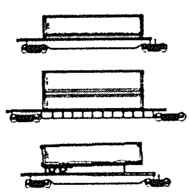
A
TECHNICAL SUMMARY
OF THE
INTERMODAL ENVIRONMENT STUDY

INCORPORATING

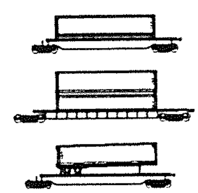
PHASE I:

Trailer-On-Flat-Car (TOFC) Rail Transport



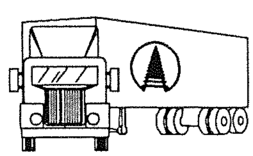
PHASE II:

Articulated COFC Spine Cars,
Articulated Double Stack Well Cars,
Articulated TOFC Spine Cars,
Rail Transport



and

PHASE III:



Interstate, Primary Highway and
Urban Street Truck Transport,
and
Lift-on/Lift-off Intermodal
Ramp Operations

Conducted by:

Association of American Railroads
Operations and Maintenance Department
Casualty Prevention Division
Damage Prevention and Freight Claims

April 1991
Report No. DP 3-91

- *Abstract* -

A comprehensive study of the domestic intermodal freight transport environment was conducted to quantify the shock and vibration influences affecting freight moving via commercial intermodal. Triaxial acceleration data profiling vibration energy spectra and shock severity distribution was collected from the floor of the transport vehicle.

TABLE OF CONTENTS

- EXECUTIVE SUMMARY -

INTRODUCTION:

More than ever, shippers are interested in how to prevent damage to their products. At the same time, the shippers are looking for the most economical ways to package, load and brace shipments in order to reduce costs. Information on the railroad environment provides shippers and their suppliers information with which to make decisions in these areas.

Changes in railroad equipment and operating practices over the last several years have resulted in a need for new data to establish the shock and vibration environment for today's domestic intermodal service.

In order to begin addressing the need for this type of information in the area of intermodal rail shipments, the AAR Freight Claim and Damage Prevention Division undertook a study of the domestic intermodal service environment.

SCOPE:

Equipment/Mode:

The study was divided into three phases. In the first phase, a standard 89' TOFC flatcar was loaded with two trailers and moved in excess of 9,000 miles. The test car was placed at various locations in several dedicated intermodal trains. Mountains, rolling hills and level terrain were traversed along two transcontinental routes, one in the United States and one in Canada.

In the second phase of the study, four loaded standard 40' ISO type containers were entered into dedicated intermodal trains operated in principal U.S. rail corridors. The test containers were moved in doublestack rail cars, on articulated COFC cars and on articulated TOFC cars over a total of more than 10,900 miles.

In the third and final phase of the study a 45' intermodal trailer was moved over 2,600 miles of interstate highway, 1,900 miles of primary (non-interstate) highway and 400 miles of urban streets. Data was also collected for lift-on/lift-off operations at several intermodal ramps.

Methodology:

Throughout the study, shock and vibration data were collected on preprogrammable data recorders. Each of these recorders housed a longitudinal, vertical and lateral (triaxial) accelerometer set.

Two data recorders were installed on each test trailer or container. One of the recorders was programmed to record random data samples at specific time intervals. This provided the random vibration data for the environmental analysis.

The second data recorder was set to record only when acceleration levels exceeded a preset threshold. This recorder provided shock data for each test vehicle.

RESULTS:

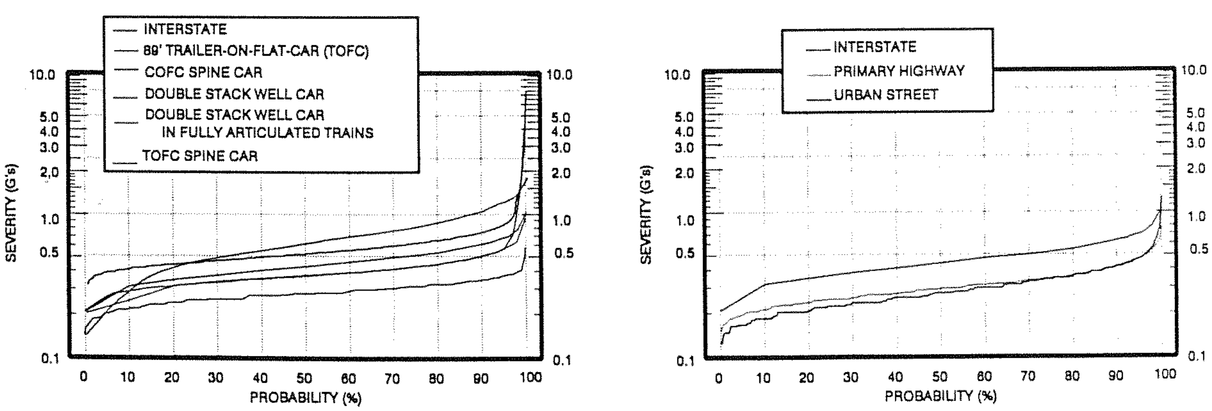
From the **shock** data, the distribution of peak-to-peak acceleration levels were defined for each type of equipment and mode of transport. The shock distributions depicted represent the average of all the data files obtained for a specific equipment type/transport mode. Basically in Figures A-C, graph lines that are higher up in the charts indicate a more severe shock distribution environment than those lines graphed towards the bottom of the chart.

In the longitudinal or lengthwise direction, the standard 89' Trailer-On-Flatcar (TOFC) shock environment was the most severe overall. Note however, that still almost 83% of the shocks observed were less than 1.0 G peak-to-peak. All other modes also compare quite favorably in this orientation.

FIGURE A

AVERAGE PROBABILITY DISTRIBUTION

LONGITUDINAL - PEAK TO PEAK



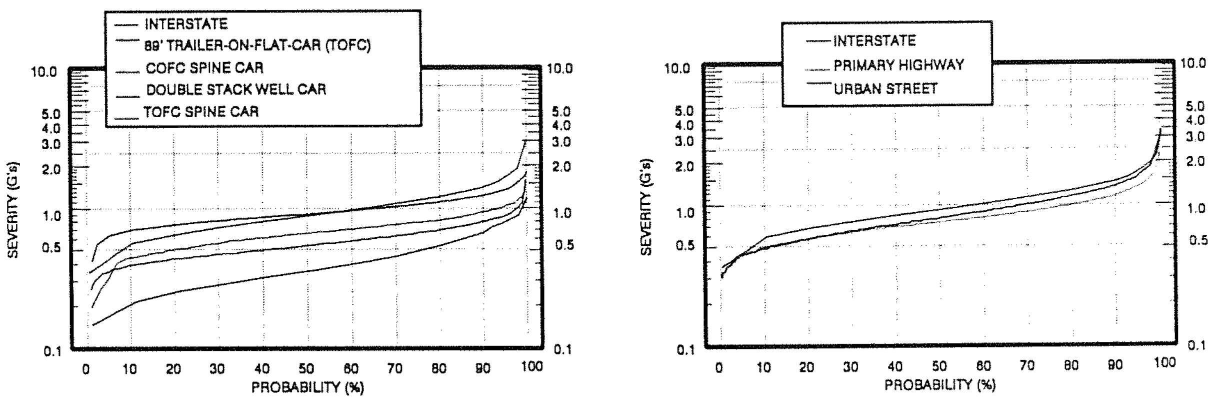
Laterally, or side-to-side shock environments are most severe in the highway modes due to greater truck sway resulting from winds, curbs, road surface irregularities and the effects of inertia during curves.

Double stack rail service outperforms everything in the lateral direction. This is largely attributable to its relative low center of gravity and improved state-of-the-art car suspension systems.

FIGURE B

AVERAGE PROBABILITY DISTRIBUTION

LATERAL - PEAK TO PEAK

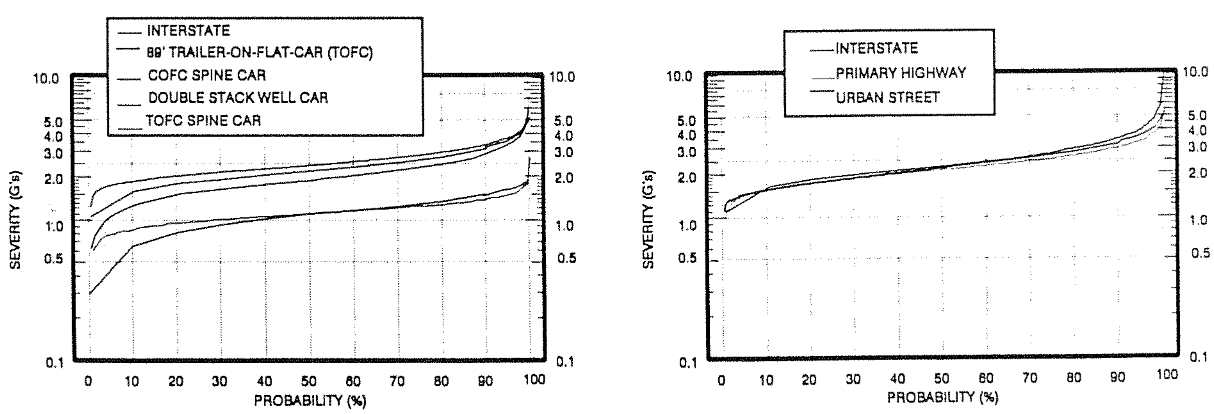


Vertically, the highway and COFC modes are very similar. TOFC modes proved the least severe, attributable to the shock damping influences of both rail car and trailer suspension systems. The shock environment in the vertical orientation is the most severe for each mode of transport.

FIGURE C

AVERAGE PROBABILITY DISTRIBUTION

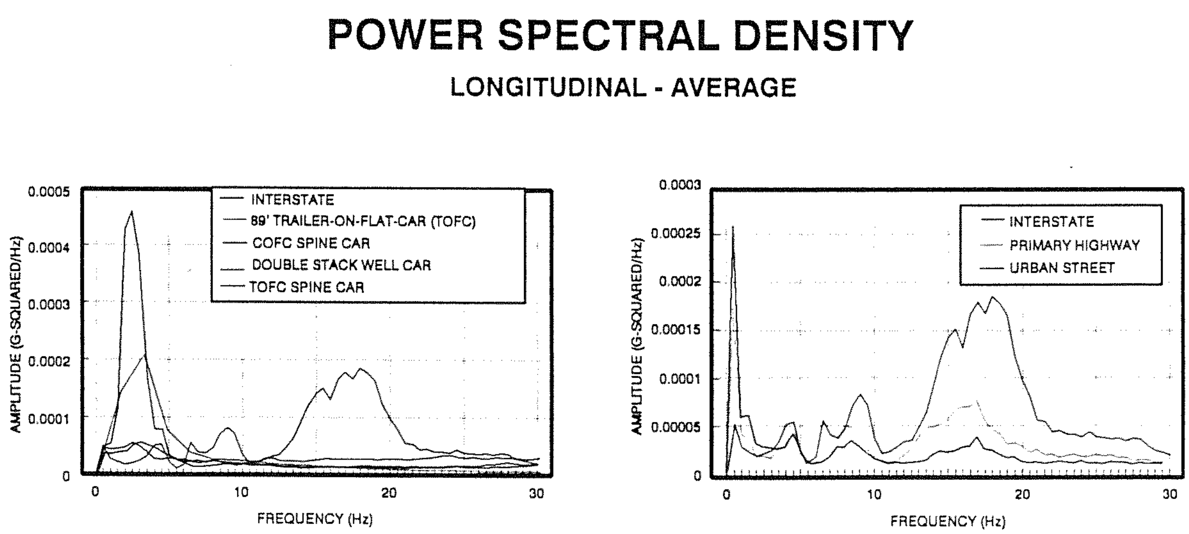
VERTICAL - PEAK TO PEAK



Vibration data was processed to generate cumulative composites of the extreme or maximum power density (energy) levels and also composites of the average power density levels. The latter are presented in Figures D-F for comparison.

In the lengthwise direction, the TOFC spine car exhibited a relatively high energy amplitude between 1 and 4 Hz (Hertz = cycles per second) reflecting "free play" of the trailer in the flatcar hitch. The high amplitudes between 0 and 2 Hz in the Primary Highway and Urban Street modes reflect vibration induced by trailer braking and accelerations. Interstate transport introduces high amplitude vibration between 15 and 20 Hz resulting from trailer body flexure.

FIGURE D

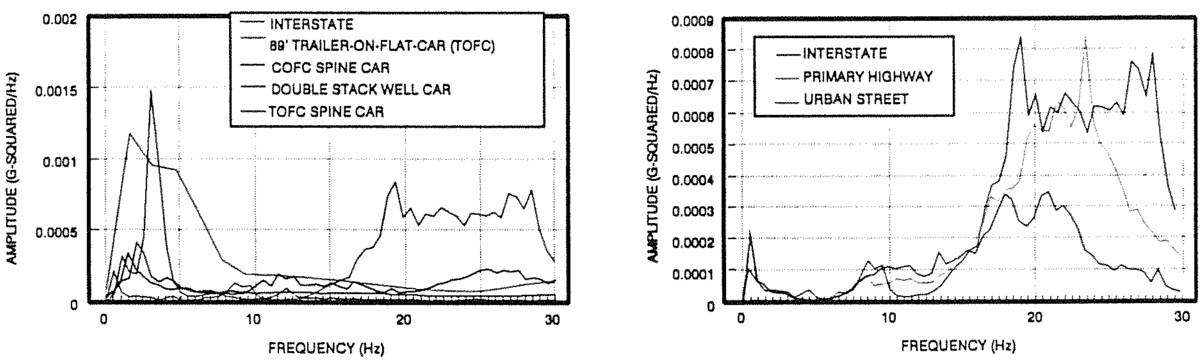


Trailer body structural resonance is most dramatically exhibited in the lateral direction for the highway modes, where the highest power amplitudes occur between 15 and 30 Hz.

FIGURE E

POWER SPECTRAL DENSITY

LATERAL - AVERAGE

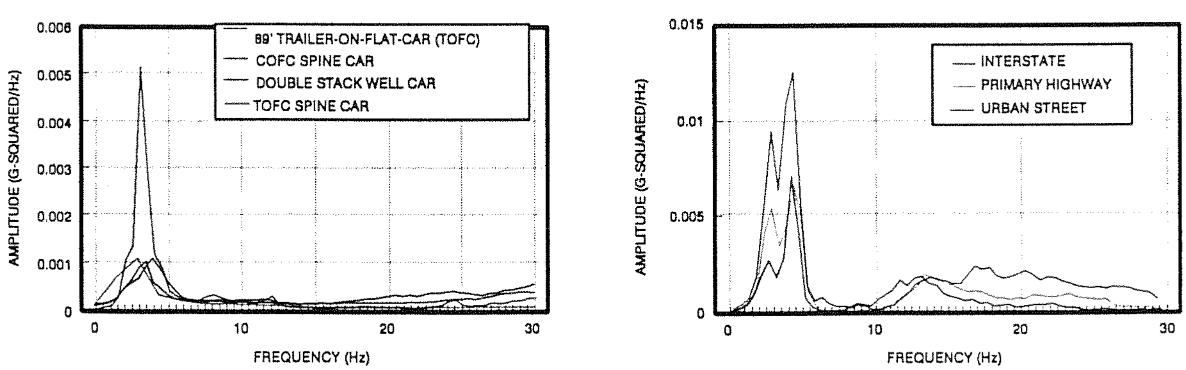


Not surprisingly, vertical vibration amplitudes are greatest between 1 and 6 Hz for the TOFC and highway modes. This is a direct correlation to the trailer suspension's natural frequency. The power amplitude for the TOFC modes are comparable to Urban Street and Primary Highway, while the Interstate vibration amplitudes are over twice as great.

FIGURE F

POWER SPECTRAL DENSITY

VERTICAL - AVERAGE



CONCLUSIONS:

Shipping freight, regardless of the transport modes, subjects it to shock and vibration dynamics which must be accounted for through conscientious packaging, loading, blocking and bracing.

Rail and truck shipping environments are really quite similar. Nominal disparities in the information obtained during this study relate to the basic, inherent differences in the types of services evaluated. Rail shipments experience low vibration effects because of multi-degree energy absorptive damping systems (i.e., rail car and trailer suspensions) and improved roadway. Truck shipments are less likely to experience high amplitude shocks because it is a (comparatively) low mass, single unit system. Intermodal shipments generally must deal with both transport environments.

Technologic advancements have and will continue to improve the transportation environment. Improvements in equipment design, new cost effective materials and methods of packaging and securing freight, and advancements in environmental monitoring systems team together to provide continued refinement of the most efficient intermodal transportation network in the world.

1.0 INTRODUCTION

There has been much research and test work to measure shock and vibration in the past. However, such work has usually been restricted due to such factors as specialized objectives, length of test and choice of instrumentation. This has in some cases led to publication of shock and vibration data that is not truly descriptive of the railroad service conditions. This is particularly true in the area of intermodal rail shipments where the railroad equipment and handling have changed significantly over the last several years.

There is a need for data to establish the railroad shock and vibration environment for comparison with other modes of transportation.

More than ever, shippers are acutely interested in how to prevent damage to their products. At the same time, the shippers are looking for the most economical ways to package, load and brace shipments in order to reduce costs. Information on the railroad environment provides shippers and their suppliers information with which to make decisions in these areas. It is the railroad industry's obligation to make this information available to customers.

In order to begin addressing the need for this type of information, the AAR Freight Claim and Damage Prevention Division conducted a study of the domestic intermodal service environment.

2.0 OBJECTIVES

A test proposal was developed to address the five primary objectives. These were:

- Collect acceleration data from test vehicles to define representative service conditions.
- Produce shock and vibration data that is truly descriptive of the railroad service conditions.
- Establish the rail shock and vibration environment for comparison with other modes of transportation.
- Provide shippers and suppliers rail environment information from which minimum packaging, loading and bracing materials and methods can be designed.

- Provide the rail industry information to assess the effect of forces acting on rail equipment.

This paper presents an overview of the methodology and results of this effort, focusing on vehicle response to the dynamics of transport.

3.0 METHODOLOGY

3.1 GENERAL

3.1.1 Phase I

A standard 89' TOFC car was loaded with two trailers and entered into three separate consecutive test sequences.

During the first sequence, the test car was coupled to a coach car from which technicians recorded detailed shock and vibration data. The test car moved in seven dedicated intermodal trains ranging in length from 22 to 65 cars. It was placed from 2 to 47 cars deep within these trains. 2,638 miles of mainline track was traversed over mountainous, rolling hills and level terrain.

The data collected during this first sequence constitutes Data Set 1. The purpose of this test sequence was to profile specific railroad operating conditions. These findings are presented in "Trailer-on-Flatcar (TOFC) Environment Study" issued December, 1989.

TABLE 1
Phase I - Test Sequence 1 - Trip Segments
Data Set 1

TRIP SEGMENT No. 1	LENGTH OF TRIP SEGMENT			TERRAIN	LENGTH/POSITION IN TRAIN
	MILES	HOURS	AVG MPH		
1	64	1:50	34.9	Flat	1/37
2	184	3:50	48.0	Flat	6/27
3	189	4:50	39.1	Flat	12/22
4	148	2:40	55.6	Gentle Rolling	4/49
5	1138	33:30	34.0	Flat to Mountainous	47/65
6	497	13:30	36.8	Rolling to Mountainous	4/30
7	418	9:13	45.2	Mountainous	4/25
TOTALS	2638	67:33	38.1		

Data was obtained from a total of 10.98% of the first test sequence.

During the second sequence, shock and vibration data was collected from the test car by six preprogrammed data recorders. The data was uploaded from these recorders at specific intervals during the sequence. The test car moved in nine different trains ranging in length from 4 to 88 cars. It was placed from 4 to 88 cars deep within these trains. 9,282 miles of mainline track was traversed along two different trans-continental routes, one across the United States and one across Canada.

In the third test sequence, one of the test trailers was unloaded from the test car and trucked 1,083 miles over Interstate highway back to the point of origin. During this third sequence (Trip Segment #8), shock and vibration data was collected from the preprogrammable data recorders.

The data obtained from the preprogrammable data recorders during Test Sequences 2 and 3 constitutes Data Set 2. This data was collected in the same format as that obtained in Phase II and III for comparison.

TABLE 2
Phase I - Test Sequences 2 and 3 - Trip Segments
Data Set 2

TRIP SEGMENT #	LENGTH OF TRIP SEGMENT			TERRAIN	POSITION OF TEST CAR/LENGTH OF TRAIN
	MILES	HOURS	AVG MPH		
1	718	unk.		Flat	-
2	989	27:40	55.4	Flat	42/75
3	2080	40:44	51.0	Flat to Rolling Plains	38/38
4	1383	43:55	31.4	Rolling Plains	88/88
5	1138	38:20	34.6	Flat to Mountainous	47/65 **
6	1500	31:03	42.6	Flat to Mountainous	4/34 *
7	1474	49:00	30.0	Mountainous	46/49
TOTALS	9282				
8	1083	18:20	59.1	Flat to Mountainous	Highway

* Average of 5 different trains.
** Represents position for 85.8% of Test Segment

3.1.2 Phase II

Four loaded, standard 40' ISO type containers were entered into dedicated intermodal trains operated in principal U.S. rail corridors. For three of the trip segments, the containers were loaded onto articulated COFC spine cars. For another three trip segments, the containers were loaded into articulated double stack rail cars. For one trip segment, the containers were placed on chassis and then loaded onto an articulated TOFC spine car.

TABLE 3
Phase II - Trip Segments

TRIP SEGMENT #	LENGTH OF TRIP SEGMENT		AVG SPEED (MPH)	EQUIPMENT TYPE	EVENTS/MILE *	% TRIP SAMPLED
	MILES	HOURS				
1	815	31:54	25.5	COFC Spine Car	8.82	5.68
2	1546	56:41	27.3	COFC Spine Car	6.93	3.20
3A	451	10:30	43.0	COFC Spine Car	11.35	7.91
3B	574	11:39	49.3			
3C	180	4:15	42.4			
4A	1997	66:16	30.1	Double Stack Well Car	17.10	2.43
4B	354	13:36	26.2			
4C	167	7:13	23.1			
5	772	32:52	23.5	Double Stack Well Car	12.89	5.92
6A	1478	48:47	30.3	Double Stack Well Car	12.04	3.20
6B	488	15:42	31.0			
7A	1846	48:03	38.4	TOFC Spine Car	2.95	3.32
7B	377	10:30	35.9			

*** The number of Events per Mile is a ratio of the number of times the 0.5 G recording trigger threshold was exceeded per mile traveled.**

Some trip segments required the test containers move in more than one train. These were differentiated in Table 3 to accurately relate the service conditions under which the containers moved.

Table 4 references the test containers position on the rail cars for each train in each trip segment. The second column references the car position in the train and its length, by the total number of cars. Note that each five platform articulated rail car is considered one car only. The third column references the number of articulated cars in the train and the position of the test car relative to other articulated equipment. The alpha designation indicates the platform or well the container occupied. Car platform designations are illustrated in Figures 1-3.

TABLE 4

TRIP SEGMENT #	POSITION/LENGTH IN TRAIN (# OF CARS)	NUMBER/POSITION ARTICULATED CARS	CONTAINER POSITION			
			CONTAINER #1	CONTAINER #2	CONTAINER #3	CONTAINER #4
1	20th of 53	1st of 6	B	A	D	E
2	38th of 56	5th of 5	B	D	E	A
	30th of 50	1st of 1	B	D	E	A
	11th of 47	1st of 5	B	D	E	A
3A	2nd of 22	1st of 9	B	C	E	A
3B	26th of 33	1st of 2	B	C	E	A
3C	33rd of 40	1st of 2	B	C	E	A
4A	18th of 27	18th of 27	A-2	B-2	A-1	B-1
4B	1st of 113	1st of 1	E-1	D-1	A-1	B-1
4C	33rd of 73	1st of 1	E-1	D-1	A-1	B-1
5	40th of 58	3rd of 10	D-1	B-1	A-1	E-1
	21st of 39	3rd of 10	D-1	B-1	A-1	E-1
6A	7th, 9th & 10th* of 11	7th, 9th & 10th	10th Car, A-1	9th Car, A-1	7th Car, B-1	9th Car, B-1
6B	20th & 21st* of 27	20th & 21st of 27		20th Car, A-1	21st Car, B-1	20th Car, B-1
	1st of 20	1st of 20	1st Car, A-1+			
7A	16th of 16	4th of 4	B	C	A	E
7B	9th of 22	2nd of 3	B	C	A	E

*** During Trip Segment #6, the containers were loaded on different rail cars.**

+ The car onto which Container #1 was placed was set out while enroute and moved on a different train for approximately one fourth of the trip segment.

3.1.3 Phase III

One loaded standard 45' intermodal trailer was used for all test segments. The trailer was moved over three types of roadway (interstate highway, primary highway and urban streets). Total mileage over all three types of roadway was 5,010 miles. Photo No. 2 is a view of the test trailer and tractor used. See Table No. 5 for over-the-highway information.

TABLE 5
Phase III - Trip Segments

Trip Segment	Segment		Avg. Speed
	Miles	Hours	
Interstate	2650	43:10	61
Primary	1932	43:75	44
Urban Streets	428	19:50	22

3.2 TEST EQUIPMENT

3.2.1 Phase I

TTX 160539 is an 89' TOFC car with standard draft gears and cushioned hitches. Its' light weight is 66,900 lbs.

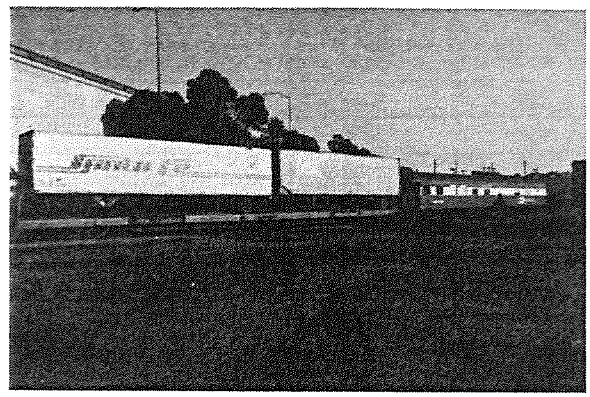


Photo No. 1 - Test car with coach in L.A. Yards.

Trailer SFVZ 252562 is a 45' x 96" general service dry van weighing 12,600 lbs. It was loaded with 48,100 lbs. of palletized cased goods secured by a wooden gate. This trailer was loaded on the 'B' end stanchion.

Trailer AARZ is a 40' x 96" general service dry van weighing 12,600 lbs. It was loaded with approximately 49,000 lbs. of palletized cinder block secured by steel strap barriers. This trailer was loaded on the 'A' end hitch of TTX 160539.

BNA-8, 'The Canadian River', is a 90' passenger car. It housed the data collection system used during the first test sequence. It was coupled to the 'A' end of the test car.

3.2.2 Phase II

Containers - Four 40′ x 8′ steel ISO type containers were used. Container #'s 1 and 2 were loaded with 45,500 lbs. of palletized cased goods. Container #'s 3 and 4 were loaded with 44,100 lbs. of palletized cinder block. The light weight of Container #'s 1 and 4 was 9,150 lbs.; Container #2 - 9,248 lbs.; and Container #3 - 8,223 lbs.

Each load was similarly braced with a wood end gate, floor blocking and reinforcing diagonals.

Railcars - The containers were transported by rail cars used in everyday rail service. No special constraints were imposed on the type or condition of equipment used.

Articulated COFC Spine Cars - These are skeletonized, five unit articulated, single stack COFC cars approximately 250′ long.

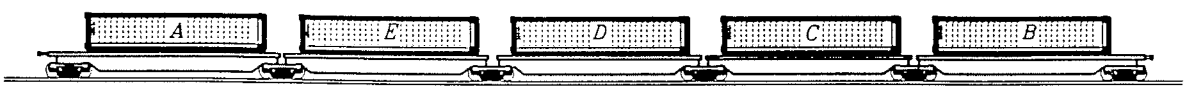


FIGURE 1

Articulated Double Stack Well Cars - These are five unit, articulated, well type COFC cars capable of carrying containers stacked two high.

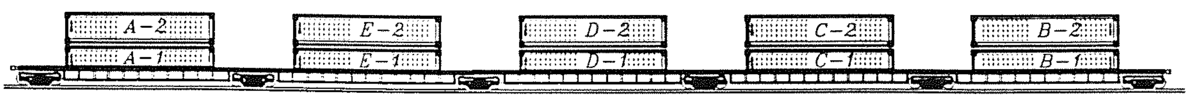


FIGURE 2

Articulated TOFC Spine Cars - These are skeletonized, five unit, articulated cars capable of carrying trailers or containers on chassis.

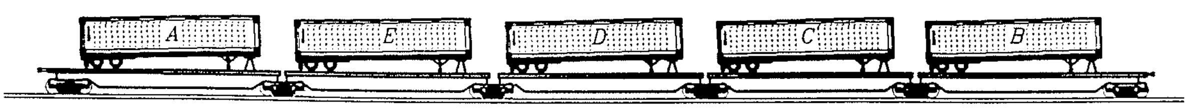


FIGURE 3

3.2.3 Phase III

One standard 45' x 102" trailer, BNZ 237804 (lt. wt. = 12,500 lbs.), was loaded with 40,280 lbs. of palletized cased goods. The load was braced with two wood end gates four feet off the nose and two at the doors. Total weight of trailer and tractor was 71,460 lbs.

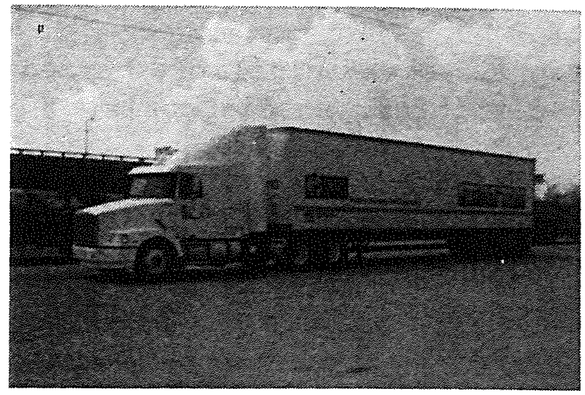


Photo No. 2
View of test trailer and tractor.

During the collection of urban street data, time was set aside for monitoring lift-on/lift-off operations at various rail yards utilizing the test trailer. Two types of lifting equipment were used. See Photo Nos. 2 and 3.

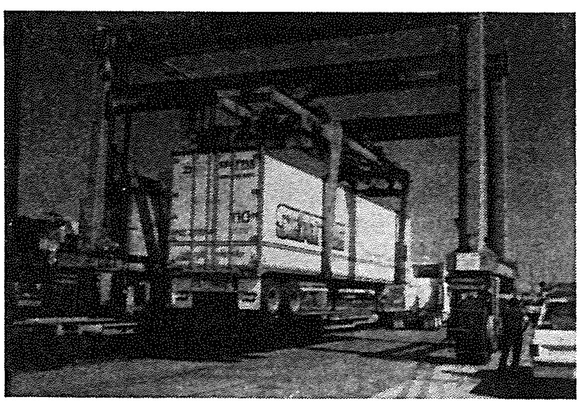


Photo No. 3
View of typical overhead (gantry style) crane.

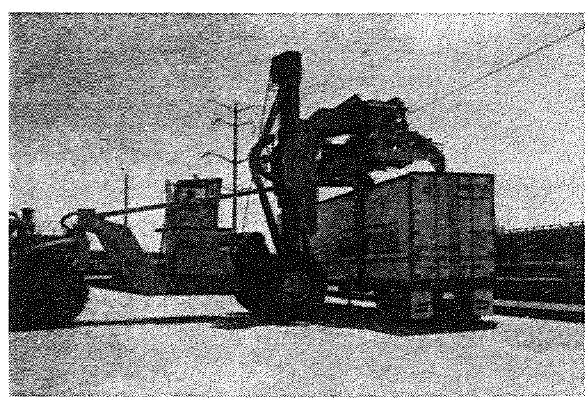


Photo No. 4
View of one type of sideloader equipment used.

3.3 DATA COLLECTION SYSTEMS

3.3.1 Phase I

Data Set #1

For the first sequence, digital data was collected from 18 acceleration transducers on an HP 9826 computer. See Table 6, Transducer Index. Signals were sampled at 128 samples/second, filtered at 30 Hz.

Lading accelerations were recorded for reference purposes only. These acceleration levels will not be evaluated in this report as they are unique to their respective lading types.

The last three accelerometers listed in Table 6 (ALV1, ARV2, AL3) comprise a "Locomotive Track Hazard Detection" (LTHD) package. The signals collected from these are to generate input files to drive the Vibration Test Unit (VTU) at the Transportation Test Center (TTC) for simulation testing.

Photo No. 5 - HP Data Collection and Support Systems in coach car.

TABLE 6
Transducer Index
Phase I - Data Set 1 - Trip Sequence 1

Acronym	Description	Location
AY1	Accel.-Carbody longitudinal	B' end over striker plate
AY2	Accel.-Trailer 1 longitudinal	Floor underside, centered over tandems
AY3	Accel.-Trailer 2 longitudinal	Floor underside, centered over tandems
AY4	Accel.-Lading in Trailer 1 longitudinal	Top of lading over AY2
AY5	Accel.-Lading in Trailer 2 longitudinal	Top of lading over AY3
AZ6	Accel.-Carbody vertical	Mid deck, centered beneath AY3
AZ7	Accel.-Trailer 1 vertical	Floor underside, centered over tandems
AZ8	Accel.-Trailer 2 vertical	Floor underside, centered over tandems
AZ9	Accel.-Lading in Trailer 1 vertical	Top of lading over AY2
AZ10	Accel.-Lading in Trailer 2 vertical	Top of lading over AY3
AX11	Accel.-Carbody lateral	Mid deck, centered beneath AY3
AX12	Accel.-Trailer 1 lateral	Floor underside, centered over tandems
AX13	Accel.-Trailer 2 lateral	Floor underside, centered over tandems
AX14	Accel.-Lading in Trailer 1 lateral	Top of lading over AY2
AX15	Accel.-Lading in Trailer 2 lateral	Top of lading over AY3
ALV1	Accel.-LTHD left vertical	B' end no. 1 axle
ARV2	Accel.-LTHD right vertical	B' end no. 1 axle
AL3	Accel.-LTHD lateral	B' end no. 1 axle
TSPD	Tach.-Train Speed	B' end no. 2 axle

The analysis of this data concentrated on car and trailer response derived from transducers AY2, AY3, AZ6, AZ7, AZ8, AX11 and AX13.

Three types of data files were created.

The first type of file created ranged from two to forty-four minutes in length. These were taken as 'representative' or typical of service conditions experienced by the test car. Specific samples were taken of long grades traversed up and downhill, crests, curves, as well as tangent level track. These files were called **ALL DATA'S**.

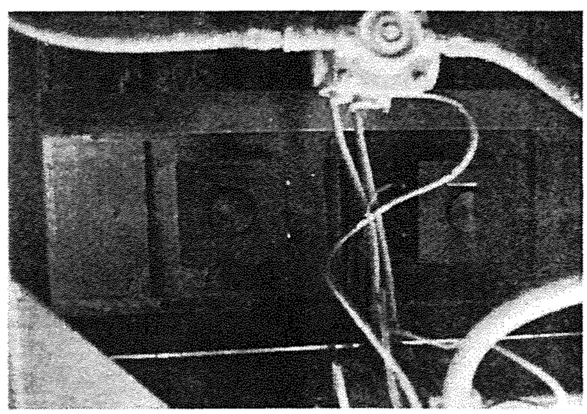
The second type is a nine second sample (1,150 data points per channel) taken at the test engineers discretion. These files contain known hunting, buff and draft, crossovers, switches and coupling events. These files are called **MANUAL ALD'S**.

The third type of data file was created whenever the acceleration level of channel AY1, longitudinal carbody, exceeded ± 0.5 G's, <u>or</u> when AX13, lateral - Trailer No. 2, exceeded ± 0.34 G's. These files consisted of 1,024 data points per channel surrounding the peak excursion(s). These are called **THRESHOLD** files.

These three file types constitute Data Set No. 1, and were recorded over Test Sequence 1. The purpose of this test sequence was to profile specific railroad operating conditions. These findings are presented in "Trailer-on-Flatcar (TOFC) Environment Study" issued in December, 1989 and are not reported herein.

Data Set #2

Throughout all three test sequences, shock and vibration data was collected on six preprogrammable data recorders. Each of these recorders housed a longitudinal, vertical and lateral (triaxial) accelerometer set. Two recorders were secured to each trailer on the underside of the floor directly over the tandem axle suspension. The two remaining were mounted to the underside of the rail car deck mid length of the car at the right side rail. See Table 7, Recorder Index.



<u>Photo No. 6</u> - Preprogrammable data recorders mounted under Trailer 1.

At each location, one of the recorders was programmed to record random data files at specific time intervals while the other was set to record only when acceleration levels exceeded a pre-set threshold. The triaxial threshold for the trailers was set at ± 0.5 G's and for the rail car at ± 1.5 G's. All six recorders were programmed to record 0.5 second files at 1600 Hz.

TABLE 7
Recorder Index
Phase I - Data Set 2 - Trip Sequences 1-3

Recorder #	Description	Location
1	Triaxial accel., Trailer 1 time trigger	Floor underside, centered over tandems
2	Triaxial accel., Trailer 1 event trigger	Floor underside, centered over tandems
3	Triaxial accel., Trailer 2 time trigger	Floor underside, centered over tandems
4	Triaxial accel., Trailer 2 event trigger	Floor underside, centered over tandems
5	Triaxial accel., Carbody time trigger	Mid deck at right side rail
6	Triaxial accel., Carbody event trigger	Mid deck at right side rail

Note: Recorder #4 was lost during the second test sequence. An adjustment was made to the base data collection plan to obtain the maximum amount of data from the test trailers. The carbody random data recorder (#5) was then used to record trailer event excursions.

3.3.2 Phase II

Each container had two electronic preprogrammable data recorders bolted to their floor, four feet in from the door threshold, laterally centered. Each of these recorders housed a longitudinal, vertical and lateral (triaxial) accelerometer set. One of these recorders was programmed to record random data files at specific time intervals while the container was in motion. The other was set to record data only when acceleration levels exceeded preset criteria.

The random (vibration) data recorders were programmed to record two second data files at 256 samples per second. A 0.1 G trigger level was assigned these recorders to prevent collection of data while the containers were stationary.

The event (shock) data recorders were also programmed to record two second data files at 256 samples per second. Recording was triggered when the acceleration level on any axis exceeded 0.5 G's for more than 15.6 milliseconds.

3.3.3 Phase III

Over-the-Highway

The test trailer had two electronic preprogrammable data recorders (as used in Phase I and II) bolted to the floor, four feet in from the door threshold, laterally centered. One of these recorders was programmed to record random data samples at specific time intervals while the trailer was in motion. The other was programmed to record data only when acceleration levels exceeded preset criteria. Recording parameters were the same as used in Phase II. The random (vibration) data recorders were programmed to record two second data files at 256 samples per second. A 0.1 G trigger level was assigned to prevent collection of data while the trailer was stationary.

The event (shock) data recorders were also programmed to record two second data files at 256 samples per second. Recording was triggered when the acceleration level on any axis exceeded 0.5 G's for more than 15.6 milliseconds.

Lift-on/Lift-off

One data recorder was used to collect lift-on/lift-off data. The recorder was positioned in the trailer in the same location as the over-the-highway test.

This recorder was programmed to record 7.7 second data files at 256 samples per second. Recording was triggered when the acceleration level on any axis exceeded 0.1 G for more than 3.9 milliseconds. These recording parameters were set in an attempt to collect data virtually continuous, as long as the trailer was in motion during the lift-on/lift-off operation.

4.0 DATA ANALYSIS: Phases I-III

Separate reports have been issued in which the data of each test phase has been analyzed. Data files from Phase I, Data Set 2, and Phases II and III were collected and processed under similar format enabling comparison of most key elements.

Significant anomalies exist between the data collected in Phase I, Test Sequence 3 - Interstate and Phase III - Interstate. Refer to the Discussion in 5.0 OBSERVATIONS.

The analysis of shock data presented herein reflects both Phase I and Phase III Interstate data. The analysis of vibration data reflects only Phase III data.

4.1 SHOCK SUMMARY (Event Data Files)

For all phases of testing, data recorders were programmed to record the most severe transient acceleration levels greater than 0.5 G's and having a pulse duration of at least 15.6 milliseconds in any axis of orientation. Table 8 summarizes the shock distribution for all modes investigated. Table 9 presents the average number of times a specified shock level was exceeded for each axis orientation per 1,000 miles.

TABLE 8
Shock Distribution Summary

Equipment Type		Average Number of Events Per Mile	% Exceeding 0.5 G Peak Acceleration Threshold		
			Longitudinal	Lateral	Vertical
Rail	89' TOFC	0.084	13.2	4.4	53.8
	COFC Spine Car	9.86	2.4	6.1	99.8
	Double Stack Well Car	14.59	0.7	3.9	94.3
	TOFC Spine Car	2.95	0	14.1	79.6
Truck	Interstate	9.33	7.8	36.4	95.8
	Primary Highway	6.36	< 0.1	27.0	97.0
	Urban Streets	7.52	< 0.1	21.6	94.1

TABLE 9
Average Number of Shocks per 1,000 Miles

	Equipment Type	Avg. Number of Longitudinal Events Greater Than or Equal to 1.0 G Peak per 1,000 Miles	Avg. Number of Lateral Events Greater Than or Equal to 1.0 G Peak per 1,000 Miles	Avg. Number of Vertical Events Greater Than or Equal to 2.0 G's Peak per 1,000 Miles
Rail	89' TOFC	2.19	0.57	0
	COFC Spine Car	5.24	0.48	25.28
	Double Stack Well Car	6.39	2.72	12.07
	TOFC Spine Car	0	0	0.11
Truck	Interstate	1.61	36.97	55.72
	Primary Highway	0	15.01	48.14
	Urban Streets	2.34	70.09	161.21

Table 10 statistically compares the shock data base.

TABLE 10
Statistical Summary - Shock Data Files
Peak G's

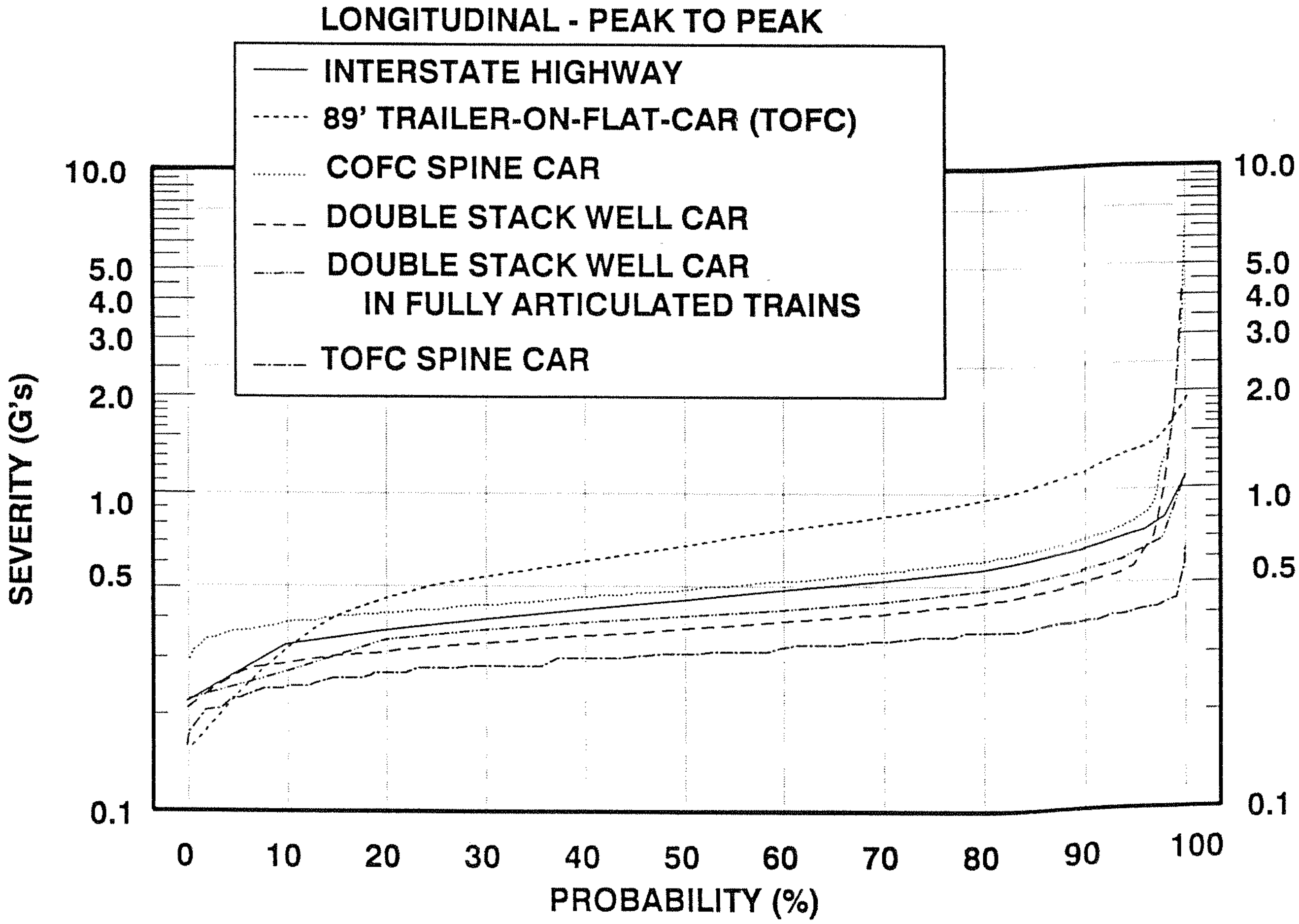
	Equipment Type	Longitudinal			Lateral			Vertical		
		Mean	Std Dev	Mean RMS	Mean	Std Dev	Mean RMS	Mean	Std Dev	Mean RMS
Rail	89' TOFC	0.31	0.20	0.09	0.20	0.15	0.08	0.41	0.15	0.18
	COFC Spine Car	0.29	0.23	0.08	0.32	0.10	0.09	1.30	0.34	0.38
	Double Stack Well Car	0.22	0.17	0.06	0.46	0.12	0.15	1.05	0.36	0.30
	TOFC Spine Car	0.16	0.04	0.06	0.38	0.12	0.17	0.60	0.13	0.21
Truck	Interstate	0.27	0.07	0.08	0.51	0.19	0.15	1.14	0.32	0.34
	Primary Highway	0.16	0.05	0.04	0.42	0.17	0.11	1.11	0.34	0.30
	Urban Street	0.14	0.06	0.04	0.42	0.18	0.11	1.03	0.44	0.26

The distribution of peak to peak acceleration levels were defined for each type of equipment and mode of transport. From these, **average** probability distributions were derived, by axis, for peak to peak accelerations. The shock distributions depicted in Figures 4-9 represent the average of all the data files obtained for a specific equipment type/transport mode. Therefore, specific discrete events, such as extreme maximum/minimum accelerations are not in evidence.

Shock distributions are differentiated by transport mode. Interstate distributions are included on rail mode distributions for comparison of long haul transport modes.

FIGURE 4

AVERAGE PROBABILITY DISTRIBUTION



Data obtained from double stack well cars while in fully articulated trains was differentiated because of the disparity in extremes of longitudinal acceleration.

FIGURE 5

AVERAGE PROBABILITY DISTRIBUTION

LONGITUDINAL - PEAK TO PEAK

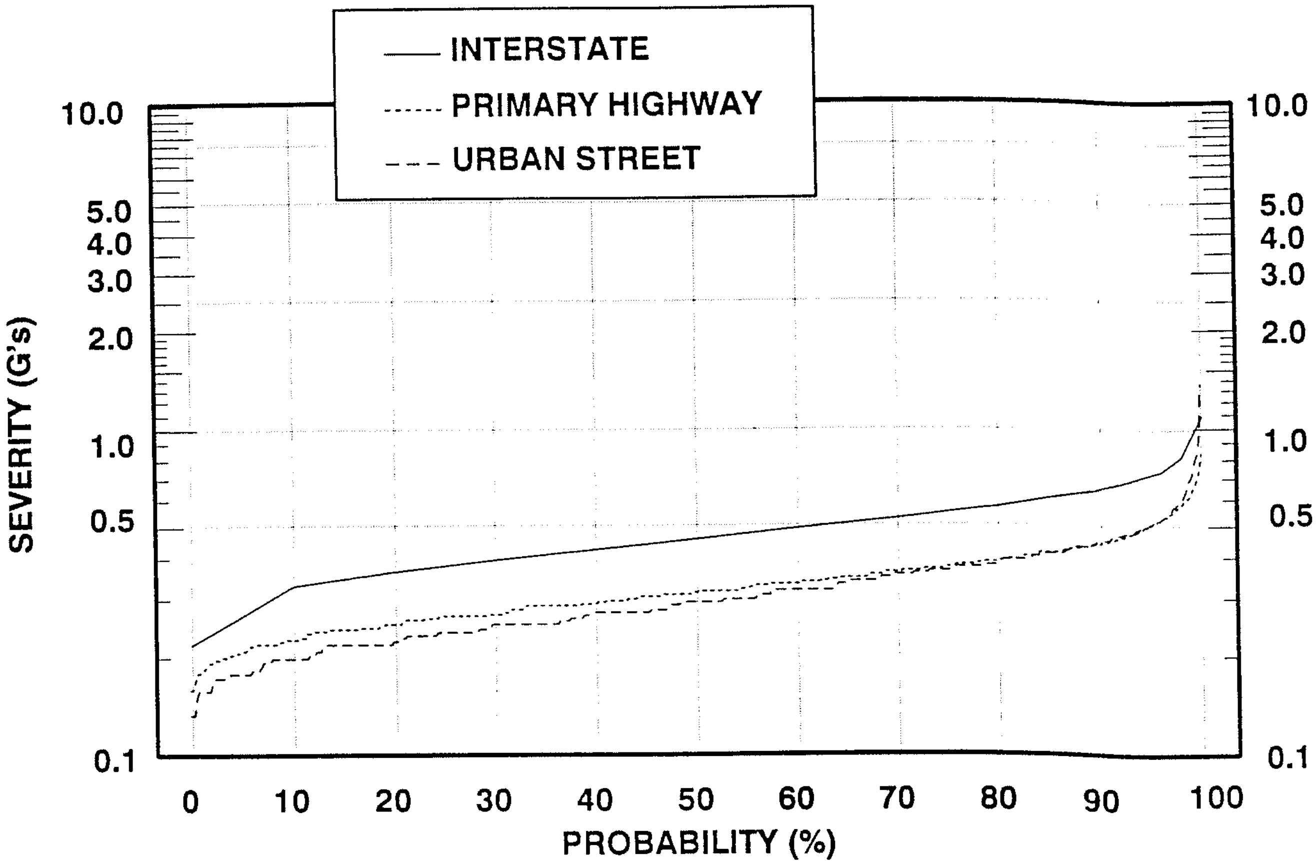


TABLE 11

Comparison of Longitudinal Shock Distribution by Percent of Total at Comparative Acceleration Levels

	Equipment Type	≤ 0.3 G	≤ 0.5 G	≤ 1.0 G	Extreme *
Rail	89' TOFC	9.2	24.5	82.9	1.92
	COFC Spine Car	0.3	52.0	97.3	6.66
	Double Stack Well Car	14.7	89.9	98.5	4.13
	Double Stack Well Car in Articulated Trains	14.3	82.7	99.9	1.03
	TOFC Spine Car	44.4	99.4	100	0.64
Truck	Interstate	16.8	64.7	99.2	1.12
	Primary Highway	44.4	94.8	100	0.82
	Urban Street	56.1	94.8	99.9	1.35

*** Maximum acceleration level presented in Figures 4 and 5.**

FIGURE 6

AVERAGE PROBABILITY DISTRIBUTION

LATERAL - PEAK TO PEAK

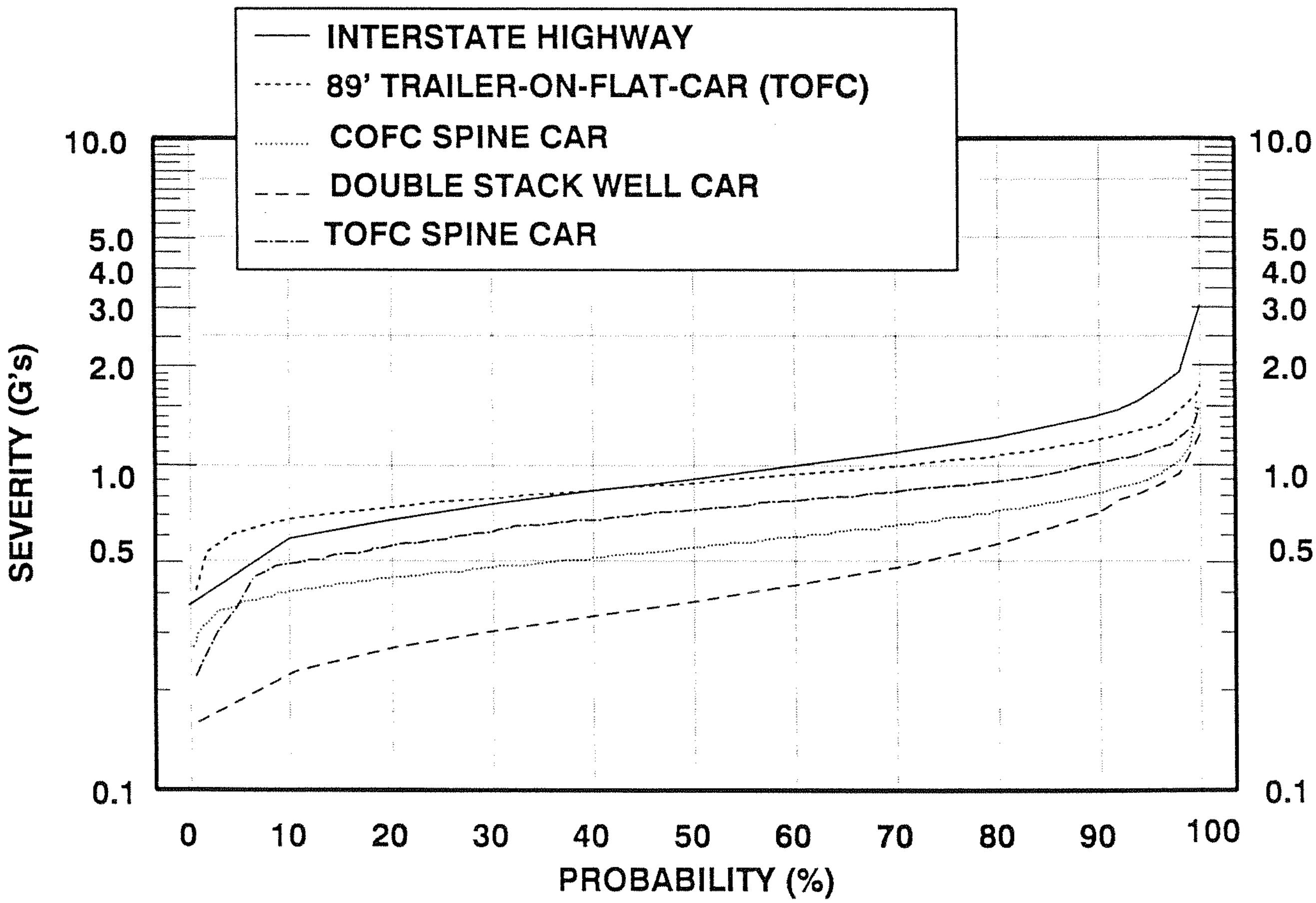


FIGURE 7

AVERAGE PROBABILITY DISTRIBUTION

LATERAL - PEAK TO PEAK

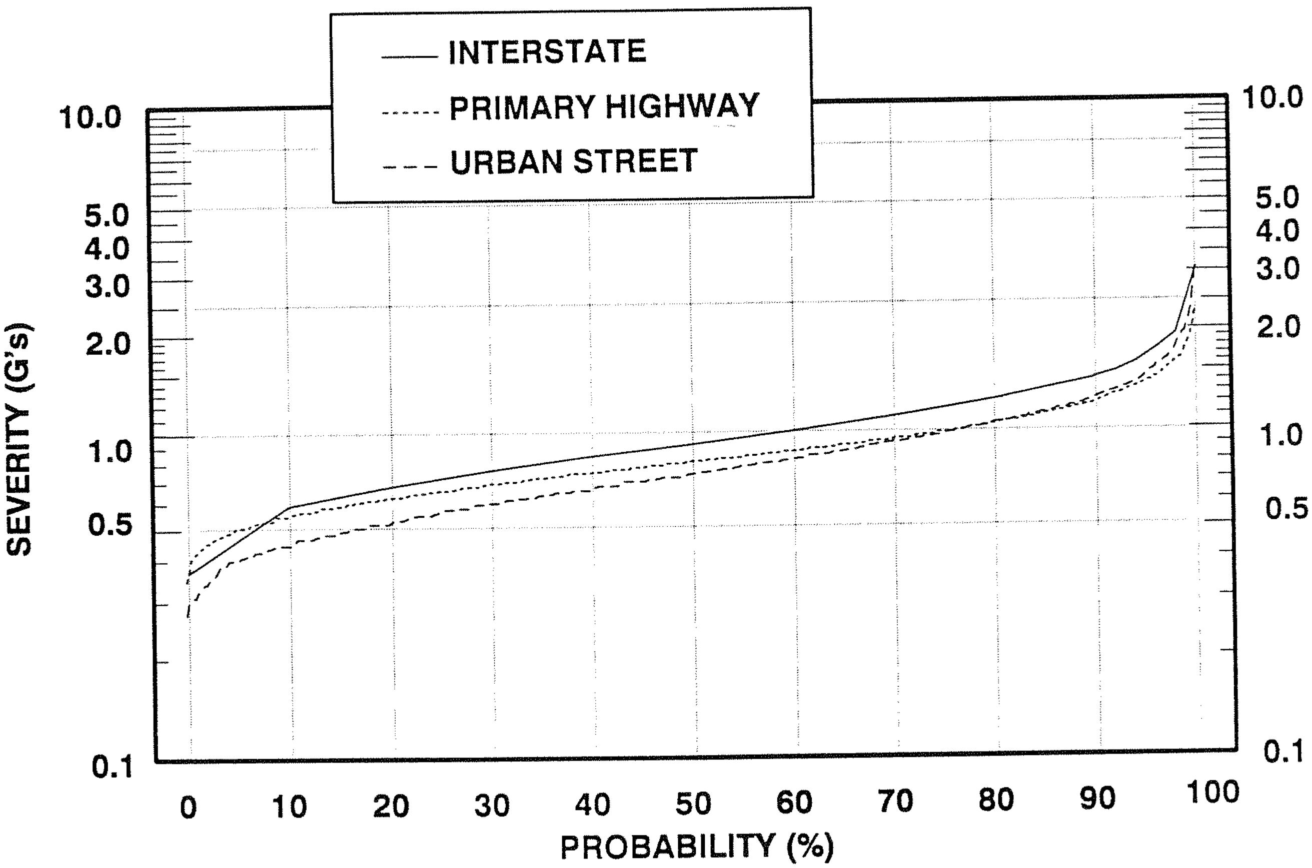


TABLE 12

Comparison of Lateral Shock Distribution by Percent of Total at Comparative Acceleration Levels

	Equipment Type	≤ 0.5 G	≤ 1.0 G	≤ 1.5 G	Extreme *
Rail	89' TOFC	1.4	69.5	97.0	1.76
	COFC Spine Car	28.6	96.7	99.8	1.69
	Double Stack Well Car	0.5	63.7	97.9	2.20
	TOFC Spine Car	7.8	86.6	99.8	1.55
Truck	Interstate	4.5	60.0	92.8	3.22
	Primary Highway	6.3	78.7	97.3	2.28
	Urban Street	17.7	78.7	95.9	2.97

* Maximum acceleration level presented in Figures 6 and 7.

FIGURE 8

AVERAGE PROBABILITY DISTRIBUTION

VERTICAL - PEAK TO PEAK

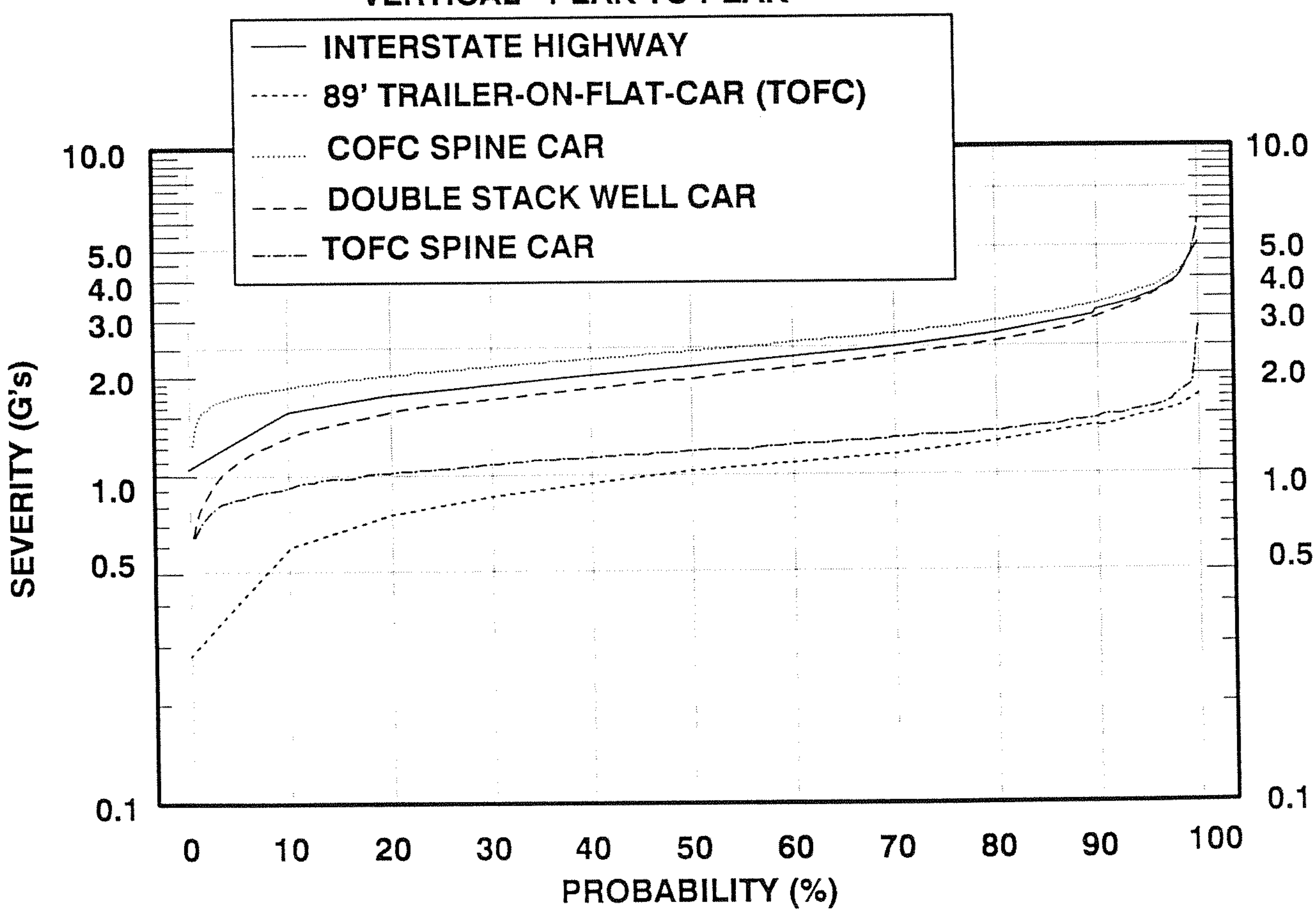


FIGURE 9

AVERAGE PROBABILITY DISTRIBUTION

VERTICAL - PEAK TO PEAK

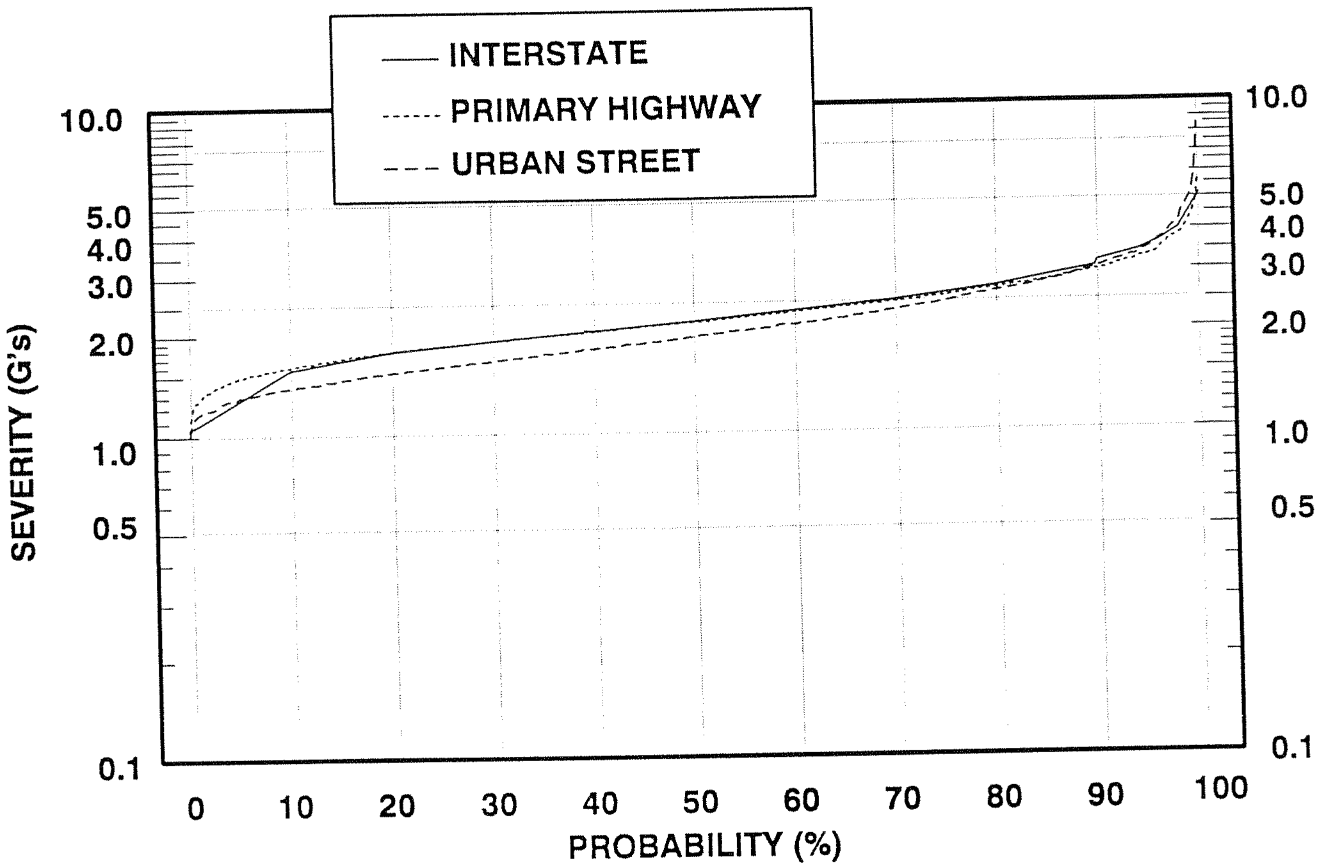


TABLE 13

Comparison of Vertical Shock Distribution by Percent of Total at Comparative Acceleration Levels

	Equipment Type	≤ 1.5 G	≤ 3.0 G	≤ 4.5 G	Extreme *
Rail	89' TOFC	95.8	100	100	1.72
	COFC Spine Car	0.8	82.1	99.2	6.17
	Double Stack Well Car	15.3	90.0	99.3	6.06
	TOFC Spine Car	90.4	100	100	2.87
Truck	Interstate	8.4	69.8	99.3	5.14
	Primary Highway	6.5	91.1	94.4	5.58
	Urban Street	20.2	90.0	98.3	8.32

* Maximum acceleration presented in Figures 8 and 9.

4.2 VIBRATION SUMMARY (Random Data Files)

For all phases of testing, data recorders were programmed to record intermittent bursts of representative (or random) vibration acceleration. For Phases II and III, a threshold exceedance criteria of 0.1 G was programmed to assure that data samples would not be collected when the test equipment was stationary. This threshold criteria was not used during Phase I. As such, Phase I vibration data is not statistically comparable.

Table 14 statistically compares the random vibration data base.

TABLE 14
Statistical Summary - Vibration Data Files
Peak G's

Equipment Type		Longitudinal			Lateral			Vertical		
		Mean	Std Dev	Mean RMS	Mean	Std Dev	Mean RMS	Mean	Std Dev	Mean RMS
Rail	COFC Spine Car	0.11	0.12	0.03	0.19	0.11	0.06	0.47	0.30	0.14
	Double Stack Well Car	0.09	0.14	0.04	0.25	0.17	0.09	0.40	0.27	0.12
	TOFC Spine Car	0.08	0.05	0.03	0.12	0.09	0.04	0.28	0.17	0.10
Truck	Interstate (Phase III)	0.11	0.06	0.03	0.31	0.16	0.09	0.67	0.40	0.20
	Primary Highway	0.09	0.05	0.03	0.30	0.18	0.09	0.54	0.54	0.16
	Urban Street	0.07	0.05	0.02	0.16	0.13	0.04	0.38	0.38	0.12

Random vibration data files were then compared in terms of average frequency of occurrence of peak RMS acceleration. RMS acceleration takes into account the time history of the waveform of a data file and gives an amplitude value which is directly related to the energy content, and therefore the destructive abilities of the vibration. For these distributions, a bin width of 0.05 G-RMS was used. Figures 10 - 15 compare the peak RMS level distribution by equipment type/transport mode for each axis.

FIGURE 10

RMS ACCELERATION DISTRIBUTION

LONGITUDINAL

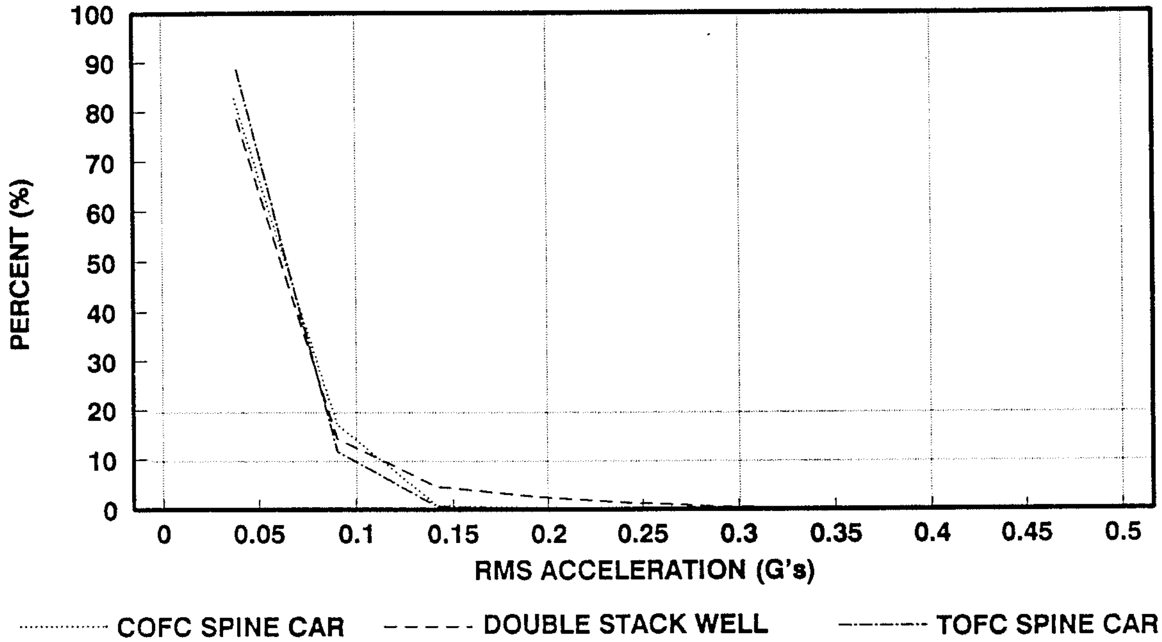
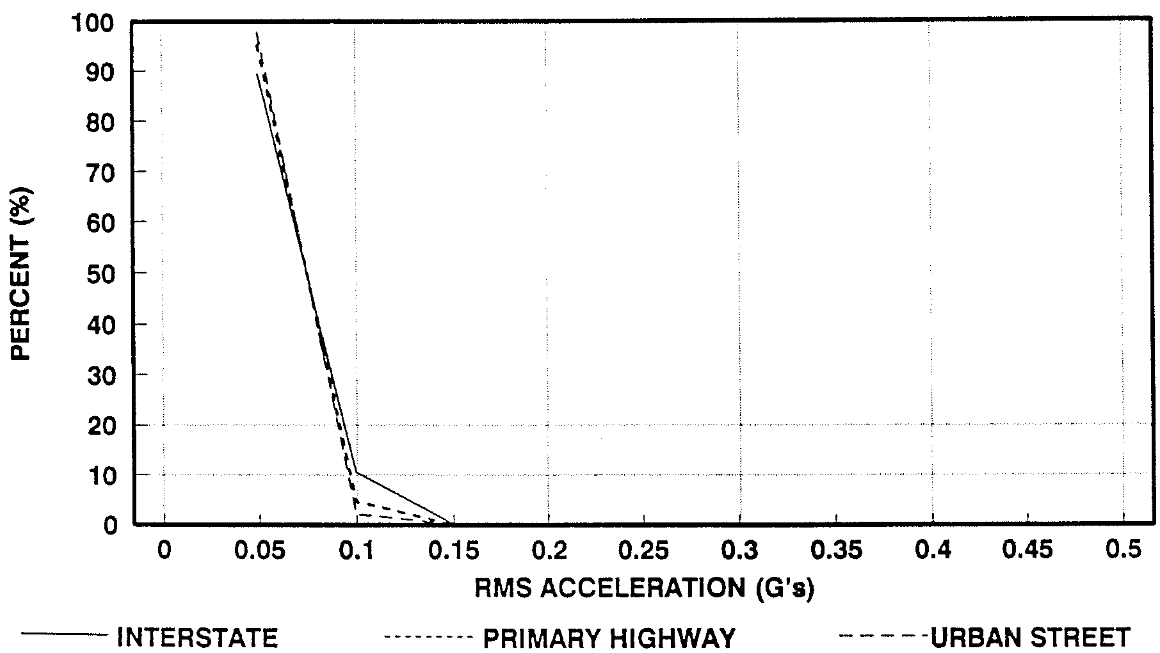


FIGURE 11

RMS ACCELERATION DISTRIBUTION

LONGITUDINAL



Longitudinal RMS acceleration levels were very similar for all modes of transport.

FIGURE 12

RMS ACCELERATION DISTRIBUTION

LATERAL

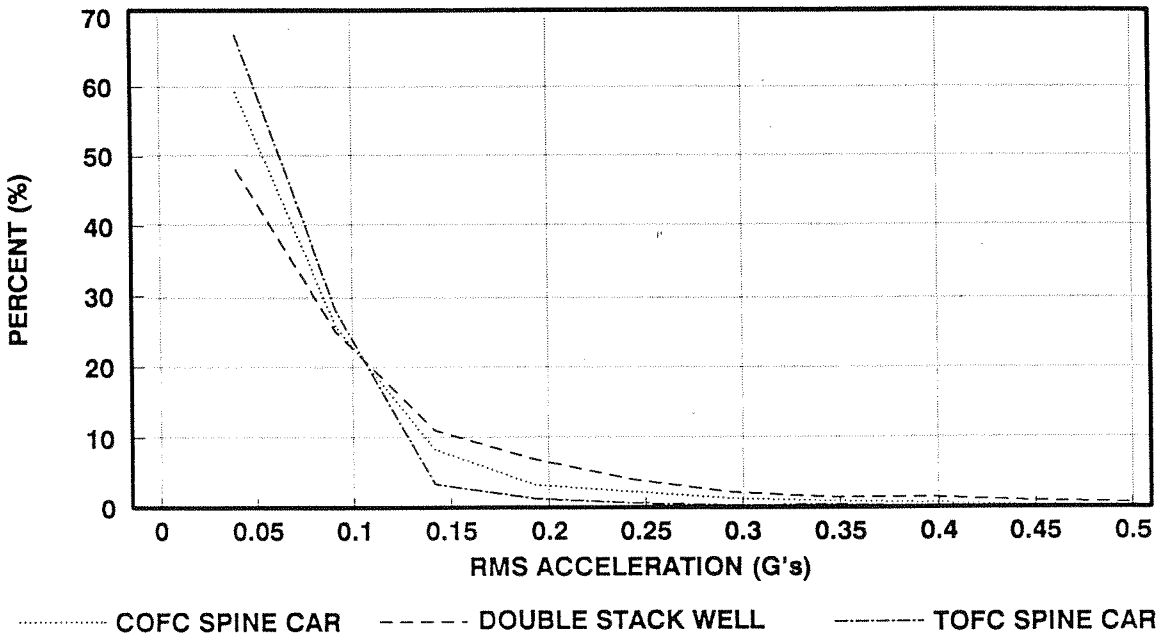
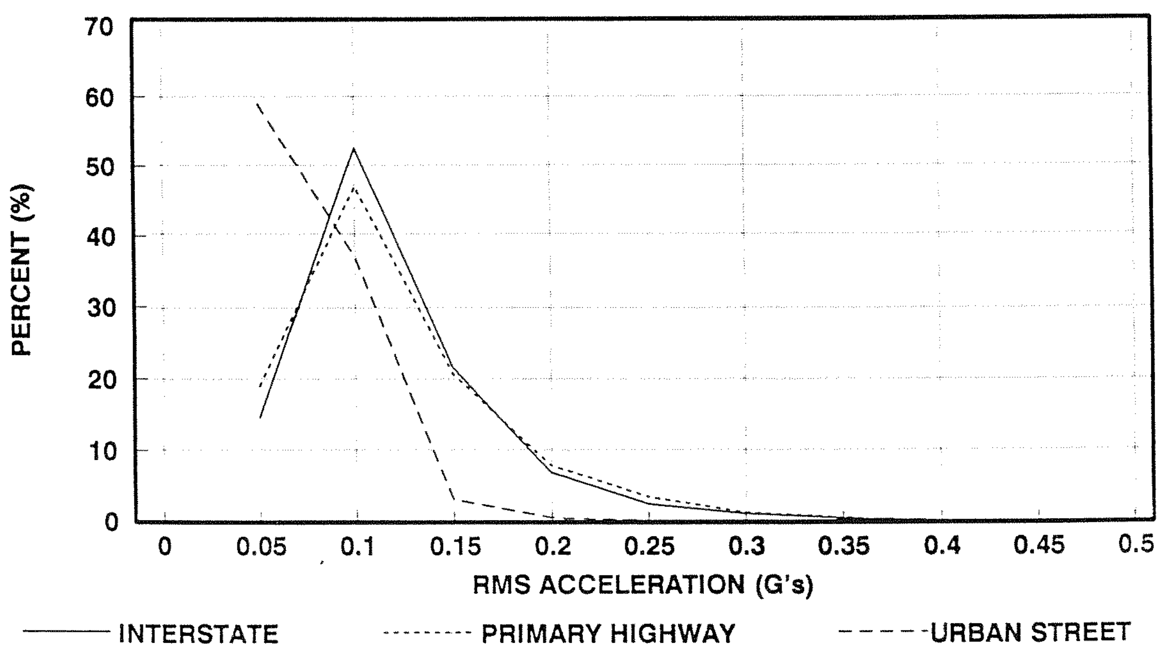


FIGURE 13

RMS ACCELERATION DISTRIBUTION

LATERAL



Lateral RMS acceleration levels were highest in the Interstate and Primary Highway modes, lowest over Urban Streets. Rail modes fell between these extremes.

FIGURE 14

RMS ACCELERATION DISTRIBUTION

VERTICAL

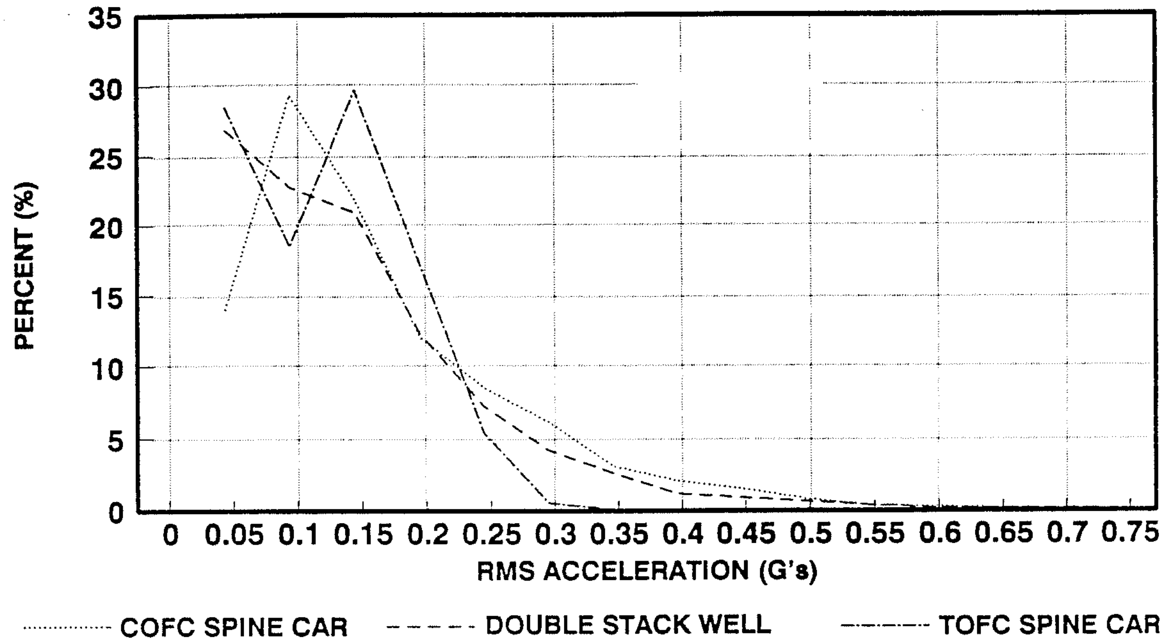
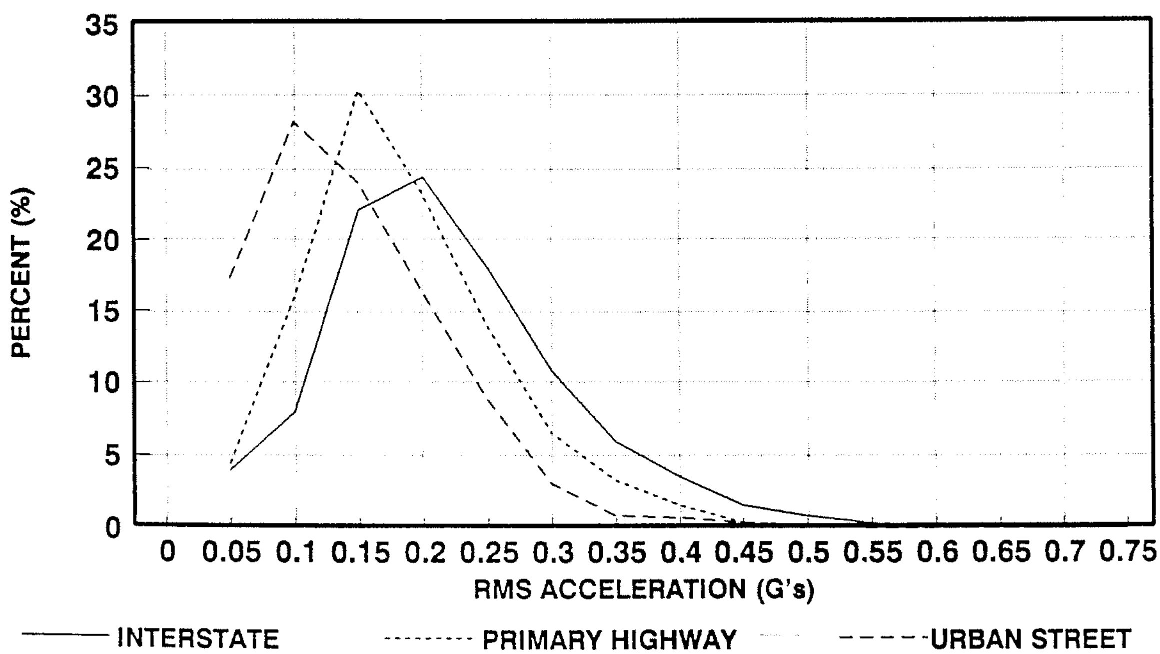


FIGURE 15

RMS ACCELERATION DISTRIBUTION

VERTICAL



Vertical RMS acceleration levels were generally higher over-the-road when compared to rail except for the extreme amplitudes of the COFC spine car and the Double Stack Well Car.

Random vibration data files were then processed to generate a cumulative composite of the extreme (mean RMS) power density levels and a cumulative composite of the average (mean RMS) power density levels for each equipment type/transport mode.

These Power Spectral Density plots are scaled to 30 Hz, to expand the resolution of low frequency energy. The frequency resolution of these plots is 0.5 Hz. The energy amplitude is linearly scaled for direct comparison.

FIGURE 16

POWER SPECTRAL DENSITY

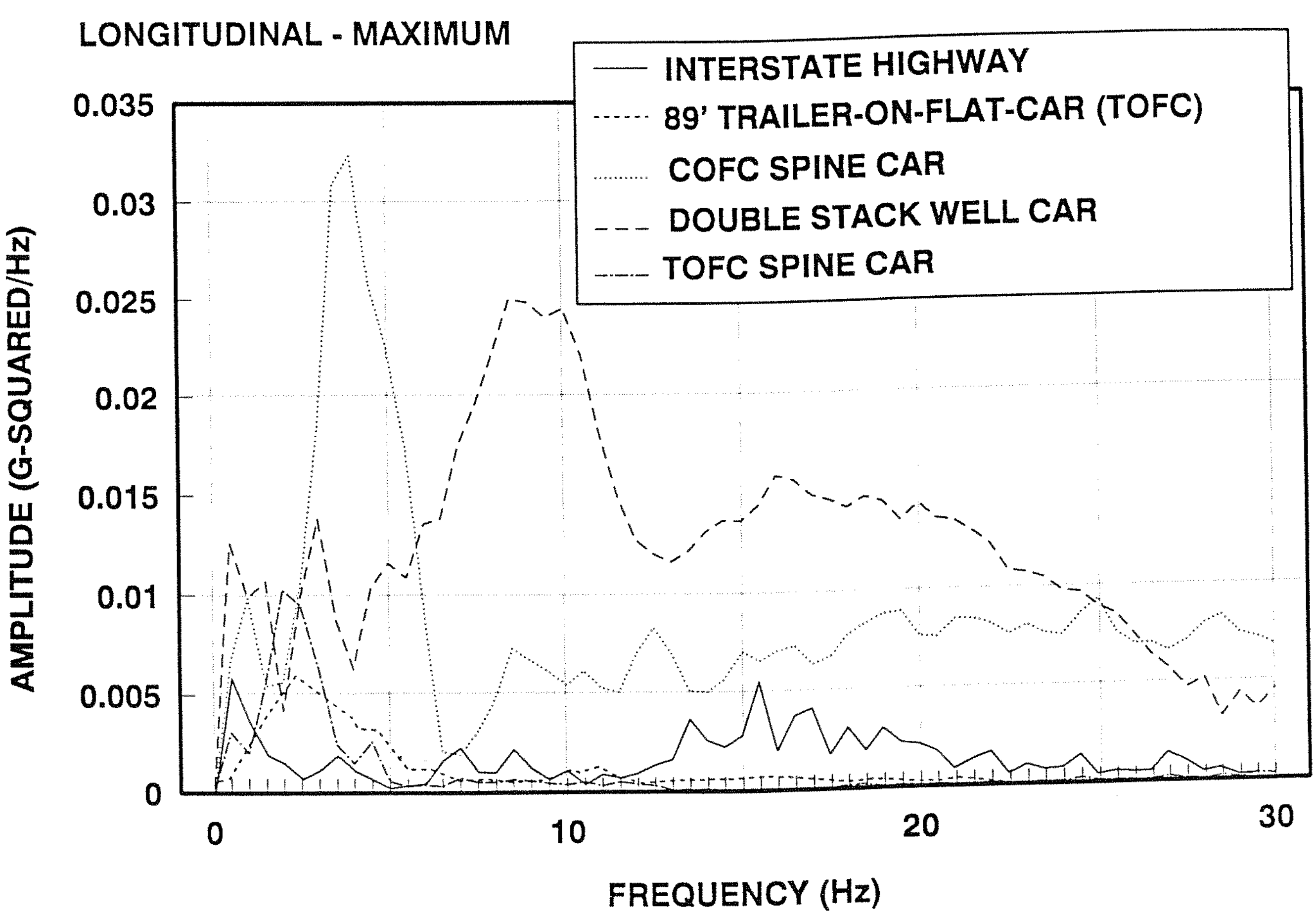


FIGURE 17

POWER SPECTRAL DENSITY

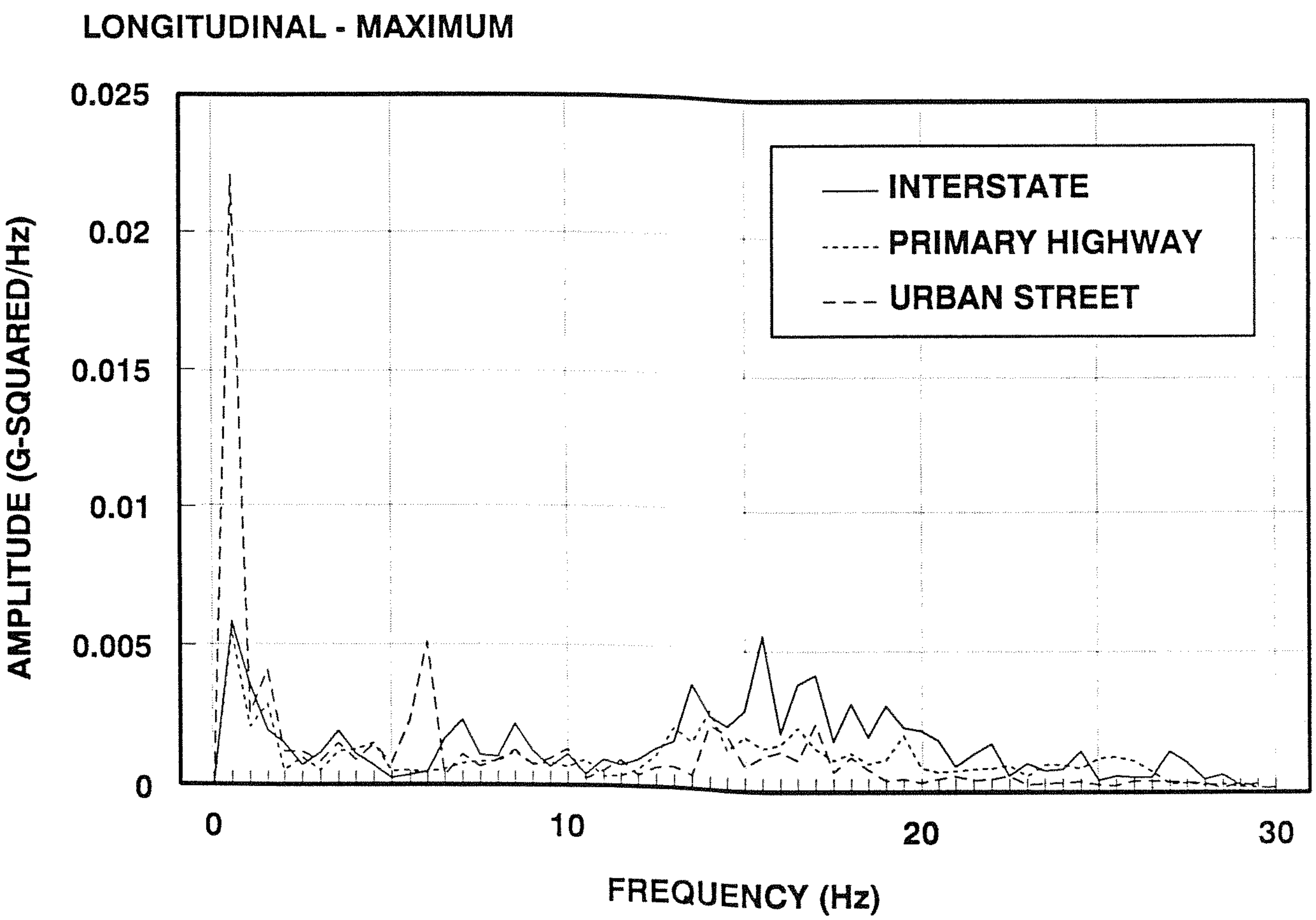


FIGURE 18

POWER SPECTRAL DENSITY

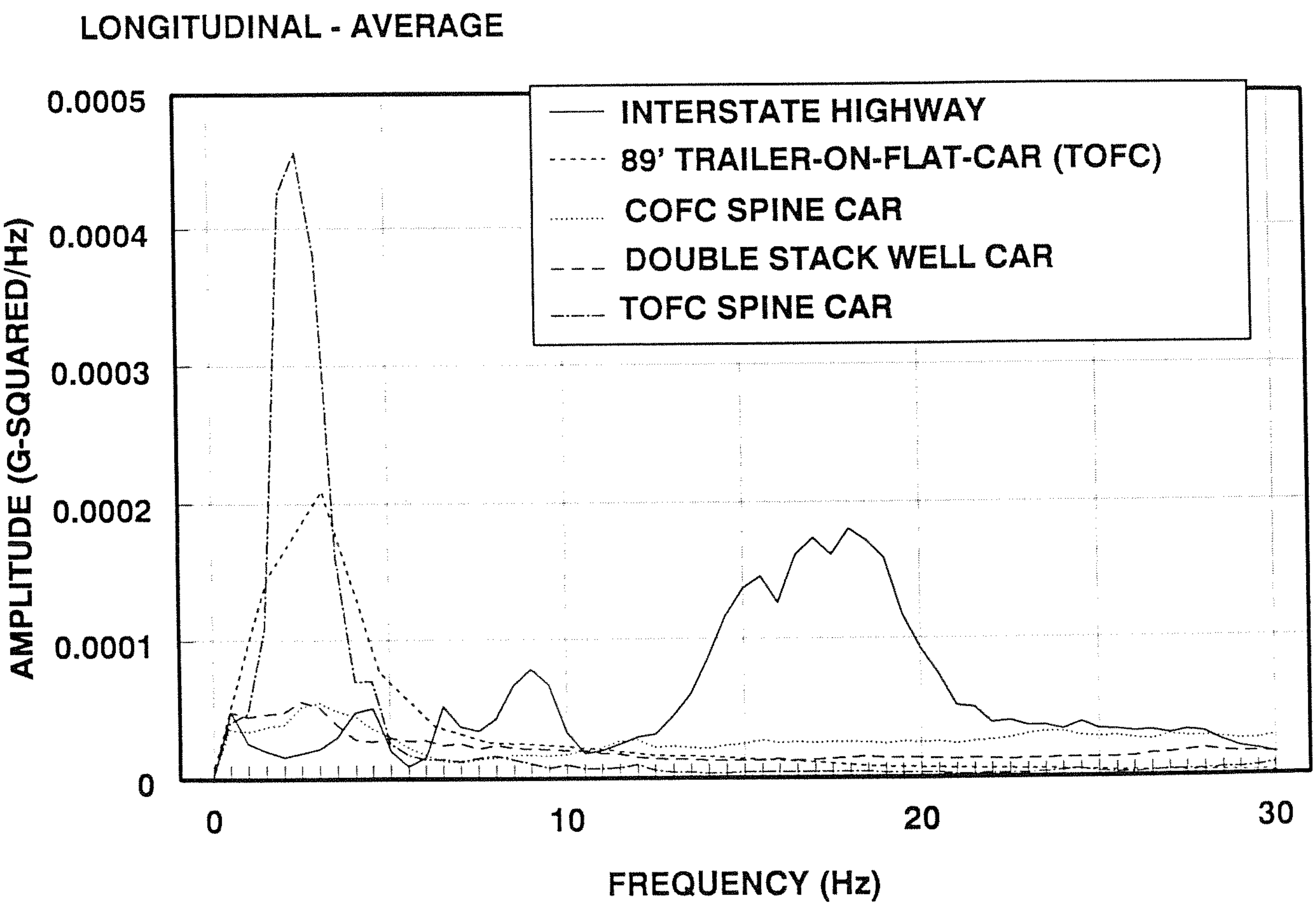


FIGURE 19

POWER SPECTRAL DENSITY

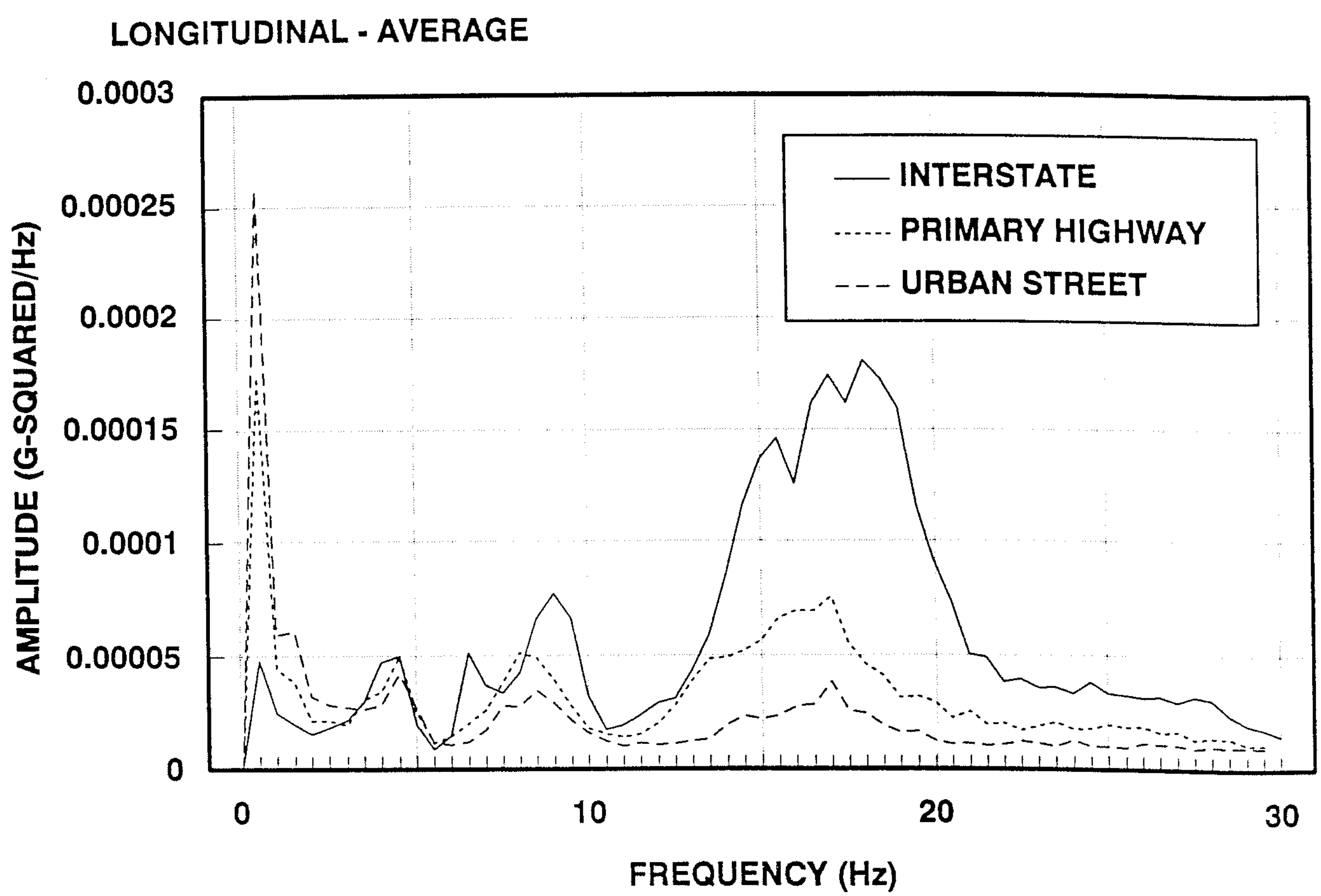


FIGURE 20

POWER SPECTRAL DENSITY

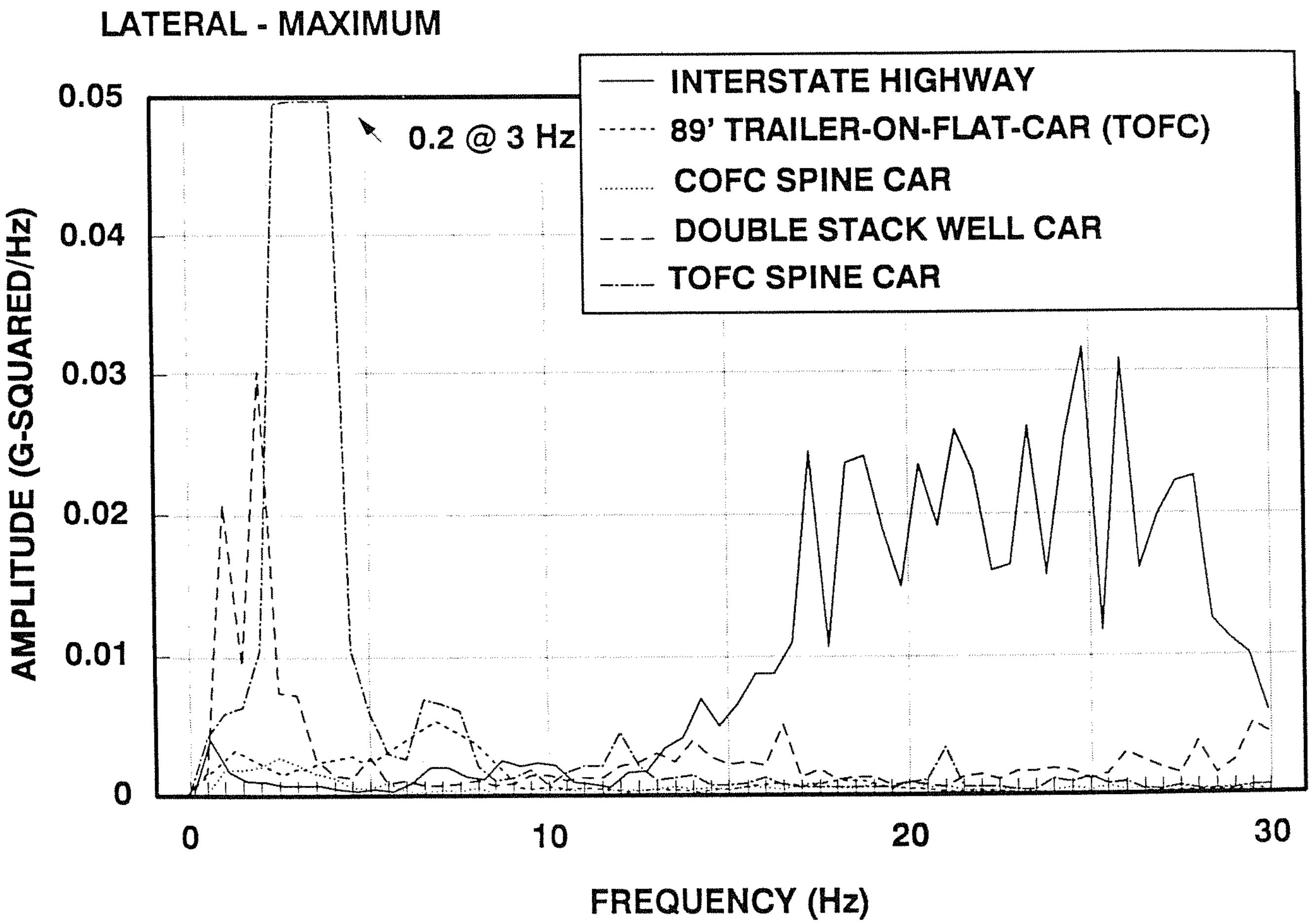


FIGURE 21

POWER SPECTRAL DENSITY

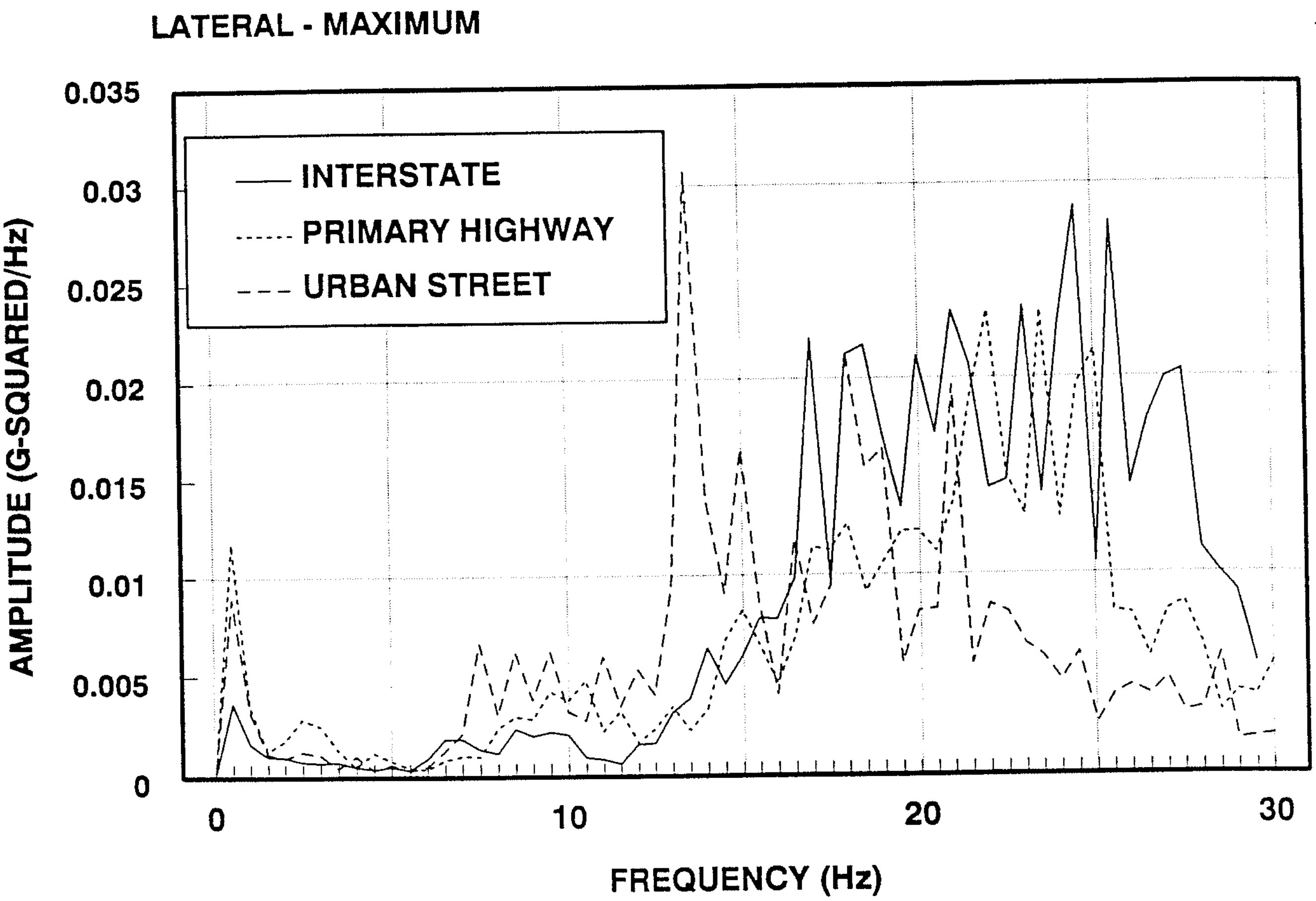


FIGURE 22

POWER SPECTRAL DENSITY

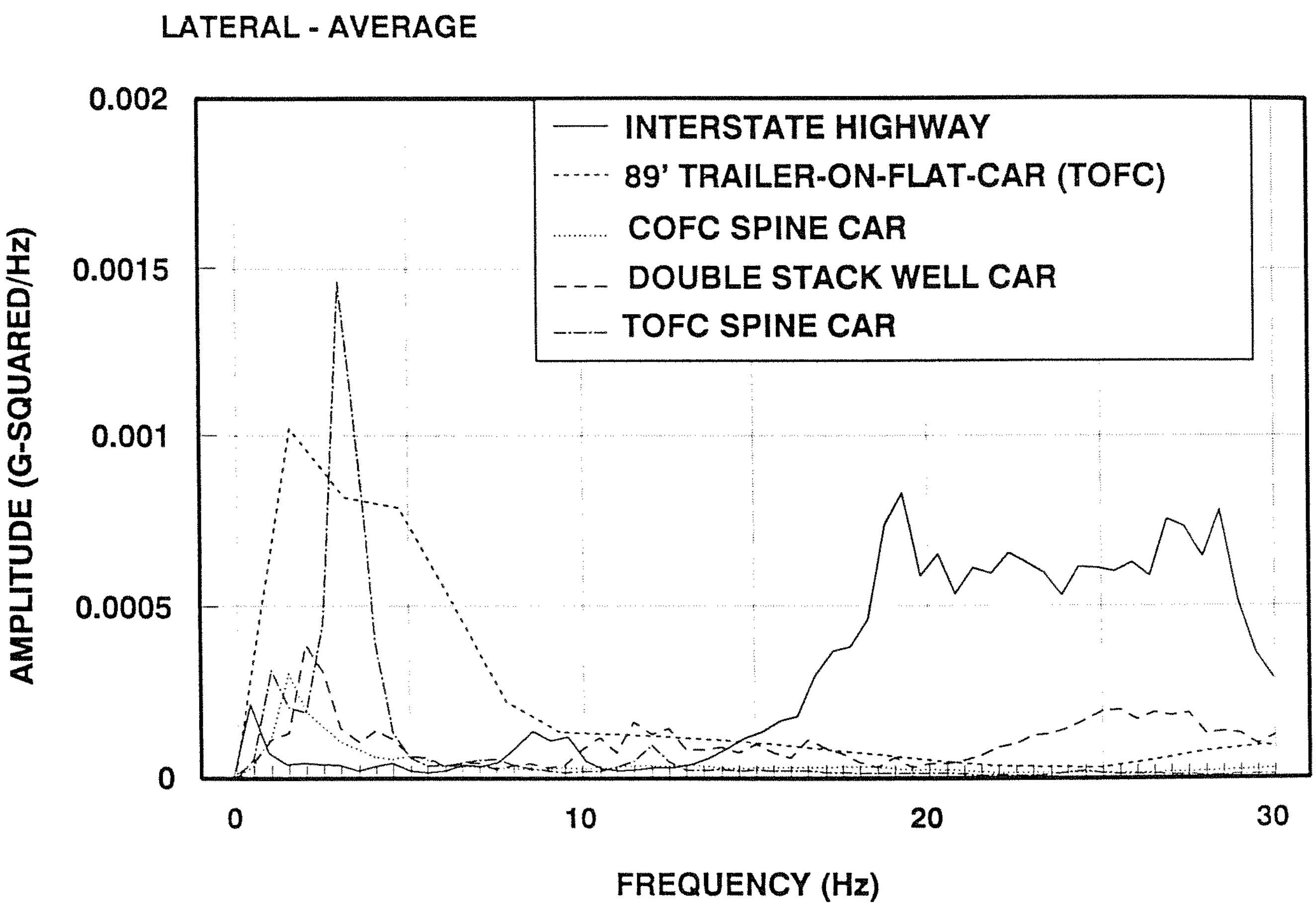


FIGURE 23

POWER SPECTRAL DENSITY

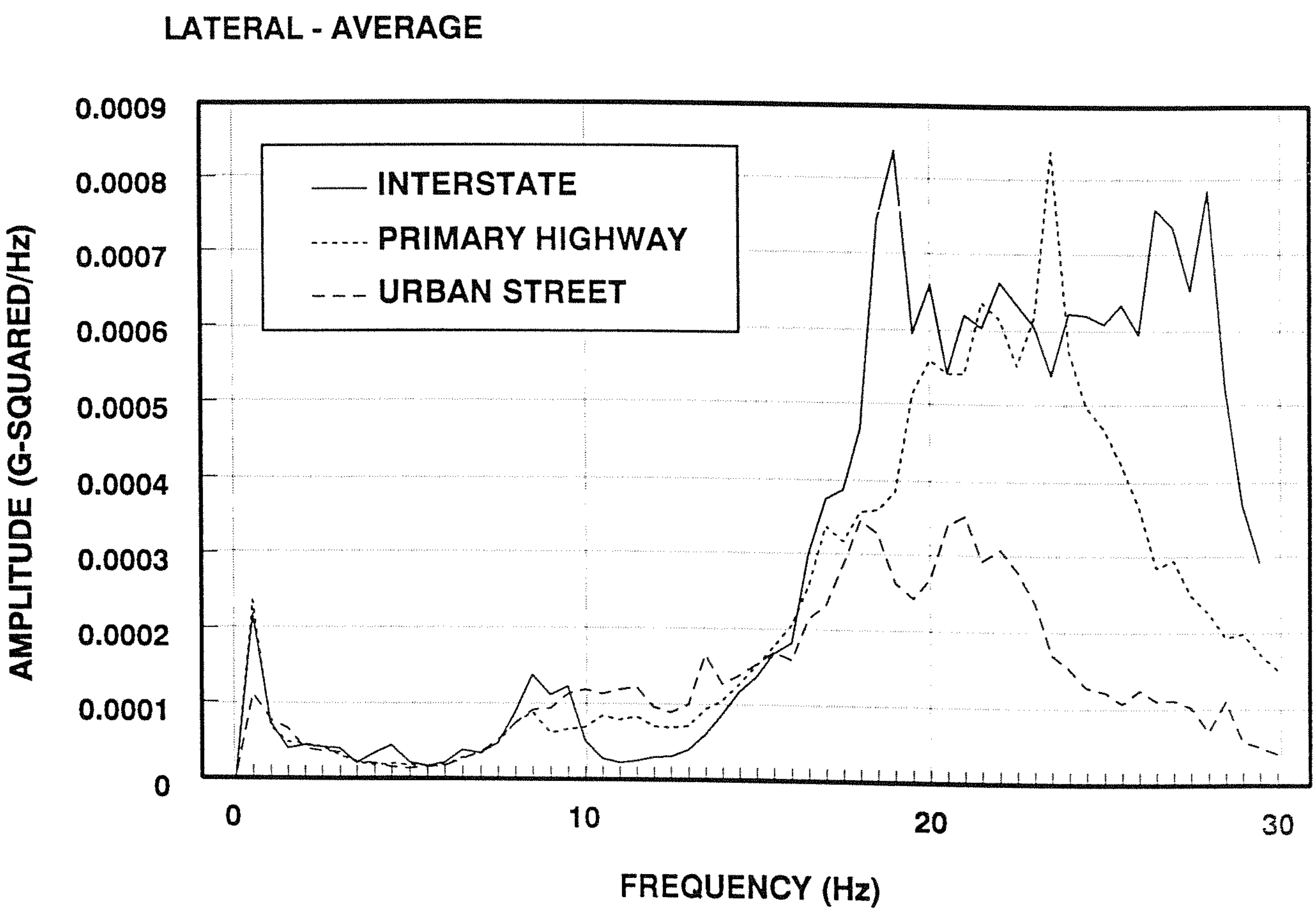


FIGURE 24

POWER SPECTRAL DENSITY

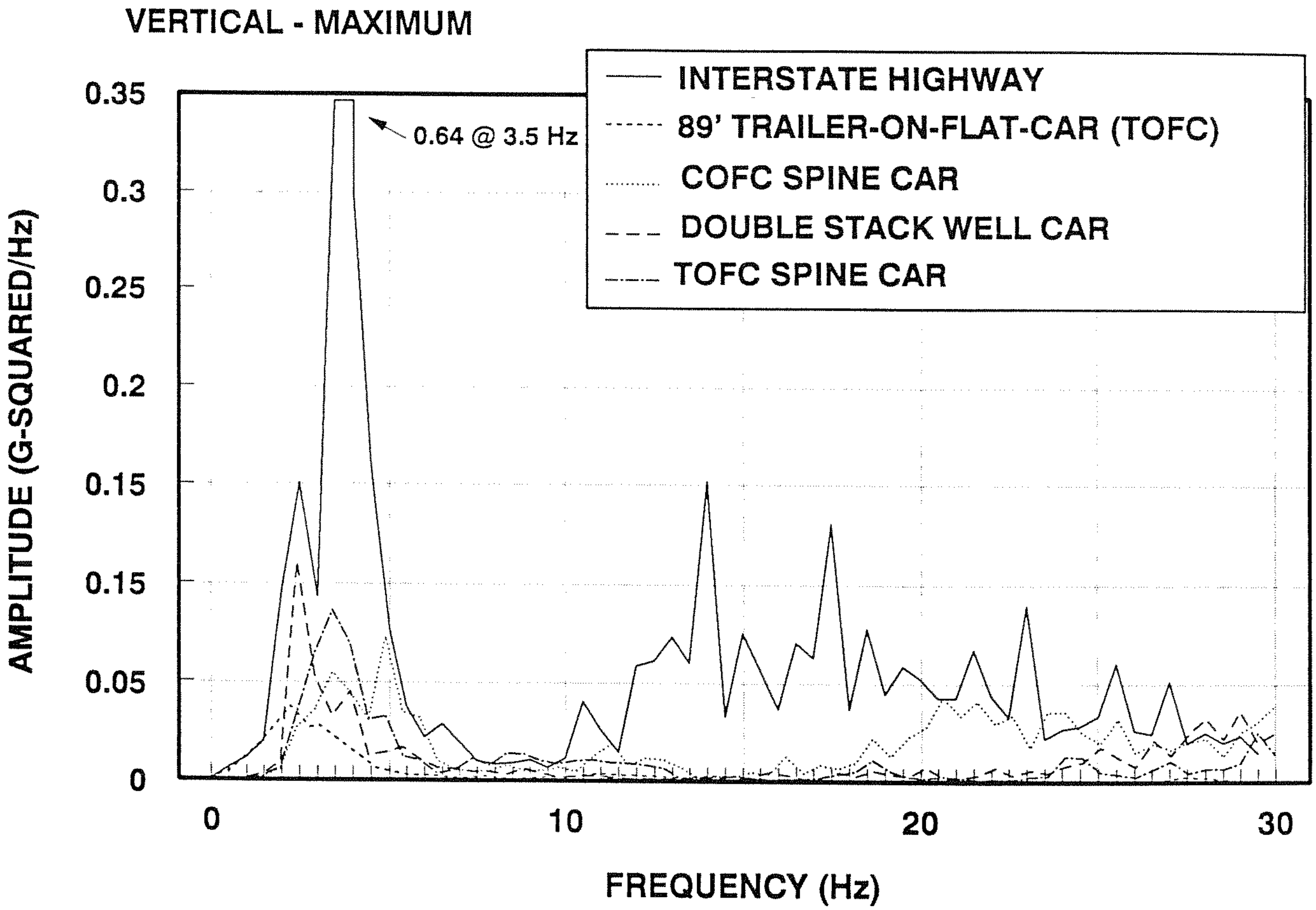


FIGURE 25

POWER SPECTRAL DENSITY

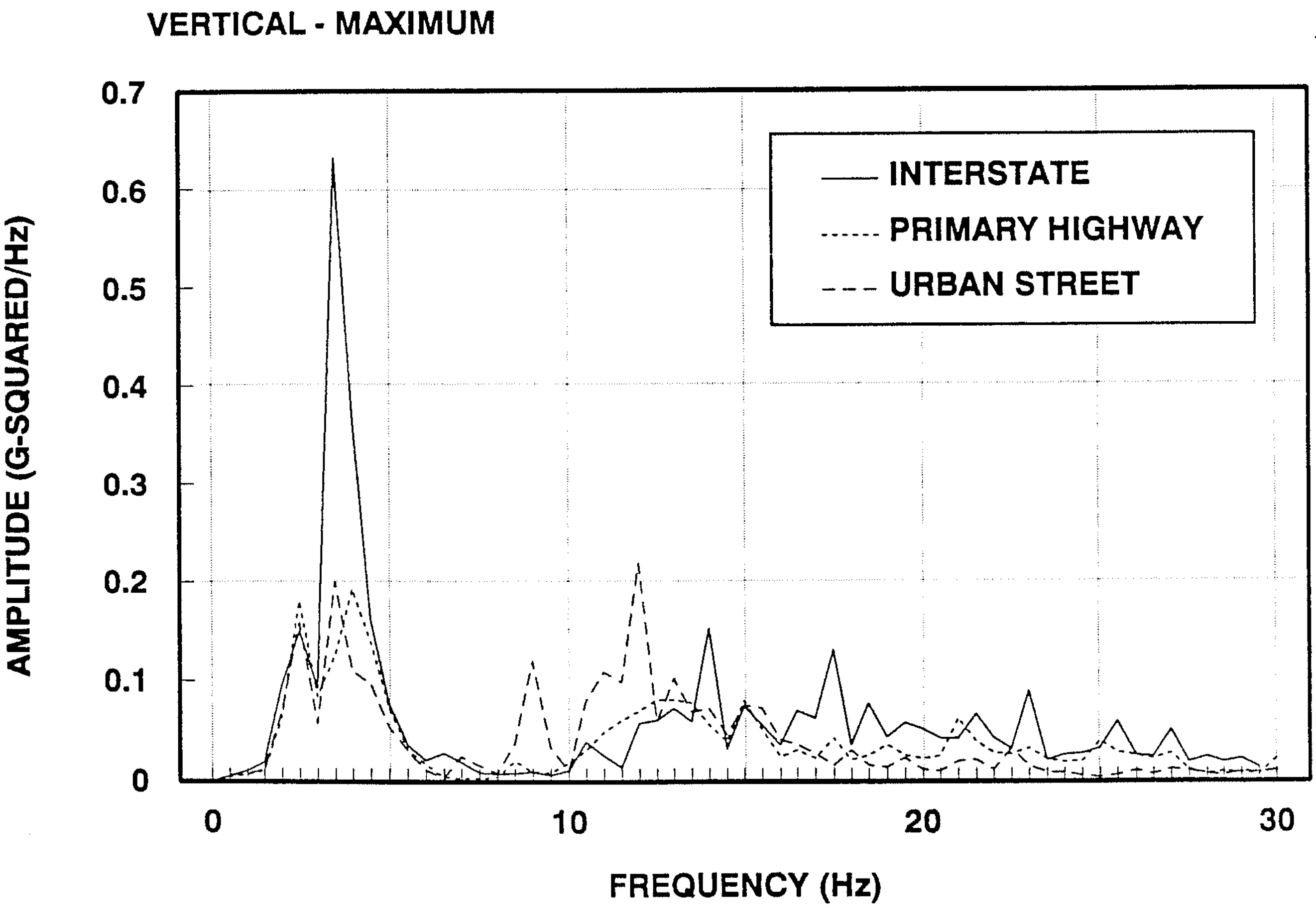


FIGURE 26

POWER SPECTRAL DENSITY

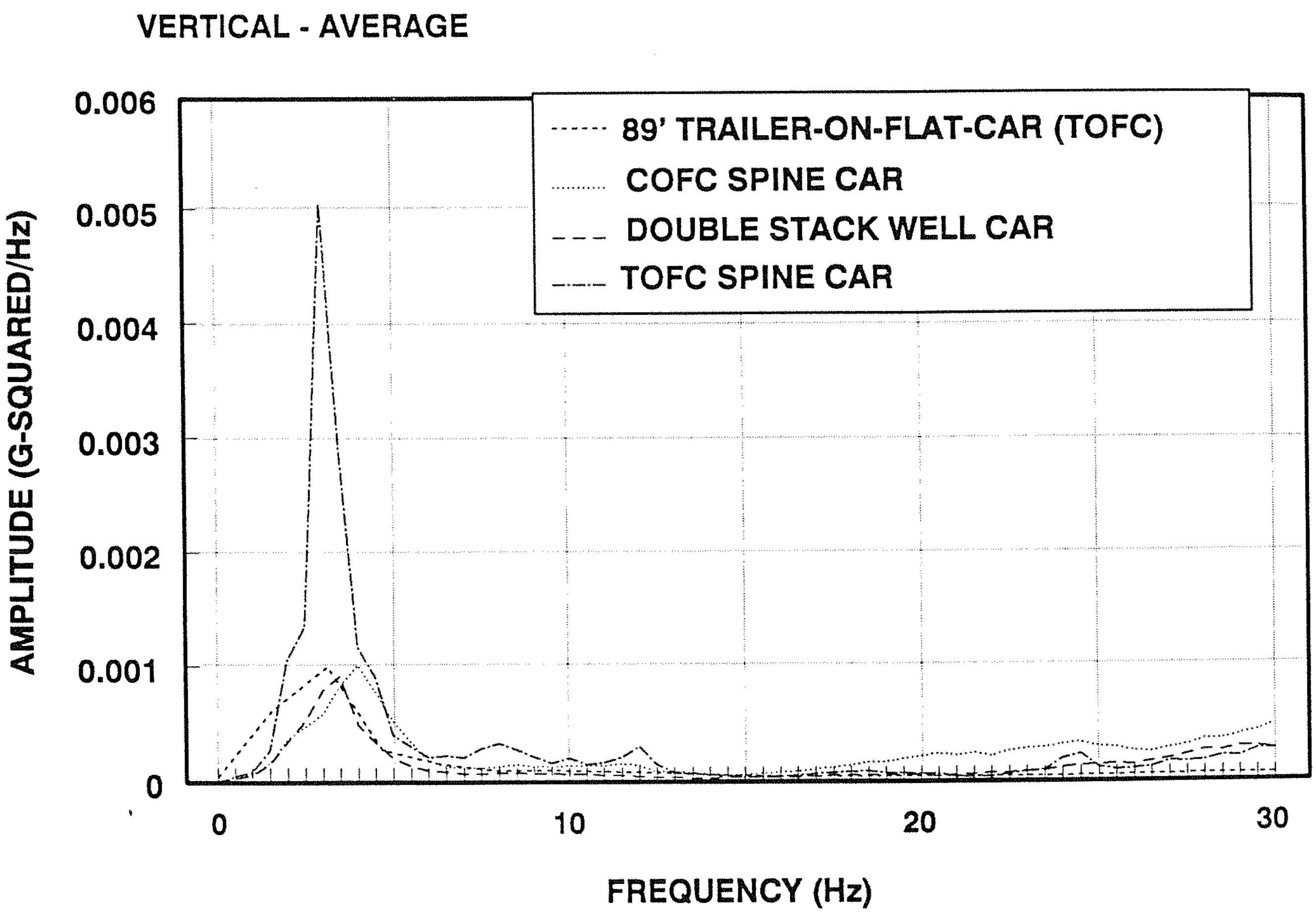
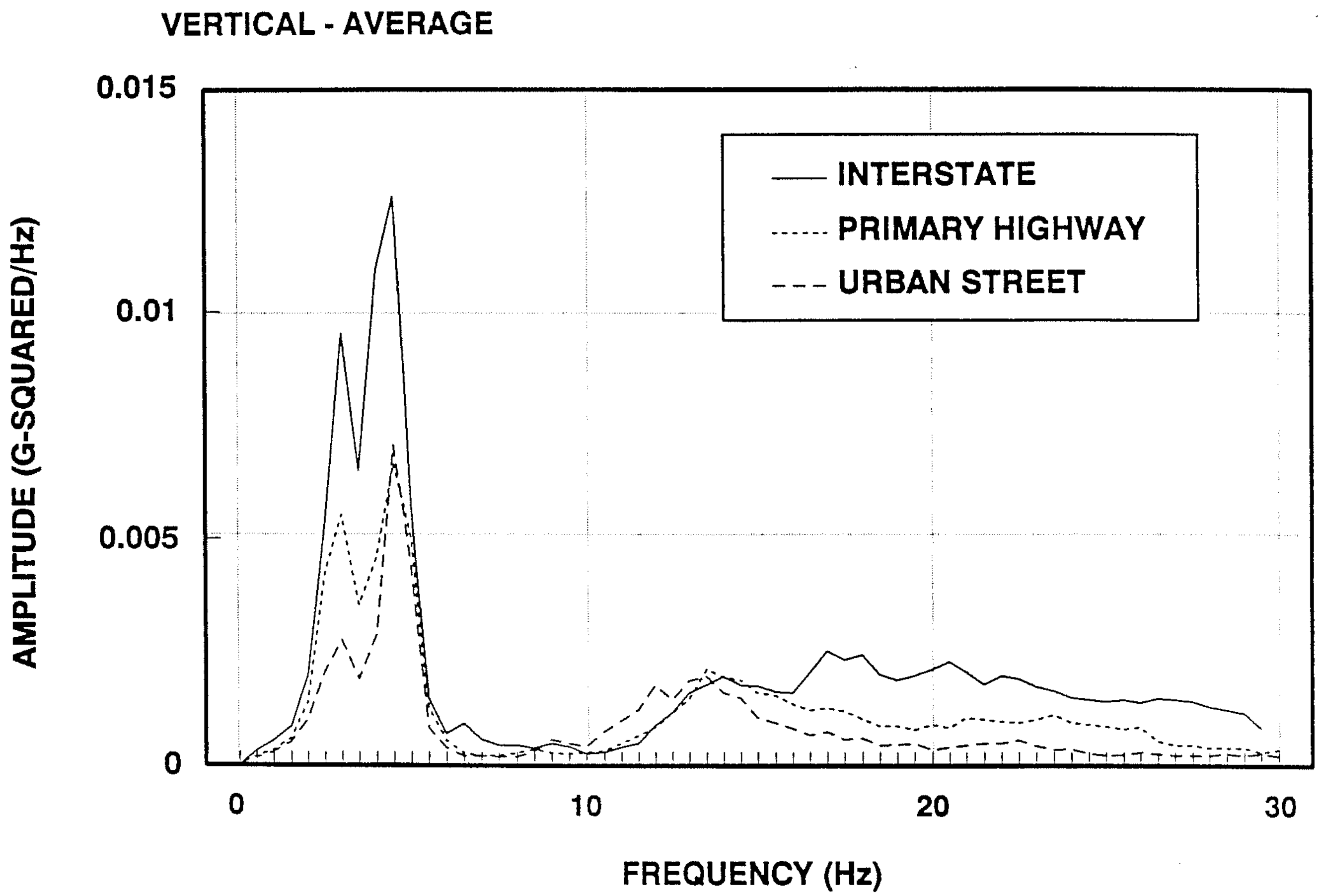


FIGURE 27

POWER SPECTRAL DENSITY



4.3 TERMINAL HANDLING SUMMARY (Lift-on/Lift-off Data Files)

During Phase III, terminal handling operations were monitored to profile transient acceleration levels occurring as a result of loading/unloading a trailer onto a rail car. One preprogrammable data recorder was used to record 7.7 second segments of data at consecutive intervals. Table 15 summarizes the volume of data obtained.

TABLE 15

Equipment Type (# of Different Units)	# of Lift-on/Lift-off Sequences	# of Data Files
Overhead Crane (3)	15	109
Sideloader (3)	15	143

The raw data files were filtered at 30 Hz with a Butterworth low pass digital filter during processing. Processed data is statistically summarized in Table 16.

TABLE 16
Statistical Summary of Lift-on/Lift-off Operations

	Extreme Acceleration Levels in G's								
Equipment Type	Longitudinal			Lateral			Vertical		
	Max	Min	Max RMS	Max	Min	Max RMS	Max	Min	Max RMS
Overhead Crane	0.79	-0.46	0.05	0.93	-0.91	0.06	2.83	-3.67	0.20
Sideloader	0.51	-0.29	0.05	1.77	-1.59	0.12	1.14	-0.93	0.11

Power spectral analysis indicated that for both types of lifting devices the dominant energy content was between 0 Hz and 2 Hz in all axes. See Figures 28 - 30.

FIGURE 28

POWER SPECTRAL DENSITY

LONGITUDINAL

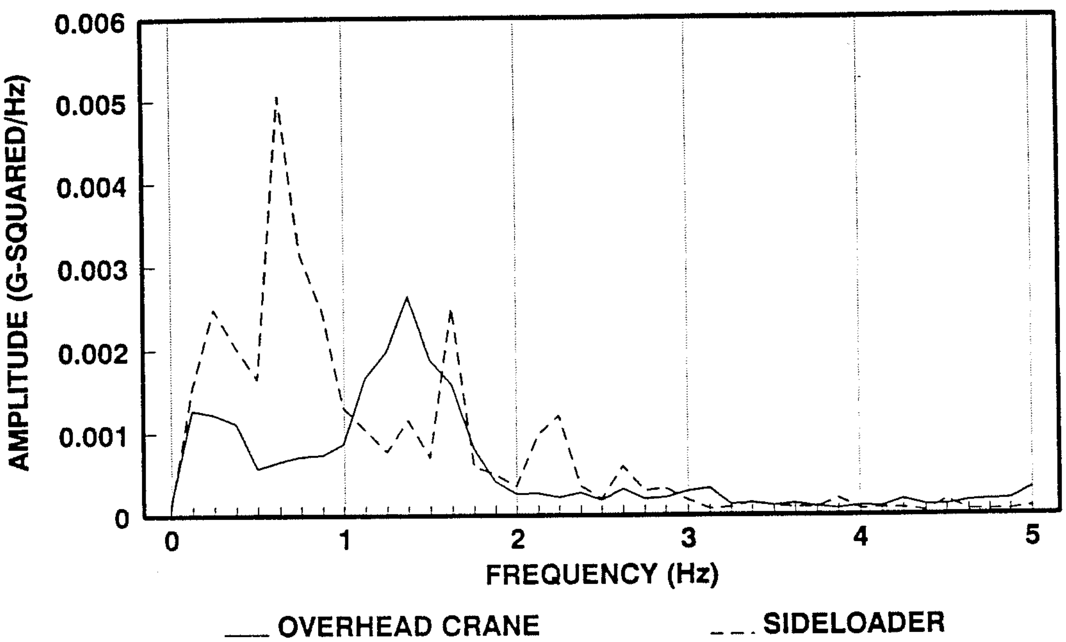


FIGURE 29

POWER SPECTRAL DENSITY

LATERAL

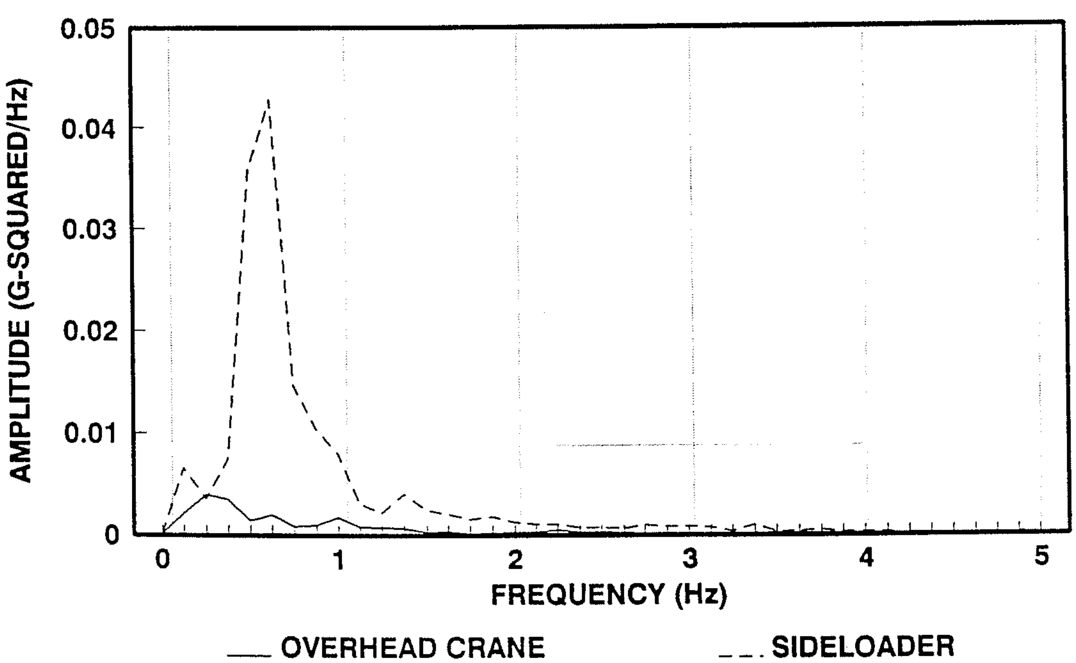
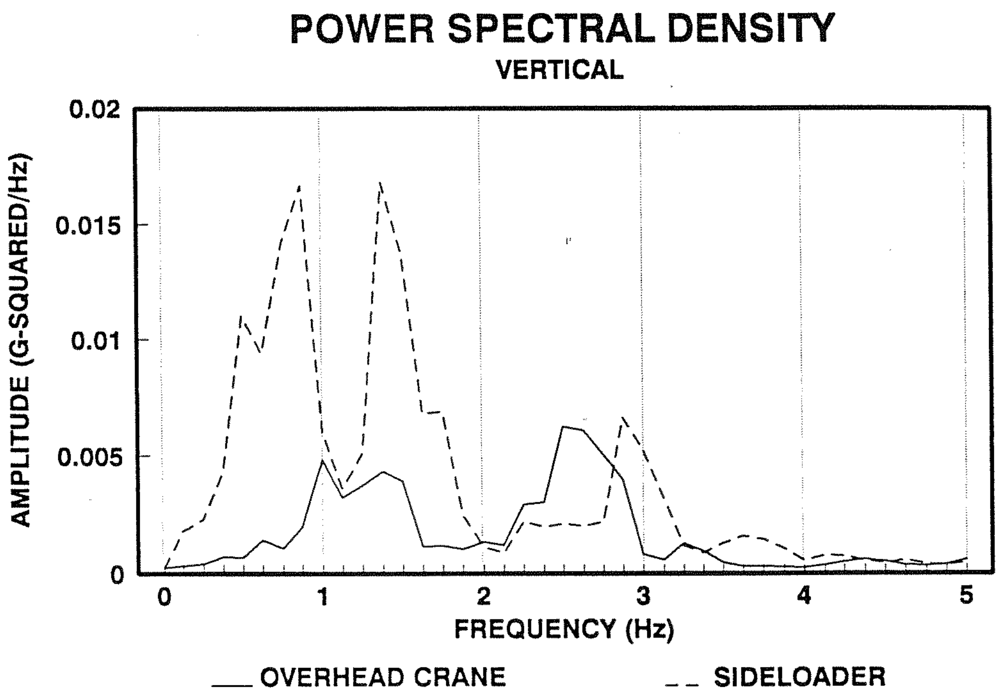


FIGURE 30



5.0 OBSERVATIONS

5.1 GENERAL

5.1.1 Phase I

Train operating speed affected trailer vibration and transient shocks more significantly than any other environmental variable studied. Average operating speed is usually a function of train length. Of all the environmental influences on freight, train length and operating speed are most readily changed, as compared to curves, grades or climatic conditions.

In general, operating speed is directly proportional to vibration energy. A trailer on a flatcar will also experience more vertical shocks, usually from suspension bounce, when traveling at a high rate of speed. Conversely we see more longitudinal buff and draft type shocks associated with the slower and accordingly longer trains.

There are obvious advantages and disadvantages to both operating philosophies. Short trains can be operated at higher speeds, satisfying many shippers needs stemming from "just in time" inventorying policies. Short trains also tend to reduce the number and severity of longitudinal shocks, which are generally considered the most severe since most freight in trailers and containers is aligned lengthwise. Increased vibrational energy in short trains may adversely affect some sensitive types of freight and accelerate load shifting.

On the other hand, longer trains may offer greater operating efficiency, hauling more tonnage at a comparative fuel savings. Because these trains are generally operated at slower speeds, vibration energy is reduced as are vertical shocks resulting from trailer bounce. Negatively, buff and draft forces ("train action") increase.

5.1.2 Phase II

Route selections were based on rail carrier input of the specific traffic corridors in which articulated equipment is used. The routes chosen offered a broad diversity in terrain and operating conditions, while still being typical or representative of articulated rail service.

It is interesting to note, that of the 13 trains in which the test containers were entered, only three (Trip Segments 4A, 6A and B) consisted entirely of articulated well cars. The remaining trains hauled primarily dedicated trailer and container traffic on conventional 89′ flatcars. In a few instances, test cars were entered into trains hauling general service freight cars.

Moving articulated equipment in mixed consists does not utilize the equipment to its greatest advantage. Articulation reduces free running slack to minimize longitudinal shock inputs generated by slack run-in/run-out. Mixed consists take away this advantage and introduce a related liability. The actual weight on rail of loaded articulated cars may range from 400,000 lbs. to 800,000 lbs., significantly heavier than conventional equipment. This increased mass could actually amplify container response to longitudinal shock inputs. Also, discrete longitudinal shock events may be transmitted into as many as ten separate container loads.

Unfortunately, it was not possible to obtain data from articulated TOFC spine cars in more than one trip segment. This is more a reflection of the limited service of this car type than of test constraints.

5.1.3 Phase III

The routes chosen for Phase III offered a broad cross section of Interstate, Primary Highway and Urban Street environment in regards to terrain and real world operating conditions. Roadways consisted of concrete and asphalt. The only adverse weather condition encountered was rain. Route selections were based on changes in surface conditions due to climatic changes. Chicago, Illinois was established as a base to work out of. Easy access to urban streets, primary highways and rail yards (lift-on/lift-off operation) was the primary reason for this location.

The majority of urban street data was collected in stop and go traffic. Interstate data contains no secondary roads. Data collection was suspended when a change in trip sequence was to occur.

In each axis, Interstate was the most severe in terms of shock. It is interesting to note that the acceleration levels for each trip sequence were within 0.5 G's of each other in each axis. Vertical peak to peak accelerations were predominantly higher in all three trip sequences with the Interstate being the highest. This was possibly due to the joints in the concrete road surface. It was noted by AAR staff riding in the tractor, that the vertical shocks were severe during this trip sequence.

Various rail yards were utilized for the collection of lift-on/lift-off data. The rail yards were not chosen for their operating conditions. They were selected for the types of equipment typical of this environment only.

In general, data analysis of this operation indicated that a majority of the accelerations were equal to or below 0.5 G's in all axes.

The few data files found in excess of 0.5 G's occurred at higher frequencies. These were more than likely caused by structural resonance.

Also, the data files having higher amplitudes were collected during the last two lift-on/lift-off cycles of each type of lift-on/lift-off sequence. Each operator of each equipment was requested to handle the test trailer normally during the first three cycles. The operator was then requested to handle the test trailer in a rough manner during the last two cycles.

This would indicate that, in general, intermodal equipment loaded and unloaded with these types of lift devices do not experience critical shock movement.

5.1.4 Overall

One of the intentions of this study was to obtain a representative overview of the dynamics of intermodal freight transport. Baseline test criteria (such as equipment size/type, load weight, traffic corridors, data recording parameters, etc.) was established at the outset by the test proposal and, for the most part, adhered to. The rationale was that by following a consistent test methodology, comparative data sets would be produced. Unfortunately this approach excludes a number of significant variables affecting freight. Evaluating a multitude of load weights, commodity types, equipment variations, etc., would no doubt yield a more comprehensive environment profile, but would also be prohibitively expensive and time consuming to conduct. What is offered here is felt to be a reasonable compromise.

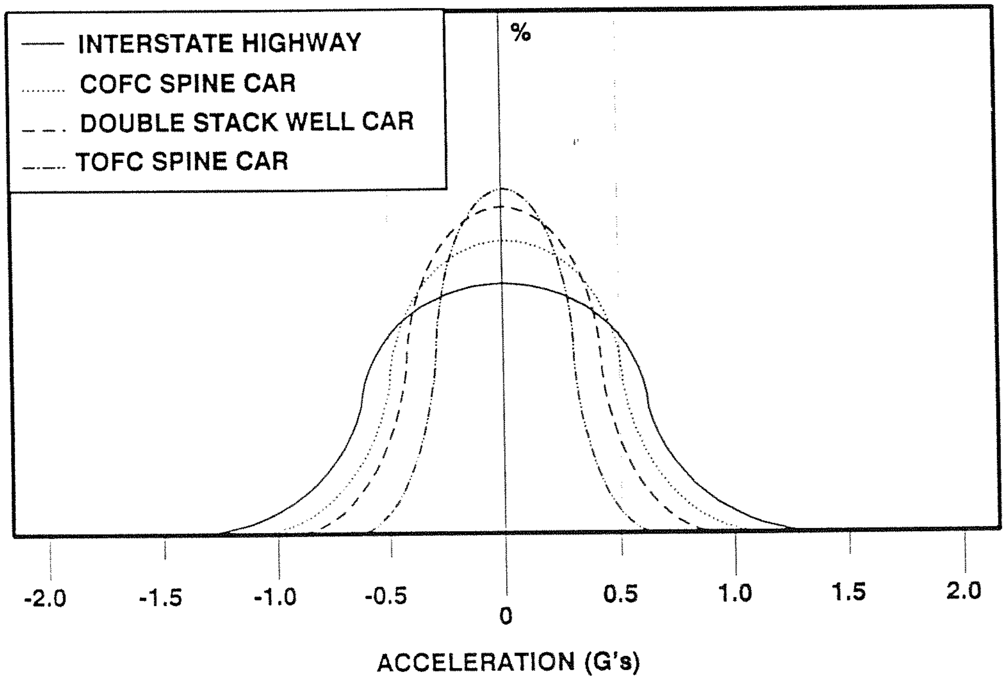
The random vibration data collected during Phase I - Test Sequence 3, Interstate, was recorded with a duration threshold criteria of 15.9 milliseconds. As a result, all files had a certain amount of low frequency content and corresponding high G-RMS energy content. This could make this data appear to have more energy content than purely random data might otherwise. Because of this bias, the data was not considered in this report.

Transient shock events are generally regarded as those discrete acceleration excursions beyond three times the standard deviation (3-sigma) of the normalized distribution of random vibration influence. Ideally, shock type data recorders would be programmed to collect data at 3-sigma and above acceleration levels. Without that predetermination however, assignment of a shock recording threshold becomes arbitrary. Our selection of a 0.5 G shock recording threshold appeared to be fairly good for TOFC transport modes but too low for all other modes investigated. Normalized (Gaussian) distribution of vertical random vibration of four of the long haul modes studied would approximate Figure 31, based on the statistical analysis of the data obtained. The modes having a 3-sigma value greater than the 0.5 G shock threshold assignment exhibit a proportionally higher number of events registered (on a per mile basis), indicating a broader distribution of their (relative) random vibration environments.

FIGURE 31

THEORETICAL PROBABILITY DENSITY FUNCTION

RANDOM VIBRATION - VERTICAL



Basically, the broader the vibration distribution, the greater its' overall energy content. So what may be categorized as shock in one mode may be within the vibration spectra of another.

Peak to peak shock acceleration values were used to portray severity because they more accurately relate the magnitude of the total change in velocity. Peak acceleration distributions are always greater than one half peak to peak for longitudinal accelerations. The same is true for vertical accelerations on TOFC and truck modes, a reflection of the vehicle suspension characteristics. In these cases, transient shock events are rarely symmetric about zero. Vertical shock for COFC modes, and lateral shock recorded by virtually any mode of transport, are usually symmetric about zero and thus their peak shock acceleration distributions approximate one half their respective peak to peak acceleration distributions.

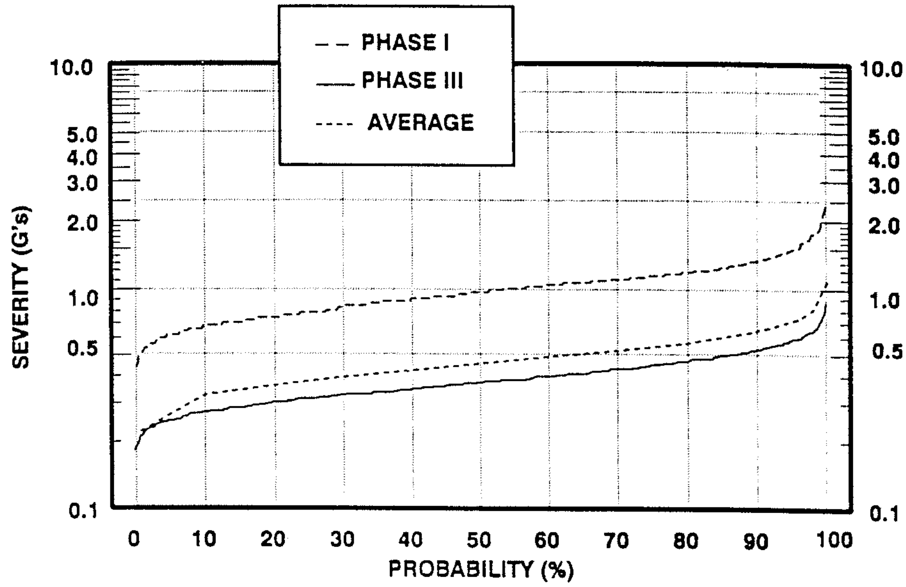
The distribution of longitudinal shock severity during Phase I - Test Sequence 3, Interstate, was markedly higher than that observed in Phase III.

FIGURE 32

AVERAGE PROBABILITY DISTRIBUTION

INTERSTATE

LONGITUDINAL - PEAK TO PEAK



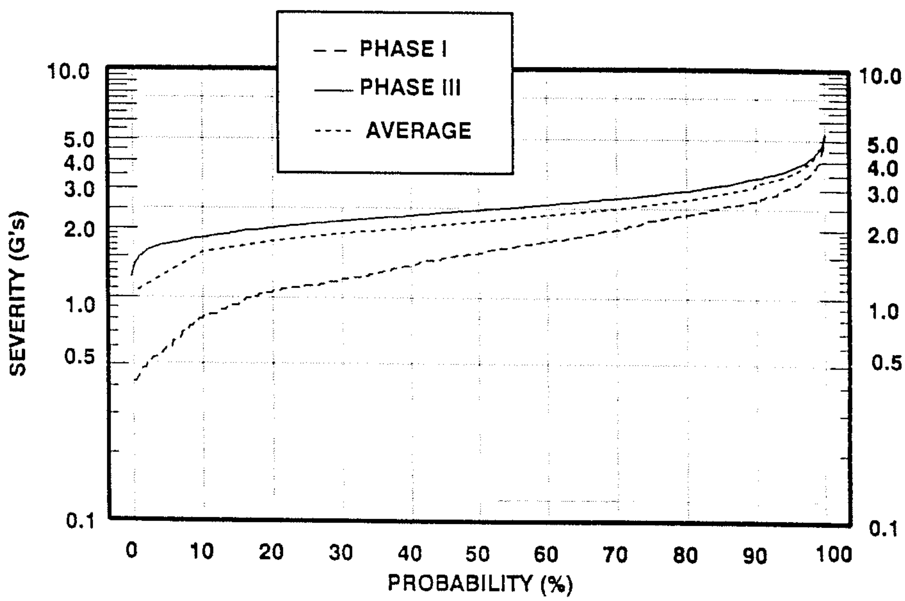
Conversely, vertical shock distribution was less severe in Phase I than Phase III.

FIGURE 33

AVERAGE PROBABILITY DISTRIBUTION

INTERSTATE

VERTICAL - PEAK TO PEAK



This data was scrutinized at length to determine the cause for this disparity. No obvious systematic inequality surfaced, but there may be logical explanations.

The data collection effort of Phase III may have been adversely influenced by having a test engineer escort the test trailer. Phase I Interstate data was collected innocuously - without the driver's knowledge. With all due respect, one is more likely to be on best behavior when under obvious scrutiny than when not.

Phase I Interstate data was gathered in the southwest United States, where Interstates are surfaced predominantly with asphalt. Asphalt roadway surfaces have few joints or grade elevation changes which would reduce (in general) the degree of vertical excitation. Phase III Interstate data was collected over predominantly concrete roadways having repetitive joints, and usually more pronounced grade changes at subgrade interruptions such as bridges and box culverts.

POSTSCRIPT

Were one predeposed to prove one mode of freight transport superior to another (i.e., rail versus truck), this study would serve well to fuel the arguments of both camps. Each mode is both similar and divergent. Similar in the common ground of dynamism: both modes are energetic, volatile systems. Divergent in their manifestations of dynamism. Rail is a system of multi-degree energy absorptive damping systems; truck is a single unit, low mass system. Rail shipments incur a less severe vibrational influence but a higher incidence of longitudinal shock transiency; truck shipments experience a greater magnitude of vibrational influence but a lower probability of lengthwise shock disturbance. Intermodal shipments generally must deal with both transport environments.

Hopefully this study will foster a realization that freight transportation involves more than just "closing the doors". Conscientious choice and prudence ensure viability in today's transport arena.

Thomas E. Feltault
Assistant Chief Engineer

John H. Blackman
Mechanical Engineer

Viola Arguello
Technical Aide

For further information or reports of each individual phase of this environment study, contact:

Association of American Railroads
Freight Claim and Damage Prevention Division
50 F Street, N.W.
Washington, D.C. 20001
(202) 639-2340