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SIMULATING TRUCK AND RAIL VIBRATION
AND IMPACT LEVELS IN AUTOMOTIVE ENGINE STREEL RACKS

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DEVELOPMENT OF CRITERION FOR SIMULATING TRUCK AND RAIL VIBRATION AND IMPACT LEVELS IN AUTOMOTIVE ENGINE STEEL RACKS

By

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ABSTRACT

DEVELOPMENT OF TEST CRITERION FOR
SIMULATING TRUCK AND RAIL VIBRATION
AND IMPACT LEVELS IN AUTOMOTIVE ENGINE STEEL RACKS

By

Paween Rojnuckarin

A study of the transport environment used to ship Ford engines in truck and rail shipments was conducted to quantify the shock and vibration levels in steel racks. Tri-axial acceleration data was collected to determine the severity of shock and vibration input from the floors of truck-trailers and rail-boxcars. The Power Spectral Density plots were developed from the data collected and these were used to simulate truck and rail shipments using electrohydraulic vibration tables. These tests can be used to make modifications in steel rack design to minimize damage to automotive components during shipping. The results showed that the highest vibration levels in the steel racks occurred at 4 Hz in the vertical axis for truck shipments, and between 12-16 Hz for rail shipments. The vibration levels in the longitudinal and lateral directions are much lower than the levels in the vertical direction for truck shipments. The highest shock level measured in rail shipments was 5.6 G in the longitudinal axis as a result of coupling.

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I would also like to thank Ford Motor Company (Engine Operations) for providing funding for conducting this study.

DEDICATION

I would like to dedicate this work to my father and my mother for their support during my graduate education.

Finally, I would like to thank my friends, Sutthipong Na Songkhla, Saifon Rusmijarern, and Sudawan Supachokouychai, for their assistance.

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1.0 INTRODUCTION

The various types of transportation and handling systems used to ship packaged products can cause damage to the products, due to the presence of shock and vibration forces. It is important to know the levels of shock and vibration that exist in various transportation modes. This information can be used with the product fragility data to design package systems that will protect the product.

Previous studies that have measured truck-trailer shipments, have shown that vibration levels in the vertical direction are the most severe compared to those in the longitudinal and lateral directions. For rail shipments, vibration levels in the longitudinal and lateral directions can be equal or higher than those in the vertical direction at higher frequencies because of irregularities in the track conditions.

Most transportation dynamics studies that measure shock and vibration levels in truck and rail shipments present the results in the form of RMS acceleration (G), or Power Spectral Density (G^2/Hz) versus frequency (Hz). The Power Spectral Density results (PSD) are also used in lab testing to simulate the conditions found in the distribution environment.

1.1 Vibration Levels in Truck Shipments.

Truck shipments are the most common method for transportation in the United States. The percentage of freight shipped by truck has continuously increased from 26% in 1950 to 37% in 1980 (National Council of Physical Distribution Management, 1982). In a truck-trailer system the two primary sources of shock and vibration forces are:

- External sources, such as road or surface irregularities, breaking and forward acceleration.
- Internal sources from the vehicle itself, such as engine vibration, drive mechanisms and wheel imbalance.

There have been several studies performed in the past two decades on measuring the shock and vibration levels in various package transportation systems. A brief summary of these studies and their findings is discussed in this section. Sharpe et al. (1974) studied the vibration environment of common motor carriers. The results showed that vertical vibration is consistently more severe than are lateral and longitudinal vibrations. Also, the study recommended that product testing at various PSD levels for a specified time period is more desirable than testing at higher acceleration levels. Higher levels are found to be present in worst case conditions and may be too severe.

Caruso and Silver (1976) studied advances in shipping damage prevention, suspension systems comparison, rear wheel position, road conditions, total payload, and drivers. The results concluded that:

- Acceleration levels and PSD levels at frequencies above 50 Hz were not significant.
- The worst ride occurred on interstate highways at high speeds.
- The worst ride occurred over the rear wheels in a lightly loaded trailer.
- Single-leaf steel suspensions produce the worst ride conditions.
- Different drivers had little effect on the results.

Magnuson (1977 and 1978), studied the effect of shock and vibration environments for large shipping containers. This study showed that both lateral and longitudinal vibration levels were greater than the vertical acceleration levels in the trucks with air suspension at frequencies below 20 Hz. Also, the type of suspension system caused little difference in vibration amplitude to shipments weighing over 15 tons.

Goff (1984) evaluated the effect of the position of the sliding leaf-spring for the wheels forward and wheels back position. The results showed that the roughest ride occurred in the spring-leaf suspension with the wheels forward.

Singh et al. (1992) compared the lateral, longitudinal, and vertical vibration levels in current commercial truck shipments. The results showed that below 20 Hz, the lateral and longitudinal vibration levels were much lower than vertical levels. However the levels in all three axes became lower and similar at frequencies above 20 Hz. Also, the more heavily loaded trailers showed higher lateral and longitudinal vibration levels than lightly loaded ones.

Pierce et al. (1992) compared the ride qualities of conventional leaf-spring, conventional air-ride, and damaged air-ride trailers. The study showed that the air-ride suspension, when maintained, gives lower vertical vibration levels on all road surfaces studied. A damaged air-ride suspension and leaf-spring suspension showed very similar response frequencies, although the damaged air-ride produced higher vertical vibration levels at frequencies below 10 Hz.

1.2 Vibration and Shock Levels in Rail Shipments.

This section reviews the various studies that measured the impact and vibration levels in railcars used to transport packages. A wide range of general guidelines related to packaging for rail shipments is presented in "The Railroad Environment, A Guide for Shipper and Railroad Personnel" (1966). A summary of these observations are:

- The vertical shocks due to track irregularities and suspension in a boxcar that exceed 2 G are very rare. Some vertical shocks can also occur during impact between two couplers which causes the cars to dip vertically downward at the striking end, and rise at the opposite end.

- The vertical vibration in a boxcar seldom exceeds 1 G when travelling over fair condition tracks. The vibration levels depend on the suspension and weight of the lading. Heavier loaded boxcars result in lower vertical vibration levels than lighter boxcars.

- Rail track joints are another cause of vertical vibration. Welded rail track produces lower vertical vibration levels.

- The longitudinal shocks in a rail-boxcar mostly occur during rail coupling. Most impacts occur at velocities below 5 MPH and generally do not produce damage to most products.

Several other studies have been conducted over the past decade by the Association of American Railroads (AAR). This association assists the various railroad companies to be able to ship products with minimum damage. A recent study evaluated the lading response to impacts for five different types of undercarriage cushion devices (AAR, 1988). The different cushion devices studied were the M901E Draft Gear, LPD unit, EOCC Model 10G unit, EOCC Model 15G unit, and COC Model 20B unit. The results showed that when comparing the coupler force versus impact speed, the LPD unit was slightly lower in force compared to the standard draft gear unit up to 6 mph, and much lower above 6 mph. The other devices were lower in force at all test speeds. A comparison of carbody acceleration versus impact speed showed that the LPD unit and the standard draft gear unit generally show similar performance. The other devices showed lower acceleration values at comparable speeds.

In a second recent study by the Association of American Railroads (1992), two types of boxcars having a cushioned and standard draft gear were compared for the resulting shock and vibration levels. The results showed that the boxcars using cushioned devices showed the least severe ride for all three axes. The boxcars using standard draft gears showed the highest acceleration levels in the longitudinal axis since this boxcar was equipped with roller side bearings that allowed a greater degree of movement, while the cushioned boxcars used constant contact side bearings. This study also provided several PSD spectrums for the various axes.

There is a continuous need to collect additional shock and vibration data. The two main factors that influence additional studies is the development of more accurate and larger data collection devices, and the modification of transport and ride surfaces that are used by a specific company. This study was funded by Ford Motor Company to measure specific routes that will be used to transport automotive engines. The automotive engine is the most expensive component of the automobile and has the largest cost value associated with shipping volume. The purpose of this study was to develop test methods that can be used to simulate the shock and vibration levels that will occur in truck and rail shipments from the engine production plant to the automobile assembly plants. These could be used to perform an accelerated evaluation of various rack systems that will be designed for the various types of engines.

The objectives of this study were:

1. To measure the shock and vibration levels in truck and rail shipments of steel racks with engines.

2. To develop test methods that could be used to simulate the shock and vibration levels.

2.0 EXPERIMENTAL DESIGN

The study measured the shock and vibration levels that would occur during truck and rail shipments from Ford's Truck Engine Plant to the Truck Assembly Plants. The engines were placed in the steel racks. Each rack holds four engines. The same racks are used to ship the engines by truck and rail. Tri-axial acceleration data was collected to determine shock and vibration levels at the floor of the truck-trailers and rail-boxcars. EDR-Model 3 (IST Corporation, Okemos, MI) environmental data recorders used in this study have three internal accelerometers that monitor the acceleration levels for the vertical, longitudinal, and lateral axes. In addition an internal memory stores the various events that are measured based on the settings of the recorder. The stored data can be downloaded to a personal computer for analysis. A rechargeable internal battery allows the recorder to be in an active measuring mode over several weeks.

In this study, three Environmental Data Recorders (EDR-3, IST Corp.) were used to measure the dynamic levels in each transport vehicle. The tri-axial accelerometers monitored the acceleration levels for vertical, longitudinal, and lateral modes at the front and rear positions for rail shipments, and rear positions for truck shipments. The various parameters used to program these recorders, and their location is discussed for each of the truck and rail shipments in this chapter.

2.1 Rail Shipments.

Two EDR Model 3 data recorders, Recorder 1 and 2, were mounted on the floor of the rail-boxcar on either end. The third recorder was mounted on the base of the steel rack bottom containing the Ford engines and located next to the input measured by Recorder 1. Recorder 1 was placed towards the locomotive end of the boxcar at the start of the trip. The boxcar travelled from the Ford Engine Plant, in Windsor, Canada, to Ford Truck Assembly Plant in Kansas City, Missouri. The route consisted of major rail tracks between the two cities. The racks were stacked three high in the boxcar.

All the data recorders were programmed to trigger and measure from all tri-axial axes. The recorders were programmed to measure approximately once every five minutes using a constant time interval recording irrespective of the vibration level. In addition they were programmed to measure all events above a minimum threshold of 0.1 G. The sampling rate was set at 1000 Hz. The pre-trigger samples were set at 64, and the post-trigger samples were set at 192. The maximum length of each event was 1000 samples or the equivalent of 1 second. The maximum number of events that could be recorded for each channel were 185. The recorder was set on "overwrite" mode, so that the most severe data events were saved.

The rail shipment was completed in 6 days. The raw data saved in each recorder was downloaded into a personal computer. This was processed and analyzed. The results are discussed in the next chapter.

2.2 Truck Shipment.

Three EDR-3 data recorders were used to measure the truck shipments. The truck shipment consisted of using a 40 foot long, leaf-spring suspension trailer. The trailer was hauled from Ford Engine Plant, in Windsor, Canada, to Ford Truck Assembly Plant in Lorain, Ohio. The route consisted of some inner city roads, and major highways between the two cities.

The racks were stacked two high in the trailer. Two data recorders (Recorder 1 and 2), were mounted on the floor of the truck at the rear on either end of the axle. Only the rear vibration levels were monitored since most previous studies have shown these to be the most severe locations. A third recorder was mounted on the base of the steel rack containing the engines and located between the input measured by Recorder 1 and 2.

All the data recorders were programmed to trigger and measure from all tri-axial axes. The recorders were programmed to measure approximately once every two minutes using a constant time interval recording irrespective of the vibration level. In addition they were programmed to measure all events above a minimum threshold of 0.1 G. The sampling rate was set at 500 Hz. The pre-trigger samples were set at 128, and the post-trigger samples were set at 128. The maximum length of each event was 512 samples or the equivalent of 1 second. The maximum number of events that could be recorded for each channel were 170. The recorder was set on "overwrite" mode, so that the most severe data events were saved.

The truck shipment was completed the same day. Similar to the rail data, this was downloaded into a personal computer and analyzed. The results are discussed in the next chapter.

3.0 DATA AND RESULTS

The shock and vibration data measured for the two types of shipments was analyzed in all the three orientations and represented as:

Channel X	-	Longitudinal
Channel Y	-	Lateral
Channel Z	-	Vertical

Table 1 is a summary of the recorded events for the rail shipments. The peak and average acceleration levels measured by the three recorders is listed. Table 2 is a summary of the recorded events in the truck shipments. The peak and average acceleration levels recorded in the three recorders is shown.

The PSD Spectrums were determined for various locations and orientations for the different shipments. The various figures describing the corresponding spectrums are listed in Table 3. Table 4 lists the various acceleration-time plots of the severe impacts measured during rail coupling in the longitudinal axis.

Figures 1 and 2 describe the vertical vibration spectrums in the rail shipments and Figure 3 describes the response in the steel rack. The data in Figures 1 and 2 can be used to program the vibration system to generate the vertical vibration levels simulating rail shipments.

Figure 1 shows the vertical vibration levels measured at the End 1 of boxcar. The spectrum shows a peak at 11 Hz. Figure 2 shows the vertical vibration levels measured at the

End 2 of the boxcar and shows a similar peak at 11 Hz. The spectrums from Figures 1 and 2 are very similar. The peak at 11 Hz corresponds to the boxcar suspension system, and the joints in the rail road tracks. The vibration levels above 12 Hz are generally lower and are a result of the uneven track surface, and boxcar structure stiffness. Figure 3 shows the vertical vibration response levels in steel racks measured at the End 1 of the boxcar. The response spectrum again is similar to Figures 1 and 2.

Figures 4 and 5 describe the vertical vibration spectrums in the truck shipments and Figure 6 describes the response in the steel rack. The spectrums in Figures 4 and 5 show a peak at 4 Hz representing the trailer suspension. These spectrums also show additional peaks between 20-90 Hz caused by various factors such as trailer structure stiffness, tire surface irregularities, engine vibrations, etc. The data in Figures 4 and 5 can be used to program the vibration system to generate the vibration levels simulating truck shipments.

Based on this data it is evident that the vertical vibration levels are generally more severe in truck shipments than rail shipments. Also the corresponding displacement of the trailer bed at 4 Hz is much higher than that present at 11 Hz for the boxcar.

The spectrums presented in Figures 7 to 18 describe the vibration spectrums in the longitudinal and lateral directions and are provided as a reference (See Table 3). The data in these spectrums is of extremely low energy level and will not play a significant role in the design criteria of the steel racks. These levels are similar to those reported in previous studies.

Figures 19 and 20 describe the most severe impacts that occurred in the boxcars during rail shipments due to rail coupling in the longitudinal direction. Figure 21 describes the response in the steel rack. Figure 19 shows the longitudinal impact level in End 1 of the boxcar during rail coupling. The curve shows a peak acceleration of 3.8 G with a duration of 28 ms. Figure 20 shows the longitudinal impact levels in End 2 of boxcar during rail coupling. The curve shows a peak acceleration of 5.6 G and a duration of 14 ms. This plot also shows a secondary impact caused by the rail car recoil. Figure 21 shows the longitudinal response impact levels for the steel racks in End 1 of the boxcar. The curve shows successive peaks of 5.6 G, -3.1 G, and 1.5 G resulting from coupling.

Figures 22 and 23 describe the most severe lateral impacts that occurred in the boxcars during rail shipments. These are a result of the swaying motion of the boxcar when travelling over uneven tracks. Figure 24 describes the response in the steel rack. Figures 22 and 23 show the lateral impact levels in End 1 and End 2 of the boxcar during rail coupling, respectively. The impact levels in End 1 show a peak acceleration of 1.7 G and a duration of 51 ms, while the impact levels in End 2 shows a peak of 6.7 G and a duration of 7 ms. Figure 24 shows the lateral impact levels for steel racks in End 1 of the boxcar during rail coupling. The lateral impact level shows a peak of 3.5 G.

When comparing the data from the steel rack impact levels in longitudinal and lateral directions, we find that the impact levels in steel racks are generally lower in the lateral direction as compared to the longitudinal direction. The longitudinal impact level shows a high acceleration peak at 5.6 G compared to 3.5 G in the lateral direction. The most severe impact in the lateral direction has a higher peak acceleration than that in the longitudinal direction, but occurred for half the duration and was therefore not as severe.

The impacts in the lateral and the longitudinal direction are severe and should be used as a criteria for testing racks designed for rail shipments. There were virtually no impacts measured in these two directions for truck shipments.

3.1 Simulated Transport Test Methods

The results from the data analyzed were used to develop a protocol to test steel racks designed to ship engines between the manufacturing plant and the various receiving plants by truck or rail. The test protocol consists of using a random vibration simulation of the PSD spectrums provided in Figures 1 and 2 for rail shipments. The test also uses a random vibration simulation of the PSD spectrums provided in Figures 4 and 5 for truck shipments. In addition, impacts in the longitudinal directions will be performed based on the data in Figures 19 and 20, and for lateral directions using data in Figures 22 and 23. The corresponding vibration test durations and the number of impacts are based on recommendations provided in ASTM D4169, D4728, and D4003.

The test can be summarized as follows:

1. Place a three high steel rack with engines on a electrohydraulic vibration table using appropriate restraining devices as recommended in ASTM D4728. Program the vibration controller to perform a random vibration test in accordance with ASTM D4728 using spectrums in Figures 1 and 2. Test the steel racks for a duration of 90 minutes using each spectrum, for a total of 180 minutes as recommended in ASTM D4169.

2. Place a two high steel rack with engines on a electrohydraulic vibration table using appropriate restraining devices as recommended in ASTM D4728. Program the vibration controller to perform a random vibration test in accordance with ASTM D4728 using spectrums in Figures 4 and 5. Test the steel racks for a duration of 90 minutes using each spectrum, for a total of 180 minutes as recommended in ASTM D4169.

3. Place a steel rack with engines in the loading configuration for a box car for longitudinal impacts on a horizontal impact testing machine. Program the horizontal impact tester to produce an impact of 5.6 G with a duration of 14 ms. Perform an impact test in accordance with ASTM D4003. Perform three repetitions using these test conditions as recommended in ASTM D4169.

4. Place a steel rack with engines in the loading configuration for a box car for lateral impacts on a horizontal impact testing machine. Program the horizontal impact tester to produce an impact of 6.7 G with a duration of 7 ms. Perform an impact test in accordance with ASTM D4003. Perform three repetitions using these test conditions as recommended in ASTM D4169.

5. Inspect the racks and engines on completion of each of the above four tests for any damage that has occurred. Appropriate modifications or design changes to the racks or engines can be made if needed based on this information.

TABLE 1: VIBRATION LEVELS RECORDED IN RAIL SHIPMENTS

		PEAK			RMS		
		X	Y	Z	X	Y	Z
RECORDER 1	MAX	3.837	1.687	3.929	1.216	0.582	1.402
	MIN	0.012	0.012	0.010	0.009	0.009	0.009
	MEAN	0.850	0.459	0.907	0.339	0.180	0.372
	S.D.	0.713	0.254	0.604	0.245	0.083	0.210
RECORDER 2	MAX	5.709	6.726	4.220	1.494	1.670	1.039
	MIN	0.037	0.012	0.014	0.010	0.011	0.011
	MEAN	0.897	0.607	0.808	0.361	0.218	0.334
	S.D.	0.721	0.671	0.510	0.239	0.152	0.182
RECORDER 3	MAX	5.594	3.496	3.361	0.934	1.154	1.256
	MIN	0.011	0.012	0.012	0.009	0.009	0.009
	MEAN	0.535	0.845	1.067	0.192	0.343	0.446
	S.D.	0.676	0.648	0.720	0.160	0.223	0.251

TABLE 2: VIBRATION LEVELS RECORDED IN TRUCK SHIPMENTS

		PEAK			RMS		
		X	**Y**	**Z**	**X**	**Y**	**Z**
RECORDER 1	MAX	0.298	0.524	1.137	0.069	0.126	0.569
	MIN	0.014	0.013	0.013	0.009	0.010	0.011
	MEAN	0.110	0.201	0.394	0.037	0.072	0.160
	S.D.	0.057	0.111	0.253	0.015	0.036	0.115
RECORDER 2	MAX	0.253	0.552	1.243	0.080	0.170	0.454
	MIN	0.012	0.010	0.010	0.004	0.009	0.009
	MEAN	0.101	0.235	0.465	0.034	0.079	0.173
	S.D.	0.052	0.140	0.291	0.016	0.042	0.106
RECORDER 3	MAX	0.510	0.849	2.657	0.124	0.190	0.455
	MIN	0.012	0.011	0.010	0.008	0.009	0.009
	MEAN	0.155	0.201	0.491	0.050	0.063	0.170
	S.D.	0.100	0.144	0.387	0.025	0.035	0.106

TABLE 3: POWER DENSITY SPECTRUMS FOR TRUCK AND RAIL SHIPMENTS

Figure	Description of Power Density Spectrum
1	Average PDS for Rail Shipments (Vertical) - End 1 of Boxcar
2	Average PDS for Rail Shipments (Vertical) - End 2 of Boxcar
3	Average PDS Response in Steel Racks (Vertical) - End 1 of Boxcar
4	Average PDS for Truck Shipments (Vertical) - Rear of Trailer, Roadside
5	Average PDS for Truck Shipments (Vertical) - Rear of Trailer, Curbside
6	Average PDS Response in Steel Racks (Vertical) - Rear of Trailer, Middle
7	Average PDS for Rail Shipments (Longitudinal) - End 1 of Boxcar
8	Average PDS for Rail Shipments (Longitudinal) - End 2 of Boxcar
9	Average PDS Response in Steel Racks (Longitudinal) - End 1 of Boxcar
10	Average PDS for Truck Shipments (Longitudinal) - Rear of Trailer, Roadside
11	Average PDS for Truck Shipments (Longitudinal) - Rear of Trailer, Curbside
12	Average PDS Response in Steel Racks (Longitudinal) - Rear of Trailer, Middle
13	Average PDS for Rail Shipments (Lateral) - End 1 of Boxcar
14	Average PDS for Rail Shipments (Lateral) - End 2 of Boxcar
15	Average PDS Response in Steel Racks (Lateral) - End 1 of Boxcar
16	Average PDS for Truck Shipments (Lateral) - Rear of Trailer, Roadside
17	Average PDS for Truck Shipments (Lateral) - Rear of Trailer, Curbside
18	Average PDS Response in Steel Racks (Longitudinal) - Rear of Trailer, Middle

TABLE 4: IMPACT CONDITIONS FOR LONGITUDINAL SHOCKS DURING RAIL COUPLING

Figure	Description of Impact Conditions
19	Impact Level in End 1 of Boxcar (Longitudinal)
20	Impact Level in End 2 of Boxcar (Longitudinal)
21	Response Impact Level in End 1 of Boxcar (Longitudinal)
22	Impact Level in End 1 of Boxcar (Lateral)
23	Impact Level in End 2 of Boxcar (Lateral)
24	Response Impact Level in End 1 of Boxcar (Lateral)

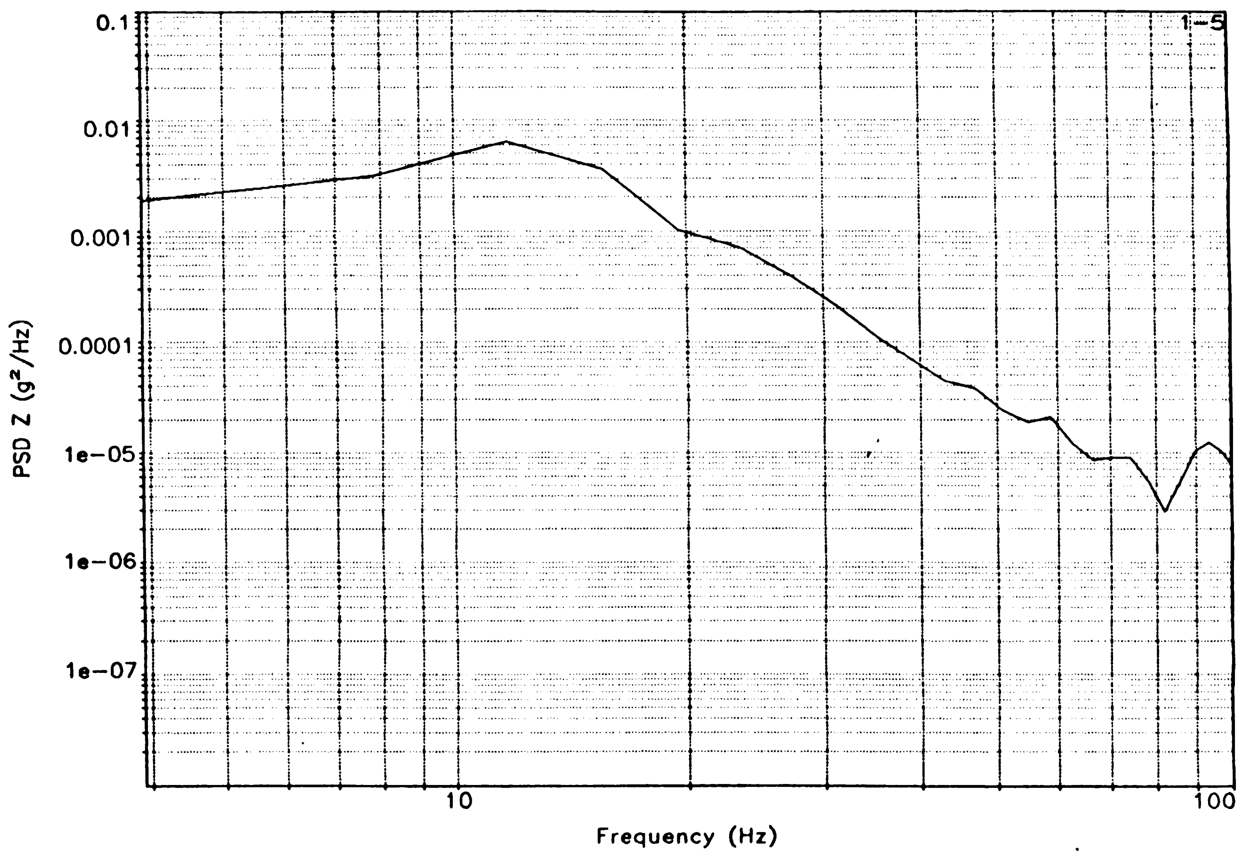

Figure 1: Vertical Vibration Levels in Rail Shipments, Boxcar Floor, End 1

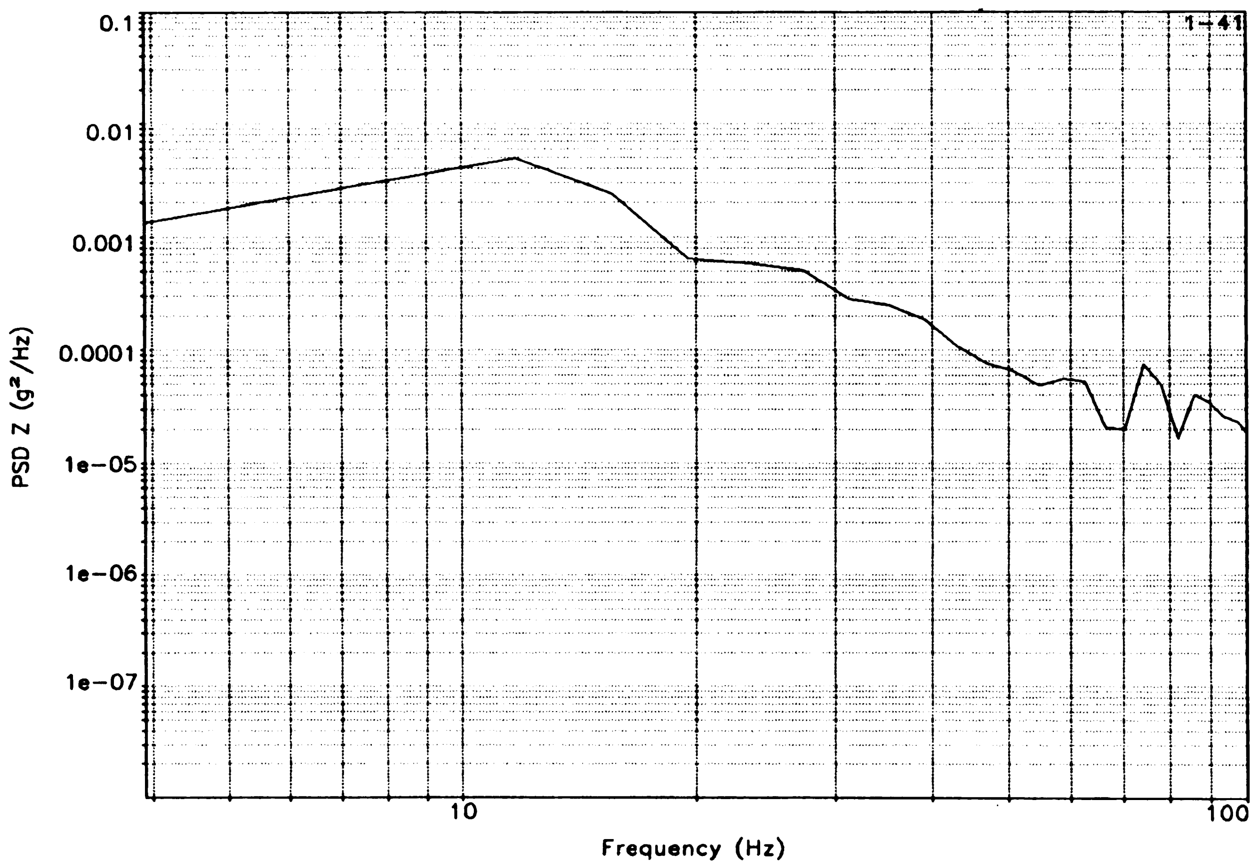

Figure 2: Vertical Vibration Levels in Rail Shipments, Boxcar Floor, End 2

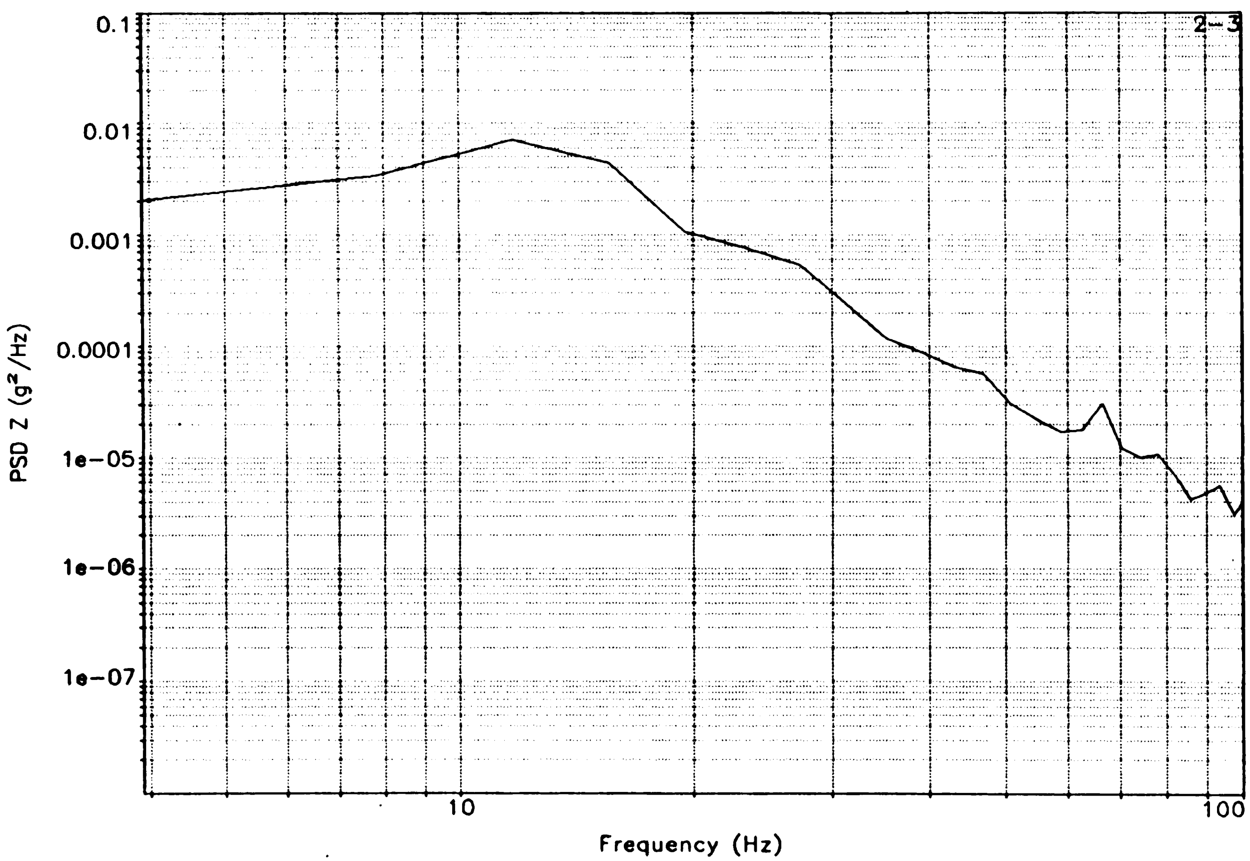

Figure 3: Vertical Vibration Levels in Rail Shipments, Base of Steel Rack, End 1

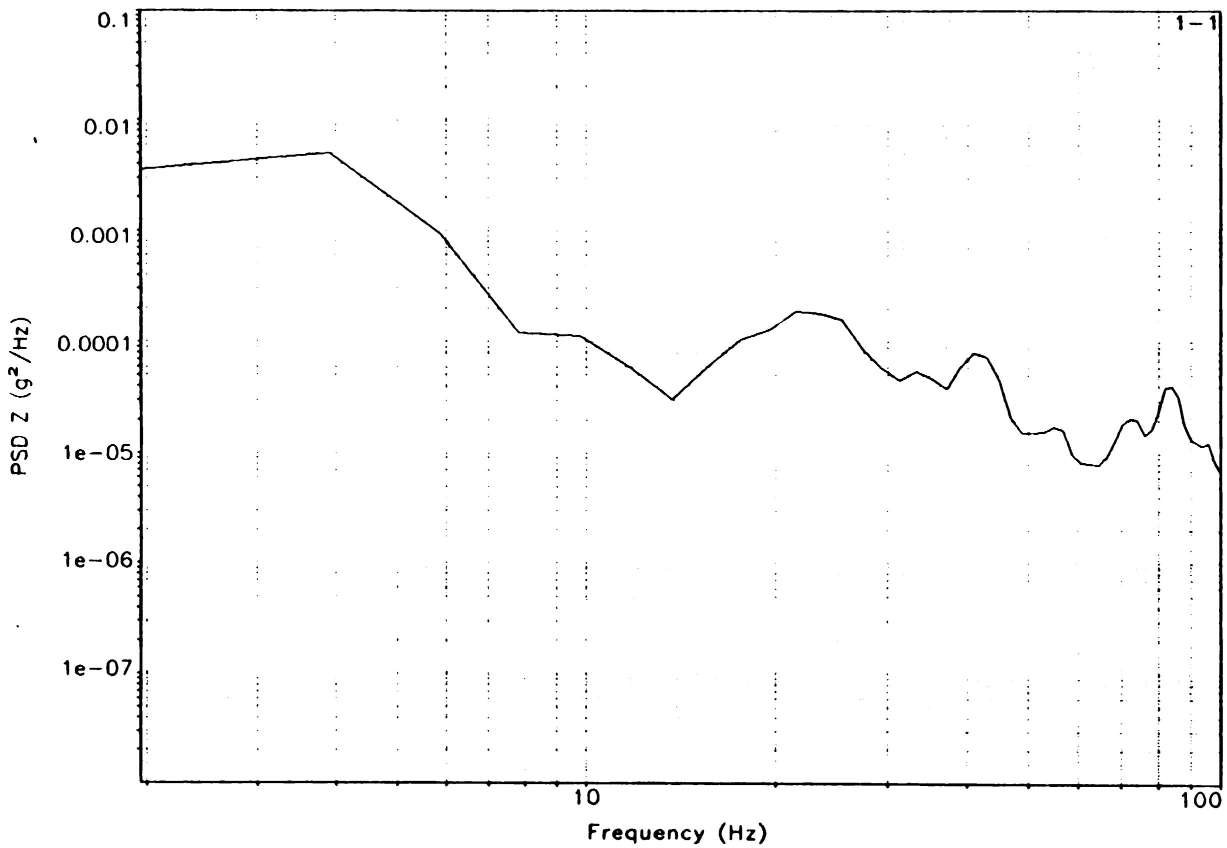

Figure 4: Vertical Vibration Levels in Truck Shipments, Rear Truck Floor, Roadside

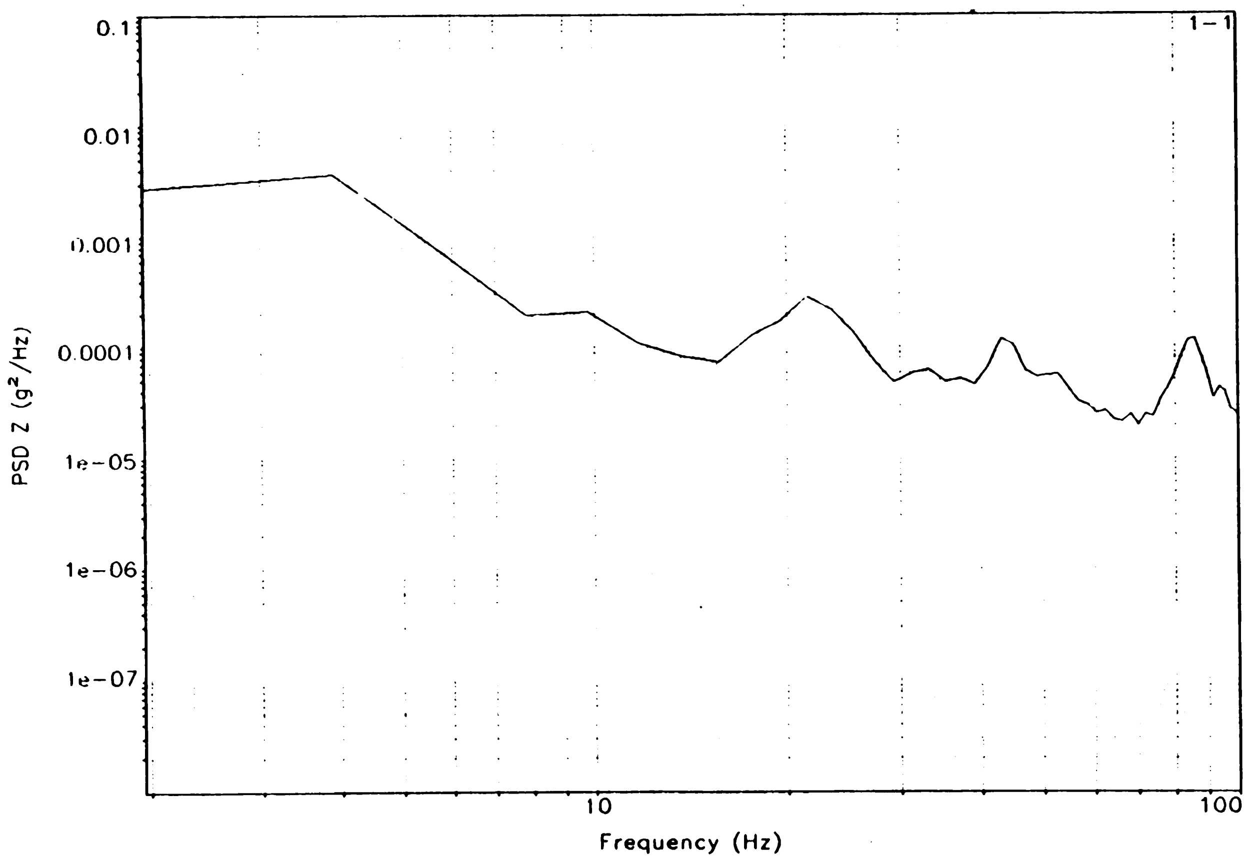

Figure 5: Vertical Vibration Levels in Truck Shipments, Rear Truck Floor, Curbside

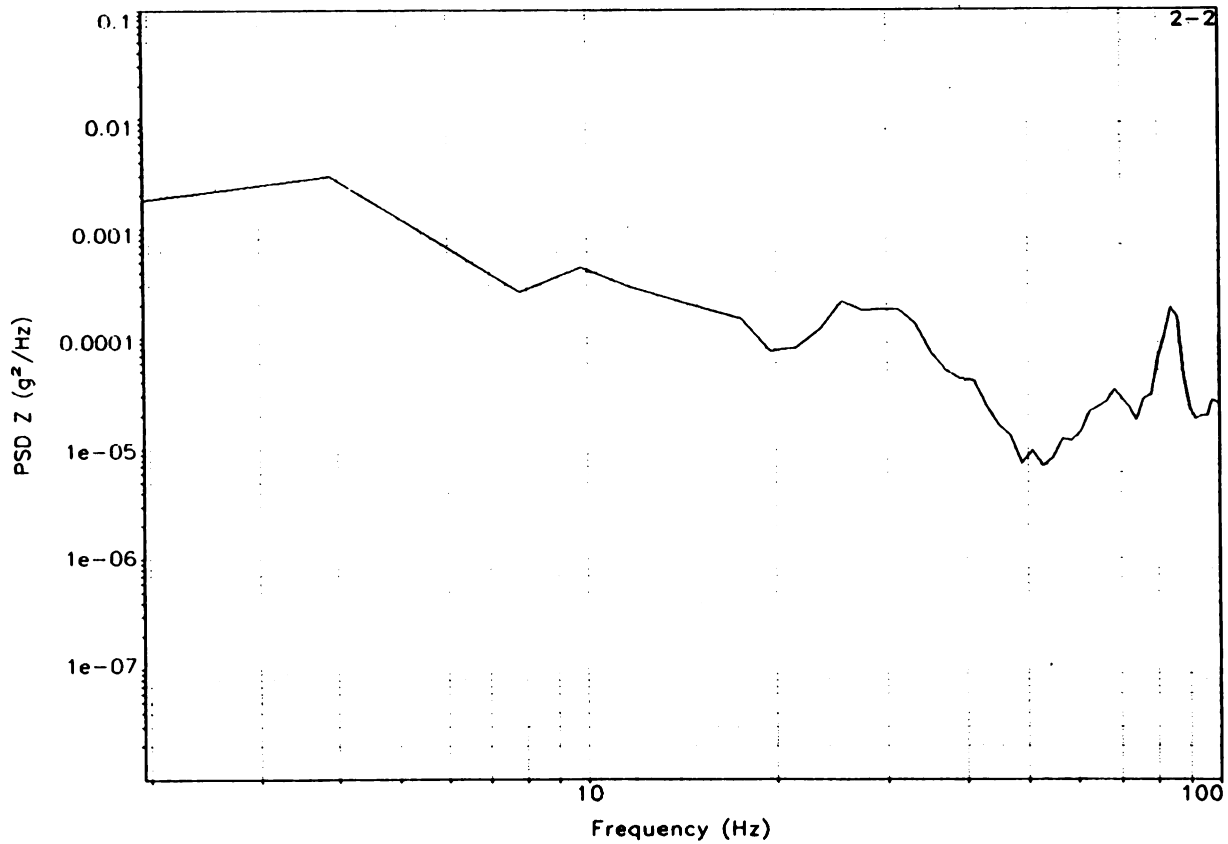

Figure 6: Vertical Vibration Levels in Truck Shipments, Rear Truck Floor, Rack Base

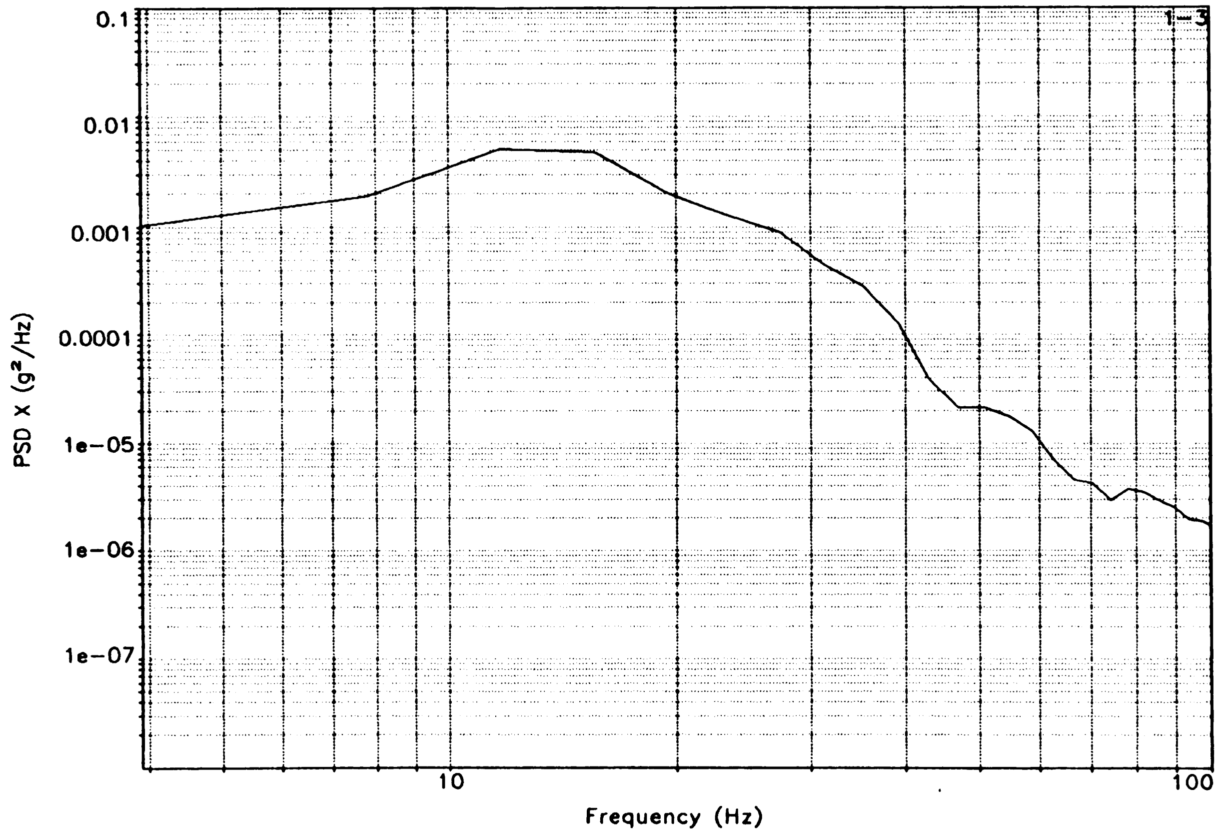

Figure 7: Longitudinal Vibration Levels in Rail Shipments, Boxcar Floor, End 1

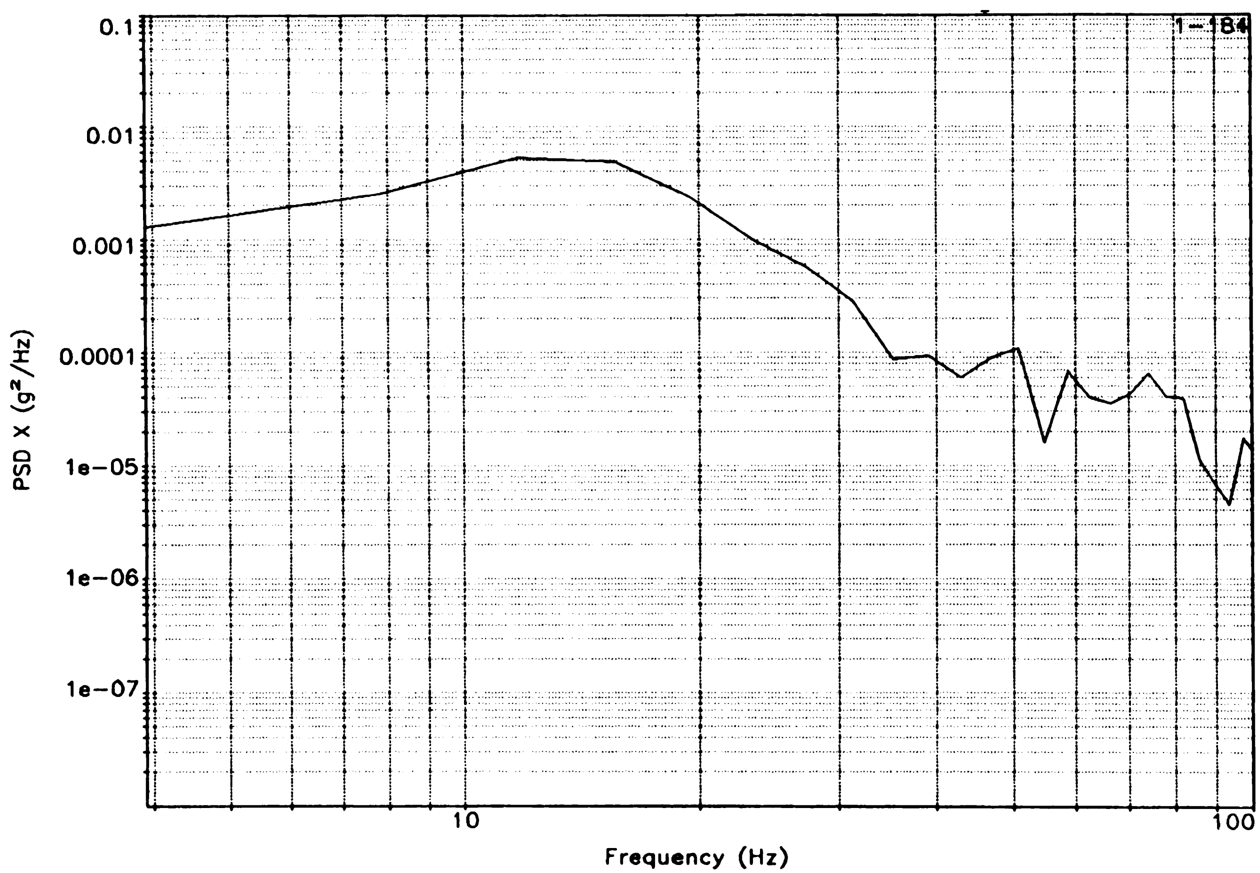

Figure 8: Longitudinal Vibration Levels in Rail Shipments, Boxcar Floor, End 2

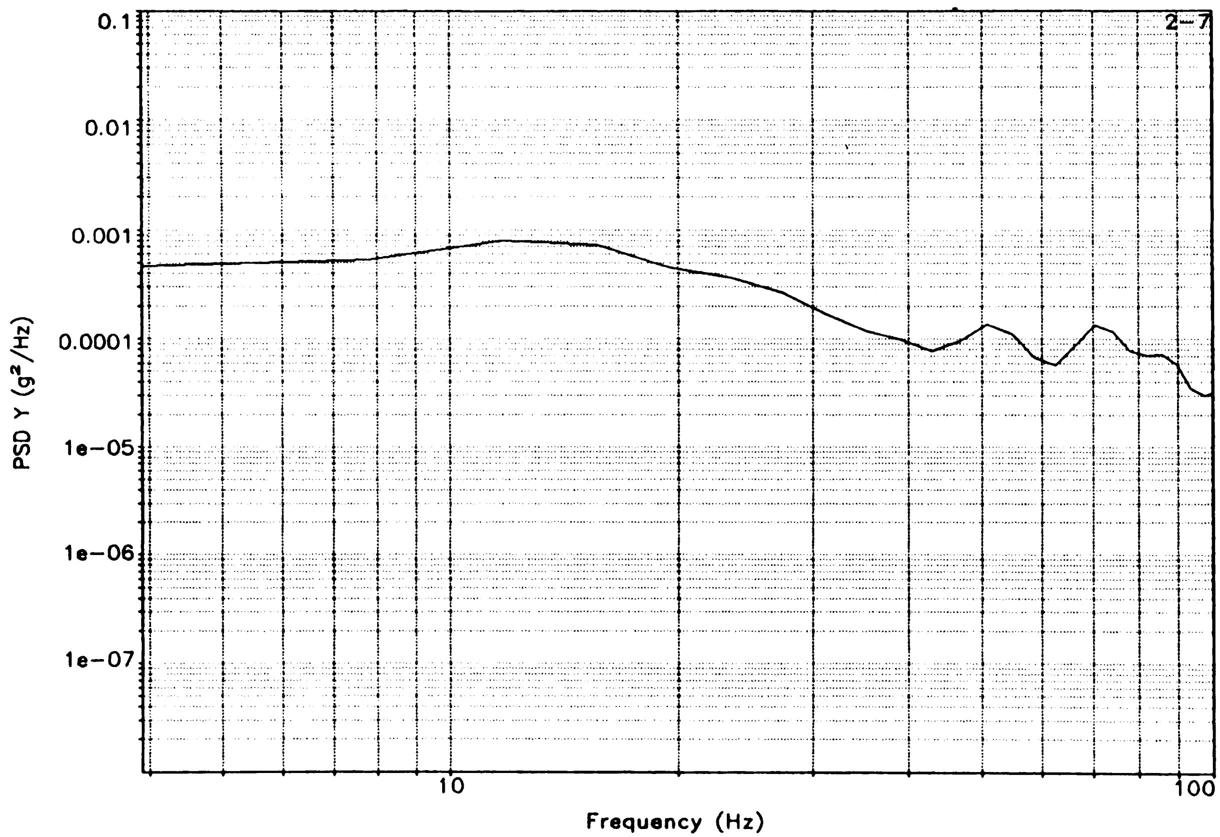

Figure 9: Longitudinal Vibration Levels in Rail Shipments, Base of Steel Rack, End 1

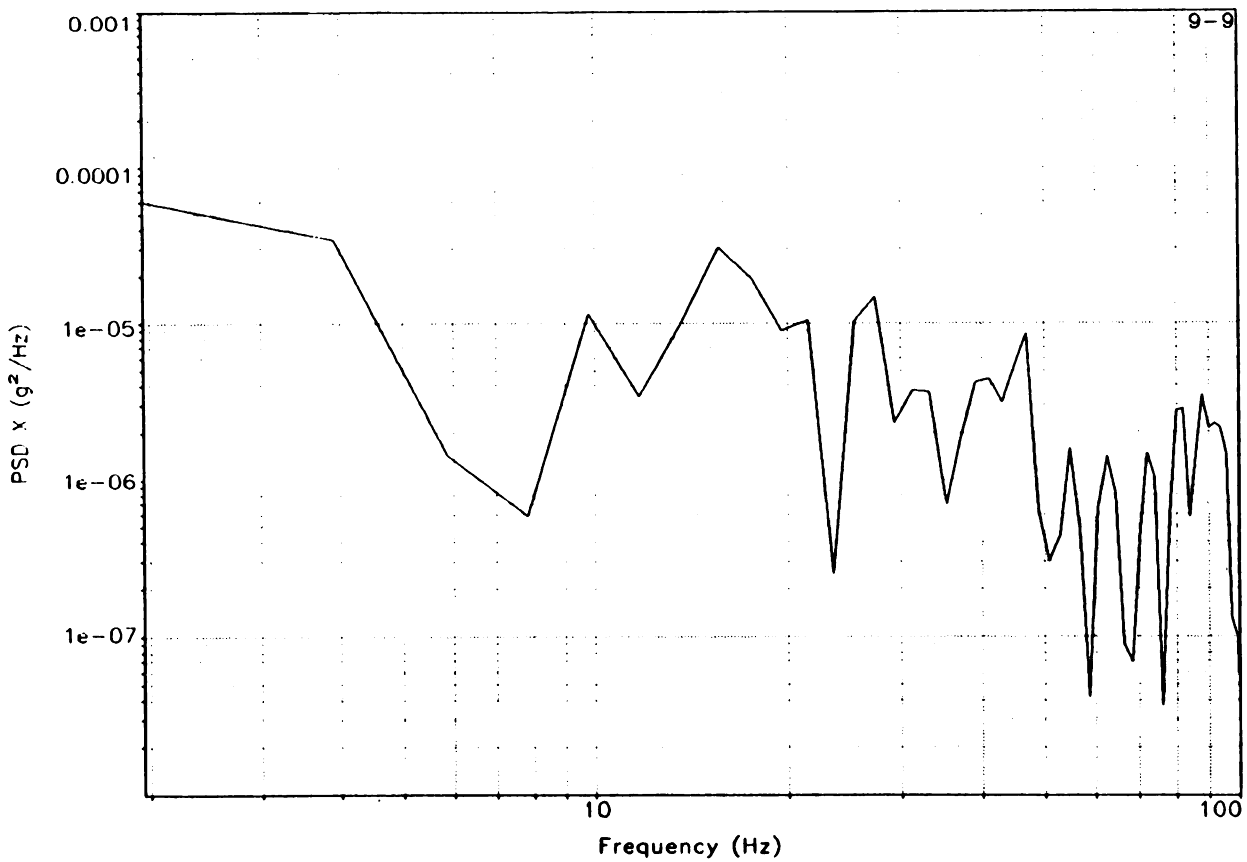

Figure 10: Longitudinal Vibration Levels in Truck Shipments, Rear Truck Floor, Roadside

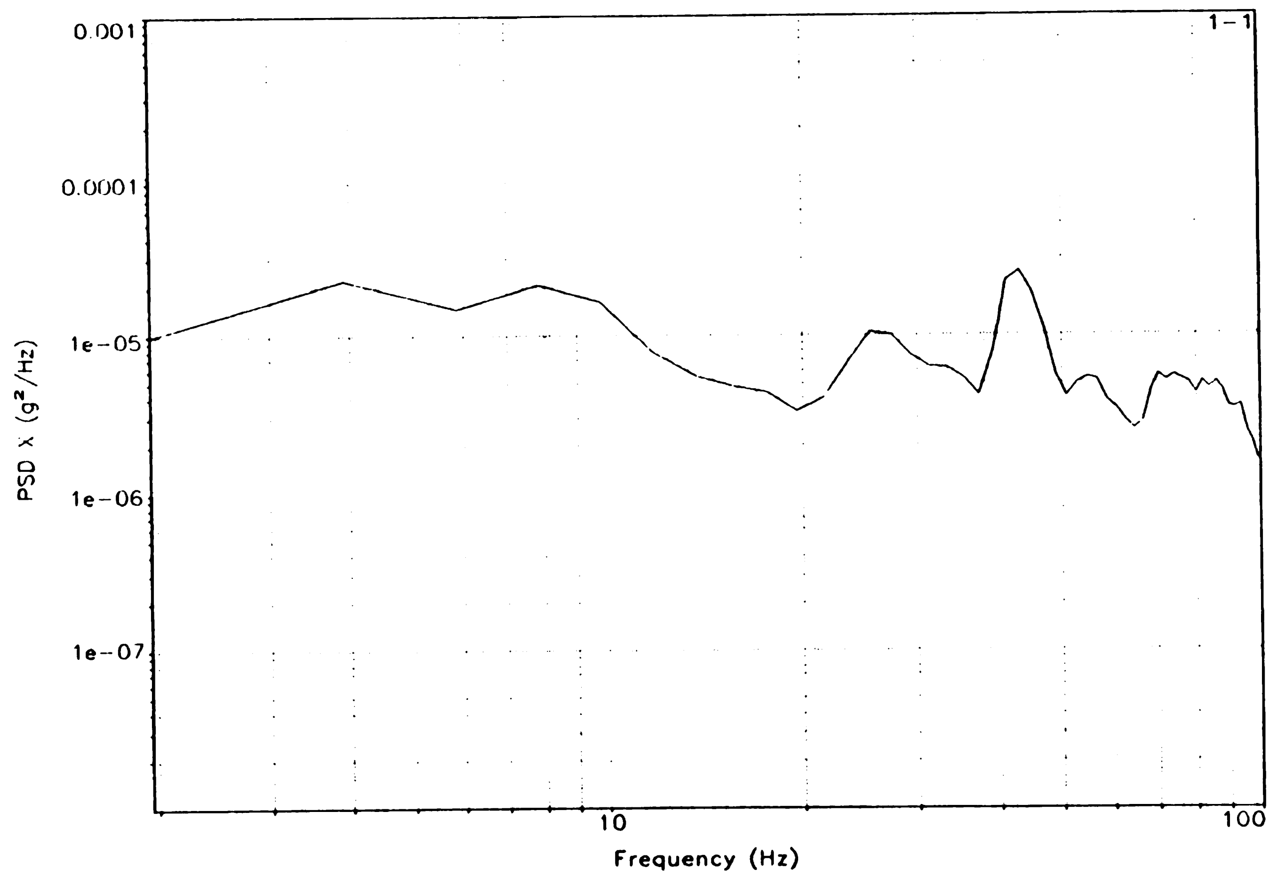

Figure 11: Longitudinal Vibration Levels in Truck Shipments, Rear Truck Floor, Curbside

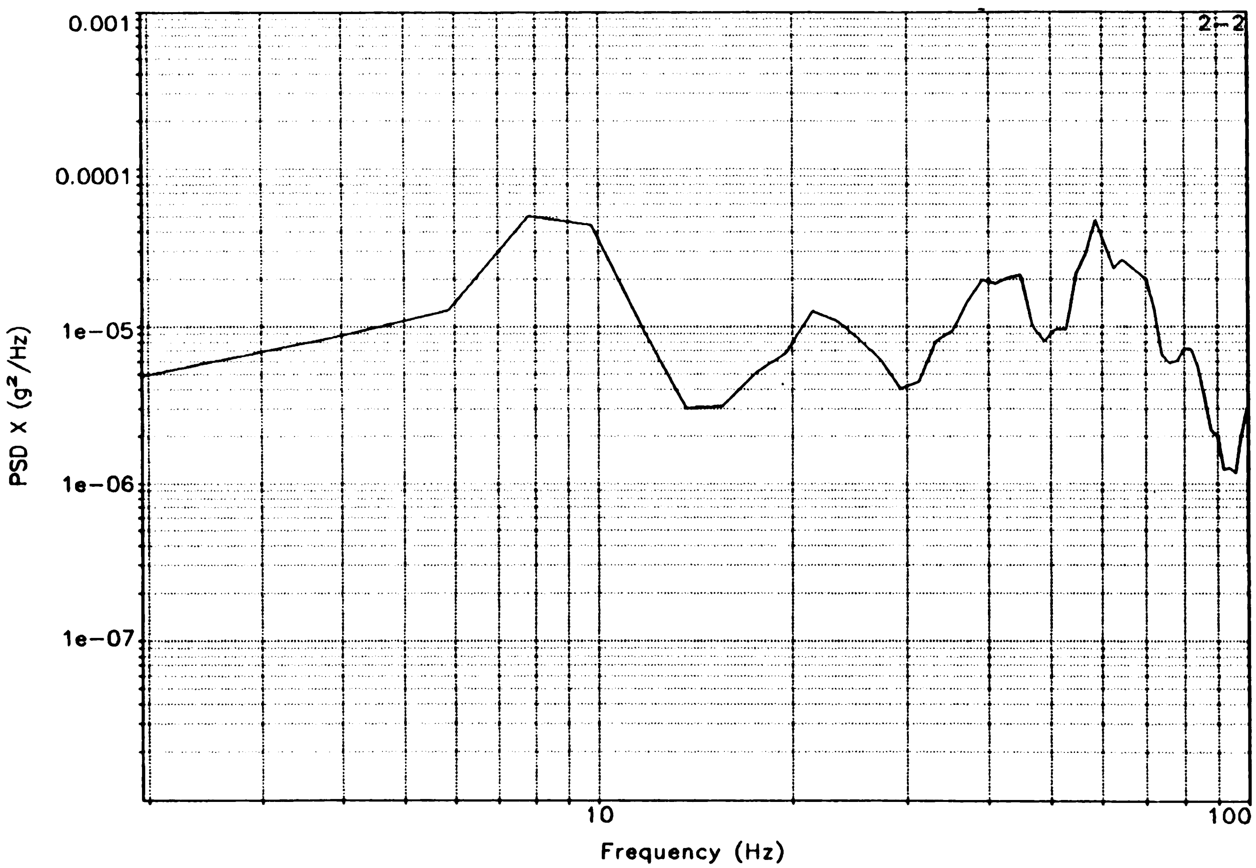

Figure 12: Longitudinal Vibration Levels in Truck Shipments, Rear Truck Floor, Rack Base

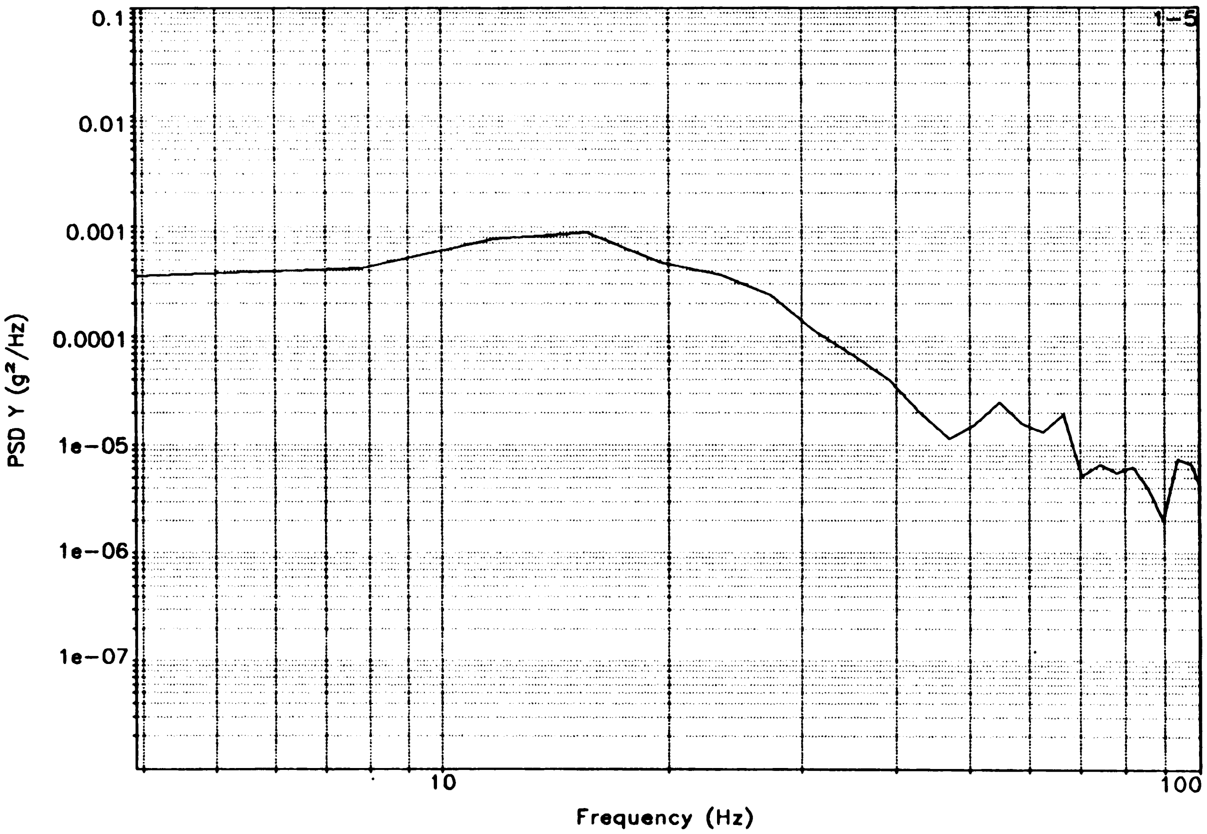

Figure 13: Lateral Vibration Levels in Rail Shipments, Boxcar Floor, End 1

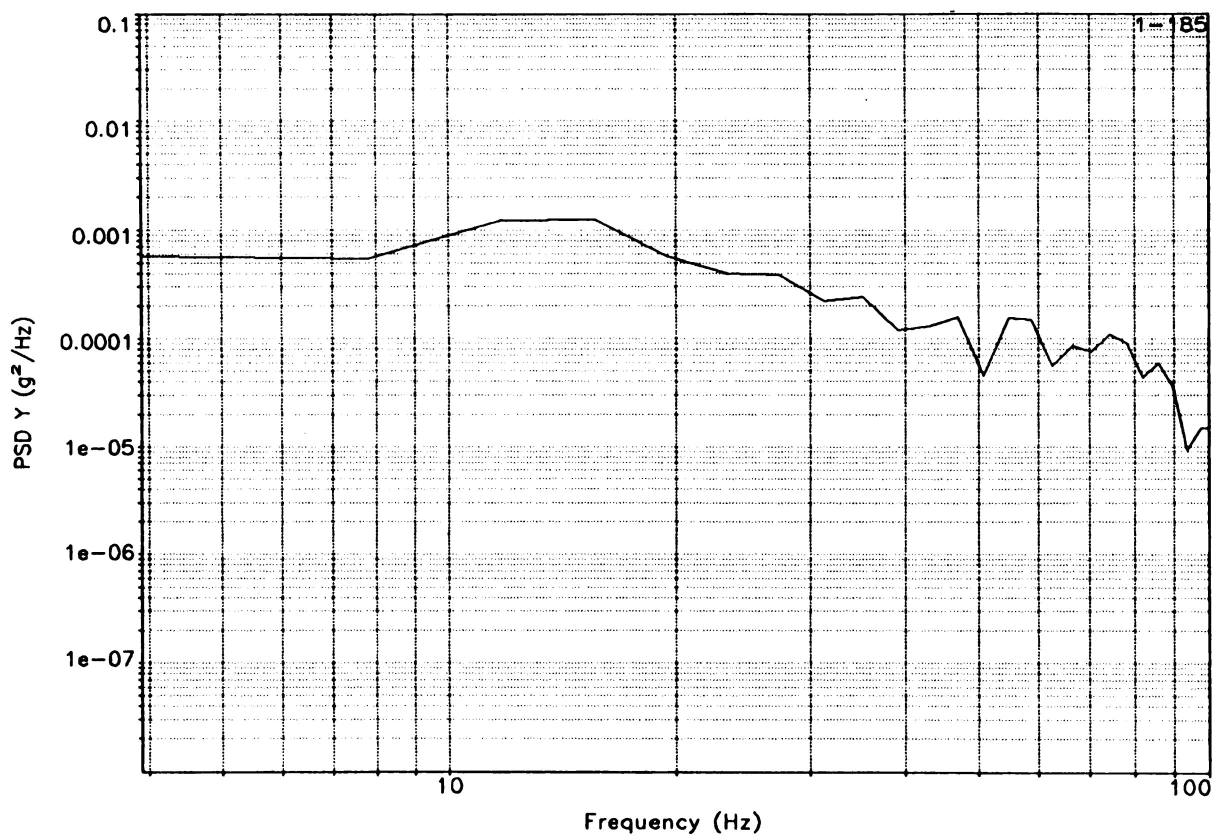

Figure 14: Lateral Vibration Levels in Rail Shipments, Boxcar Floor, End 2

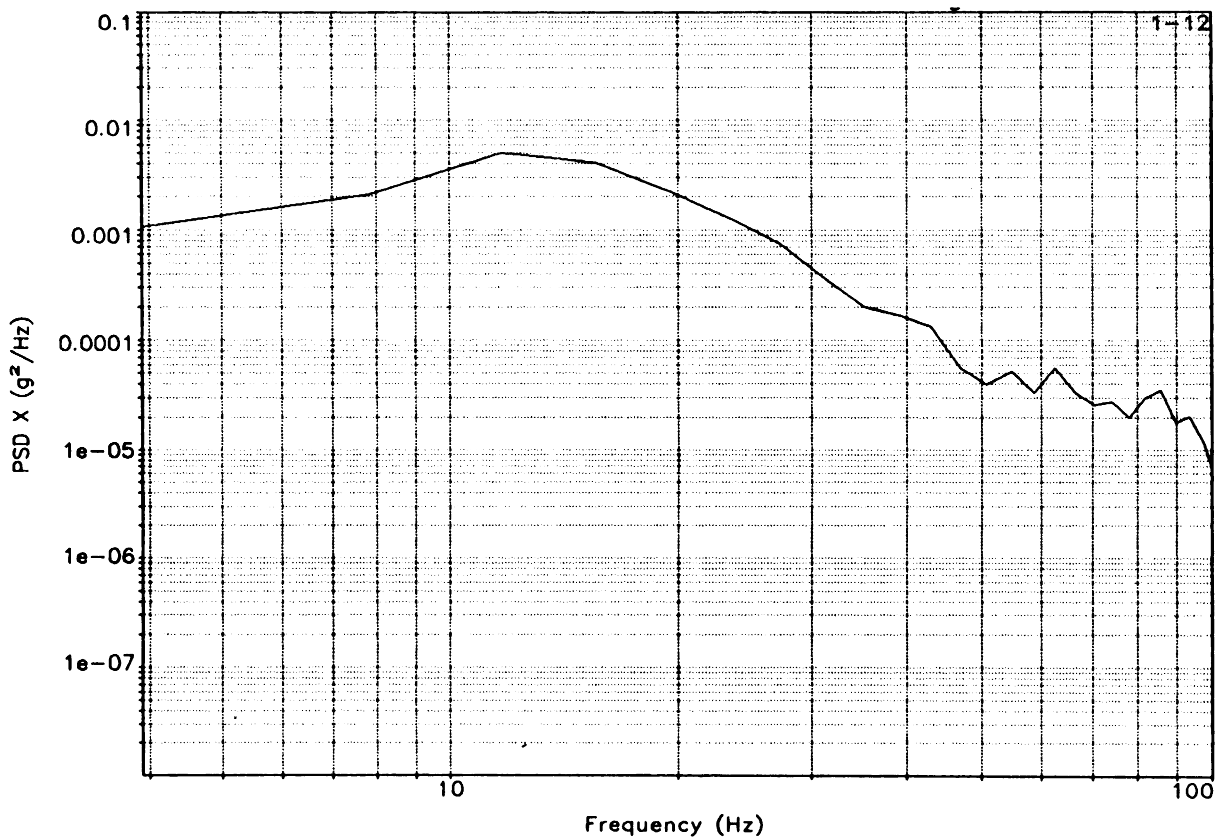

Figure 15: Lateral Vibration Levels in Rail Shipments, Base of Steel Rack, End 1

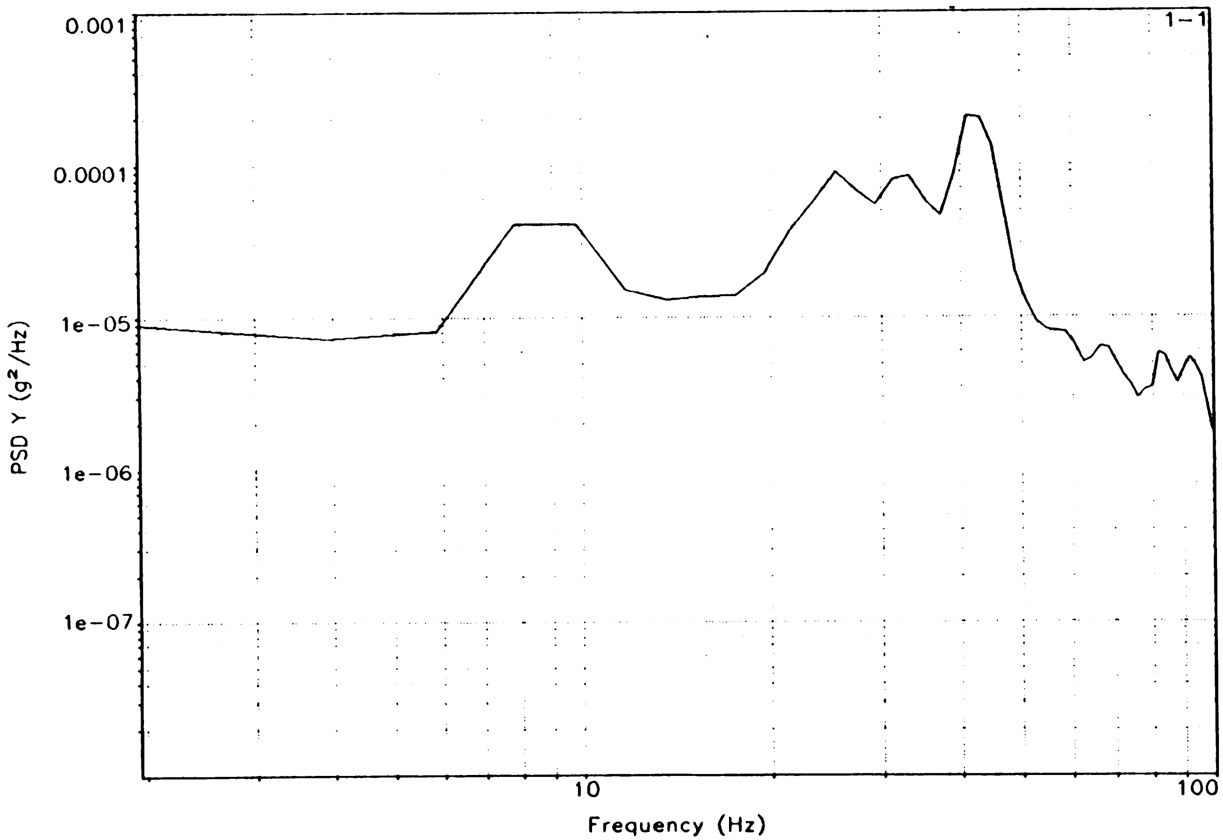

Figure 16: Lateral Vibration Levels in Truck Shipments, Rear Truck Floor, Roadside

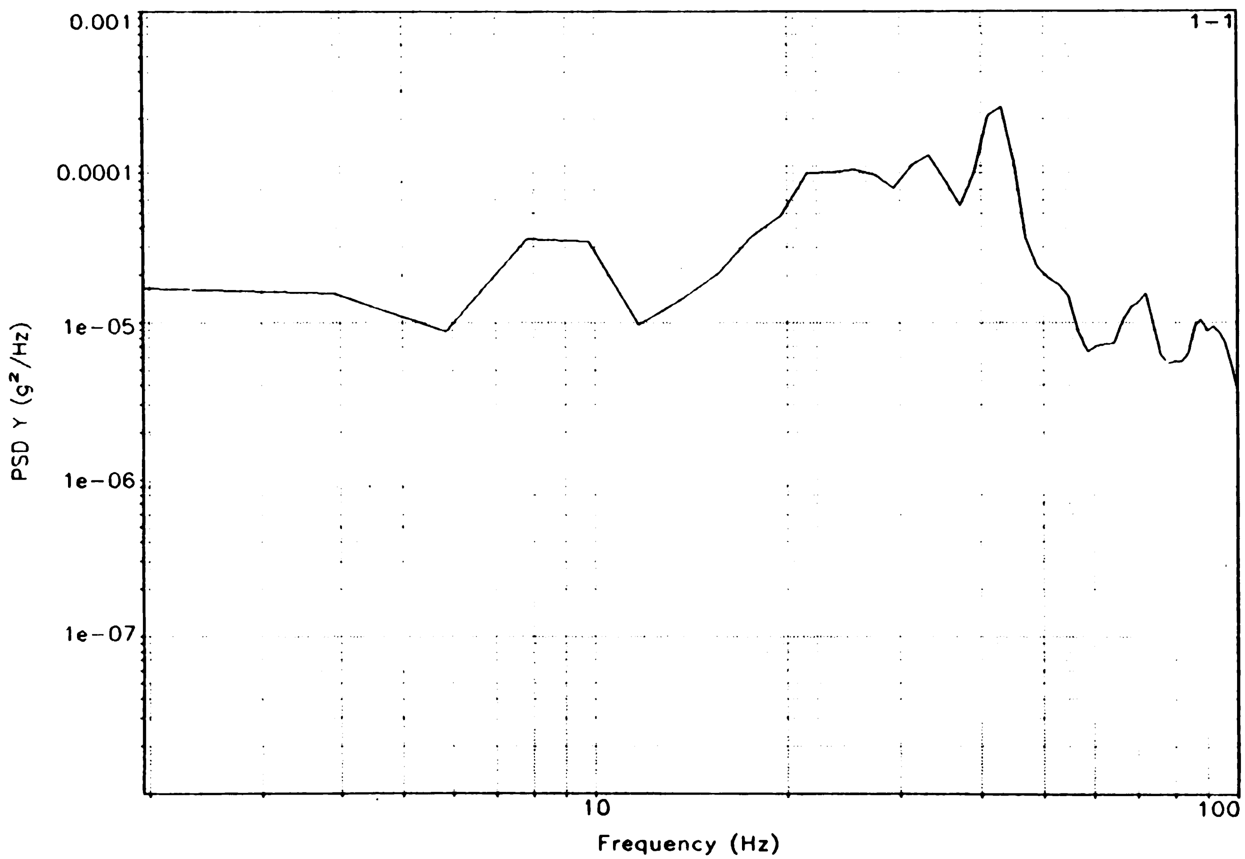

Figure 17: Lateral Vibration Levels in Truck Shipments, Rear Truck Floor, Curbside

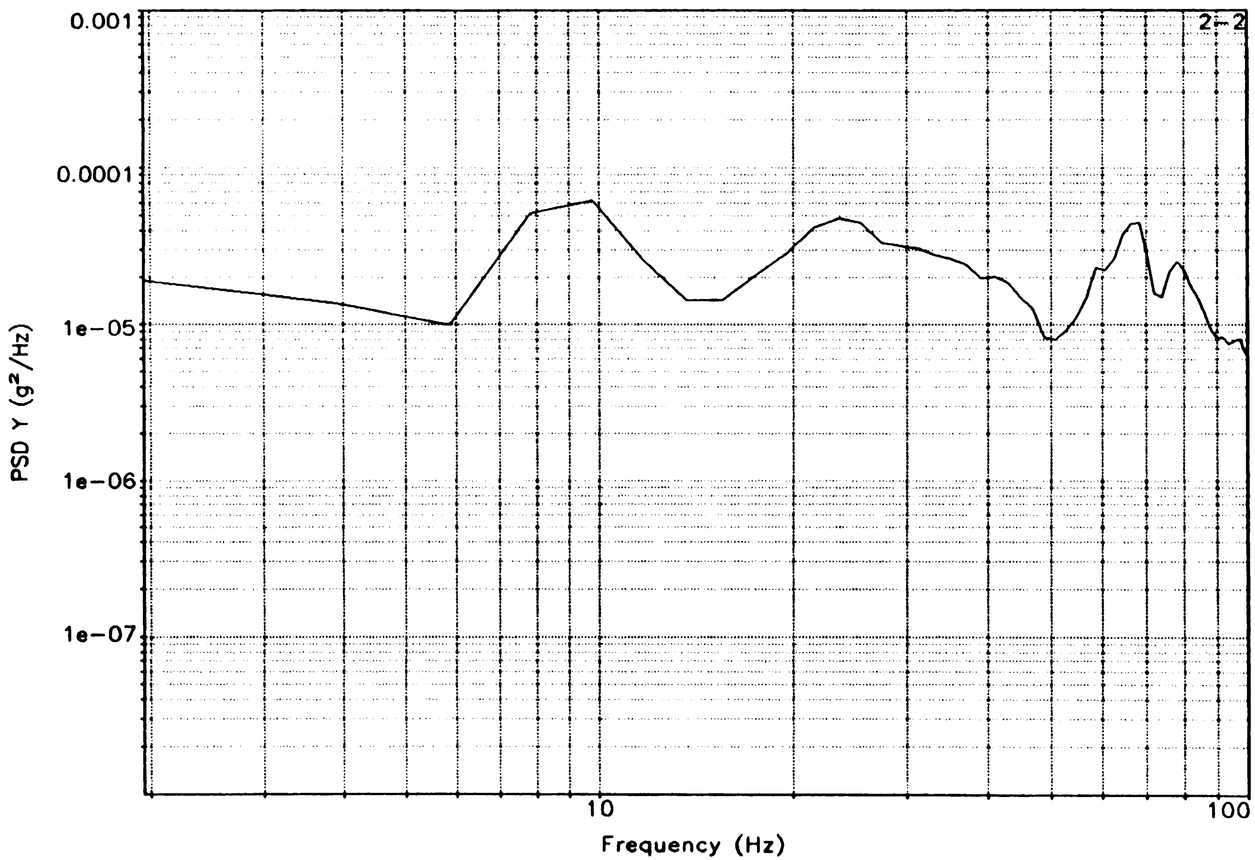

Figure 18: Lateral Vibration Levels in Truck Shipments, Rear Truck Floor, Rack Base

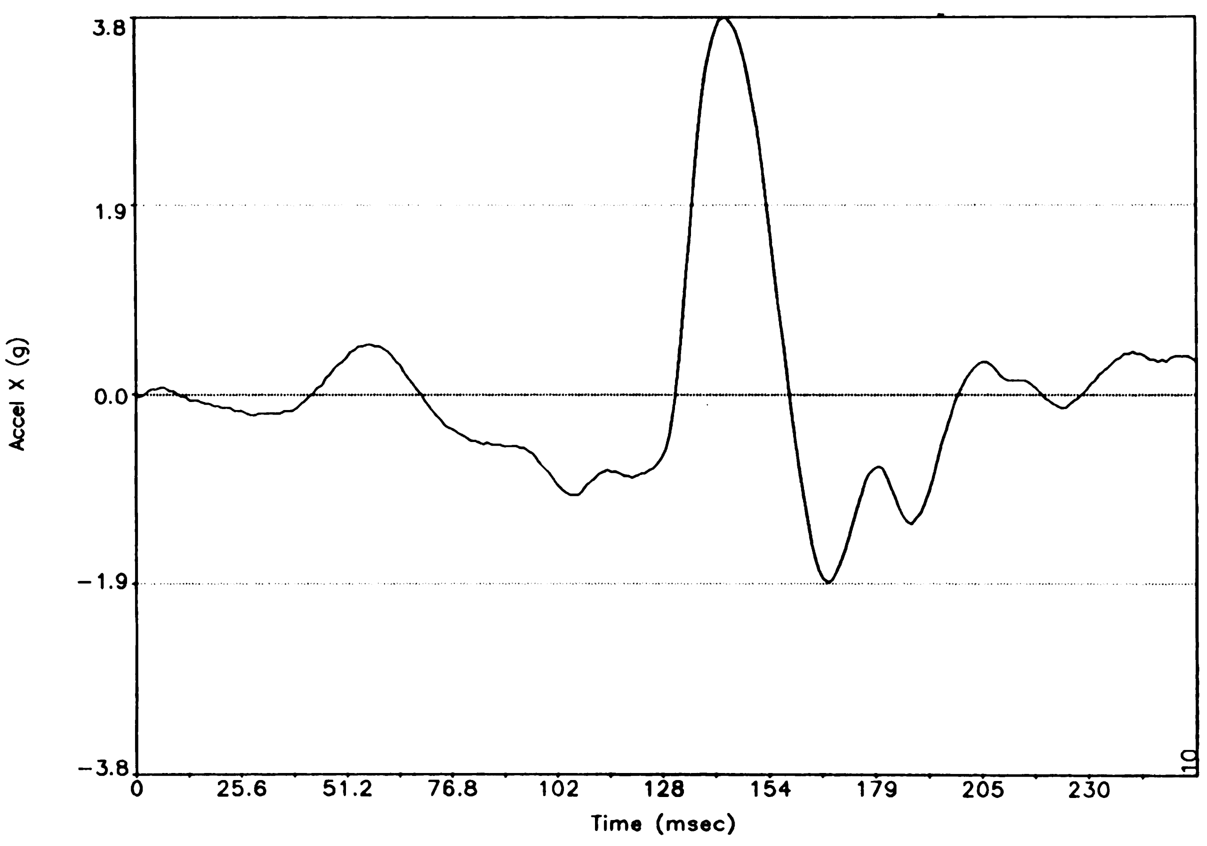

Figure 19: Longitudinal Impact Levels in Rail Shipments, End 1

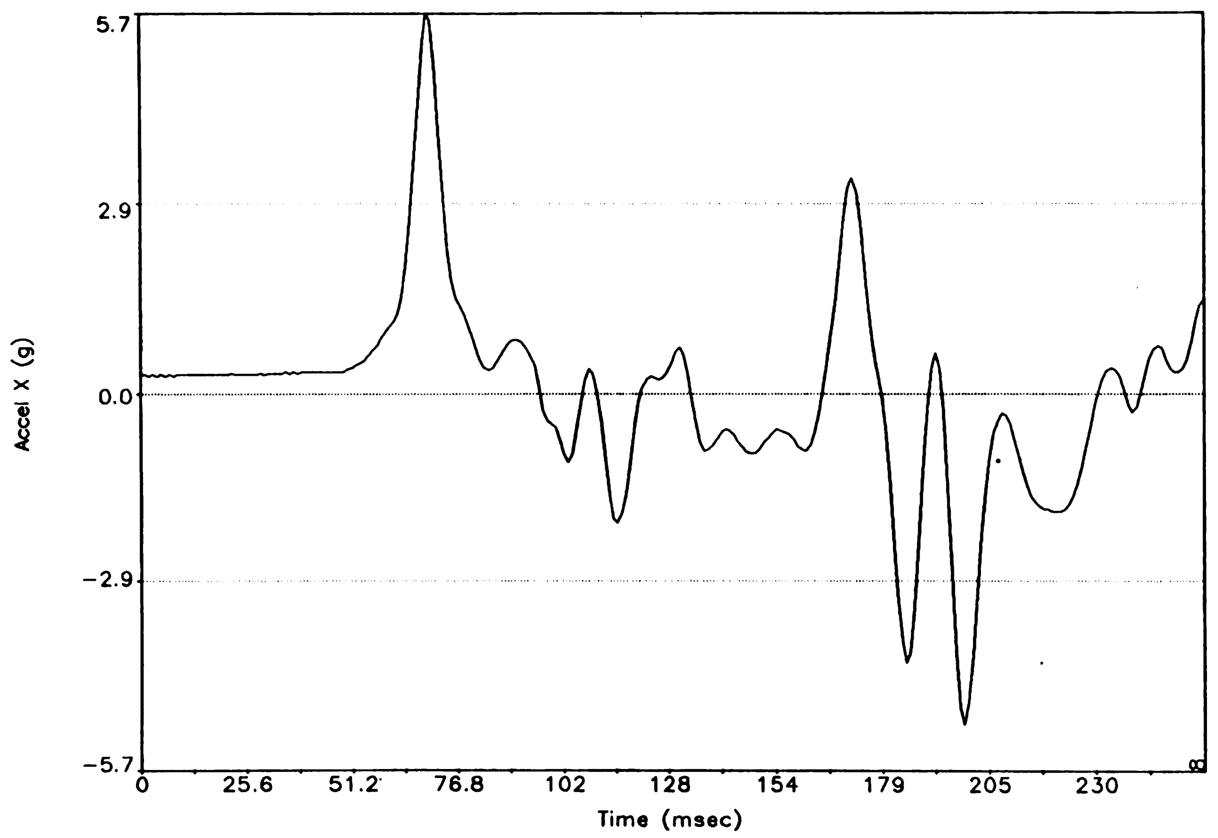

Figure 20: Longitudinal Impact Levels in Rail Shipments, End 2

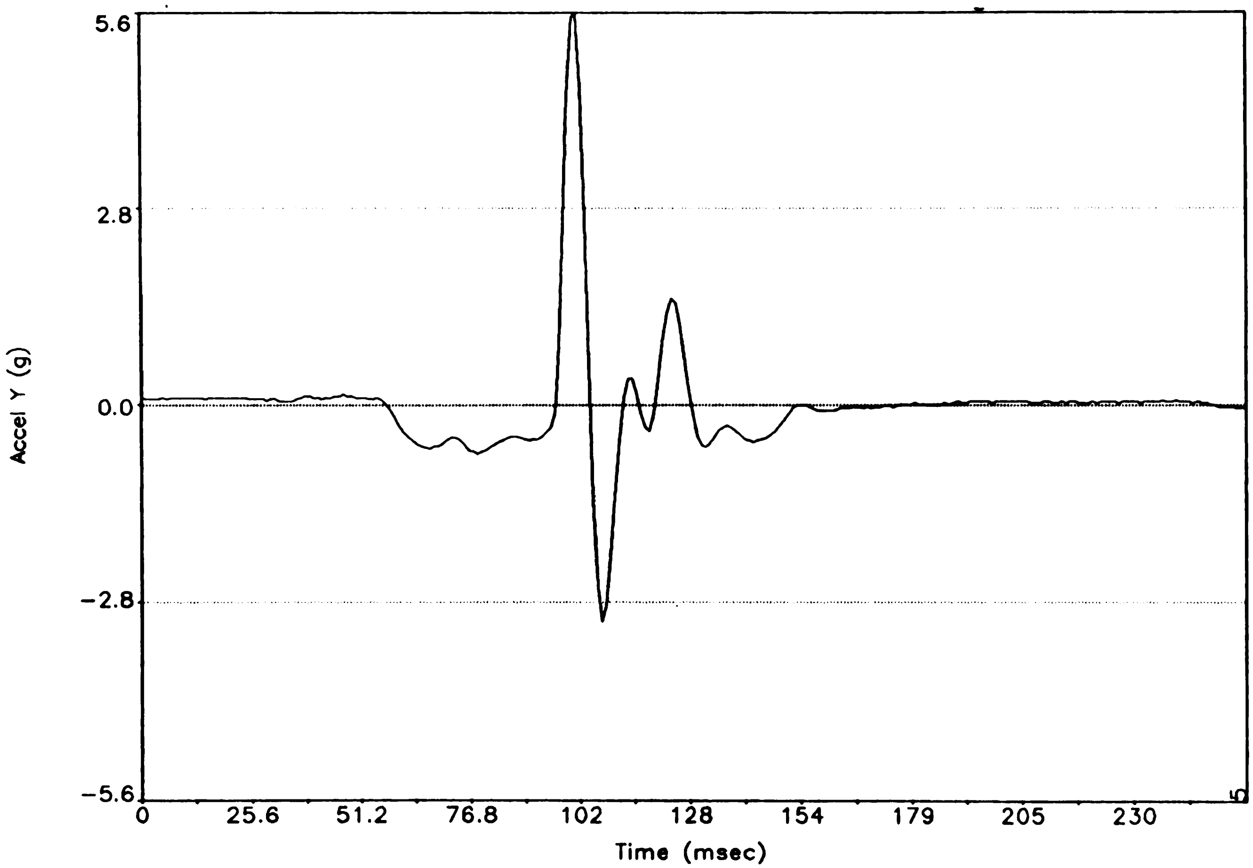

Figure 21: Longitudinal Impact Levels in Rail Shipments, Base of Steel Rack

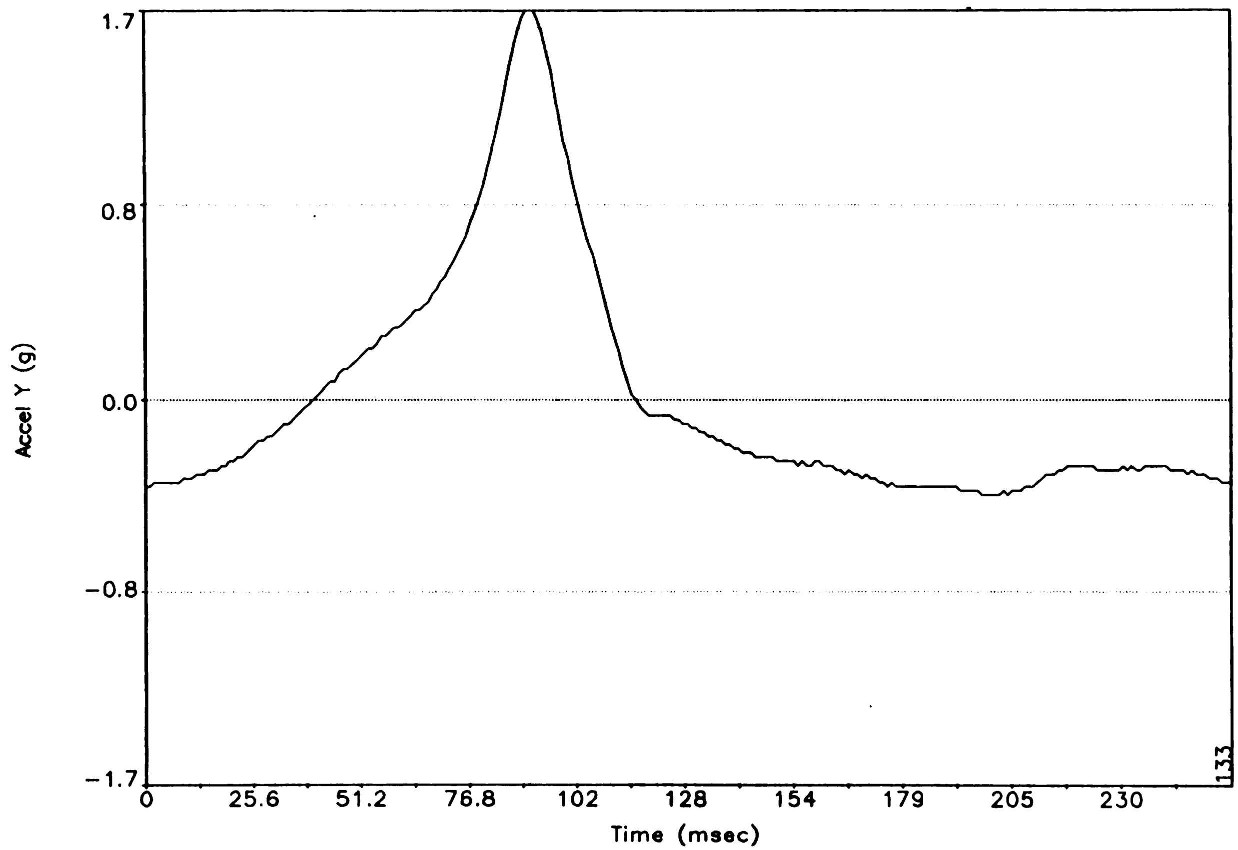

Figure 22: Lateral Impact Levels in Rail Shipments, End 1

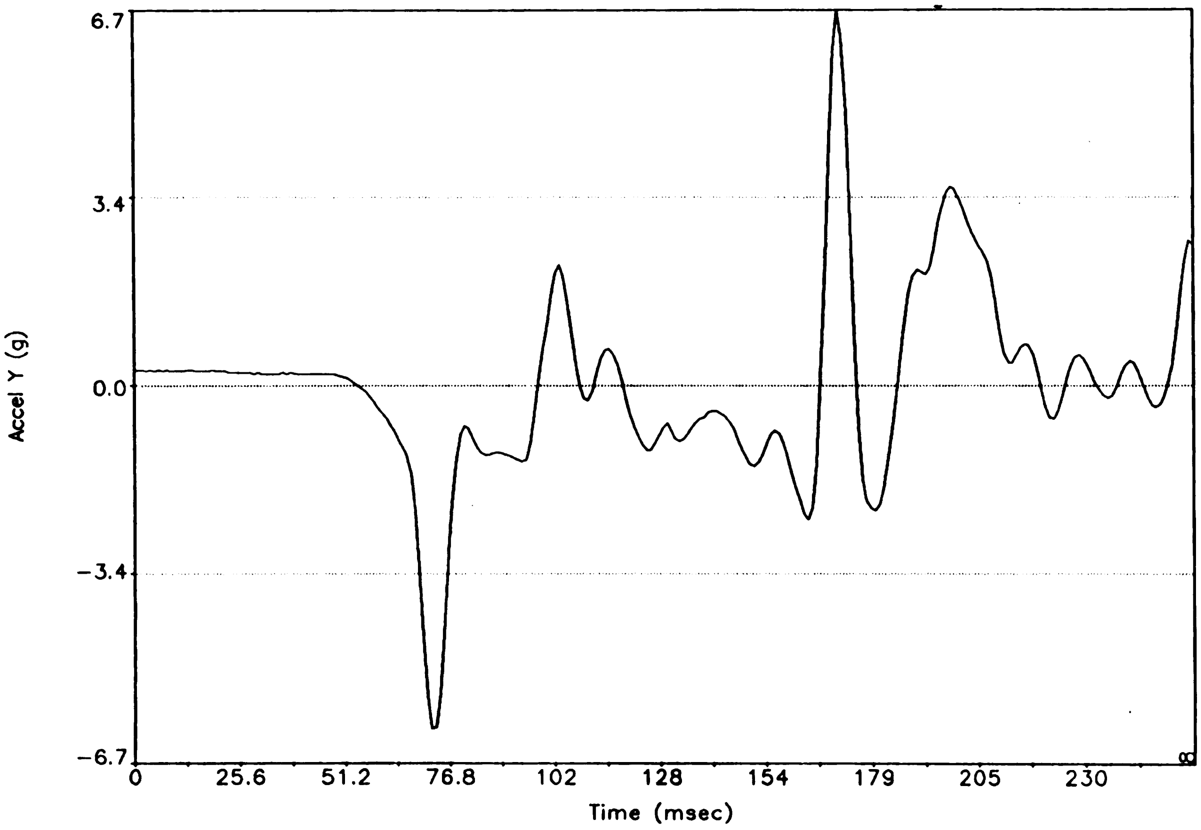

Figure 23: Lateral Impact Levels in Rail Shipments, End 2

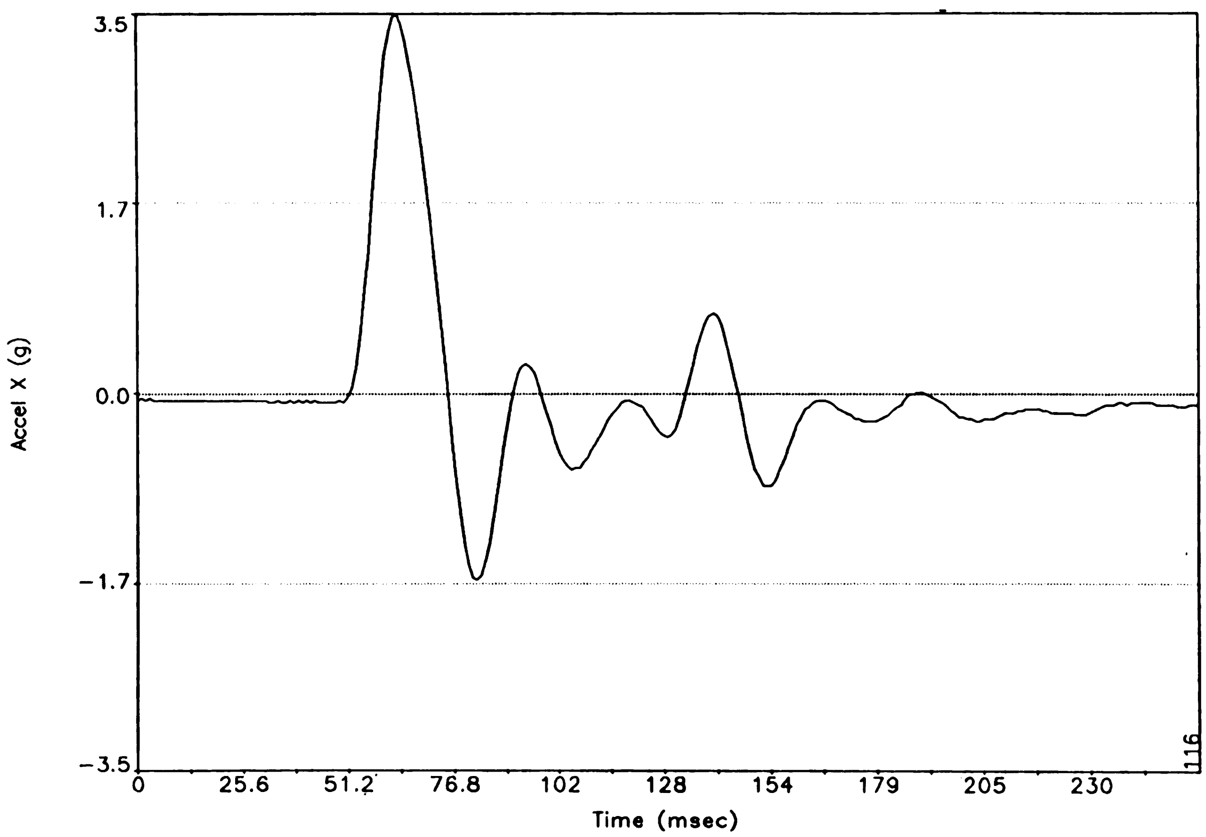

Figure 24: Lateral Impact Levels in Rail Shipments, Base of Steel Rack

4.0 CONCLUSIONS

Based on the data collected and the results discussed in the previous chapter, the following conclusions were made:

1. The vertical vibration levels in truck shipments are more severe than those in rail shipments, especially at frequencies below 20 Hz. The vertical vibration levels in truck shipments are the highest at 4 Hz and those for rail shipments at 11 Hz.

2. The impacts occurring in the longitudinal direction are more severe than those in the lateral direction for rail shipments. The impacts in these two directions for truck shipments were negligible.

3. The lateral and longitudinal vibration levels in truck shipments are negligible as compared to vertical vibration.

4. The lateral and longitudinal vibration levels in rail shipments are slightly higher than those for truck shipments.

5. A test protocol was developed in accordance with ASTM standards to perform vibration and impact tests on steel racks containing automotive engines. This protocol consists of the follwing:

- Place a three high steel rack with engines on a electrohydraulic vibration table using appropriate restraining devices as recommended in ASTM D4728. Program the vibration controller to perform a random vibration test in accordance with ASTM D4728 using spectrums in Figures 1 and 2. Test the steel racks for a duration of 90 minutes using each spectrum, for a total of 180 minutes as recommended in ASTM D4169.

- Place a two high steel rack with engines on a electrohydraulic vibration table using appropriate restraining devices as recommended in ASTM D4728. Program the vibration controller to perform a random vibration test in accordance with ASTM D4728 using spectrums in Figures 4 and 5. Test the steel racks for a duration of 90 minutes using each spectrum, for a total of 180 minutes as recommended in ASTM D4169.

- Place a steel rack with engines in the loading configuration for a box car for longitudinal impacts on a horizontal impact testing machine. Program the horizontal impact tester to produce an impact of 5.6 G with a duration of 14 ms. Perform an impact test in accordance with ASTM D4003. Perform three repetitions using these test conditions as recommended in ASTM D4169.

- Place a steel rack with engines in the loading configuration for a box car for lateral impacts on a horizontal impact testing machine. Program the horizontal impact tester to produce an impact of 6.7 G with a duration of 7 ms. Perform an impact test in accordance with ASTM D4003. Perform three repetitions using these test conditions as recommended in ASTM D4169.

- Inspect the racks and engines on completion of each of the above four tests for any damage that has occurred. Appropriate modifications or design changes to the racks or engines can be made if needed based on this information.

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