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Shock and Vibration Environments for Large Shipping Container During Truck Transport (Part I)

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Cliff F. Magnuson

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

Cliff F. Magnuson
Applied Mechanics Division II 1282
Sandia Laboratories, Albuquerque, NM 87115

ABSTRACT

The purpose of this study was to obtain vibration and shock data during truck shipment of heavy cargo. Currently available data were taken on trucks bearing lighter loads than the loads of current interest. In addition, the new data are expected to be useful in the determination of any trends of vibration and shock environments with increased cargo weight. These new data were obtained on a "piggyback" basis during truck transport of 195 700 N (44,000 lb) cargo which consisted of a spent fuel container and its supporting structure from Mercury, Nevada, to Albuquerque, New Mexico. The routes traveled were US 95 from Mercury, Nevada, to Las Vegas, Nevada; US 93 from Las Vegas to Kingman, Arizona; and I-40/US 66 from Kingman to Albuquerque, New Mexico. Speeds varied from very slow during hill climbs to 101 km/hr (63 mph). A comparison of these data with a collectively reduced set of data for cargo weights varying from no-load to 133 400 N (30,000 lb) showed that the zero to peak amplitude levels of vibration were significantly lower for frequencies less than 40 Hz in the vertical axis and that there was a reduction in the vibration amplitude levels in all axes for frequencies greater than 500 Hz. The shock response amplitude was less severe for the entire frequency spectrum in the vertical axis, but it was not significantly different in the other axes. Data measurements were made on a truck shipment of a 249 100 N (56,000 lb) container over the same routes as were used for the shipment discussed in this report. These data will be presented in a subsequent report along with any additional data trends that result from studies of trucks carrying increased cargo weight.

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SUMMARY

This report contains descriptions of shock and vibration environments which were measured during truck shipment of a 195 700 N (44,000 pound) container mounted on a tandem axle trailer which was pulled by a tandem axle tractor from Mercury, Nevada, to Albuquerque, New Mexico.

Vibration data show the highest level of input vibration to cargo to be:

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

The shock data show simple half-sine pulses which conservatively represent the maximum expected severities of shock, which are superimposed on and mixed with vibration, to be:

Axis	Peak Acceleration (g)	Pulse Duration (ms)
Longitudinal	2.5	32
Transverse	2.2	50
Vertical	2.6	67

SHOCK AND VIBRATION ENVIRONMENTS FOR LARGE SHIPPING CONTAINER DURING TRUCK TRANSPORT (Part I)

Introduction

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 environmental conditions of transport to be applied to determine their effects on packages of radioactive materials. However, the appendix 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 must be 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 truck and rail shock and 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 ERDA/DOD and ERDA Transportation Environment Data Banks. Determine the best, simply stated estimates of environments for large shipping containers on truck and rail car.

(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. 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. The present investigation is concerned with truck shipment of cargo heavier than the cargo used in previous measurements.

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 (Reference 1). 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 investigation, an ERDA/ECT funded program, Sandia Laboratories procured a representative spent fuel shipping container for use in a series of full scale vehicle-container impact tests. Since the container had been in service, it required decontamination prior to these planned tests. The decontamination was accomplished at the ERDA/Nevada Test Site at Mercury, Nevada. After decontamination, the container was to be moved to Sandia Laboratories, Albuquerque, New Mexico. Transportation of the container from one ERDA facility to another provided an excellent opportunity to conduct the test reported 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 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 characteristics (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 tabulated, and data were taken at these locations during the shipment. The drivers of the Tri-State tractor and the Sandia personnel following in another vehicle were in communication by means of walkie-talkies so that location of the road features to be included in the data samples was 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 Ashfork, Arizona, to Albuquerque, New Mexico, the highway segments over which data were taken were four lane, divided highways made from both concrete and blacktop. The final segments were through mountainous and high desert country.

In addition to the road types discussed above, samples were also recorded to determine the characteristics of shock superimposed on and mixed with the vibration. Eight cattle guard crossings, two railroad crossings, and four bridge crossings were encountered. The speeds at which these events were traversed were from 72 km/hr (45 mph) to 93 km/hr (58 mph).

Shipping Configuration

The trailer on which the container was mounted (Figure 1) was manufactured by Fruehauf. It was 10.7 metres (35 feet) long and was equipped with an air suspension system. The tractor was a White Freightliner equipped with tandem axles with "Velvet-Ride" suspension system.

The container was supported on either 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 252 600 N (56,780 pounds). The total weight of the shipment including the tractor was 337 400 N (75,840 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 started and stopped 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 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 identification of specific events. Twelve data channels were used to record the excitations being experienced by the accelerometers.

Four sets of three accelerometers were used to measure the environment in each of the major axes (longitudinal, transverse, and vertical) at the structure supporting the container (Figures 2 and 3). One set of three piezoelectric accelerometers and one set of three piezoresistive accelerometers were mounted at each end of the container. The two types of accelerom-

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

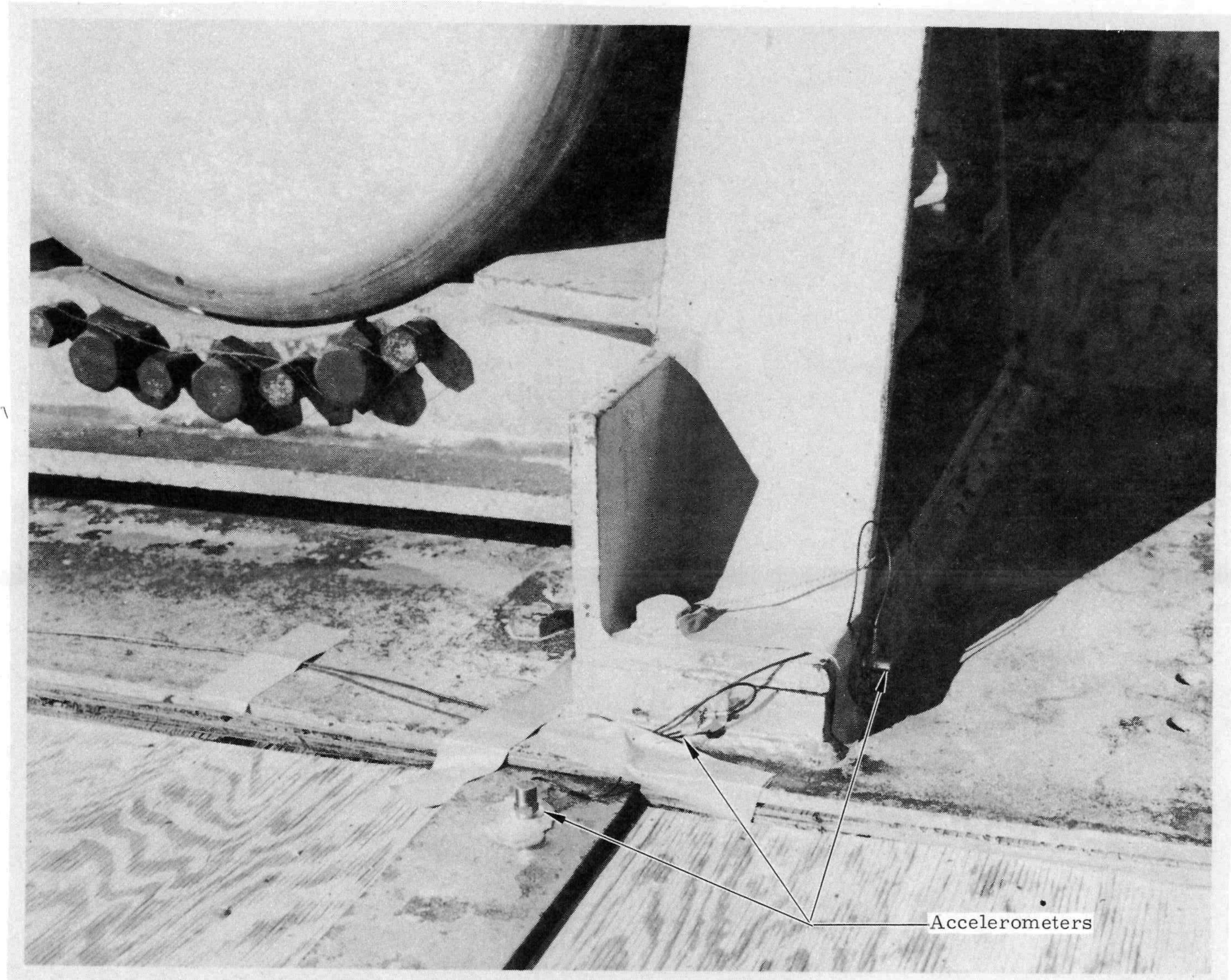

Figure 2. Left Front Accelerometer Placement

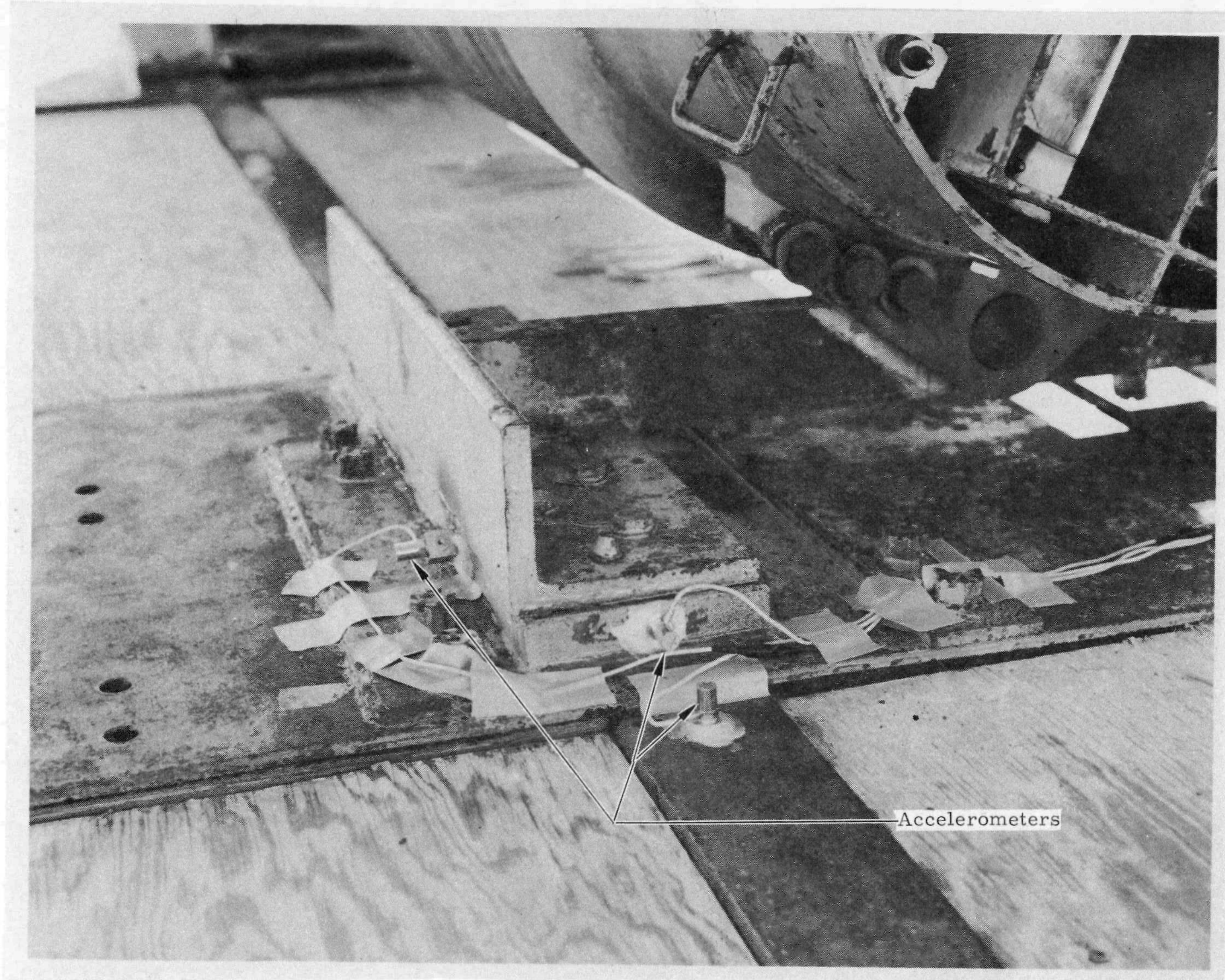

Figure 3. Left Rear Accelerometer Placement

eters were used to provide data over frequencies from 0 to 1900 Hz. The output from these accelerometers was recorded on magnetic tape after the signal had been conditioned by the DAS. The cable on the vertical piezoelectric accelerometer on the forward end of the container was scuffed such that no data were obtained from the accelerometer.

Test Results

The environmental descriptions presented in this section are summaries of data obtained during the truck shipment of the 195 700 N (44,000 pounds) 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.

Vibration is the excitation which occurs whenever the carrier is in motion and is produced by the carrier suspension system and carrier frame members reacting to travel over surface irregularities in highways as well as the vibration generated by the carrier motive system.

Superimposed shock is that which often results in higher amplitudes of cargo response than that produced by vibration. Characteristically it consists of decaying transient pulses which are superimposed on and mixed with the vibration. For trucks the superimposed shock is produced by crossing railroad tracks, bridge approaches, and cattle guards and by striking pot holes.

Explanation of Data

Vibration definitions presented herein are zero to peak acceleration amplitude levels which envelop 99 percent of all amplitudes measured in each frequency band. The remaining one percent of the data was considered to represent superimposed shock and was treated separately. The distribution of the 99 percent acceleration amplitudes in each frequency band is random, for which the probability distribution is very nearly Gaussian. The acceleration amplitudes were measured at the interface between the cargo and the cargo floor.

The data for shock were reduced in single-degree-of-freedom 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. Response spectra are used because they permit translation of complex input into a more useful engineering format and permit statistical analysis of diverse individual phenomena. In these response spectra, three percent damping was used because our experience shows this to be representative of the response of metal to metal connections.

Data Reduction

The data samples were recorded on magnetic tape before and during 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 "noise" in each channel. An oscillograph record of the entire data tape was produced to correlate 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 using 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 using 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 then combined using 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. The vertical axis produced the same as, or greater, acceleration amplitudes than the other axes over the entire frequency spectrum from zero to 1900 Hz. The amplitude level varied from 0.27 g in the 0-5 Hz frequency band to 0.52 g over the 20-350 Hz frequency bands and then gradually decreased to 0.05 g in the 1000-1900 Hz frequency band.

The highest 99 percent zero to peak acceleration level in the longitudinal axis was 0.27 g in the 10-20 Hz frequency band. The amplitude levels increased from 0.14 g in the 0-5 Hz frequency band to 0.27 g in the 10-20 Hz frequency band and then decreased to 0.01 g at 1000 Hz.

The highest 99 percent zero to peak acceleration level in the transverse or lateral axis was 0.27 g in the 10-40 Hz frequency bands. Again, the amplitude levels increased from the lower frequency bands to 0.27 g at 10 Hz and decreased above 40 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
195 700 N (44,000 Pound) Cargo

	Input to Cargo (g) 99% Level of 0 to Peak Amplitude		
Frequency Band - Hz	Longitudinal Axis	Transverse Axis	Vertical Axis
0-5	0.14	0.14	0.27
5-10	0.19	0.19	0.19
10-20	0.27	0.27	0.27
20-40	0.10	0.27	0.27
40-80	0.14	0.14	0.52
80-120	0.07	0.10	0.52
120-180	0.07	0.10	0.52
180-240	0.05	0.10	0.52
240-350	0.05	0.10	0.52
350-500	0.05	0.05	0.14
500-700	0.04	0.04	0.07
700-1000	0.03	0.07	0.07
1000-1400	0.01	0.04	0.05
1400-1900	0.01	0.05	0.05

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 in producing 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 equal to or greater than the response spectra in the other two axes. All three axes showed high response at approximately 15 Hz, which is the frequency at which tires respond the greatest. The response of the longitudinal and vertical axes also showed peaks, but these were of lower amplitudes at lower frequencies where the suspension system responds the most. The response spectra for all three axes are shown in Figures 4, 5, and 6.

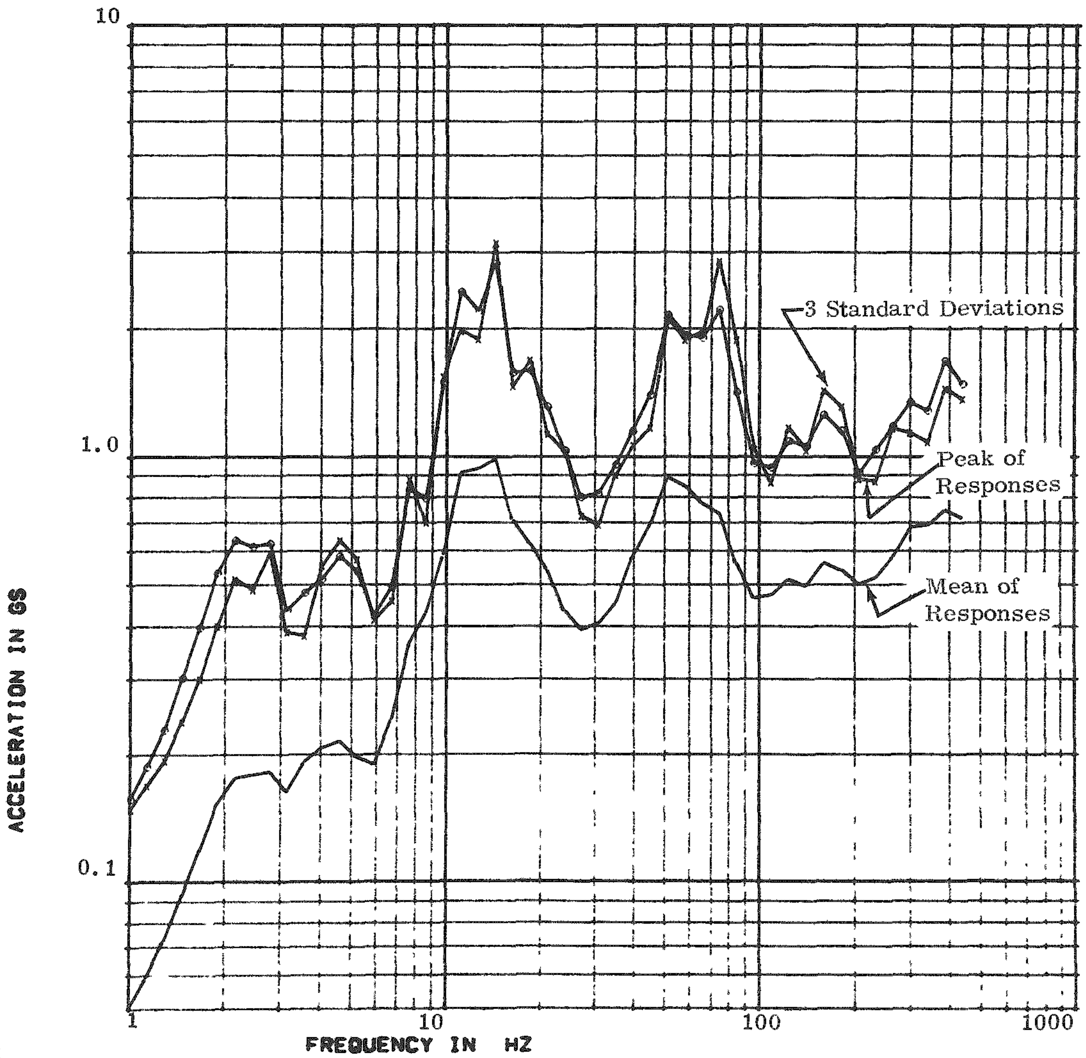

Figure 4. Superimposed Shock Response Spectra--3% Damping--Longitudinal Axis

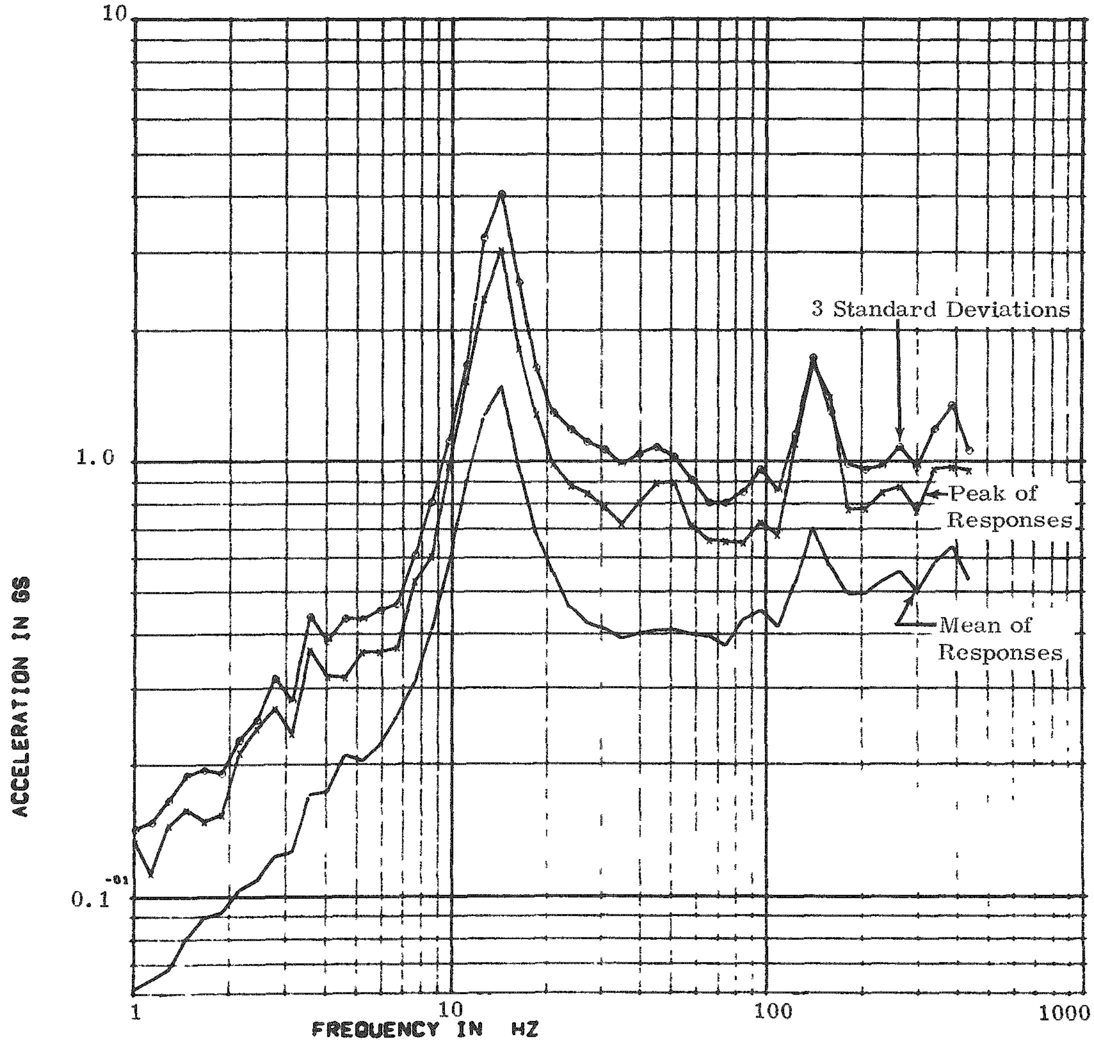

Figure 5. Superimposed Shock Response Spectra--3% Damping--Transverse Axis

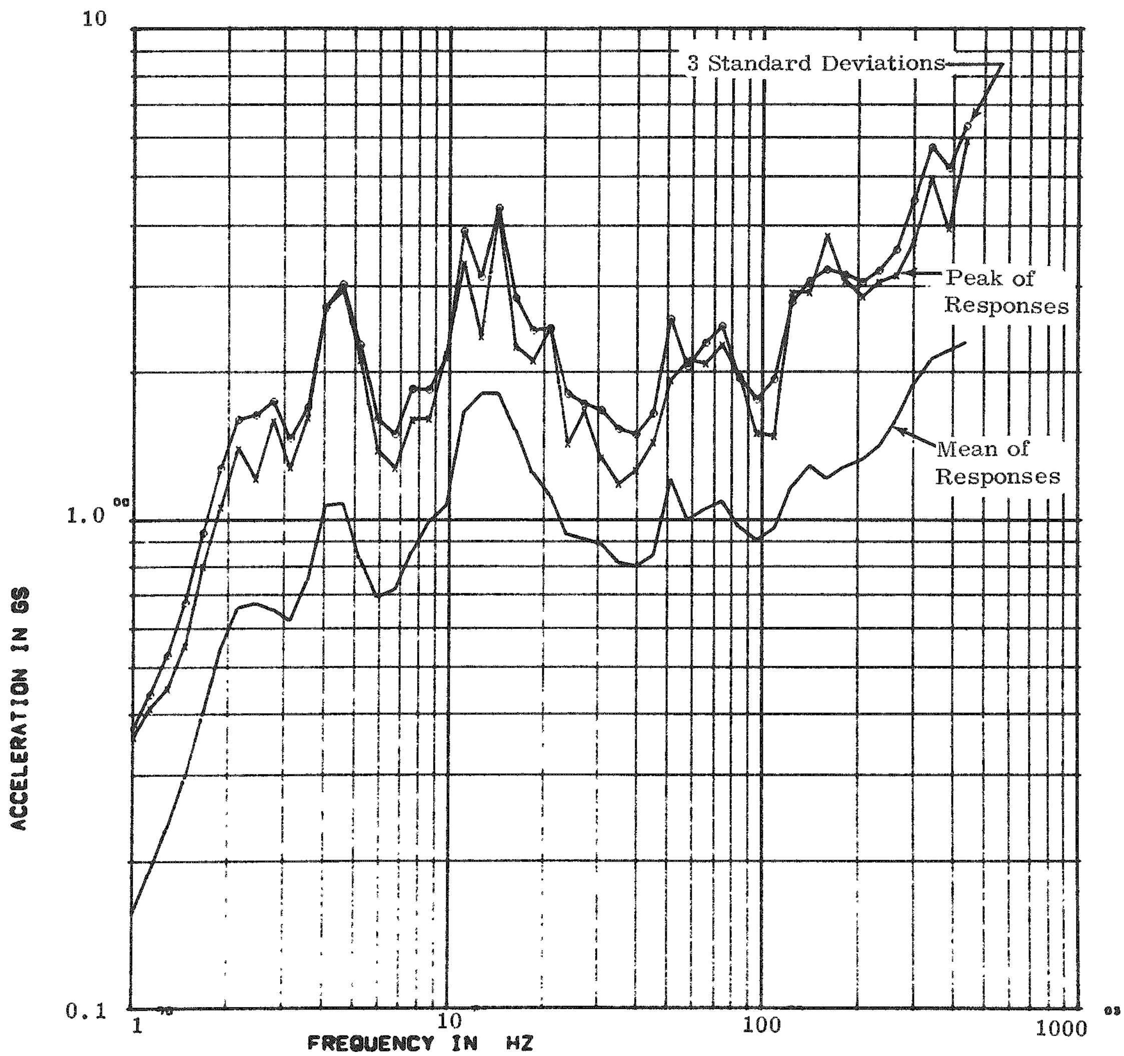

Figure 6. Superimposed Shock Response Spectra--3% Damping--Vertical Axis

Single Pulse Representation of Shock -- Simple 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 test data. The comparison method usually introduces a conservatism because the response spectra from test data are enveloped by the single pulse response spectra up to a 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-deviation for that axis. Table II shows a comparison of the characteristics of single half-sine pulses for the different levels of response.

TABLE II

Truck Shock Represented by Single Half-Sine Pulses

Axis	Peak Acceleration (g)	Pulse Duration (ms)	Velocity Change (m/sec)	Velocity Change (ft/sec)
(From Response Spectra of 3-Standard-Deviations)				
Longitudinal	2.5	32	0.5	1.6
Transverse	2.2	50	0.7	2.2
Vertical	2.6	67	1.1	3.5
(From Response Spectra of Absolute Peak Responses)				
Longitudinal	1.9	32	0.4	1.2
Transverse	1.7	50	0.5	1.7
Vertical	2.6	67	1.1	3.5
(From Response Spectra of Mean Responses)				
Longitudinal	0.7	32	0.1	0.5
Transverse	0.8	50	0.2	0.8
Vertical	1.0	77	0.5	1.6

Comparison With Earlier Data

Comparing the data obtained on the shipment of 195 700 N (44,000 pounds) cargo with that reported in Reference 1, which was a compilation of data obtained during shipments varying from no-load to 133 400 N (30,000 pounds), shows the following:

Vibration: The most significant difference in the zero to peak amplitude levels of vibration was the reduction in the vertical axis from zero to 40 Hz and above 500 Hz in all axes.

Shock: The shock response produced in the vertical axis during the heavier cargo shipment was less than that reported for lighter cargo across the entire frequency spectrum. The peak acceleration of the three-standard-deviation representative single pulse decreased from 7.0 g to 2.6 g.

The response spectra for the transverse axis during the heavier shipment were generally lower than those reported in Reference 1 except in the 8 to 18 Hz frequency range. While the peak acceleration of the signal half-sine input pulse having a response spectrum that envelops the three-standard-deviation response spectrum only decreased from 2.3 g to 2.2 g, the pulse duration of that simple pulse increased from 19 ms to 50 ms.

The response spectra for the longitudinal axis did not change significantly in amplitude, but the frequencies at which the heavier cargo responded were slightly different. The peak acceleration of the single half-sine pulse, which has a response spectrum that envelops the three-standard-deviation response spectrum, decreased from 2.8 g to 2.5 g, but, again, the pulse duration increased (from 20 ms to 32 ms).

References

1. SAND 76-0427, "Shock and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks," C. F. Magnuson and L. T. Wilson, Sandia Laboratories, Albuquerque, NM.

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