Shock and Vibration Environments For A Large Shipping Container During Truck Transport (Part II)

Clifford F. Magnuson

Sandia Laboratories

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SHOCK AND VIBRATION ENVIRONMENTS
FOR A LARGE SHIPPING CONTAINER
DURING TRUCK TRANSPORT (PART II)

Clifford F. Magnuson

Sandia Laboratories
Albuquerque, New Mexico 87185
operated by
Sandia Corporation
for the
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3

ABSTRACT

The purpose of this study was to obtain vibration and shock data
during truck shipment of heavy cargo. These data were for use in
determining any trends of vibration and shock environments with
increased cargo weight. The new data were obtained on a
"piggyback" basis during truck transport of 249 100N (56,000-
pound) cargo which consisted of a spent fuel container and its
supporting structure. The truck was driven from Mercury, Nevada,
to Albuquerque, New Mexico. The routes traveled were US 95 from
Mercury, Nevada, to Las Vegas, Nevad.; US 93 from Las Vegas to
Kingman, Arizona, and I-40/US 66 from Kingman to Albuquerque, New
Mexico. Speeds varied from very slow to 88 km/hr (55 mph). A
comparison of data from similar experiments with cargo weights
varying from no-load to this load shows that the zero-to-peak
acceleration amplitude levels of vibration are highest when trucks
carry relatively light loads. This is true for the longitudinal
and vertical axes of the vehicles in most frequency bands and for
the transverse axis above 700 Hz. The shock response acceleration
amplitudes for heavier cargo weights were less severe above 3 Hz
in the vertical axis and higher between 8 and 20 Hz in the
transverse axis. The highest acceleration amplitude of shock
response in the longitudinal axis below about 20 Hz was produced
in a trailer having a spring suspension system and carrying the
249 100N (56,000 pounds) load.

CONTENTS

FIGURES

TABLES

SUMMARY

This report contains descriptions of shock and vibration environments which were measured during truck shipment of a 249 100N (56,000-pound) container mounted on a three-axle trailer which was pulled by a tandem axle tractor from Mercury, Nevada, to Albuquerque, New Mexico. This report also presents comparisons of shock and vibration environments for different cargo weights for which data are available.

The following vibration data from tests show the highest level of input vibration to cargo weighing 249 100N (56,000 pounds):

Axis	Zero-to-Peak Acceleration (g)	Frequency Range (Hz)
Longitudinal	0.27	0-1900
Transverse	0.19	0-1900
Vertical	0.52	0-1900

Comparison of vibration data from tests show that for cargo weighing more than 133 400N (30,000 pounds)§ there is little difference in the vibration amplitudes when the trailers are equipped with air or spring suspension systems.

The following simple half-sine pulses conservatively represent the maximum expected severities of shock which is superimposed on and mixed with vibration when the cargo weighs 249 100N (56,000 pounds).

Axis	Peak Acceleration (g)	Pulse Duration (ms)
Longitudinal	2.2	83
Transverse	1.6	40
Vertical	2.9	59

9

Comparison of shock data from different tests show that in the longitudinal axis, increased cargo weight produced higher responses between 1 and 20 Hz and lower responses above 80 Hz. In the transverse axis, the heavier cargo produced higher responses between 8 and 20 Hz but lower responses in other frequencies. In the vertical axis, the responses were lower for heavier cargo above 3 Hz.

Introduction

The packaging and transport of fissile radioactive materials are regulated by the U. S. Nuclear Regulatory Commission by means of the Code of Federal Regulations Title 10, Part 71. Appendix A of these regulations specifies the environmental conditions of transport that are to be applied to determine their effects on packages of radioactive materials. However, Appendix A does not specify numerically the frequencies or amplitudes of vibration and shock environments nor does it mention their expected occurrence rate as a function of shipment time and/or mileage. As a result, when evaluating a package for licensing applications, assumptions regarding these environments are made by each applicant.

To provide guidance in this area, the U. S. Nuclear Regulatory Commission contracted with Sandia Laboratories to gather and evaluate data regarding the truck and rail shock and the vibration environments normally encountered in transporting large shipping casks. The project is divided into three tasks:

1. Extract, review, and reduce shock and vibration environment definitions currently on file in both the DOE/DOD and DOE Transportation Environment Data Banks. *Determine the best, simply stated estimates of* environments for large shipping containers on trucks and railroad cars.

2. Conduct dynamic analyses of the shock environment experienced by cargo in rail switching and coupling to identify the dependence of the shock environment on heavy cargo weights and on shock attenuation couplers.

11

The results are to be used to refine further the shock
load description. Existing mathematical models of
freight cars will be altered to study these special
concerns.

3. Identify, during the performance of Tasks 1 and 2, the
need for additional data. The tests which are necessary
to obtain these data are to be planned. Actual
measurements will be obtained on a "piggyback" basis.

Tasks 1 and 2 were reported in Reference 1. Data obtained during
transport of a 195 700N (44,000-pound) container were reported in
Reference 2. The present investigation is concerned with truck cargo
weighing 249 100N (56,000 pounds).

All data reported herein were taken in English units. The metric
(SI) values presented result from rounded conversions from the English
values.

Test Description

This test was conducted to obtain data on the vibration and shock
environments experienced during truck shipment of cargo which was
heavier than the cargo shipments on which data were previously obtained
(References 1 and 2). Changes, if any, in the environmental levels to
which cargo is exposed with increasing total cargo weight were to be
identified.

Test Procedure

In a separate DOE/ECT funded investigation, Sandia Laboratories
procured two representative spent fuel shipping containers for use in a
series of full-scale vehicle-container impact tests. Since the con-
tainers had been in service, they required decontamination prior to
these planned tests. The decontamination was accomplished at the DOE/
Nevada Test Site at Mercury, Nevada. After decontamination, the con-
tainers were moved to Sandia Laboratories, Albuquerque, New Mexico.

Transportation of the containers from one DOE facility to another
provided an excellent opportunity to conduct the tests reported in
Reference 2 and herein on a "piggyback" basis.

The shipment route was determined by Tri-State Motor Transit
Company through their normal routing procedures. The data measurements
were conducted on a sampling basis; therefore, Sandia personnel
conducted a pretest route survey by driving from Albuquerque to Mercury
to identify potential shock-producing road characteristics (bridges,
railroad crossings, cattle guards) as well as to identify different
road types (rough and smooth blacktop, rough and smooth concrete, and
divided and undivided highways). The locations of various road
segments over which data were to be sampled were established; and data
were taken at these locations during the shipment. During the test,
the drivers of the Tri-State tractor and the Sandia personnel following
in another vehicle were in radio communication so that the locations of
the road features to be included in the data samples were identified by
personnel in both vehicles. The data sampling system was operated
remotely by Sandia personnel when the desired sampling points were
encountered.

Highway Description

The routes traveled were US 95 from Mercury, Nevada, to Las Vegas,
Nevada; US 93 from Las Vegas, Nevada, to Kingman, Arizona; and
I-40/US 66 from Kingman, Arizona to Albuquerque, New Mexico.

The highway from Mercury to Las Vegas was four lane, divided,
smooth blacktop through flat country. The highway from Las Vegas to
Hoover Dam and through urban and semi-urban communities included
three-, four-, and six-lane divided blacktop roads. The highway from
east of Hoover Dam to Kingman, Arizona, was relatively rough, two-lane
blacktop, undivided highway over rolling countryside. The segment from
Kingman, Arizona to Seligman, Arizona was smooth, two-lane, undivided
blacktop over very level country. From Ashford, Arizona, to
Albuquerque, New Mexico, the highway segments over which data were

taken were four-lane, divided highways made from bot). concrete and blacktop. The final segments were through mountainous and high desert country.

Data were also recorded to determine the characteristics of shock superimposed on and mixed with the vibration. Two cattle guard crossings, two railroad crossings, and five bridges were encountered. The speeds at which these were transversed ranged from 42 km/hr (26 mph) to 88 km/hr (55 mph).

Shipping Configuration

The trailer on which the container was mounted (Figure 1) was manufactured by Fruehauf. It was 12.2 metres (40 feet) long and was equipped with a three-axle, spring suspension system. The tractor was a White Freightliner equipped with tandem axles with a "velvet-ride" suspension system.
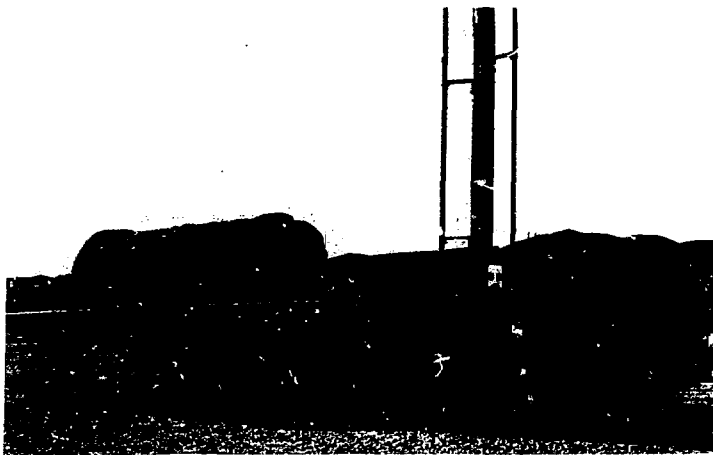

Figure 1. Shipping Configuration of Trailer, Container, and Data Acquisition System

The container was supported at each end by structures which were fastened to structural members of the trailer. It was manufactured by Knapp Mills, Incorporated, and was previously owned by the General Electric Company. The weight of the cask, support structure, and trailer was 305 100N (68,600 pounds). The total weight of the shipment, including the tractor, was 378 700N (85,140 pounds).

Instrumentation

The instrumentation consisted of accelerometers with associated cabling, and a data acquisition system (DAS) which was designed and fabricated at Sandia Laboratories. The DAS contained the signal conditioning equipment and a tape recorder to provide a record of the output from the transducers. The DAS could be operated remotely by radio link, so data sampling was controlled by Sandia personnel who were following the truck.

Fourteen data channels were available on the DAS. One channel was used to record the IRIG time being generated by the DAS. This was done to permit identification of specific segments on the data tape for data reduction. One data channel was used to provide coded identification of specific events. Twelve data channels were used to record the excitation being experienced by the accelerometers.

Four sets of three accelerometers each were used to measure the environment at each of the major axes (longitudinal, transverse, and vertical) at the structure supporting the container (Figure 2). Three piezoelectric accelerometers and three piezoresistive accelerometers were mounted at each end of the container. Two types of accelerometers were used to provide data over frequencies from 0 Hz to 1900 Hz. The output from these accelerometers was recorded on magnetic tape after the signal had been conditioned by the DAS.
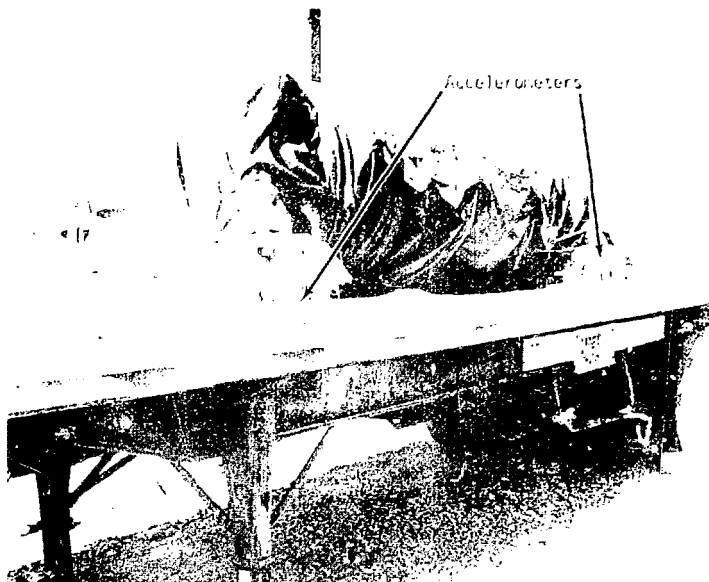
Figure 2. Left Side Accelerometer Placement

Test Results

The environmental descriptions presented in this section summarize the data obtained during the truck shipment of the 249 100N (56,000-pound) cargo from Mercury, Nevada, to Albuquerque, New Mexico.

Definitions of Dynamic Environments

Dynamic excitations delivered to cargo may be described as a mixture of vibration, occasional shock superimposed on the vibration, and isolated shock which occurs in single events such as rail coupling.

[illegible]

[illegible] represent [illegible] The distribution of the 99 percent acceleration amplitudes [illegible] is random, [illegible] Gaussian. [illegible] interface between the cargo and the cargo floor.

The data for shock were reduced to single-degree-of-freedom shock response spectra format. These spectra predict the maximum acceleration amplitude at which various single-degree-of-freedom systems would respond when subjected to the transient inputs. Shock spectra are used because they permit translation of complex inputs into a more useful engineering format and permit statistical summarizing of diverse individual phenomena. In generating these response spectra, three-percent damping was used because experience has shown this is representative of the response of metal-to-metal connections.

Data Reduction

The data samples were recorded on magnetic tape before and after the shipment. A data event was recorded prior to the start of the shipment when there were no dynamic excitations being experienced.

This data event was used to determine the background, electrical "noise" in each channel. An oscillograph record of the entire data tape was produced in order to allow correlation of specific events with the associated data tape segments to be used for data reduction. The events were identified for data reduction as either vibration or shock. Vibration data were reduced by the data reduction program VIBRAN. This program counts the number of zero-to-peak acceleration amplitudes in predetermined amplitude ranges in preselected frequency bands. After the VIBRAN records were available, those records in which data were above the "noise" level were selected for combination into a composite record by program VAIL. The VAIL program combines VIBRAN records and displays the resulting distribution of zero-to-peak amplitudes in the same format as the individual VIBRAN records.

The superimposed shock records were reduced in response spectra format. The individual response spectra were than combined by program ZSTP. This program produces the mean response spectrum of the spectra being combined, the peak acceleration of all the records combined, and the three standard deviations about the mean level of response of the records which were combined.

Truck Data

Vibration -- The vibration data presented herein are zero-to-peak acceleration amplitude levels which envelop 99 percent of all amplitudes measured in each frequency band. The vibration levels presented are those which define the input to the cargo.

The highest of the 99-percent zero-to-peak accelerations occurred in the vertical axis. These amplitude levels were between 0.19 g and 0.52 g from 0 Hz to 500 Hz and were at 0.10 g from 500 Hz to 1900 Hz.

The highest of the 99-percent zero-to-peak accelerations in the longitudinal axis was 0.27 g, which occurred in the 0-Hz to 5-Hz frequency band. The acceleration amplitude levels were lower in all other frequencies.

The highest of the 99-percent zero-to-peak accelerations in the transverse axis was 0.19 g, which occurred in the 10-Hz to 20-Hz frequency band. As was the case for the vertical axis, the amplitude levels decreased above 500 Hz. Details of the 99-percent zero-to-peak amplitude levels in each frequency band and each axis are presented in Table I.

TABLE I

Truck Vibration 249 100N (56,000-Pound) Cargo

Frequency Band (Hz)	Input to Cargo (g); 99% Level of Zero-to-Peak Amplitude		
	Longitudinal Axis	Transverse Axis	Vertical Axis
0-5	0.27	0.10	0.52
5-10	0.14	0.07	0.27
10-20	0.19	0.19	0.37
20-40	0.10	0.07	0.19
40-80	0.10	0.10	0.37
80-120	0.07	0.10	0.37
120-180	0.07	0.10	0.52
180-240	0.05	0.10	0.52
240-350	0.07	0.14	0.52
350-500	0.05	0.07	0.37
500-700	0.05	0.02	0.10
700-1000	0.05	0.02	0.10
1000-1400	0.14	0.05	0.10
1400-1900	0.03	0.02	0.10

Shock -- The shock data presented were obtained during the same test as the truck vibration data but from different specific events. The shock data were obtained from measurements taken when the truck encountered railroad crossings, cattle guard crossings, and bridge approaches. The data define the response at the interface between the cargo and the cargo floor.

The data are presented in shock response spectra format. Three-percent damping was used to produce the response spectra because experience has shown this to be representative of the response of metal-to-metal structures. The data present the results of combining the individual response spectra in each of the major axes (longitudinal, transverse, and vertical). Each plot presents the mean, peak, and three-standard-deviation response spectra.

The vertical axis produced response spectra which were higher in amplitude than the other two axes at all frequencies. All three axes showed high response at approximately 15 Hz, which is the frequency at which tires have the greatest response. At approximately 2.5 Hz, all three axes showed peak response but of lower amplitudes than those at 15 Hz. Near this frequency, suspension systems have the greatest response. The response spectra for all three axes are shown in Figures 3, 4, and 5.

Single-Pulse Representation of Shock — Single-input pulses are a convenient way of approximating complex input shock pulses for evaluating mechanical structures. The single-input pulses presented were obtained by comparing their response spectra with the response spectra obtained from the test data. The comparison method usually introduces conservatism because the response spectra from test data are enveloped by the single-pulse response spectra up to the highest frequency of interest. Several simple pulses can be selected to define an input pulse. In this report, half-sine pulses are used.

The peak acceleration of the selected half-sine input pulses for the three-standard-deviation and absolute peak response spectra do not vary significantly. The peak acceleration of simple pulses which have response spectra that envelop the mean of the combined response spectra for each axis are generally about half the amplitude of the other two spectra for the absolute peaks and three standard deviations for that axis. Table II shows a comparison of the characteristics of single half-sine pulses for the different levels of response.
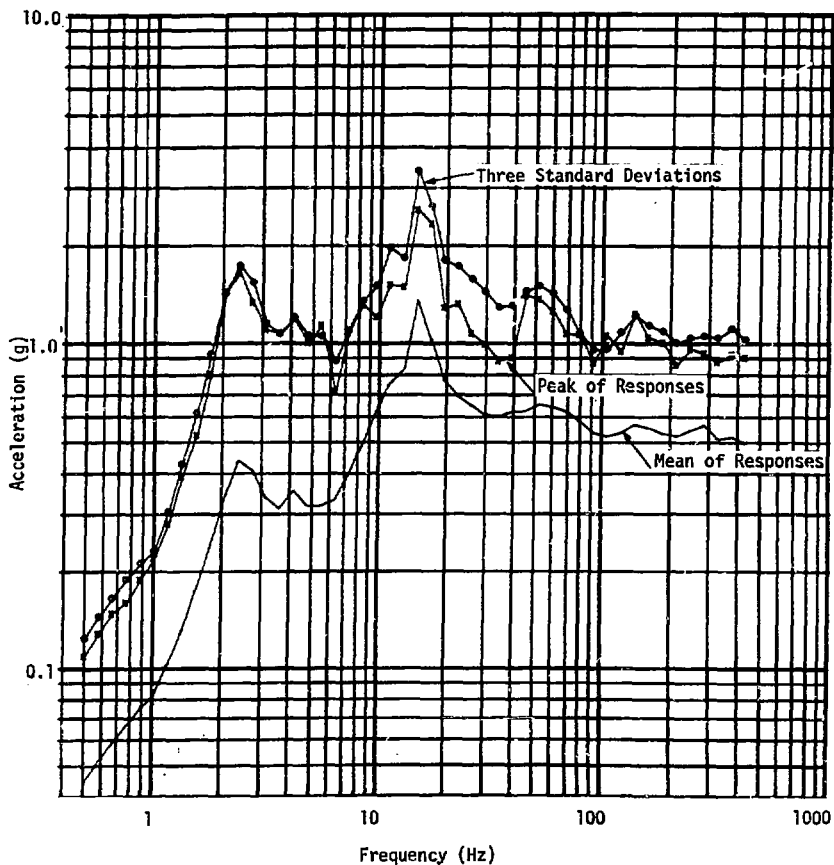
Figure 3. Superimposed Shock Response Spectra,
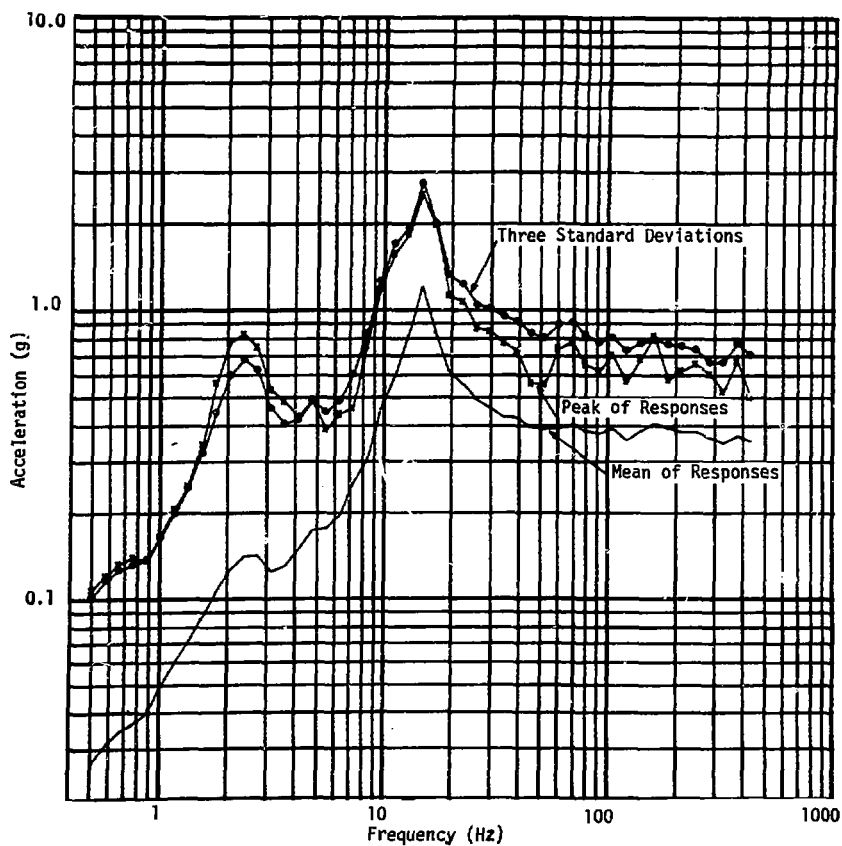3% Damping, Longitudinal Axis

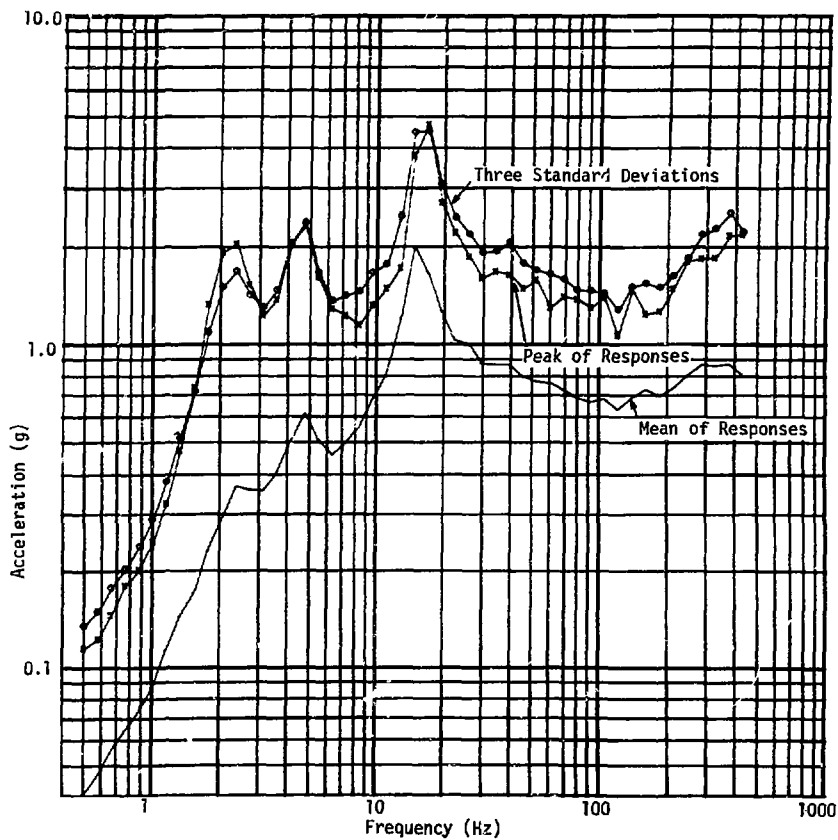Figure 4. Superimposed Shock Response Spectra,
3% Damping, Transverse Axis

Figure 5. Superimposed Shock Response Spectra, 3% Damping, Vertical Axis

TABLE II

Truck Shock Represented by Single Half-Sine Pulses

Axis	Peak Acceleration (g)	Pulse Duration (ms)	Velocity Change	
			(m/s)	(ft/s)
From Response Spectra of Three-Standard-Deviations				
Longitudinal	2.2	83	1.1	3.7
Transverse	1.6	40	0.4	1.3
Vertical	2.6	67	1.1	3.5
From Response Spectra of Absolute Peak Responses				
Longitudinal	1.8	91	1.0	3.3
Transverse	1.3	59	0.5	1.6
Vertical	2.9	59	1.1	3.5
From Response Spectra of Mean Responses				
Longitudinal	0.8	50	0.2	0.8
Transverse	0.7	37	0.2	0.5
Vertical	1.3	37	0.3	1.0

Comparison of Truck Data

Vibration

Comparison of the zero-to-peak vibration amplitude levels shows
that the highest vibration input occurs when trucks carry relatively
light loads. This is particularly true for the longitudinal and
vertical axes in most frequency bands and for the transverse axis in
frequencies above 700 Hz. For cargo weighing more than 133 400N
(30,000 pounds), there is little difference in the vibration amplitudes
regardless of the type of suspension systems on the trailers. Table
III presents zero-to-peak vibration amplitude levels for different

cargo weights. Figures 6, 7, and 8 present the same data comparison in graphical form. The data cover three cargo weights.

TABLE III

Truck Vibration Comparison Zero-to-Peak Amplitude Levels

Frequency Band (Hz)	Input to Cargo (g) 99% Level of Zero-to-Peak Amplitude								
	Longitudinal Axis			Transverse Axis			Vertical Axis		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
0-5	0.10	0.14	0.27	0.10	0.14	0.10	2.00	0.27	0.52
5-10	0.08	0.19	0.14	0.06	0.19	0.07	1.04	0.19	0.27
10-20	0.84	0.27	0.19	0.15	0.27	0.19	1.68	0.27	0.37
20-40	0.51	0.10	0.10	0.24	0.27	0.07	1.20	0.27	0.19
40-80	0.36	0.14	0.10	0.42	0.14	0.10	0.50	0.52	0.37
80-120	0.24	0.07	0.07	0.27	0.10	0.10	0.87	0.52	0.37
120-180	1.23	0.07	0.07	0.21	0.10	0.10	0.63	0.52	0.52
180-240	0.87	0.05	0.05	0.12	0.10	0.10	0.87	0.52	0.52
240-350	0.24	0.05	0.07	0.15	0.10	0.14	0.63	0.52	0.52
350-500	0.24	0.05	0.05	0.15	0.05	0.07	0.42	0.14	0.37
500-700	0.87	0.04	0.05	0.15	0.04	0.02	0.87	0.07	0.10
700-1000	1.50	0.03	0.05	0.87	0.07	0.02	1.17	0.07	0.10
1000-1400	0.87	0.01	0.14	1.17	0.04	0.05	1.17	0.05	0.10
1400-1900	0.39	0.01	0.03	0.24	0.05	0.02	0.87	0.05	0.10

(1) Cargo weight: no load to 133 400N (30,000 pounds). Spring and air suspension systems (Reference 1).

(2) Cargo weight: 195 700N (44,000 pounds). Air suspension system (Reference 2).

(3) Cargo weight: 249 100N (56,000 pounds). Spring suspension system.
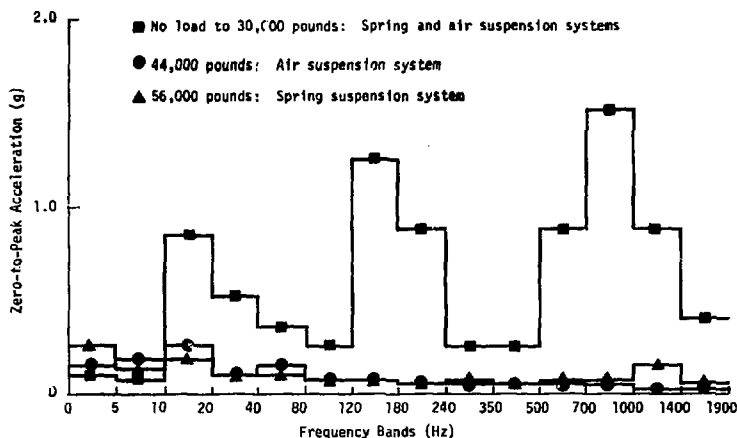
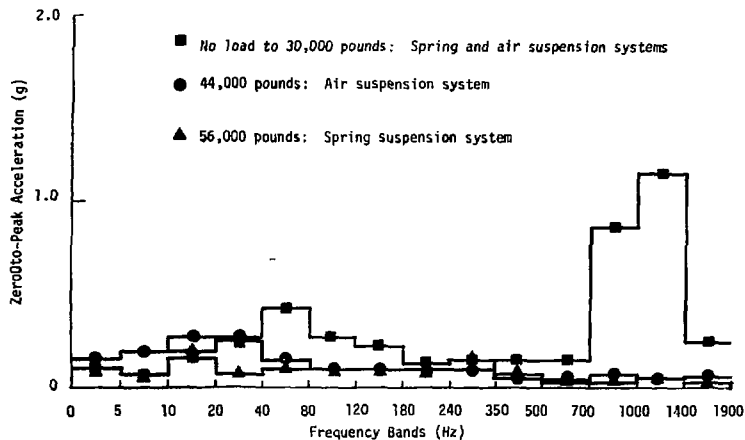Figure 6. Comparison of Truck Vibration Data,
Longitudinal Axis

Figure 7. Comparison of Truck Vibration Data,
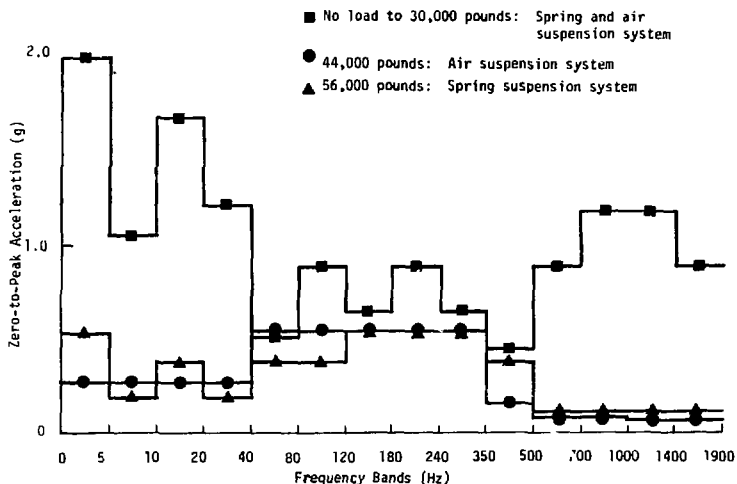Transverse Axis

Figure 8.   Comparison of Truck Vibration Data,
Vertical Axis

Superimposed Shock, Longitudinal Axis

Heavier cargo weight produced a higher amplitude of response in
the longitudinal axis in the 1-Hz to 20-Hz frequency range. These are
the frequencies at which suspension systems and tires have the greatest
response. Above 80 Hz, the response is lower in amplitude than that
for lighter cargo. Comparison of longitudinal axis response spectra
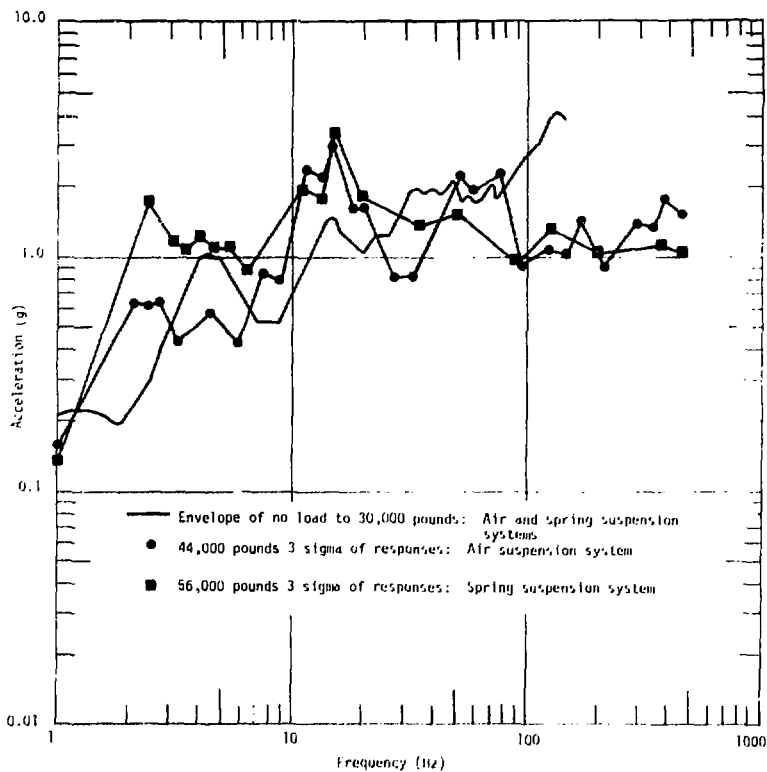obtained from test data is shown in Figure 9.

Figure 9.   Comparison of Response Spectra From Truck Data 3%
Damping, Longitudinal Axis

Superimposed Shock, Transverse Axis

As is the case for the longitudinal axis, heavier cargo do not produce higher response in the transverse axis in the 5 Hz to 20 Hz frequency range. This higher response appears to be caused by the high excitation at about 15 Hz, which is the frequency at which the tires responded. Above 20 Hz, the response is lower in amplitude for the heavier cargo. Comparison of transverse axis response spectra obtained from test data is shown in Figure 10.
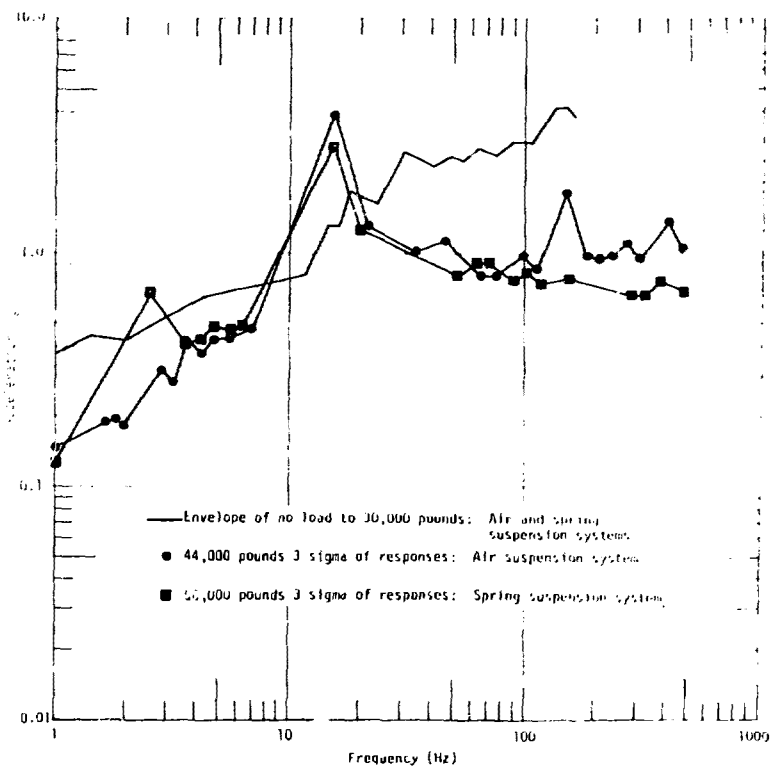

Figure 10.   Comparison of Response Spectra From Truck Data
3% Damping, Transverse Axis

Superimposed Shock, Vertical Axis

The response for the vertical axis is lower for heavy cargo in all frequencies above about 3 Hz. As in the other two axes, the response caused by suspension system and tire hop excitation can be identified below about 20 Hz. Comparison of vertical axis response spectra obtained from test data is shown in Figure 11.
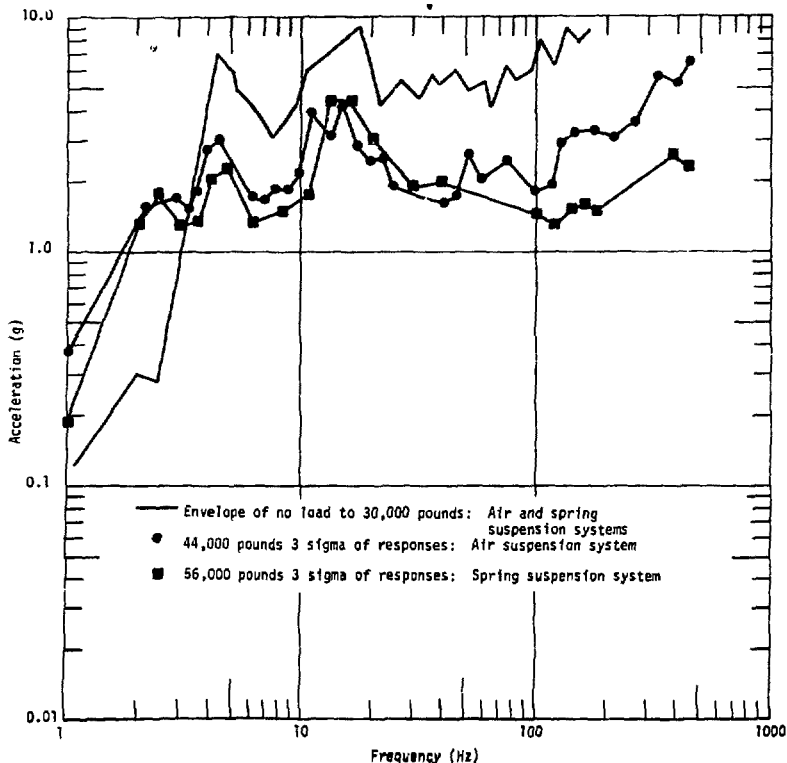

Figure 11. Comparison of Response Spectra From Truck Data
3% Damping, Vertical Axis

Single-Pulse Representation of Superimposed Shock

Comparison of simple, half-sine input pulses which have response spectra that envelop the response spectra obtained from test data show that for the longitudinal axis, the pulse duration increases with increasing cargo weight and this causes an increased velocity change under the single pulse; this is true even though the peak acceleration of the half-sine pulse decreases with increased cargo weight. The longer duration of the single pulse results from the enveloping of higher response at the lower frequencies.

As is the case for the longitudinal axis, the peak acceleration of half-sine input pulses which may represent the shock pulse for the transverse axis decrease with increased cargo weight. In this axis, the pulse duration and the resulting velocity change are greatest for the 195 70GN (44,000-pound) test data.

The simple single half-sine input pulses, which may represent the shock for the vertical axis, change considerably from the light cargo to those for the 195 700N (44,000-pound) cargo but do not change in amplitude or duration with additional increase in cargo weight. Table IV presents comparisons of simple single half-sine pulses which can be used to represent the shock which is superimposed on and mixed with the vibration during truck transport.

TABLE IV

Comparison of Truck Shock Represented by Single Half-Sine Pulses

Axis	Peak Acceleration (g)	Duration (ms) (1)	V (m/s)	V (ft/s)
Longitudinal	2.8	20	0.3	1.1
Transverse	2.3	19	0.3	0.9
Vertical	7.0	77	3.3	10.9
		(2)		
Longitudinal	2.5	32	0.5	1.6
Transverse	2.2	50	0.7	2.2
Vertical	2.6	67	1.1	3.5
		(3)		
Longitudinal	2.2	83	1.1	3.7
Transverse	1.6	40	0.4	1.3
Vertical	2.6	67	1.1	3.5

(1) Cargo weight: no load to 133 400N (30,000 pound) spring and air suspension systems (Reference 1) envelope of data.

(2) Cargo weight: 195 700N (44,000 pounds) air suspension; data from response spectra of three- standard-deviations (Reference 2).

(3) Cargo weight: 249 100N (56,000 pounds) spring suspension system; data from response spectra of three standard-deviations.

References

1. C. F. Magnuson and L. T. Wilson, Shock and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks, SAND76-0427, Sandia Laboratories, Albuquerque, New Mexico, June 1977.

2. C. F. Magnuson, Shock and Vibration Environments for Large Shipping Container During Truck Transport (Part I), SAND77-1110, Sandia Laboratories, Albuquerque, New Mexico, September 1977.