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ATIONAL GOVERNMENT-INDUSTRY RESEARCH PROGRAM ON TRACK-TRAIN DYNAMICS

02-Track-Train Dynamics

PRELIMINARY EVALUATION OF
RAIL VIBRATION TECHNIQUES
FOR RAIL FORCE MEASUREMENTS

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13. ABSTRACT

It has been postulated that the vibrational response of a railroad rail, subjected to a sharp mechanical impact, should vary according to the magnitude of the internal longitudinal force.

In order to test this hypothesis, a series of tests were conducted at the A.A.R.'s Track Research Laboratory in Chicago, Illinois. These tests involved measurements of the complex acoustic spectra generated in a test rail section by sharp mechanical impacts to the head, as the longitudinal force levels were varied, in increments of about 12,500 pounds, from zero to approximately 200,000 pounds. Also studied were the feasibility of a rail-mounted accelerometer and microphone, located near but not in contact with the rail head, as response transducers, and the effects of changes in geometry between the points of impact (excitation) and response measurement.

The results indicated that there were shifts in the relative magnitudies of specific frequency components, as the longitudinal force levels varied, but due the complex nature of the vibrational responses, additional measurements and analyses are needed.

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EXECUTIVE SUMMARY

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1.0 INTRODUCTION

The increasing usage of continuously welded rail (CWR) by various railroads has been responsible for improving ride quality, and reducing rail end batter and other associated problems. This increased usage of CWR has, however, introduced a new type of problem, involving an increased incidence of track failures resulting from higher internal rail forces. These forces, when compressive, can cause buckling, and when tensile, can cause pull aparts. The primary causes of these forces are temperature changes and the action of passing trains. The reader is directed to Reference [1]* for a more detailed description of these problems.

Current technology is sufficient to free the rails of these undesired forces, providing that they can be identified and measured [2]. However, there is at present no means of identifying these forces that are suitable for field use. Most current methodologies used to measure forces in structural members require that the member be either instrumented (e.g., strain gaged) or subjected to detailed external surface examinations (e.g., x-ray diffraction).

All of the above approaches attempted to date [1] have demonstrated major drawbacks, when used in the railroad

* The numbers in square brackets refer to the References, listed in Section 6.0 of this report.

operating environment. It has been suggested [1] that the ideal measurement methodology and associated instrumentation should have the following desirable attributes.

(1) Ruggedly constructed and capable of surviving in the field;

(2) Easy to handle and require only limited interpretation of data;

(3) Nondestructive to the rail and associated track sturcture;

(4) Not require any disturbance of the track structure, either during the measurements or during calibration, if the latter is at all necessary;

(5) Require minimium or no calibration. If calibration is needed, it should not require heavy equipment or significant amounts of track time;

(6) Independent of, or readily compensated for:

- rail size
- rail metallurgy and/or previous heat treatment
- rail head wear
- work hardening or softening of the rail head
- internal/external rail defects

(7) Require minimium or no surface preparation

of the rail;

(8) Provide for direct measurement of net (absolute) longitudinal force.

(9) Should not have to be permanently affixed to the rail or track structure;

(10) Should permit "continuous," or at a minimium, very frequent measurements of rail forces from a moving vehicle.

It is the purpose of this report to discuss one suggested method for the measurement of rail forces, and to present the results of preliminary laboratory tests using this method.

2.0 THEORETICAL BACKGROUND

The basic premise of this method is that there is a change in the acoustic response of a longitudinally-loaded rail when sharply impacted, in contrast to the rail's response to a similar impact when unloaded. It was expected that this change in acoustic response would be a function of the magnitude of the load present in the rail, and if so, would provide a non-destructive means for measuring longitudinal rail forces that did not require instrumentation of the rail itself.

The origin of this method can be found in elementary physics, and illustrated by the fact that a violin string changes pitch when tightened. This idea has recently received attention regarding possible railroad rail applications. Some preliminary work was done in 1975 at Princeton University, and subsequently followed up with early tests at the

AAR in January of 1979. A conference [3] was subsequently sponsored by the AAR and FRA to specifically discuss this problem. Foster-Miller Associates, Inc. have recently published a report [4] that concerned itself with this concept. All of this work, however, was of a preliminary nature, and did not really address the subject of on-site rail installations, such as would be found in the field. This investigation was, therefore, intended to fill that gap.

In order to test the hypothesis, an experiment was designed to address the following questions:

What is the effect of longitudinal rail forces on the rail's response?

Is the phenomenon repeatable?

Is the response determined or influenced by end-of-rail effects?

3.0 TEST METHOD

It was decided that the most practical way to test the hypothesis was by means of a test on a short section of track, and an appropriate section at the AAR's Track Laboratory in Chicago was selected. This track consisted of two 39 foot lengths of 136 RE rail (Figure 1), spiked four spikes per tie to newly-laid ties. The ties were set in newly-laid crushed limestone ballast that had been tamped the week prior to the test. The ties were on approximately 19-1/2 inch centers. The rail was unsecured at both ends. In general, the track was considered to be of main line quality.

The test apparatus consisted of a pendulum that was used to excite the rail, and positioned at the approximate center of one rail section (Figure 2). Weights of 0.243 lb., 1.053 lb. and 1.94 lb. were used to strike the rail. Hydraulic jacks were used to induce compressive forces in the rail (Figure 3). The load was measured initally by means of strain gages mounted on the neutral axis of the rail (Figure 4). Once a high degree of correlation between the hydraulic pressure and strain gages readings had been obtained, the pressure readings were used directly to determine the forces in the rail.

The acoustic response of the rail was first measured by means of an accelerometer attached to the rail (Figure 5). Later, measurements of the response were made with a microphone. During the course of the experiment various portions of the rail were excited, including the head, web and base. The rail was excited at a point located over a tie and over a crib. Similarly, the acoustic response was measured at various locations along the rail section. The measured response of the rail was processed by means of a spectrum analyzer, connected to an x-y plotter which provided a permanent record of the results.

The rail section was excited under both unloaded and loaded conditions, in which the longitudinal forces were varied from about 14 kips to about 200 kips, the higher values being in the range where buckling might occur under high ambient temperature field conditions.

4.0 TEST PLAN AND EXPERIMENTAL TEST SET-UP

Using the test set-up described in the previous Section, five series of tests were conducted, as summarized in Table 1.

The first test series was conducted to determine if the hydraulic loading system (a modified rail puller) in any way affected the reponse of the rail. Since it was planned to use the rail puller system to induce varying forces in the rail during the remainder of the test series, and leave it in place when no force was needed, the first important step was to determine if the presence of the rail puller system had any effect. In order to do this, the rail was excited both with and without the rail pullers attached. No difference in rail response was found, and the rest of the test series was able to proceed.

The second test series was performed to determine the effect of accelerometer mounting arrangements. Different accelerometer mounting positions, e.g., screwed into the rail, or screwed into a plate welded to the rail, and the acoustical response from a nearby microphone yielded basically the same response when tested under identical excitation and measurement conditions.

This test series established that an acceptable way to measure force in a rail with an accelerometer is to mount the accelerometer directly on the rail, and thus avoid any of the potential problems associated with the use of a plate mounting, which provides an additional interface that must be properly secured. In studying the possible effects of the plate, the analysis shown in Appendix A was run, and it is included in order to provide some information about end effects in both the plate and the rail.

The accelerometer mounting involved drilling and tapping a hole in the rail at various locations and then screwing the accelerometer directly into the hole. The accelerometer was frequently checked to be sure that the rail impacts did not loosen it. This method provided good data for any mounting location on the rail.

Using a microphone located about ten inches from the rail, it was found that the microphone's response was essentially the same as that obtained from the rail-mounted accelerometer. This was verified with several different excitation and measurement set-ups. This permitted the test series to proceed using only the microphone, and it was used successfully for the remainder of the test series.

In the third test series the effects of varying the locations of both the excitation and measurement points were investigated. This series determined which of the many combinations of excitation and measurement locations provided the most useful results. As examples, different combinations, such as exciting the rail head on one side and measuring with the accelerometer on the other side, were compared with moving the accelerometer mounting point down to the web. The general conclusion from this test series was that for accelerometer measurements the excitation and measurement locations must be on opposite sides of the rail.

The web and head areas both provided satisfactory excitation points in the laboratory, but the web is preferred for field work because of the basic tie versus crib issue.

The selection of the web as the impact point also solved the problem of exciting a rail with a significant amount of head wear.

When a microphone is used, it should be on the opposite side of the rail's excitation point and located at some distance from the rail (e.g., about 10 inches). Time did not permit additional investigations of the relationships between the measured response and microphone positions and/or directivity.

In summary, up to this point the test series had established a successful methodology for measuring forces in rail, which included the following considerations:

(1) The use of a hydraulic rail puller system will not influence the force measurements;

(2) The force measurements should be made on opposite sides of the rail web;

(3) A microphone can be successfully substituted for an accelerometer, thus providing a more convenient measurement technique, and

(4) The microphone should be positioned at approximately a right angle to the rail web.

A fourth test series was done to determine measurement repeatability, and consisted of exciting the rail four separate times at various internal force levels, making graphical traces of the averaged output at each force level and overlaying them. Good agreement was found among the overlays, and it was concluded that repeatability of the tests was very good. As an example, Figure 6 illustrates the differences among two separate groups of four spectral averages at 500 psi and taken at two different times. These differences consist mainly of the relative amplitude differences of two spectral lines at 3240 Hz. and 6700 Hz., with relative amplitude differences of 1.5 and 1.0, respectively.

A fifth test series was conducted to obtain a quantitative measurement of the differences in rail response spectra between 7000 and 500 psi, which correspond to 192,500 and 13,750 lbs. of internal rail force, respectively. Typical spectra are shown in Figure 7. The results of this test series showed that a considerable amplitude shift occurs, which appears to be rail-force related. Figure 8 shows the spectrum for a 500 psi loading and the difference spectrum between a 7000 and a 500 psi loading. Figure 9 shows the difference of 4 spectral averages at 7000 psi and 4 spectral averages at 500 psi. (In the latter case, it is important to keep the 7000 psi level very constant, otherwise measurement deviations seem to occur. However, this should be the subject of a further investigation). The third graph in this Figure is 500 psi spectrum. It can be seen that there is a significant shift in the relative response amplitudes as a function of internal rail force level. This same general pattern was also obtained with the acoustical measurements, although the spectral envelopes were somewhat different.

The output was also plotted on a linear scale, as opposed to the log scale, used previously. Figure 10 (traced from the original data) gives a composite reproduction of these spectra. On the expanded scale of 1-5 KHz., one can notice the variations shown in Table 2.

In order to identify a force level, one has to examine several spectral lines, and it appears that they experience a gradual frequency shift as a function of force level. The greatest amplitude shifts, however, occurred in the 1 to 10 KHz. range, and this area needs additional work.

5.0 CONCLUSIONS

The tests performed at the AAR's Track Laboratory resulted in the following conclusions.

1. The phenonomenon of a rail's acoustical response variation with changes in internal force levels can be measured by the impulse excitation method, using an accelerometer and/or a microphone, and the results are reproducible for a given rail section. In these tests the rail end effects appeared to be negligibly small.
2. The internal rail force has a marked effect upon the acoustical response. Preliminary data has shown that the results obtained by use of an accelerometer or a microphone displayed similar variations. It also appears likely that bands of force levels can be measured by examining the response of a rail to impulse excitations.
3. These tests were performed on a 136 RE rail section. It is conceivable that the response pattern is characteristic for each

rail type, and that for field determinations of rail force patterns, the appropriate data must be available for comparison.

6.0 REFERENCES

1. Zarembski, A. M., "On the Nondestructive In-Track Measurement of Longitudinal Rail Force," Association of American Railroads, Research Report No. R-406, Chicago, Illinois, June 1980.

2. American Railway Engineering Association, Manual For Railway Engineering, Chicago, Illinois, March 28, 1979.

3. U. S. Department of Transportation/Federal Railroad Administration, "Nondestructive Techniques for Measuring the Longitudinal Force in Rails," Proceedings of the Joint Government-Industry Conference held in Washington, D. C. on February 26-27, 1979, Draft Report, April, 1980.

4. Lusignea, R., Prahl, F. And Maser, K., "The Effect of Axial Load on the Flexural Dynamic Response of a Rail," Foster-Miller Associates, Inc., Waltham, Mass., Ibid, pp. 88-116.

Table 1. Test Plan Summary

Test Series	Purpose	Longitudinal Rail Load (psi)	Measurement Taken by
1	Evaluate Influence of Hydraulic Rail Pullers	500 to 7000, In 500 to 1000 psi Increments	Accelerometer Only
2	Study Type of Accelerometer Mounting Arrangement	Same	Accelerometer and Microphone
3	Evaluate Best Excitatation and Measurement Locations	Same	Microphone Only
4	Check Reproducibility of Measurements	500 and 7000 psi only	Same
5	Evaluate Acoustic Response of Rail at Various Longitudinal Force Levels	Same	Same

Table 2

Acoustic Response Frequency Maxima,
For Various Longitudinal Compressive Rail Force Levels

Longitudinal Compressive Rail Force (in psi)	Approximate Frequency Maxima (in KHz.)									
500	1.7	1.9	3.0	3.5				4.7		
3000					3.7	4.1				
5000						4.1	4.3		4.8	
7000						4.1				4.9

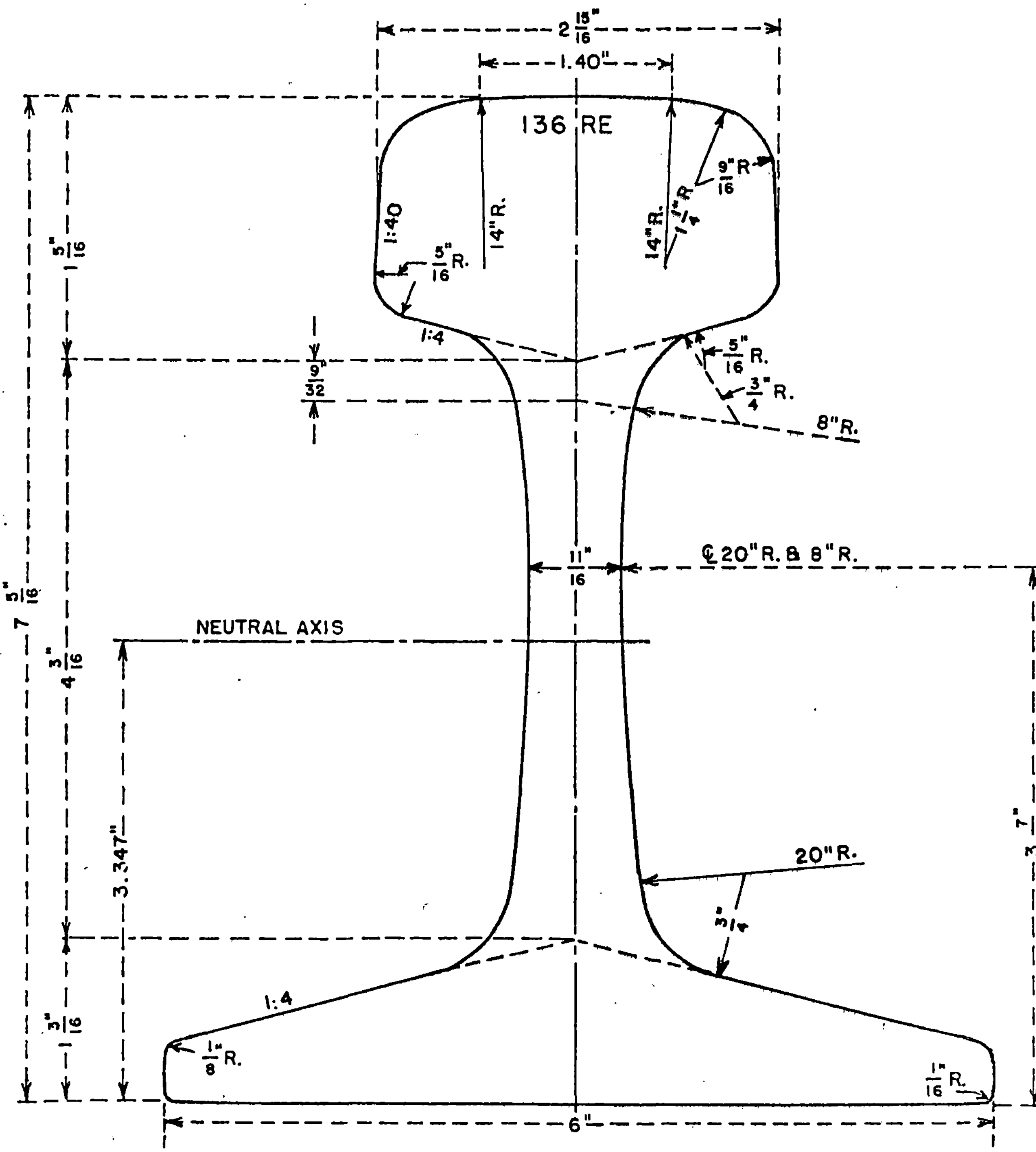


Figure 1. Dimensional Cross Section of 136RE Rail.

Figure 2. Test Apparatus for Measuring the Acoustic Response of a 136RE Test Rail Section From Impact Excitations.

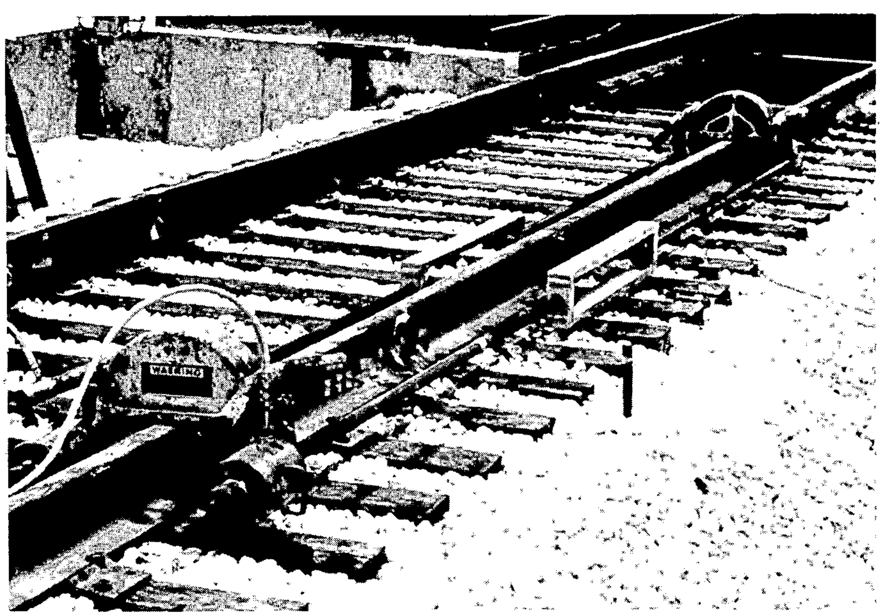


Figure 3. Hydraulic Jacks (Rail Pullers) for Applying Longitudinal Compressive Forces in a 136RE Test Rail Section.

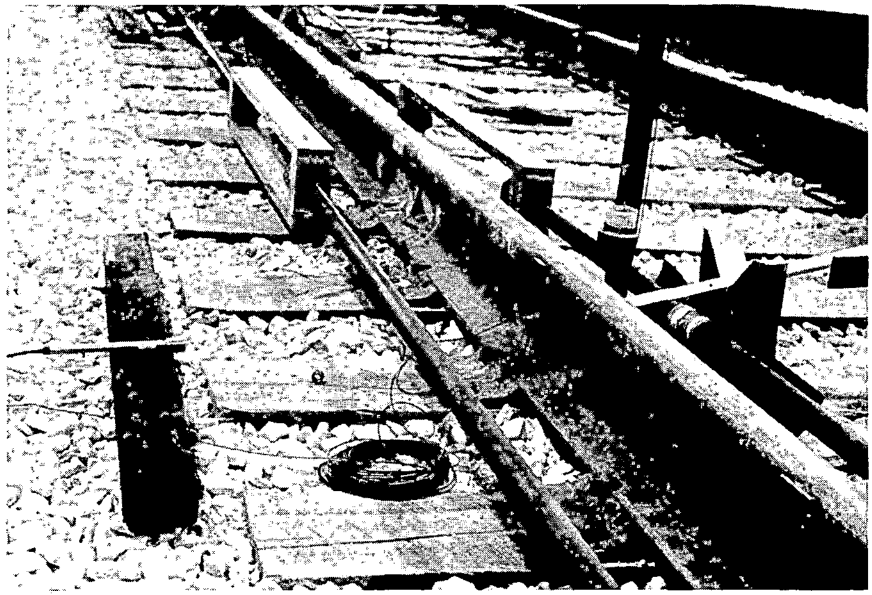


Figure 4. Typical Strain Gage Installation on a 136RE Test Rail Section for Measuring Longitudinal Compressive Forces.

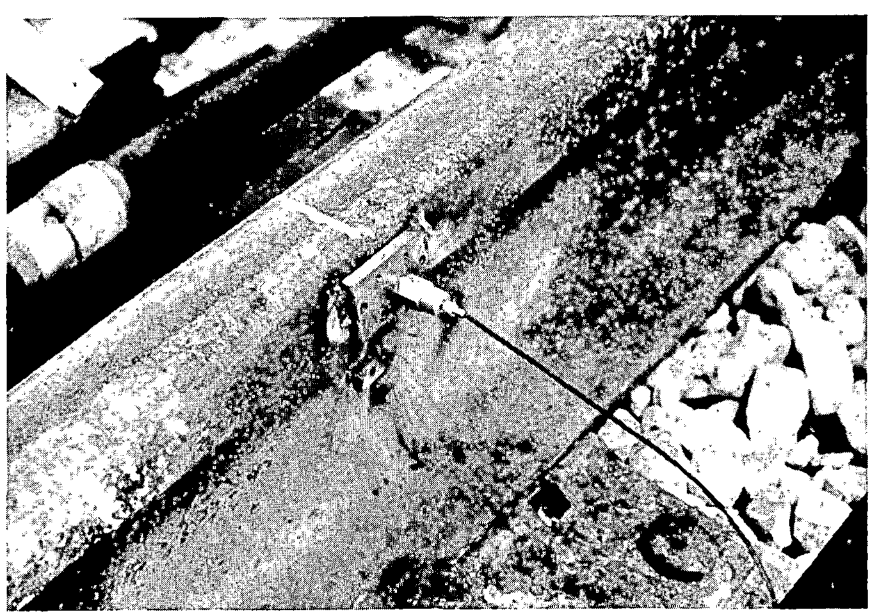


Figure 5. Typical Accelerometer Installation on a 136RE Test Rail for Measuring the Acoustic Responses to Impact Excitations.

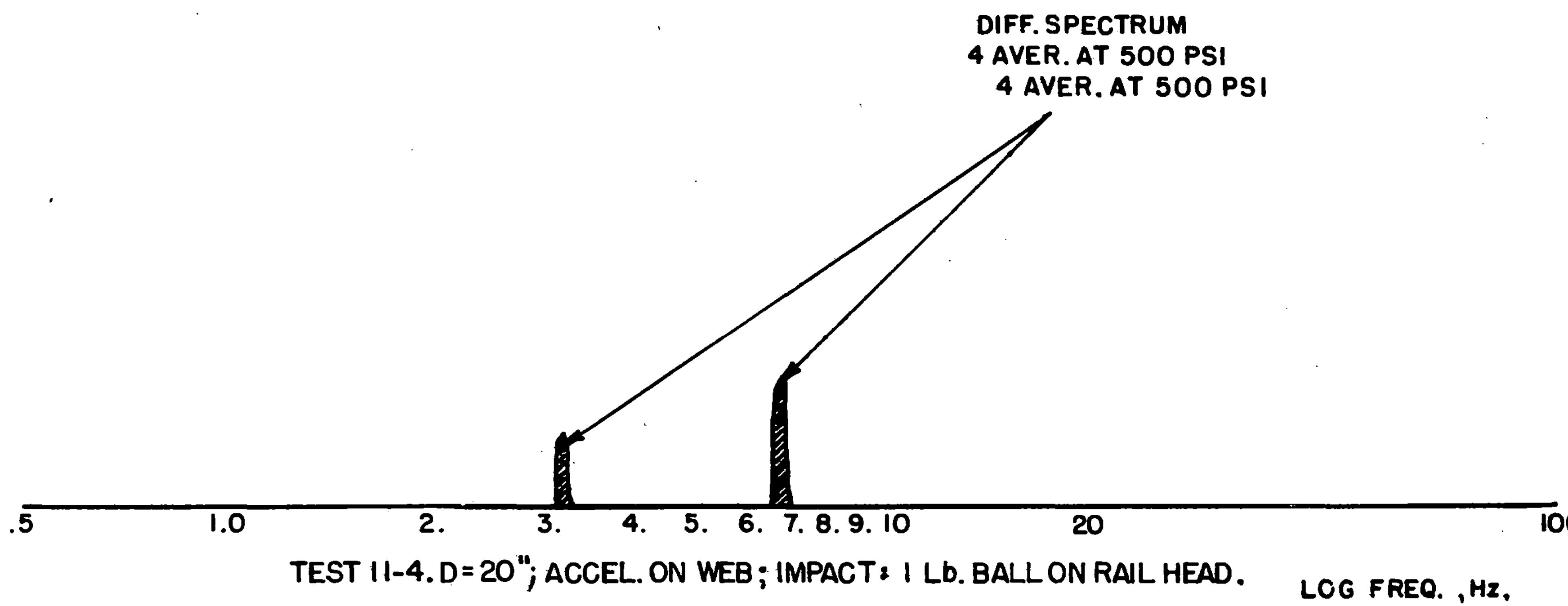


Figure 6. Typical Acoustic Response Spectra From Impact Excitations of 136RE Test Rail Section at 500 psi Longitudinal Compressive Rail Force. Overlay Shows Differences Among Two Separate Groups of Four Spectral Averages, Taken at Different Times.

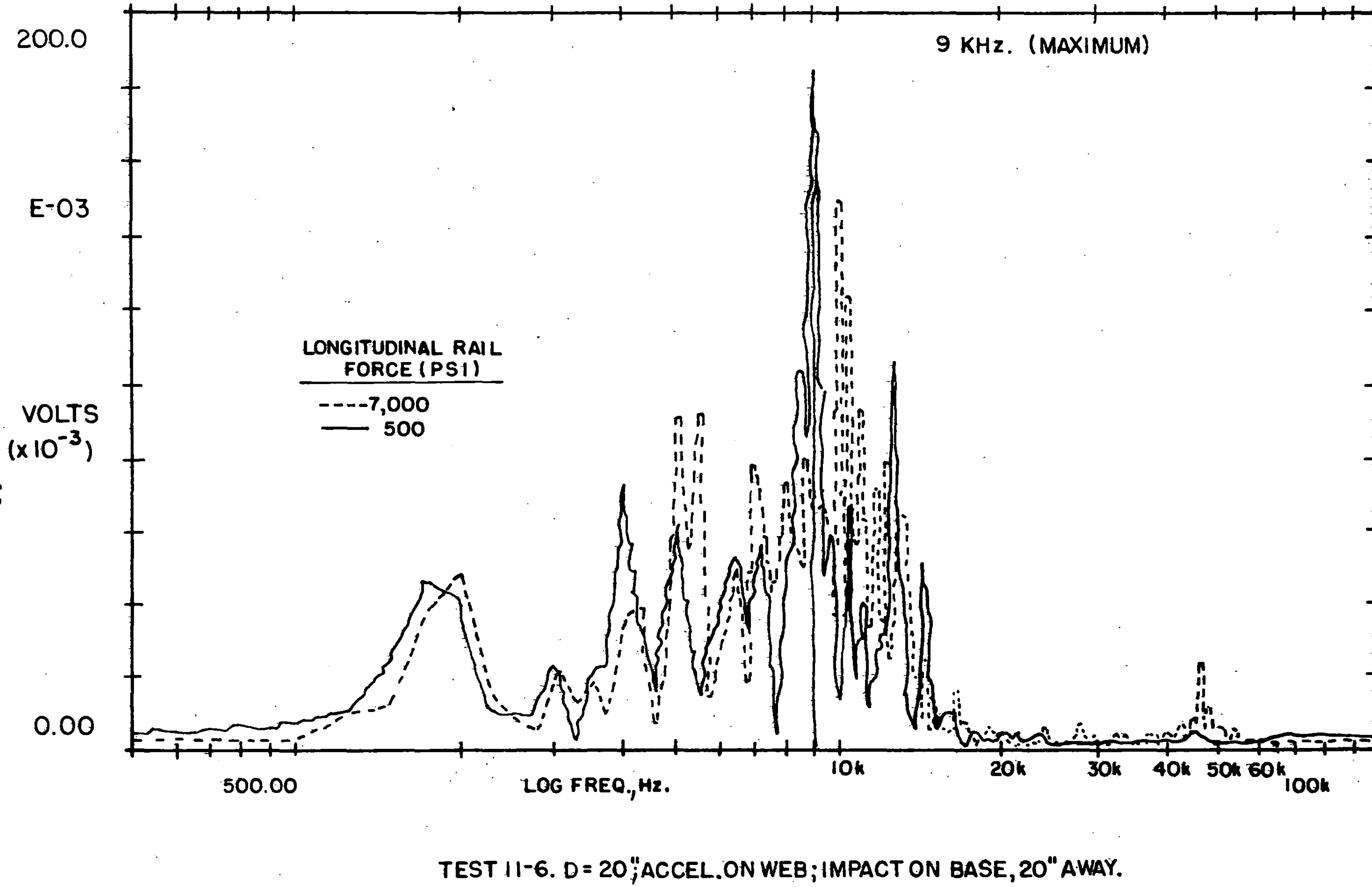
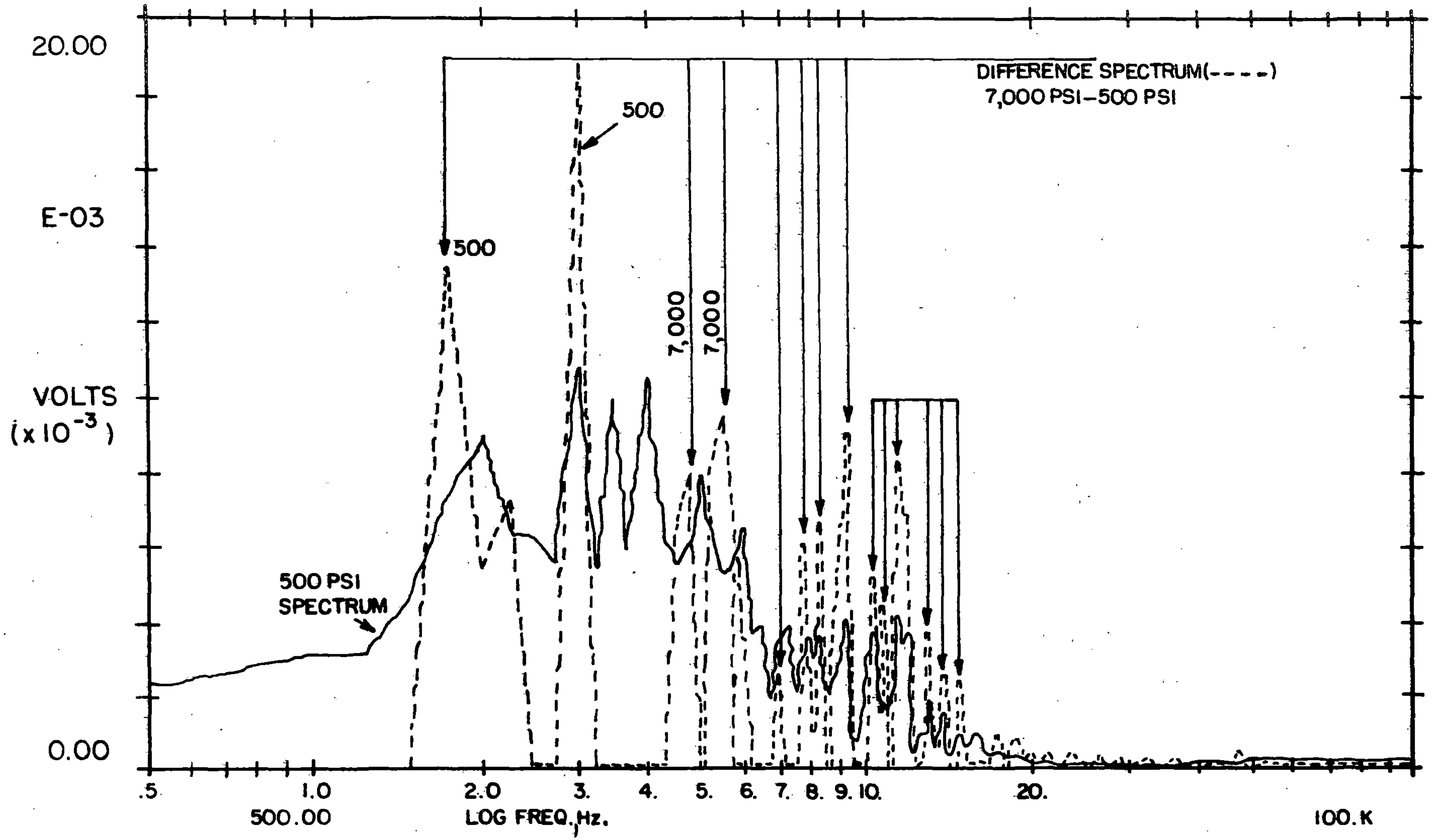


Figure 7. Typical Acoustic Response Spectra From Impact Excitations of 136 RE Test Rail Section. Curves Shown for 500 and 7000 psi Longitudinal Compressive Rail Forces.



TEST 11-4. D= 20"; ACCEL. ON WEB; IMPACT: 1 Lb. BALL ON RAILHEAD.

Figure 8. Acoustic Response Spectra From Impact Excitations of 136RE Test Rail Section. Curves for 500 psi Longitudinal Compressive Rail Force Compared with the Difference Curves for 500 and 7000 psi Longitudinal Compressive Rail Forces.

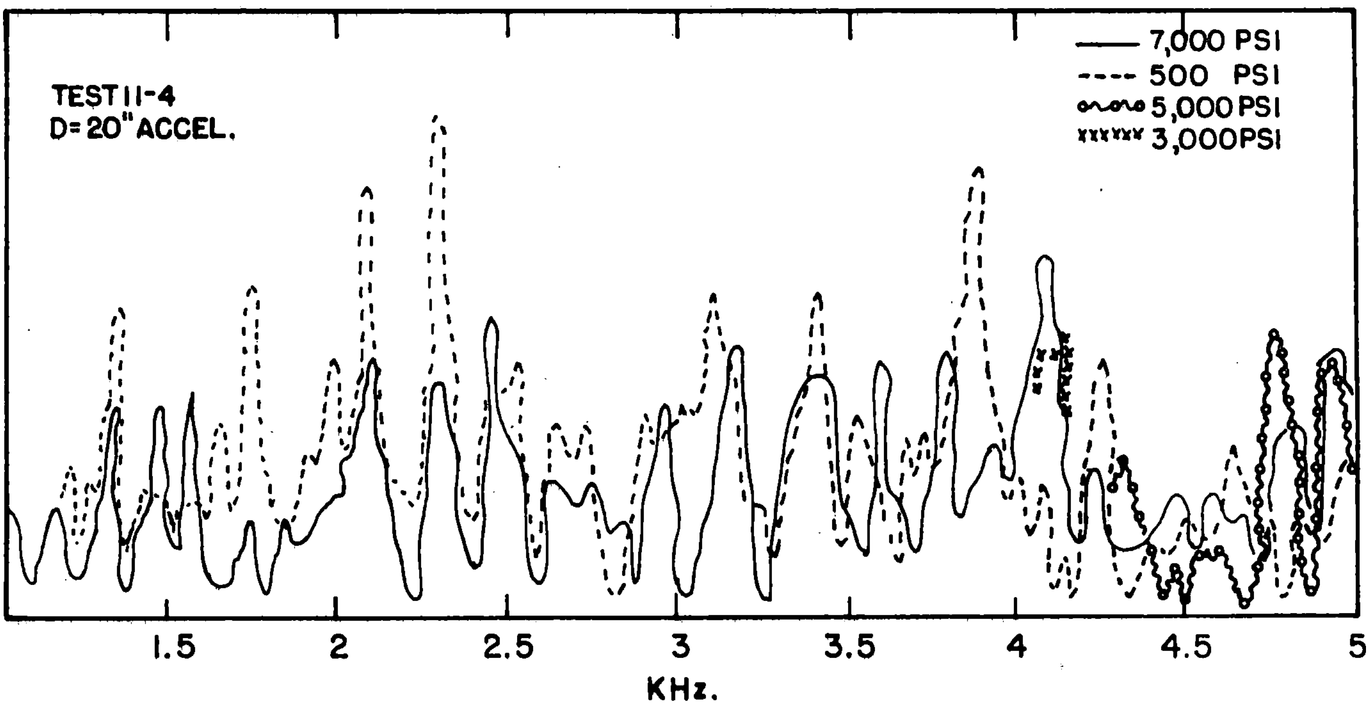


Figure 9. Acoustic Response Spectra from Impact Excitations of 136 RE Test Rail Section. Curves Shown for 500, 3000, 5000 and 7000 psi Longitudinal Compressive Rail Forces.

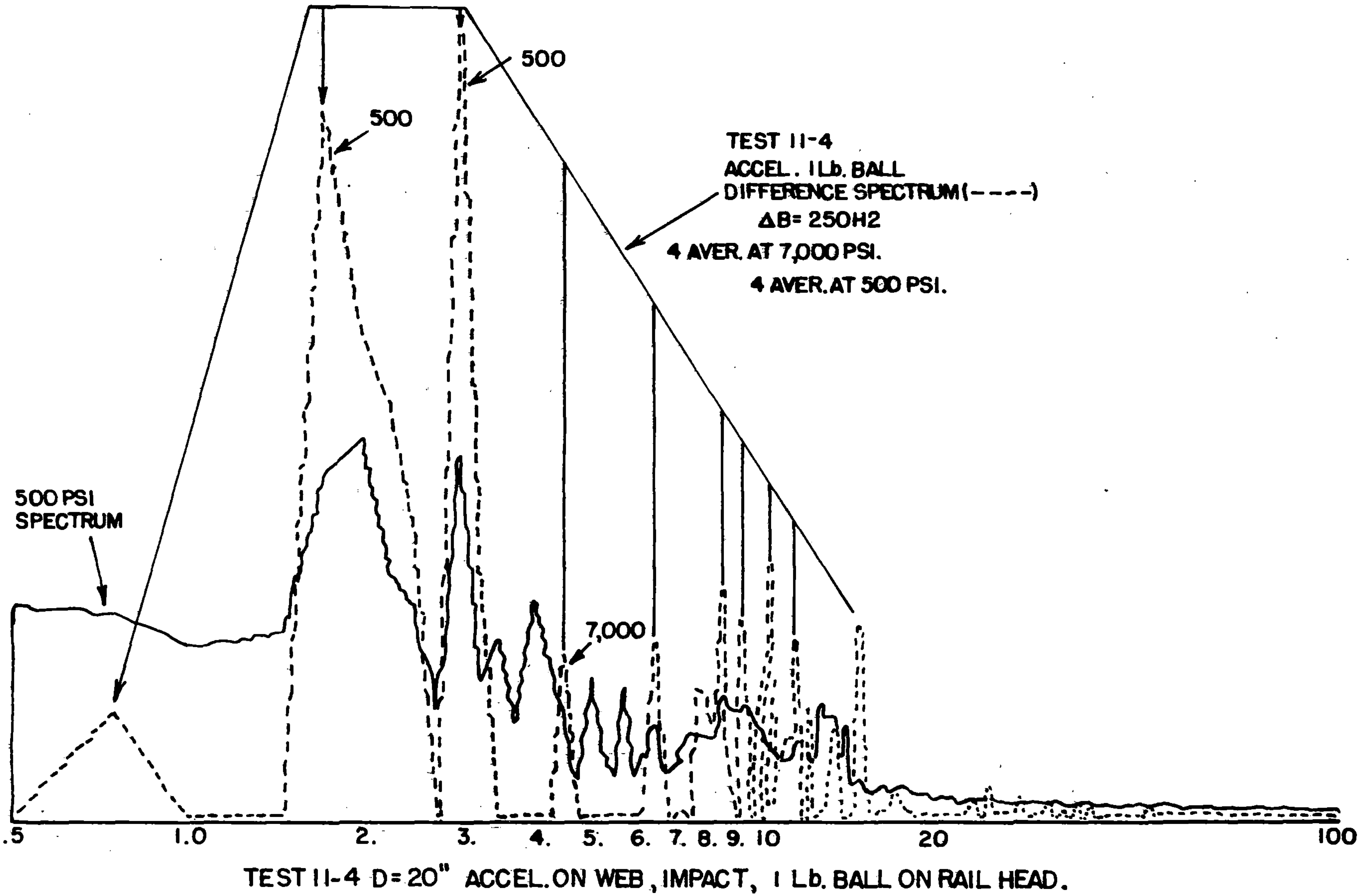


Figure 10. Typical Acoustic Response Spectra From Impact Excitations of 136RE Test Rail Section at 500 and 7000 psi Longitudinal Compressive Rail Forces.

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