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MEASUREMENT OF RIDE VIBRATIONS ON SEMITRAILERS INCORPORATING DIFFERENT SUSPENSIONS

R.L. Nisonger
R.D. Ervin

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Highway Safety Research Institute
The University of Michigan
Ann Arbor, Michigan 48109

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16. Abstract

Measurements were made of the ride vibrations of van-type semitrailers employing differing trailer suspension types. Data were processed to yield (1) power spectra describing the steady-state vibrations prevailing on two sections of interstate highway and (2) time histories of trailer accelerations deriving from the traverse of a bridge approach discontinuity. Results serve to compare the gross differences in cargo isolation that is achieved with each of the three types of trailer suspensions.

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1.0 INTRODUCTION

This document reports the results of tests conducted on three North American Van Lines semitrailers which were outfitted with differing suspensions. The suspensions tested were a four-leaf spring suspension, a Mor-Ryde suspension and an air suspension. The trailers outfitted with these suspensions were tested on three roadway segments to evaluate comparative ride vibrations on a smooth and a rough paved surface and also at a bridge approach incorporating abrupt surface level change.

The trailers were loaded identically and pulled by the same two-axle highway tractor which had multi-leaf front and rear suspensions. Each trailer was instrumented with accelerometers over the rear suspension and at the trailer midpoint to monitor the trailer vibrations. An accelerometer was also mounted on the tractor frame at the fifth wheel centerline to measure the accelerations encountered at the front of the trailer. Signals from these transducers were recorded on magnetic tape and analyzed using a discrete-sampling spectrum analyzer. The analysis yielded spectral densities of acceleration at the transducer locations, as well as phase relationships between the various signals and time histories of local accelerations.

This document is arranged to provide, firstly, a presentation of the test methodology in Section 2.0, followed by a summary of test results, a discussion of the general causes of cargo damage and a statement of the conclusions. Included as an appendix are all of the power spectral densities and time histories deriving from individual test runs.

2.0 TEST METHODOLOGY

2.1 Test Vehicles

Tandem axle semitrailers employing three different suspensions were tested in combination with a single-drive-axle tractor. The semitrailers were each pulled with a 1973 Ford W9000 diesel-powered COE tractor. This tractor had gross axle weight ratings of 10,860 lbs front and 19,040 lbs rear, both limited by the load ratings of the installed 10.00-20/F tires. Front springs were rated at 5,600 lbs each, and rear springs at 10,500 lbs each (plus a 2,250-lb "helper" auxiliary leaf). The tractor wheelbase was 134 inches, and the fifth wheel was set directly over the center of the rear axle. This tractor was previously owned by North American Van Lines and thus is representative of tractors used in service with the trailers that were tested.

The semitrailers were all 45-foot van-type vehicles, diverted from the North American New Products fleet with identical loadings of cartoned washing machines. Cargo weight in each trailer was 24,970 lbs. The trailers are, respectively, identified as follows:

1) Trailer No. 7646, manufactured by Kentucky Trailers in 1976, with air ride suspension.
2) Trailer No. 118377, manufactured by Kentucky Trailers in 1977, with Mor-Ryde suspension.
3) Trailer No. 6390, manufactured by Kentucky Trailers in 1974, with leaf spring suspension.

2.2 Instrumentation

Each vehicle combination was equipped with three Schaevitz LSBG-10 accelerometers to monitor vertical vibrations of the trailer frame at the midpoint and rear suspension locations and on the tractor frame at the fifth wheel centerline. These accelerometer locations provide vibration information at locations critical to the analysis of the vehicle ride response. Data signals were recorded, without filtering, onto a Honeywell 5600C FM tape recorder. Signal amplitudes were scaled through a calibrated serial attenuation unit to assure that maximum signal level was utilized without saturation of the recorder. Playback of recorded data onto a pen chart recorder permitted signal amplitude assessment so as to guide the selection of an optimum attenuation scale for each pavement section and trailer combination.

2.3 Test Procedures

Each test combination was tested over three surfaces at 45 and 55 mph. Test surfaces were selected to provide a range of road roughness inputs from new, very smooth bituminous expressway to aging, pock-marked concrete, plus a bridge approach discontinuity. The actual sites used for testing were:

No. 1) I-94 East between Mile Markers 180-181
(smooth bituminous)

No. 2) I-94 West between Mile Markers 75-74
(rough concrete)

No. 3) US-23 North at Silver Lake Road
(bridge approach discontinuity)

These surfaces are referred to by number in the remainder of the report.

For the continuous surfaces (Nos. 1 and 2), data were collected over a one-mile segment to assure an adequate sample length for averaging of the spectral densities to obtain a steady-state spectrum. Concerning the bridge approach data, a reference timing mark was applied to a control channel as the vehicle first contacted the discontinuity so the direct time history responses could be identified.

2.4 Data Processing

The accelerometer signals were scaled by the on-board signal processing unit and recorded on FM tape. The recorded data were then analyzed using a Hewlett-Packard 3582A Spectrum Analyzer. The spectrum analyzer was used to process both the "steady-state" vibrational environment of the vehicles on surfaces 1 and 2 and the transient behavior associated with surface 3.

Spectral densities and phase relationships were generated for the tests on surfaces 1 and 2. The spectral densities were used to determine the dominant frequencies of vibration, that is, those frequencies at which the largest accelerations are transmitted to the trailer and its cargo. The phase relationships between the various frame locations were then used to determine the mode shape of these dominant responses. Averages were taken over several samples of each test to increase the accuracy of the spectra and to eliminate responses not due to the random road inputs.

Since the bridge crossing transients lasted only a few seconds, averaging was impossible in these tests and therefore the spectral density measures are somewhat meaningless. Thus the analysis of these data was confined to the time histories of the crossings using the spectra only to approximate the dominant frequencies of response.

3.0 SUMMARY OF TEST RESULTS

Acceleration spectral densities are used to describe the vibrational environment of the various locations on the trailer and tractor. Spectral densities are a measure of the mean square acceleration over a finite frequency bandwidth around a given frequency. In this study, units of g^2/Hz are assigned to the spectral density. Plots of spectral density versus frequency (see Figure 1) are used to identify the frequencies at which the response of the system to the road input is greatest. The peaks of the spectrum generally correspond to natural frequencies, or resonances, of the system.

Figure 1 illustrates the acceleration spectra of the three trailers at the front, middle, and rear as the trailer passes over a rough section of expressway at 55 mph. This test condition approximates an environment to which cargo could be exposed for long periods of time while traveling over deteriorating roadways. The acceleration spectra over the trailer suspension show the air suspension to have a generally lower vibration level than the Mor-Ryde or the steel suspension over virtually the entire frequency range of 0-25 Hz. Locations of the first peak in each spectra give indications of the relative stiffness of each system, with lower frequency peaks indicating a lower nominal spring rate. Comparison of these "first peaks" illustrates that the air suspension is the lowest and the steel spring the highest in nominal rate. Other details of these spectra worth noting are the high acceleration levels prevailing with the Mor-Ryde suspension at 10-15 Hz and with the steel suspension above 15 Hz. While the vibration levels observed at the higher frequencies are substantially lower than the levels associated with the primary peaks at 2-4 Hz, such accelerations could be very significant if the cargo elements possess a lightly-damped natural frequency in this range.

The spectra measured at the fifth wheel kingpin (i.e., trailer front) illustrate that the tractor suspension determines the vibration levels such that all three trailers show essentially the same spectra. Since the vibrational environment at the front of the trailer is primarily

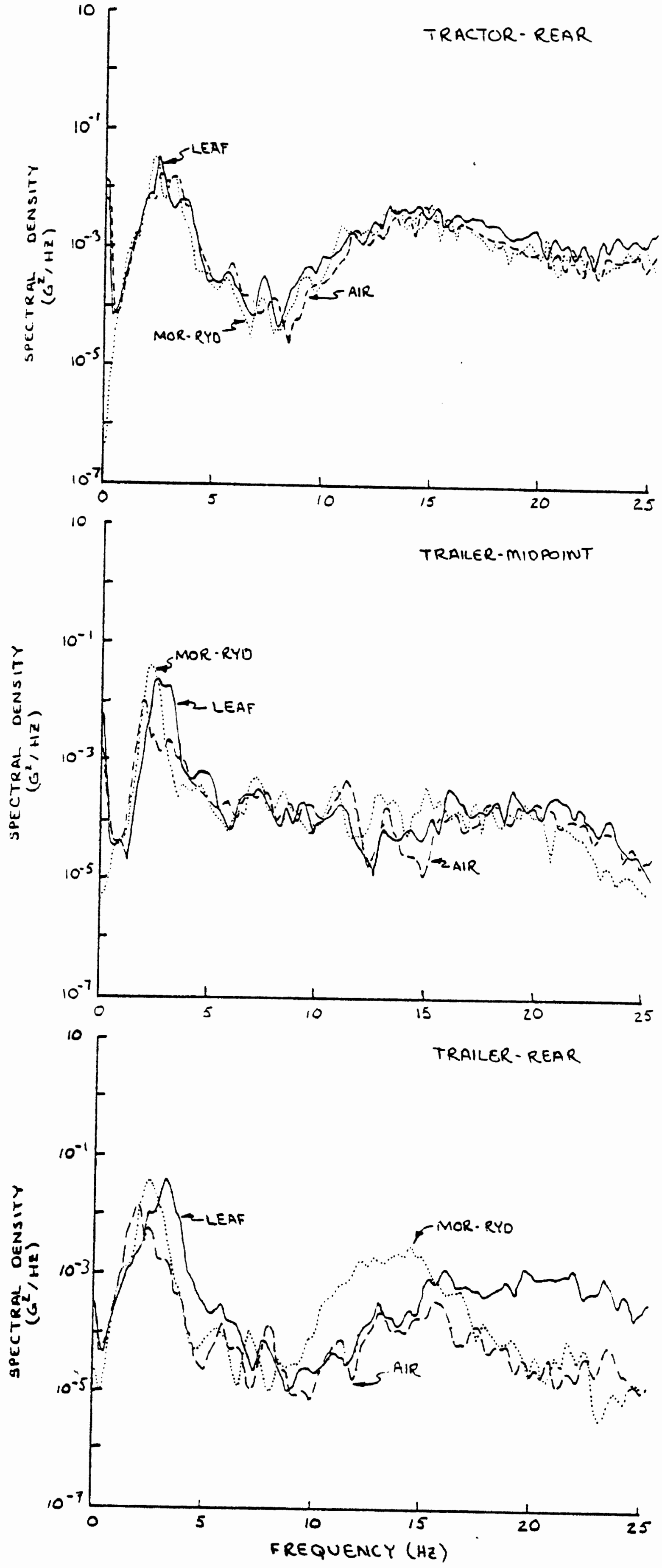

Figure 1. Comparison of trailer responses on surface #2.

dependent upon the tractor suspension, one can readily appreciate that improvement of this environment by means of selection of trailer suspension alone is not likely.

The trailer-midpoint spectra closely resemble the trailer-rear spectra except at the higher (>10 Hz) frequencies where the midpoint response is attenuated.

Abrupt inputs to the trailer suspension have the potential of causing freight damage due to the high accelerations that can be experienced during the transient response. Bridge approaches provide such an input and are encountered frequently along the interstate highway system. Examination of the acceleration time history resulting from such bridge crossings yields information concerning the relative capabilities of the different suspension systems to isolate the cargo from the shock associated with the step input of the bridge approach. Figure 2 contains the acceleration histories of the three trailers during a bridge crossing. These time histories represent the local acceleration occurring at the rear of the trailer (i.e., directly above the rear suspension) as the vehicle crosses the surface discontinuity at 55 mph. The most important feature of the response is the peak value of acceleration insofar as freight damage occurring from such a transient loading will be of the nature of "first-level-crossing" mechanical failures. The air suspension is seen to provide the best isolation from the imposed shock with a peak acceleration of approximately .5 g while the Mor-Ryde and the steel suspensions exhibit peaks of .9 and 1.6 g, respectively.

These transients also provide information about the system damping. The Mor-Ryde suspension, for example, is seen as very lightly damped since the acceleration signal "rings" for several seconds after the vehicle traverses the surface discontinuity. The steel spring appears less lightly damped and the response dies out fairly quickly while the air suspension is very well damped and decays almost immediately.

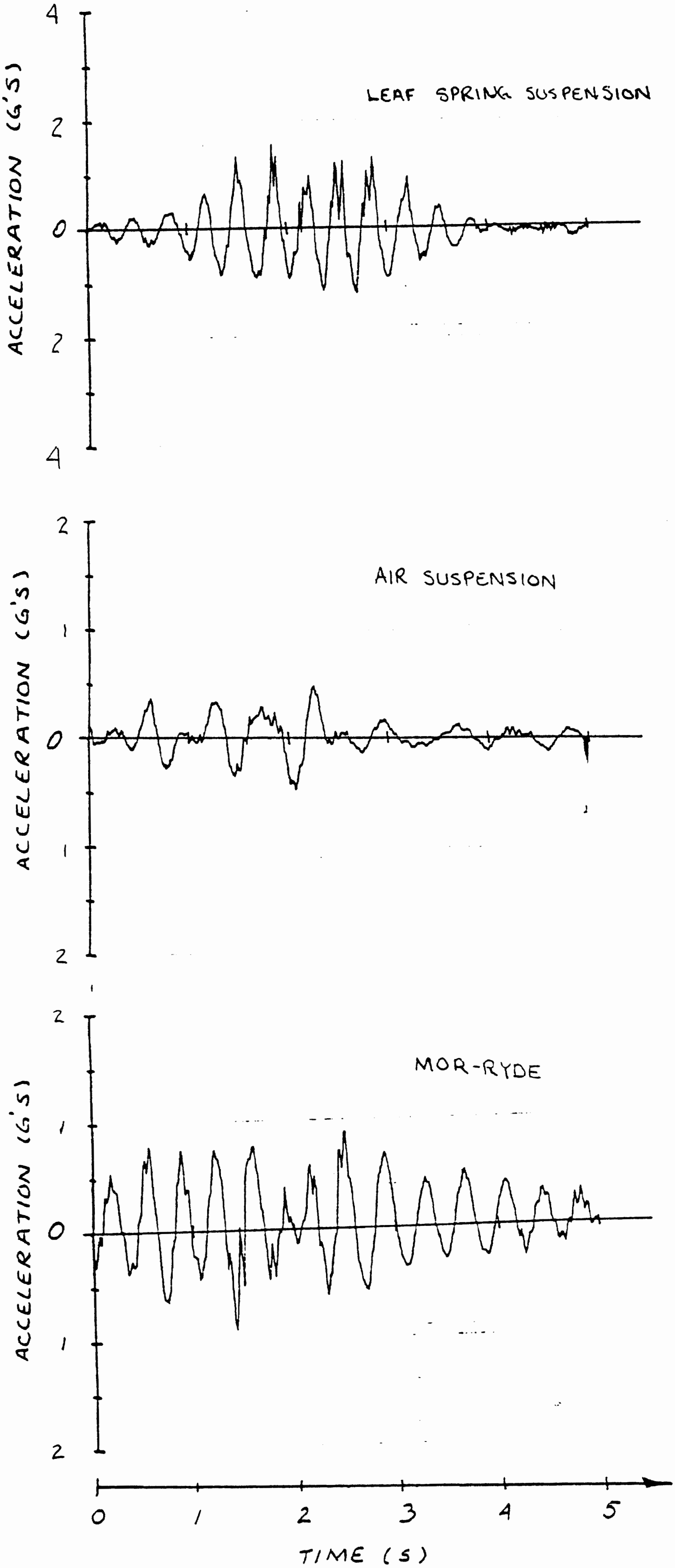

Figure 2. Comparison of trailer responses over rear suspension on bridge approach. Note the differing scale used in presenting data for the leaf-spring suspension.

4.0 DISCUSSION OF TRAILER VIBRATION AS A CAUSE OF CARGO DAMAGE

The significant consequence of trailer vibration is damage to the cargo being transported. From a simplistic viewpoint, it would appear that there are two major modes of freight damage; namely, damage due to fatigue failures and damage due to abrupt mechanical failures accompanying discrete, severe events. In the context of motor freight operations fatigue damage results from the continuous vibration encountered while traveling over rough road surfaces while the single event damage would occur due to shock loading as the vehicle negotiates large surface discontinuities. Both of these conditions must be considered when evaluating the performance of suspension systems.

The cargo itself must also be considered when analyzing the relationship of vibration to cargo damage. In particular, the natural resonances of the cargo, as well as the fatigue strength and ultimate strength, all enter into the question of cargo survival in a given vibrational environment. Freight with natural resonant frequencies coinciding with those of the tractor-trailer system, itself, will be more likely to suffer damage due to fatigue than freight whose natural resonances are mismatched with those of the vehicle. In light of this sensitivity, it follows that certain trailer suspensions (or tractor suspensions) may be better suited for one cargo than another.

Certain general statements can be made regarding the vibration response of the North American trailers which were tested.

- Vibration levels decrease with decreased speed over rough surfaces.
- Periodic force variations deriving from tire and wheel nonuniformities become dominant while traveling over very smooth surfaces.
- Loaded trailers tend to exhibit a dominant bouncing mode in the vicinity of 2 to 3 Hz.

• Trailer accelerations experienced over an uneven section of bridge approach involved, primarily, the excitation of this bouncing mode. Accordingly, the likelihood of product damage for components susceptible to severe loading in the range 2-3 Hz would be approximately proportional to the relative amplitudes of acceleration observed with the differing suspension types.

5.0 CONCLUSIONS

The results of this test program indicate that the air-suspended trailer experienced the lowest level of vibration on the continuous road surfaces and transmitted the lowest level of peak acceleration to the cargo while negotiating the surface discontinuity. The damping of this suspension is also superior to both the Mor-Ryde and the steel spring suspensions, resulting in considerably quicker recovery from severe transients.

All three suspension systems which were examined provide a level of ride quality at the rear of the trailer that was equal or superior to that provided at the front of the trailer by the tractor's multi-leaf suspension. Thus, in order to improve the total ride quality of the trailer, tractor as well as the trailer suspensions must be selected to afford adequate isolation of the cargo from the road roughness input.

APPENDIX

DETAILED MEASURES OF TRAILER VIBRATION RESPONSE

This appendix contains the spectral densities and time histories used in this analysis of trailer ride. The data are arranged by trailer, with responses on both road surfaces and the bridge approach included at 45 and 55 mph. Spectral densities are presented for the response to continuous surfaces (1 and 2) and time histories for tests on surface 3.

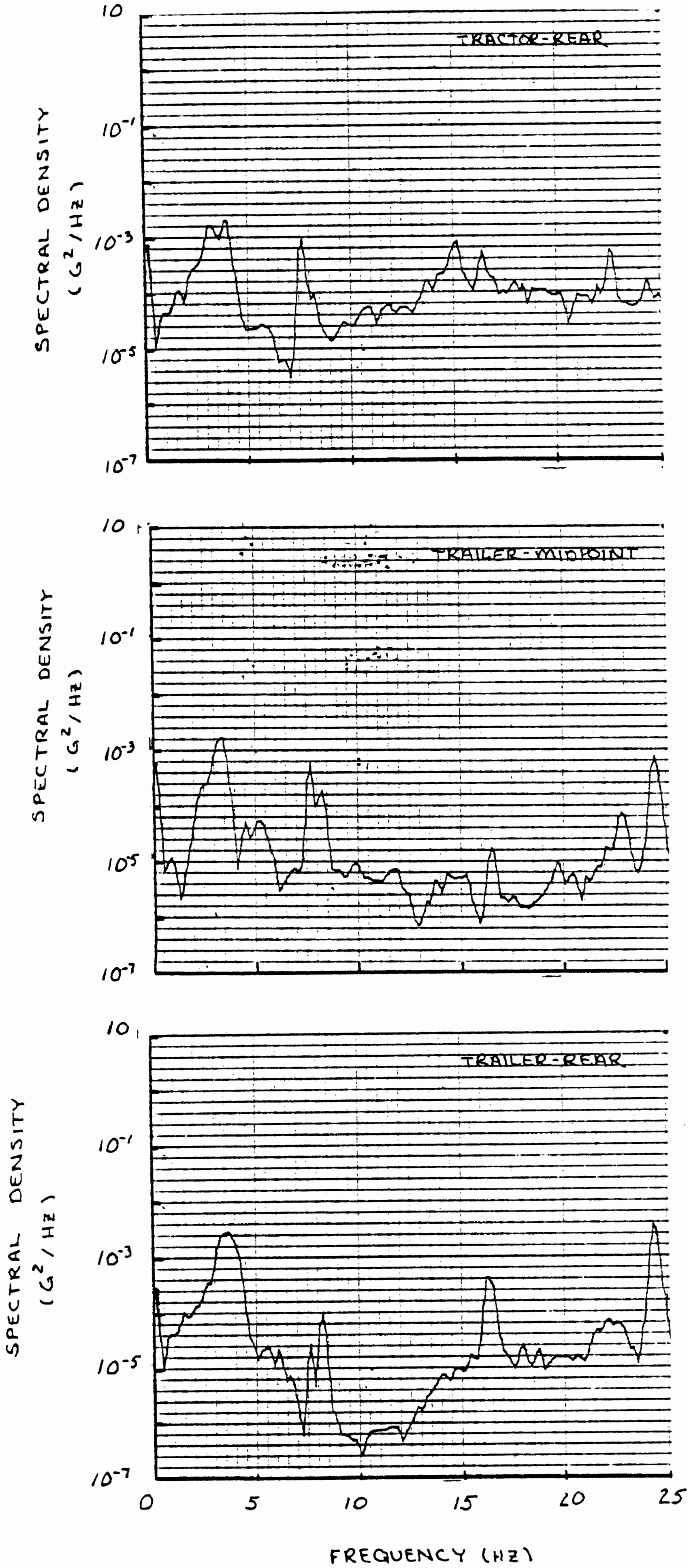

Figure A.1. Response of trailer with leaf-spring suspension, surface 1, 55 mph.

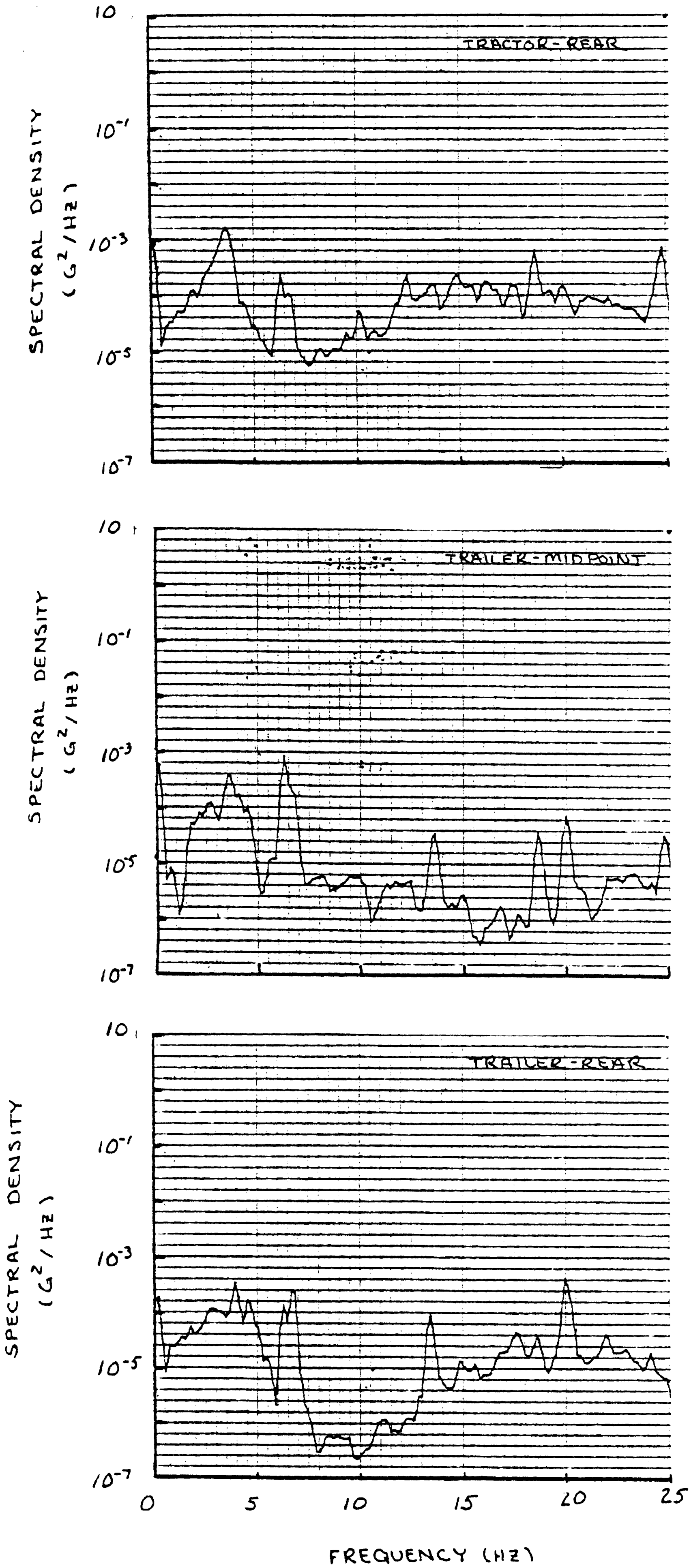

Figure A.2. Response of trailer with leaf-spring suspension, surface 1, 45 mph.

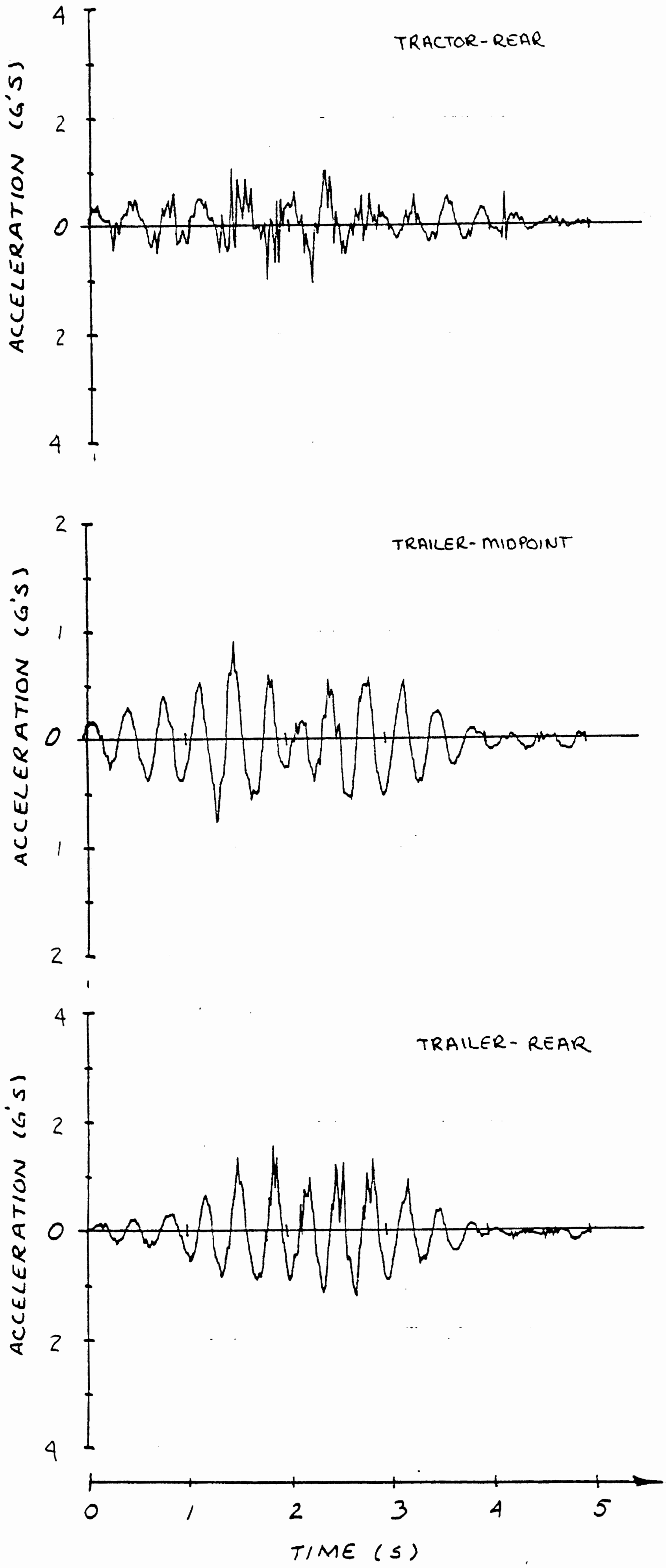

Figure A.5. Response of trailer with leaf-spring suspension, bridge approach, 55 mph.

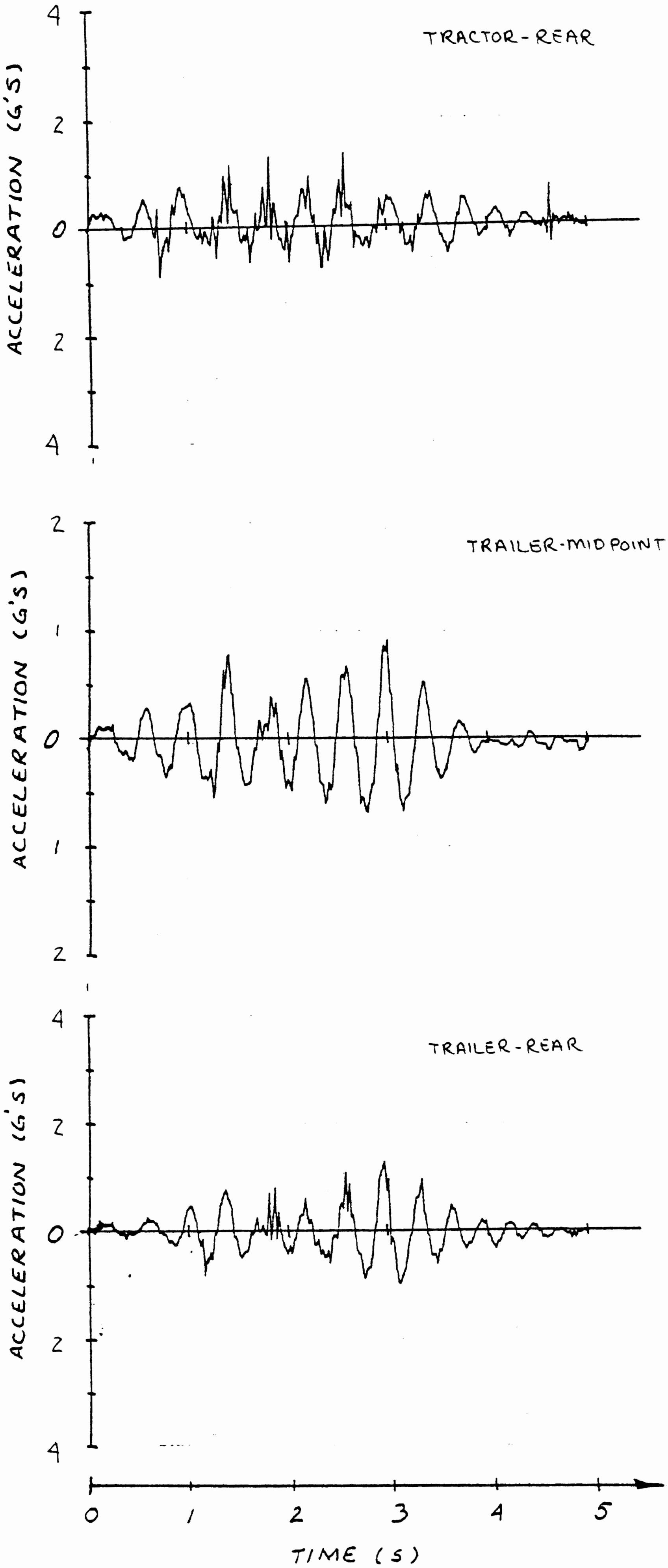

Figure A.6. Response of trailer with leaf-spring suspension, bridge approach, 45 mph.

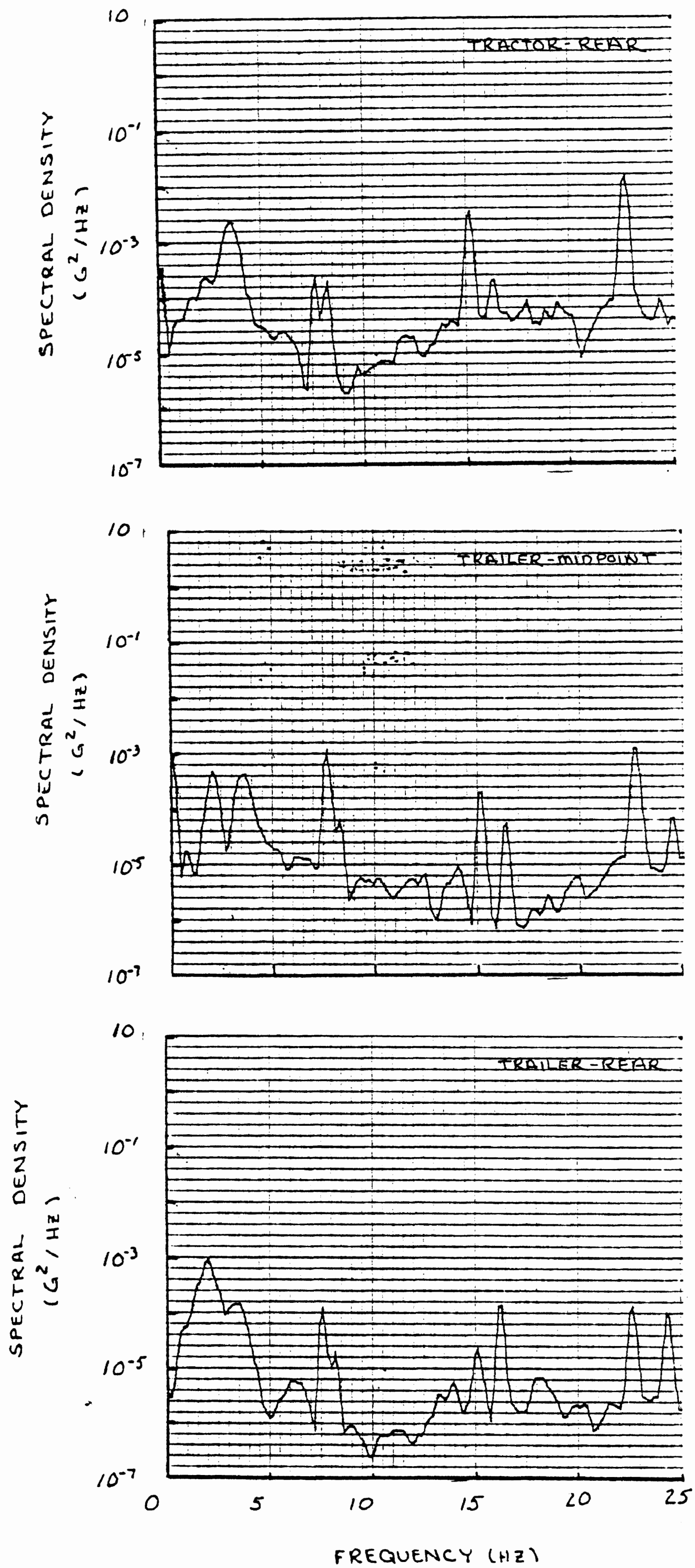

Figure A.7. Response of trailer with air suspension, surface 1, 55 mph.

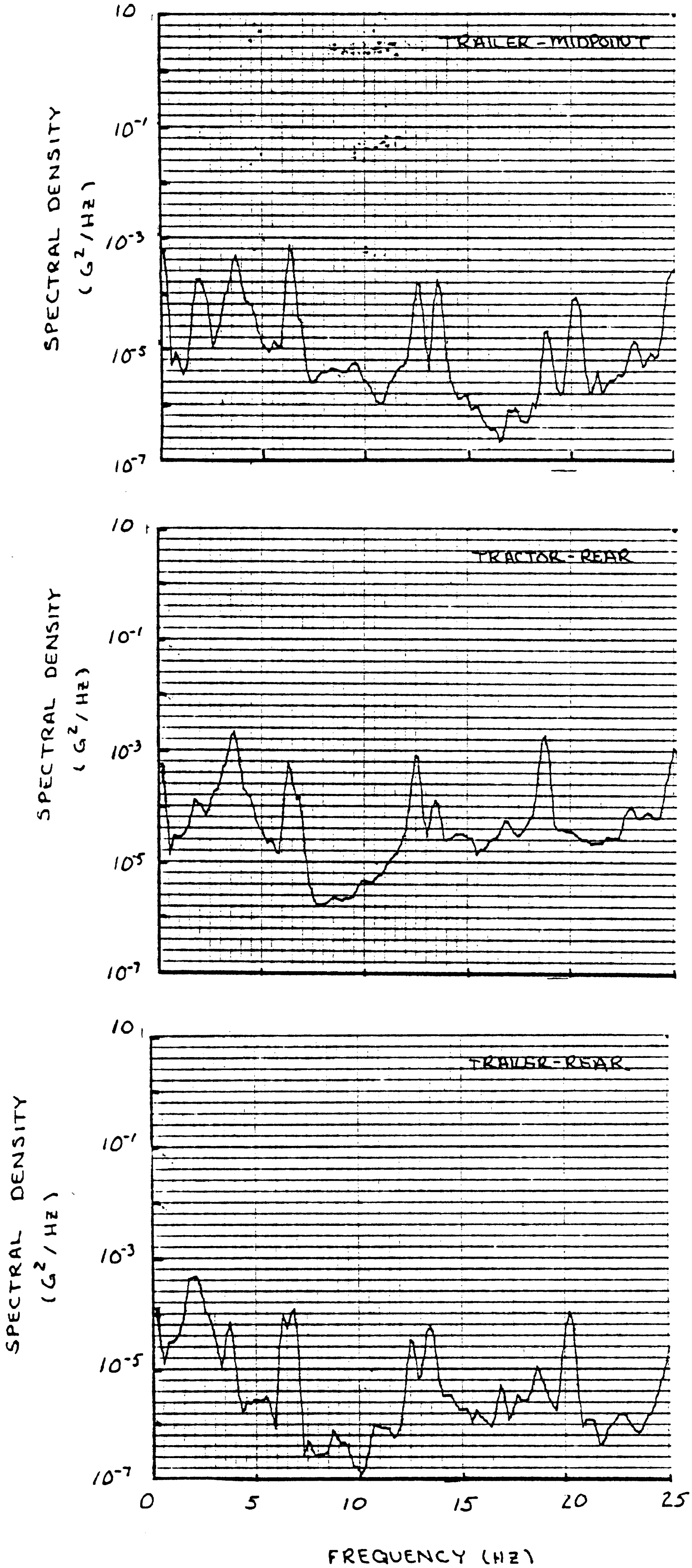

Figure A.8. Response of trailer with air suspension, surface 1, 45 mph.

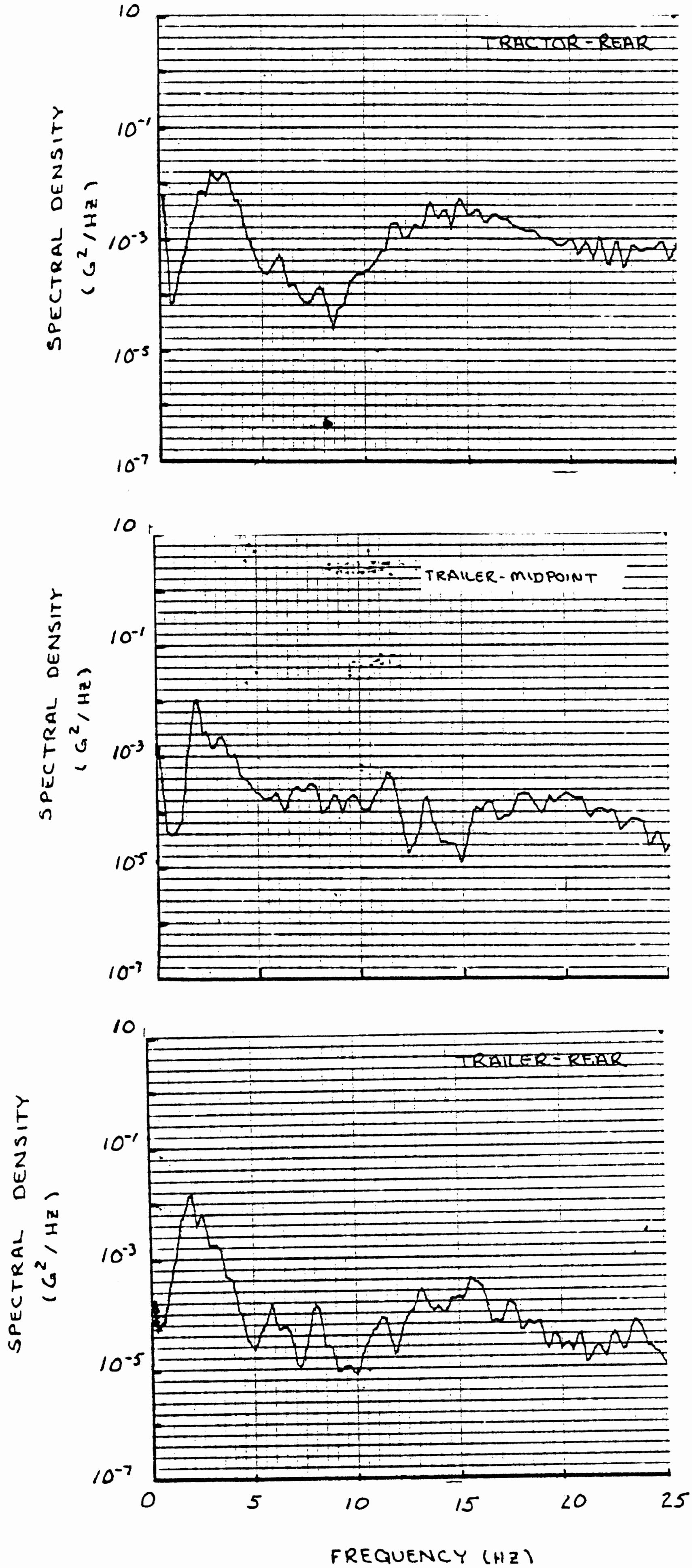

Figure A.9. Response of trailer with air suspension, surface 2, 55 mph.

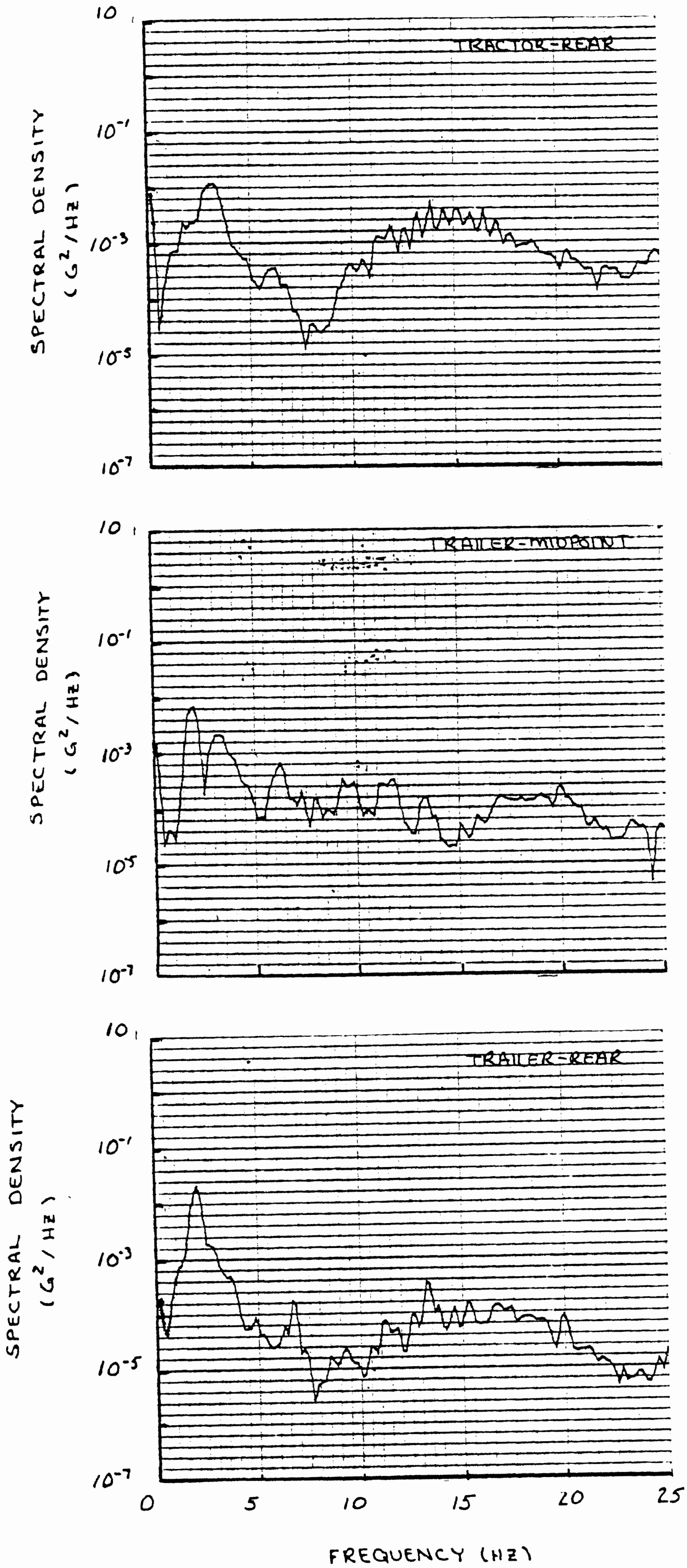

Figure A.10. Response of trailer with air suspension, surface 2, 45 mph.

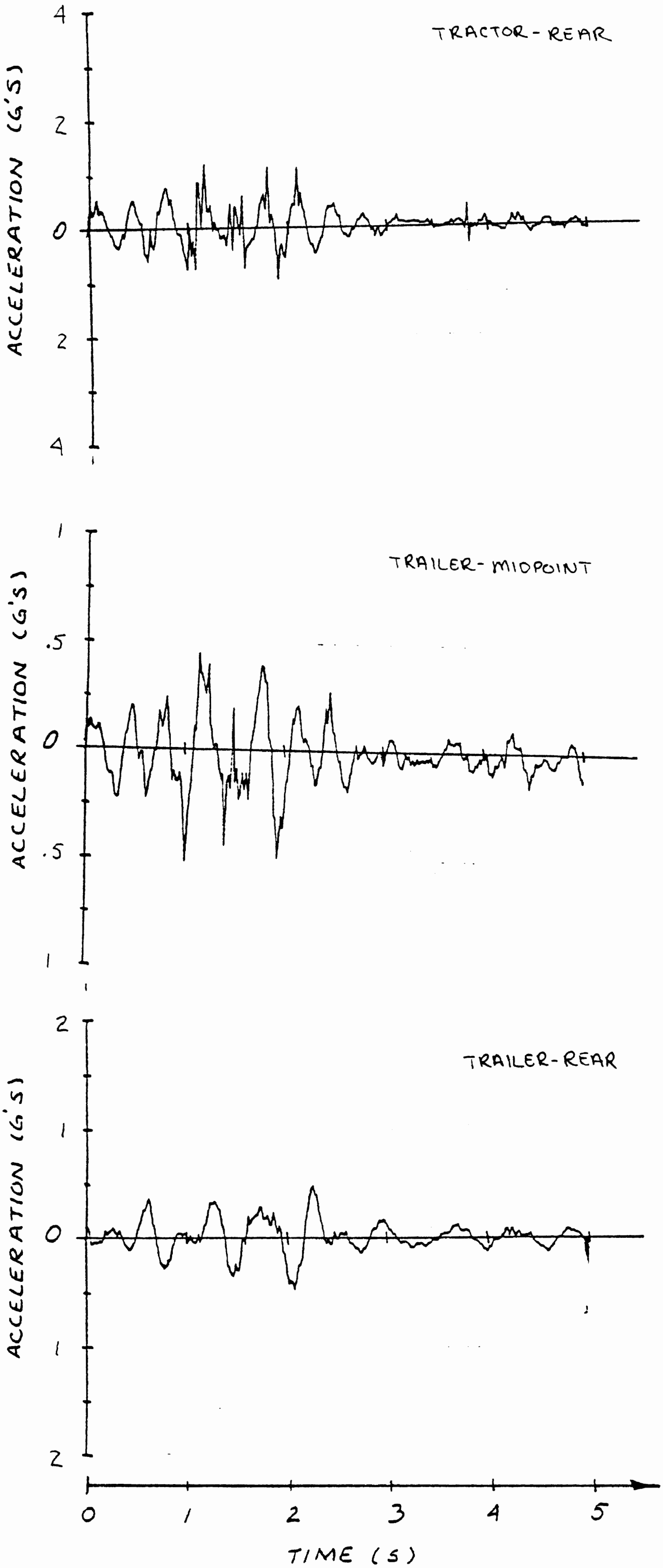

Figure A.11. Response of trailer with air suspension, bridge approach, 55 mph.

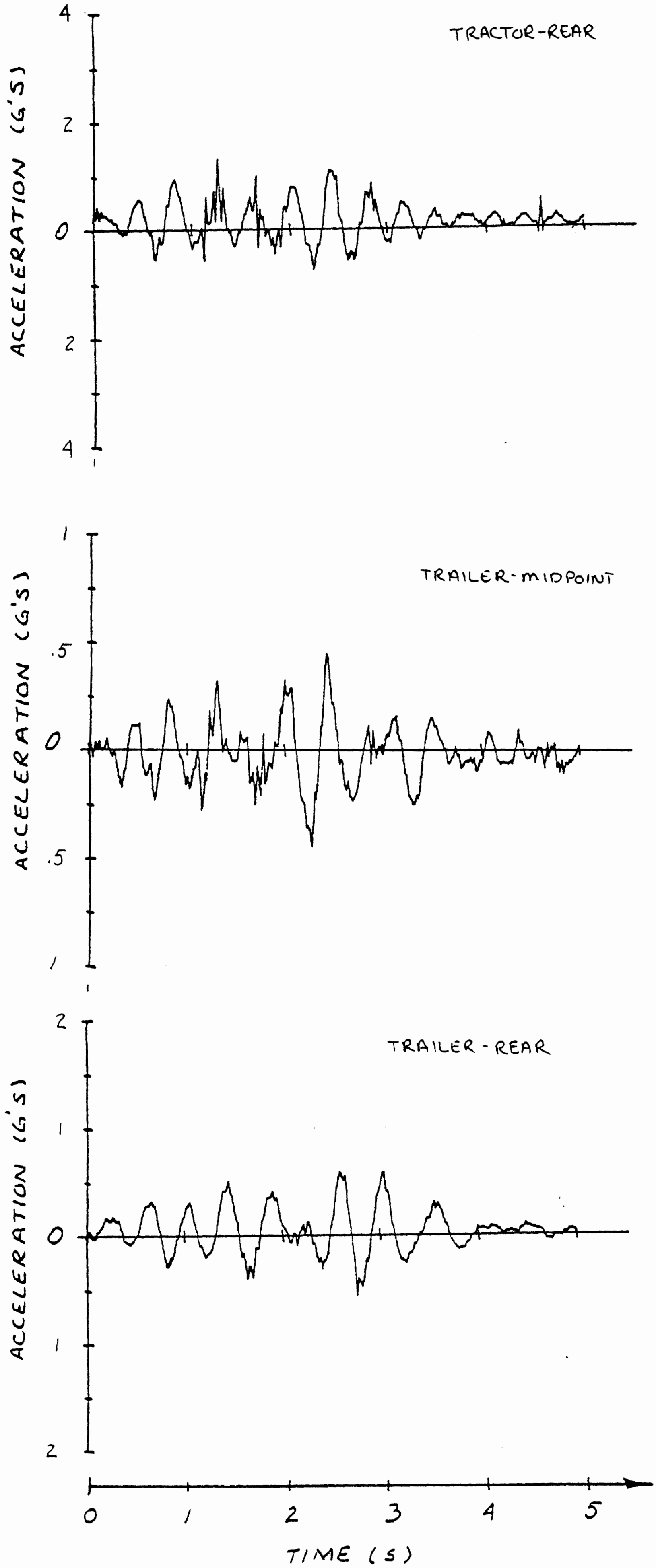

Figure A.12. Response of trailer with air suspension, bridge approach, 45 mph.

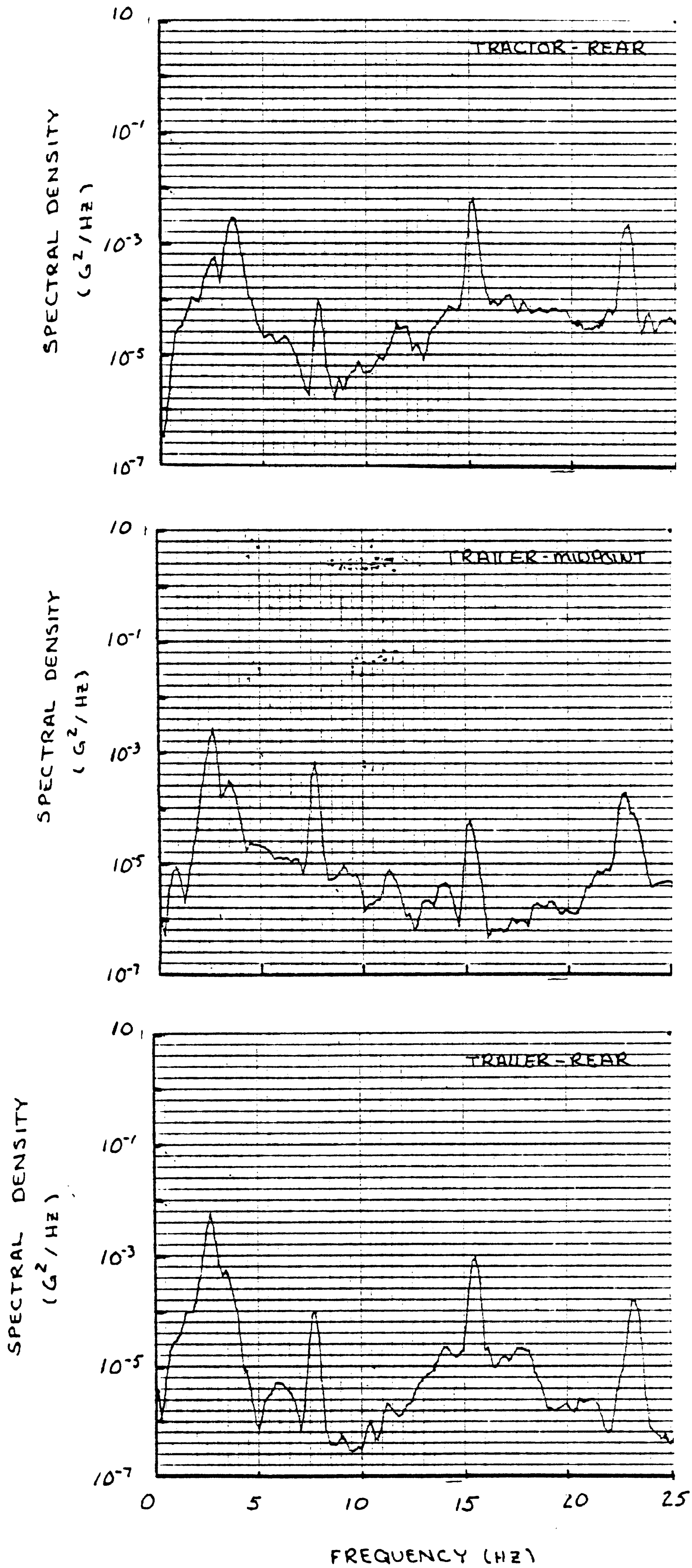

Figure A.13. Response of trailer with Mor-Ryde suspension, surface 1, 55 mph.

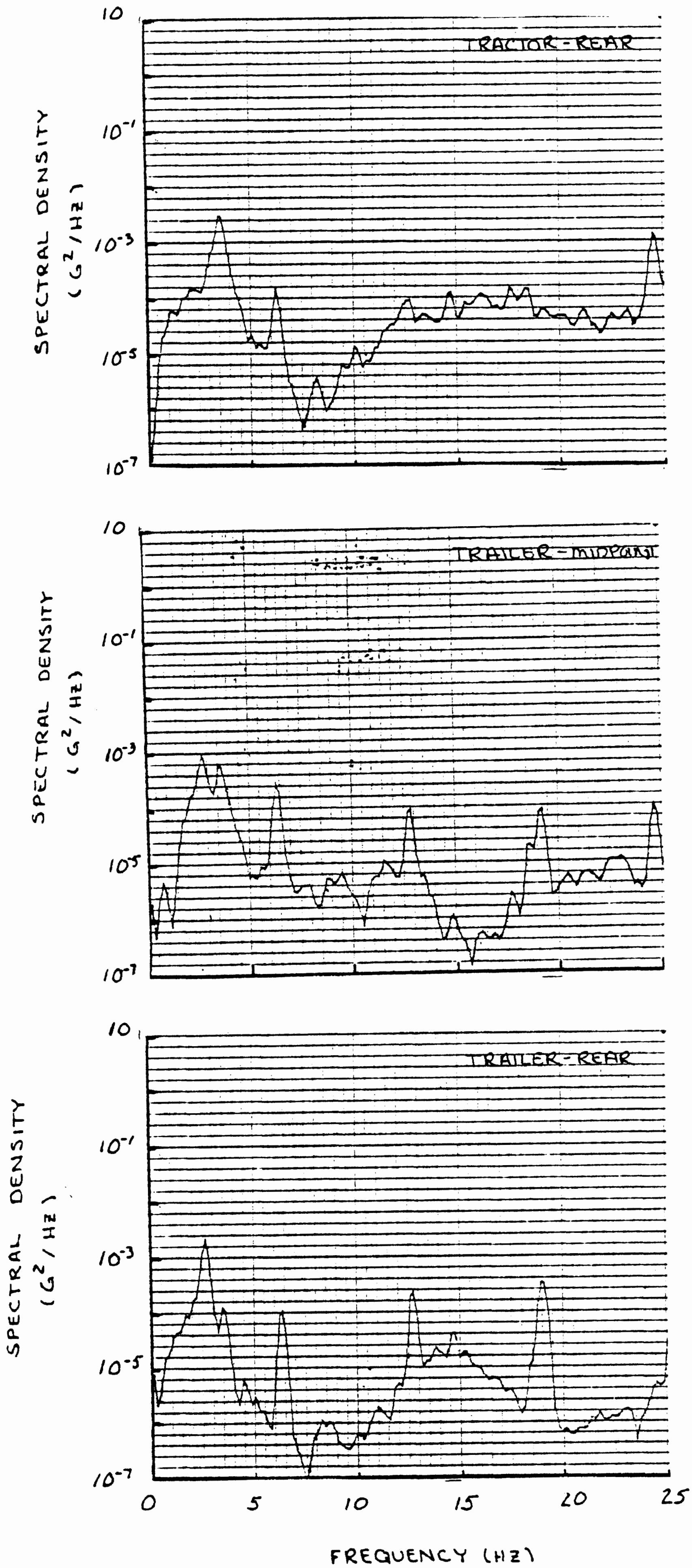

Figure A.14. Response of trailer with Mor-Ryde suspension, surface 1, 45 mph.

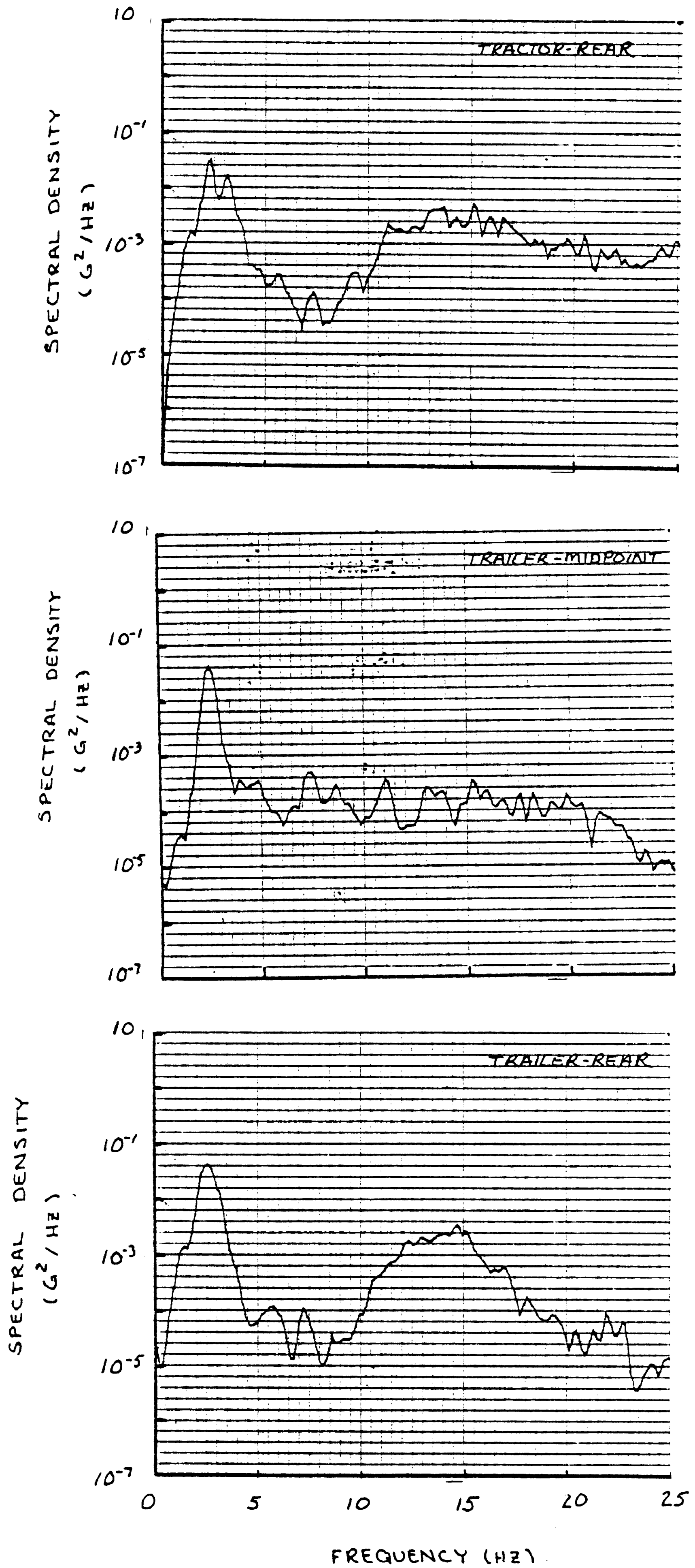

Figure A.15. Response of trailer with Mor-Ryde suspension, surface 2, 55 mph.

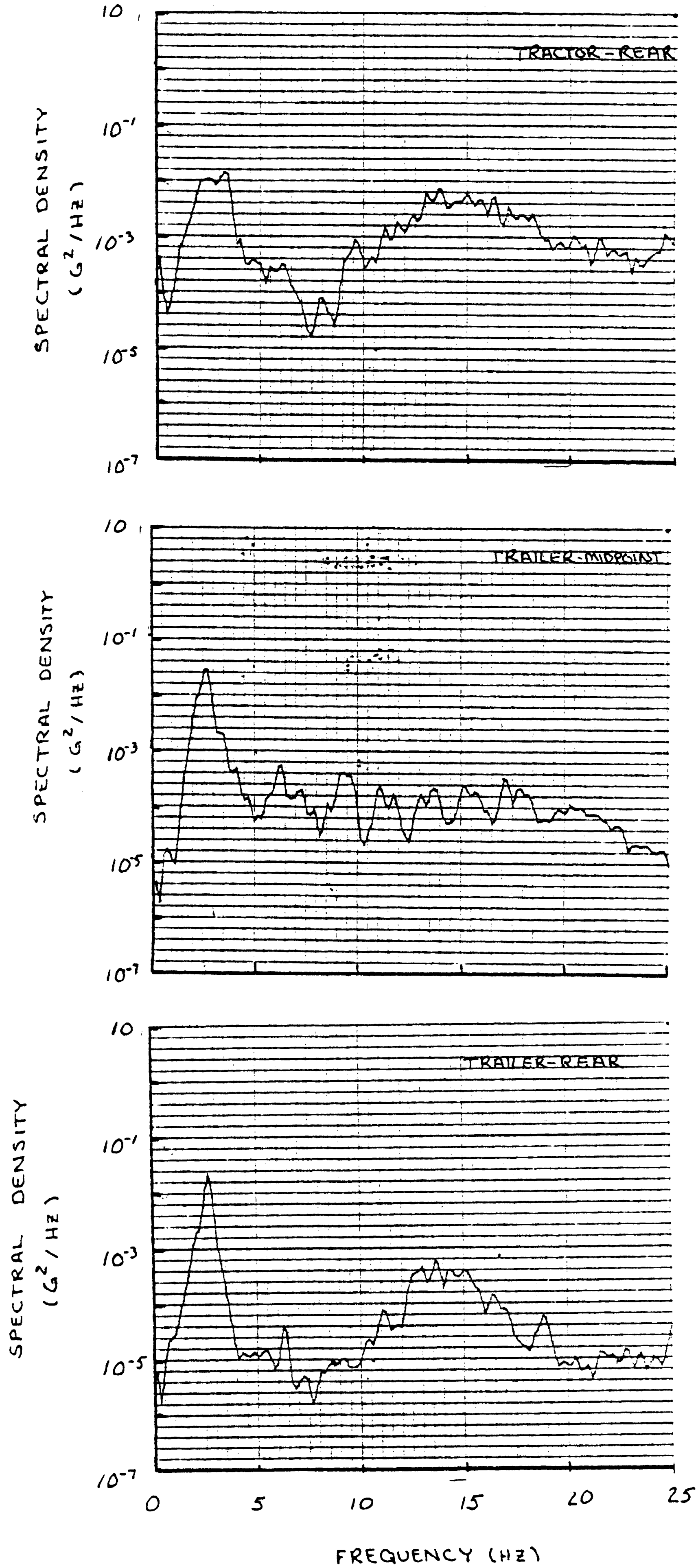

Figure A.16. Response of trailer with Mor-Ryde suspension, surface 2, 45 mph.

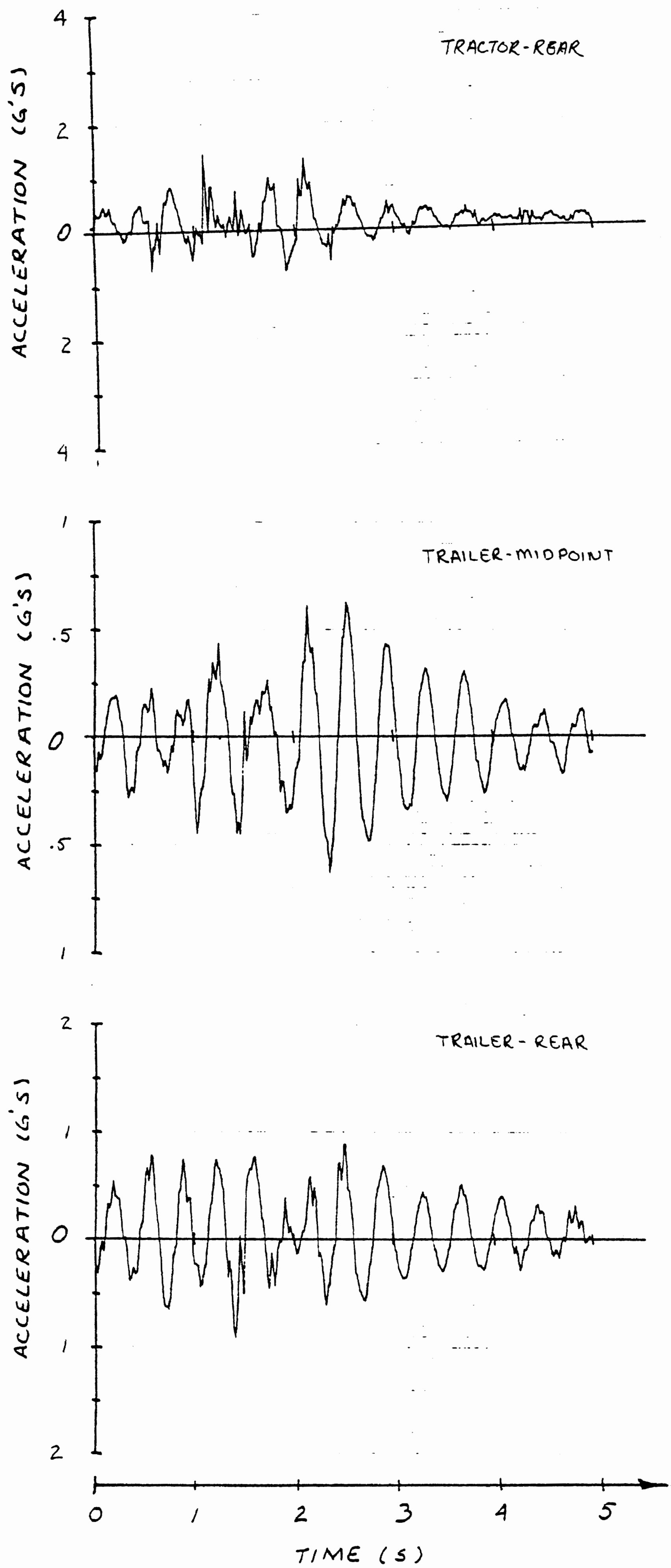

Figure A.17. Response of trailer with Mor-Ryde suspension, bridge approach, 55 mph.

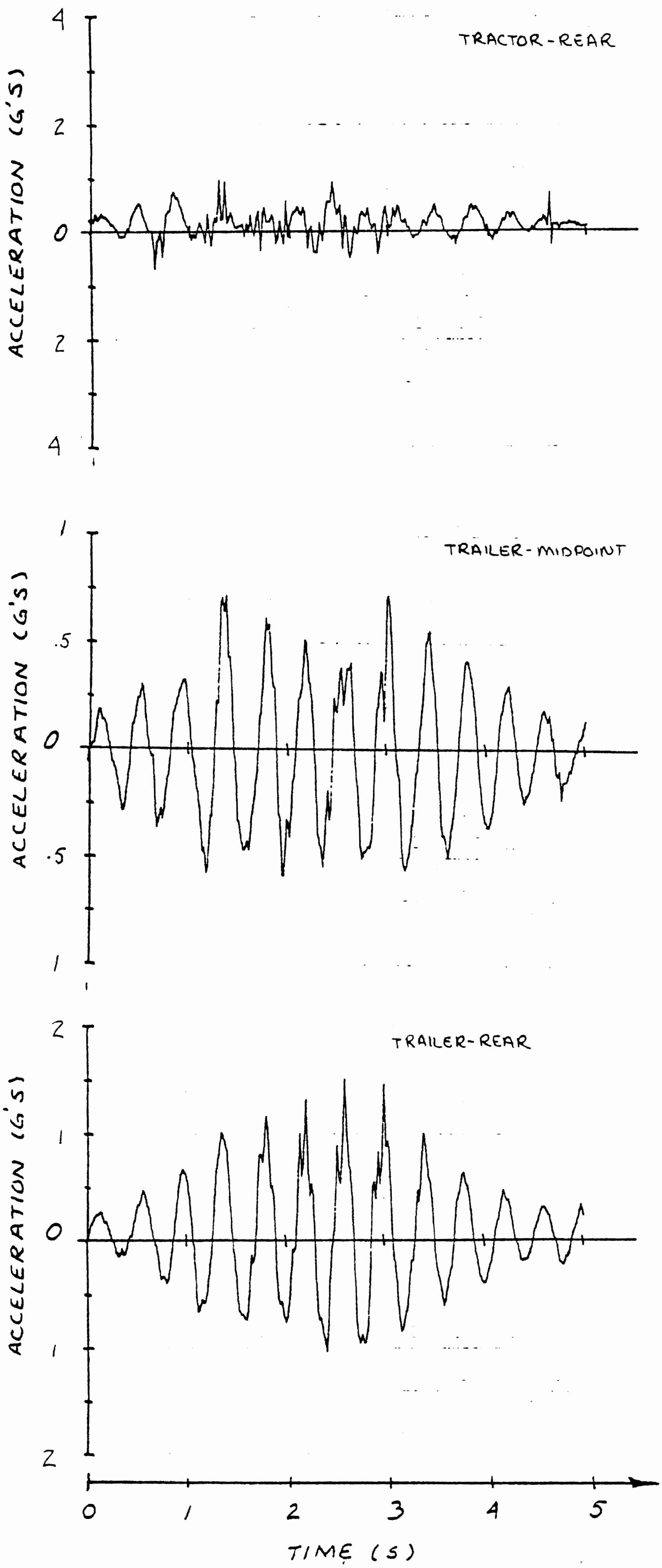

Figure A.18. Response of trailer with Mor-Ryde suspension, bridge approach, 45 mph.