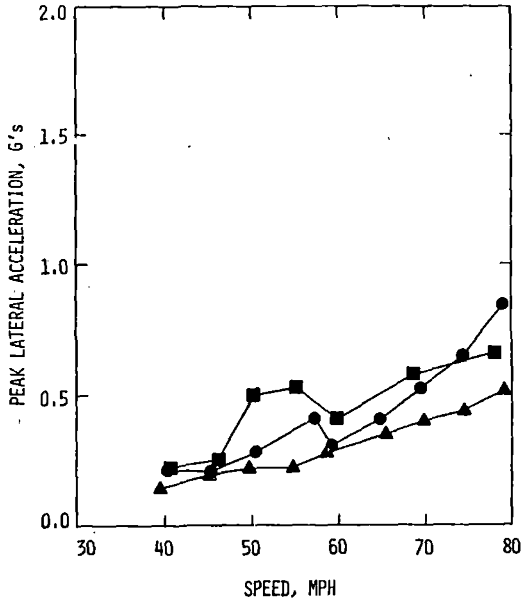


FIGURE 5.3.1-34 PEAK LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - RIGID TRUCKS/EMPTY CARS

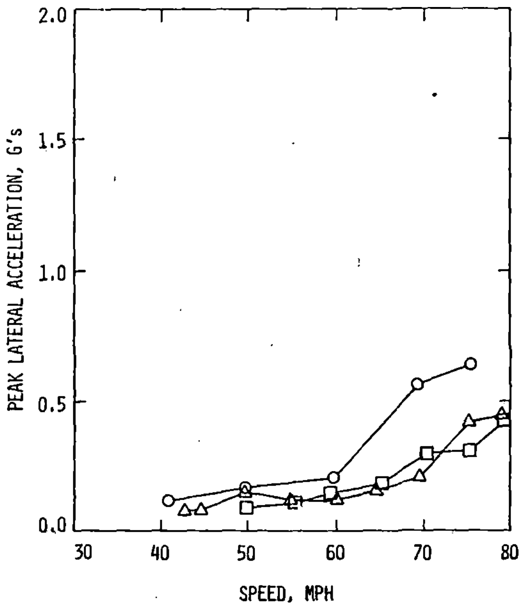


FIGURE 5.3.1-35 PEAK LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - RADIAL TRUCKS/LOADED CARS

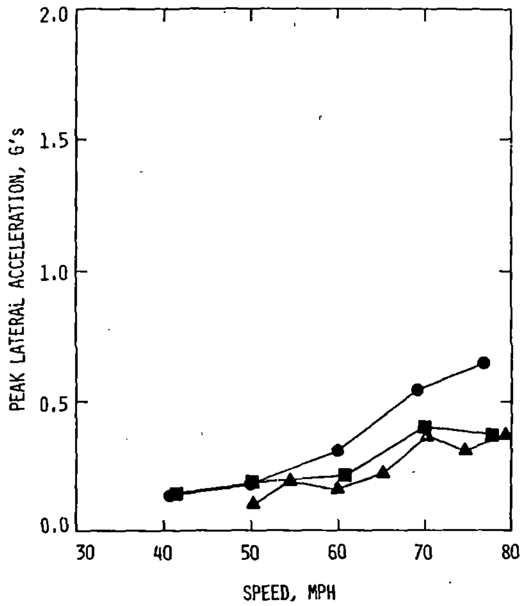


FIGURE 5.3.1-36 PEAK LATERAL ACCELERATION AT CARBODY CENTER/SILL LEVEL VERSUS SPEED - RIGID TRUCKS/LOADED CARS

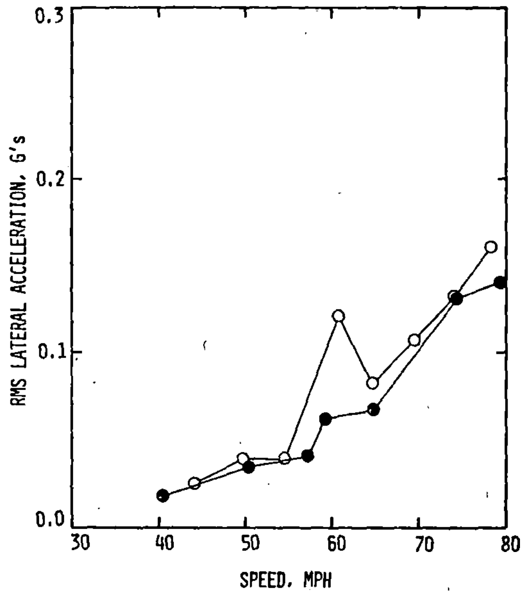


FIGURE 5.3.1-37 RMS LATERAL ACCELERATION AT LEADING AXLE/LEADING TRUCK VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/EMPTY CARS

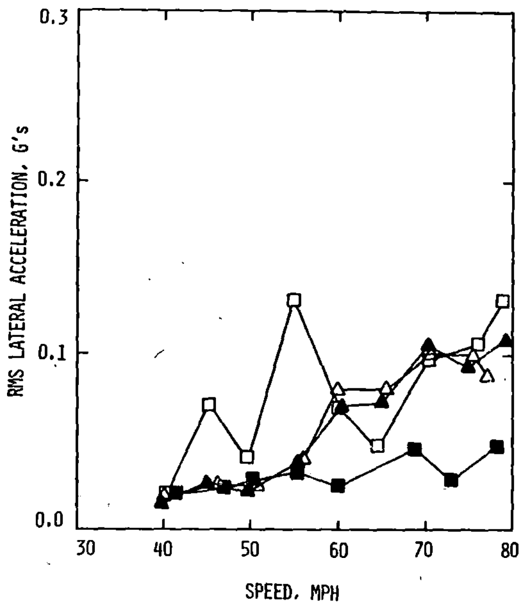


FIGURE 5.3.1-38 RMS LATERAL ACCELERATION AT LEADING AXLE/LEADING TRUCK VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/EMPTY CARS

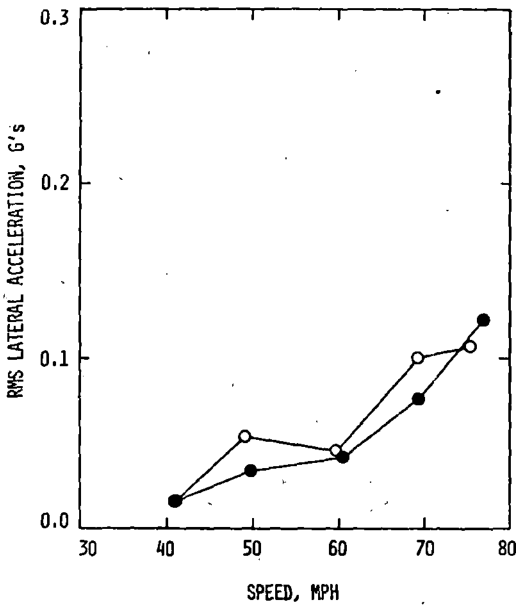


FIGURE 5.3.1-39 RMS LATERAL ACCELERATION AT LEADING AXLE/LEADING TRUCK VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/LOADED CARS

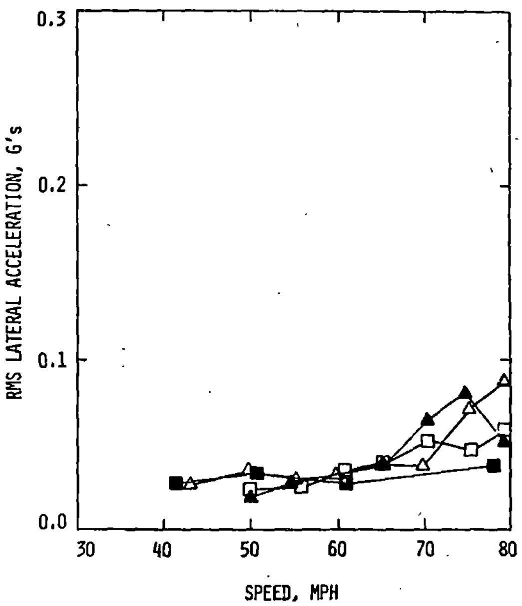


FIGURE 5.3.1-40 RMS LATERAL ACCELERATION AT LEADING AXLE/LEADING TRUCK VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/LOADED CARS

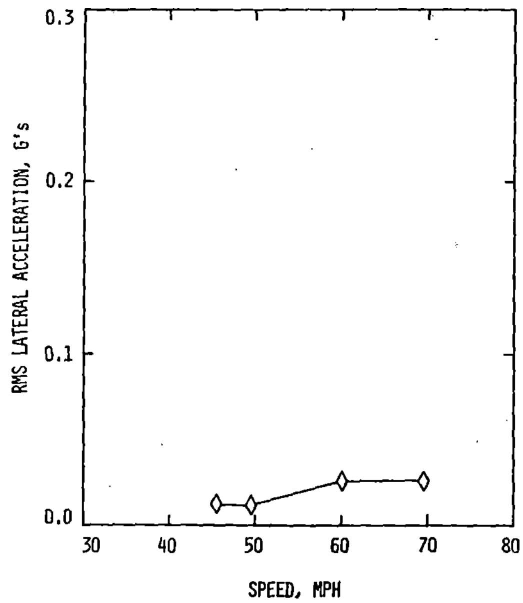


FIGURE 5-3.1.41 RMS LATERAL ACCELERATION AT LEADING AXLE/LEADING TRUCK VERSUS SPEED - PRIMARY + SECONDARY SUSPENSION TRUCKS/LOADED CARS

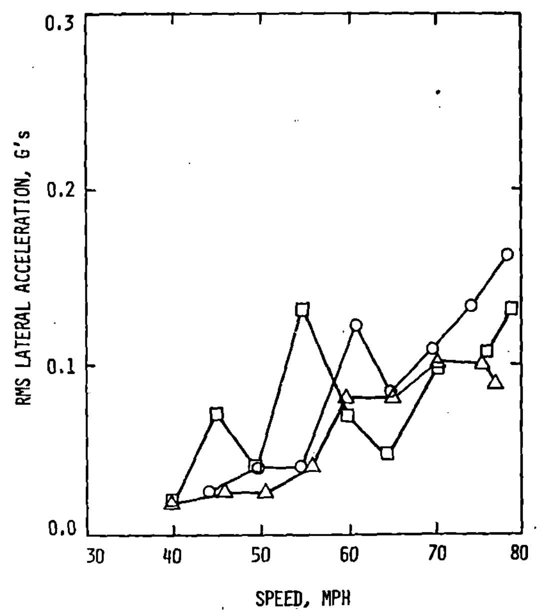


FIGURE 5.3.1-42 RMS LATERAL ACCELERATION AT LEADING AXLE/LEADING TRUCK VERSUS SPEED - RADIAL TRUCKS/EMPTY CARS

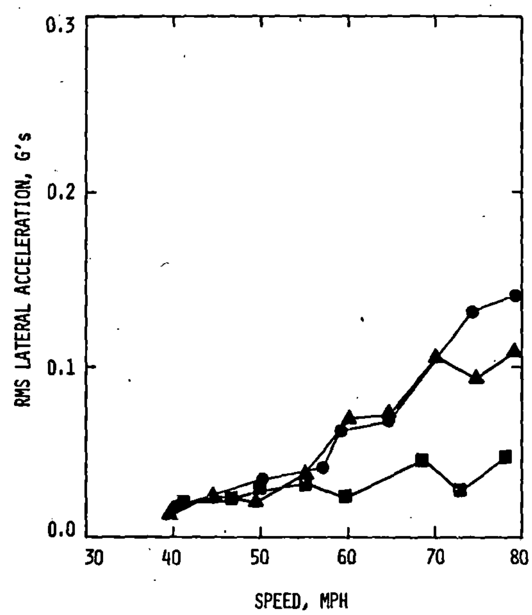


FIGURE 5.3.1-43 RMS LATERAL ACCELERATION AT LEADING AXLE/LEADING TRUCK VERSUS SPEED - RIGID TRUCKS/EMPTY CARS

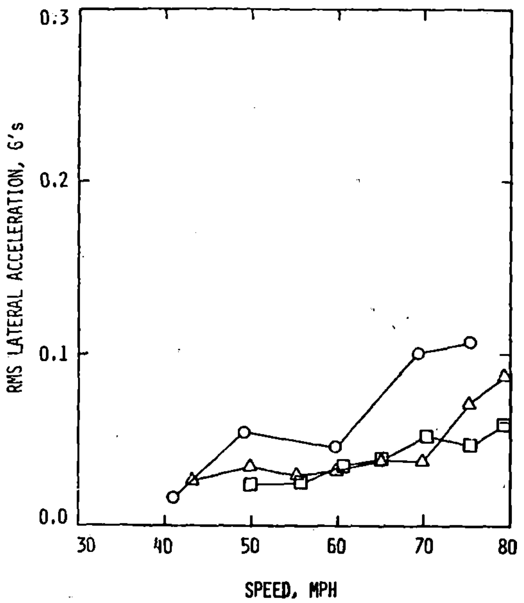


FIGURE 5.3.1-44 RMS LATERAL ACCELERATION AT LEADING AXLE/LEADING TRUCK VERSUS SPEED - RADIAL TRUCKS/LOADED CARS

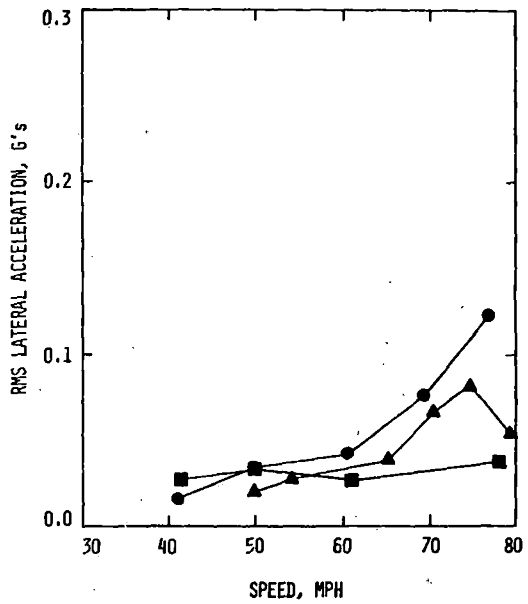


FIGURE 5.3.1-45 RMS LATERAL ACCELERATION AT LEADING AXLE/LEADING TRUCK VERSUS SPEED - RIGID TRUCKS/LOADED CARS

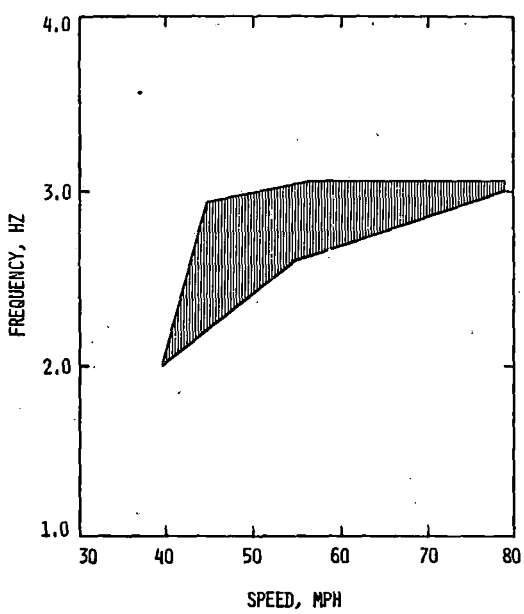


FIGURE 5.3.1-46 RANGE OF CHARACTERISTIC FREQUENCY OF HUNTING - ALL TEST CONDITIONS

TABLE 5.3.1-1. RESULTS OF TEST DATA ANALYSIS IN LATERAL STABILITY REGIME, PRIMARY & SECONDARY TRUCKS, EMPTY CAR

Truck Classification	Phenomenological Behavior	Range of Critical Speed(mph)	Hunting Frequency(Hz)	Track Excitation Frequency(Hz)	RMS Lateral Acceleration (g's)	Peak Lateral Accel. (g's)	Percentage of Time of Occurrence of Observed Phenomenon
Primary Suspension Trucks ○	Moderate Amplitude Intermittent Hunting	60	2.70	2.30	0.12-0.14	0.55-0.60	60-65
	Sustained Hunting	79	3.0	3.0	0.12-0.16	0.85-0.88	100
●	Moderate Amplitude Intermittent Hunting	65-70	2.70	2.5-2.6	0.11-0.12	0.63-0.65	60-65
	High Amplitude Intermittent Hunting	79	3.0	3.0	0.12-0.14	0.80-0.84	75-80
△	Moderate Amplitude Intermittent Hunting	60-65	2.70-2.80	2.30-2.50	.05-0.10	0.34-0.43	60-65
Secondary Suspension Trucks □	Moderate Amplitude Intermittent Hunting	45	2.90	1.70	0.10	0.35-0.43	65-70
	Sustained Hunting	55-60	2.90	2.0-2.30	0.20-0.24	0.65-0.68	100
▲	Moderate Amplitude Intermittent Hunting	60-65	2.70-3.0	2.30-2.50	0.07-0.09	0.50-0.60	60-65
■	Moderate Amplitude Intermittent Hunting	60-65	2.70	2.30-2.50	0.08-0.12	0.41-0.50	60-65

TABLE 5.3.1-2. RESULTS OF TEST DATA ANALYSIS IN LATERAL STABILITY REGIME, PRIMARY & SECONDARY TRUCKS, LOADED CAR

Truck Classification	Phenomenological Behavior	Range of Critical Speed(mph)	Hunting Frequency(Hz)	Track Excitation Frequency(Hz)	RMS Lateral Acceleration (g's)	Peak Lateral Accel. (g's)	Percentage of Time of Occurrence of Observed Phenomenon
Primary Suspension Trucks ○	Moderate Amplitude Intermittent Hunting	70-75	2.70	2.60-2.80	0.07-0.11	0.60-0.70	40-50
●		70-79	2.70	2.60-3.0	0.10-0.14	0.60-0.75	55-60
△	Moderate Amplitude Intermittent Hunting	75-79	2.70-3.0	2.80-3.0	0.10-0.14	0.48-0.5	80-85
Secondary Suspension Trucks □		79	3.0	3.0	0.07-0.09	0.41-0.43	15-20
▲		70-75	2.80	2.60-2.80	0.07-0.08	0.50-0.55	30-35
■		70	2.70	2.60	0.10-0.14	0.35-0.40	80
Primary + Secondary Suspension Trucks ◇	None	N/A	N/A	N/A	N/A	N/A	N/A

TABLE 5-3.1-3. RESULTS OF TEST DATA ANALYSIS IN LATERAL STABILITY REGIME, RADIAL AND RIGID TRUCKS, EMPTY CAR

Truck Classification		Phenomenological Behavior	Range of Critical Speed(mph)	Hunting Frequency(Hz)	Track Excitation Frequency(Hz)	RMS Lateral Acceleration (g's)	Peak Lateral Accel. (g's)	Percentage of Time of Occurrence of Observed Phenomenon
Radial Trucks	△	Moderate Amplitude Intermittent Hunting	60-65	2.7-2.8	2.3-2.5	0.05-0.10	0.34-0.43	60-65
	□	Moderate Amplitude Intermittent Hunting	45	2.9	1.70	0.10	0.35-0.43	65-70
		Sustained Hunting	55-60	2.90	2.0-2.30	0.2-0.24	0.65-0.68	100
	○	Moderate Amplitude Intermittent Hunting	60	2.70	2.30	0.12-0.14	0.55-0.60	60-65
		Sustained Hunting	79	3.0	3.0	0.12-0.16	0.87-0.88	100
Rigid Trucks	▲	Moderate Amplitude Intermittent Hunting	60-65	2.70-3.0	2.3-2.5	.07-0.09	0.46-0.48	60-65
	●	Moderate Amplitude Intermittent Hunting	65-70	2.70	2.5-2.6	0.105-0.12	0.63-0.65	60-65
		High Amplitude Intermittent Hunting	79	3.0	3.0	0.12-0.14	0.80-0.84	75-80
	■	Moderate Amplitude Intermittent Hunting	60-65	2.7	2.3-2.5	0.08-0.12	0.50-0.60	60-65

TABLE 5.3.1-4. RESULTS OF TEST DATA ANALYSIS IN LATERAL STABILITY REGIME, RADIAL AND RIGID TRUCKS, LOADED CAR

Truck Classification		Phenomenological Behavior	Range of Critical Speed(mph)	Hunting Frequency(Hz)	Track Excitation Frequency(Hz)	RMS Lateral Acceleration (g's)	Peak Lateral Accel. (g's)	Percentage of Time of Occurrence of Observed Phenomenon
Radial Trucks	△	Moderate Amplitude Intermittent Hunting	75-79	2.7-3.0	2.8-3.0	0.1-0.14	0.48-0.50	80-85
	□		79	3.0	3.0	0.07-0.09	0.41-0.43	15-20
	○		70-75	2.7	2.6-2.8	.07-0.11	0.60-0.70	40-50
Rigid Trucks	▲	Moderate Amplitude Intermittent Hunting	70-75	2.8	2.6-2.8	0.07-0.08	0.50-0.55	30-35
	●		70-79	2.7	2.6-3.0	0.1-0.14	0.6-0.75	55-60
	■		70	2.7	2.6	0.1-0.14	0.35-0.40	80
Unconventional	◇	None	N/A	N/A	N/A	N/A	N/A	N/A

TABLE 5.3.2-1. WHEEL UNLOADING INDEX LEVELS FOR PRIMARY & SECONDARY SUSPENSION TRUCKS

Truck		Empty Car			Loaded Car		
		Average	Standard Deviation	WUI_{95}	Average	Standard Deviation	WUI_{95}
Primary Suspension Trucks	○	0.454	0.218	0.744	.252	0.136	0.512
	●	0.177	0.069	0.297	0.182	0.068	0.307
Secondary Suspension Trucks	△	0.564	0.135	0.783	0.190	0.053	0.281
	□	0.156	0.218	0.343	0.241	0.101	0.400
	▲	0.314	0.126	0.553	0.277	0.058	0.368

TABLE 5.3.2-2. WHEEL UNLOADING INDEX LEVELS FOR RADIAL AND RIGID TRUCKS

Truck		Empty Car			Loaded Car		
		Average	Standard Deviation	WUI_{95}	Average	Standard Deviation	WUI_{95}
Radial Trucks	△	0.564	0.135	0.783	0.190	0.053	0.281
	□	0.156	0.083	0.343	0.241	0.101	0.400
	○	0.454	0.218	0.744	0.252	0.136	0.512
Rigid Trucks	▲	0.314	0.126	0.553	0.277	0.058	0.368
	●	0.177	0.069	0.297	0.182	0.068	0.307

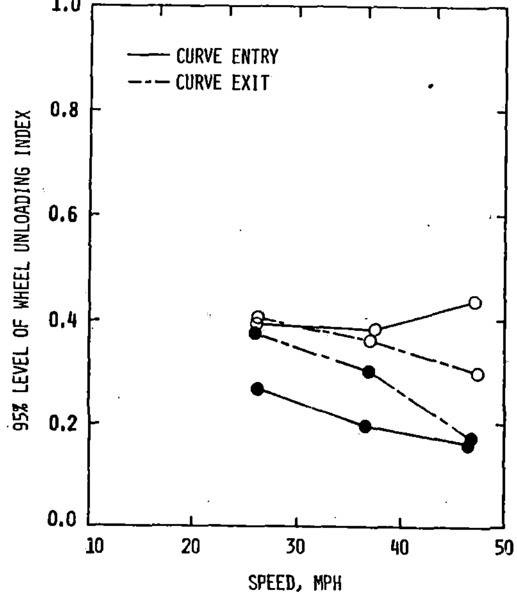


FIGURE 5.3.2-3 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/LOADED CARS/2.5° CARS

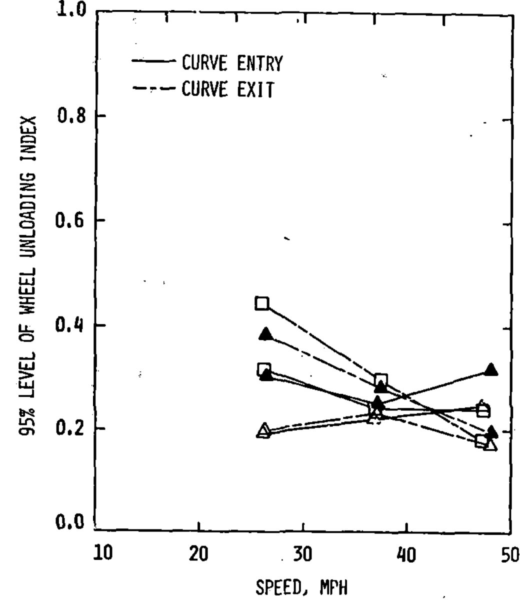


FIGURE 5.3.2-4 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/LOADED CARS/2.5° CURVE

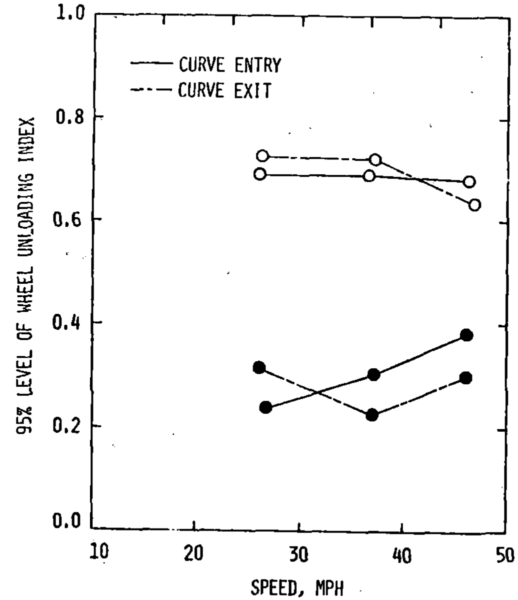


FIGURE 5.3.2-1 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/EMPTY CARS/2.5° CURVE

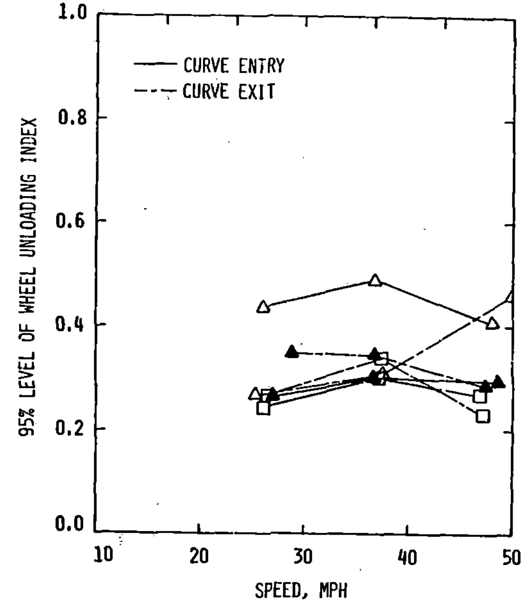


FIGURE 5.3.2-2 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/EMPTY CARS/2.5° CURVE

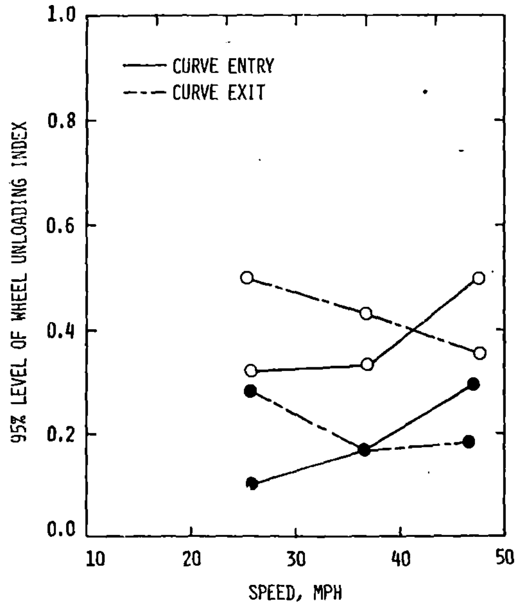


FIGURE 5.3.2-7 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/LOADED CARS/3.2° CURVE

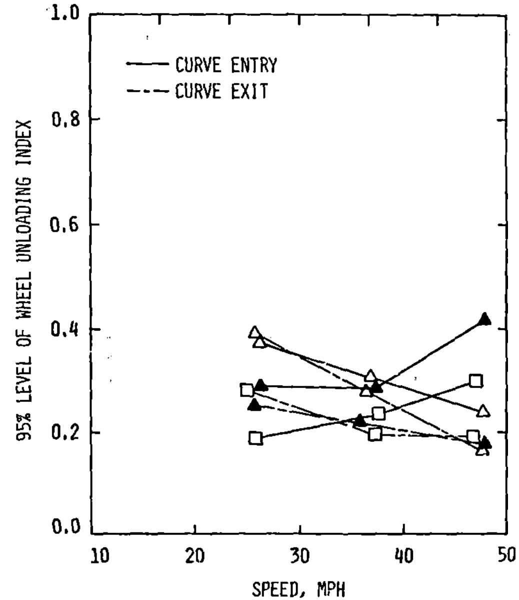


FIGURE 5.3.2-8 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/LOADED CARS/3.7° CURVE

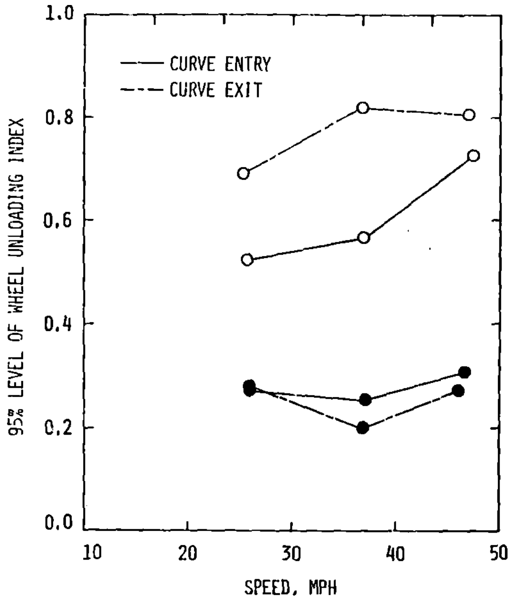


FIGURE 5.3.2-5 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/EMPTY CARS/3.7° CURVE

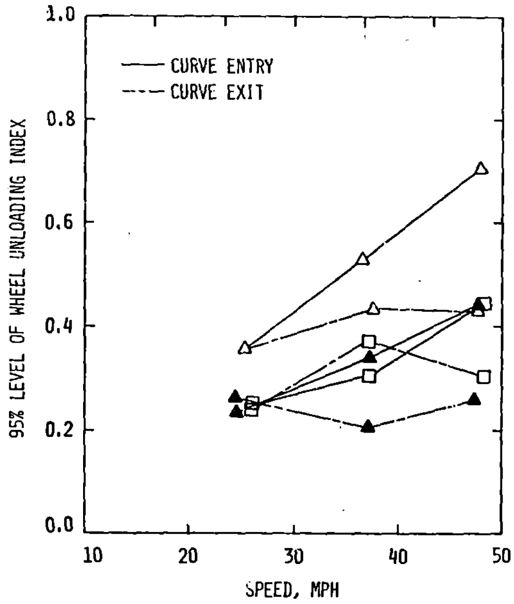


FIGURE 5.3.2-6 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/EMPTY CARS/3.7° CURVE

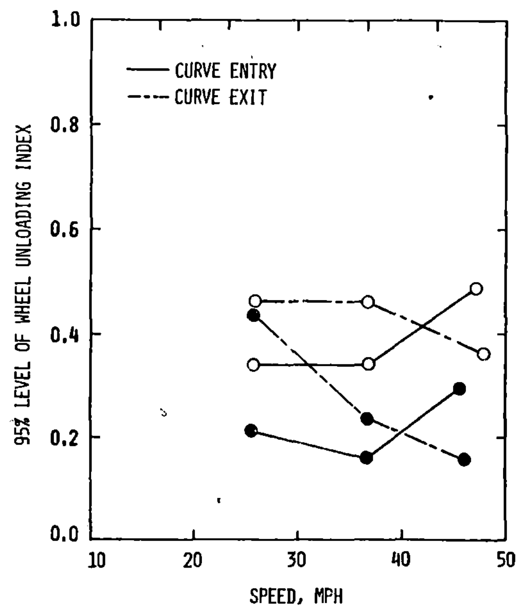


FIGURE 5.3.2-11 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/LOADED CARS/5.2° CURVE

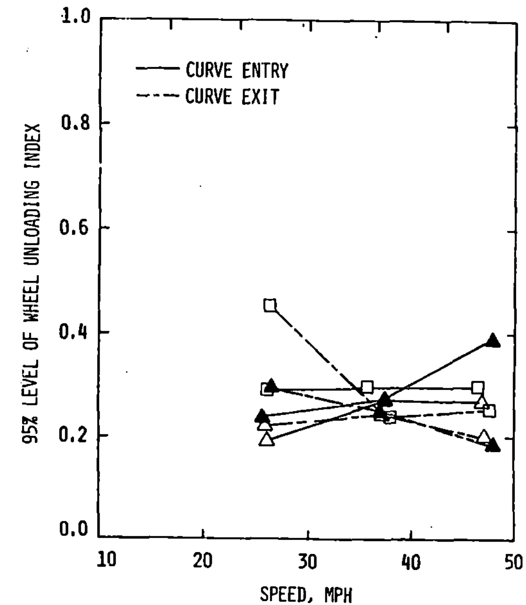


FIGURE 5.3.2-12 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/LOADED CARS/5.2° CURVE

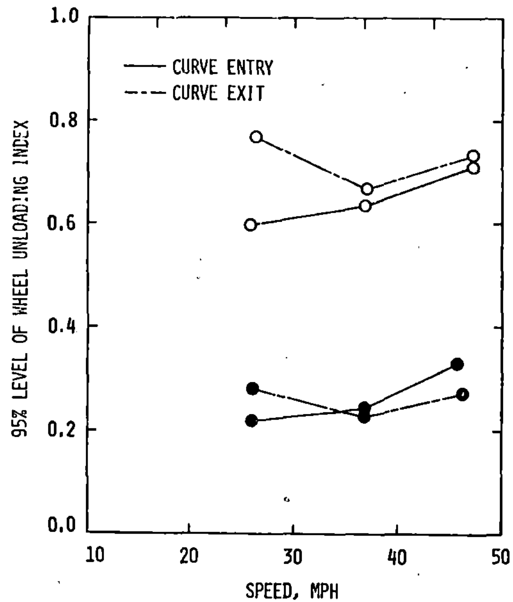


FIGURE 5.3.2-9 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/EMPTY CARS/5.2° CURVE

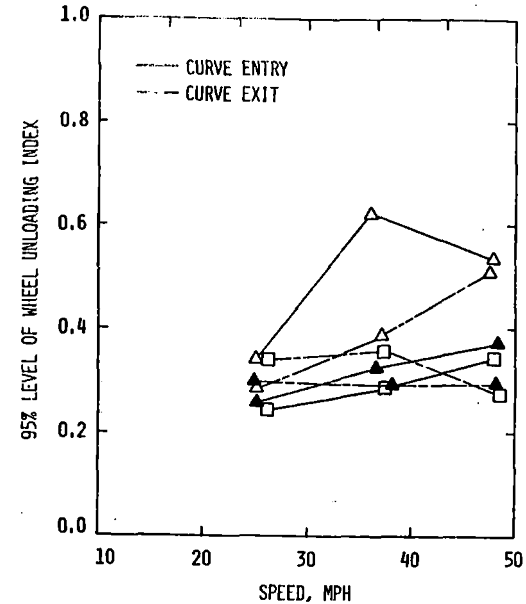


FIGURE 5.3.2-10 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/EMPTY CARS/5.2° CURVE

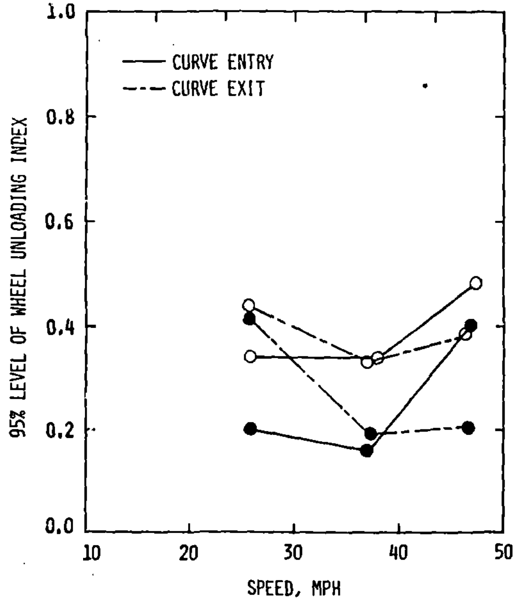


FIGURE 5.3.2-15 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/LOADED CARS/6.2° CURVE

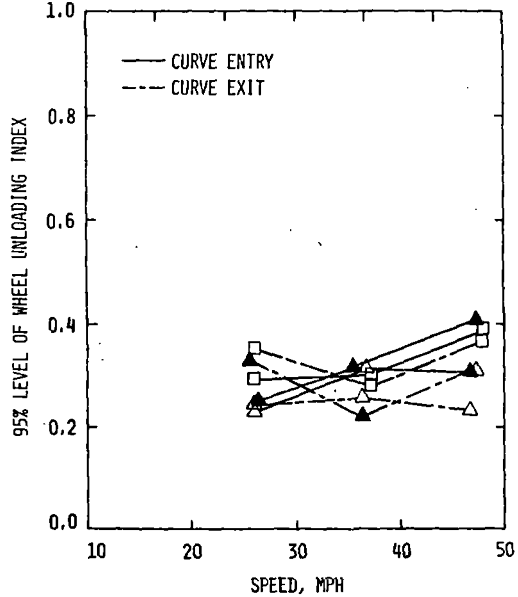


FIGURE 5.3.2-16 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/LOADED CARS/6.2° CURVE

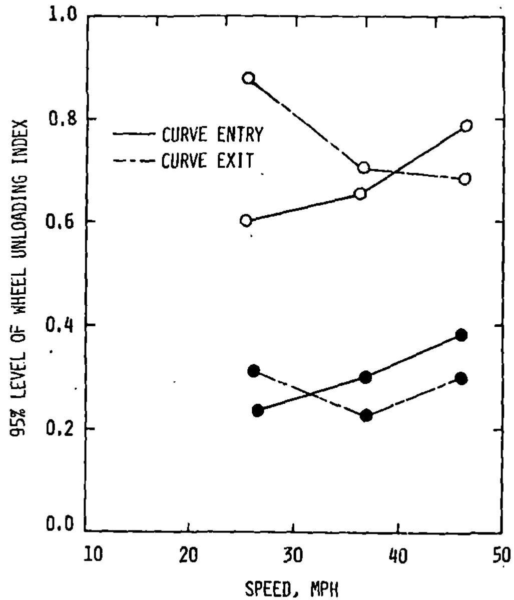


FIGURE 5.3.2-13 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - PRIMARY SUSPENSION TRUCKS/EMPTY CARS/6.2° CURVE

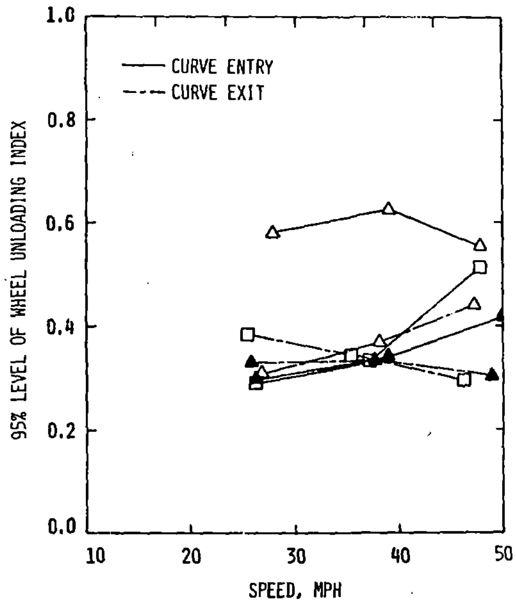


FIGURE 5.3.2-14 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - SECONDARY SUSPENSION TRUCKS/EMPTY CARS/6.2° CURVE

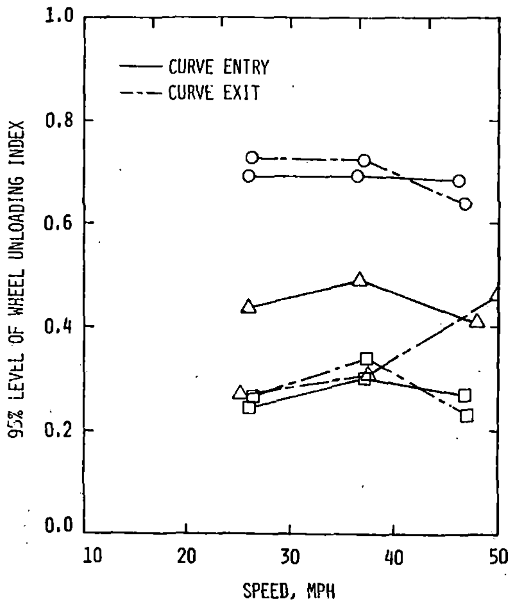


FIGURE 5.3.2-17 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RADIAL TRUCKS/EMPTY CARS/2.5° CURVE

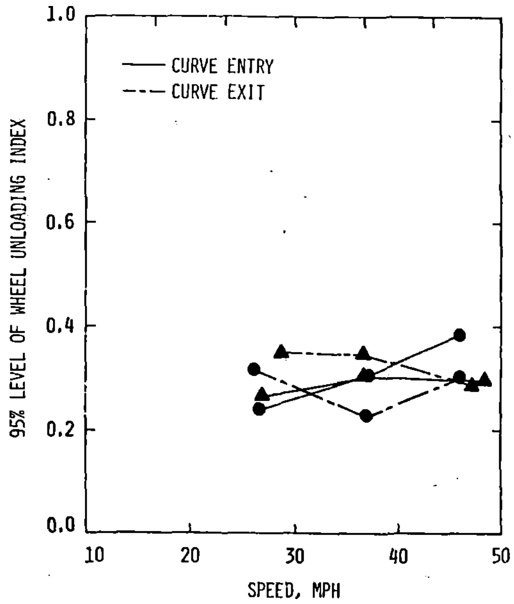


FIGURE 5.3.2-18 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RIGID TRUCKS/EMPTY CARS/2.5° CURVE

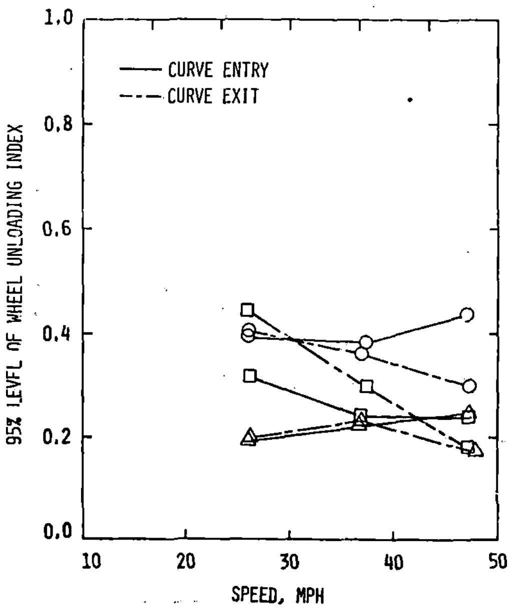


FIGURE 5.3.2-19 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RADIAL TRUCKS/LOADED CARS/2.5° CURVE

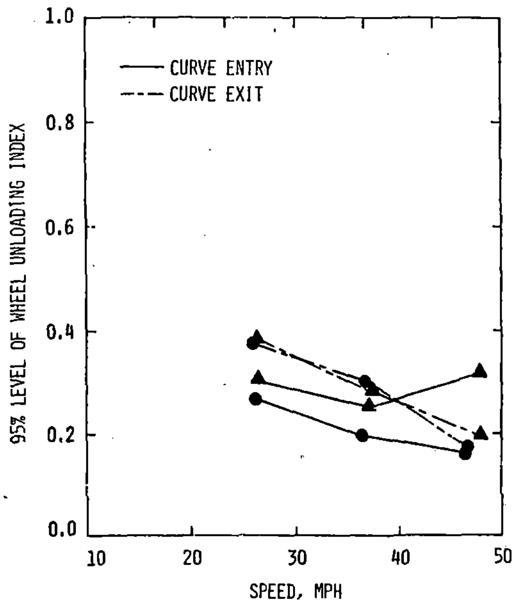


FIGURE 5.3.2-20 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RIGID TRUCKS/LOADED CARS/2.5° CURVE

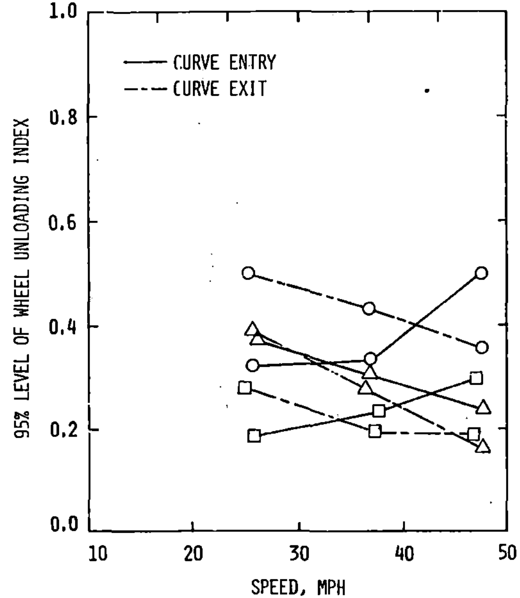


FIGURE 5.3.2-23 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RADIAL TRUCKS/LOADED CARS/3.7° CURVE

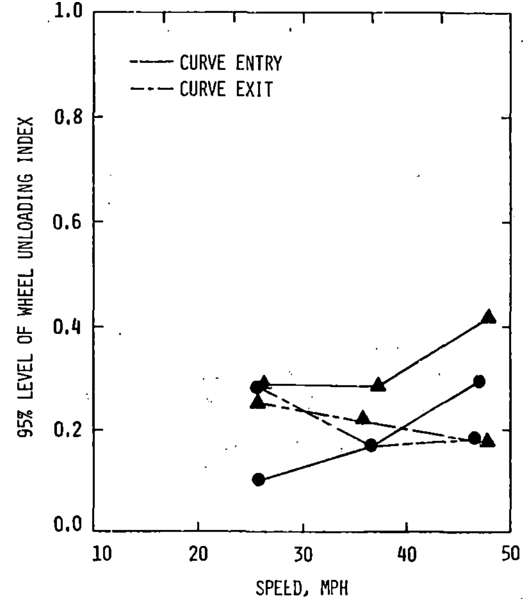


FIGURE 5.3.2-24 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RIGID TRUCKS/LOADED CARS/3.7° CURVE

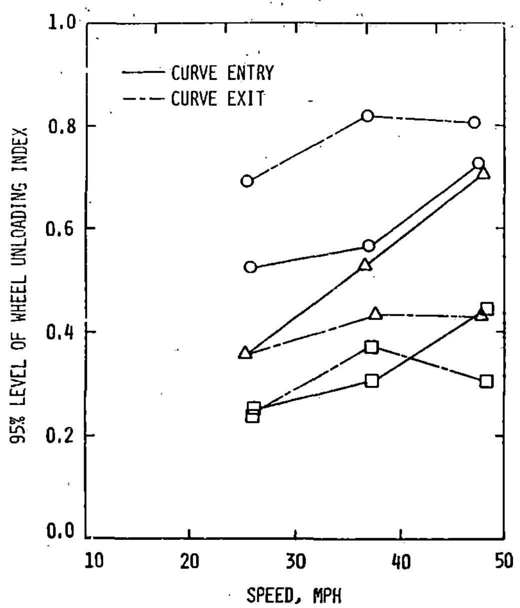


FIGURE 5.3.2-21 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RADIAL TRUCKS/EMPTY CARS/3.7° CURVE

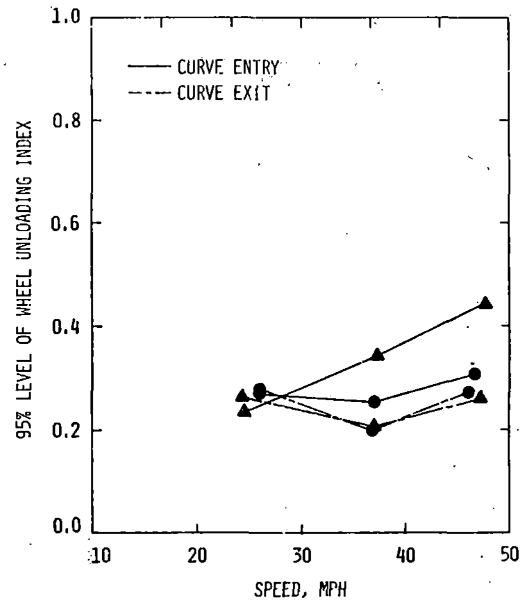


FIGURE 5.3.2-22 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RIGID TRUCKS/EMPTY CARS/3.7° CURVE

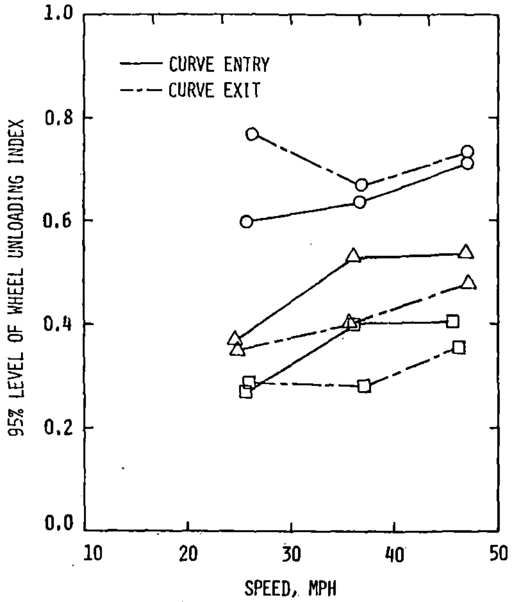


FIGURE 5.3.2-25 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RADIAL TRUCKS/EMPTY CARS/5.2° CURVE

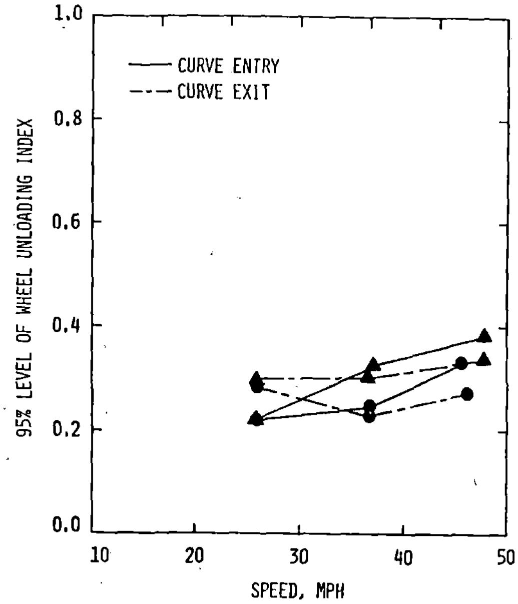


FIGURE 5.3.2-26 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RIGID TRUCKS/EMPTY CARS/5.2° CURVE

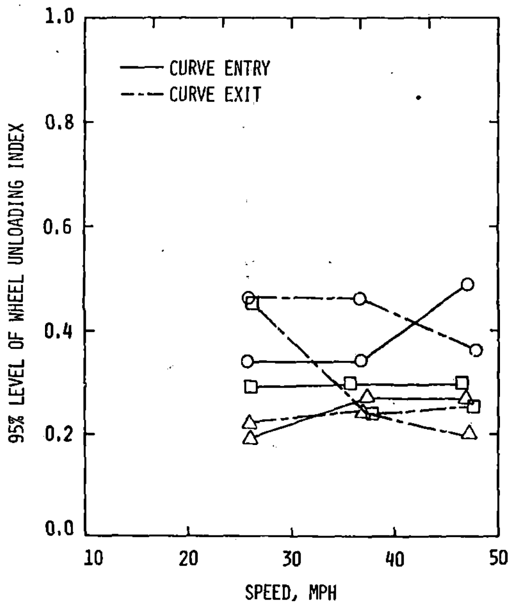


FIGURE 5.3.2-27 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RADIAL TRUCKS/LOADED CARS/5.2° CURVE

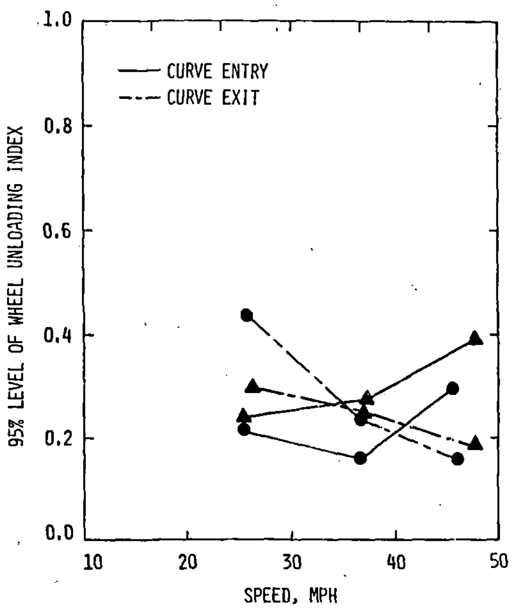


FIGURE 5.3.2-28 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RIGID TRUCKS/LOADED CARS/5.2° CURVE

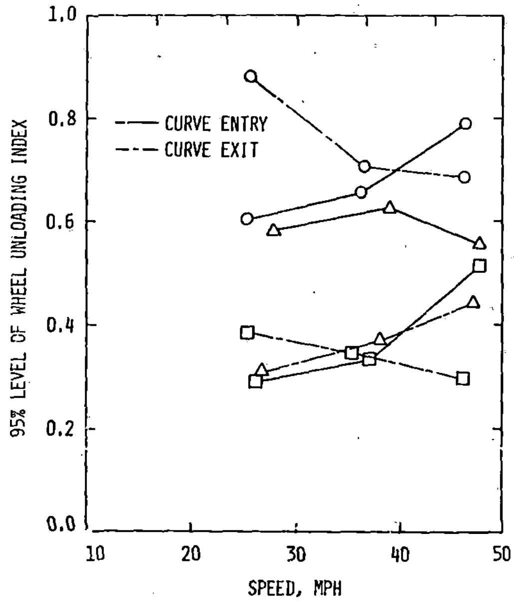


FIGURE 5.3.2-29 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RADIAL TRUCKS/EMPTY CARS/6.2° CURVE

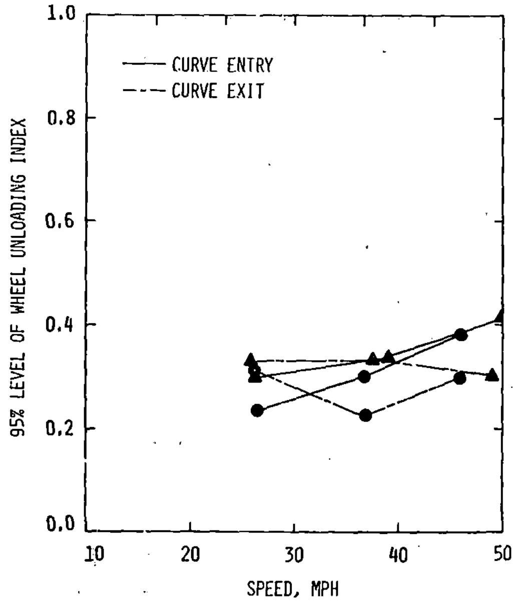


FIGURE 5.3.2-30 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RIGID TRUCKS/EMPTY CARS/C.2° CURVE

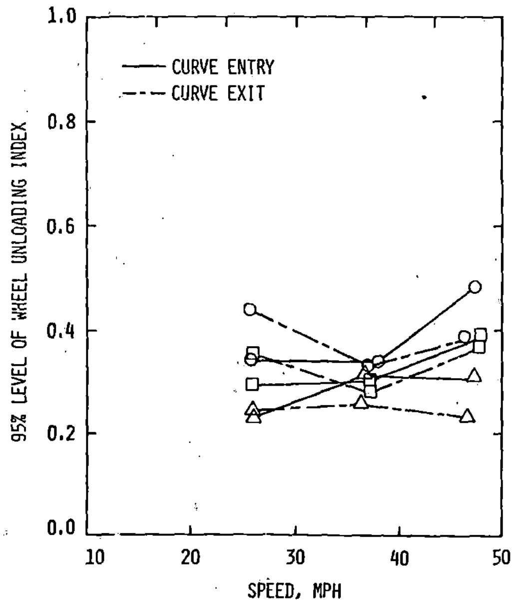


FIGURE 5.3.2-31 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RADIAL TRUCKS/LOADED CARS/6.2° CURVE

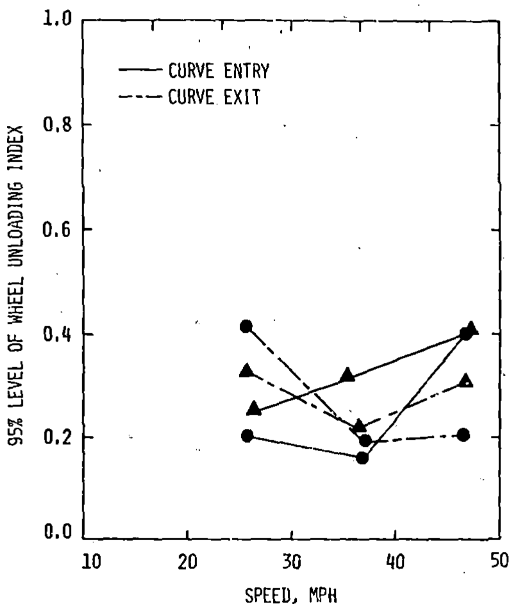


FIGURE 5.3.2-32 95% LEVEL OF WHEEL UNLOADING INDEX VERSUS SPEED - RIGID TRUCKS/LOADED CARS/6.2° CURVE

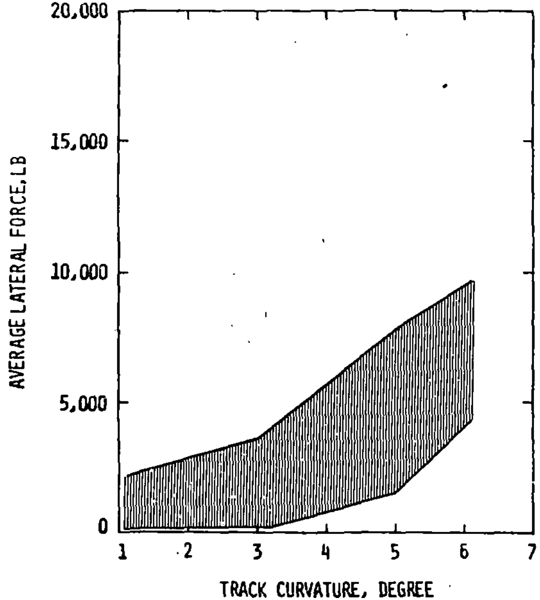


FIGURE 5.3.3-3 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE/NEAR BALANCE SPEED/PIGHT HAND CURVES/TYPE II TRUCKS WITH LOADED HOPPER CARS

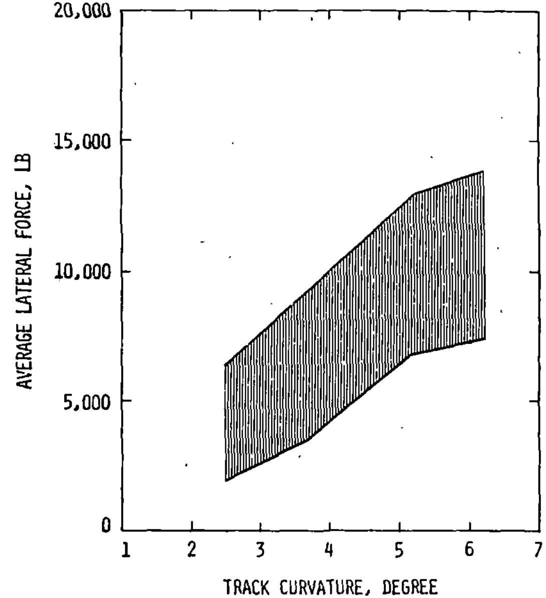


FIGURE 5.3.3-4 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE/NEAR BALANCE SPEED/LEFT HAND CURVES/TYPE II TRUCKS WITH LOADED HOPPER CARS

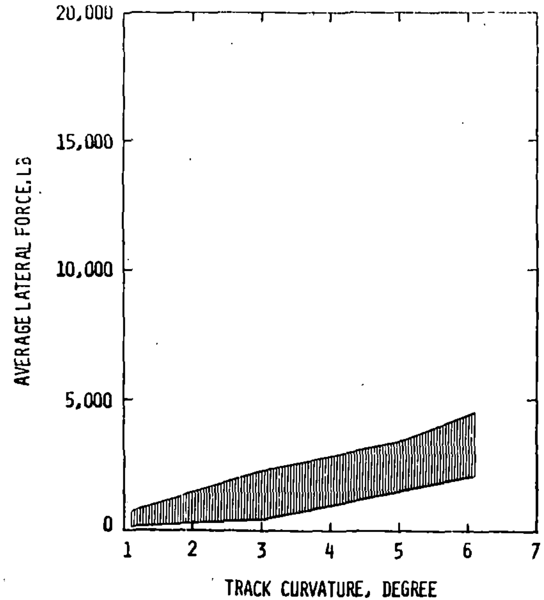


FIGURE 5.3.3-1 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE/NEAR BALANCE SPEED/RIGHT HAND CURVES/ TYPE II TRUCKS WITH EMPTY HOPPER CARS

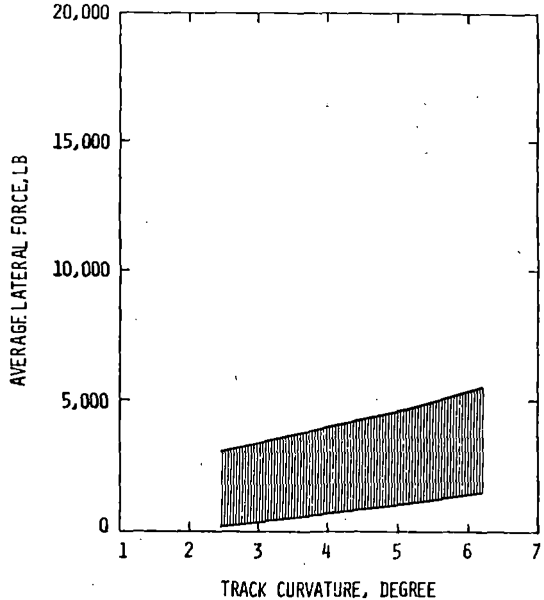


FIGURE 5.3.3-2 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE/NEAR BALANCE SPEED/LEFT HAND CURVES/TYPE II TRUCKS WITH EMPTY HOPPER CARS

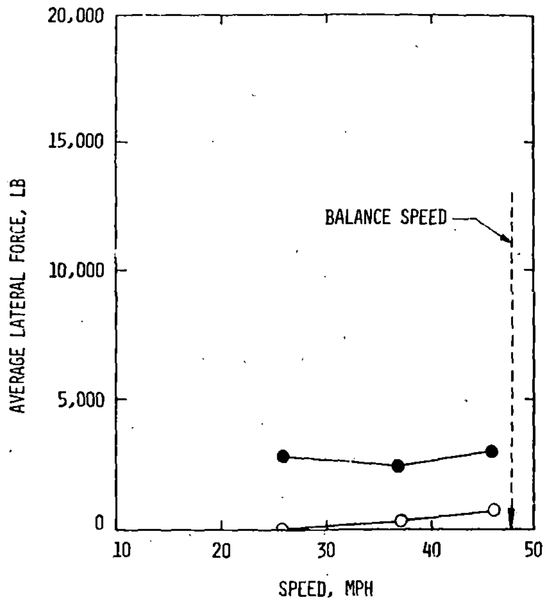


FIGURE 5.3.3-5 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

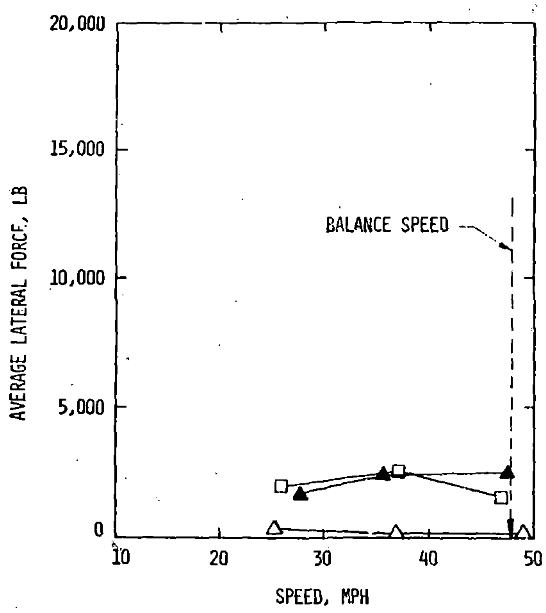


FIGURE 5.3.3-6 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

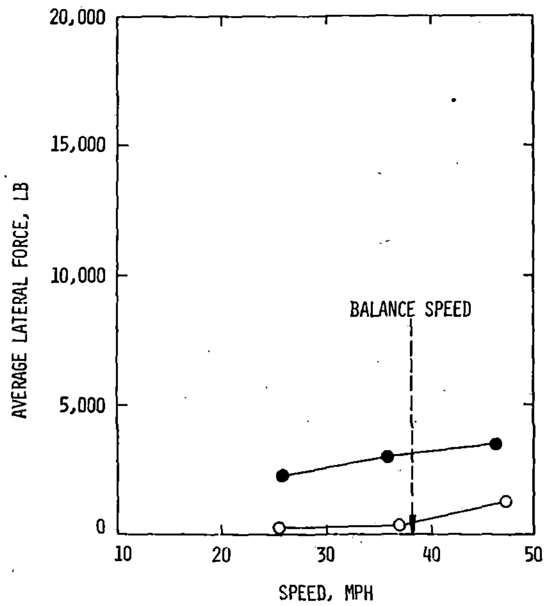


FIGURE 5.3.3-7 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

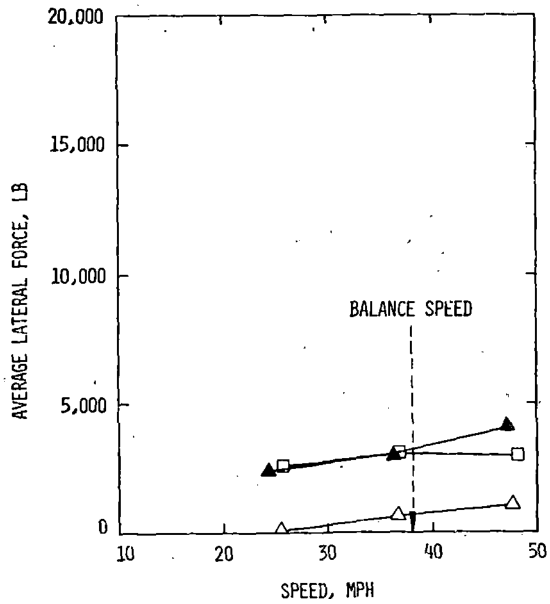


FIGURE 5.3.3-8 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

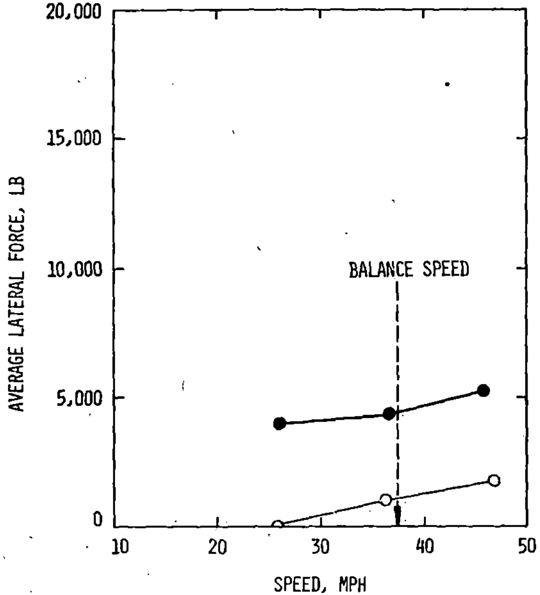


FIGURE 5.3.3-11 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

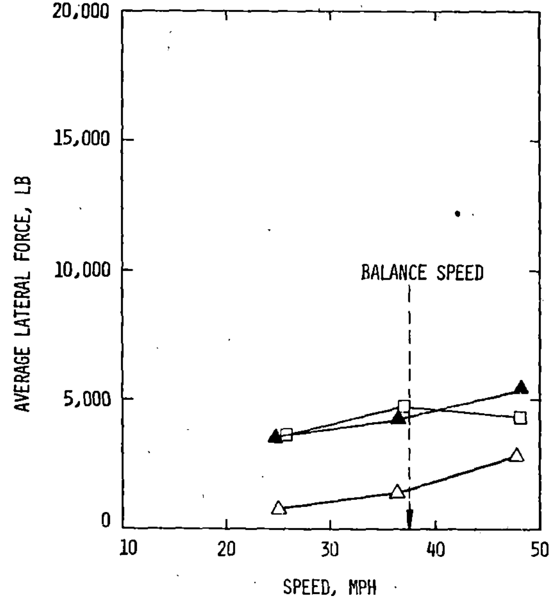


FIGURE 5.3.3-12 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

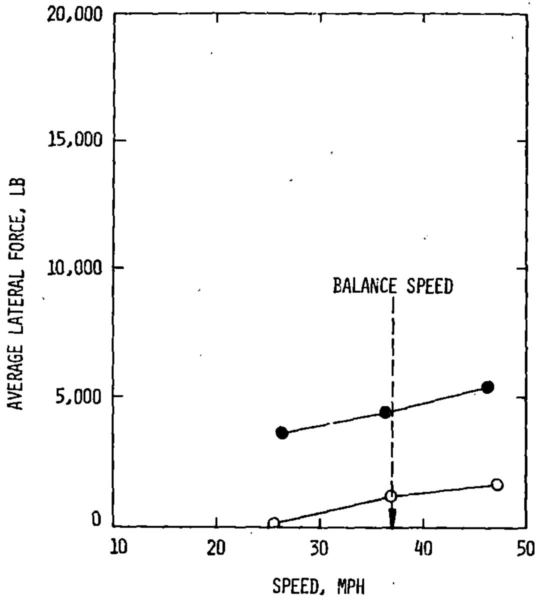


FIGURE 5.3.3-9 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

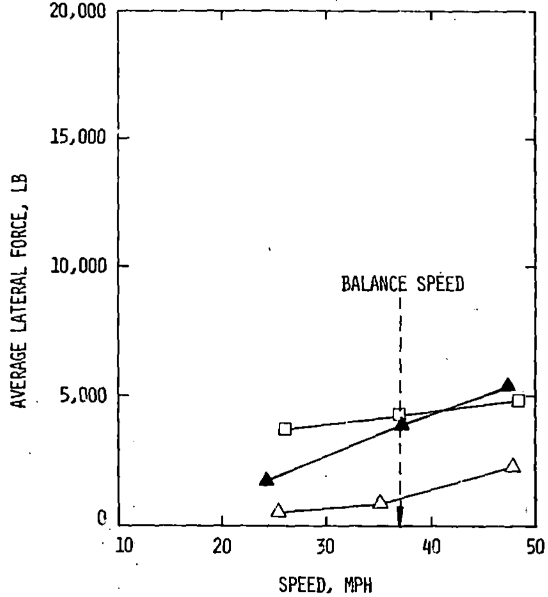


FIGURE 5.3.3-10 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

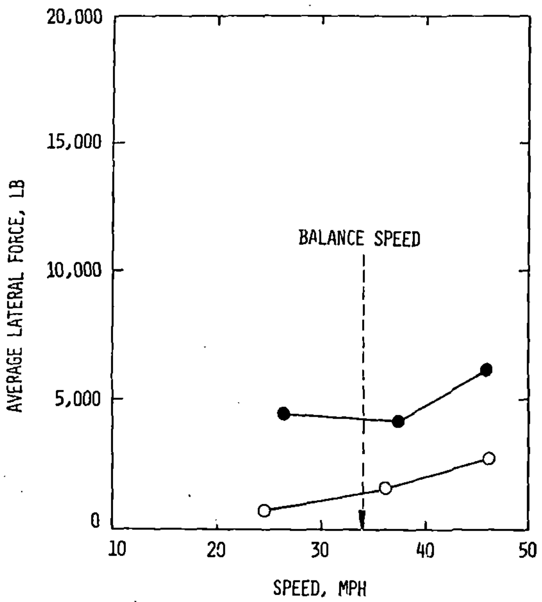


FIGURE 5.3.3-13 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

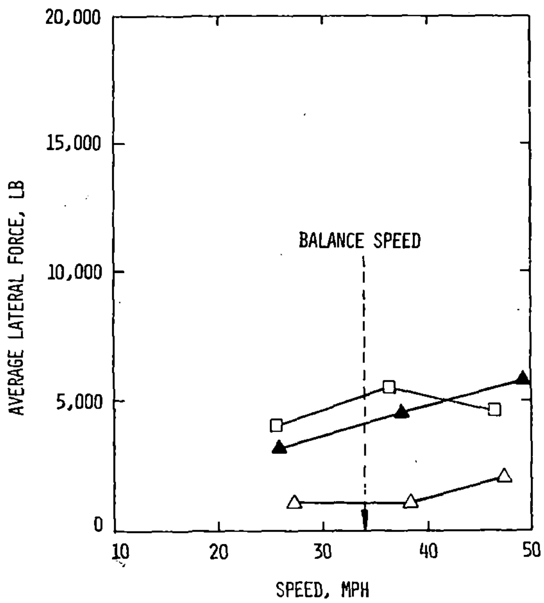


FIGURE 5.3.3-14 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

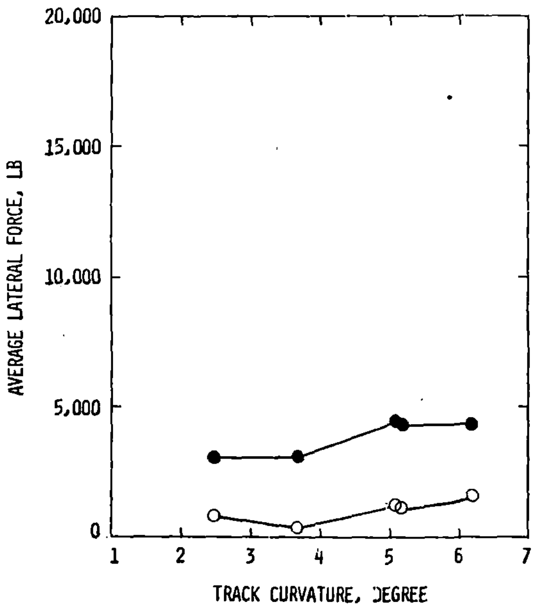


FIGURE 5.3.3-15 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

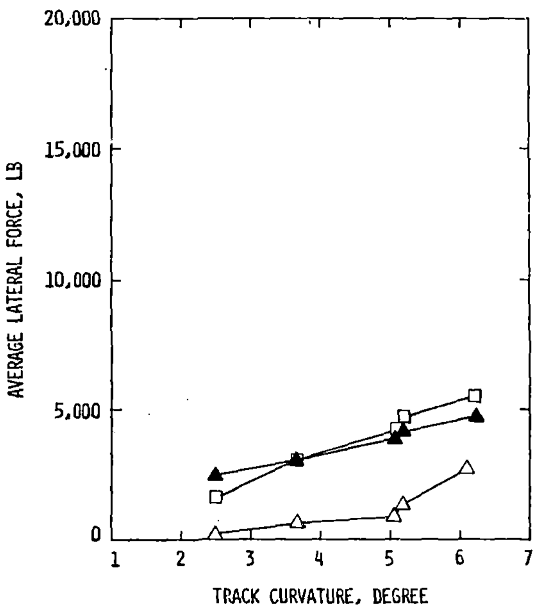


FIGURE 5.3.3-16 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

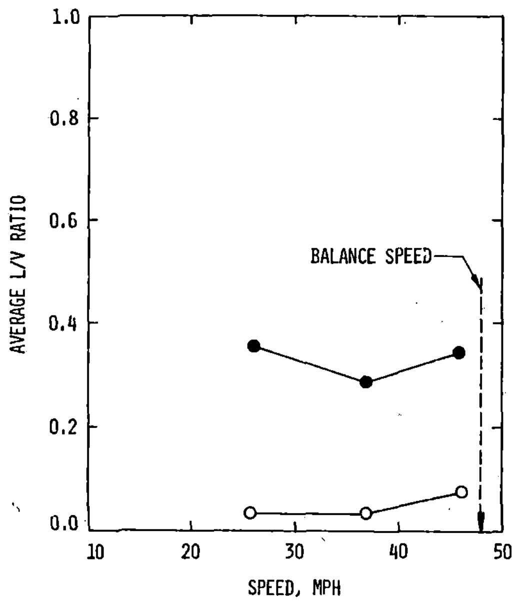


FIGURE 5.3.3-17 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

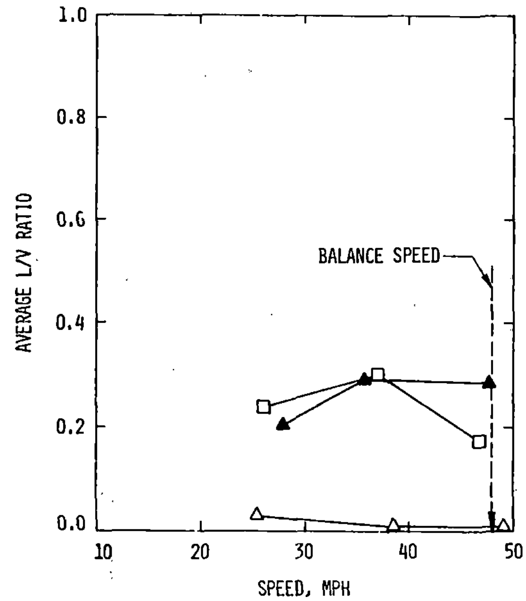


FIGURE 5.3.3-18 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

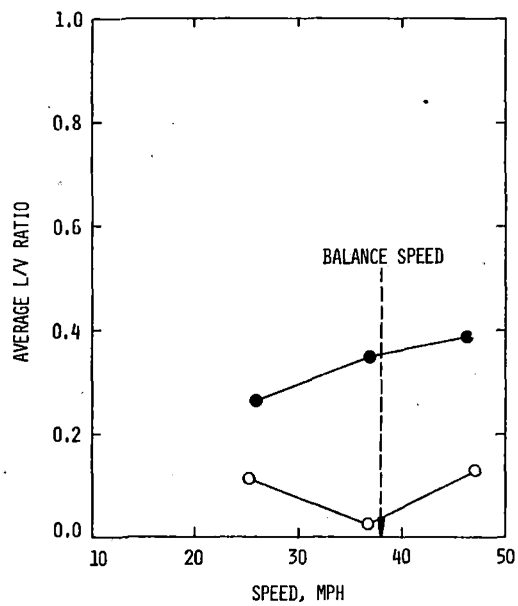


FIGURE 5.3.3-19 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

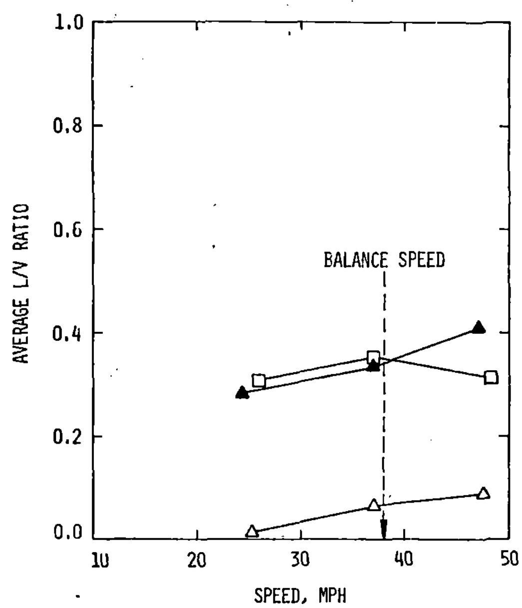


FIGURE 5.3.3-20 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

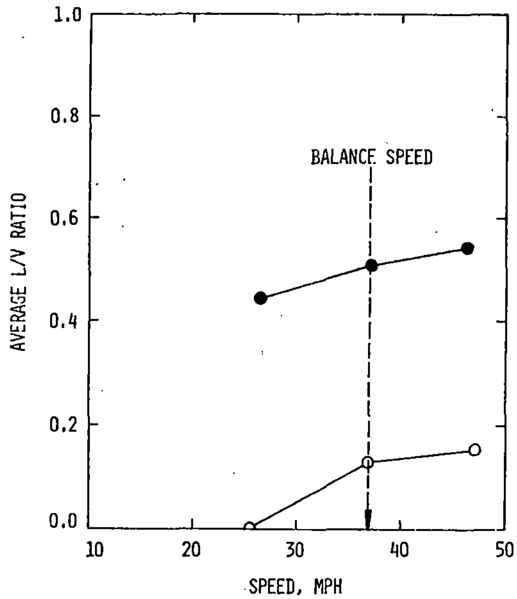


FIGURE 5.3.3-21 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/PRIMARY SUSPENSION

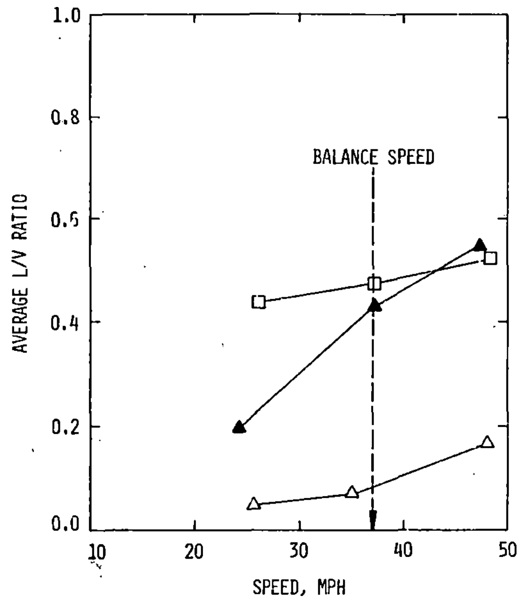


FIGURE 5.3.3-22 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

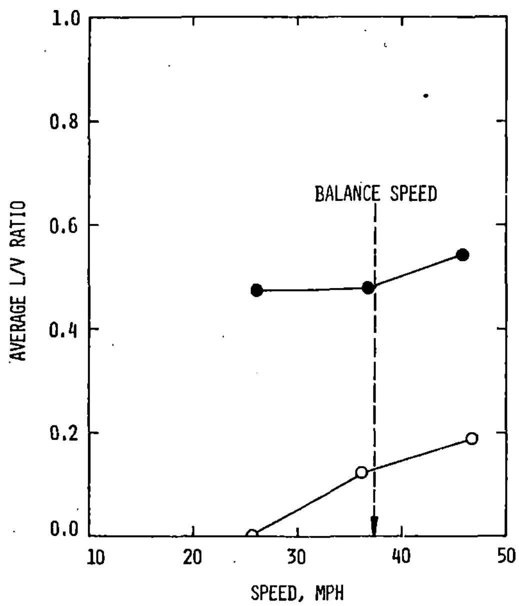


FIGURE 5.3.3-23 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

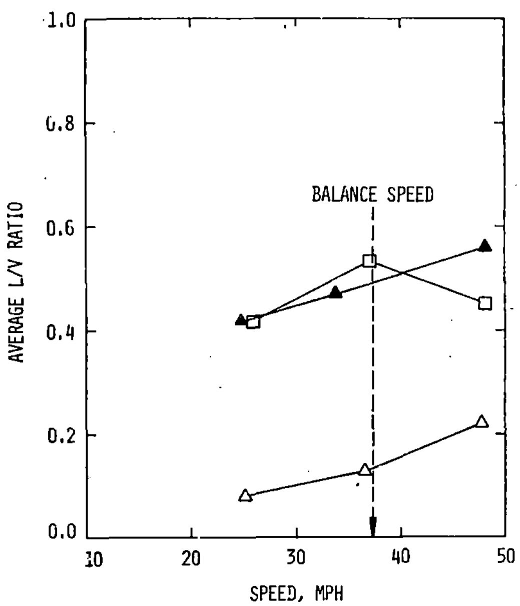


FIGURE 5.3.3-24 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

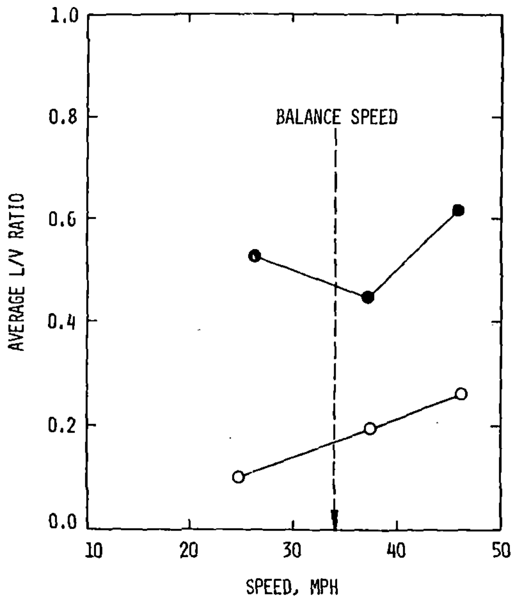


FIGURE 5.3.3-25 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

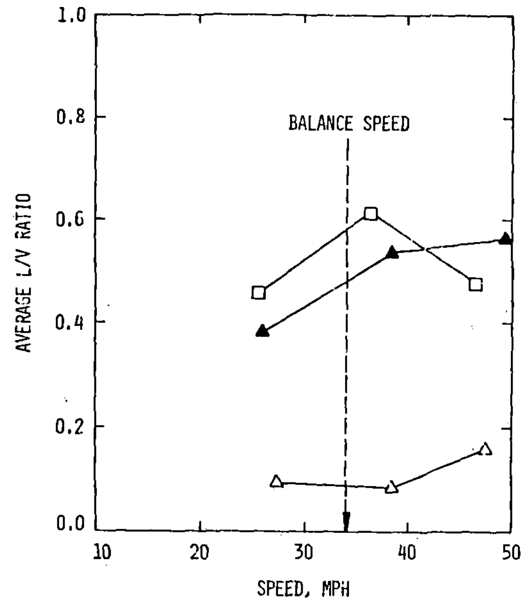


FIGURE 5.3.3-26 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

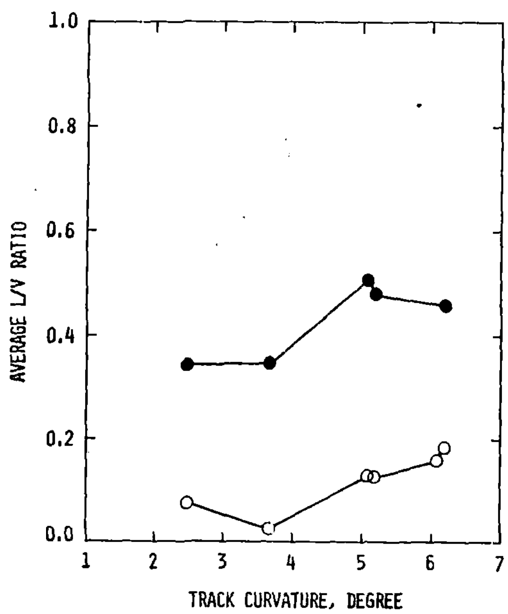


FIGURE 5.3.3-27 L/V RATIO ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - PRIMARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

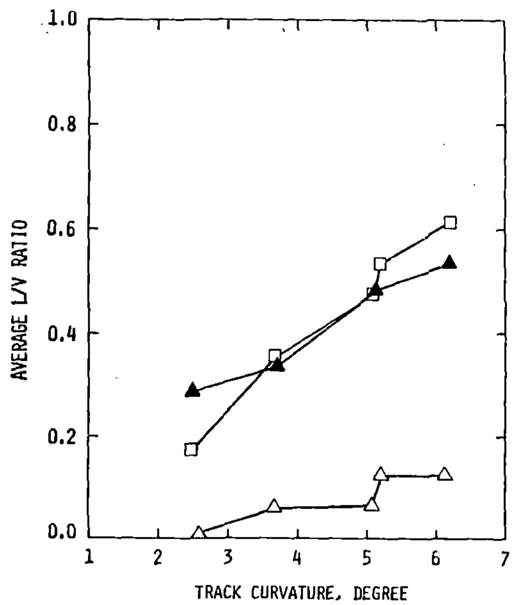


FIGURE 5.3.3-28 L/V RATIO ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - SECONDARY SUSPENSION TRUCKS/EMPTY HOPPER CARS

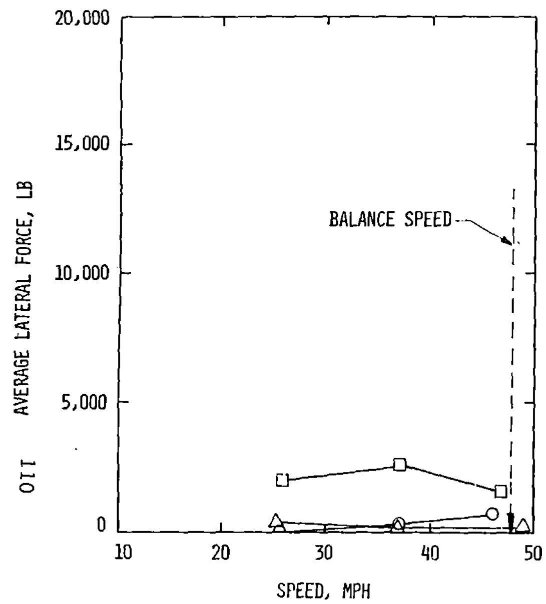


FIGURE 5.3.3-29 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/RADIAL TRUCKS/EMPTY HOPPER CARS

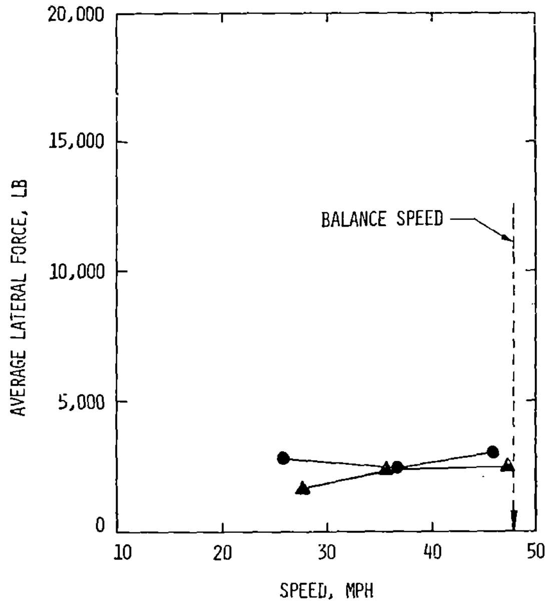


FIGURE 5.3.3-30 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/RIGID TRUCKS/EMPTY HOPPER CARS

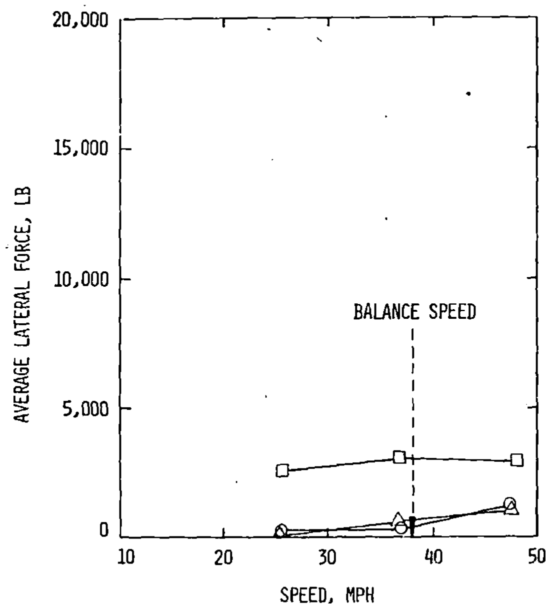


FIGURE 5.3.3-31 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/RADIAL TRUCKS/EMPTY HOPPER CARS

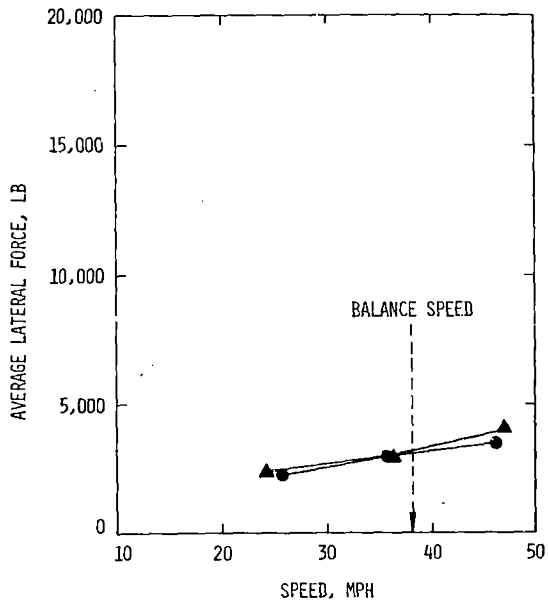


FIGURE 5.3.3-32 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/RIGID TRUCKS/EMPTY HOPPER CARS

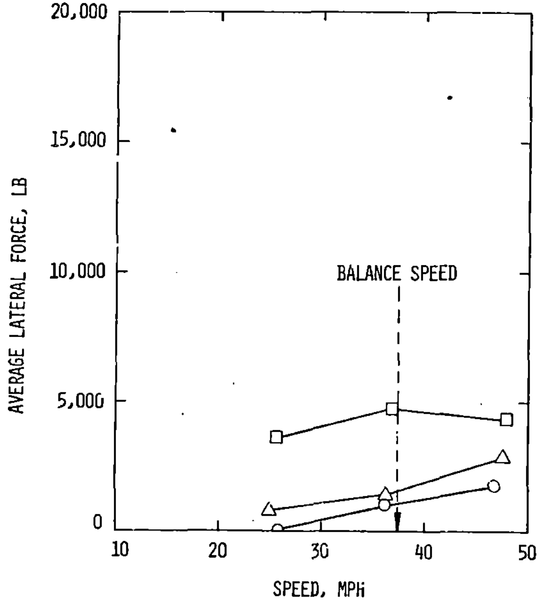


FIGURE 5.3.3-35 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/RADIAL TRUCKS/EMPTY HOPPER CARS

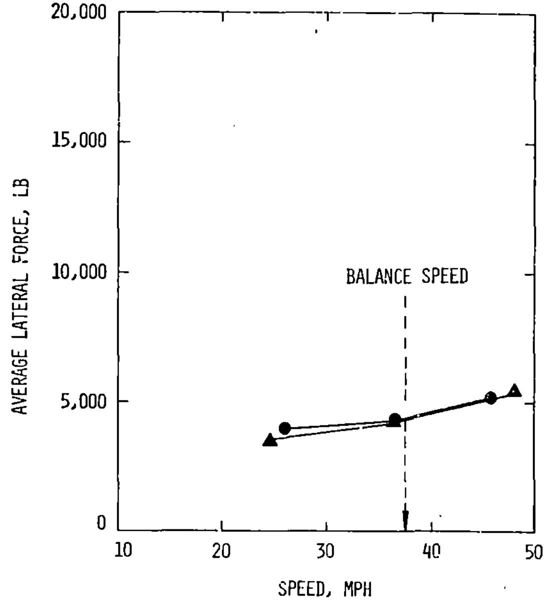


FIGURE 5.3.3-36 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/RIGID TRUCKS/EMPTY HOPPER CARS

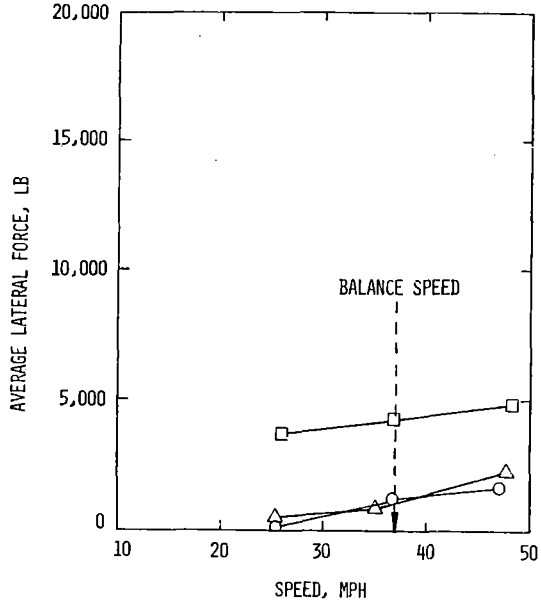


FIGURE 5.3.3-33 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/RADIAL TRUCKS/EMPTY HOPPER CARS

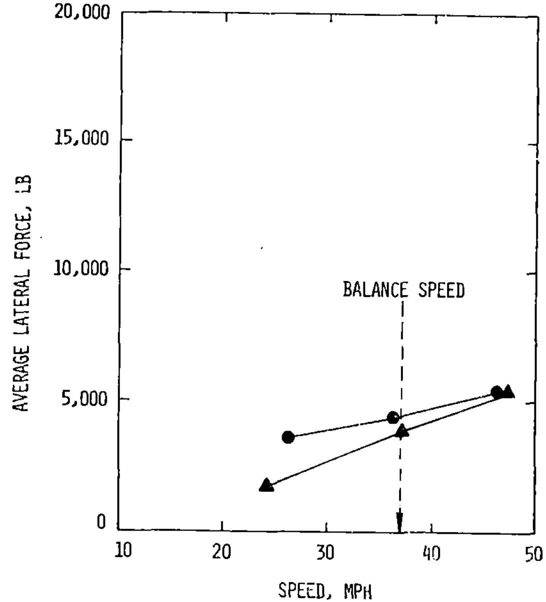


FIGURE 5.3.3-34 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/RIGID TRUCKS/EMPTY HOPPER CARS

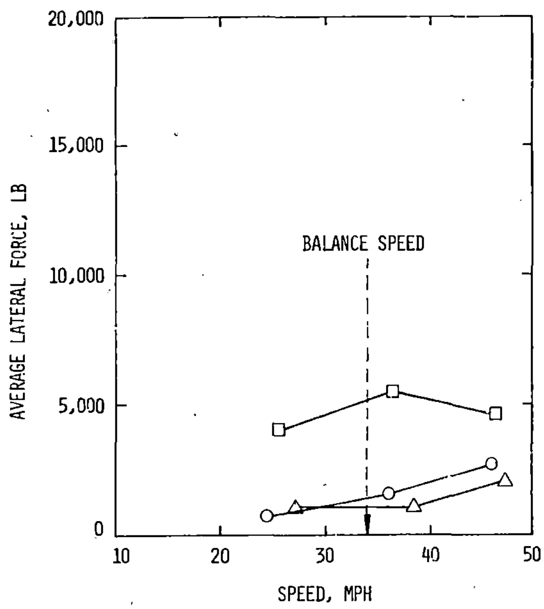


FIGURE 5.3.3-37 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/RADIAL TRUCKS/EMPTY HOPPER CARS

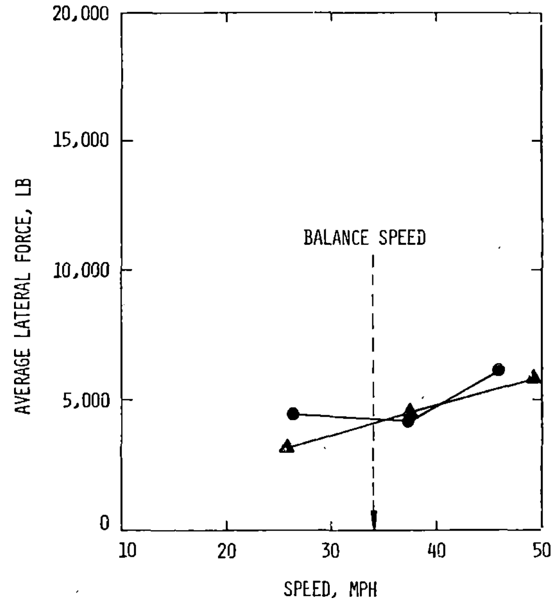


FIGURE 5.3.3-38 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/RIGID TRUCKS/EMPTY HOPPER CARS

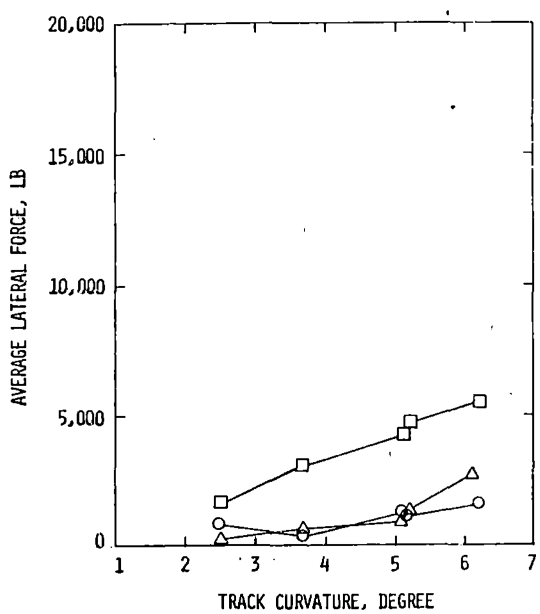


FIGURE 5.3.3-39 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - RADIAL TRUCKS/EMPTY HOPPER CARS

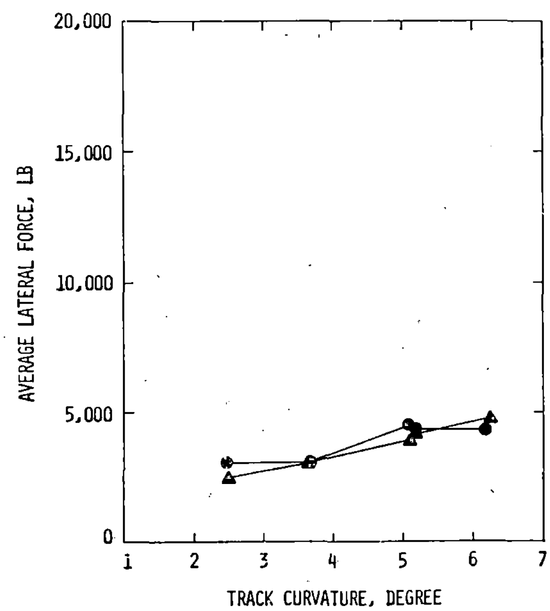


FIGURE 5.3.3-40 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - RIGID TRUCKS/EMPTY HOPPER CARS

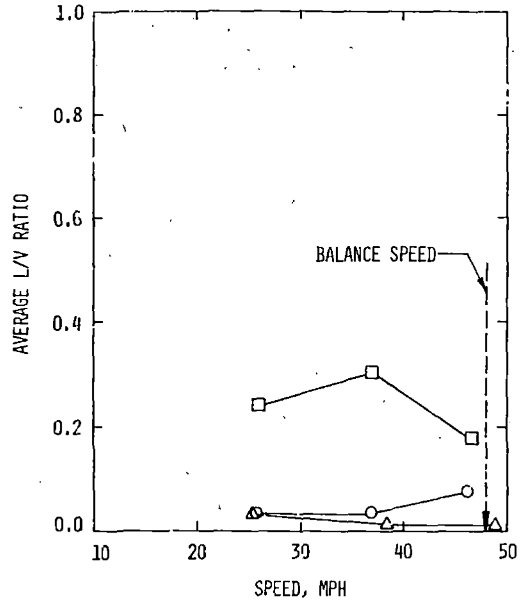


FIGURE 5.3.3-41 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/RADIAL TRUCKS/ EMPTY HOPPER CARS

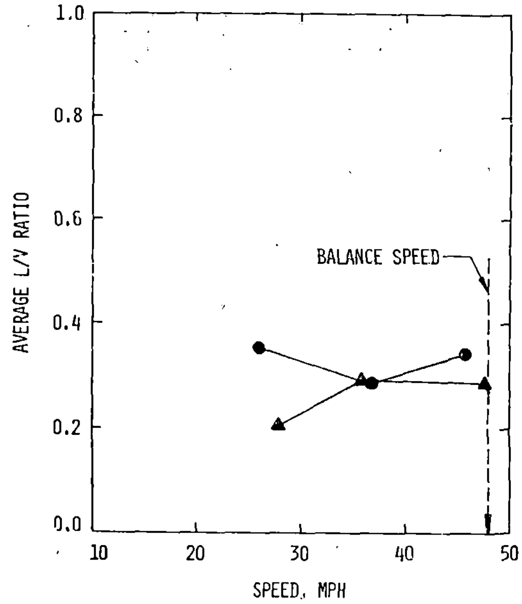


FIGURE 5.3.3-42 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/RIGID TRUCKS/ EMPTY HOPPER CARS

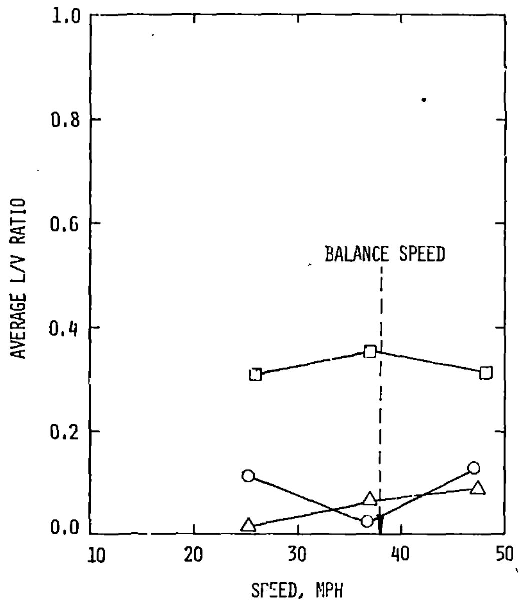


FIGURE 5.3.3-43 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/RADIAL TRUCKS/ EMPTY HOPPER CARS

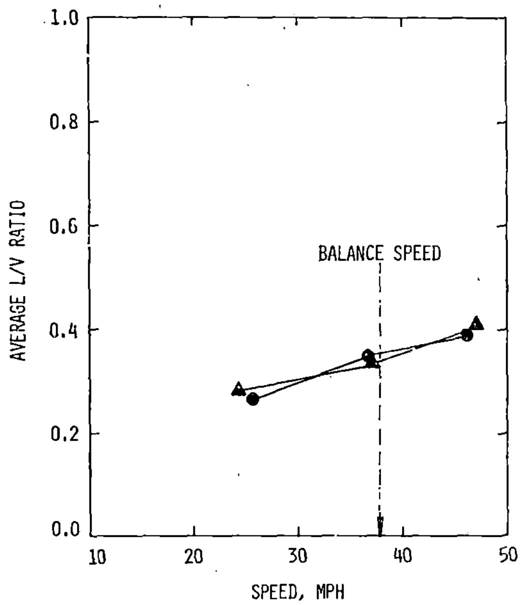


FIGURE 5.3.3-44 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/RIGID TRUCKS/ EMPTY HOPPER CARS

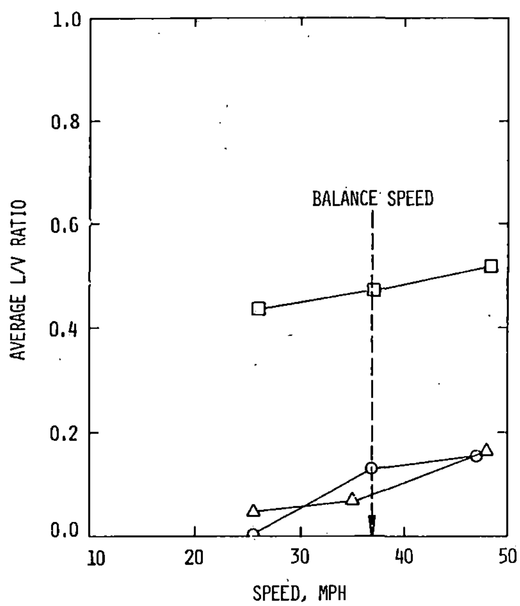


FIGURE 5.3.3-45 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/RADIAL TRUCKS/ EMPTY HOPPER CARS

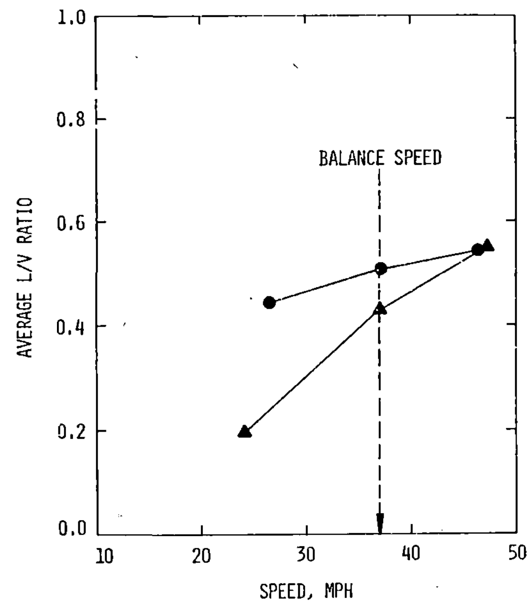


FIGURE 5.3.3-46 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/RIGID TRUCKS/ EMPTY HOPPER CARS

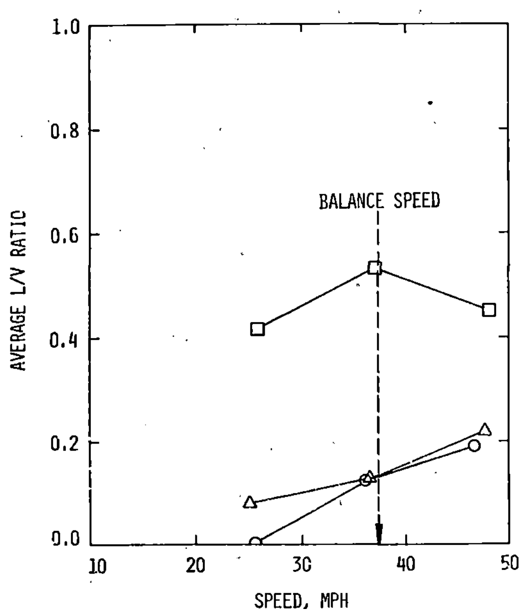


FIGURE 5.3.3-47 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/RADIAL TRUCKS/ EMPTY HOPPER CARS

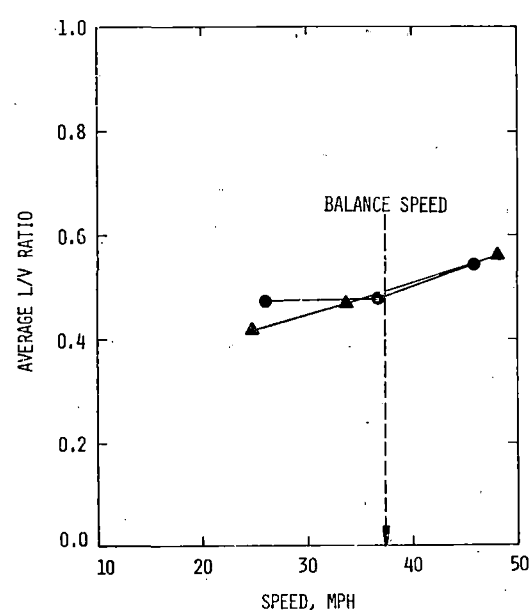


FIGURE 5.3.3-48 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/RIGID TRUCKS/ EMPTY HOPPER CARS

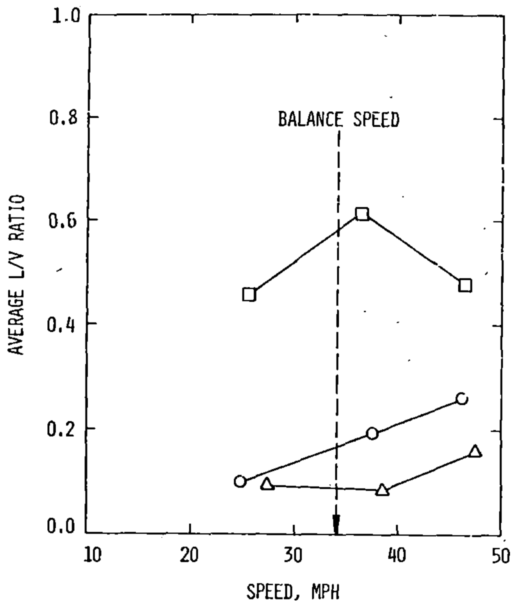


FIGURE 5.3.3-49 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/RADIAL TRUCKS/ EMPTY HOPPER CARS

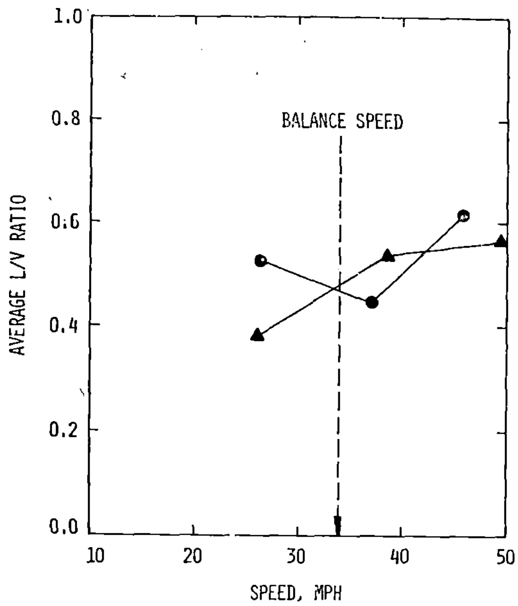


FIGURE 5.3.3-50 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/RIGID TRUCKS/EMPTY HOPPER CARS

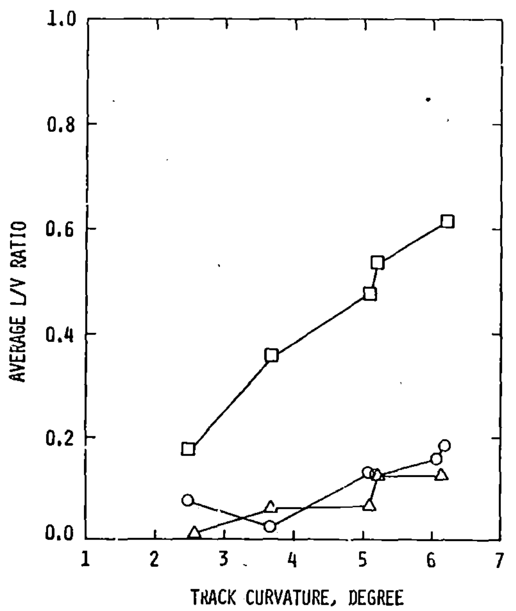


FIGURE 5.3.3-51 L/V RATIO ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - RADIAL TRUCKS/EMPTY HOPPER CARS

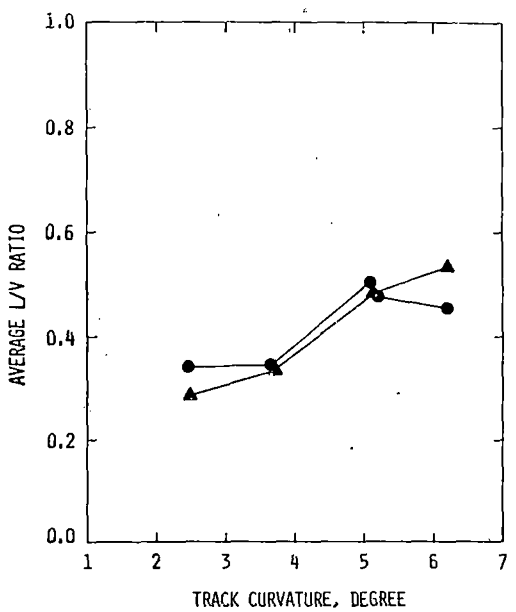


FIGURE 5.3.3-52 L/V RATIO ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - RIGID TRUCKS/EMPTY HOPPER CARS

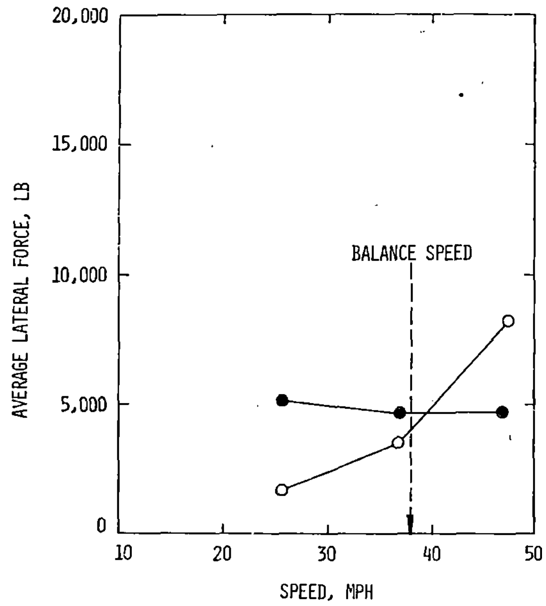


FIGURE 5.3.3-55 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

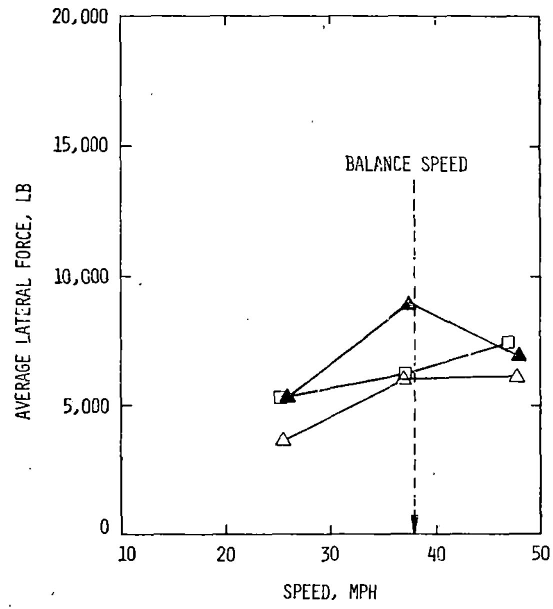


FIGURE 5.3.3-56 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

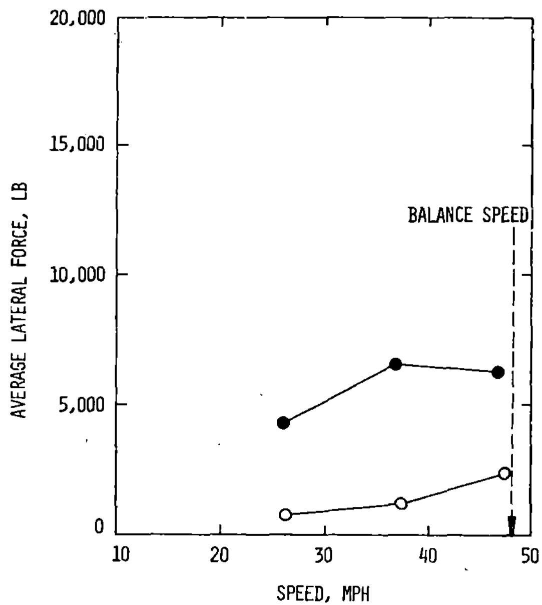


FIGURE 5.3.3-53 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

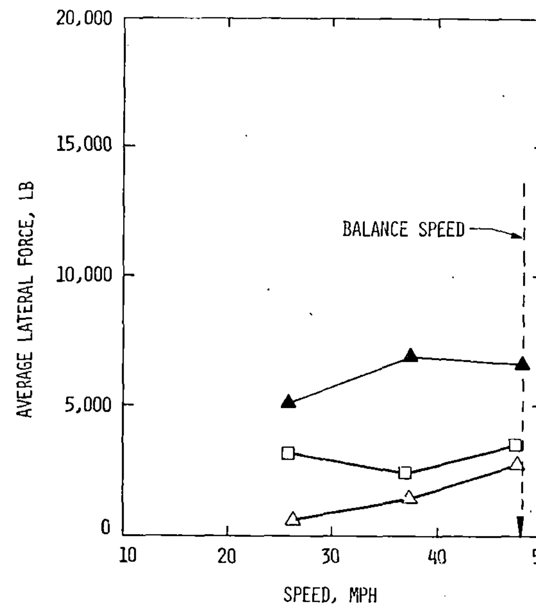


FIGURE 5.3.3-54 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

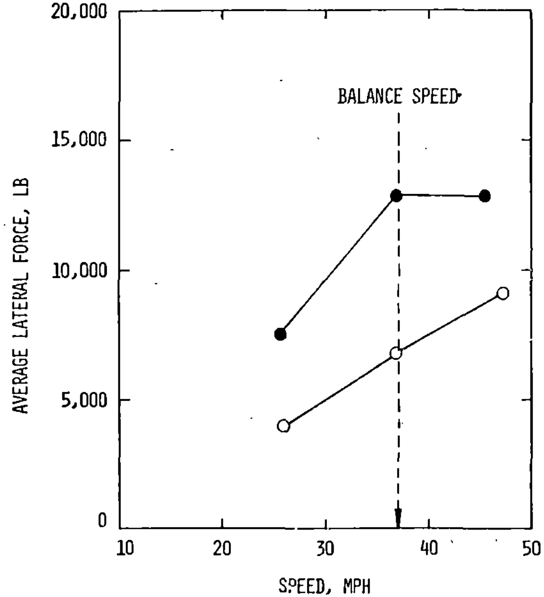


FIGURE 5.3.3-59 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

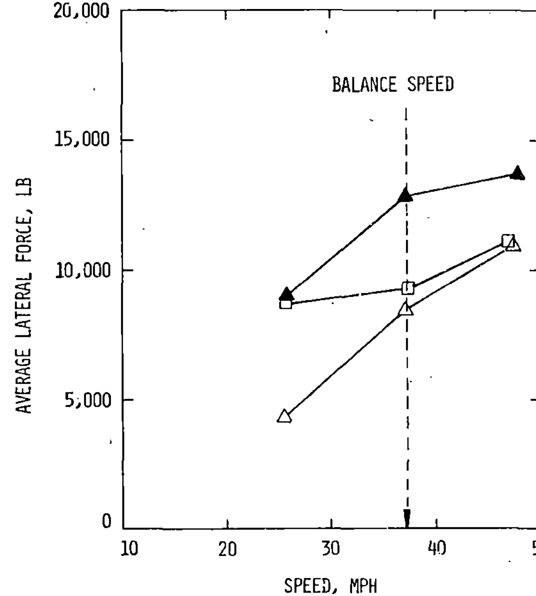


FIGURE 5.3.3-60 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

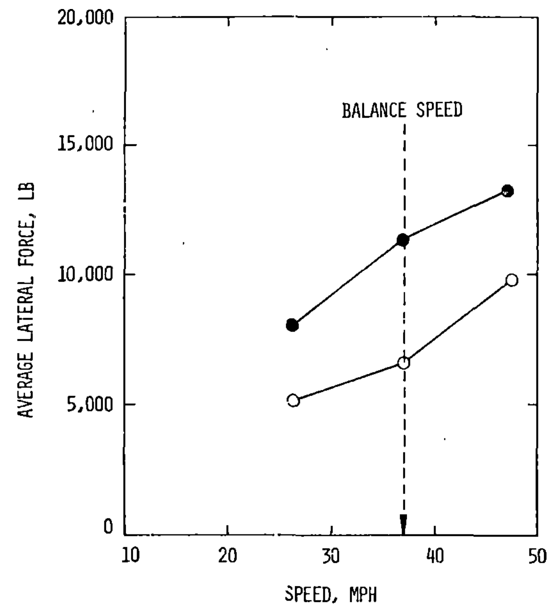


FIGURE 5.3.3-57 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

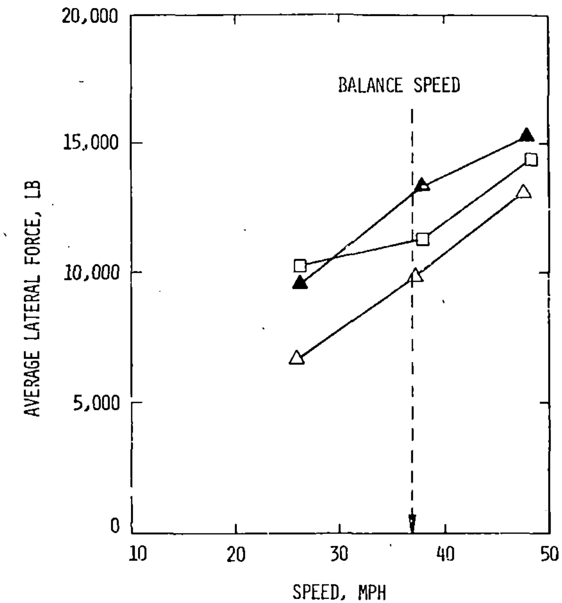


FIGURE 5.3.3-58 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

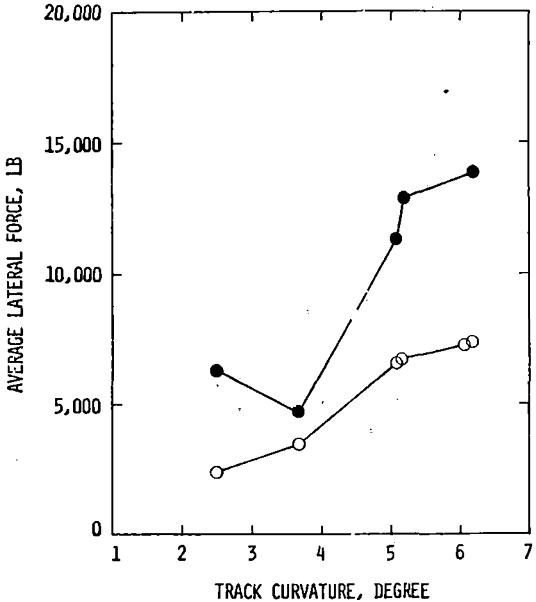


FIGURE 5.3.3-63 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

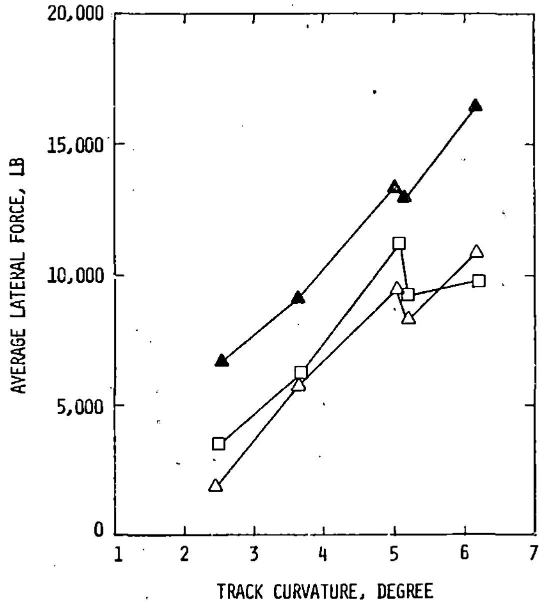


FIGURE 5.3.3-64 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

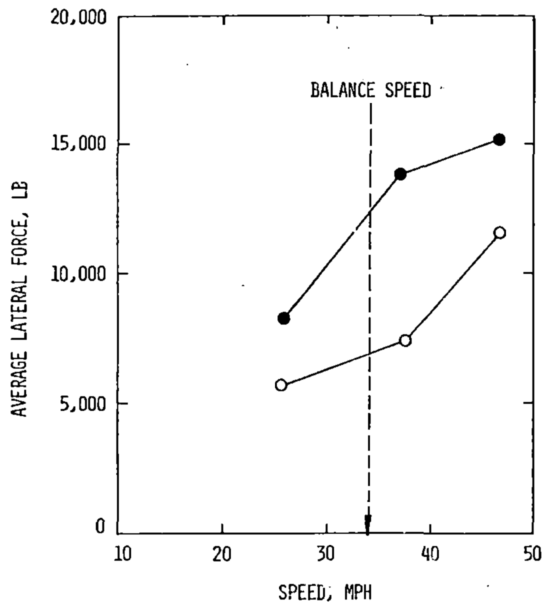


FIGURE 5.3.3-61 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

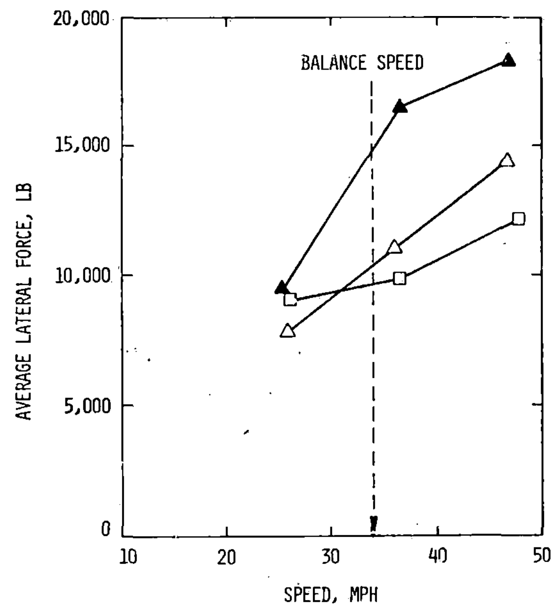


FIGURE 5.3.3-62 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

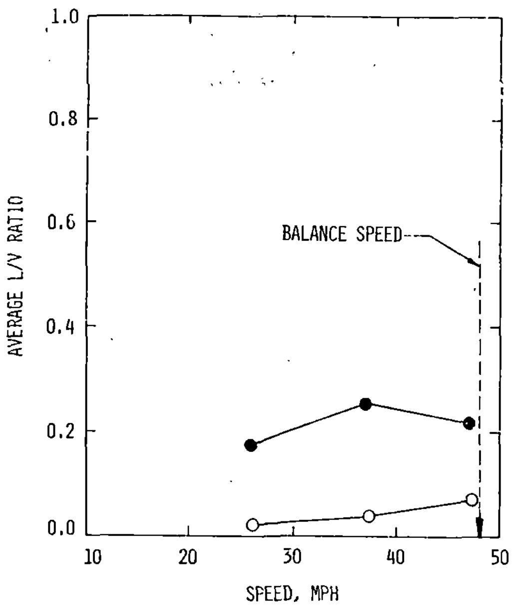


FIGURE 5.3.3-65 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

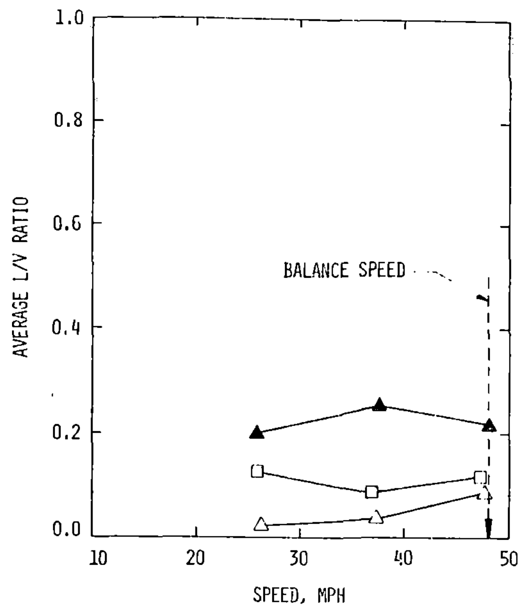


FIGURE 5.3.3-66 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

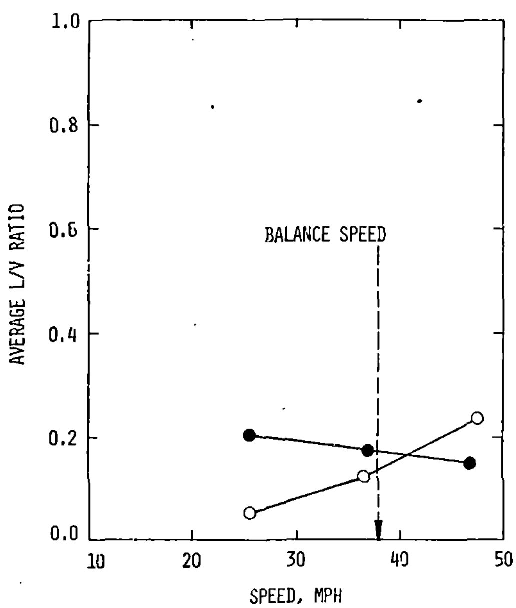


FIGURE 5.3.3-67 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

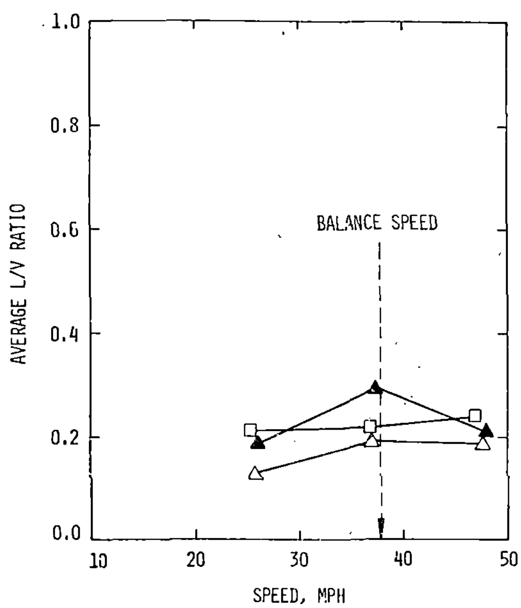


FIGURE 5.3.3-68 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

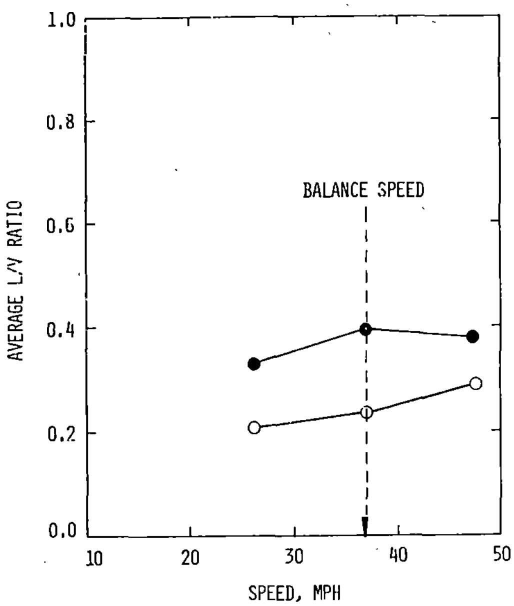


FIGURE 5.3.3-69 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

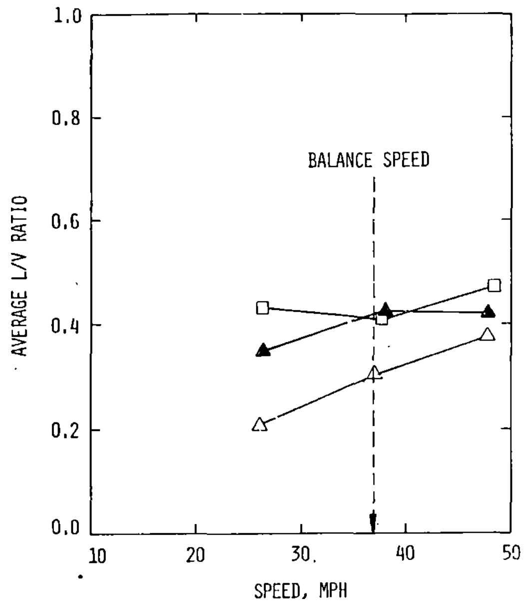


FIGURE 5.3.3-70 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

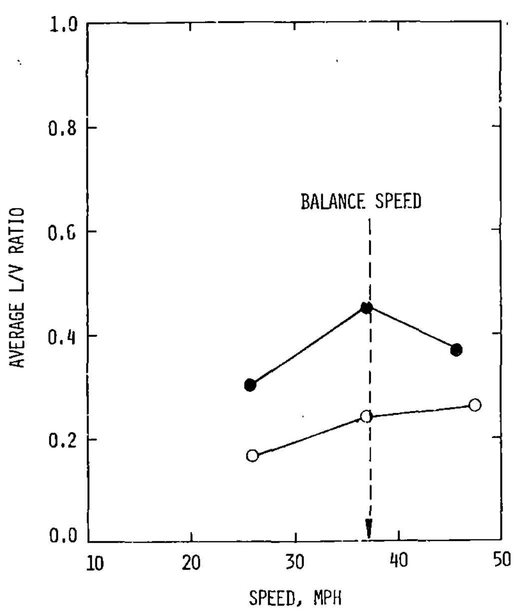


FIGURE 5.3.3-71 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

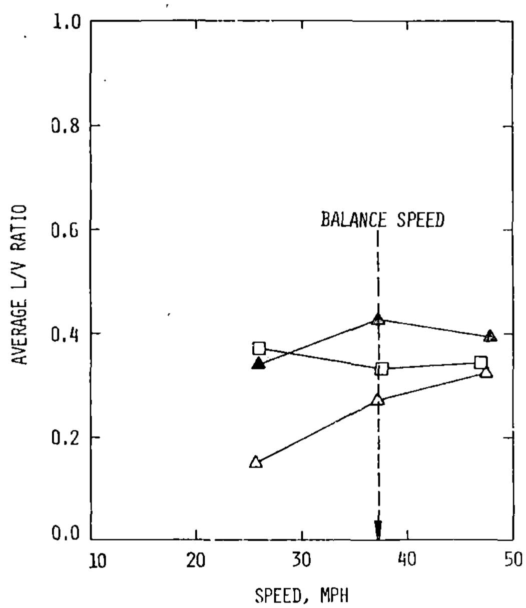


FIGURE 5.3.3-72 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

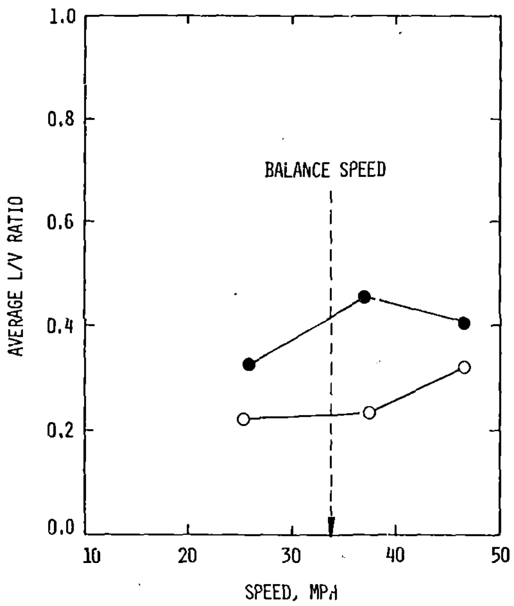


FIGURE 5.3.3-73 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

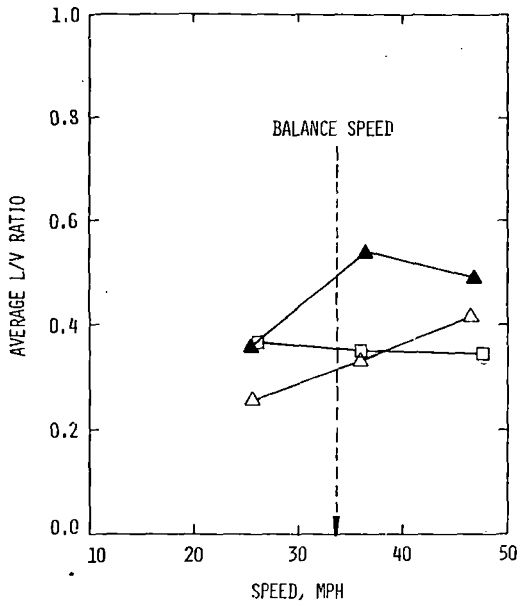


FIGURE 5.3.3-74 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

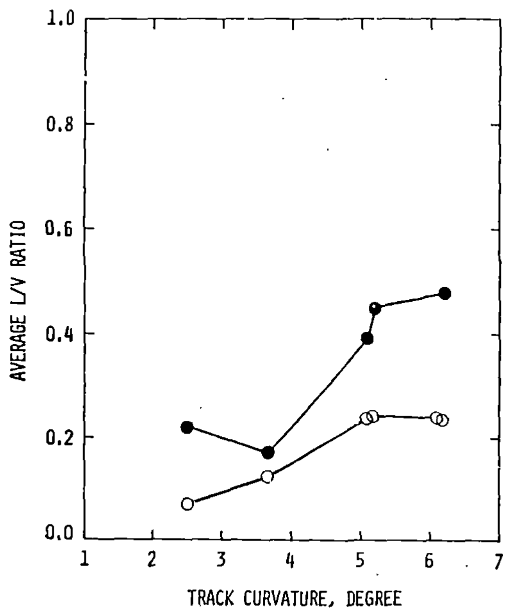


FIGURE 5.3.3-75 L/V RATIO ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - PRIMARY SUSPENSION TRUCKS/LOADED HOPPER CARS

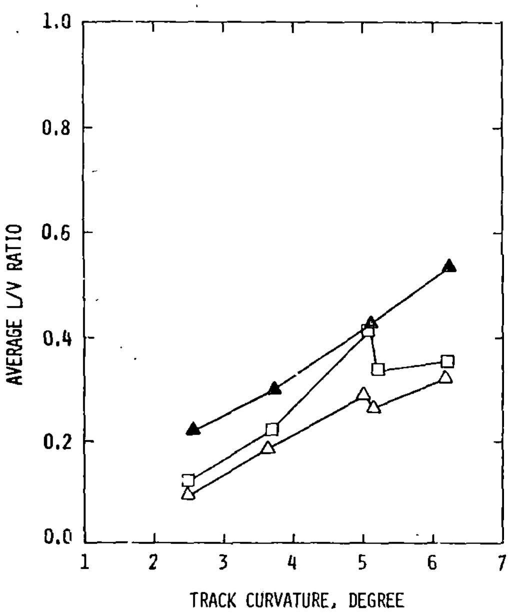


FIGURE 5.3.3-76 L/V RATIO ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - SECONDARY SUSPENSION TRUCKS/LOADED HOPPER CARS

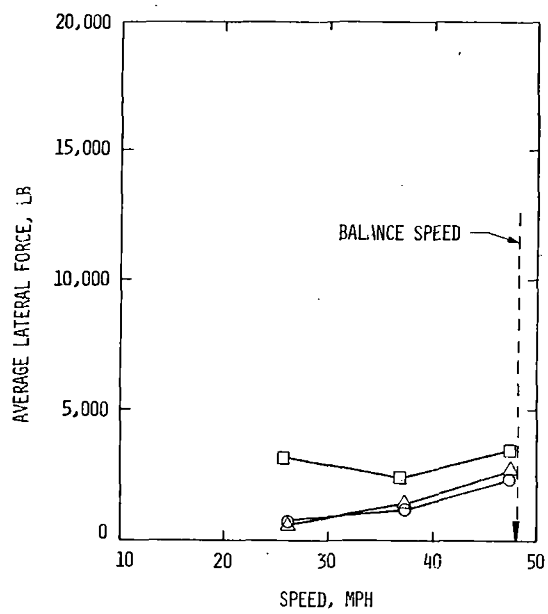


FIGURE 5.3.3-77 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/RADIAL TRUCKS/LOADED HOPPER CARS

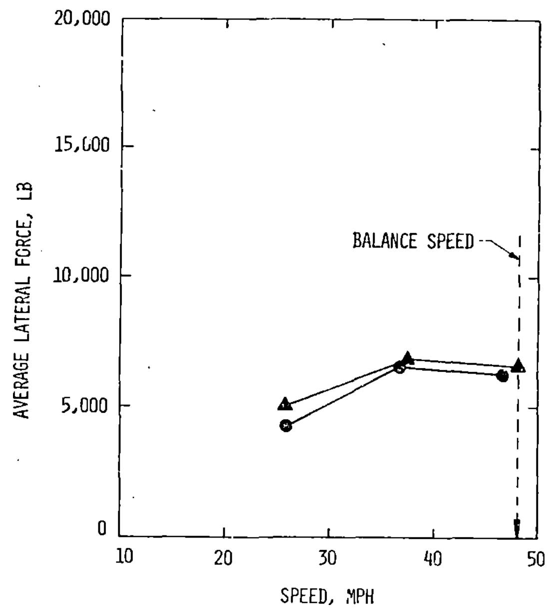


FIGURE 5.3.3-78 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/RIGID TRUCKS/LOADED HOPPER CARS

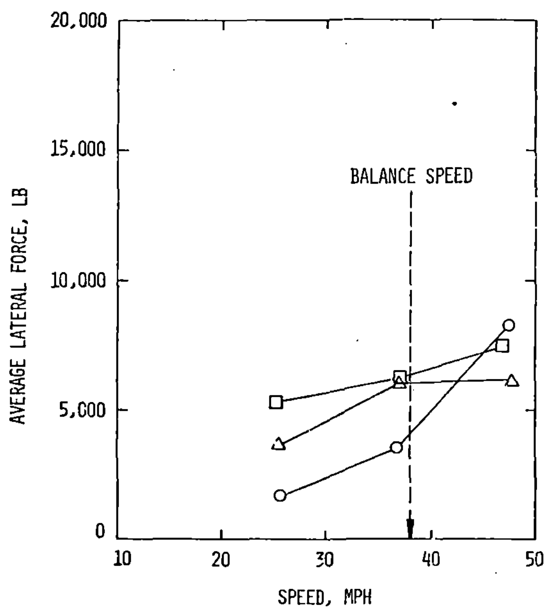


FIGURE 5.3.3-79 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/RADIAL TRUCKS/LOADED HOPPER CARS

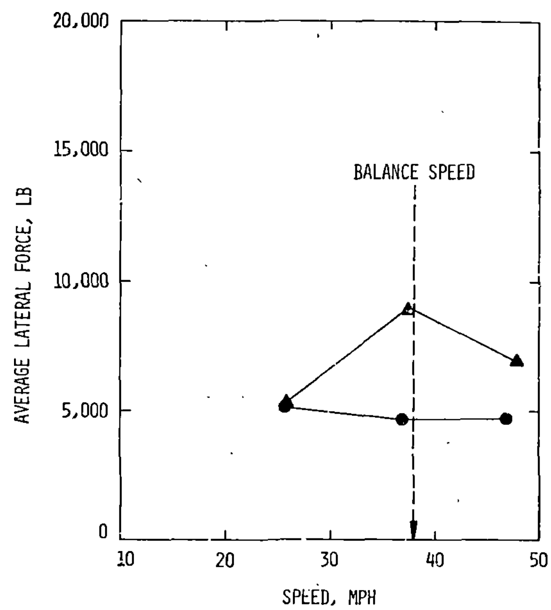


FIGURE 5.3.3-80 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/RIGID TRUCKS/LOADED HOPPER CARS

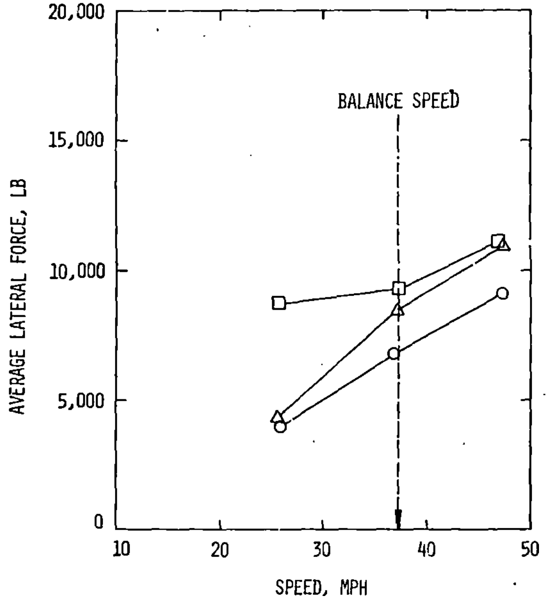


FIGURE 5.3.3-83 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE - RADIAL TRUCKS/LOADED HOPPER CARS

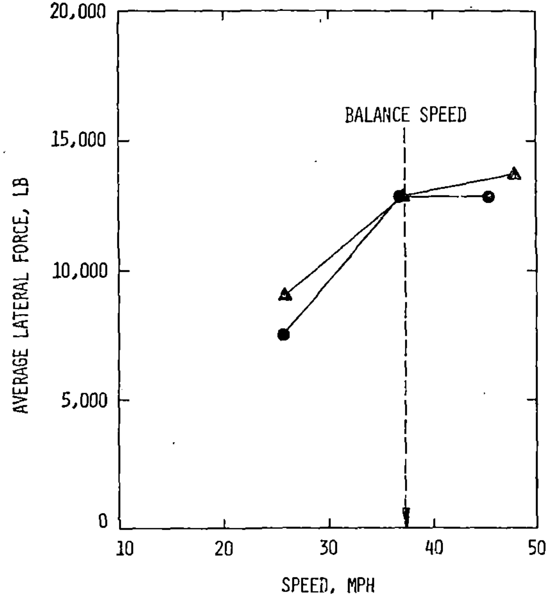


FIGURE 5.3.3-84 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/RIGID TRUCKS/LOADED HOPPER CARS

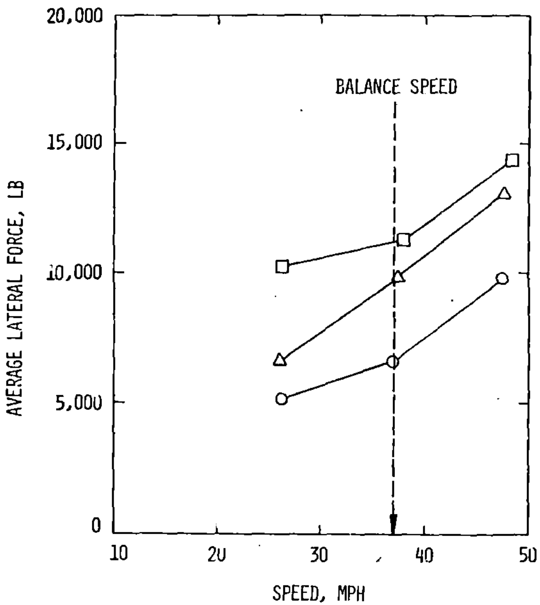


FIGURE 5.3.3-81 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/RADIAL TRUCKS/LOADED HOPPER CARS

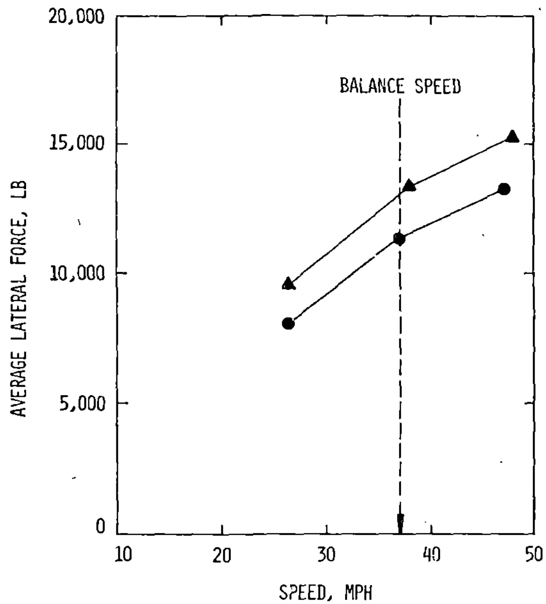


FIGURE 5.3.3-82 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/RIGID TRUCKS/LOADED HOPPER CARS

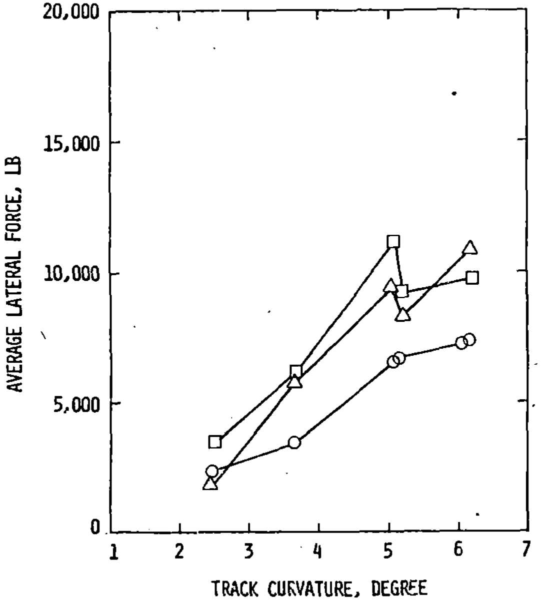


FIGURE 5.3.3-87 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - RADIAL TRUCKS/LOADED HOPPER CARS

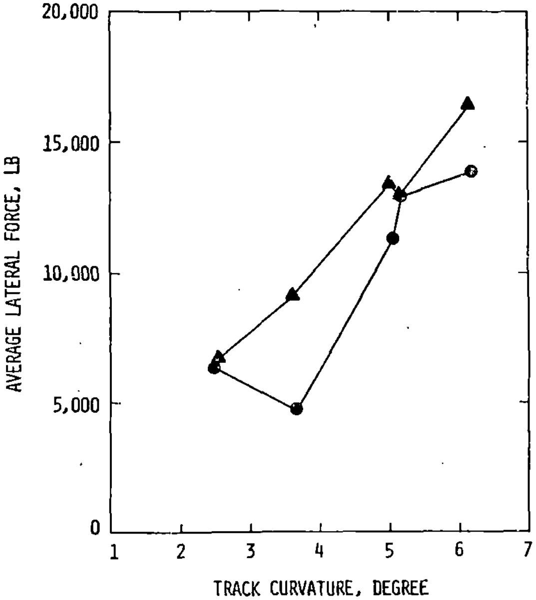


FIGURE 5.3.3-88 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - RIGID TRUCKS/ LOADED HOPPER CARS

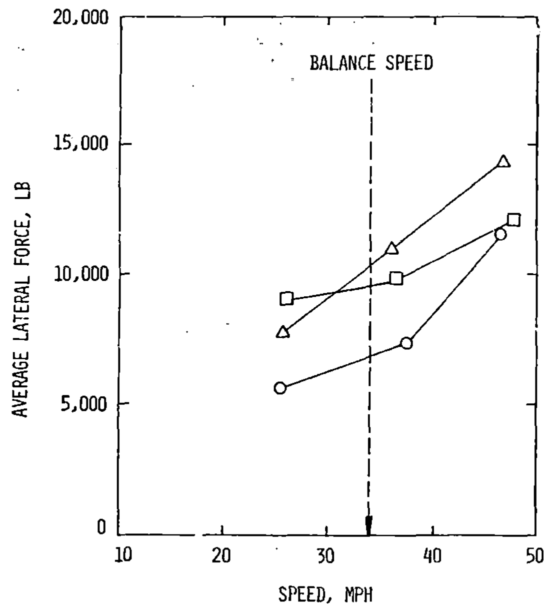


FIGURE 5.3.3-85 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/RADIAL TRUCKS/LOADED HOPPER CARS

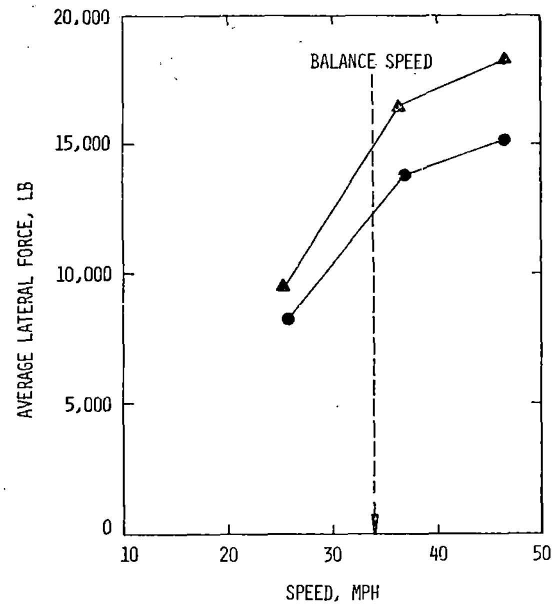


FIGURE 5.3.3-86 LATERAL FORCE ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/RIGID TRUCKS/LOADED HOPPER CARS

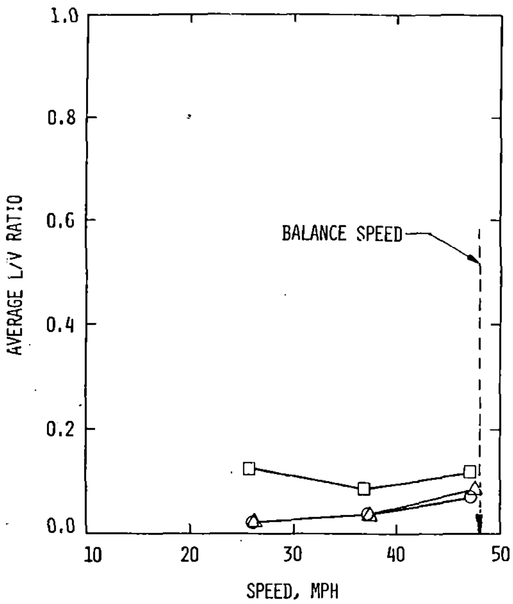


FIGURE 5.3.3-89 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/RADIAL TRUCKS/ LOADED HOPPER CARS

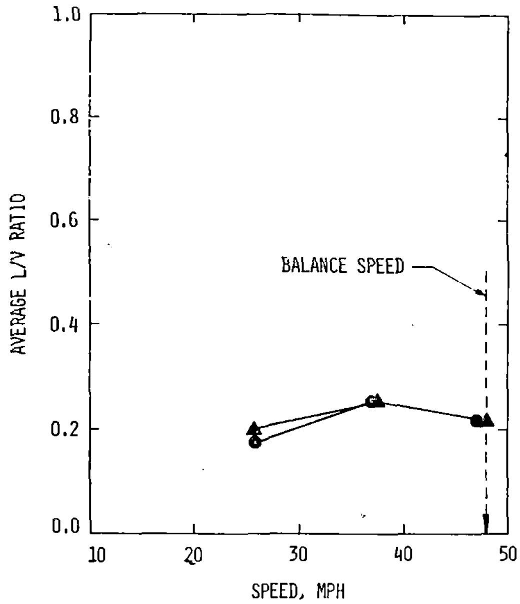


FIGURE 5.3.3-90 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 2.5° CURVE/RIGID TRUCKS/ LOADED HOPPER CARS

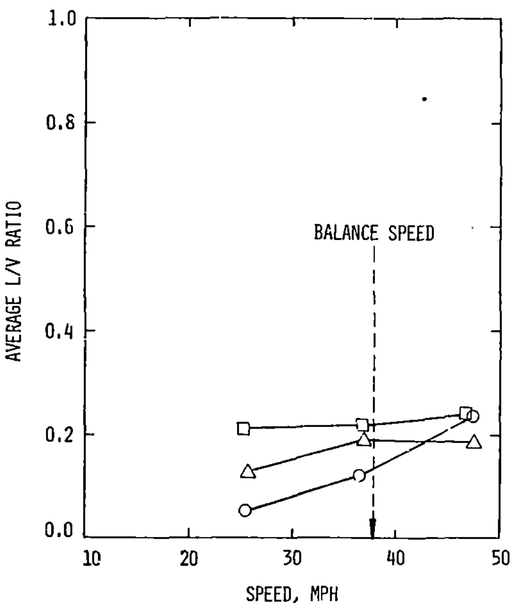


FIGURE 5.3.3-91 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/RADIAL TRUCKS/ LOADED HOPPER CARS

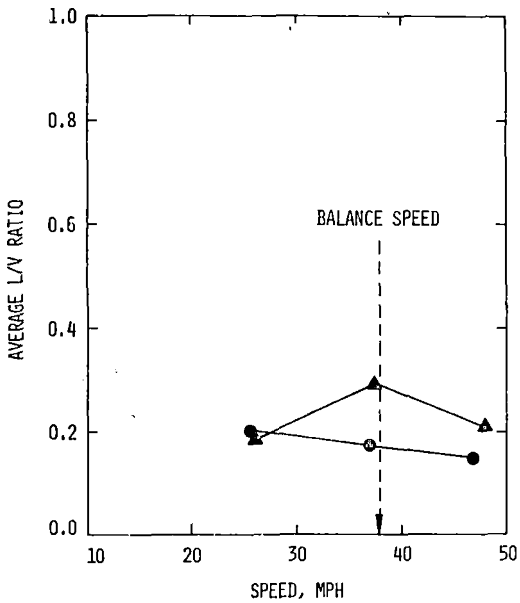


FIGURE 5.3.3-92 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 3.7° CURVE/RIGID TRUCKS/ LOADED HOPPER CARS

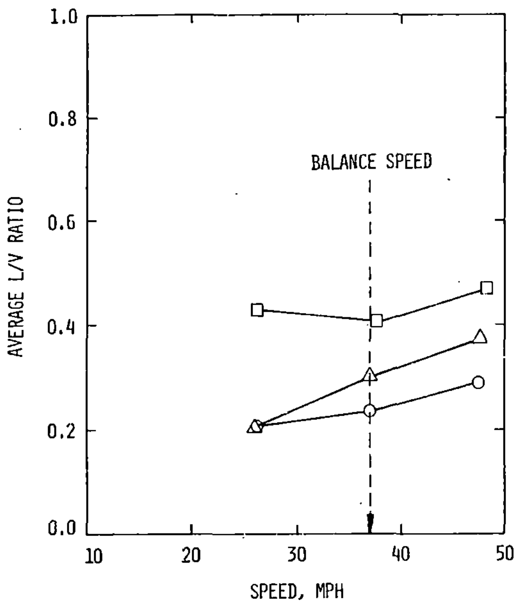


FIGURE 5.3.3-93 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/RADIAL TRUCKS/ LOADED HOPPER CARS

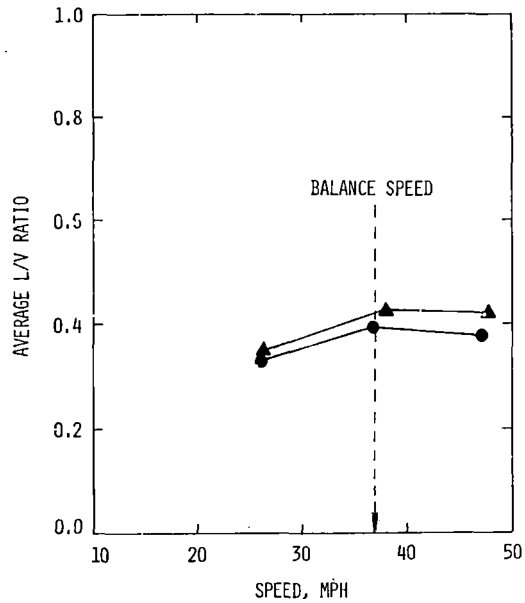


FIGURE 5.3.3-94 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.1° CURVE/RIGID TRUCKS/ LOADED HOPPER CARS

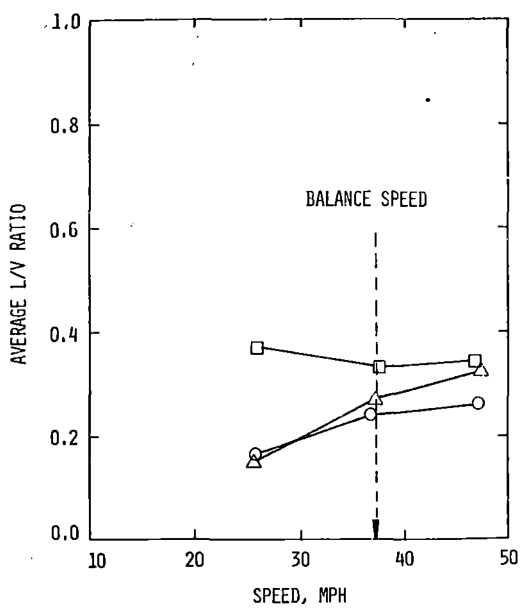


FIGURE 5.3.3-95 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/RADIAL TRUCKS/ LOADED HOPPER CARS

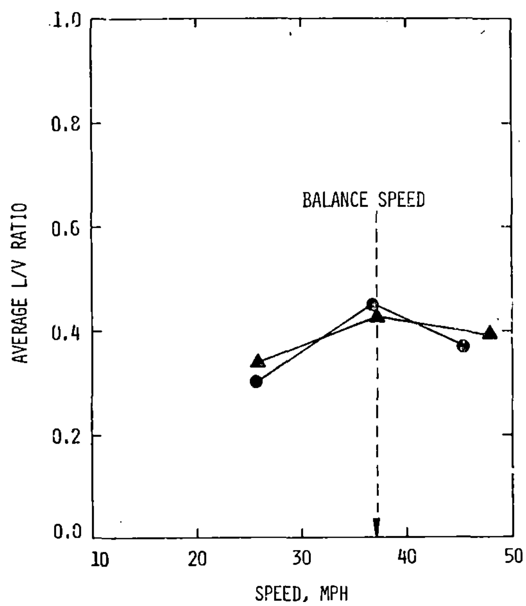


FIGURE 5.3.3-96 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 5.2° CURVE/RIGID TRUCKS/ LOADED HOPPER CARS

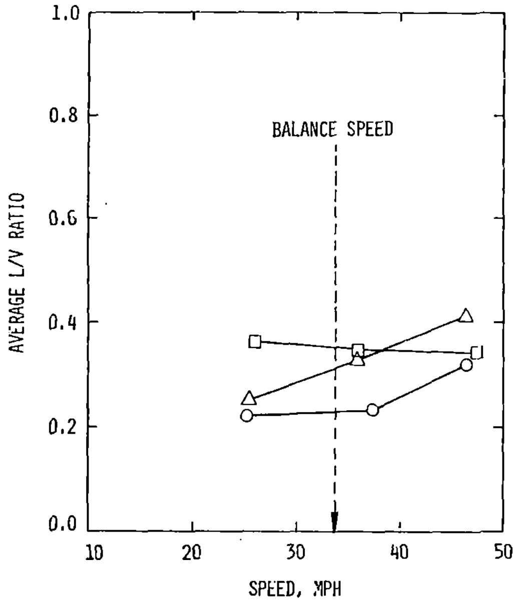


FIGURE 5.3.3-97 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/RADIAL TRUCKS/ LOADED HOPPER CARS

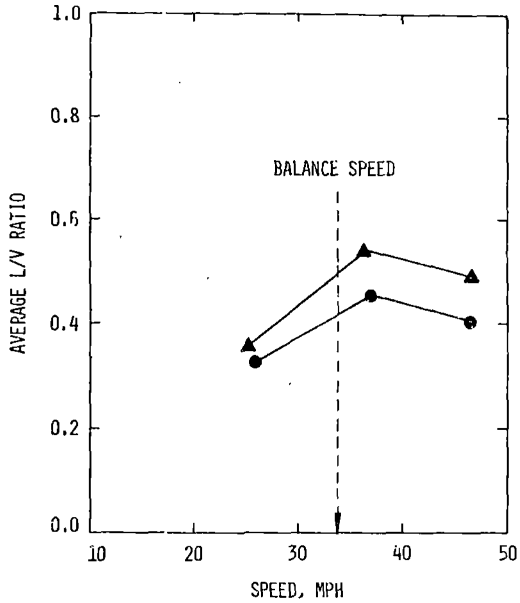


FIGURE 5.3.3-98 L/V RATIO ON LEADING OUTER WHEEL VERSUS SPEED - 6.2° CURVE/RIGID TRUCKS/ LOADED HOPPER CARS

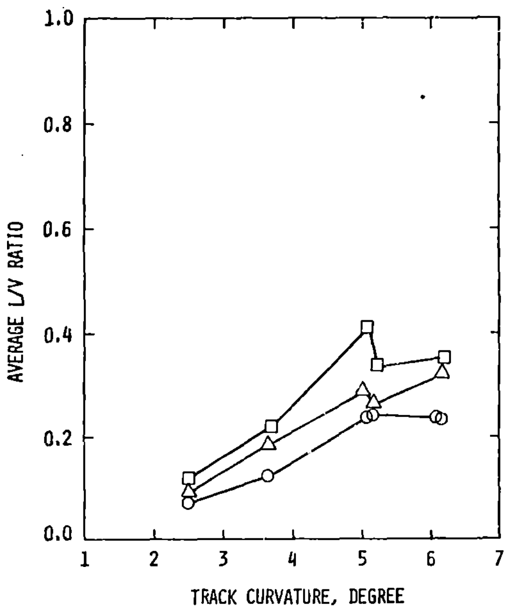


FIGURE 5.3.3-99 L/V RATIO ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES - RADIAL TRUCKS/ LOADED HOPPER CARS

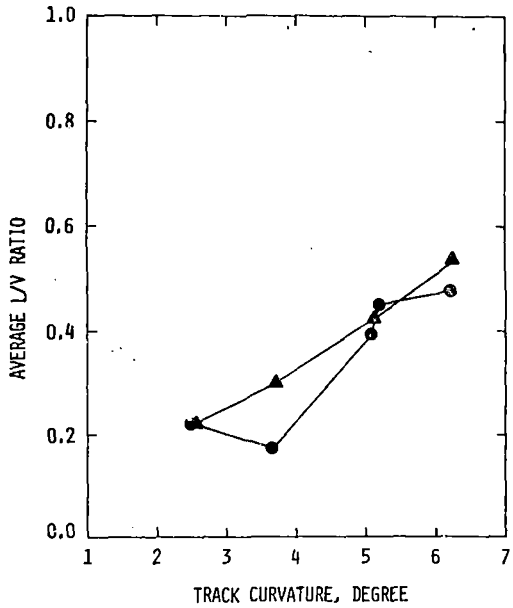


FIGURE 5.3.3-100 L/V RATIO ON LEADING OUTER WHEEL VERSUS DEGREE OF CURVATURE/NEAR BALANCE SPEED - LEFT HAND CURVES - RIGID TRUCKS/LOADED HOPPER CARS

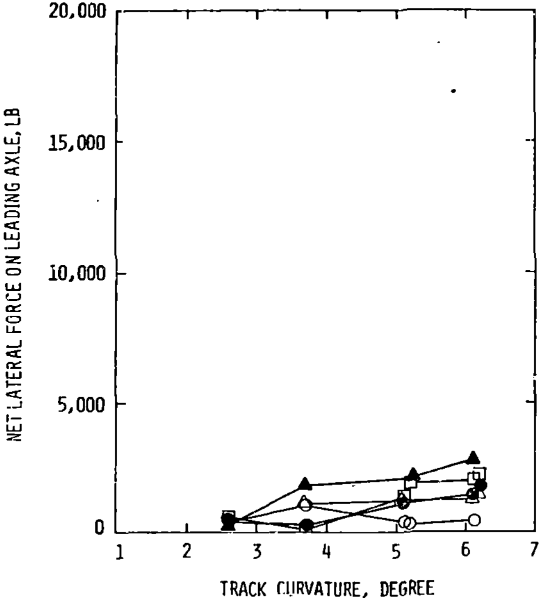


FIGURE 5.3.3-103 AVERAGE NET LATERAL FORCE ON LEADING AXLE VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES/ EMPTY HOPPER CARS

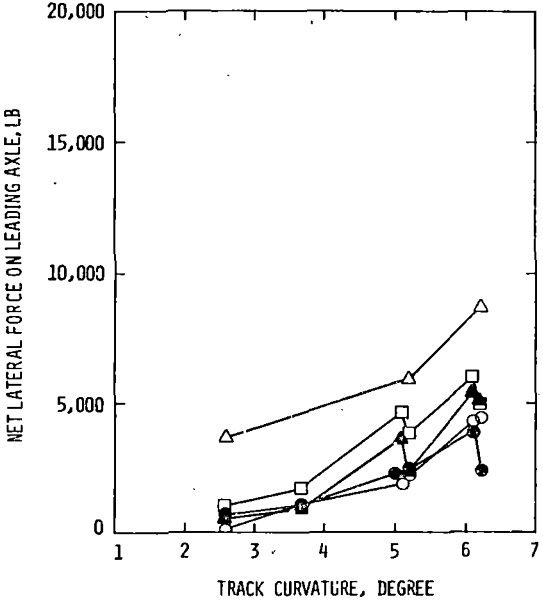


FIGURE 5.3.3-104 AVERAGE NET LATERAL FORCE ON LEADING AXLE VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LEFT HAND CURVES/ LOADED HOPPER CARS

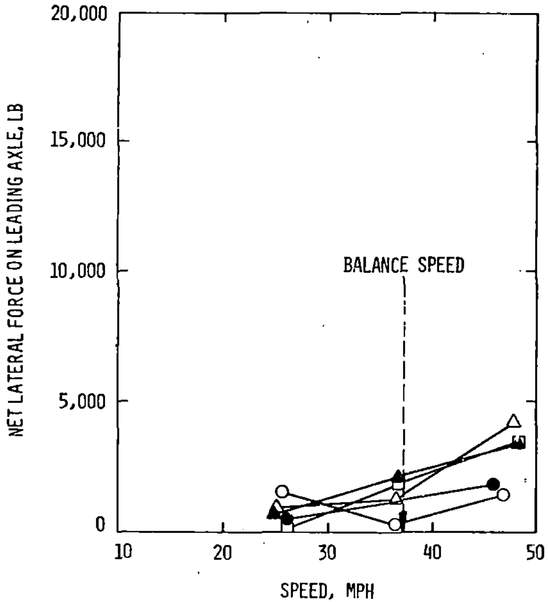


FIGURE 5.3.3-101 AVERAGE NET LATERAL FORCE ON LEADING AXLE VERSUS SPEED - 5.2^{o} CURVE, EMPTY HOPPER CARS

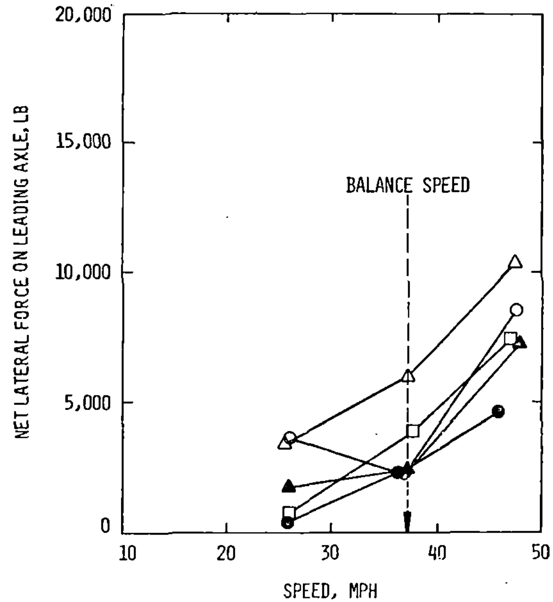


FIGURE 5.3.3-102 AVERAGE NET LATERAL FORCE ON LEADING AXLE VERSUS SPEED - 5.2^{o} CURVE, LOADED HOPPER CARS

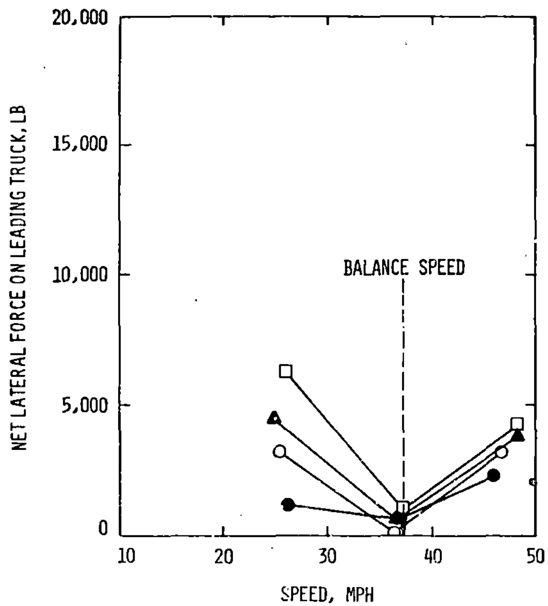


FIGURE 5.3.3-105 AVERAGE NET LATERAL FORCE ON LEADING TRUCKS VERSUS SPEED - 5.2° CURVE/ EMPTY HOPPER CARS

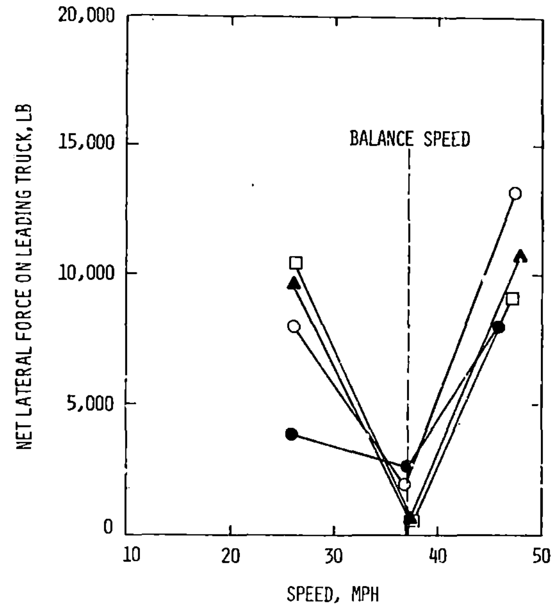


FIGURE 5.3.3-106 AVERAGE NET LATERAL FORCE ON LEADING TRUCKS VERSUS SPEED - 5.2° CURVE/ LOADED HOPPER CARS

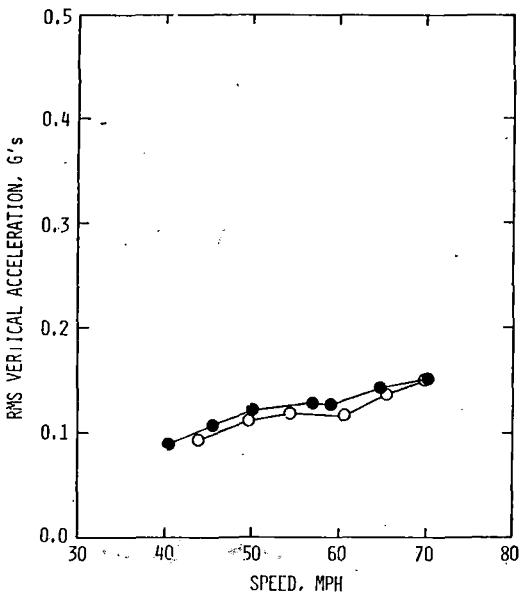


FIGURE 5.3.4-1 RMS VERTICAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/PRIMARY SUSPENSION TRUCKS

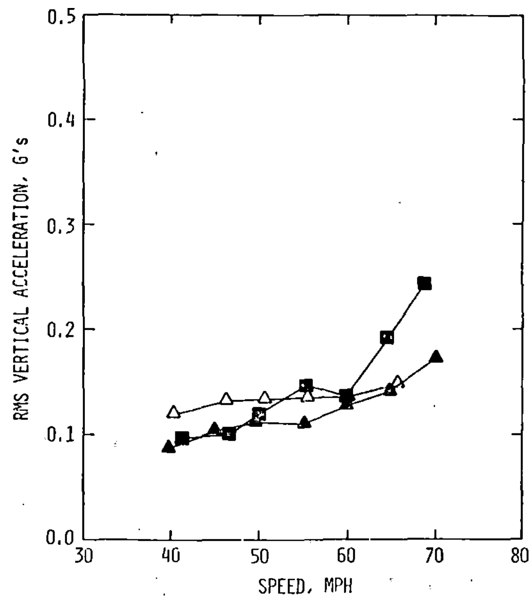


FIGURE 5.3.4-2 RMS VERTICAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/SECONDARY SUSPENSION TRUCKS

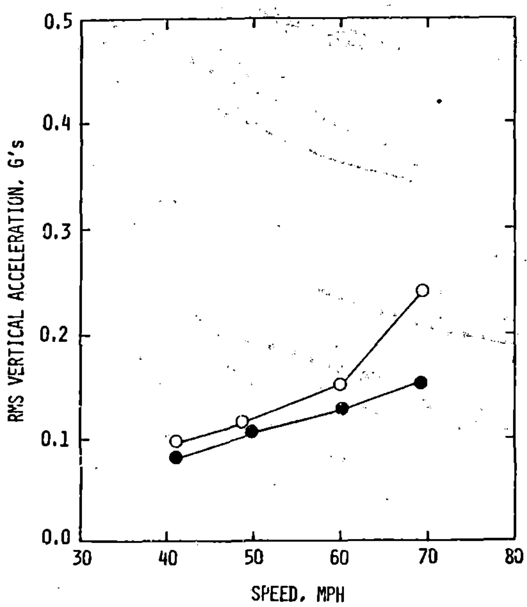


FIGURE 5.3.4-3 RMS VERTICAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/PRIMARY SUSPENSION TRUCKS

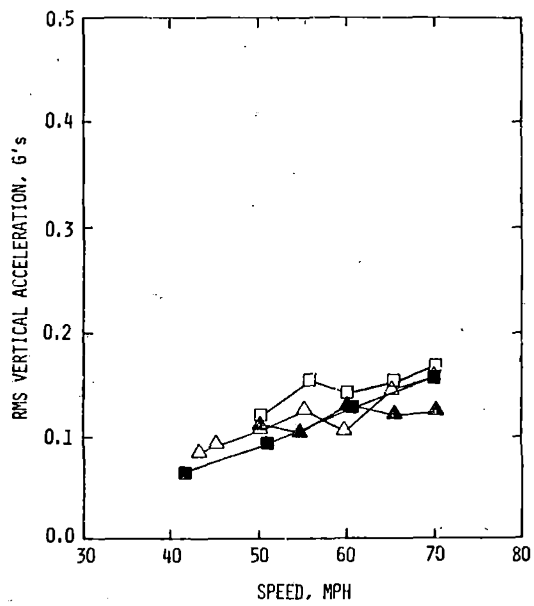


FIGURE 5.3.4-4 RMS VERTICAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/SECONDARY SUSPENSION TRUCKS

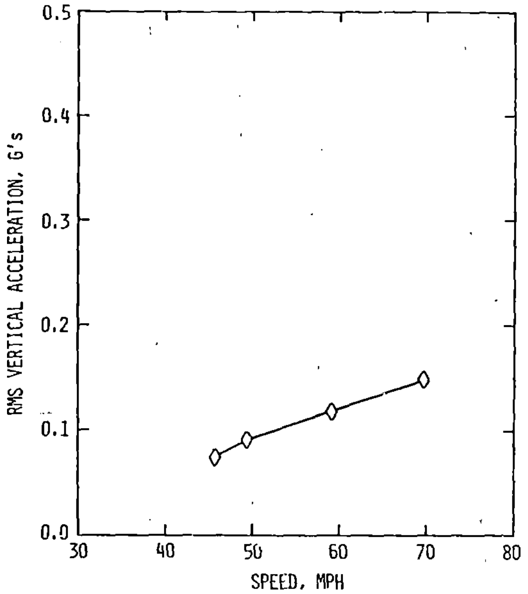


FIGURE 5.3.4-5 RMS VERTICAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ PRIMARY + SECONDARY SUSPENSION TRUCKS

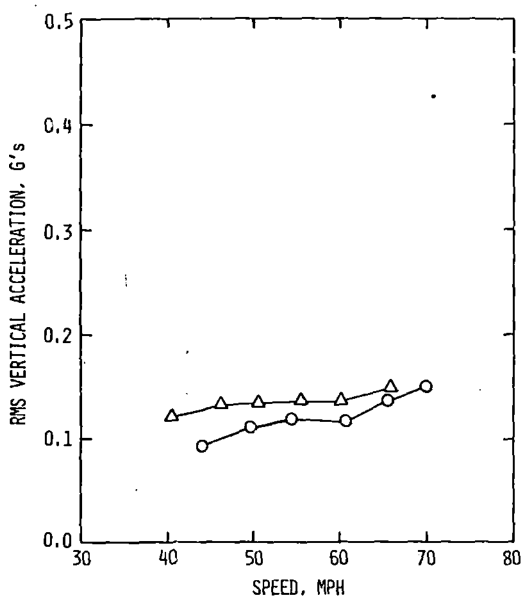


FIGURE 5.3.4-6 RMS VERTICAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/ RADIAL TRUCKS

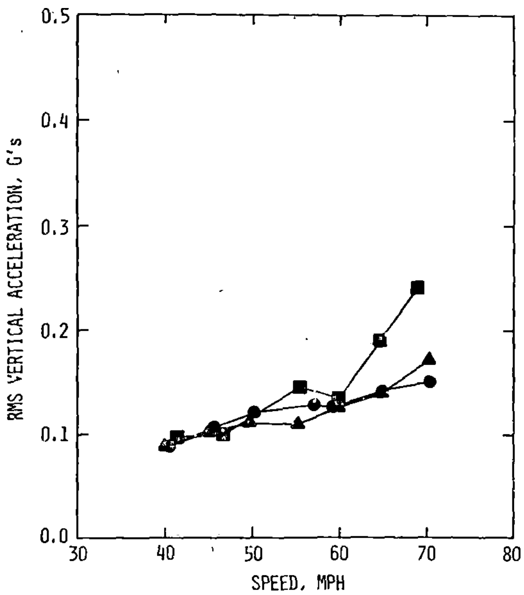


FIGURE 5.3.4-7 RMS VERTICAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/ RIGID TRUCKS

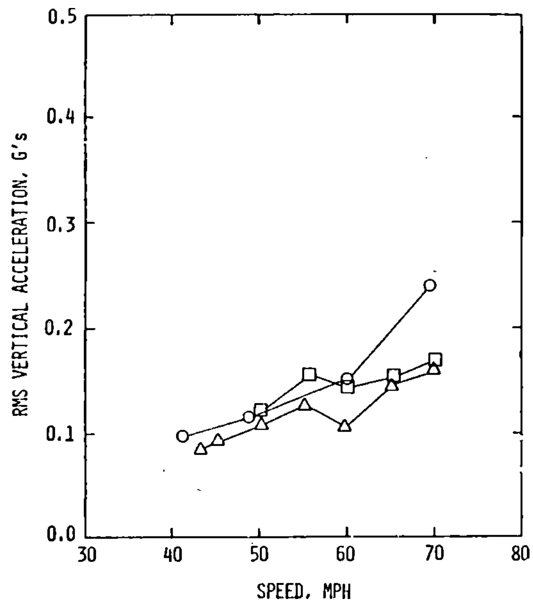


FIGURE 5.3.4-8 RMS VERTICAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ RADIAL TRUCKS

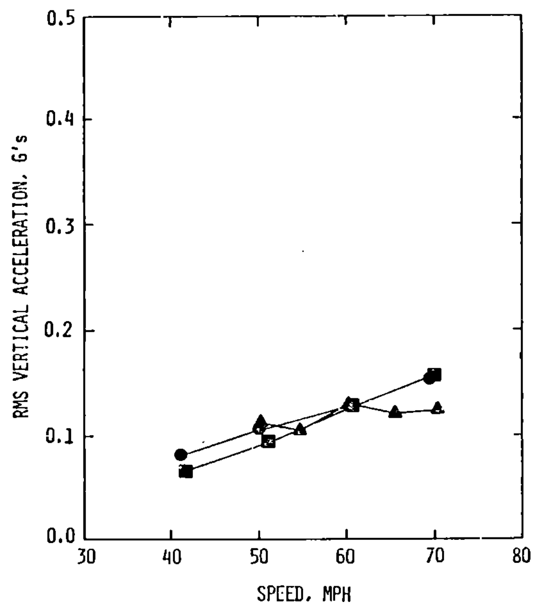


FIGURE 5.3.4-9 RMS VERTICAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ RIGID TRUCKS

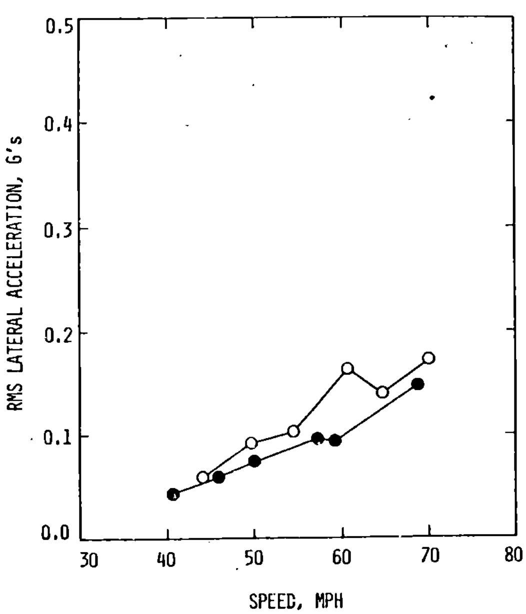


FIGURE 5.3.4-10 RMS LATERAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/ PRIMARY SUSPENSION TRUCKS

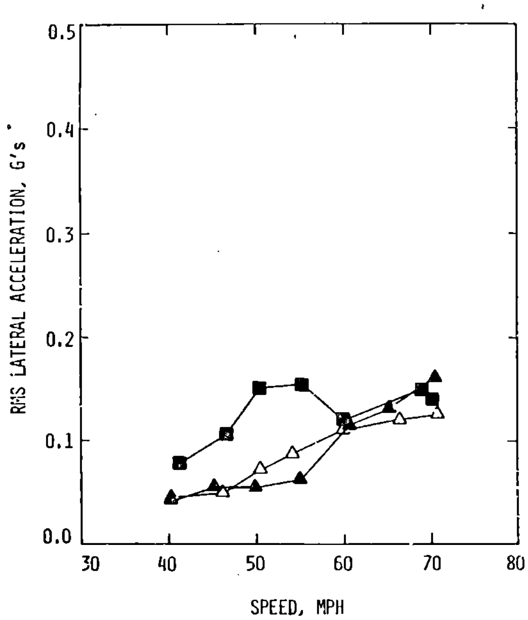


FIGURE 5.3.4-11 RMS LATERAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/ SECONDARY SUSPENSION TRUCKS

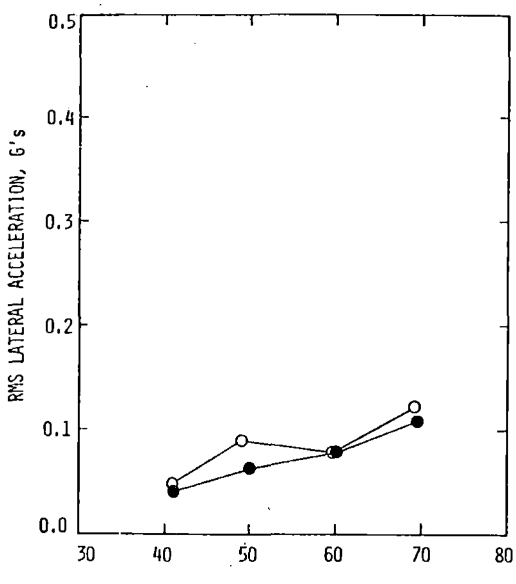


FIGURE 5.3.4-12 RMS LATERAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ PRIMARY SUSPENSION TRUCKS

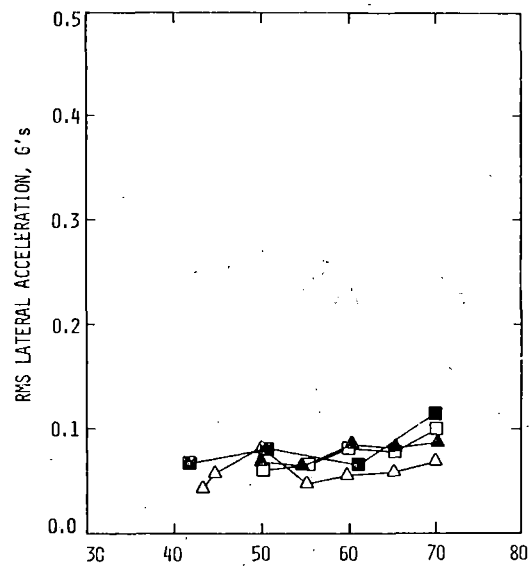


FIGURE 5.3.4-13 RMS LATERAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ SECONDARY SUSPENSION TRUCKS

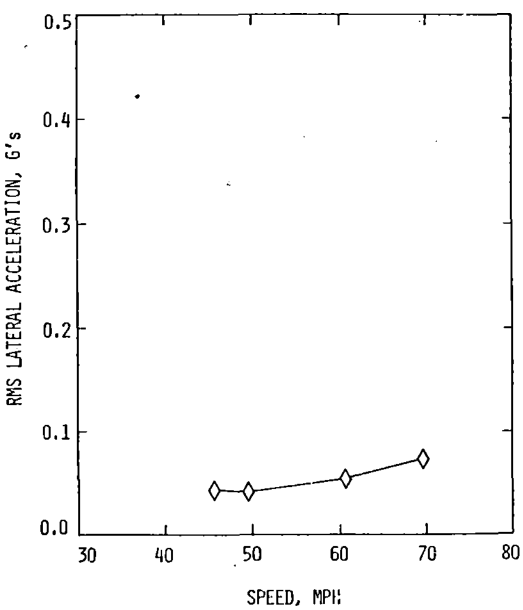


FIGURE 5.3.4-14 RMS LATERAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ PRIMARY + SECONDARY SUSPENSION TRUCKS

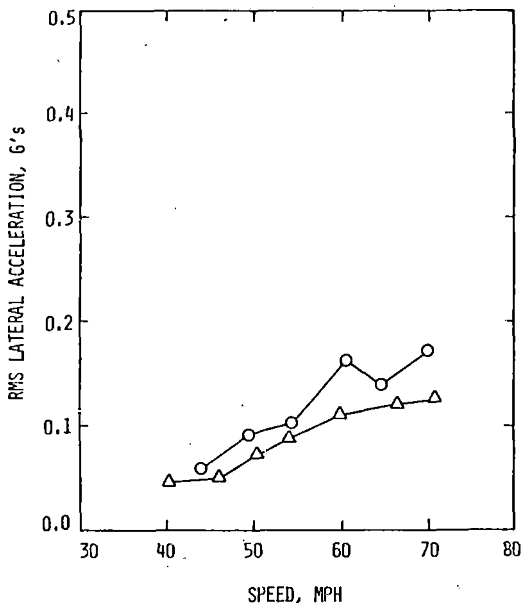


FIGURE 5.3.4-15 RMS LATERAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/ RADIAL TRUCKS

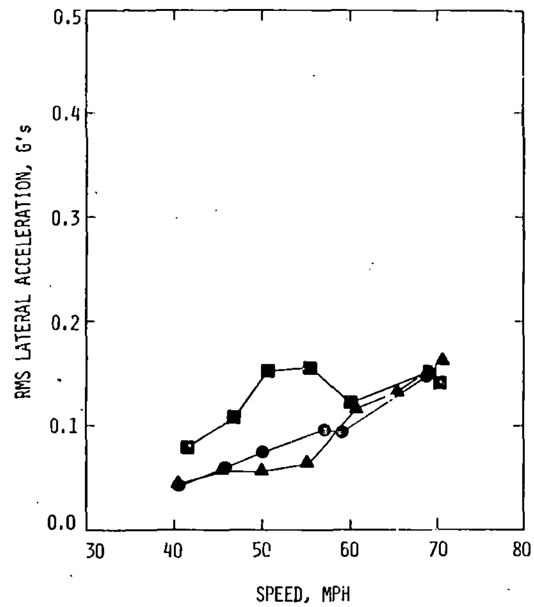


FIGURE 5.3.4-16 RMS LATERAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/ RIGID TRUCKS

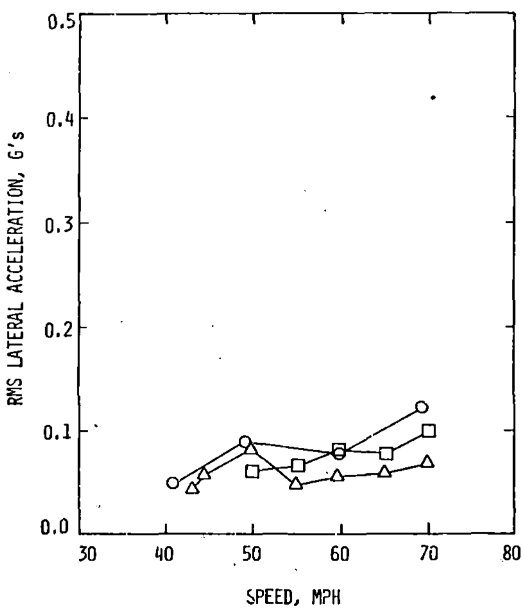


FIGURE 5.3.4-17 RMS LATERAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ RADIAL TRUCKS

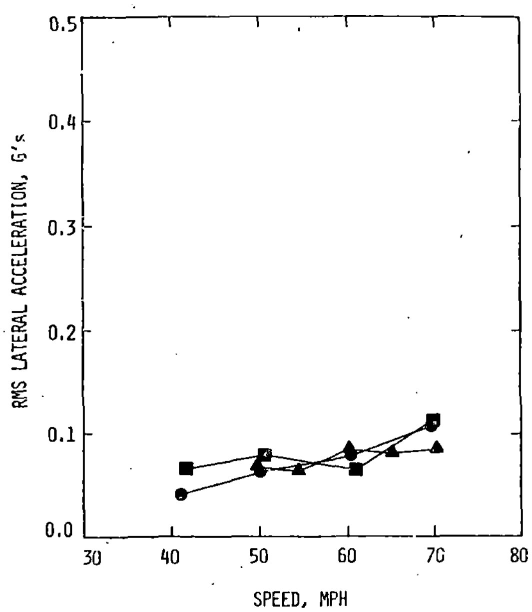


FIGURE 5.3.4-18 RMS LATERAL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ RIGID TRUCKS

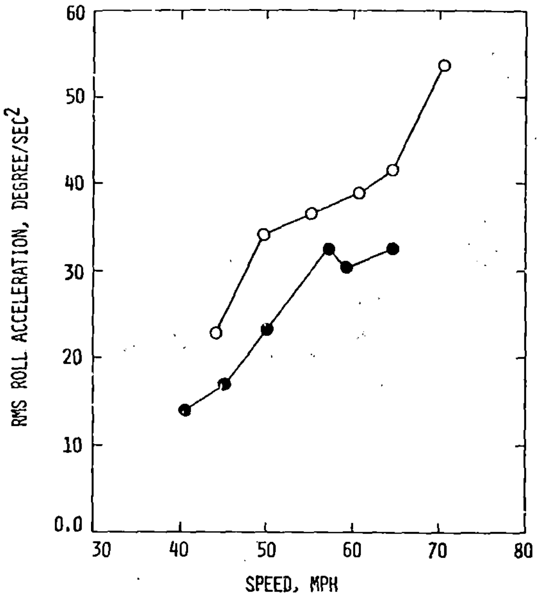


FIGURE 5.3.4-19 RMS ROLL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/ PRIMARY SUSPENSION TRUCKS

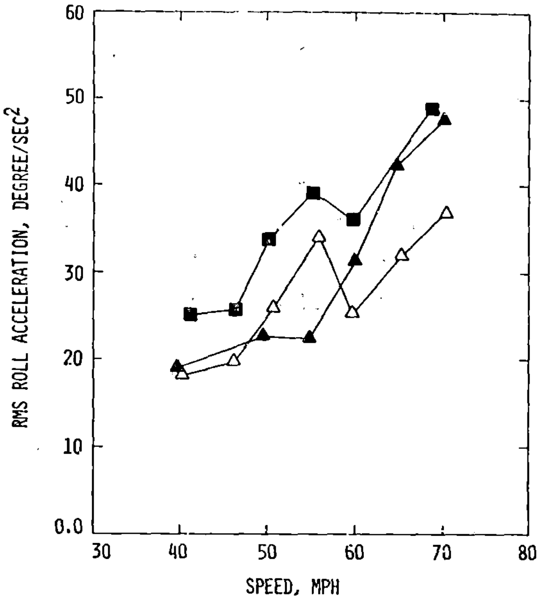


FIGURE 5.3.4-20 RMS ROLL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/ SECONDARY SUSPENSION TRUCKS

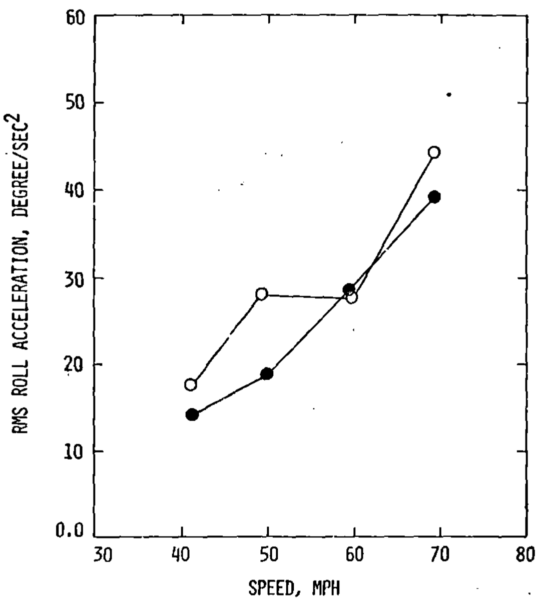


FIGURE 5.3.4-21 RMS ROLL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ PRIMARY SUSPENSION TRUCKS

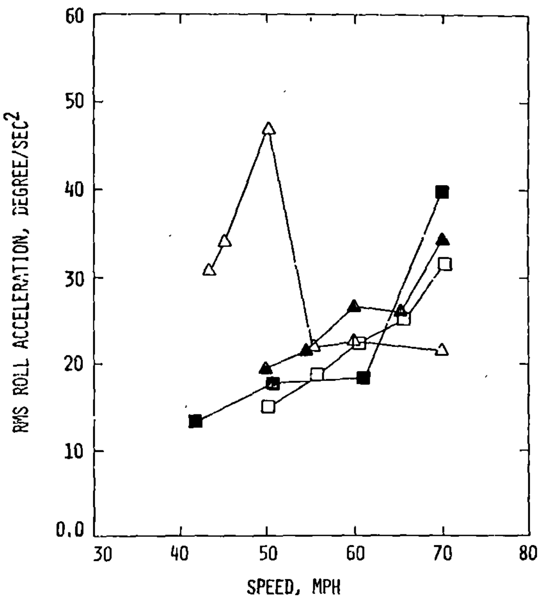


FIGURE 5.3.4-22 RMS ROLL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ SECONDARY SUSPENSION TRUCKS

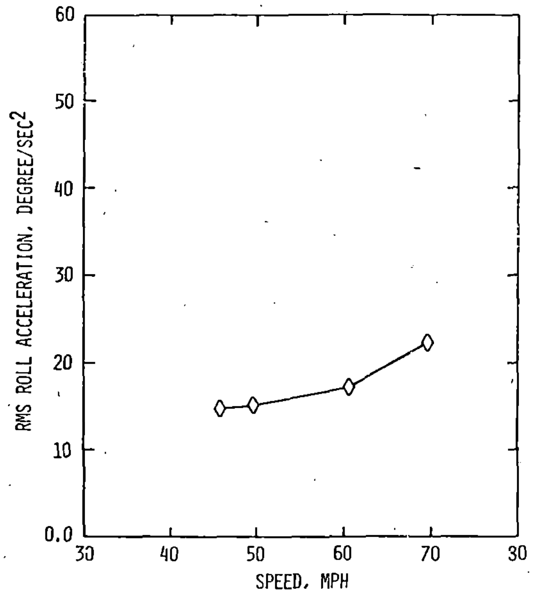


FIGURE 5.3.4-23 RMS ROLL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ PRIMARY + SECONDARY SUSPENSION TRUCKS

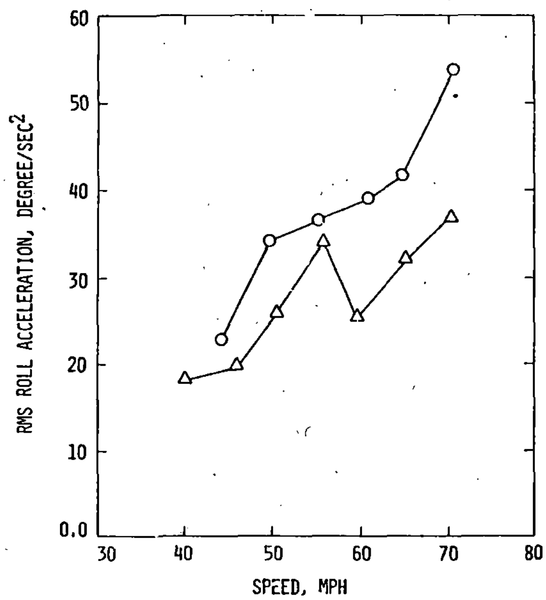


FIGURE 5.3.4-24 RMS ROLL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/ RADIAL TRUCKS

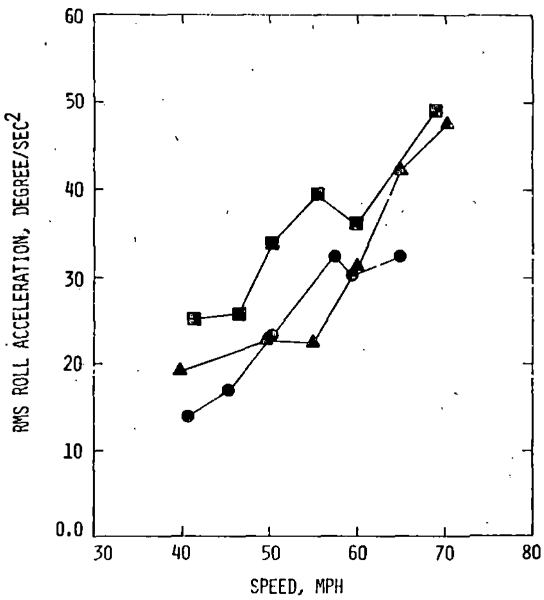


FIGURE 5.3.4-25 RMS ROLL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/EMPTY CARS/ RIGID TRUCKS

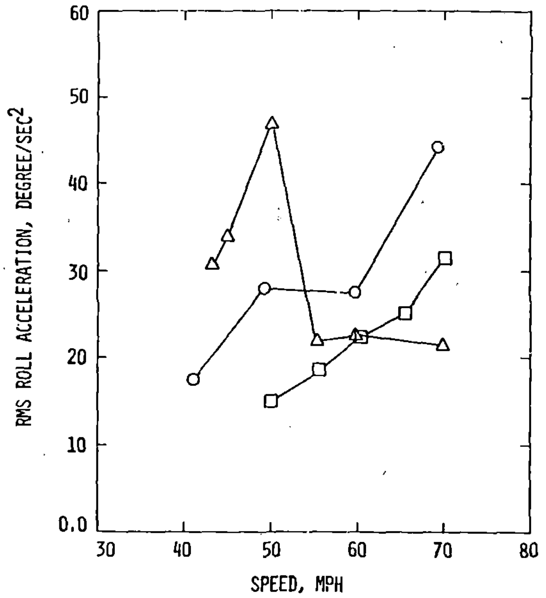


FIGURE 5.3.4-26 RMS ROLL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ RADIAL TRUCKS

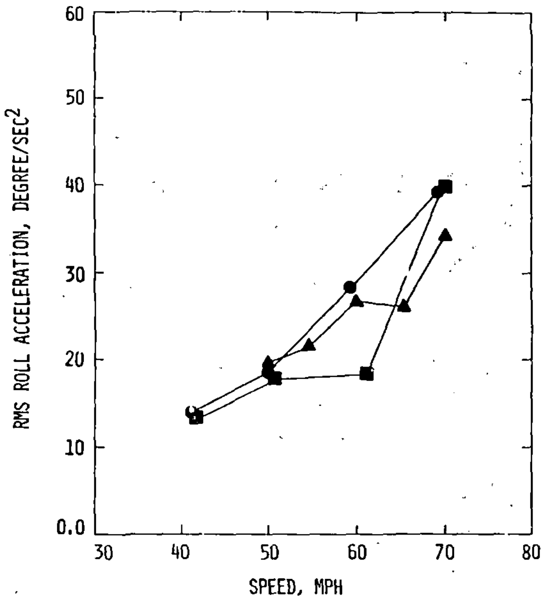


FIGURE 5.3.4-27 RMS ROLL ACCELERATION VERSUS SPEED - 0-20 HZ FREQUENCY BAND/LOADED CARS/ RIGID TRUCKS

SECTION 6 - PERFORMANCE SPECIFICATIONS

A principal objective of the Truck Design Optmization Project has been the development of a set of performance specifications which the premium design freight car trucks shall be expected to meet. The performance characterization of Type II trucks derived from the field test and analytic efforts during TDOP/Phase II provided the basis for such a set of specifications. However, since the test program was limited in its extent in terms of the test variable parameters, and also since much data on the effects of component degradation in service remain to be acquired, the performance specifications provided in this document should be considered preliminary in nature. As further data and results become available on the performance capabilities of the Type II trucks, these specifications could be expanded and enhanced to evolve into a more comprehensive set of specifications universally applicable to premium freight car trucks under a wider variety of operating conditions and equipment parameters.

6.1 SCOPE

Although it was envisioned that the performance specifications developed on the basis of work performed during the project would be applicable to freight car trucks universally, it is considered essential to keep in perspective the finite frontiers of the effort undertaken during the project when applying the specifications to evaluate freight car trucks. Under conditions comparable to those covered by the project effort, it is indeed believed that the recommended specifications will be applicable. Caution is urged, however, in determining what constitutes a set of comparable conditions for evaluation.

Initially, it was conceived that the development of performance specifications would be on the basis of experimental and analytic investigations of a comprehensive set of freight car truck/carbody configurations that would represent commercially available vehicle systems on the market. Furthermore, the analytic investigations were to be conducted using available analytic tools subject to validation during the project. For various reasons, both technical and economical, compromises had to be made in the course of the project resulting in limitations of these investigations which are reflected in the results.

The recommended performance specifications are organized by performance regimes. In each regime, the parametric conditions associated with the recommended guidelines on quantitative performance are outlined. In using the performance specifications, it is advisable to relate them to these parametric conditions to ensure that application of the specifications are to conditions equivalent to, or at least comparable to, the conditions listed.

6.2 DEVELOPMENT OF PERFORMANCE SPECIFICATIONS

The basis on which the performance specifications were developed was the performance field test data acquired from field tests conducted during TDOP Phase II. The field test data were analyzed in each of the performance regimes to yield quantitative measures of performance represented by performance indices. The validity of specific details or trends within each regime was corroborated through physical reasoning, comparison with conventional wisdom in railroad literature, and, whenever possible, through the use of test data from other sources.

Extreme behavior of individual trucks, attributable to specific considerations relatable either to hardware conditions or to test conditions, were excluded from the recommended specifications. Such exclusions were made after careful and deliberate engineering evaluations of associated conditions and also after comparative studies with published results. Nevertheless, they do constitute engineering judgment and contain an element of subjective evaluation.

In the interest of coordinating the results with the industry, the recommended guideline performance specifications were discussed with industry representatives at the TDOP Consultants' meetings. Final results were subjected to review by industry and government representatives and comments derived from this review process were accounted for in the final specifications presented in this section.

6.3 RECOMMENDED QUANTITATIVE LEVELS OF PERFORMANCE

This section presents the quantitative levels of performance that may be expected of the Type II freight car trucks in each of the performance regimes under the applicable conditions.

6.3.1 Lateral Stability Performance Specifications

Parametric conditions associated with the guideline performance specifications in this regime are:

Equipment Carbodies:	-	100-ton open hopper car (with 100-ton Type II trucks)
	-	70-ton open hopper car (with 70-ton Type II trucks)
Wheel Profiles:	-	CN profile (new) (with 100-ton Type II trucks)
	-	AAR Std. 1:20 Taper profile (new) (with 70-ton Type II trucks)
Track High Speed Tangent Track:		Class 4, Mainline, BJR
Operating Conditions Speed:		40 to 79 mph
Lading:		Carbodies in empty and fully loaded conditions

Recommended performance specifications are given in Figures 6.3.1-1 through 6.3.1-4. The given bands of performance levels indicate values that may be reasonably expected to be obtained under the nominal operating conditions and associated reasonable variations. The upper bounds on the bands of quantitative performance levels constitute limiting values on the corresponding parameters.

6.3.2 Trackability Performance Specifications

Parametric conditions associated with the guideline performance specifications in the subregime of track twist are:

Equipment

Carbodies: 100-ton open hopper car

Wheel Profiles: CN Profile (new)

Track: Yard, BJR, 16° curve (-0.26 inch superelevation)

Operating Conditions

Speed: 10 mph

Lading: Carbodies in empty and fully loaded conditions

Recommended performance specifications are given in Table 6.3.2-1.

TABLE 6.3.2-1. WUI_{95} LEVELS FOR TYPE II FREIGHT CAR TRUCKS

Performance Index	Empty Cars	Loaded Cars
Wheel Unloading Index (95% level)	0.30 - 0.55	0.28 - 0.37

Note: 95% level denotes that the given values shall not be exceeded in more than 5% of the time.

Parametric conditions associated with the guideline performance specifications in the subregime of curve entry/exit are:

Equipment

Carbodies: 100-ton open hopper car

Wheel Profiles: CN profile (new)

Track: Class 4, BJR, Curved Track, 1.1° - 6.2°

Operating Conditions

Speed: 25 - 48 mph

Lading: Carbodies in empty and loaded conditions

Recommended performance specifications in the curve entry/exit subregime are given in Figures 6.3.2-1 through 6.3.2-8.

6.3.3 Steady State Curve Negotiation Performance Specifications

Parametric conditions associated with the guideline performance specifications in this regime are:

Equipment

Carbodies: 100-ton open hopper car

Wheel Profiles: CN profile (CN)

Track: Class 4, BJR, Curved Track 1.1° - 6.2°

(See Figure 5.1.3-1 for data pertaining to the curve zone.)

Operating Conditions

Speed: 25 - 48 mph

Lading: Carbodies, in empty and fully loaded conditions

Recommended performance specifications are presented in Figures 6.3.3-1 through 6.3.3-20. Due to the radical differences between the radial and rigid trucks among the Type II freight car trucks in this performance regime, the limiting performance associated with rigid trucks is indicated separately, in addition to the performance level bands associated with the radial trucks. The broken lines, always at a level higher than the performance bands in the figures, represent the upper limits recommended for the rigid trucks. This exception, in separating the two subclasses of trucks among the Type II designs, is considered warranted since better performance on the part of rigid trucks on curved track is not attainable at this time and imposing such demands is not considered reasonable. The bends in the curves representing the rigid trucks' performance occur at the balance speed.

6.3.4 Ride Quality Performance Specifications

Parametric conditions associated with the guideline performance specifications in the regime of ride quality are:

Equipment

Carbodies:
— 100-ton open hopper car (with 100-ton Type II trucks)
— 70-ton open hopper car (with 70-ton Type II trucks)

Wheel Profiles:
— CN profile (new) (with 100-ton Type II trucks)
— AAR Sta. 1:20 Taper profile (new) (with 70-ton Type II trucks)

Track

High Speed Tangent Track: Class 4, Mainline, BJR

(See Appendix B for details on track geometry.)

Operating Conditions

Speed: 40 - 79 mph

Lading: Carbodies in empty and fully loaded conditions

Recommended performance specifications are given in Figures 6.3.4-1 thru 6.3.4-6. The bands of performance levels indicate the values of performance indices likely to be obtained under comparable nominal operating conditions with their associated reasonable levels of variations. The upper boundary of the performance bands represent the limiting levels of performance in each case.

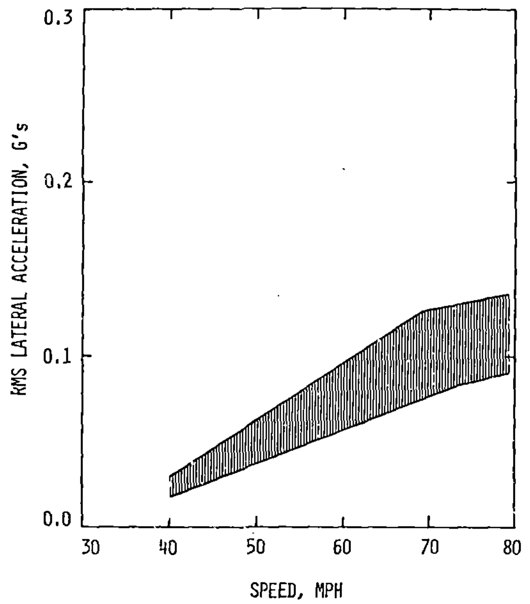


FIGURE 6.3.1-1 RMS LATERAL ACCELERATION LEVELS FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS

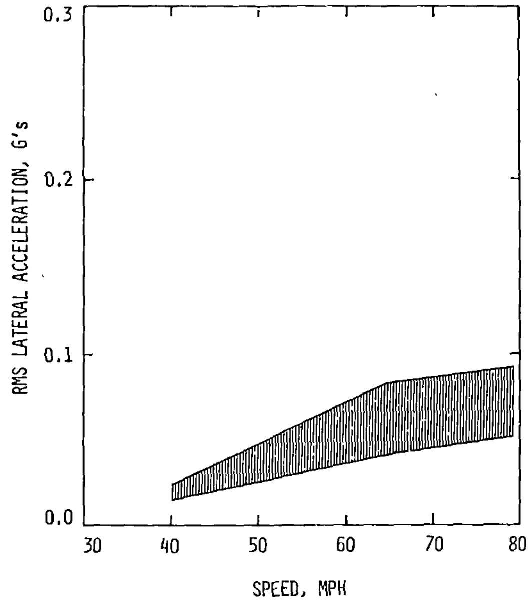


FIGURE 6.3.1-2 RMS LATERAL ACCELERATION LEVELS FOR TYPE II FREIGHT CARS TRUCKS WITH LOADED OPEN HOPPER CARS

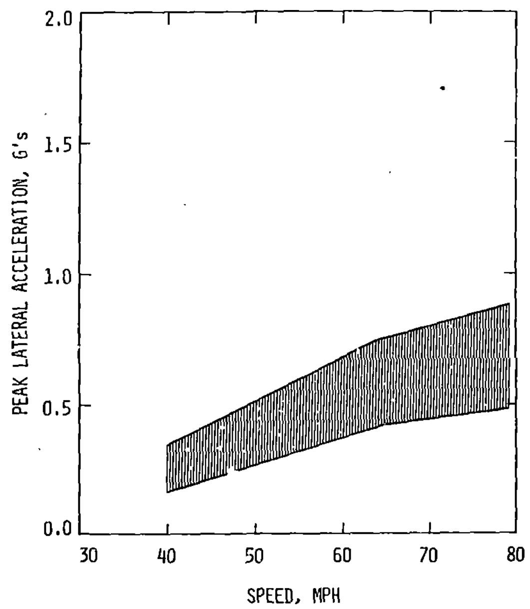


FIGURE 6.3.1-3 PEAK LATERAL ACCELERATION LEVELS FOR TYPE II FREIGHT CARS TRUCKS WITH EMPTY OPEN HOPPER CARS

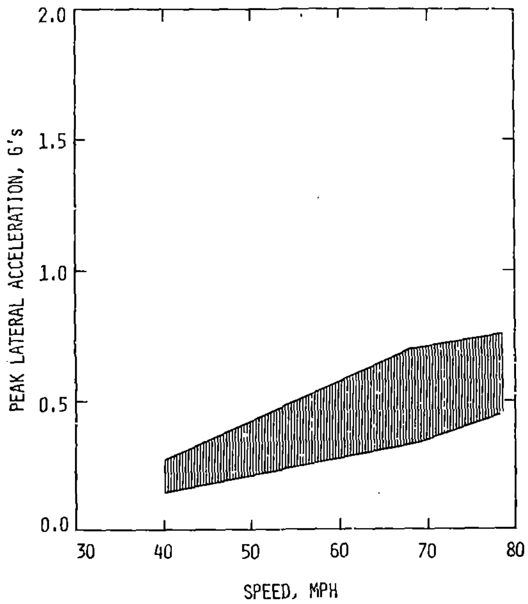


FIGURE 6.3.1-4 PEAK LATERAL ACCELERATION LEVELS FOR TYPE II FREIGHT CARS TRUCKS WITH LOADED OPEN HOPPER CARS

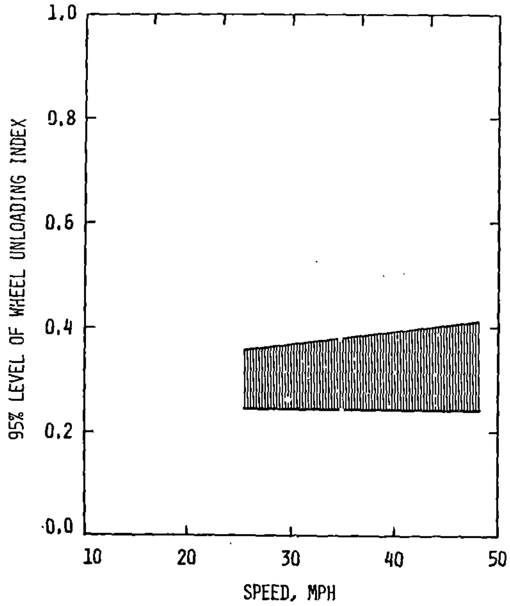


FIGURE 6.3.2-1 WUI_{95} LEVELS FOR TYPE II TRUCKS WITH EMPTY OPEN HOPPER CARS - 2.5° CURVES ENTRY/EXIT

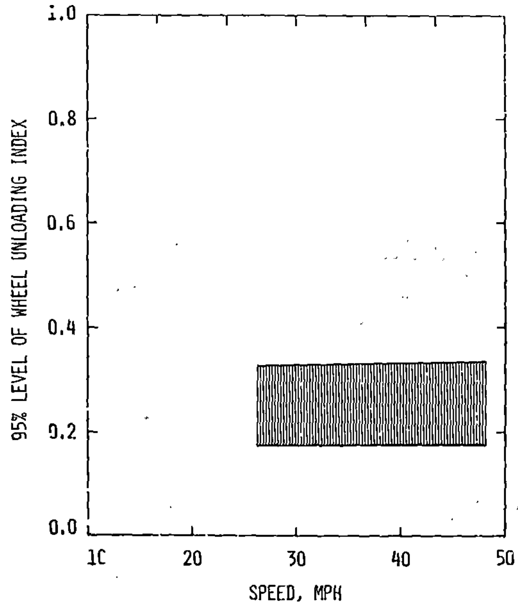


FIGURE 6.3.2-2 WUI_{95} LEVELS FOR TYPE II TRUCKS WITH LOADED OPEN HOPPER CARS - 2.5° CURVES ENTRY/EXIT

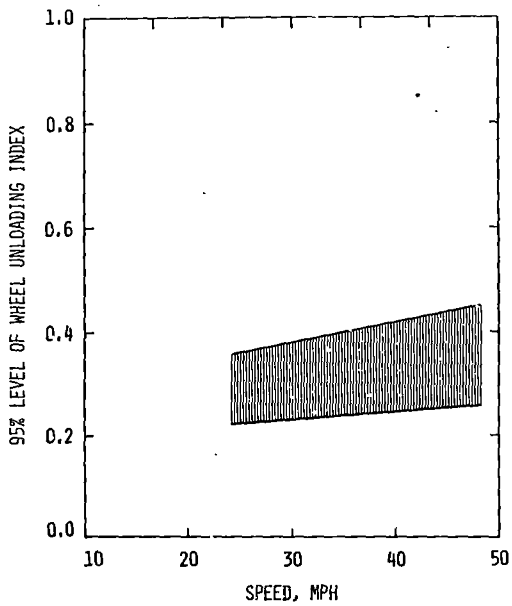


FIGURE 6.3.2-3 WUI_{95} LEVELS FOR TYPE II TRUCKS WITH EMPTY OPEN HOPPER CARS - 3.7° CURVES ENTRY/EXIT

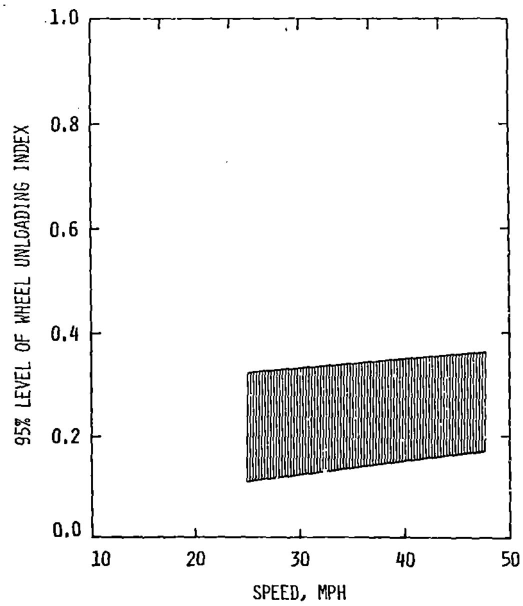


FIGURE 6.3.2-4 WUI_{95} FOR TYPE II TRUCKS WITH LOADED OPEN HOPPER CARS - 3.7° CURVES ENTRY/EXIT

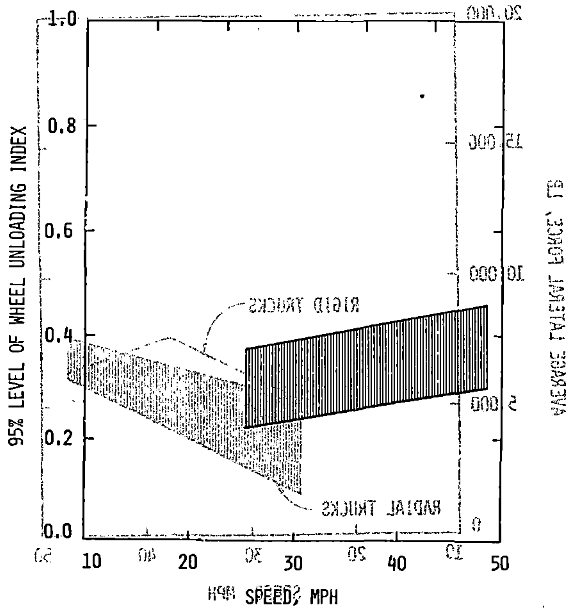


FIGURE 6.3.2-7 WUI_{95} LEVELS FOR TYPE II TRUCKS WITH EMPTY OPEN HOPPER CARS – 6.2° CURVES ENTRY/EXIT

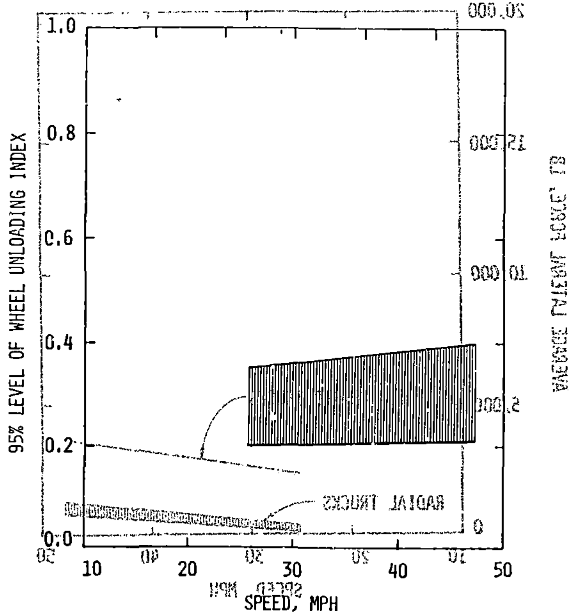


FIGURE 6.3.2-8 WUI_{95} LEVELS FOR TYPE II TRUCKS WITH LOADED OPEN HOPPER CARS – 6.2° CURVES ENTRY/EXIT

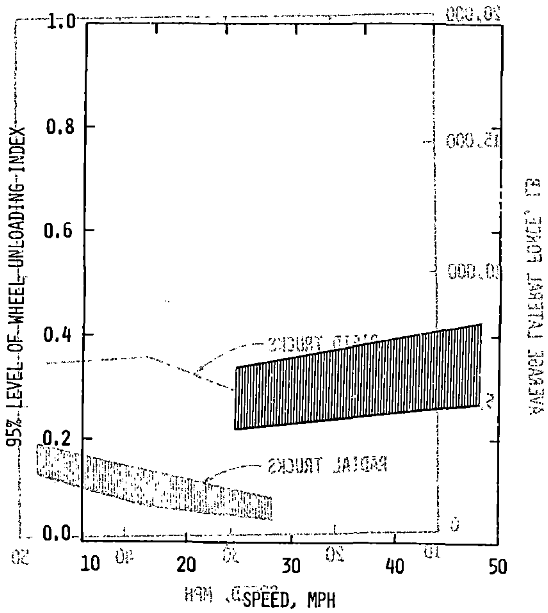


FIGURE 6.3.2-5 WUI_{95} FOR TYPE II TRUCKS WITH EMPTY OPEN HOPPER CARS - 5.2° CURVES ENTRY/EXIT

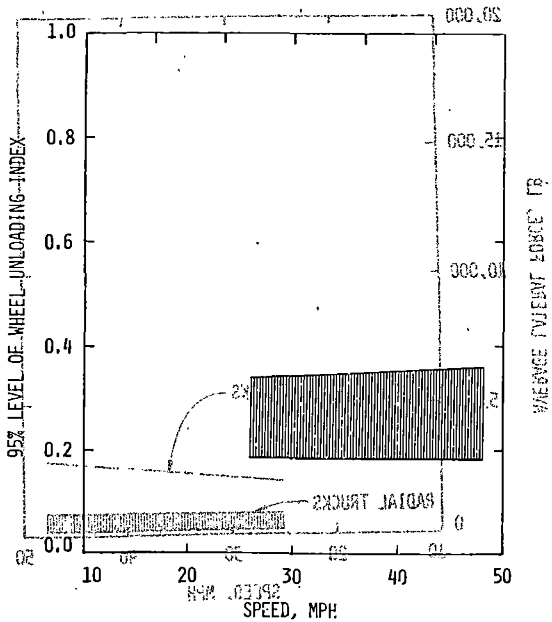


FIGURE 6.3.2-6 WUI_{95} LEVELS FOR TYPE II TRUCKS WITH LOADED OPEN HOPPER CARS - 5.2° CURVES ENTRY/EXIT

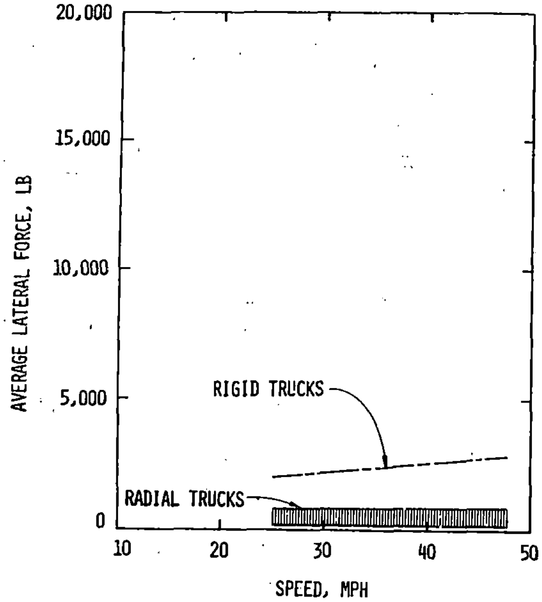


FIGURE 6.3.3-1 LATERAL FORCE ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS - 2.5° CURVES

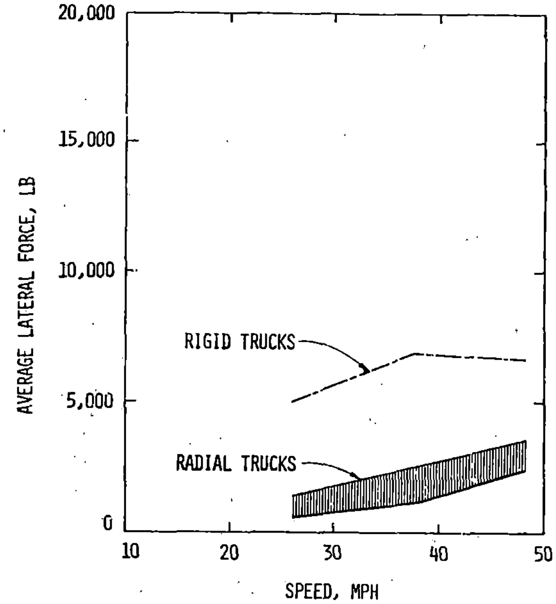


FIGURE 6.3.3-2 LATERAL FORCE ON LEADING OUTFR WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS - 2.5° CURVES

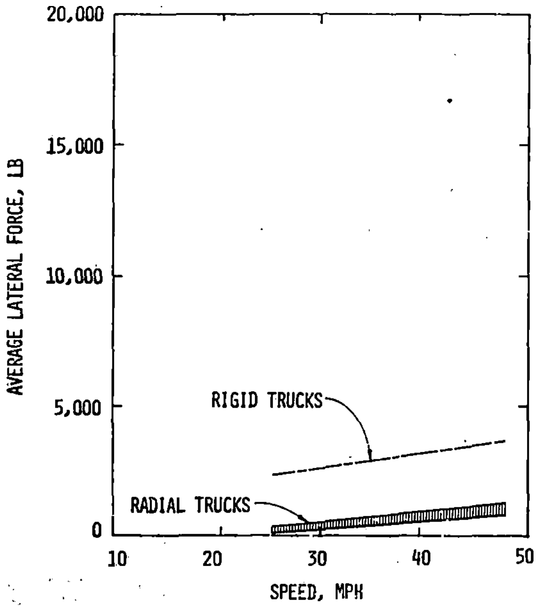


FIGURE 6.3.3-3 LATERAL FORCE ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS - 3.7° CURVES

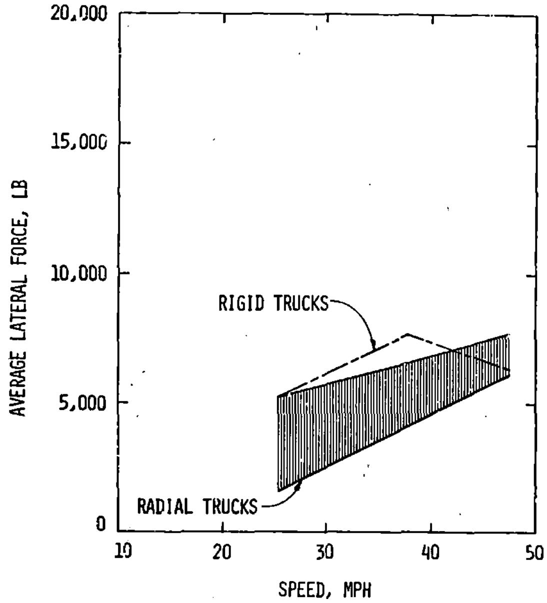


FIGURE 6.3.3-4 LATERAL FORCE ON LEADING OUTER WHEEL FOR TYFE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS - 3.7° CURVES

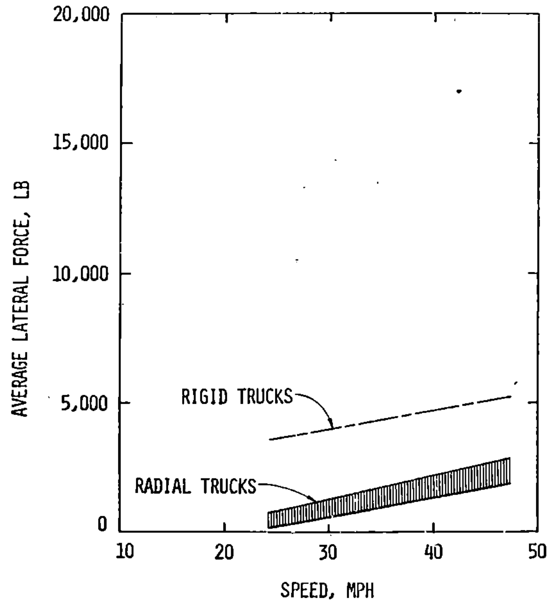


FIGURE 6.3.3-7 LATERAL FORCE ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS - 6.2° CURVES

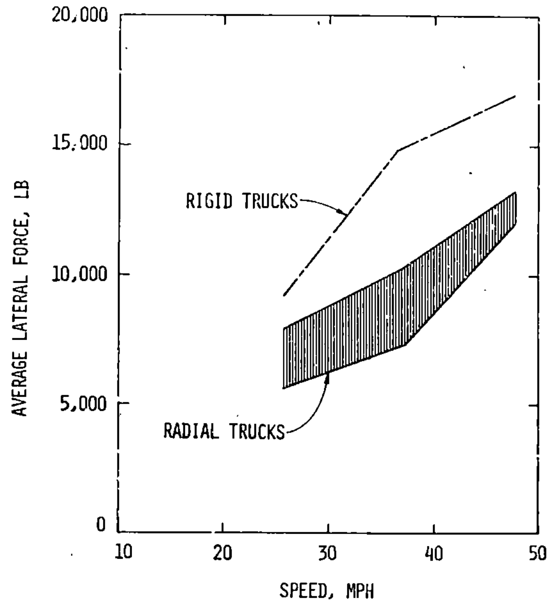


FIGURE 6.3.3-8 LATERAL FORCE ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS - 6.2° CURVES

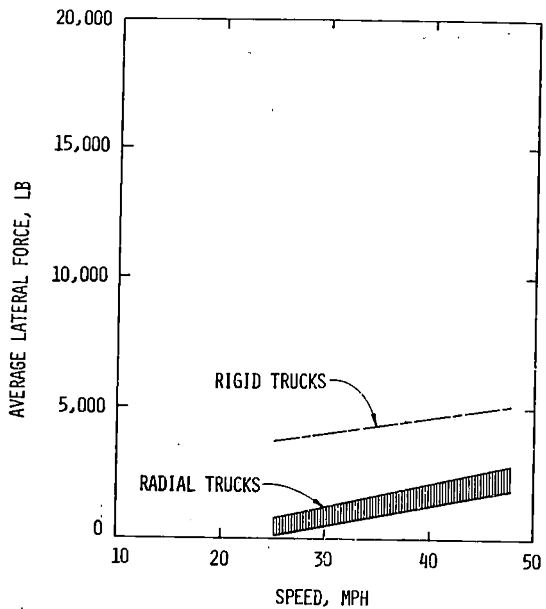


FIGURE 6.3.3-5 LATERAL FORCE ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS - 5.2° CURVES

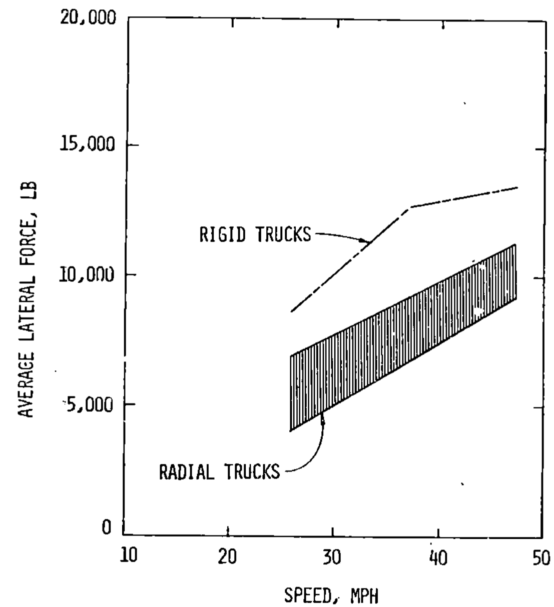


FIGURE 6.3.3-6 LATERAL FORCE ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS - 5.2° CURVES

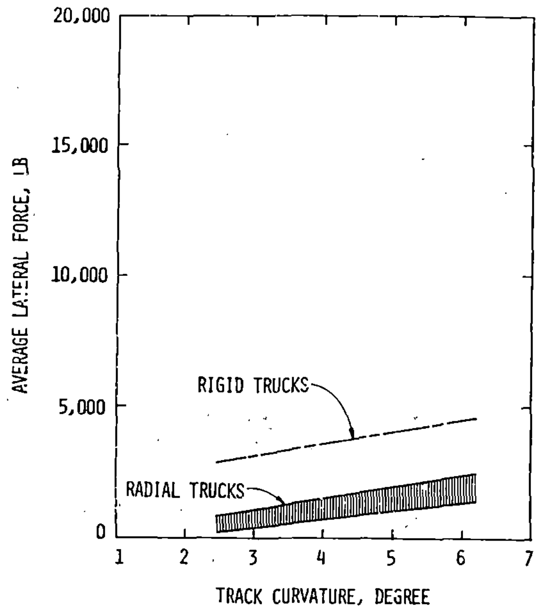


FIGURE 6.3.3-9 LATERAL FORCE ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCK WITH EMPTY OPEN HOPPER CARS AT BALANCE SPEED ($\pm$ 2.5 MPH)

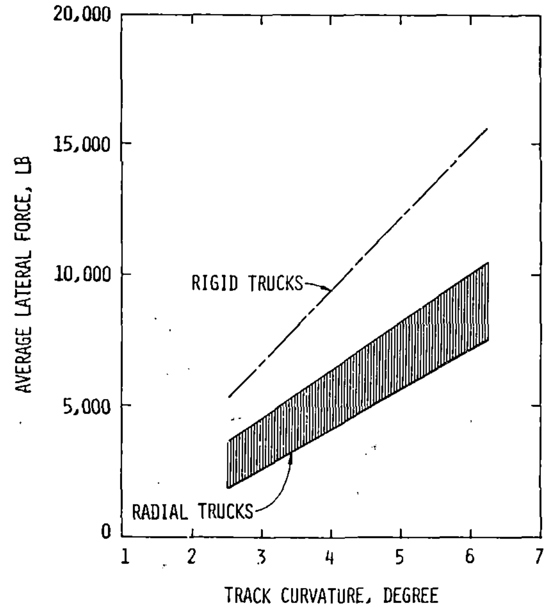


FIGURE 6.3.3-10 LATERAL FORCE ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCK WITH LOADED OPEN HOPPER CARS AT BALANCE SPEED ($\pm$ 2.5 MPH)

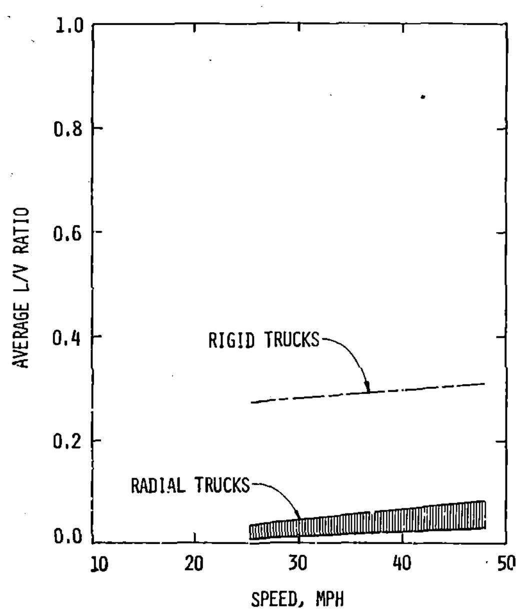


FIGURE 6.3.3-11 L/V RATIO ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS - 2.5° CURVES

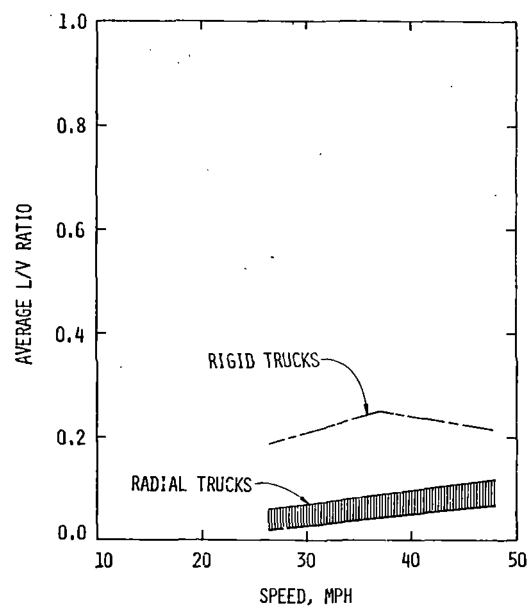


FIGURE 6.3.3-12 L/V RATIO ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS - 2.5° CURVES

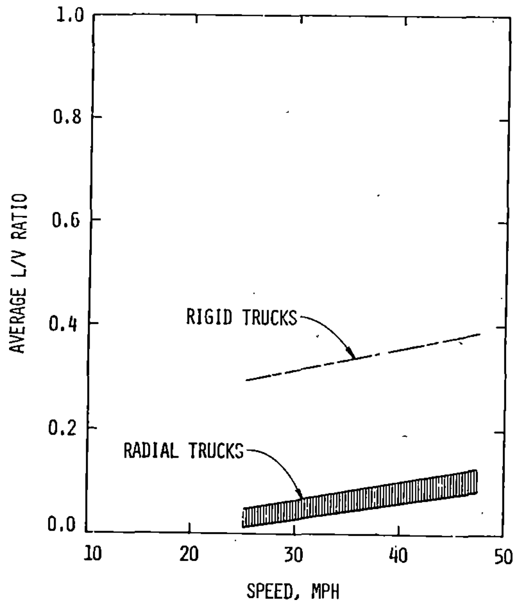


FIGURE 6.3.3-13 L/V RATIO ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS - 3.7° CURVES

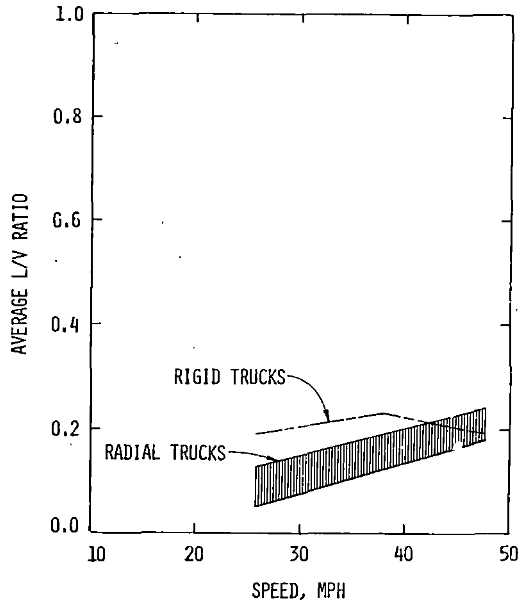


FIGURE 6.3.3-14 L/V RATIO ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS - 3.7° CURVES

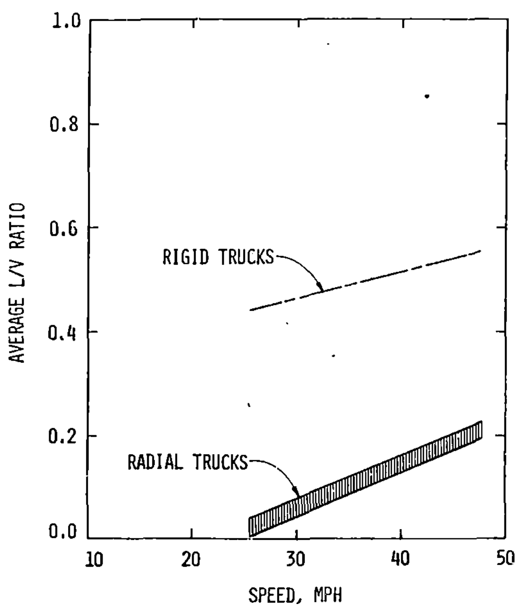


FIGURE 6.3.3-15 L/V RATIO ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS - 5.2° CURVES

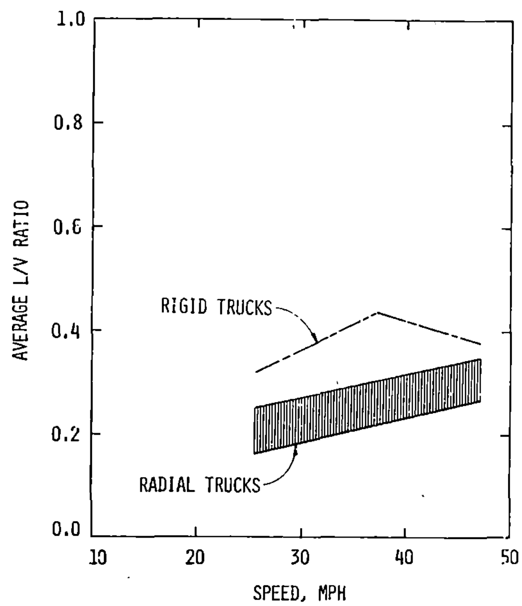


FIGURE 6.3.3-16 L/V RATIO ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS - 5.2° CURVES

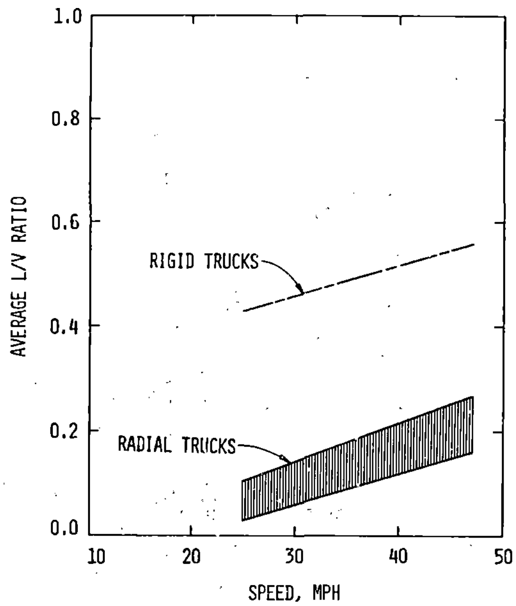


FIGURE 6.3.3-17 L/V RATIO ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CAR - 6.2° CURVES

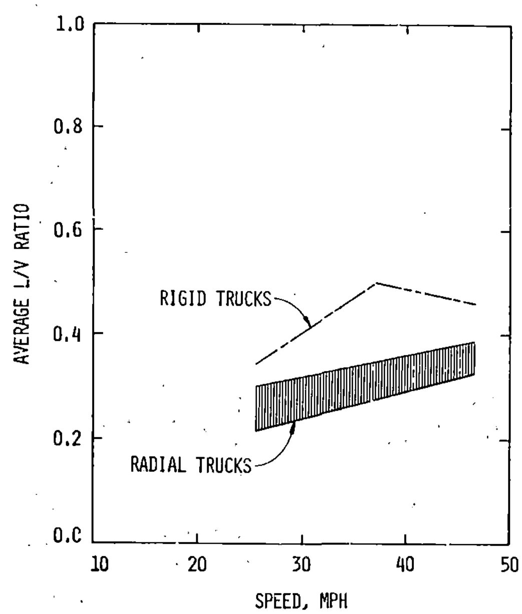


FIGURE 6.3.3-18 L/V RATIO ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CAR - 6.2° CURVES

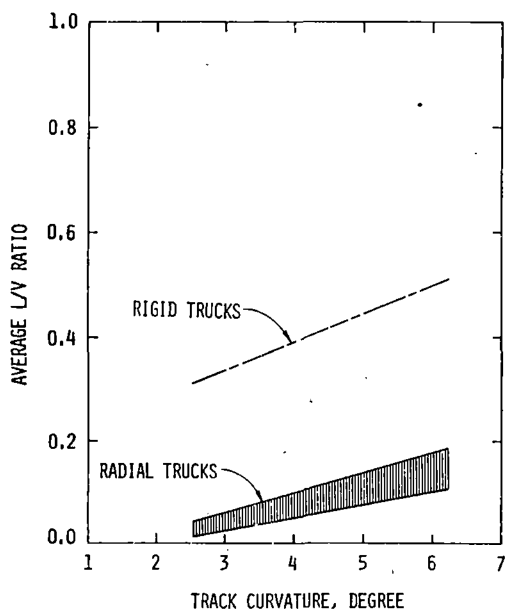


FIGURE 6.3.3-19 L/V RATIO ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS AT BALANCE SPEED ($\pm$ 2.5 MPH)

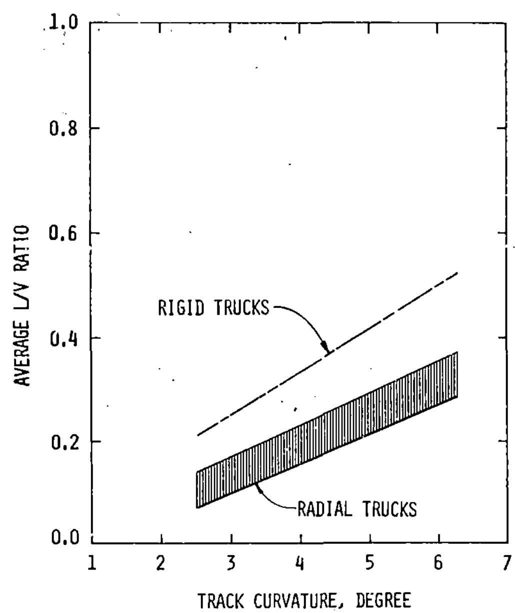


FIGURE 6.3.3-20 L/V RATIO ON LEADING OUTER WHEEL FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS AT BALANCE SPEED ($\pm$ 2.5 MPH)

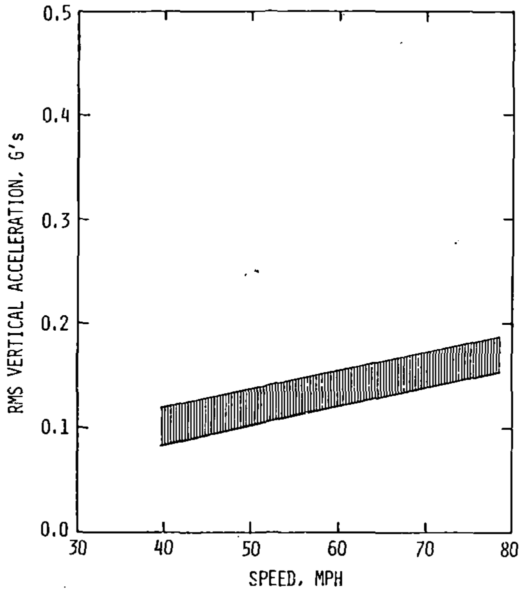


FIGURE 6.3.4-1 RMS VERTICAL ACCELERATION LEVELS (0-20 HZ) FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS

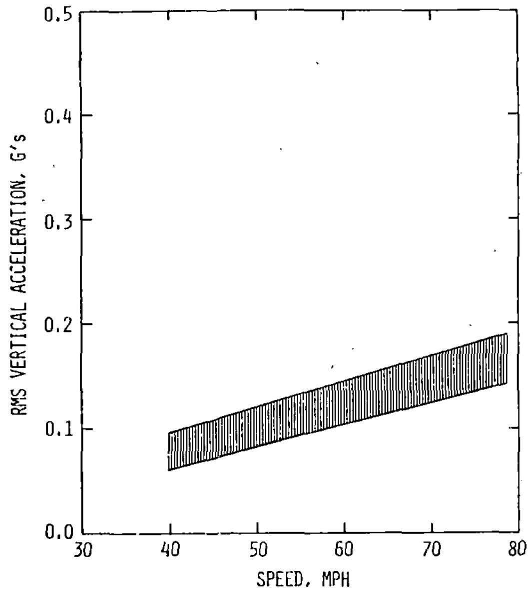


FIGURE 6.3.4-2 RMS VERTICAL ACCELERATION LEVELS (0-20 HZ) FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS

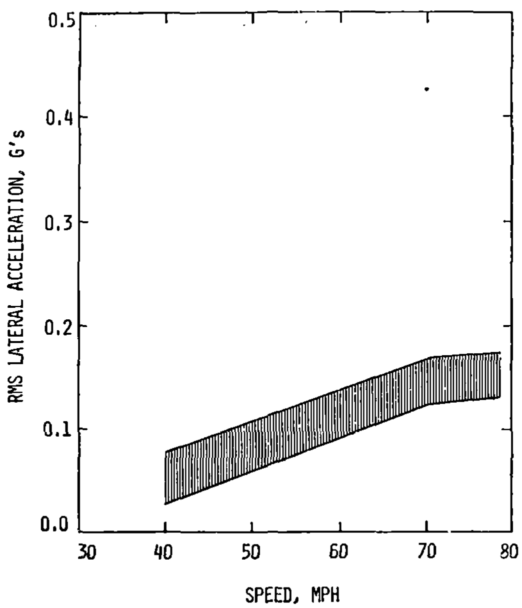


FIGURE 6.3.4-3 RMS LATERAL ACCELERATION LEVELS (0-20 HZ) FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS

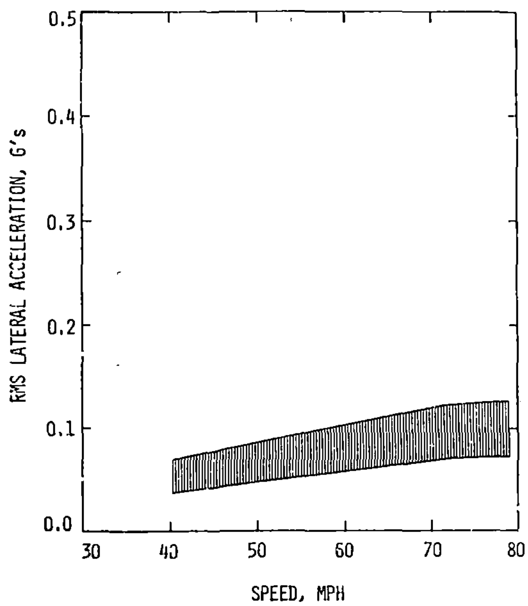


FIGURE 6.3.4-4 RMS LATERAL ACCELERATION LEVELS (0-20 HZ) FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS

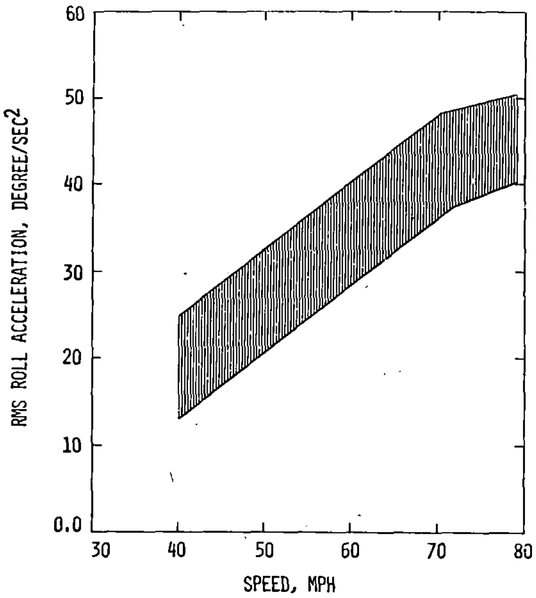


FIGURE 6.3.4-5 RMS ROLL ACCELERATION LEVELS (0-20 HZ) FOR TYPE II FREIGHT CAR TRUCKS WITH EMPTY OPEN HOPPER CARS

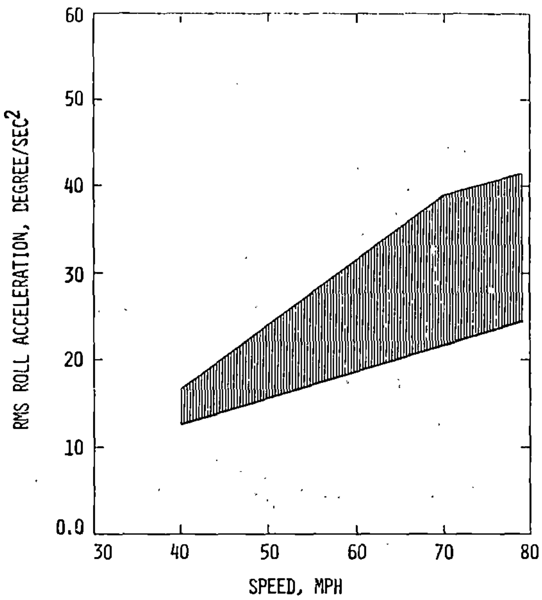


FIGURE 6.3.4-6 RMS ROLL ACCELERATION LEVELS (0-20 HZ) FOR TYPE II FREIGHT CAR TRUCKS WITH LOADED OPEN HOPPER CARS

REFERENCES

1. P.V., RamaChandran, and ElMadany, M.M., "Truck Design Optimization Project Phase II/Performance Characterization of Type I Freight Car Trucks", FRA Report FRA/ORD-81/10, January 1981, National Technical Information Service, Springfield, VA.

2. Cappel, K.L., "Truck Design Optimization Project Phase II/Introductory Report", FRA/ORD-78/53, November, 1978, National Technical Information Service, Springfield, VA.

3. RamaChandran, P.V., "Truck Design Optimization Project Phase II/Selection of Type II Trucks for Testing", TDOP Report TR-09/DOT-FR-742-4277, Wyle Laboratories, Colorado Springs, CO., May 1979.

4. Gibson, David W., "Truck Design Optimization Project Phase II/Type II Truck Test Plan", Wyle Laboratories Document No. C-901-007-A, Contract No. DOT-FR-742-4277, October 1979/revised April 1980.

5. "Survey Results Report - Track Geometry Measurements in Support of Truck Design Optimization Program", Report No. DOT-FR-79-25, July 30, 1979.

6. "Survey II Results Report - Track Geometry Measurements in Support of Truck Design Optimization Program", Report No. DOT-FR-80-15, February 1980.

7. Tennikait, H.G., "Instrumented Wheelset Systems for Product Performance Analysis", FRA/ORD-77/58, 1977.

8. "Advanced Data Analysis and Reduction System (ADARS)", Proprietary Computer Application Package, Wyle Laboratories, Colorado Springs, CO.

APPENDIX A - ANGLE OF ATTACK

INTRODUCTION

Measurement of the wheel/rail angle of attack was one of the goals of the TDOP Phase II test program. Considerable effort was expended in developing a vehicle-borne angle of attack measurement system. The field test data acquired through this instrumentation package included the six Type II 100-ton trucks equipped with CN wheel profiles. The cars were tested in empty and loaded conditions. The test data showed, in general, considerable scatter. However, analysis of the data was precluded due to schedule constraints. Therefore, some test data results which may be useful for subsequent research efforts, are presented here.

INSTRUMENTATION SYSTEM

Angle of attack data are provided by non-contacting position sensors mounted on the right side of each axle of the leading truck. Two sensors measure the relative sideframe to wheel displacement, and two others measure the relative sideframe to rail displacement. The difference between the two sensors gives the relative angle; the difference between the sideframe to wheel and the sideframe to rail angles results in the angle of attack (see Figures A-1 through A-4). The sensors are of the eddy current type, which result in signals based on the average distance from the sensor to a surface.

RESULTS

The results of the angle of attack of the Type II trucks are presented in Figures A-5 through A-28. Figures A-5 through A-24 give the average angle of attack as a function of vehicle speed, while Figures A-25 through A-28 give the average angle of attack as a function of the degree of track curvature near balance speed.

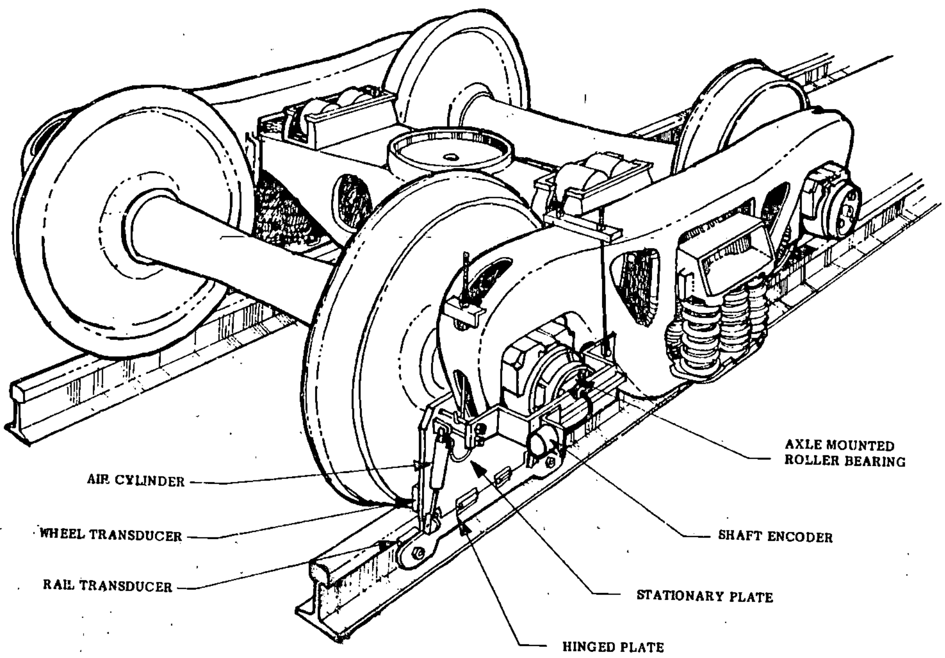


FIGURE A-1. WHEEL TO RAIL DISPLACEMENT MEASUREMENT FIXTURE SHOWN IN RUNNING POSITION

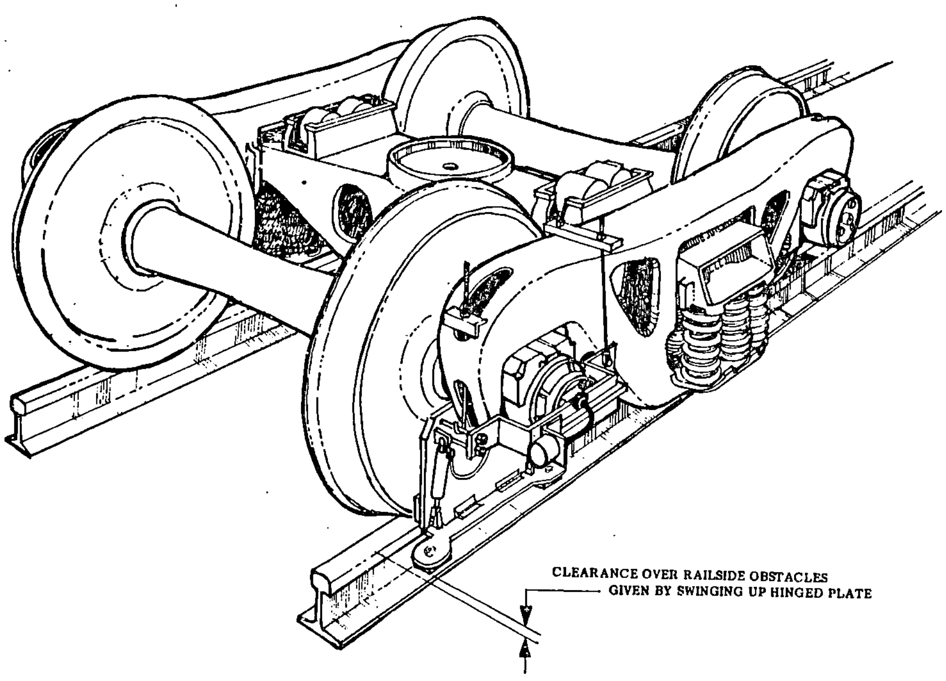
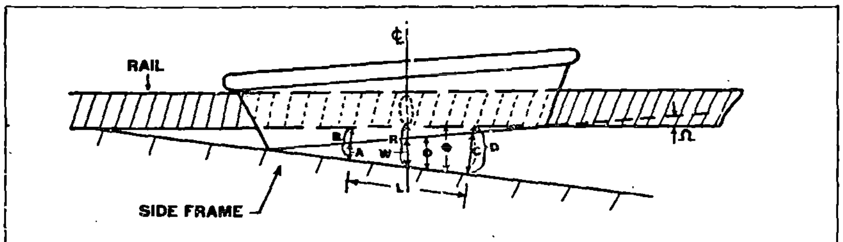


FIGURE A-2. WHEEL TO RAIL DISPLACEMENT MEASUREMENT FIXTURE SHOWN IN RAISED POSITION



θ = RAIL TO SIDEFRAME $\measuredangle \cong \frac{C-B}{L}$ RADIANS = $\frac{C-B}{L}$ (57.3) DEGREES

ϕ = WHEEL TO SIDEFRAME $\measuredangle \cong \frac{D-A}{L}$ RADIANS = $\frac{D-A}{L}$ (57.3) DEGREES

Ω = WHEEL TO RAIL $\measuredangle = \theta - \phi$

R = SIDEFRAME TO RAIL DISTANCE = $\frac{B+C}{2}$

W = SIDEFRAME TO WHEEL DISTANCE = $\frac{A+D}{2}$

R/W = RAIL WHEEL POSITION = R-W

FIGURE A-3. WHEEL/RAIL POSITION MEASUREMENT

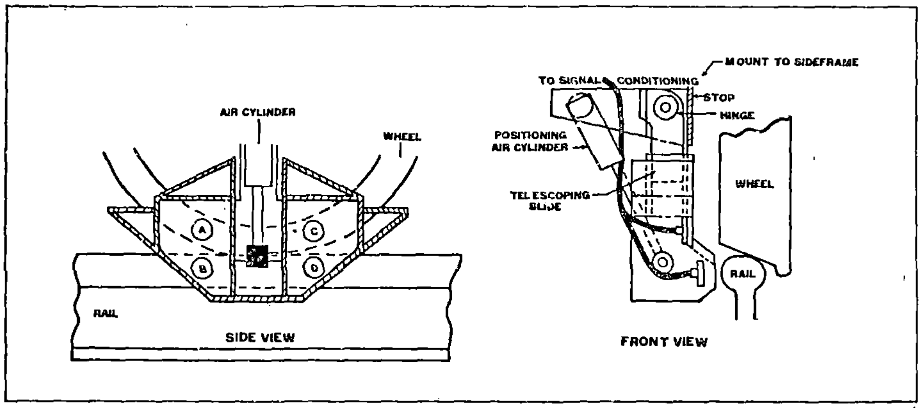


FIGURE A-4. WHEEL/RAIL MEASUREMENT SYSTEM

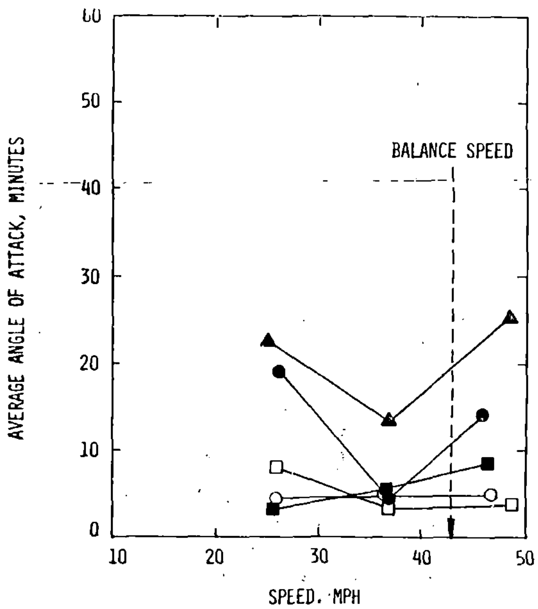


FIGURE A-5. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 1.1° RH CURVE, EMPTY CARS

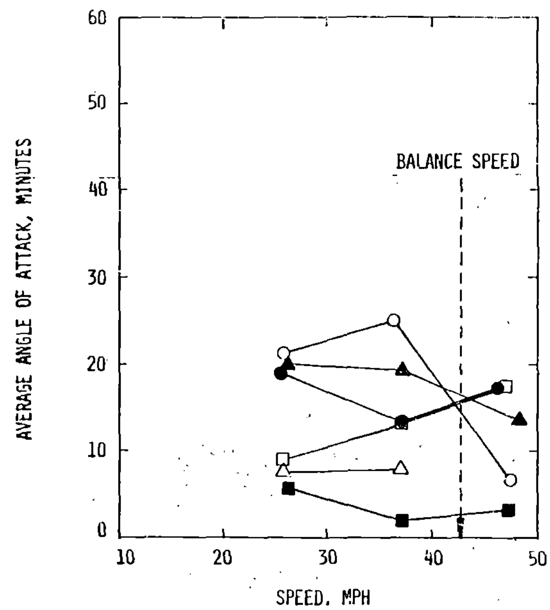


FIGURE A-6. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 1.1° RH CURVE, LOADED CARS

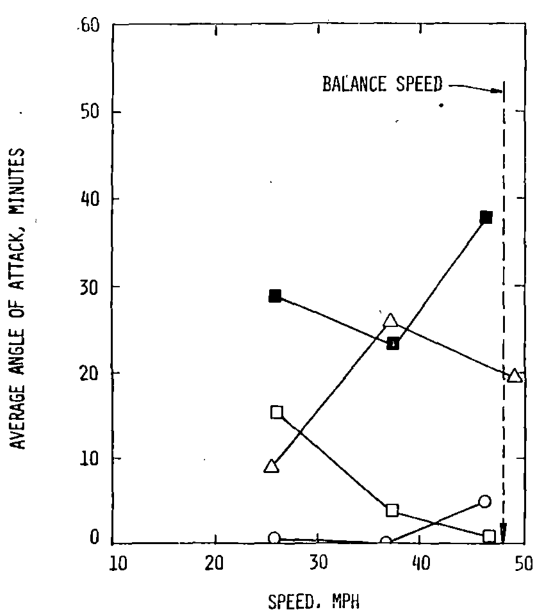


FIGURE A-7. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 2.5° LH CURVE, EMPTY CARS

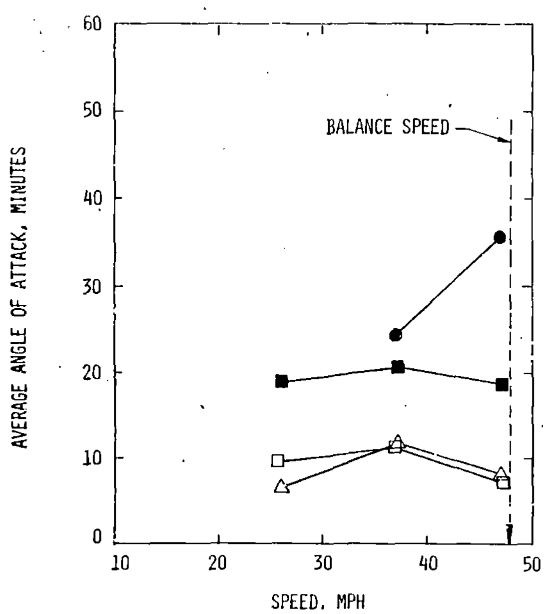


FIGURE A-8. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 2.5° LH CURVE, LOADED CARS

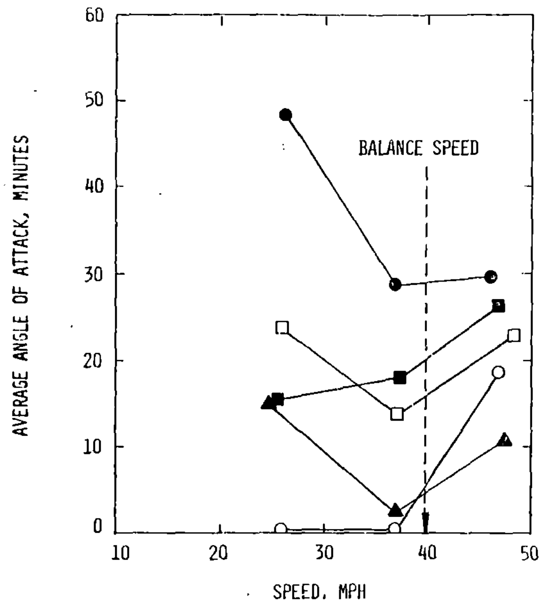


FIGURE A-9. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 3.0° RH CURVE, EMPTY CARS

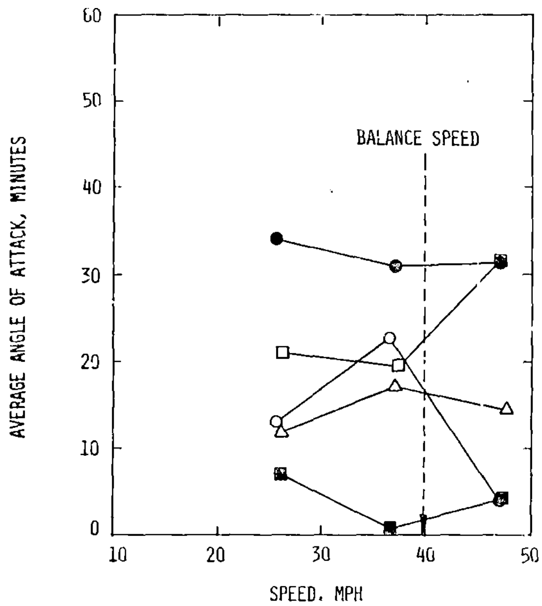


FIGURE A-10. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 3.0° RH CURVE, LOADED CARS

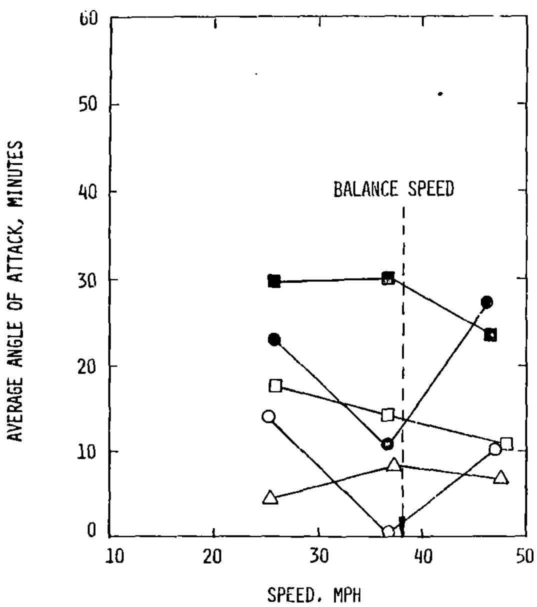


FIGURE A-11. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 3.7° LH CURVE, EMPTY CARS

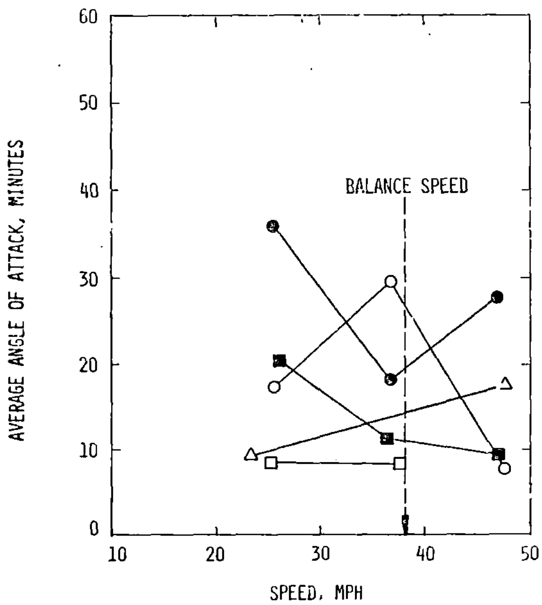


FIGURE A-12. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 3.7° LH CURVE, LOADED CARS

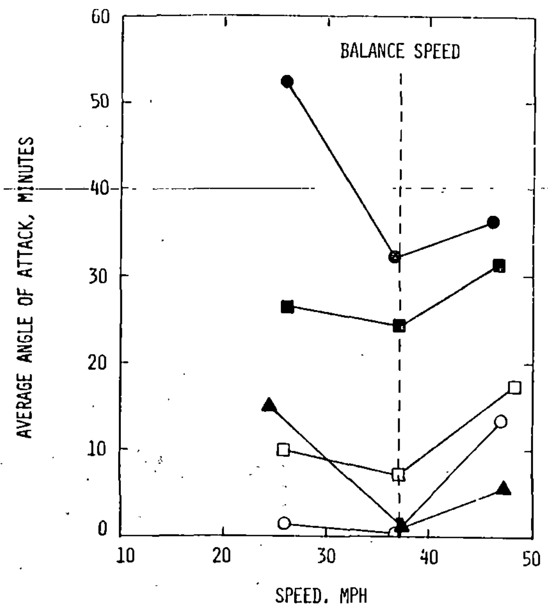


FIGURE A-13. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 5.0° RH CURVE, EMPTY CARS

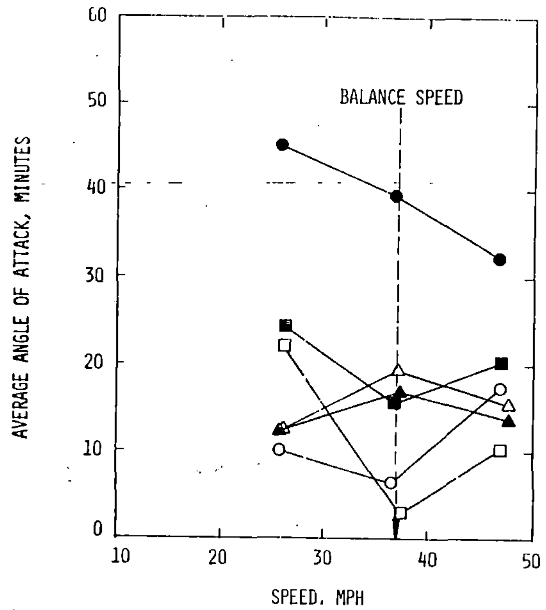


FIGURE A-14. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 5.0° RH CURVE, LOADED CARS

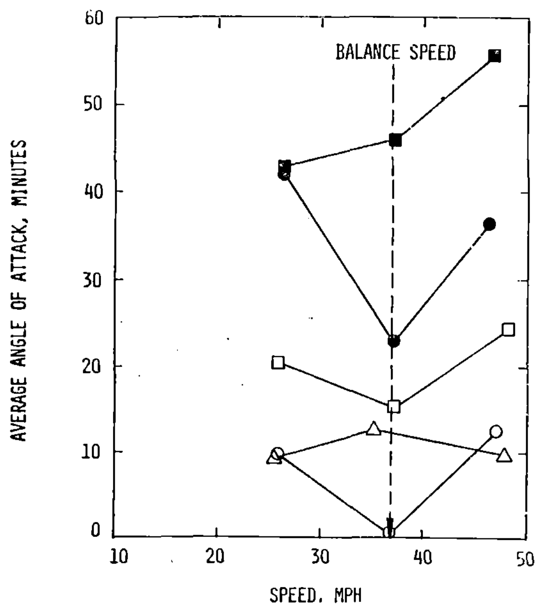


FIGURE A-15. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 5.1° LH CURVE, EMPTY CARS

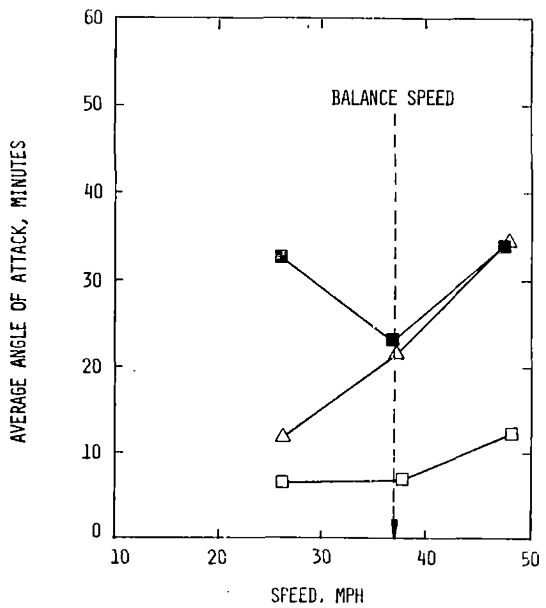


FIGURE A-16. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 5.1° LH CURVE, LOADED CARS

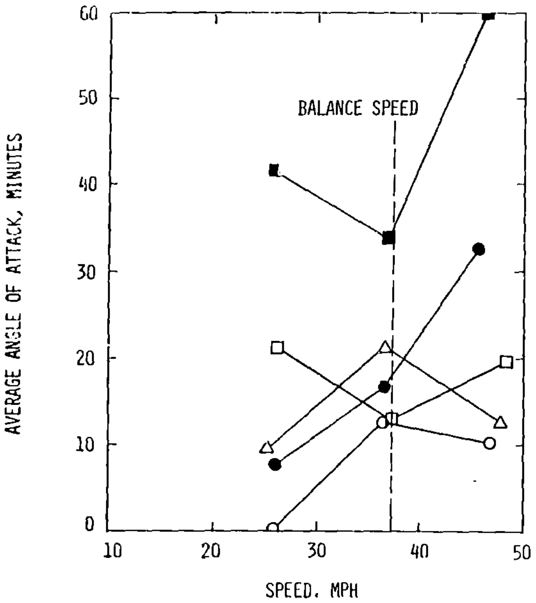


FIGURE A-17. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 5.2° LH CURVE, EMPTY CARS

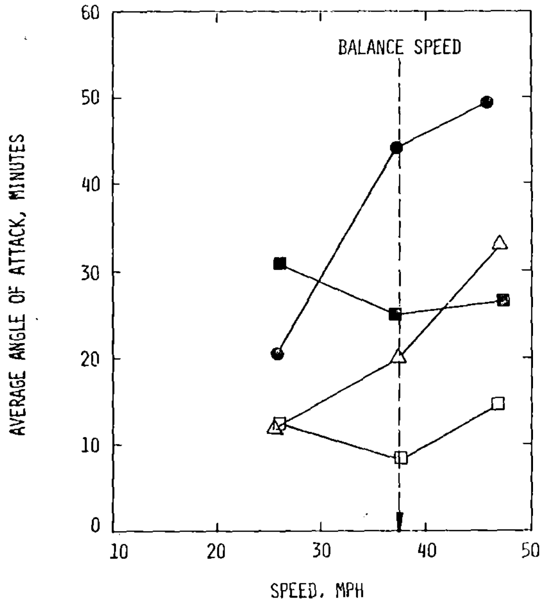


FIGURE A-18. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 5.2° LH CURVE, LOADED CARS

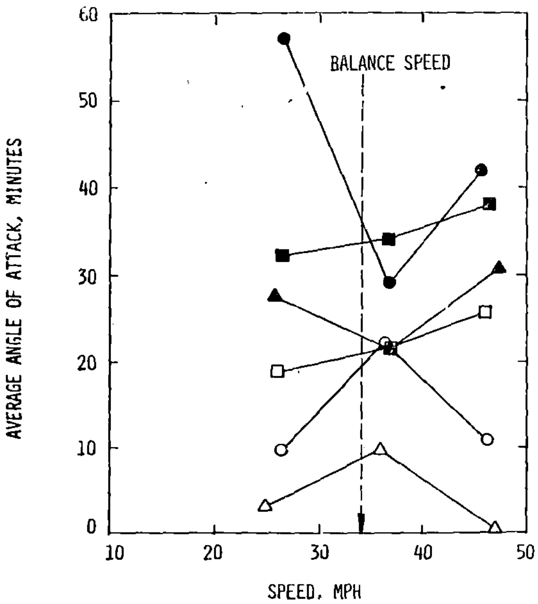


FIGURE A-19. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 6.1° RH CURVE, EMPTY CARS

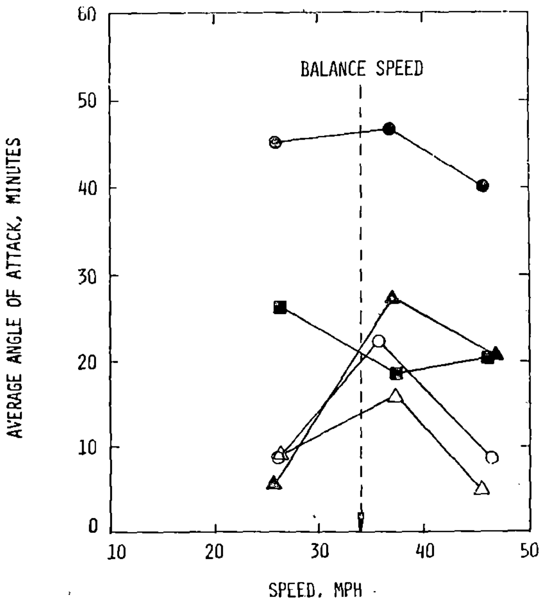


FIGURE A-20. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 6.1° RH CURVE, LOADED CARS

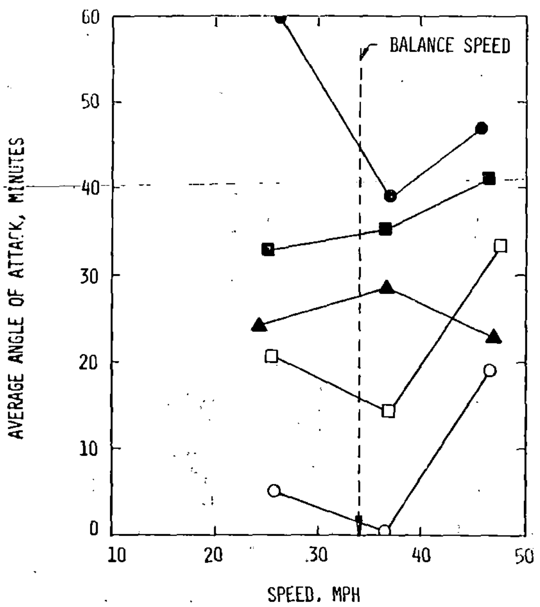


FIGURE A-21. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 6.2° RH CURVE, EMPTY CARS

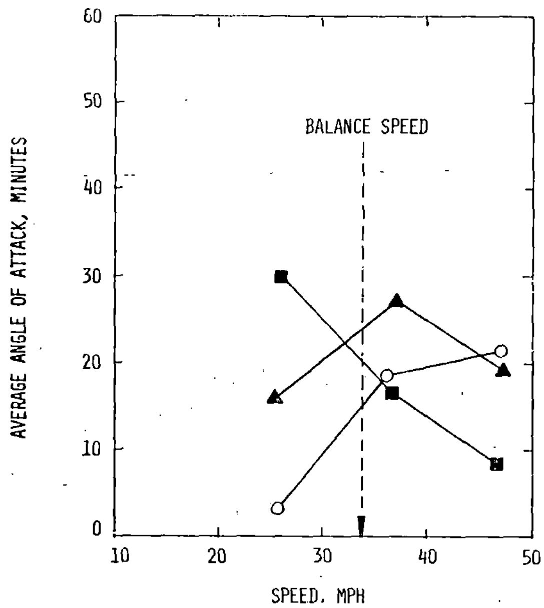


FIGURE A-22. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 6.2° RH CURVE, LOADED CARS

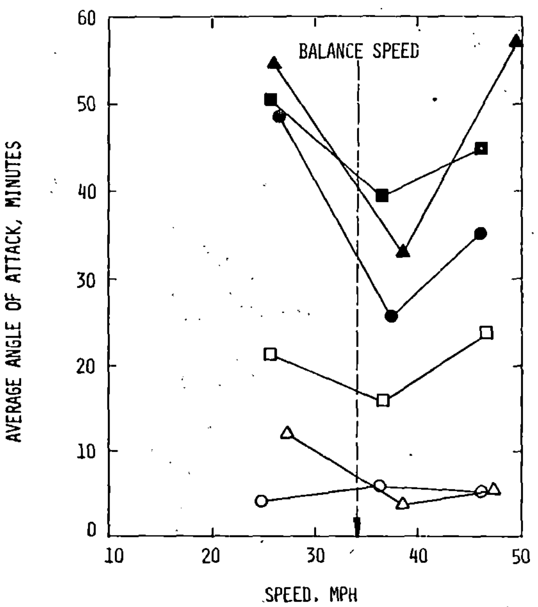


FIGURE A-23. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 6.2° LH CURVE, EMPTY CARS

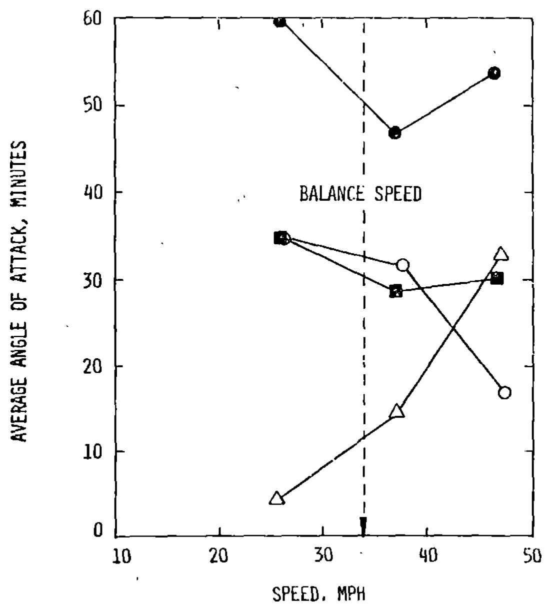


FIGURE A-24. AVERAGE ANGLE OF ATTACK VERSUS SPEED - 6.2° LH CURVE, LOADED CARS

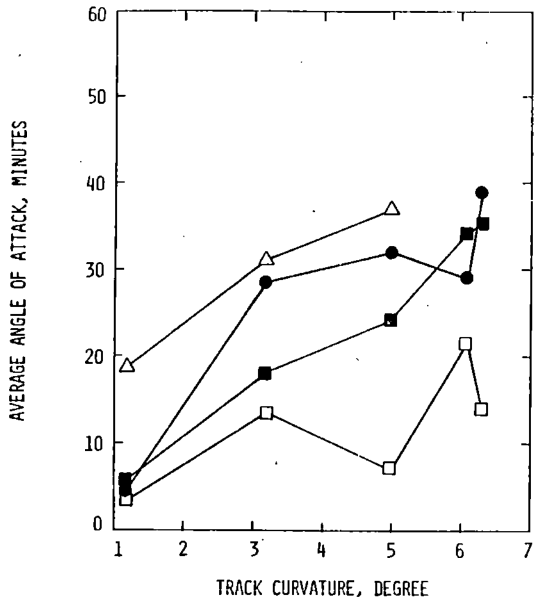


FIGURE A-25. AVERAGE ANGLE OF ATTACK VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - RH CURVES, EMPTY CARS

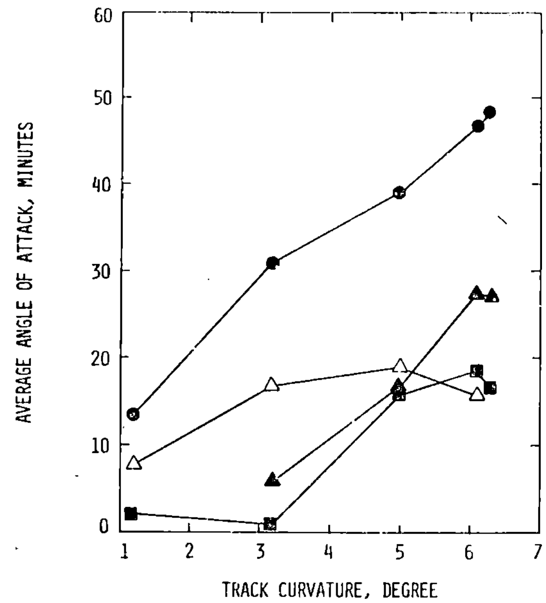


FIGURE A-26. AVERAGE ANGLE OF ATTACK VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - RH CURVES, LOADED CARS

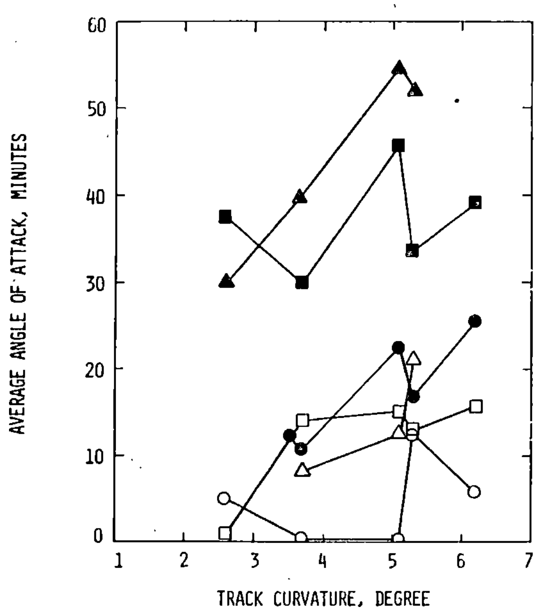


FIGURE A-27. AVERAGE ANGLE OF ATTACK VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LH CURVES, EMPTY CARS

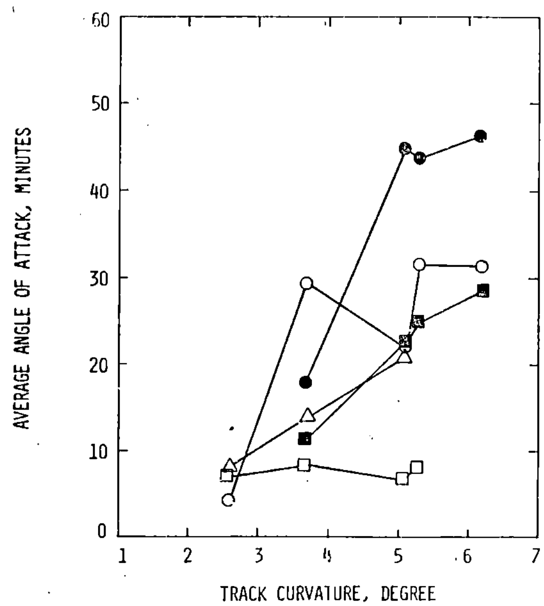


FIGURE A-28. AVERAGE ANGLE OF ATTACK VERSUS DEGREE OF CURVATURE NEAR BALANCE SPEED - LH CURVES, LOADED CARS

APPENDIX B – TRACK GEOMETRY DATA

To be able to correlate response measurements made on test vehicles with a known track input, track geometry measurements were made twice over a period of about one year. The first set of measurements was taken during the first week in November 1978, (Reference 5). The second set of track geometry measurements were taken in December 1979, (Reference 6). Both tests utilized the T-6 Track Geometry Survey Car.

The survey was conducted over the five test zones used in testing of freight car trucks during Phase II, south of Las Vegas, Nevada on Union Pacific trackage (see Table B-1). These zones ranged from eight miles to 0.22 miles in length and contained a full spectrum of track conditions. Measurements of each test zone were taken at six-inch sample intervals as the survey car passed through the zone, normally once in each direction.

The track parameters which are reported are: right and left alignment, gauge, right and left profile, crosslevel, and curvature (degrees per 100 ft.). A digital tape of these parameters (including speed and ALD) has been supplied to Wyle in the form of both space curve and short mid-chord offset. The track properties and the statistical analysis of the geometry parameters are given in Table B-2 (Reference 6). Typical power spectral densities are shown in Figures B-1 through B-16.

TABLE B-1. TEST ZONES

Site Number	Site Designation/Description		
1	Location	-	Arden to Sloan, NV
	Mileposts	-	321.5 to 314
	Track Type	-	Class 4 - Curved
	Rail Type	-	133-pound Jointed
	Speed Limit	-	40 mph
2	Location	-	Boulder Junction to Arden, NV
	Mileposts	-	326.5 to 321.5
	Track Type	-	Class 4 - Tangent
	Rail Type	-	133-pound Jointed
	Speed Limit	-	79 mph
3	Location	-	Las Vegas, NV
	Mileposts	-	Las Vegas, Yard
	Track Type	-	Curved, 16 Degrees
	Rail Type	-	Unknown
	Speed Limit	-	10 mph
	Distance	-	0.22 miles
4	Location	-	Blue Diamond Spur, NV
	Mileposts	-	1.5 to 8
	Track Type	-	Class 2 - Curved and Tangent
	Rail Type	-	131-pound Jointed
	Speed Limit	-	20 mph
5	Location	-	Balch to Crucero, CA
	Mileposts	-	210.5 to 204.5
	Track Type	-	Class 4 - Tangent
	Rail Type	-	133-pound CWR
	Speed Limit	-	79 mph

TABLE B-2. TRACK PROPERTIES AND STANDARD DEVIATIONS OF TRACK ALIGNMENT, GAUGE, PROFILE, AND CROSS-LEVEL

Test Zone	Section	Milepost	Distance Procesed foot	Rail Length foot	Alignment			Gauge inch	Profile			Cross Level inch
					Left inch	Right inch	Average inch		Left inch	Right inch	Average inch	
1	Sloan to Arden	314 to 321.5	39424	39	0.144	0.145	0.136	0.23	0.115	0.126	0.114	-
	Arden to Sloan	321.5 to 314	39424	39	0.145	0.147	0.137	0.23	0.106	0.124	0.109	-
2	Arden to Boulder Junction	321.5 to 326.5	26112	39	0.084	0.083	0.069	0.142	0.114	0.106	0.101	0.172
	Boulder Junction to Arden	326.5 to 321.5	26112	39	0.09	0.086	0.077	0.134	0.092	0.126	0.100	0.175
3	Las Vegas yard (East Bound)	-	1536	39	0.936	0.926	0.922	0.414	1.236	1.150	1.183	-
	Las Vegas Yard (West Bound)	-	1536	39	0.907	0.907	0.900	0.322	1.162	1.249	1.196	-
4	Blue Diamond Spur (East Bound)	1.5 to 8	34304	33 & 39	0.182	0.179	0.173	0.183	0.132	0.153	0.129	-
	Blue Diamond Spur (West Bound)	8 to 1.5	33792	33 & 39	0.141	0.144	0.134	0.181	0.127	0.151	0.126	-
5	Crucero to Balch	204.5 to 210.5	31232	Welded	.084	0.083	0.070	0.136	0.090	0.084	0.082	0.285
	Balch to Crucero	210.5 to 204.5	31744	Welded	0.077	0.088	0.072	0.133	0.083	0.102	0.088	0.285

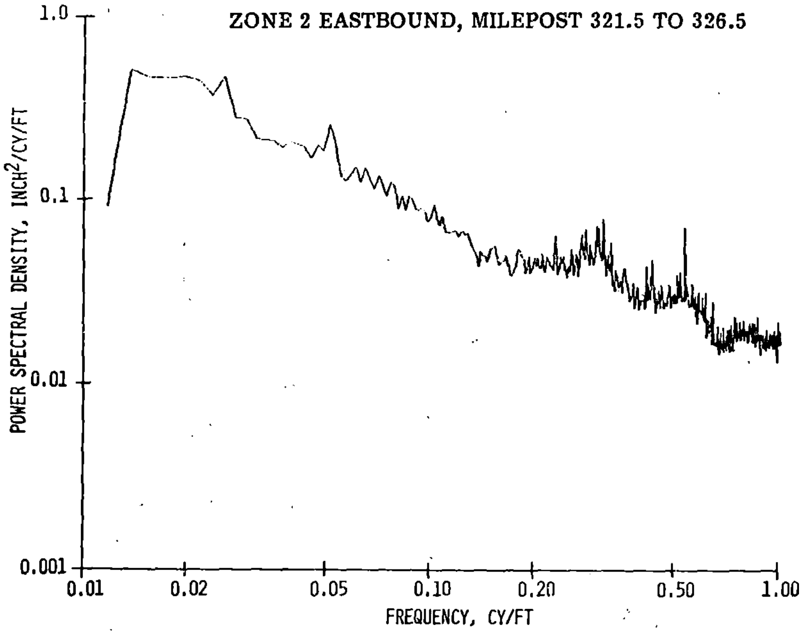


FIGURE B-1. POWER SPECTRAL DENSITY - ZONE 2, LEFT ALIGNMENT

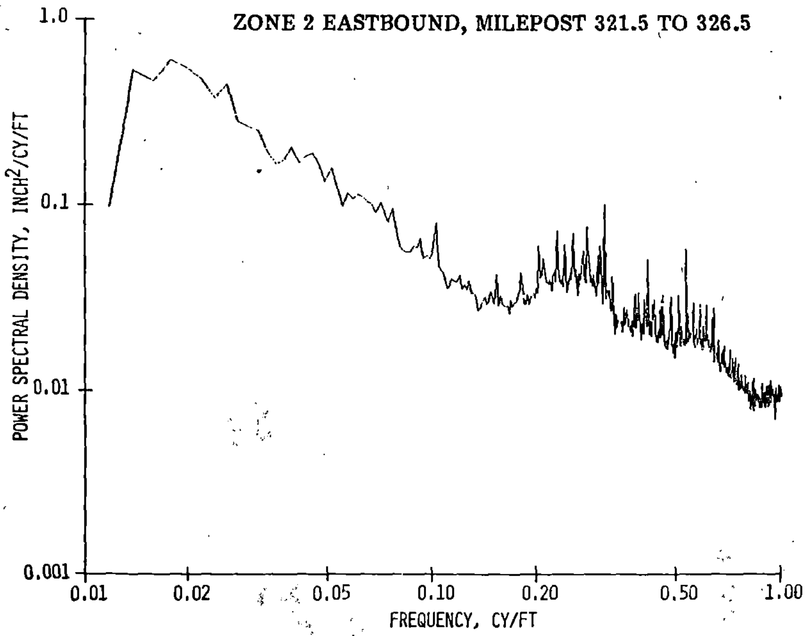


FIGURE B-2. POWER SPECTRAL DENSITY - ZONE 2, RIGHT ALIGNMENT

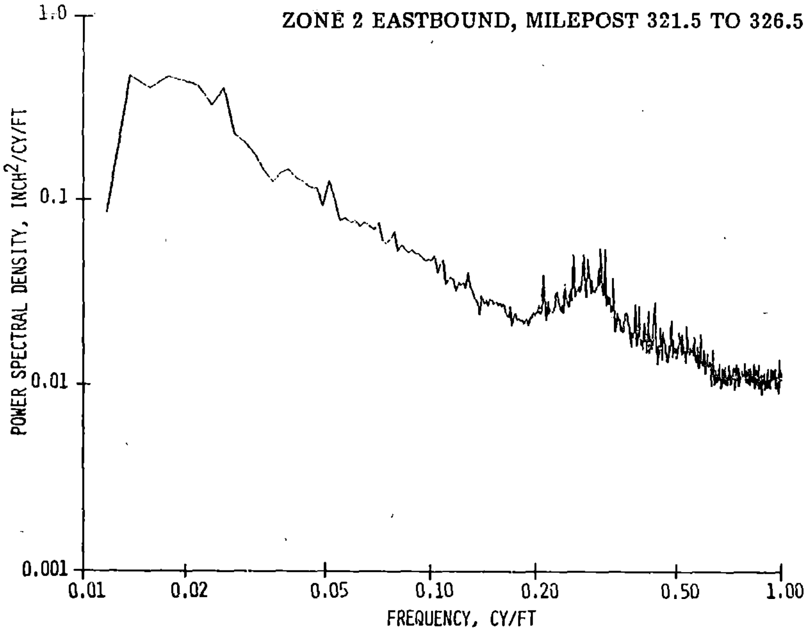


FIGURE B-3. POWER SPECTRAL DENSITY - ZONE 2, AVERAGE ALIGNMENT

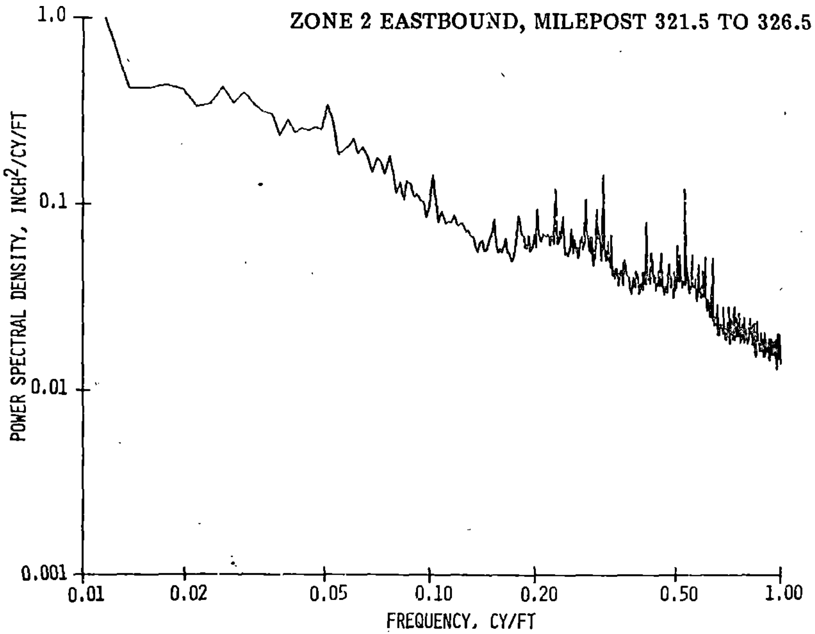


FIGURE B-4. POWER SPECTRAL DENSITY - ZONE 2, GAUGE

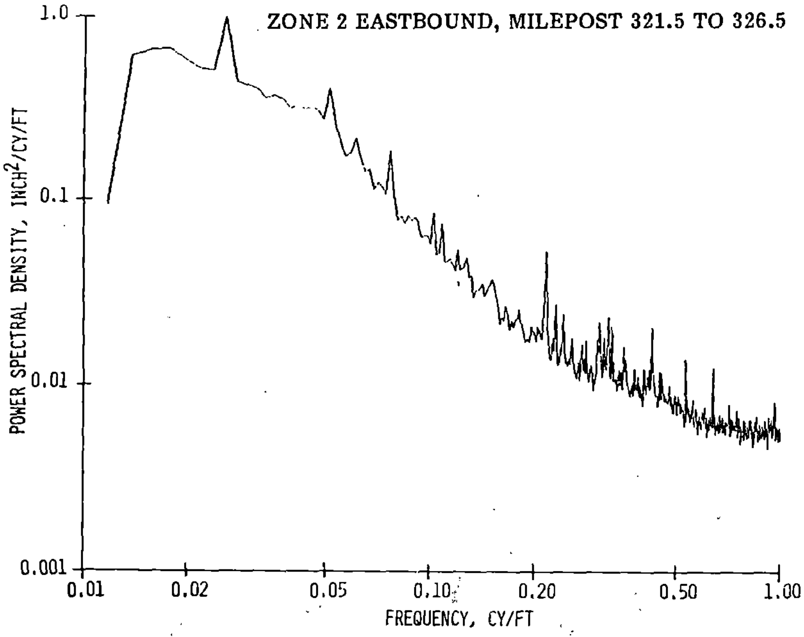


FIGURE B-5. POWER SPECTRAL DENSITY - ZONE 2, LEFT PROFILE

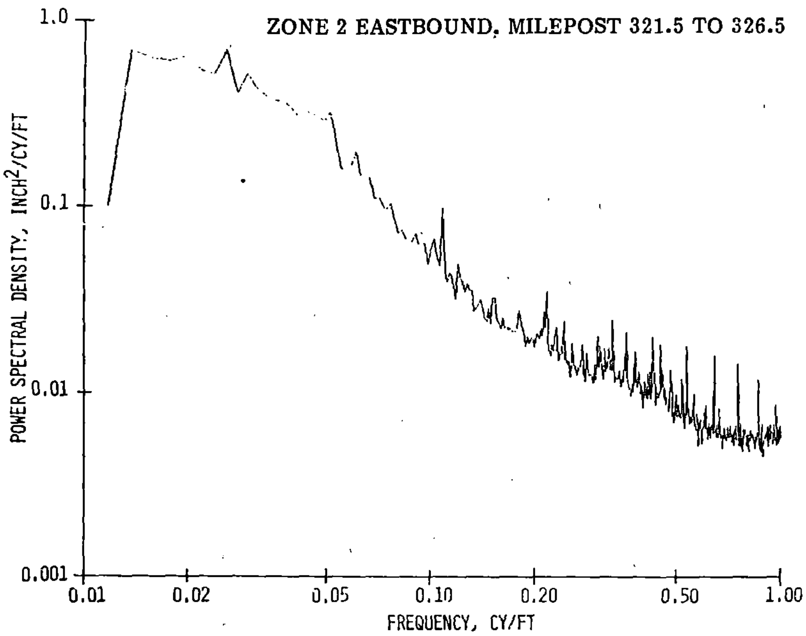


FIGURE B-6. POWER SPECTRAL DENSITY - ZONE 2, RIGHT PROFILE

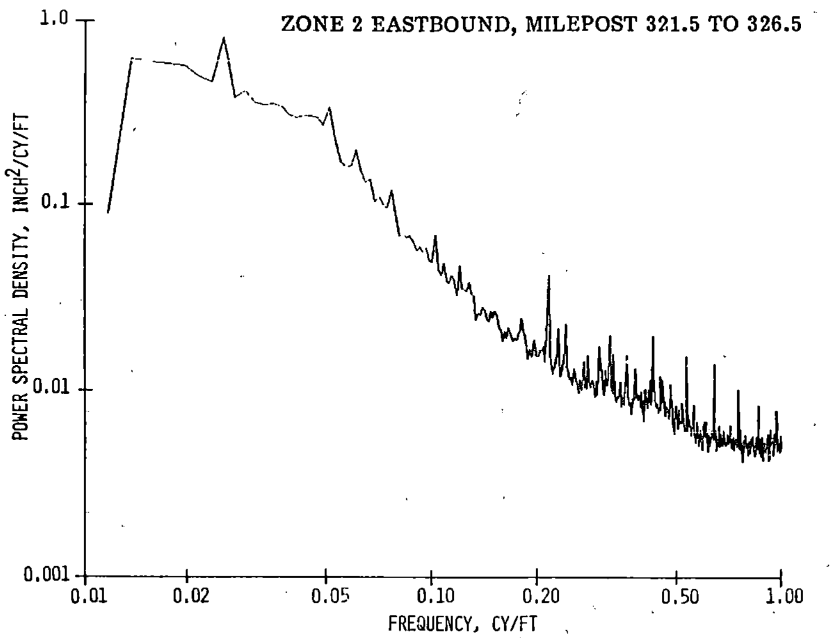


FIGURE B-7. POWER SPECTRAL DENSITY - ZONE 2, AVERAGE PROFILE

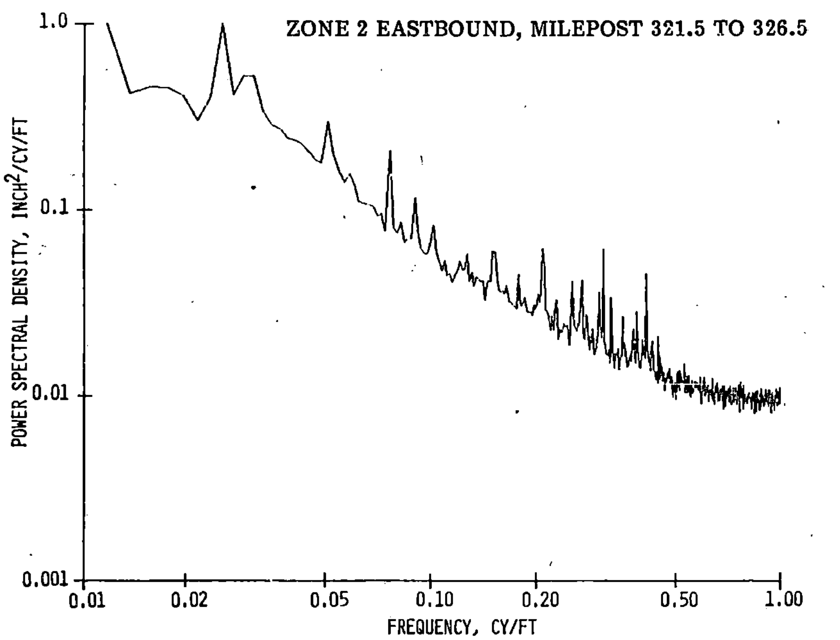


FIGURE B-8. POWER SPECTRAL DENSITY - ZONE 2, CROSSLEVEL

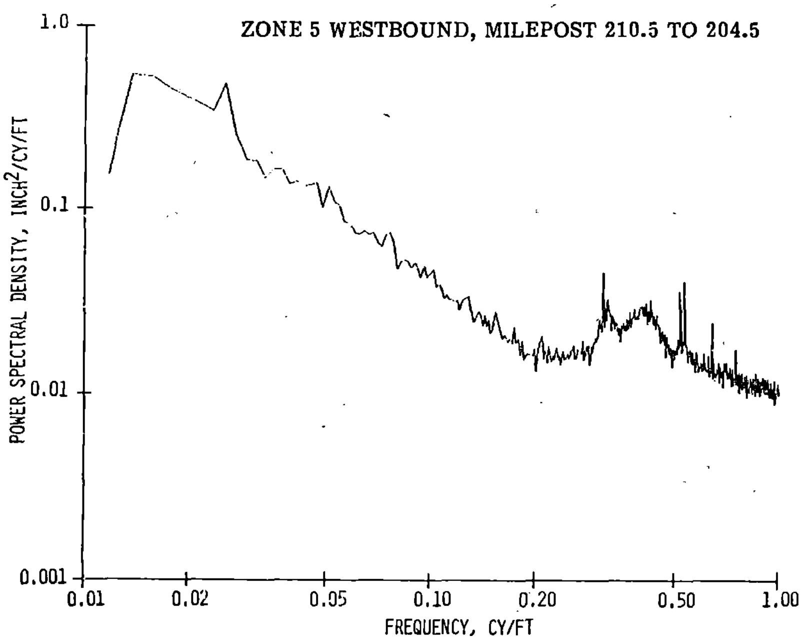


FIGURE B-9. POWER SPECTRAL DENSITY - ZONE 5, LEFT ALIGNMENT

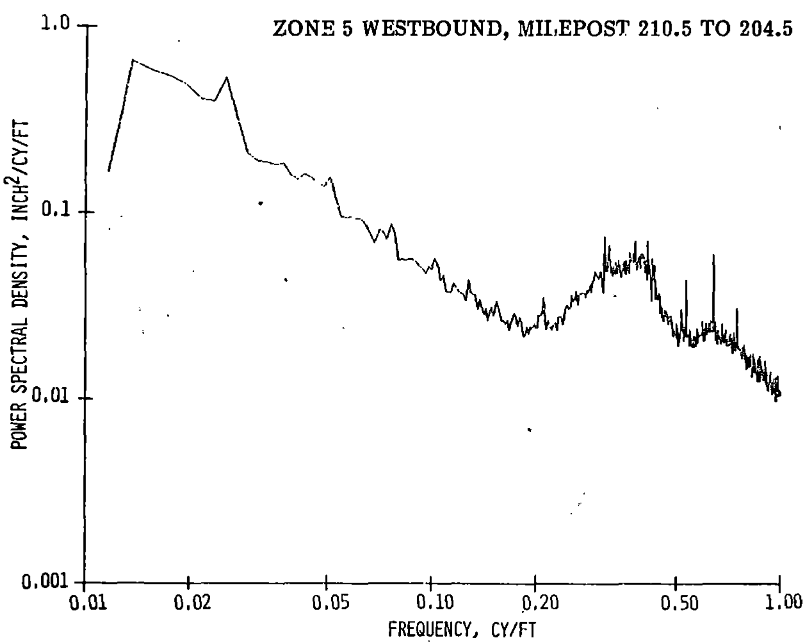


FIGURE B-10. POWER SPECTRAL DENSITY - ZONE 5, RIGHT ALIGNMENT

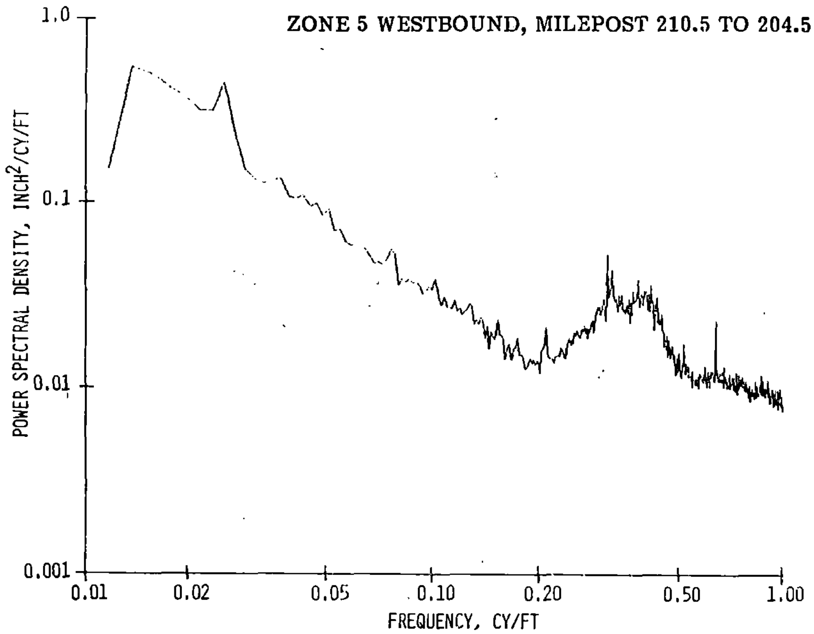


FIGURE B-11. POWER SPECTRAL DENSITY - ZONE 5, AVERAGE ALIGNMENT

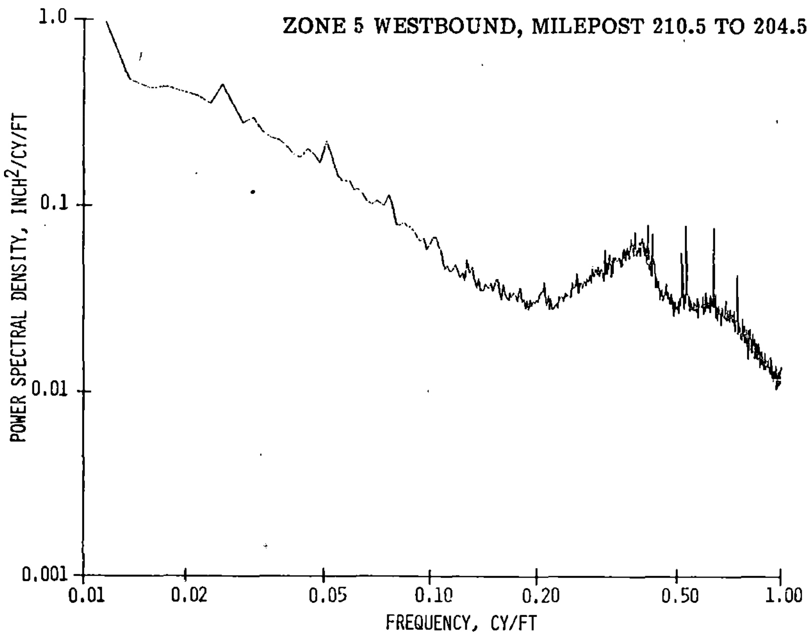


FIGURE B-12. POWER SPECTRAL DENSITY - ZONE 5, GAUGE

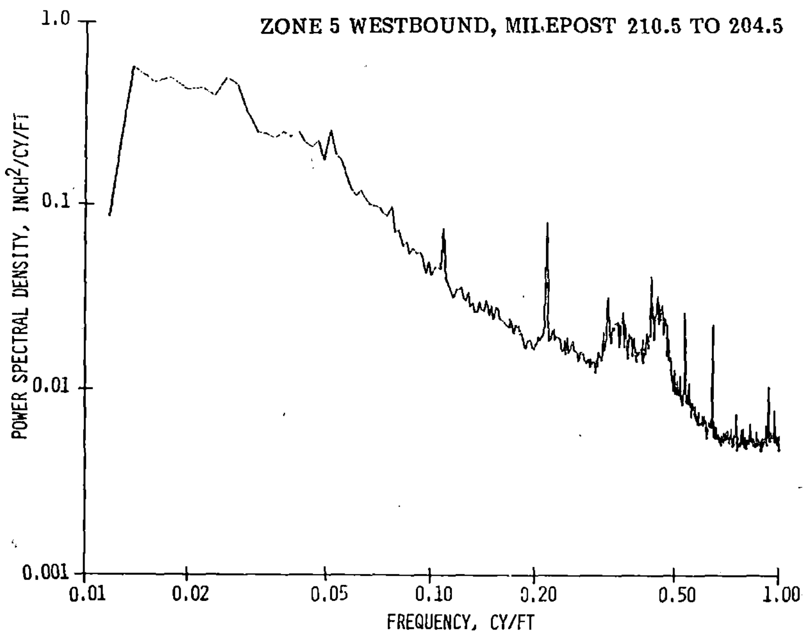


FIGURE B-13. POWER SPECTRAL DENSITY - ZONE 5, LEFT PROFILE

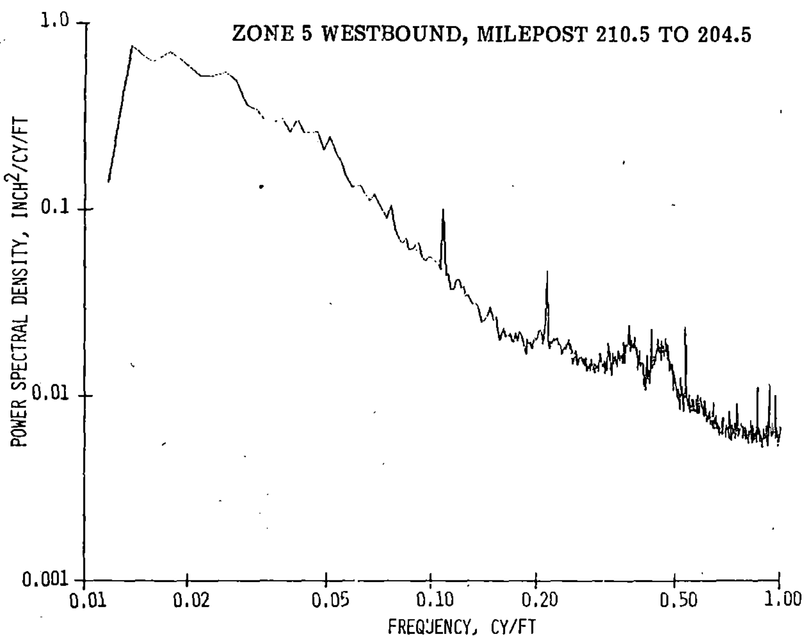


FIGURE B-14. POWER SPECTRAL DENSITY - ZONE 5, RIGHT PROFILE

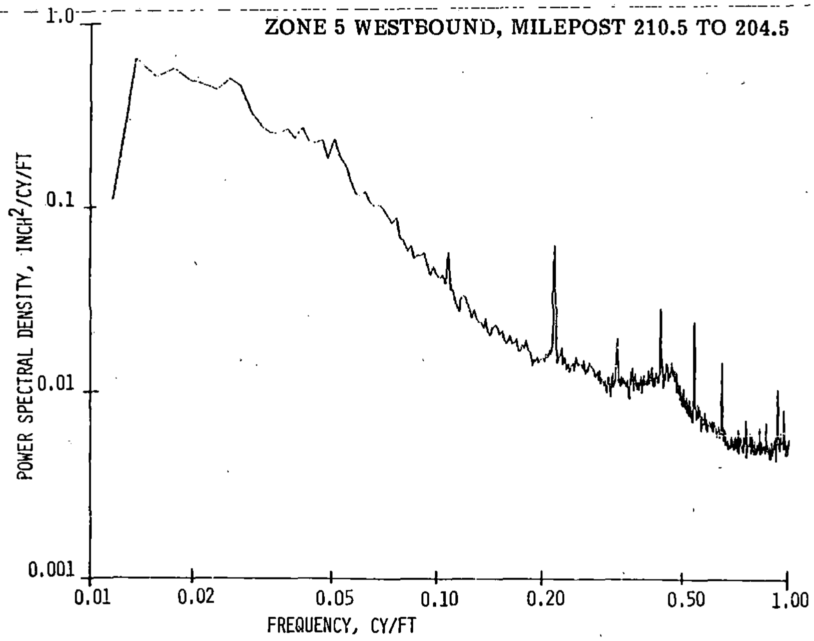


FIGURE B-15. POWER SPECTRAL DENSITY - ZONE 5, AVERAGE PROFILE

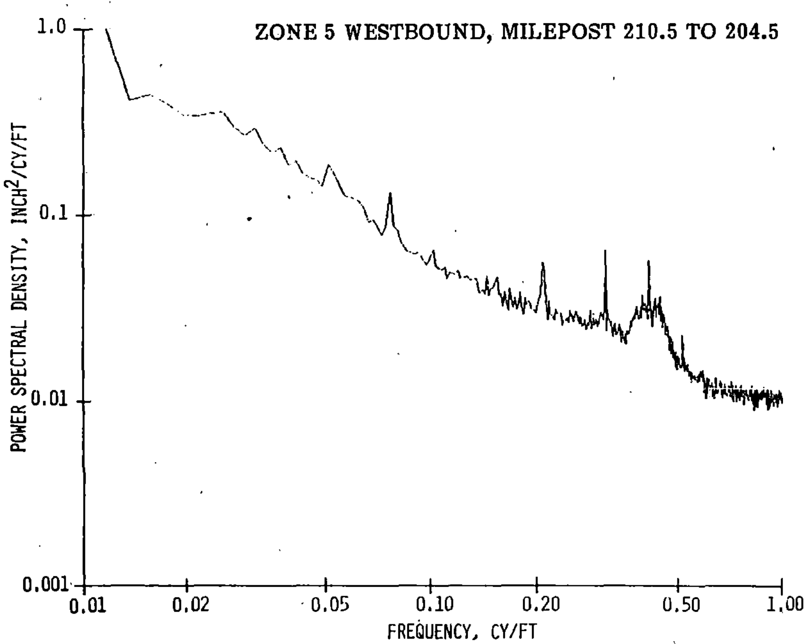


FIGURE B-16. POWER SPECTRAL DENSITY - ZONE 5, CROSSLEVEL

Truck Design Optimization Project: Phase II: Performance Specifications for Type II Trucks, 1981
US DOT, FRA, PV RamaChandran, MM El Madany