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RAILROAD CAR COUPLING SHOCK, VERTICAL MOTION, AND ROLLER BEARING TEMPERATURE

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16. Abstract

Data were collected in a study of railroad car operating environment. Measurements were made on wheel bearing operating temperatures, coupling impact shock, and vertical motion of the car due to rail travel. Tests were conducted using an instrumented consist at the Transportation Test Center (TTC) at Pueblo, CO, in July and August 1976.

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PREFACE

The work described in this report was performed under the Rail Equipment Safety Program for the Office of Rail Safety Research as part of the Federal Railroad Administration's program to improve safety in railroad operations.

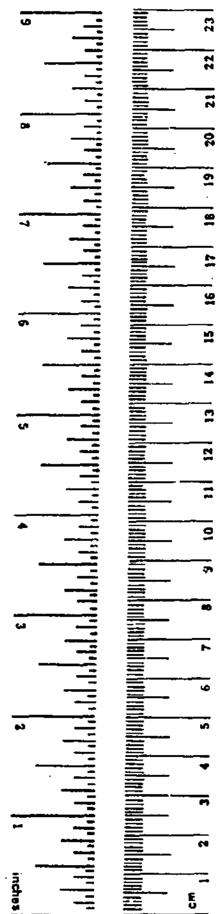
The report contains results of an operating environment measurement program undertaken by the Naval Surface Weapons Center (NSWC) to evaluate the reliability of the Department of Transportation System for Train Accident Reducti (DOT-STAR). DOT-STAR is a railroad safety system which is under development NSWC to stop a train in the event of an overheated bearing or a local derailment. Three aspects of operating environments were measured: operating temp atures of the roller bearings, shock on the car due to coupling impact, and vertical motion of the car due to travel over the rails. This program was conducted in conjunction with the Accelerated Life Tests (ALT) for thermal protection of tank cars.

Tests were conducted using the instrumented consist for ALT at the DOT Transp tation Test Center (TTC) Pueblo, CO. The report discusses the reasons for making these measurements and how each of the measurements was made. The results of these measurements and the conclusions drawn from them are given.

METRIC CONVERSION FACTORS

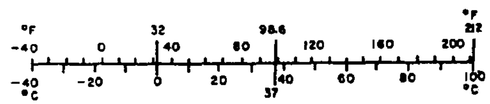
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ILLUSTRATIONS

EXECUTIVE SUMMARY

The work described in this report was performed under the Rail Equipment Safety Program for the Office of Rail Safety Research as part of the Federal Railroad Administration's program to improve safety in railroad operations.

The report contains results of an operating environment measurement program undertaken by the Naval Surface Weapons Center (NSWC) to evaluate the reliability of the Department of Transportation System for Train Accident Reduction (DOT-STAR). DOT-STAR is a railroad safety system developed by NSWC to stop a train in the event of an overheated bearing or a local derailment. Three aspects of the operating environments were measured: temperatures of the tank car roller bearings, the shock on the car due to coupling impact, and vertical motion of the car due to travel over the rails. This program was conducted in conjunction with the Accelerated Life Tests (ALT) of the thermal protection of the railroad tank cars.

Tests were conducted using the instrumented consist for ALT at the Transportation Test Center (TTC) in Pueblo, CO. The report discusses the reasons for making these measurements and the conclusions drawn from them. The roller bearing operating temperature measurements were made:

a) To determine the normal operating temperature of railroad roller

b) To determine if the normal operating temperatures of the roller bearing at high ambient temperatures are sufficient to cause a false alarm of the DOT-STAR hot bearing sensor.

The coupling impact shock environment of the tank car was determined:

To measure the vertical shock (direction of DOT-STAR derailment sensor sensitivity) induced by coupling impact to find if coupling impact represents a false alarm threat to the DOT-STAR derailment sensor.

Vertical motion of the car was measured:

1) To compare the condition of the test track at TTC with revenue-service railroad mainlines.

2) To determine if travel over the normal test loop causes DOT-STAR derailment sensor false alarms.

3) To determine if the shims or track perturbations causes DOT-STAR derailment sensor false alarms.

4) To determine what shim height is necessary to cause sideframe stresses equivalent to those experienced on railroads.

Detailed data can be found in the four appendices. The following is a summary of the test results and conclusions:

A. Thermal

Roller bearing adapters operate approximately 70°F (38C°)[*A] above ambient conditions.

There is a large convective heat loss as heat is transferred from the bearing adapter to the DOT-STAR thermal sensor.

Even under extreme ambient conditions, a normally operating roller bearing does not cause DOT-STAR thermal sensor false alarms.

B. Coupling Impact (Horizontal Shock)

Maximum coupling impact shocks were measured as 100 g, 12 fps (3.65 m/s) at the coupler and 70 g, 8 fps (2.43 m/s) on the sideframe.

Coupling impact did not cause a false actuation of the DOT-STAR derailment sensor.

C. Car Vertical Motion

At no time did the vertical acceleration of either the sideframe or the end sill exceed 20 g.

In no instance did the vertical velocity of the sideframe or end sill exceed 1.5 fps (0.46 m/s).

In no instance did the vertical displacement of the sideframe or end sill exceed 1.0 in. (2.54 cm).

[A*] In this report, absolute temperature is given in °F(°C), relative temperature in F°(C°).

Nothing was measured which would cause a false alarm of the DOT-STAR derailment sensor.

These conclusions are based on test results conducted on the TTC track, which is in much better condition than mainline rail.

1. INTRODUCTION AND BACKGROUND

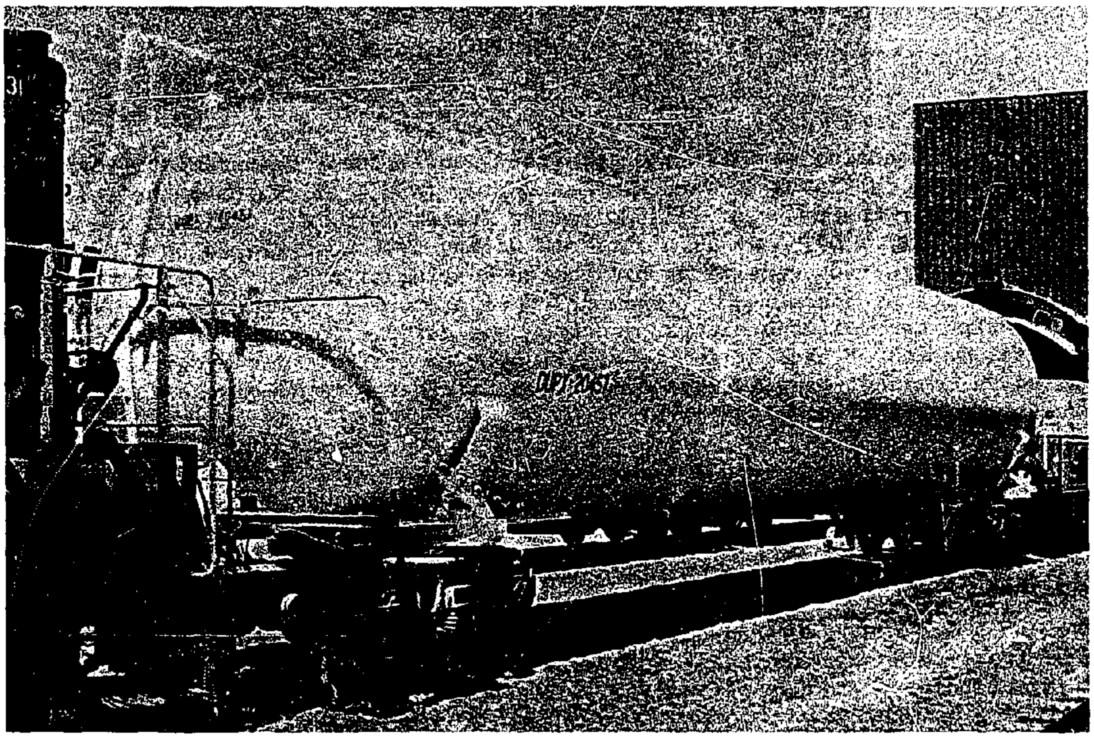
This report contains results of an operating environment measurement program undertaken by the Naval Surface Weapons Center (NSWC) to evaluate the reliability of the Department of Transportation System for Train Accident Reduction (DOT-STAR). DOT-STAR is a railroad safety system developed by NSWC to stop a train in the event of an overheated bearing or a local derailment. Three aspects of operating environments were measured: operating temperatures of the tank car roller bearings, shock on the car due to coupling impact, and vertical motion of the car due to travel over the rails. The program was conducted in conjunction with the Accelerated Life Tests (ALT) of the thermal protection of railroad tank cars.

The report will discuss the reasons for making these measurements and how each of the measurements was made. The results of these measurements and the conclusions which can be drawn from them will be given. For the convenience of the reader, only the most significant results will be discussed in the text of this report. Detailed data can be found in the four appendixes.

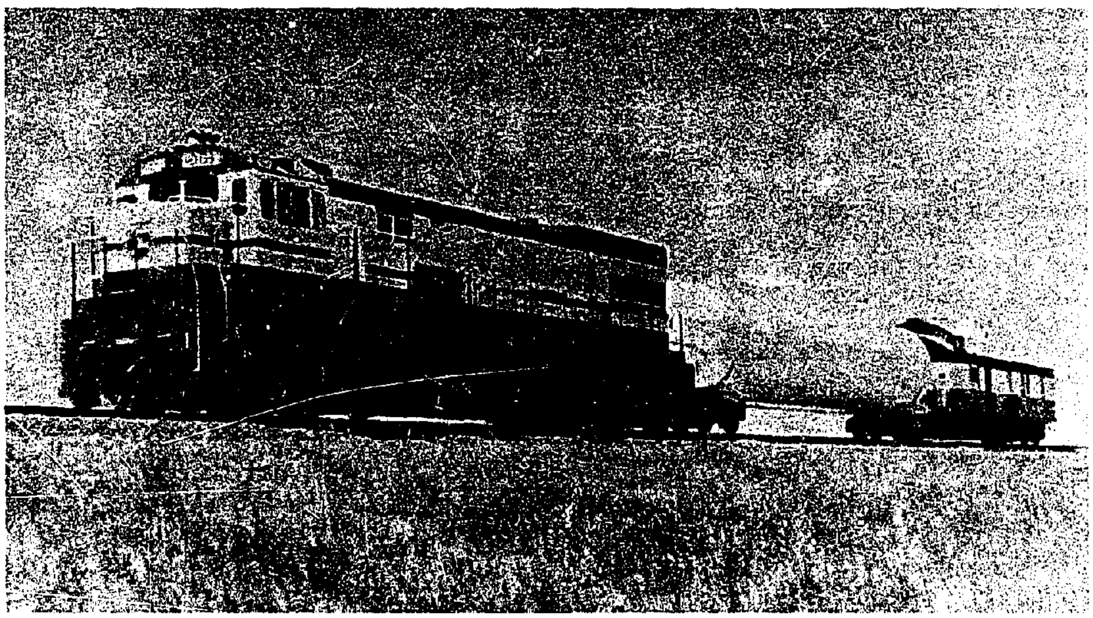
The ALT program attempts to compress the ten year operating service life of a railroad tank car into one year to evaluate the several different types of fire-retardant coatings applied to the tankage sections of the car. By agreement between the Transportation Systems Center (TSC) and NSWC, a subordinate objective of the ALT program is to evaluate the reliability of the Department of Transportation System for Train Accident Reduction (DOT-STAR). DOT-STAR is a railroad safety system developed by NSWC to stop a train in the event of an over-heated bearing or a local derailment. Some of the data taken during this environmental measurement program was used to support the DOT-STAR tests.

The tank car instrumented for this measurement program was car DUPX 20457 shown in Figure 1. This car is a type 112A tank car. The car has a light weight (unloaded) of 91,200 lbs. (41,450 kg) and a capacity of 33,622 gallons (127,620 liters). This car was equipped with a Dupont design HM 109[1] head shield. The car had a spray coated fire retardent coating 150 mils (3.81 mm) thick. For all of the measurements made during this program, except the empty coupling impact shocks, the test car was loaded with approximately 20,000 gallons (75,600 liters) of water for a gross track weight of 260,000 lbs. (118,200 kg).

[1]Head shield is part of a tank car designed to protect the tank from rupture due to being struck by the coupler of another car.



INSTRUMENTED TANK CAR DUPX 20457



TYPICAL CONSIST USED FOR ALT PROGRAM ENVIRONMENTAL MEASUREMENTS

FIGURE 1 TEST CAR AND TEST CONSIST

The test consist used for most of the measurements made during this program is shown in Figure 1. The test tank car, instrumented with measurement transducers, was sandwiched between the powering locomotive and a dynomometer car (dyno car). The dyno car housed the transducer signal conditioning and recording electronics.

2. ROLLER BEARING OPERATING TEMPERATURE MEASUREMENTS

The roller bearing operating temperature measurements were made for the following reasons:

a. To determine the normal operating temperature of railroad roller bearings at a representative train speed.

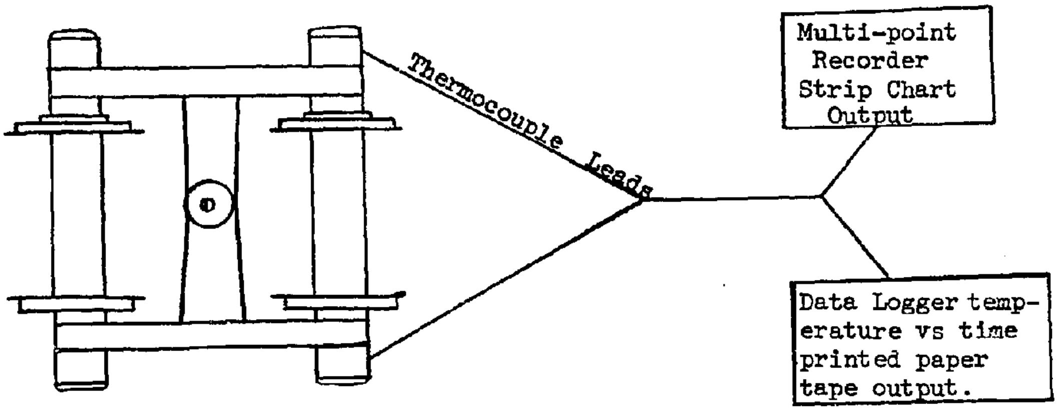
b. To determine if the normal operating temperature of the roller bearings at high ambient temperatures was sufficient to cause a false alarm of the DOT-STAR hot bearing sensor.

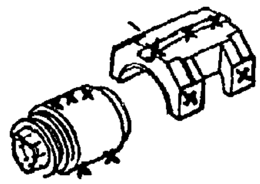
The roller bearing operating temperature measurements were made by instrumenting two roller bearing adapters with 10 thermocouples each. The thermocouples were special type k thermocouples with high temperature insulation, sheathed in a potted steel jacket. These two instrumented adapters were installed over the L4 wheel and the R3 wheel bearings of car DUPX 20457. The thermocouple locations and instrumentation set-up for these measurements is shown in Figure 2. Figure 2 also shows an instrumented adapter installed on the car.

The instrumented tank car was pulled around the 14 mile (22.5 km) loop of the Railroad Test Track (RTT) shown in Figure 3. After one loop, the test was interrupted to allow TTC personnel to take films of the consist. This photographic coverage required forty minutes and frequent stops and starts. After the photographic session, the test car was pulled around the RTT at 45 mph (72 km/hr) until the temperatures of the bearings stabilized.

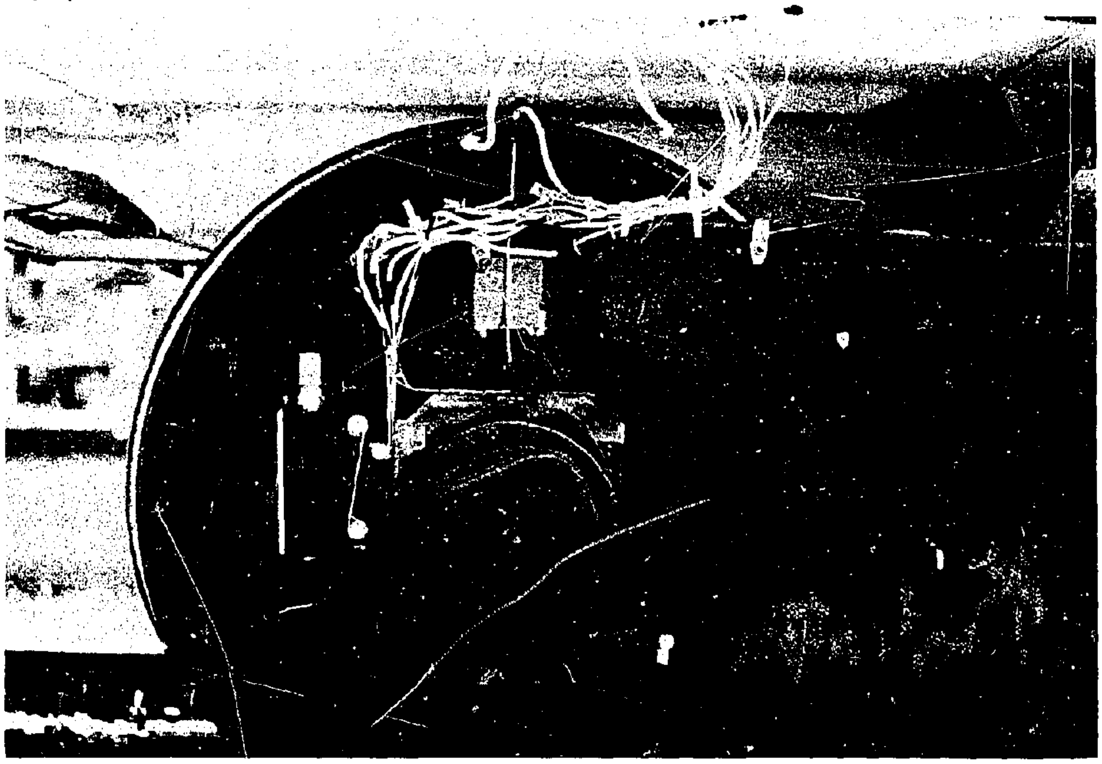
The results of the roller bearing operating temperature measurements will be reported in terms of the three thermocouples on each adapter which reflect the heat transfer path from the bearing to the DOT-STAR thermal sensor. These three thermocouple locations are shown in Figure 4.

Figure 5 is a plot of temperature versus time for these three thermocouple locations on the R3 wheel bearing adapter. Figure 6 is a plot of temperature versus time for these three thermocouple locations on the L4 wheel bearing adapter (L4 and R3 wheels are defined in Figure 8). Figure 6 also has a plot of temperature versus time for a thermocouple installed on the aluminum thermal probe of the DOT-STAR thermal sensor. The reason for the higher starting or ambient temperature of the L4 wheel adapter is that the L or left side of the car was exposed to bright sun all morning before the test.





X - Typical thermocouple locations



INSTRUMENTED BEARING ADAPTER INSTALLED IN SIDEFRAME

FIGURE 2 TEMPERATURE MEASUREMENT INSTRUMENTATION

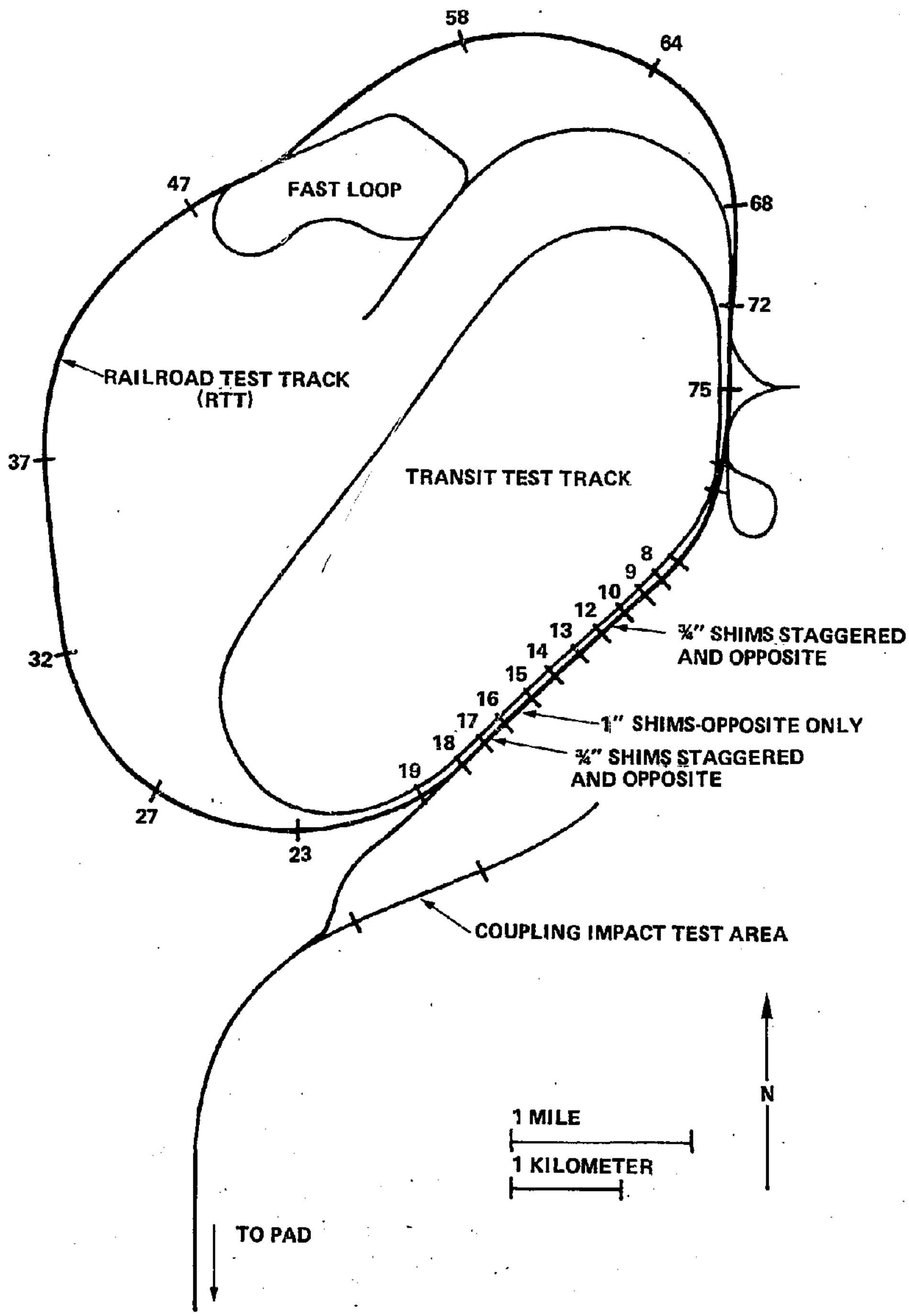


FIGURE 3 TRANSPORTATION TEST CENTER RAILROAD TEST TRACK (RTT) LOOP

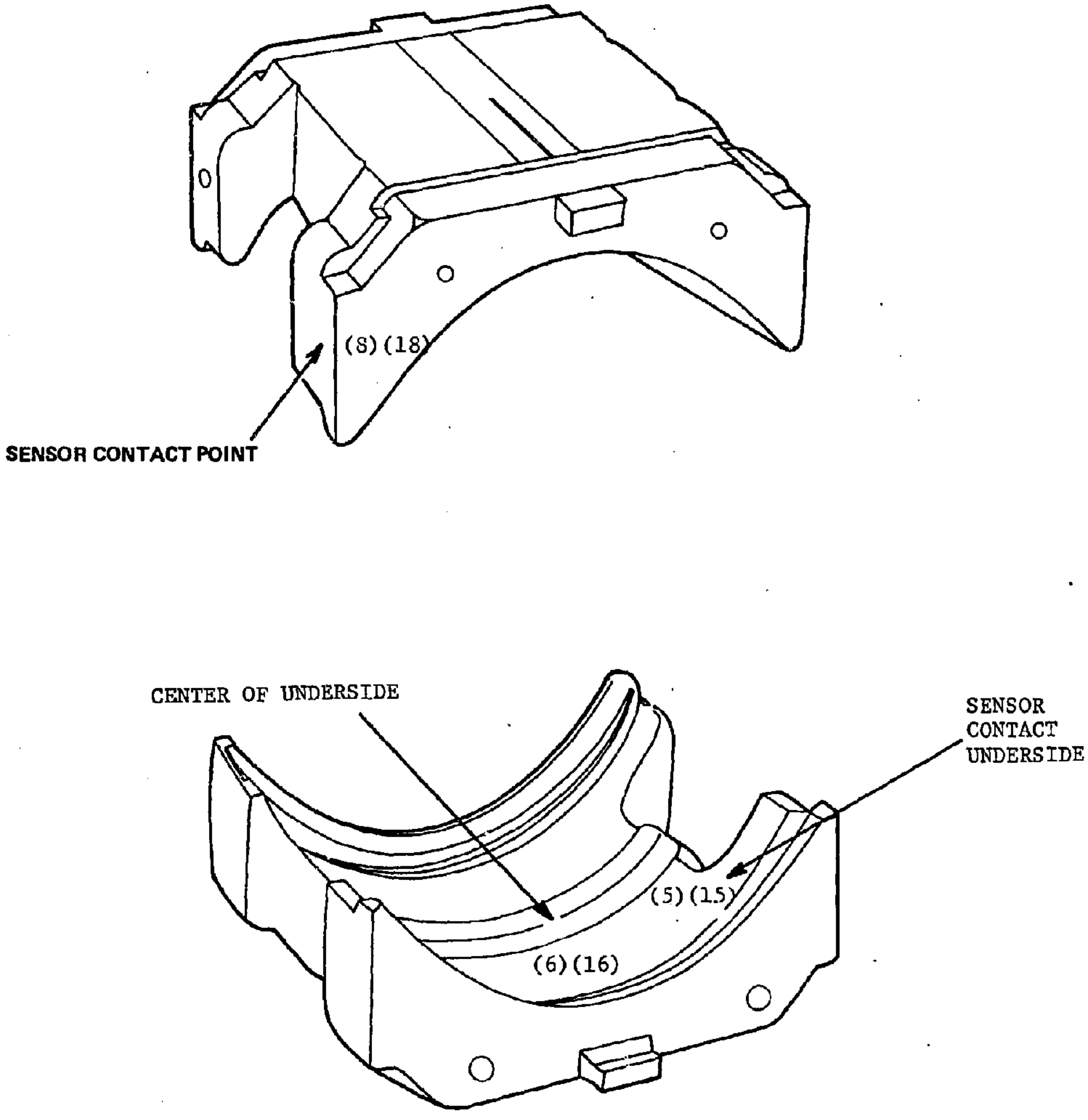


FIGURE 4 BEARING ADAPTER THERMOCOUPLE LOCATIONS

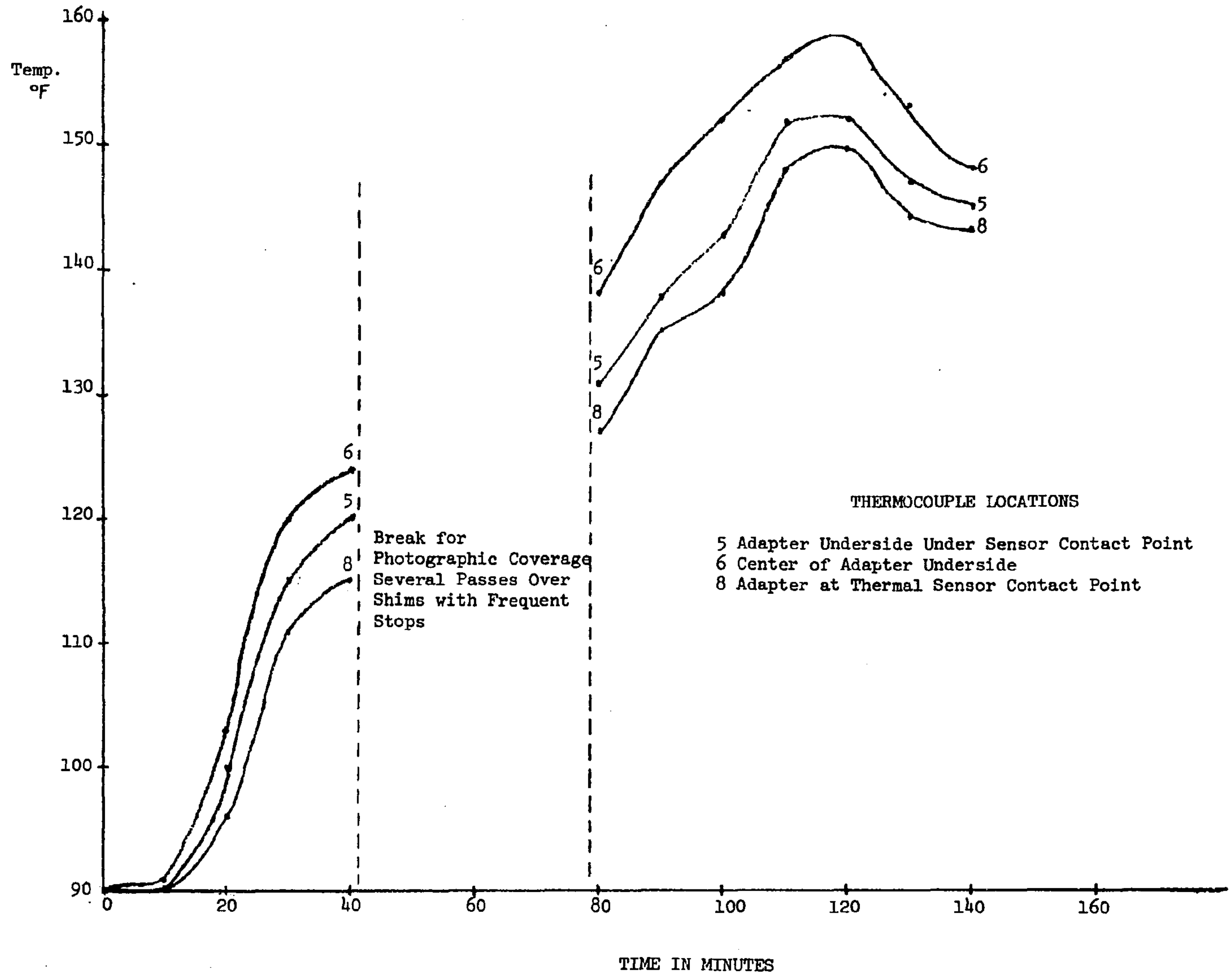


FIGURE 5 ROLLER BEARING OPERATING TEMPERATURES R3 WHEEL ADAPTER

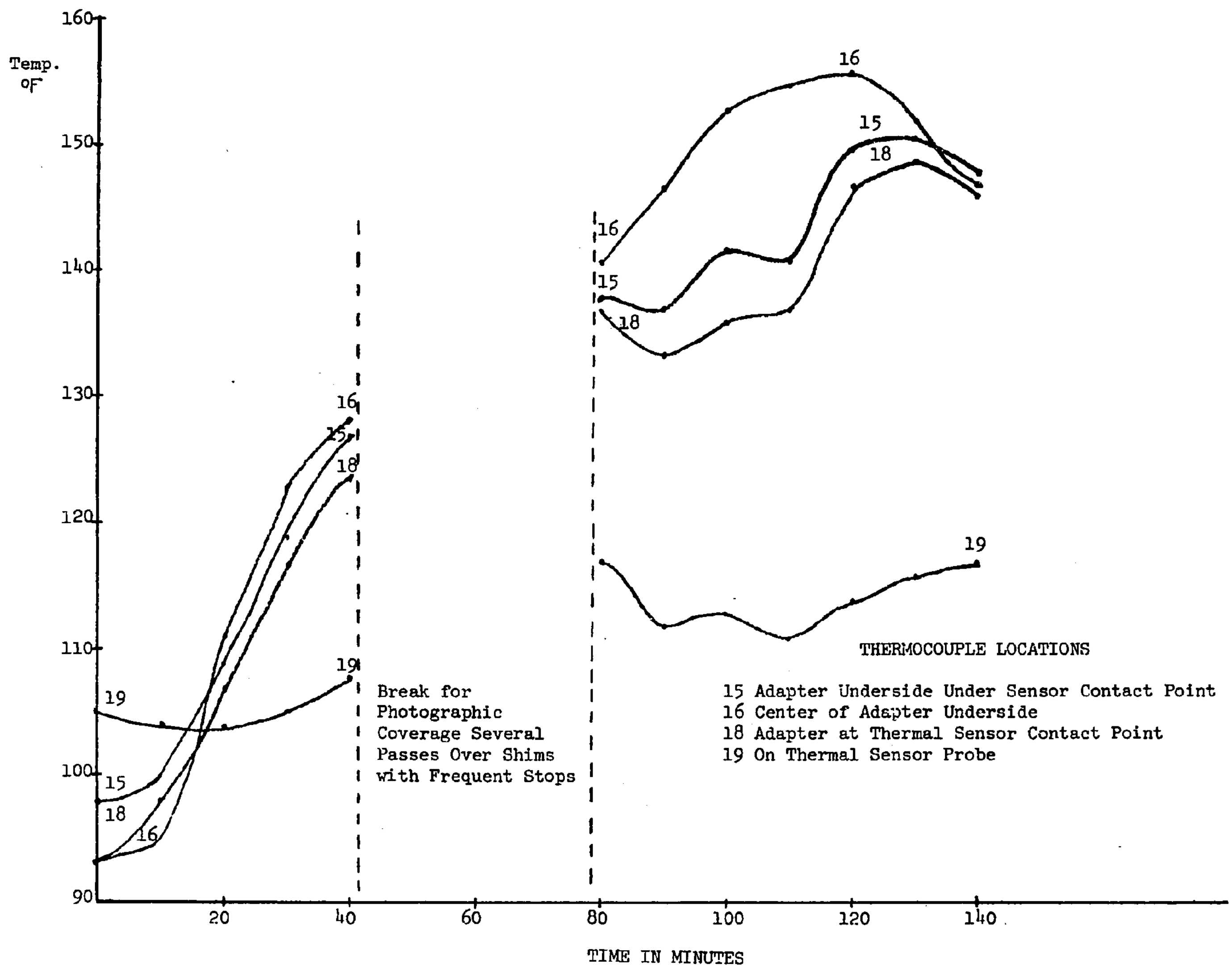


FIGURE 6 ROLLER BEARING OPERATING TEMPERATURES L4 WHEEL ADAPTER

Heat is transferred from the operating roller bearing to the underside of the adapter. The center of the underside of the adapters (points 6, 16) were expected to be the hottest points on the adapters. These points reached a maximum of 159°F (71°C) and 156°F (69°C), respectively. The temperature drops about 6F°(3C°) as heat is transferred to the point (points 5, 15) on the underside of each adapter directly under the DOT-STAR sensor contact point. At these points, the maximum temperatures were respectively 152°F (67°C) and 151°F (66°C). An approximate 2F°(1C°) temperature drop takes place in each adapter as the heat is transferred from the underside of the adapters to the point of DOT-STAR sensor contact on each adapter (points 8, 18). Here the respective maximum temperatures were 150°F (66°C) and 149°F (65°C). Thermocouple #19, measuring the temperature on the aluminum probe of the DOT-STAR sensor in contact with the 34 wheel adapter, measured a maximum temperature of 117°F (47°C).

The reason for the large temperature drop 32F°(18C°) from the sensor contact point on the adapter to the thermal sensor probe is largely due to convection. The thermal sensor probe is exposed to a strong air stream (forced convection) as the train moves.

There was concern that, under very hot ambient temperatures or hot initial temperatures, a normally operating bearing could cause a DOT-STAR hot bearing false alarm. For the measurements taken at TTC, the ambient temperature of the roller bearing adapter was approximately 90°F (32°C). The normal operation of the roller bearing caused a 70F°(21C°) rise in temperature above ambient. One hundred-sixty degrees Fahrenheit (71°C) is widely accepted as the maximum temperature a dark body exposed to intense solar radiation will reach on a hot day. Assuming this, 160°F (71°C) to be a worst case ambient temperature, if the same temperature rise of 70F°(21C°) is experienced, the worst case normal operating temperature will be 230°F (110°C). This temperature would drop to 220°F(105°C) at the DOT-STAR sensor contact point. Due to the strong convective losses, the temperature would further drop to below 200°F (94°C) on the thermal sensor itself. Since the DOT-STAR thermal sensor is set to stop the train when the sensor reaches 250°F (121°C) a normally operating roller bearing should not cause a false alarm of the thermal sensor even under extreme ambient conditions. However, it should be noted that it is not known at this time whether it is accurate to assume that the bearing temperature rise at 45 mph and 90°F (32°C) ambient temperature is applicable at other conditions.

3. COUPLING IMPACT SHOCK MEASUREMENTS

The coupling impact shock environment of the tank car was measured for the following two reasons:

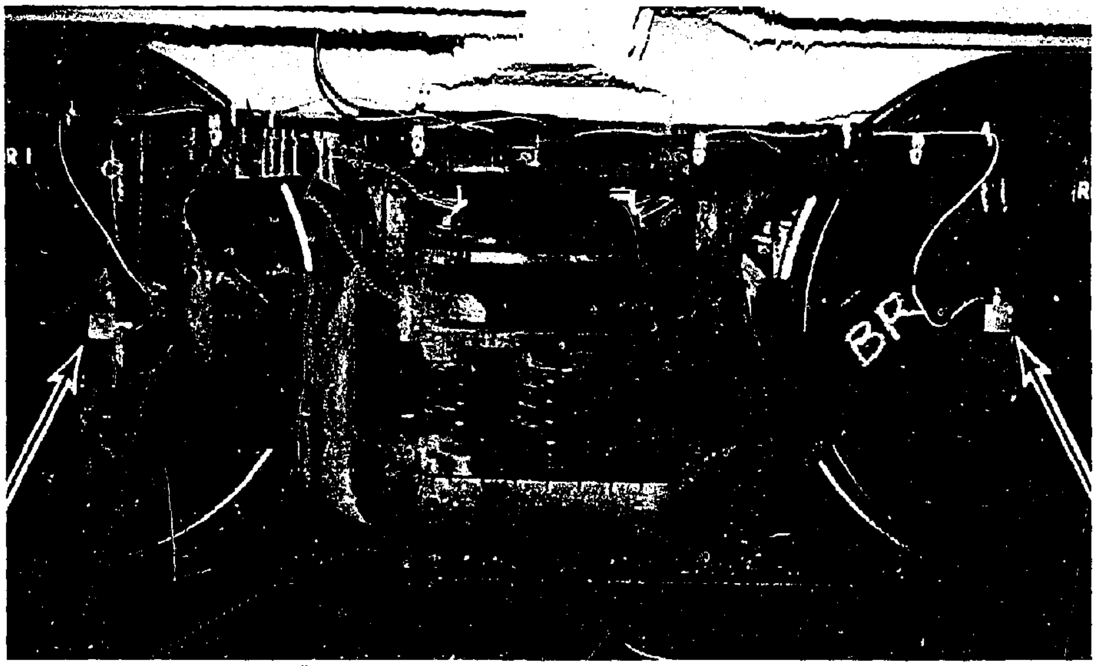
a. To quantitatively define the coupling impact shock for possible future laboratory evaluation of tank car fire retardant coatings.

b. To measure the vertical shock (direction of DOT-STAR derailment sensor sensitivity) induced by coupling impact to determine if coupling impact represents a false alarm threat to the DOT-STAR derailment sensor.

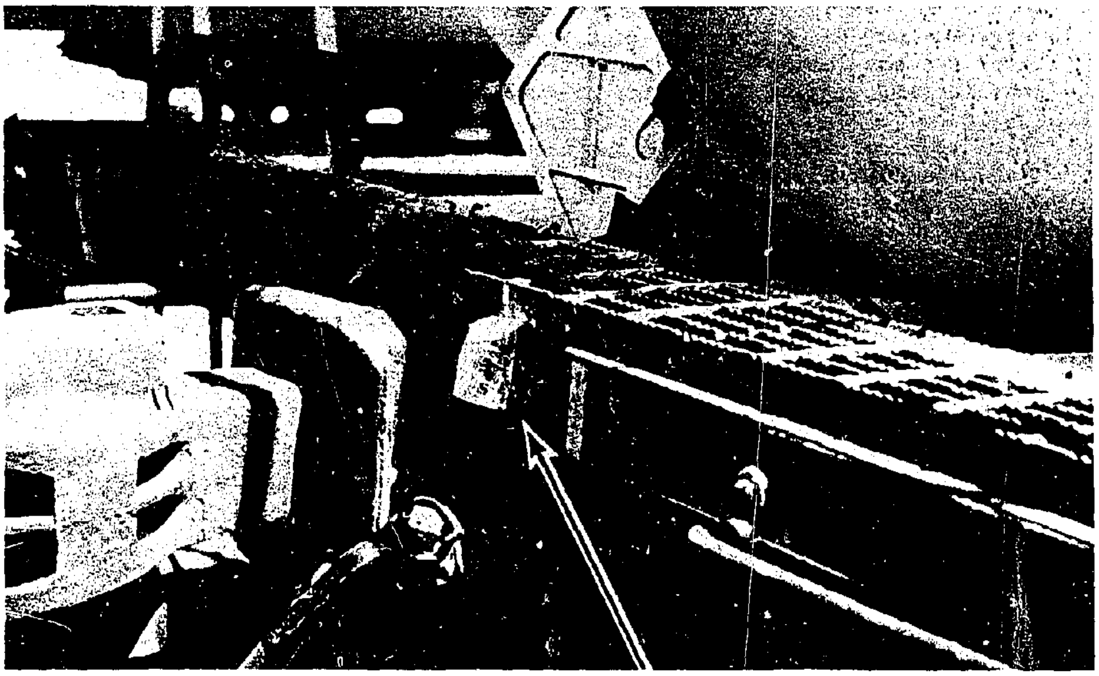
To make the coupling impact shock measurements, the tank car DUPX 20457 was instrumented with six piezoresistive accelerometers. One accelerometer was mounted on each end sill of the car near the coupler. These two accelerometers were mounted in the direction of impact (horizontal). An accelerometer mounted on the car end sill is shown in Figure 7. The other four accelerometers were mounted on the B truck of the tank car. Two accelerometers were mounted on each sideframe of the truck, one accelerometer next to each wheel-bearing assembly. Accelerometers mounted on a sideframe are also shown in Figure 7. Two of the four accelerometers mounted on the sideframe were mounted in the direction of impact, one was mounted vertically and one was mounted horizontally in the direction perpendicular to the direction of impact. A sketch showing all six accelerometer locations is given in Figure 8.

The measurements were taken by amplifying the output of the accelerometers and recording the amplified signal with a magnetic tape recorder operating at 15 inches per second with extended range FM electronics. The amplified accelerometer outputs were also monitored on the spot with a direct writing oscillograph. Voice identification and IRIG-B time code were also recorded on magnetic tape for all the accelerometer measurements. The coupling impact instrumentation set-up inside the dyno car is shown in Figure 8.

The coupling impacts were done by pushing the DUPX 20457 car (hammer) into a backstop of two empty tank cars coupled to two stationary locomotives with their brakes locked (anvil). The dyno car, containing the instrumentation, was coupled to the pushing

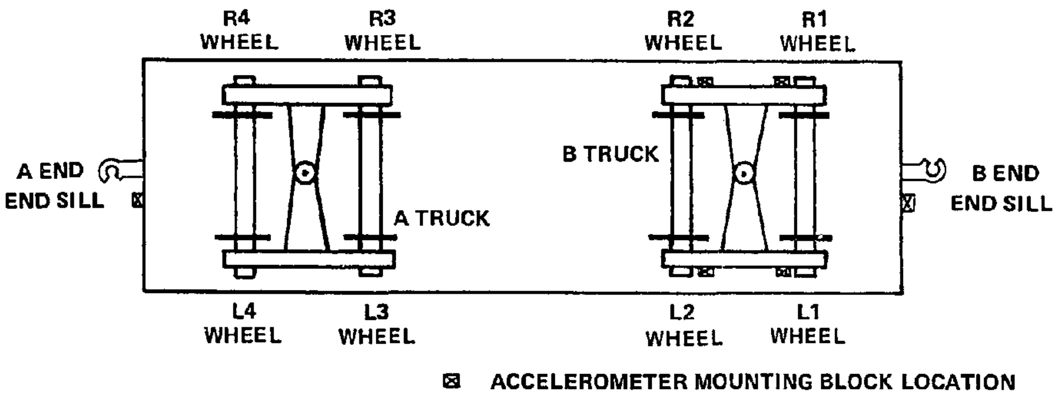


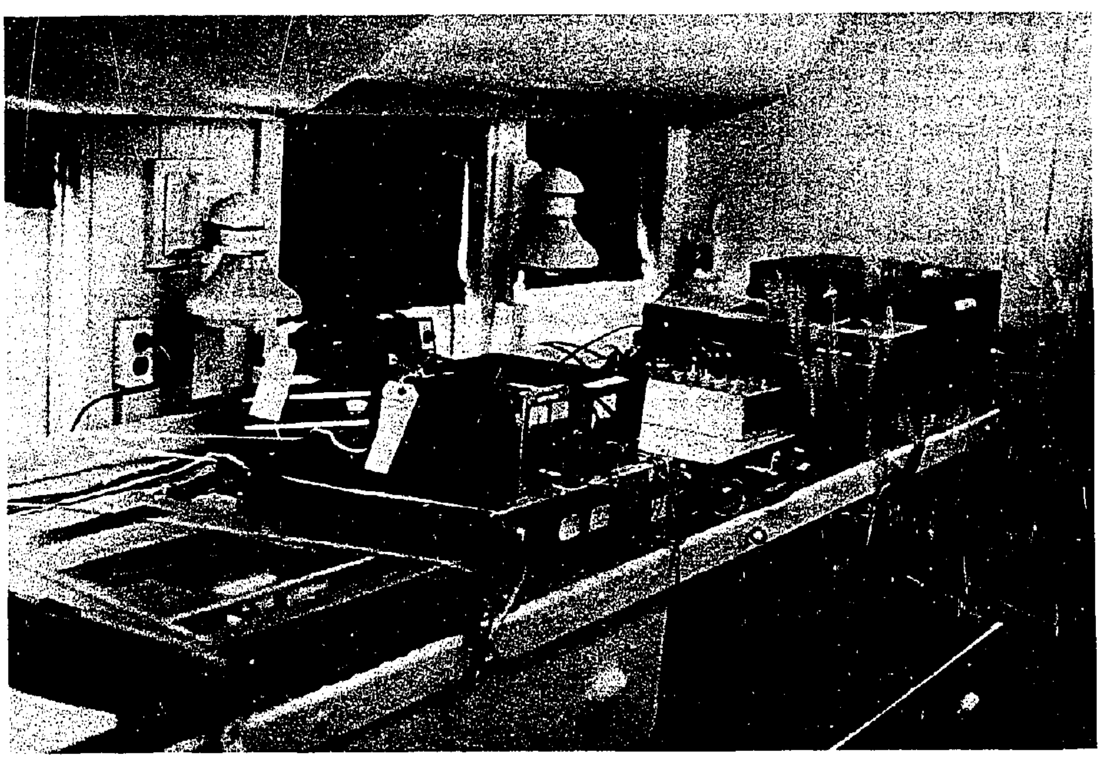
ACCELEROMETERS INSTALLED-SIDEFRAME



ACCELEROMETER INSTALLED ON END SILL

FIGURE 7 ACCELEROMETER LOCATIONS





COUPLING IMPACT AND TRACK CHARACTERIZATION INSTRUMENTATION SET UP INSIDE THE DYNO CAR

FIGURE 8 COUPLING IMPACT AND TRACK CHARACTERIZATION INSTRUMENTATION

locomotive. DUPX 20457 was coupled to the dyno car. When the pushing locomotive got up to the desired speed, DUPX 20457 was uncoupled from the dyno car. As DUPX 20457 continued toward the anvil, the locomotive and dyno car stopped and DUPX 20457 pulled the instrumentation cable from the payout arm on the dyno car (see Figure 9). Coupling impact occurred when DUPX 20457 coupled with the backstop consist.

A total of twenty-six coupling impact shocks were measured. Three of these impacts were with DUPX 20457 loaded and the A-end of DUPX 20457 striking the impact barrier. Eleven impacts were made with the car loaded and the B-end of the car coupling with the barrier. Twelve impacts were made with the car empty and the B-end of the car coupling with the barrier. The impact velocities or striking speeds ranged from 4.5 - 9.5 mph (7.24 - 15.3 km/hr) $\pm$ .1 mph as measured by a state police radar gun.

The data taken during the coupling impact shock tests are summarized in Appendix A. Appendix A is a series of plots of maximum acceleration versus impact speed. Plots were made for both sideframe and end sill accelerometer locations for both full and empty impacts. The plots for loaded impacts are more scattered because the car was fully loaded by weight, but only partially loaded by volume. This created a sloshing effect during the loaded coupling impacts. This slosh caused the coupling impact to be more severe if the slosh was in phase with the impact and less severe if the slosh was out of phase with the impact.

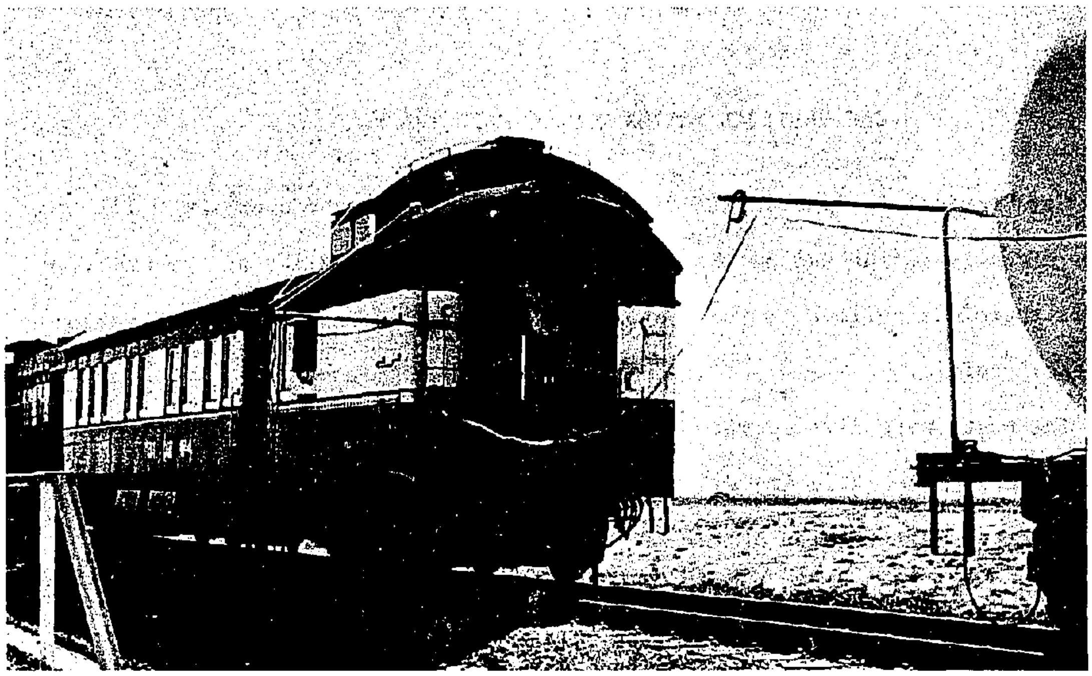
The coupling impact shock as measured showed a maximum acceleration of 100 g and a velocity change of 12 fps (3.65 meters/sec) on the car sill of the end impacting. The maximum levels measured on the sideframe were 70 g with a maximum velocity change of 8 fps (2.43 meters/sec). The shock in the vertical direction (the direction of importance to the DOT-STAR derailment sensor) showed maximum of 25 g and .5 fps (.15 meters/sec). Short duration shocks of this level will not cause false alarms of the derailment sensor.

A sample of impact raw data in its entirety is given in Appendix B. For four typical (low and high speed, loaded and empty) the following is presented for each of the six accelerometer channels:

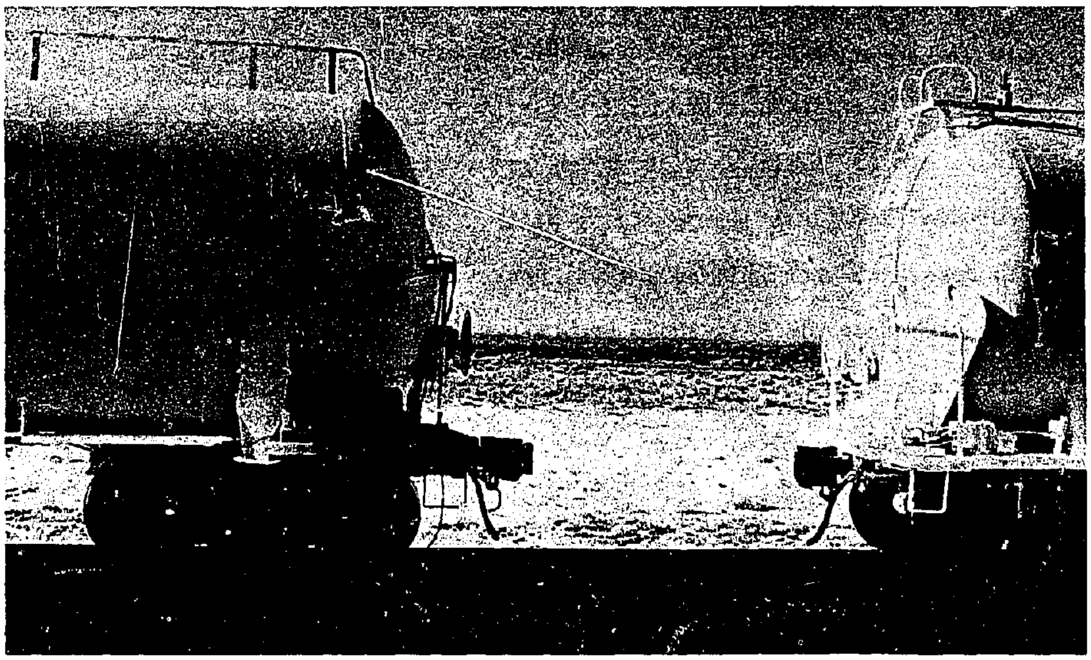
a. Acceleration versus time (unfiltered)

b. Acceleration versus time (filtered at 30 Hz)

c. Velocity Change



INSTRUMENTED CAR PULLING CABLE FROM DYNO CAR



INSTRUMENTED CAR STRIKING IMPACT BARRIER CAR

FIGURE 9 COUPLING IMPACT TEST SEQUENCE

4. CAR VERTICAL MOTION DUE TO RAIL TRAVEL

Car vertical motion results from the passage of the car over the rail. It is directly influenced by the track geometry and the quality of the track, and is therefore defined in this report as a measure of track characterization or track profile.

The tests were divided into two parts: A characterization or profile of the entire 14 mile (22.5 km) RTT test loop shown in Figure 3, and a characterization of a small section of the RTT purposely roughened by forcing metal shims under the tie plates to raise the rails from the ties.

The track characterization tests were done for the following reasons:

a. To compare the condition of the test track at TTC to commercial railroad mainline.

b. To determine if the travel over the normal test loop would cause DOT-STAR derailment sensor false alarms.

c. To determine if the shims or track perturbations would cause DOT-STAR derailment sensor false alarms.

d. To determine what shim height was necessary to cause sideframe stresses equivalent to those experienced on commercial railroads.

The instrumentation for the track characterization tests was the same as for the coupling impact shock tests except the orientations of the accelerometers were changed. The end sill accelerometers in this instance were oriented vertically. Two sideframe accelerometers were oriented vertically. One sideframe accelerometer was mounted horizontally along the track, and one sideframe accelerometer was mounted horizontally, perpendicular to the track.

The tests were conducted by making two loops around the entire test oval at 45 mph (72 km/hr) with the recording equipment running constantly. Several passes were then made over the shimmed portion of the test loop. The details of the shimming arrangement are shown in Figure 10. The shims were placed at 39 ft (11.9 m) rail lengths. The shims were intended to create a rough spot on the track equivalent to an old worn rail joint. The rough spots created were not abrupt discontinuities, they were like half sine pulses on the track.

The entire track characterization data is contained on six reels of magnetic tape of one-half hour playing time each. Some of the more significant acceleration records from these tapes are presented in Appendix C. Figure 11 is a sample of the type of record contained in Appendix C. Figure 11 gives an acceleration record for the most severe track irregularity encountered (other than the shims) on the RTT test loop. Appendix C contains acceleration records for the following cases:

a. Typical smooth track near marker 11

b. Typical smooth track near marker 19

c. Rough track near marker 70

d. Rough track near marker 58

e. Switch near marker 5

f. One inch shims at 45 mph

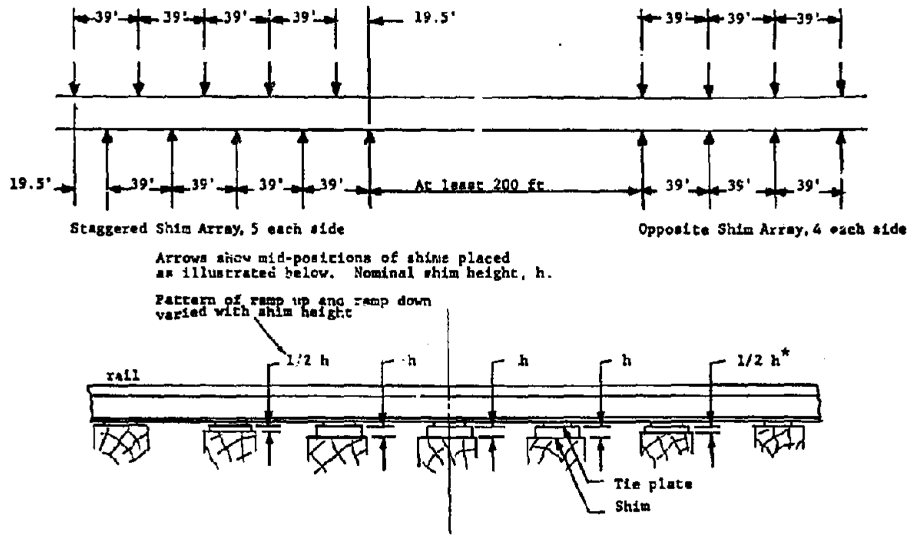
g. One inch shims at 55 mph

Appendix D contains several records of car vertical motion (acceleration, velocity, and displacement) caused by travel over the rails. Figure 12 is an example of the type of vertical velocity data contained in Appendix D. Figure 13 is an example of the vertical displacement data contained in Appendix D. Refer to the cover page of Appendix D for specific cases covered by the appendix.

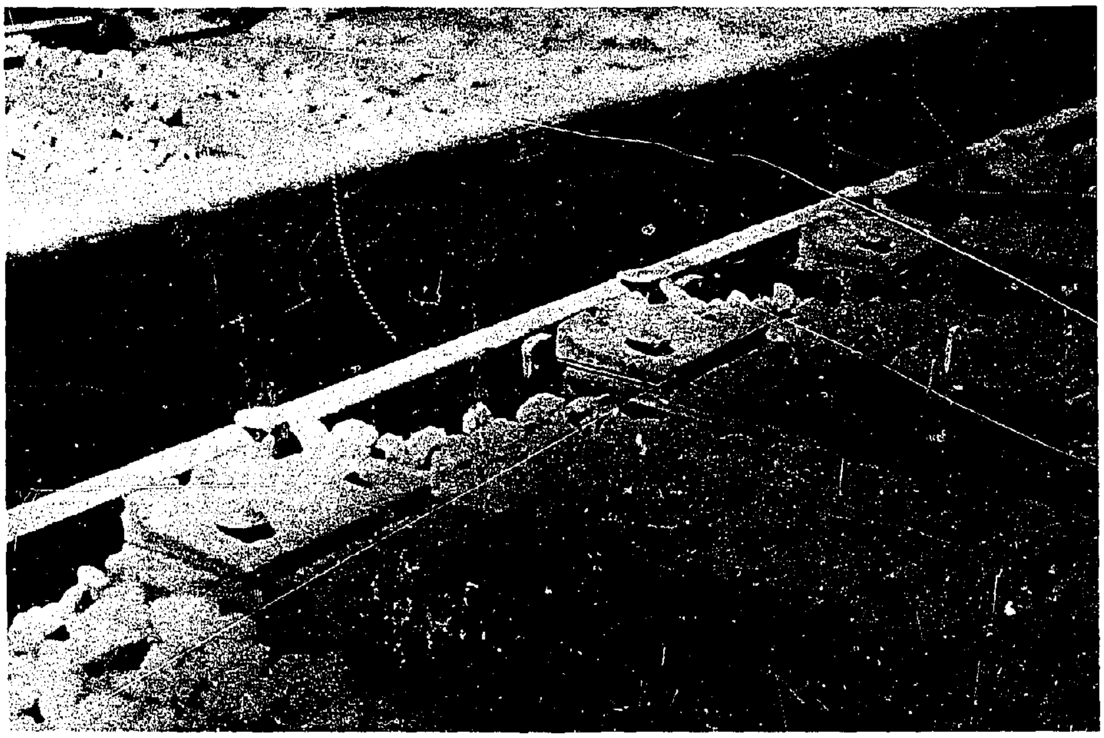
The data taken during the track characterization tests can be summarized as follows:

a. At no time did the vertical acceleration of either the sideframe or the end sill exceed 20 g.

b. In no instance did the vertical velocity of either the sideframe or the end sill exceed 1.5 fps (.45 meter/sec).



DETAIL OF SHIMMED TRACK SECTION



METAL SHIMS BETWEEN TIE AND TIE PLATE

FIGURE 10 TRACK SHIMMING DETAILS FOR TRACK CHARACTERIZATION TESTS

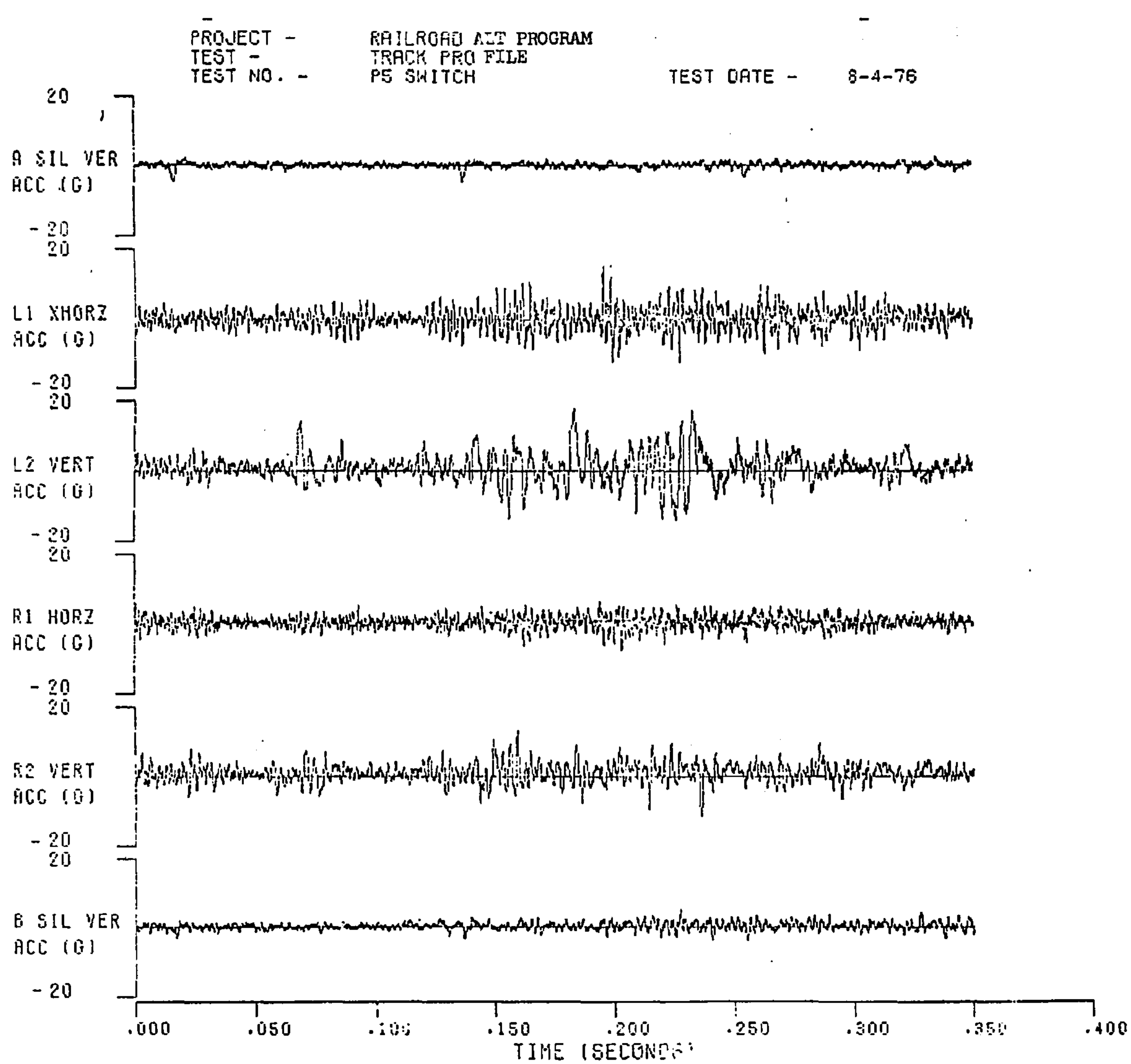


FIGURE 11 MOST SEVERE OVER-THE ROAD SHOCK

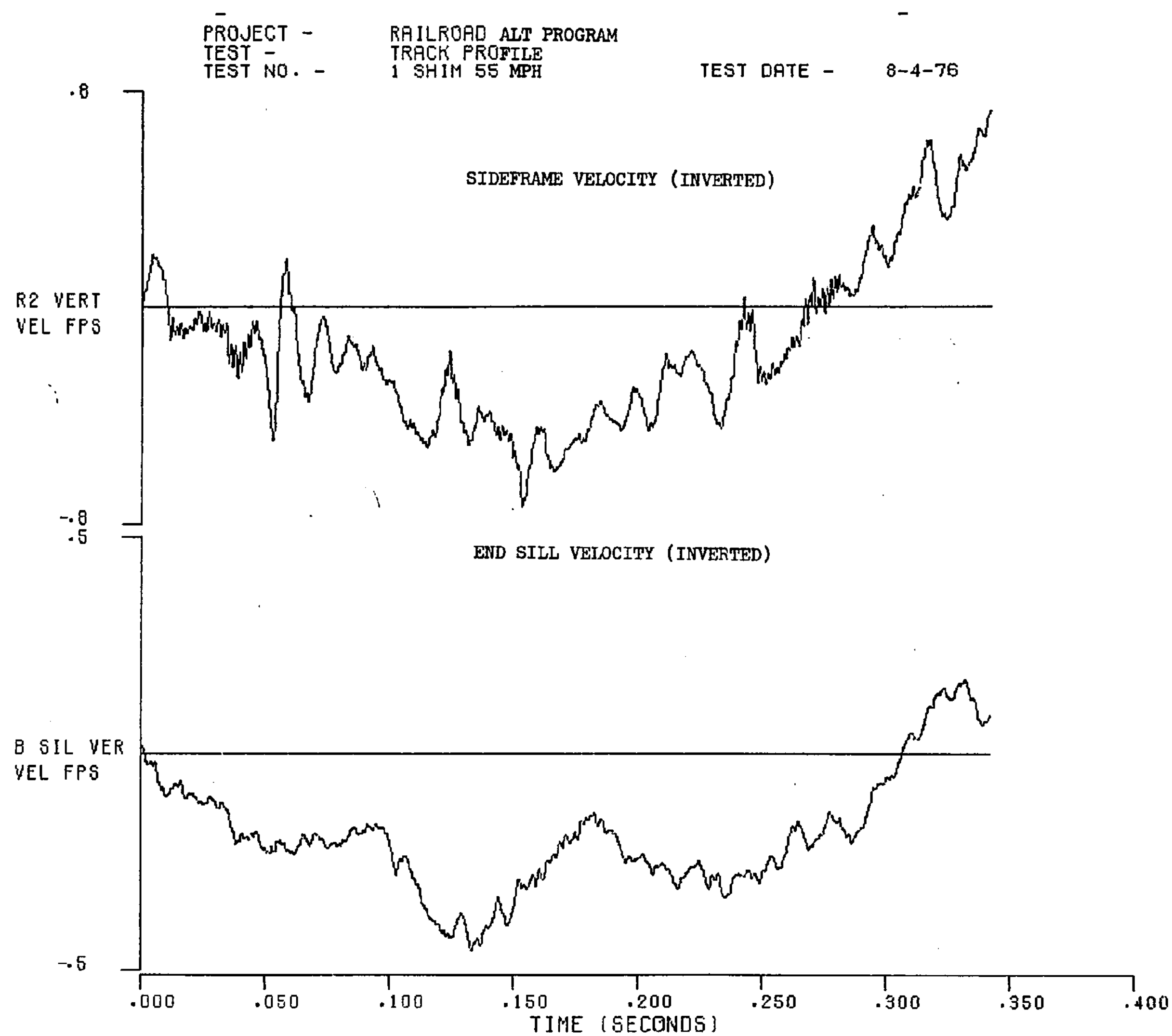


FIGURE 12 SIDEFRAME AND END SILL VERTICAL VELOCITIES CAUSED BY ONE-INCH SHIMS

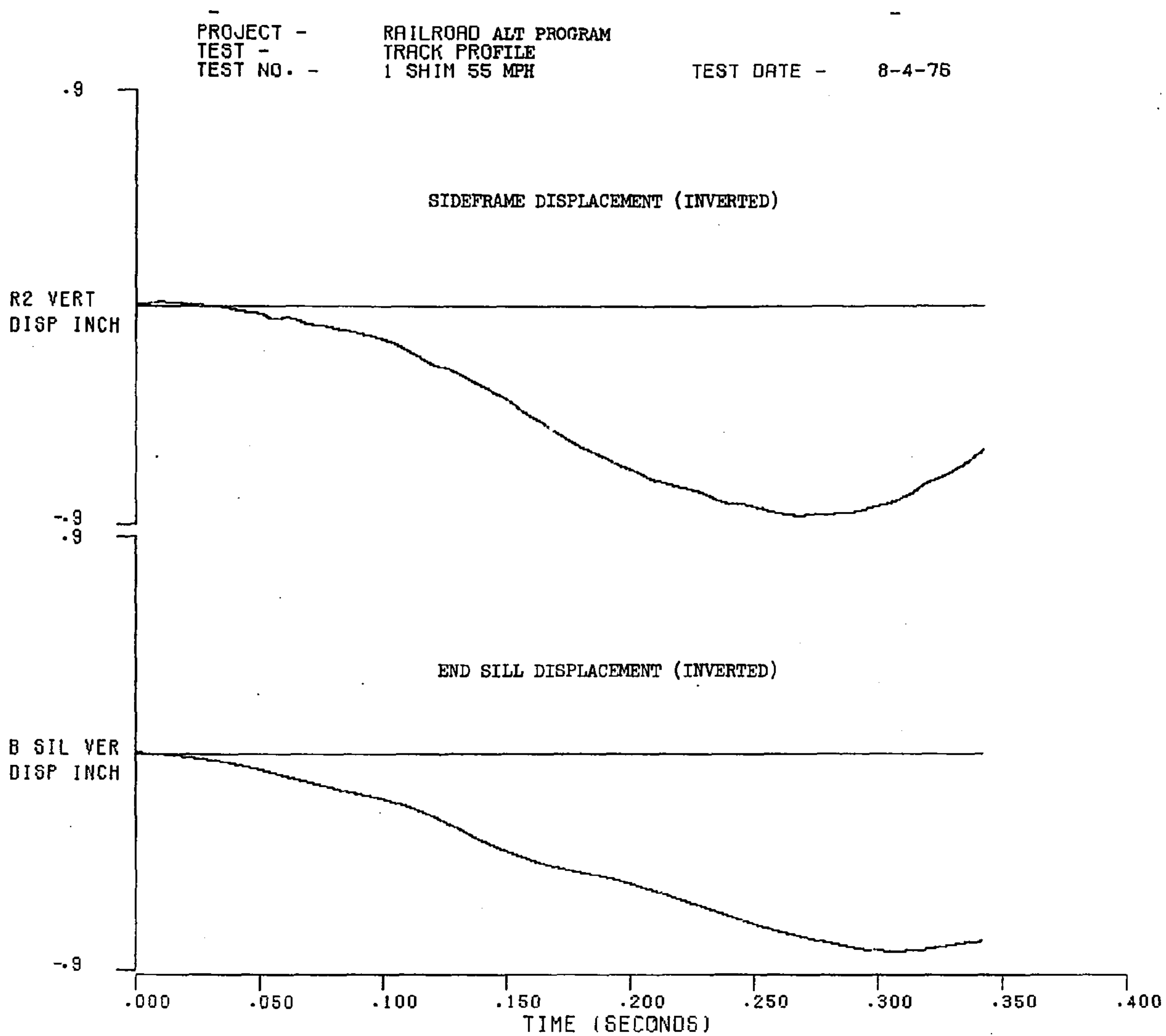


FIGURE 13 SIDEFRAME AND END SILL DISPLACEMENT CAUSED BY ONE-INCH SHIMS

c. In no instance did the vertical displacement of the sideframe or the end sill exceed one inch (2.54 cm).

d. Displacement approaching one inch (2.54 cm) occurred only during passes over .75 inch (1.91 cm) or one inch (2.54 cm) shims.

Car vertical motion limited to these values should not cause false alarms of the DOT-STAR derailment sensor.

The track characterization data taken over the test track at TTC can be compared to similar data taken over the mainline of the Duluth Mesabi and Iron Range Railway (DM&IR) in northern Minnesota. THE DM&IR is a commercial railroad active in the DOT-STAR program. Much of the DM&IR track has been characterized as part of the DOT-STAR program. The comparison between TTC track and DM&IR track is as follows:

	TTC TEST TRACK	DM&IR MAINLINE SUMMER	DM&IR MAINLINE WINTER
Maximum Acceleration (g)	20	35	130
Maximum Velocity Change (fps)	1.2	4	9.7
Train Speed (mph)	45 mph	35 mph	35 mph

The DM&IR is considered to be a well maintained commercial railroad. The track at TTC gave a much smoother ride than the DM&IR track. This smoothness is emphasized by the fact that the measurements made over the TTC track were made at 45 mph (72.5 km/hr), while the measurements over the DM&IR rails were made at 35 mph (56.4 km/hr). The reason for the big seasonal difference in the levels measured over the DM&IR track is that the roadbed freezes to a depth of several feet and, thus, becomes much harder in the winter in northern Minnesota.

As previously mentioned, characterization tests were to determine the shim height necessary to produce sideframe loading equivalent to that experienced on commercial track. Strain gage data which had been taken previously on commercial rail indicated that a total increase of 260,000 lb. (180,000 kg)(sum of the four sideframe load increases) was not uncommon on commercial track. TTC personnel instrumented the four sideframes to the DUPX 20457 with strain gages to measure the increase in load carried by each sideframe as the DUPX 20457 passed over the shimmed section of track.

Various shim sizes were tried to achieve the desired loading. Shimming arrangements of h = 1/4 inch (.63 cm) and h = 1/2 inch (1.27 cm) proved inadequate (see Figure 10 for a definition of h). Shimming arrangements of h = 3/4 inch (1.90 cm) and h = 1 inch (2.54 cm) were found to produce the desired sideframe load when the shimmed sections were traversed at 40 - 55 mph (64 - 88 km/hr).

Figure 14 gives an acceleration record of a pass over one inch (2.54 cm) shims filtered to eliminate all frequencies above 20 Hz. The loaded weight of the tank car is 260 000 lbs (118 000 kg). A low frequency acceleration of one g would cause an additional load of 260 000 lbs (118 000 kg) to be carried by the four sideframes of the tank car. The low frequency acceleration levels of approximately one g shown in Figure 14 provide a rough verification of the strain gage measurements made by TTC personnel.

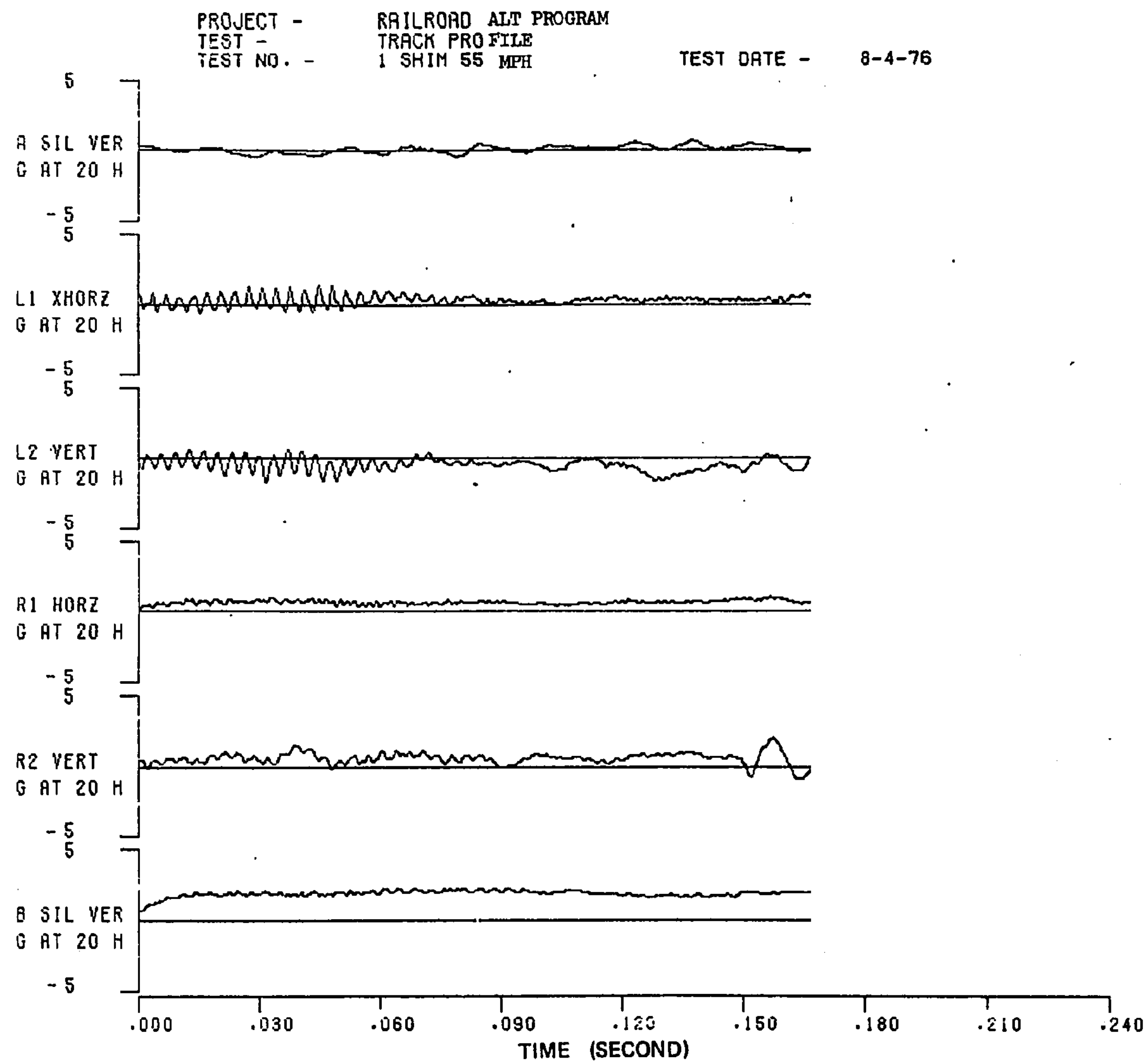


FIGURE 14 ONE-INCH SHIM ACCELERATIONS FILTERED AT 20 HZ

5. RESULTS AND CONCLUSIONS

The following results and conclusions can be stated from the measurements made by NSWC personnel at TTC in support of the ALT and DOT-STAR programs:

a. Roller bearing adapters operate approximately 70F° (38C°) above ambient conditions.

b. There is a large convective heat loss as heat is transferred from the bearing adapter to the DOT-STAR thermal sensor.

c. Even under extreme ambient conditions, a normally operating roller bearing should not cause DOT-STAR thermal sensor false alarms.

d. Maximum coupling impact shocks were measured as 100 g, 12 fps (3.65 m/s) at the coupler and 70 g, 8 fps (2.43 m/s) on the sideframe.

e. Coupling impact should not cause a false alarm of the DOT-STAR derailment sensor.

f. At no time during track characterization did the vertical acceleration of either the sideframe or the end sill exceed 20 g.

g. In no instance during track characterization did the vertical velocity of the sideframe or end sill exceed 1.5 fps (0.46 m/s).

h. In no instance during track characterization did the vertical displacement of the sideframe or end sill exceed one inch (2.54 cm).

i. Nothing was measured during track characterization which would cause a false alarm of the DOT-STAR derailment sensor.

j. The test track at TTC is in much better condition than mainline commercial rail.

k. NSWC accelerometer measurements provided a rough verification of TTC strain gage measurements.

APPENDIX A

COUPLING IMPACT SUMMARY PLOTS

A - 1 This appendix contains plots which summarize the data taken during the coupling impact shock tests. These plots were made by plotting maximum acceleration versus impact speed and velocity change (maximum velocity change by integration of the measured acceleration) versus impact speed for both car loaded and car empty impacts. The maximum accelerations and the velocity changes were obtained from the records in Appendix B.

A - 2 This appendix compares loaded impacts to empty impacts on the same page for the following cases:

a) End Sill Accelerations - Both A end and B end

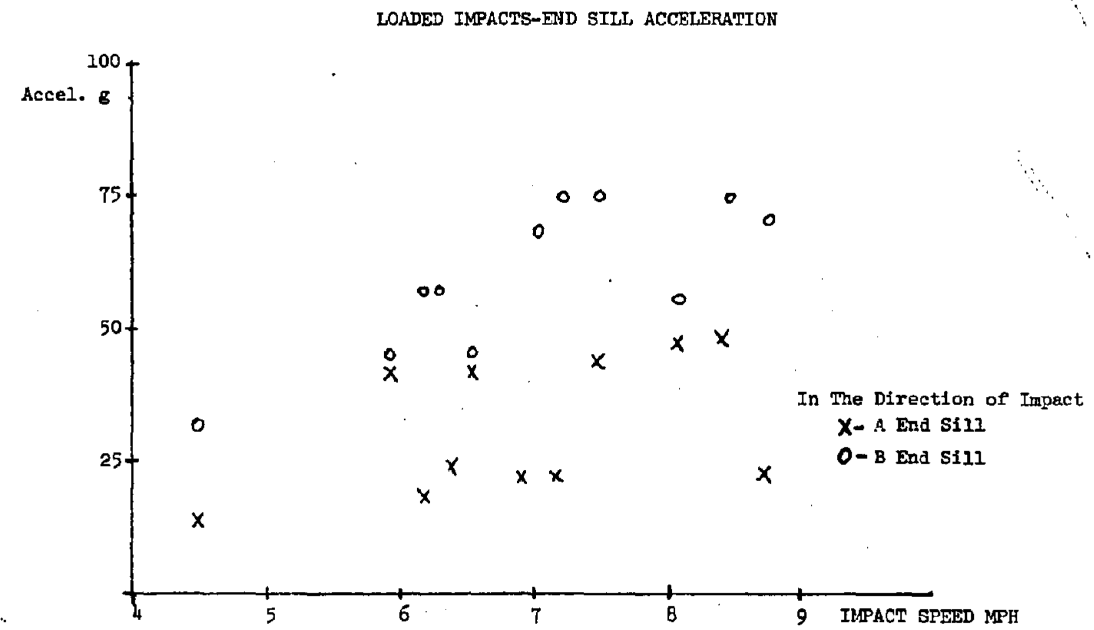
b) End Sill Velocity Change - Both A end and B end

c) Sideframe Accelerations - Both left and right sideframe

d) Sideframe Velocity Change - Both left and right sideframe

e) Sideframe Vertical Acceleration

f) Sideframe Vertical Velocity Change.



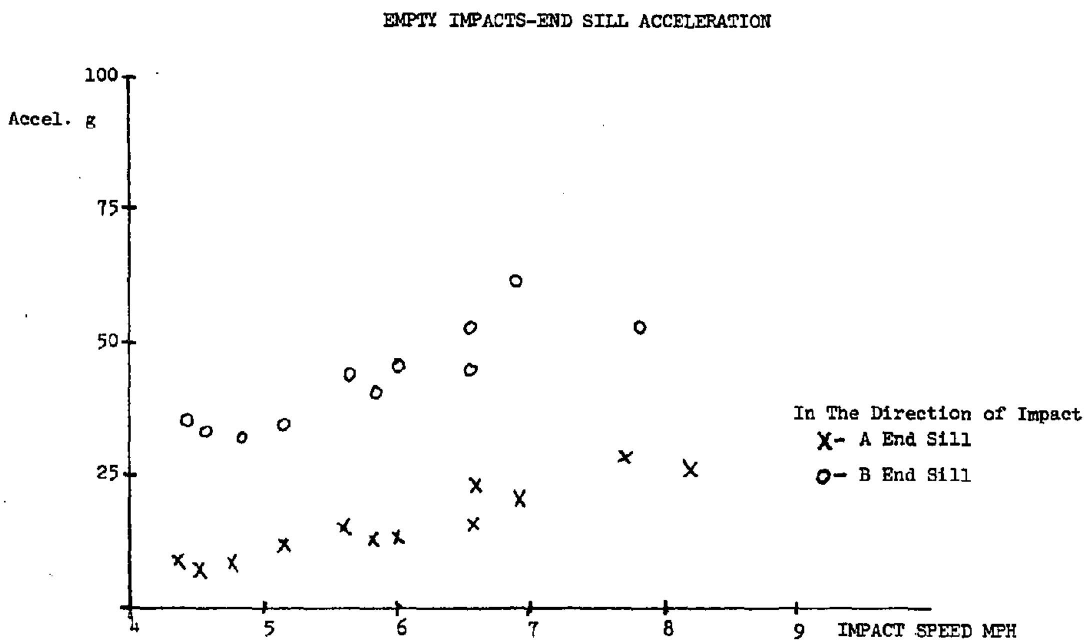
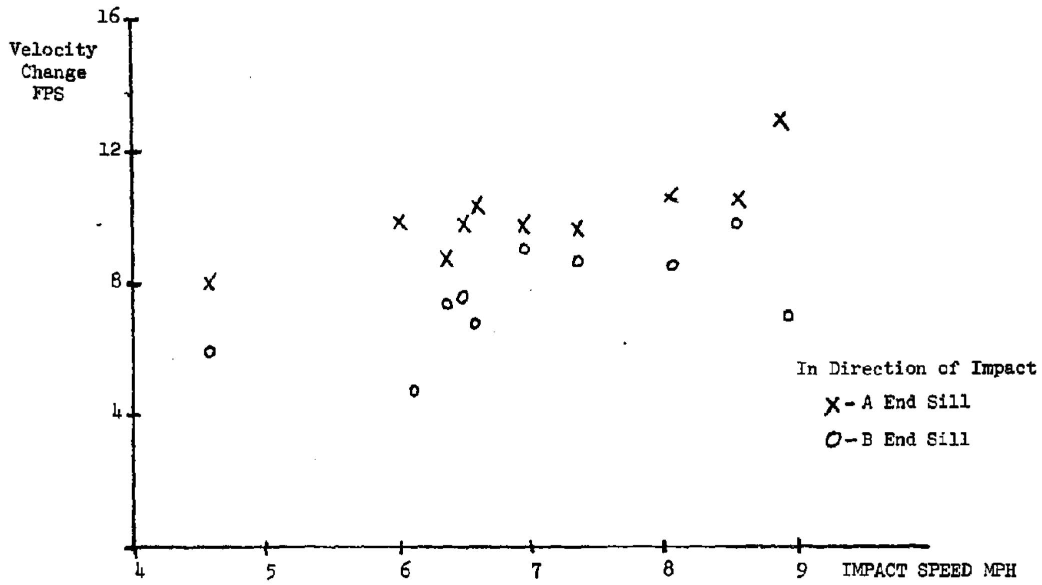


FIGURE A-1 COUPLING IMPACT SUMMARY PLOTS

LOADED IMPACTS-END SILL VELOCITY CHANGE



EMPTY IMPACTS-END SILL VELOCITY CHANGE

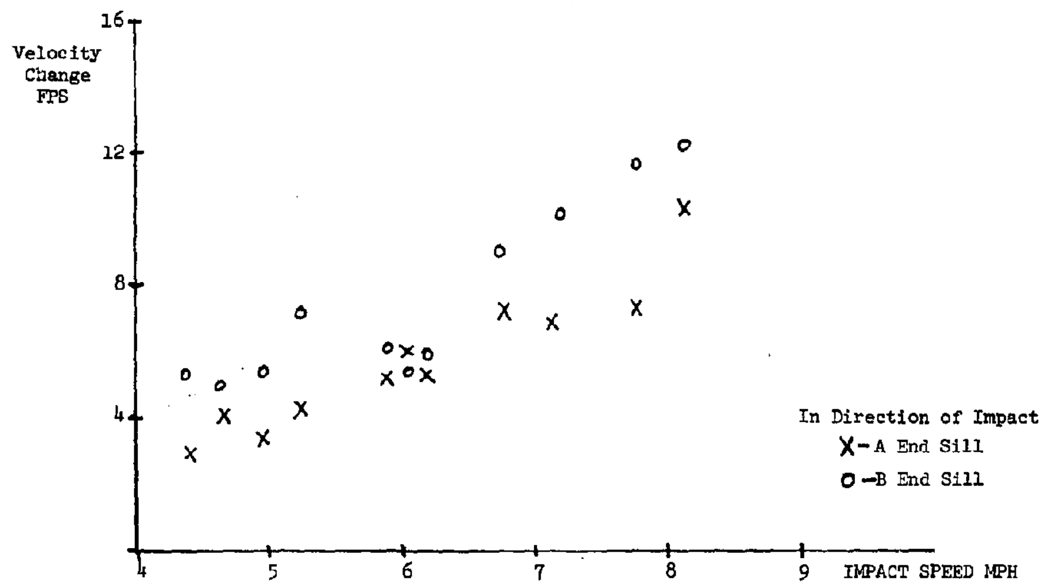
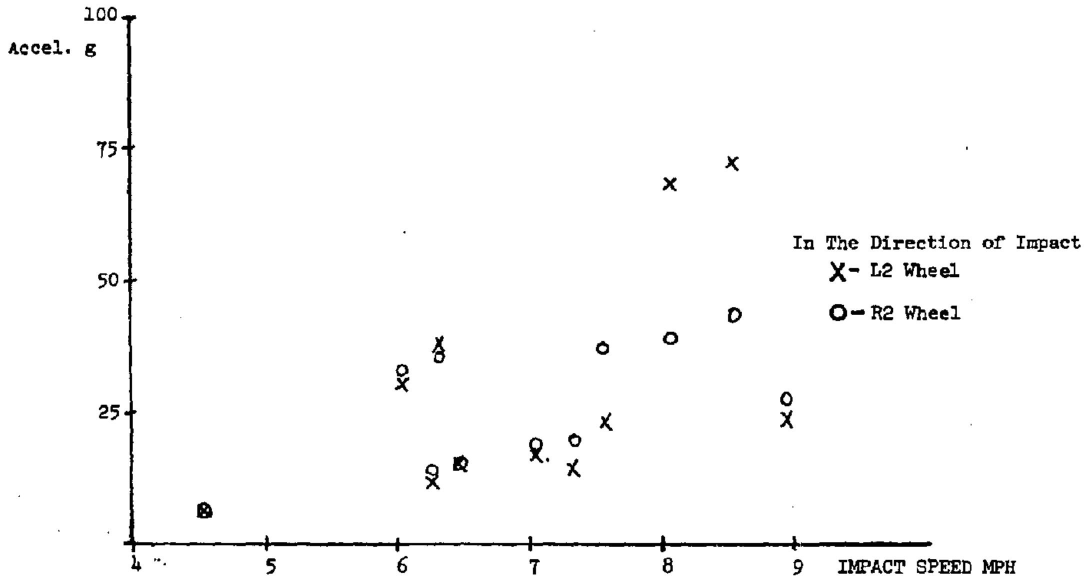


FIGURE A-2 COUPLING IMPACT SUMMARY PLOTS

LOADED IMPACTS-SIDEFRAME ACCELERATION



EMPTY IMPACTS-SIDEFRAME ACCELERATION

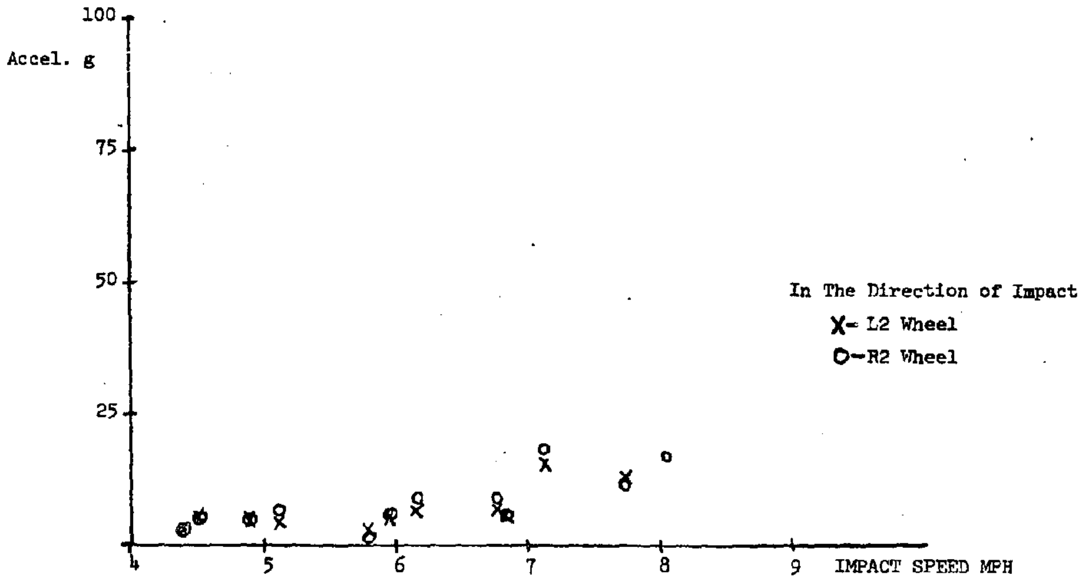
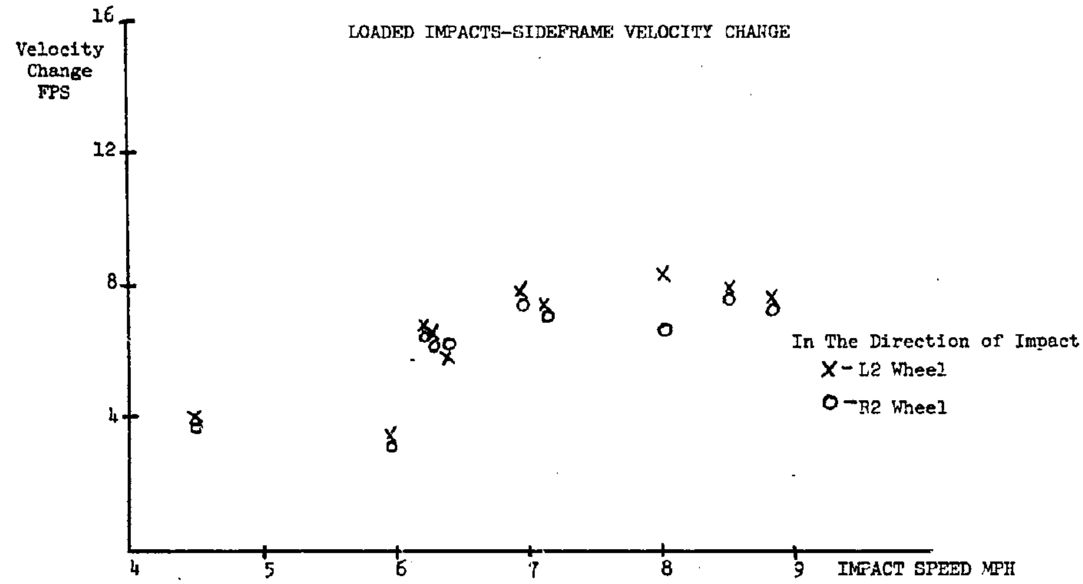


FIGURE A-3 COUPLING IMPACT SUMMARY PLOTS



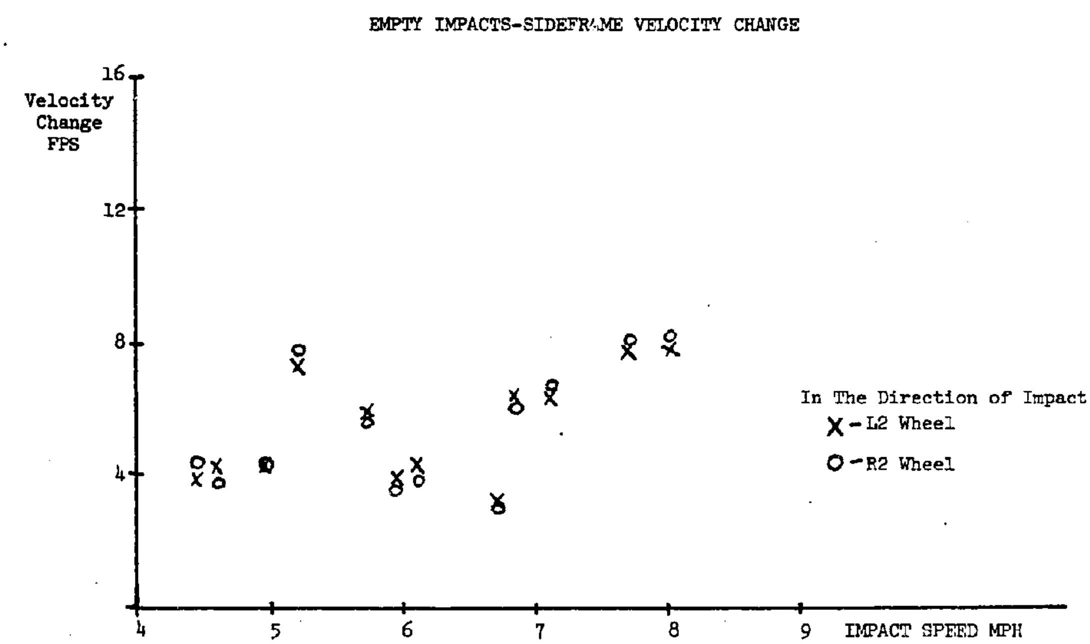


FIGURE A-4 COUPLING IMPACT SUMMARY PLOTS

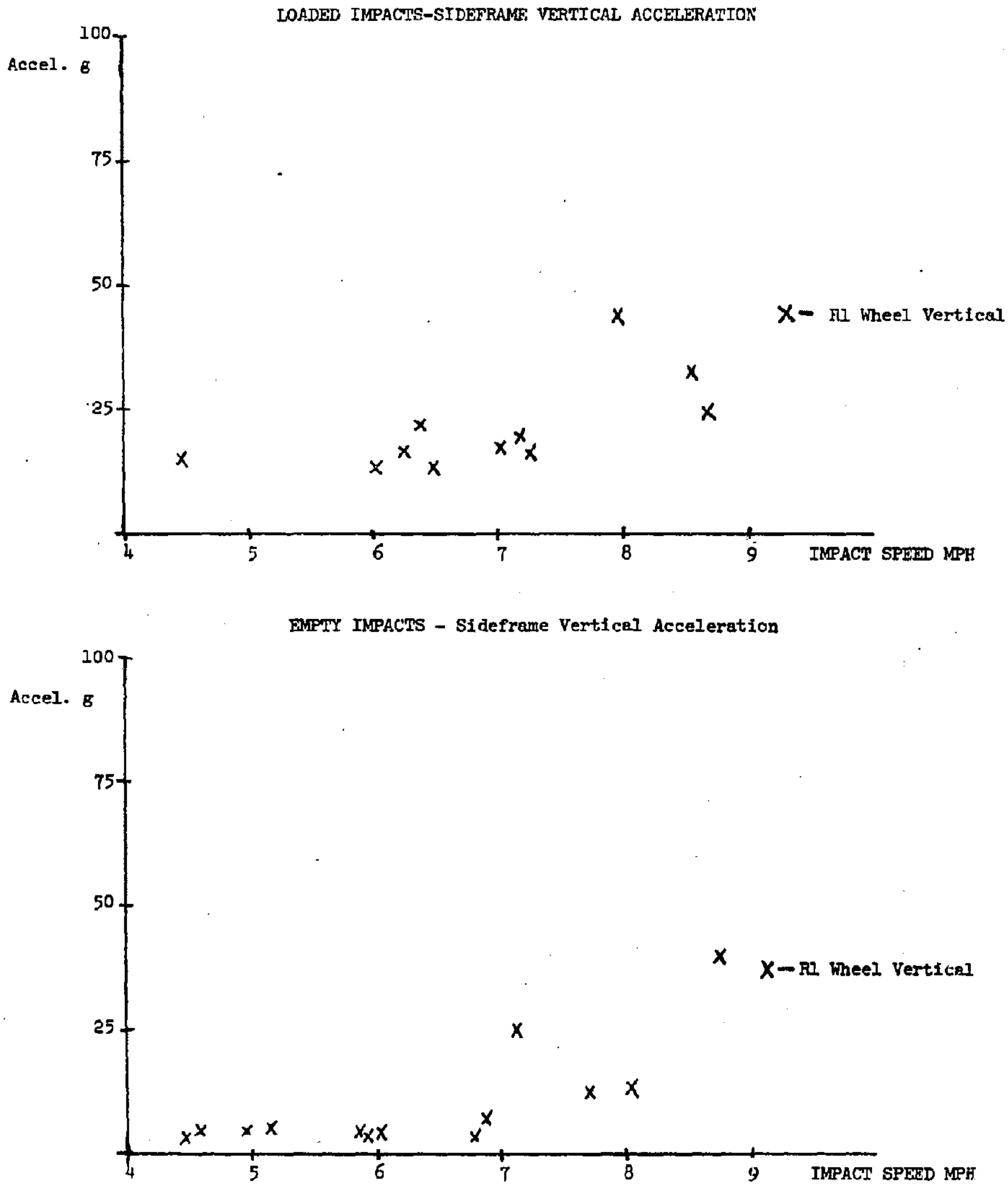
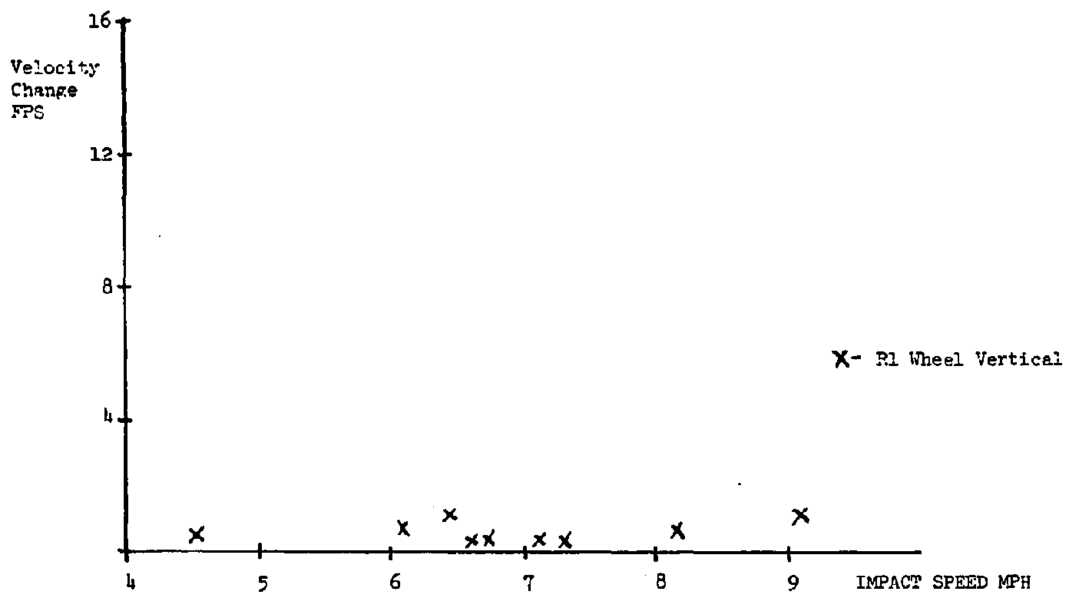


FIGURE A-5 COUPLING IMPACT SUMMARY PLOTS

LOADED IMPACT-SIDEFRAME VERTICAL VELOCITY CHANGE



EMPTY IMPACTS - Sideframe Vertical Velocity Change

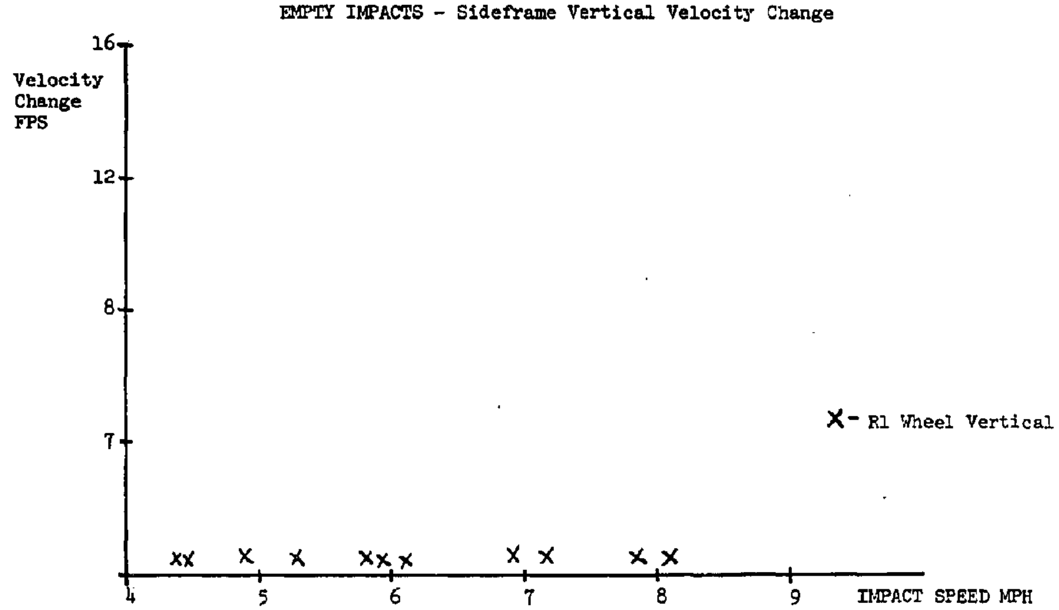


FIGURE A-6 COUPLING IMPACT SUMMARY PLOTS

APPENDIX B

COUPLING IMPACT SHOCK DATA

This appendix contains a selection of data taken during the coupling impact shock tests. Accelerations were measured at the following six locations on the instrumented tank car for each of the 26 coupling impacts measured:

a. A end sill horizontal acceleration

b. L1 wheel horizontal acceleration perpendicular to impact

c. L2 wheel horizontal acceleration

d. R1 wheel vertical acceleration

e. R2 wheel horizontal acceleration

f. B end sill horizontal acceleration

For four typical impacts, the following three graphs are presented, each showing the six variables listed above.

a. acceleration versus time (unfiltered)

b. acceleration versus time (filtered at 30 Hz)

c. velocity change

The first three impacts in the series were with the A truck end of the car impacting; the remaining 23 impacts were done with the B truck or the instrumented truck end impacting. More impacts were done with the instrumented truck forward because the forward or impacting truck was thought to be shocked more severely than the trailing truck. This appendix shows results for four B truck end impacts:

a. car loaded, 4.5 mph (6' km/h) impact speed,

b. car loaded, 8.7 mph (14.0 km/h) impact speed,

c. Car empty, 4.5 mph (6.8 km/h) impact speed,

d. car empty, 8.0 mph (12.9 km/h) impact speed.

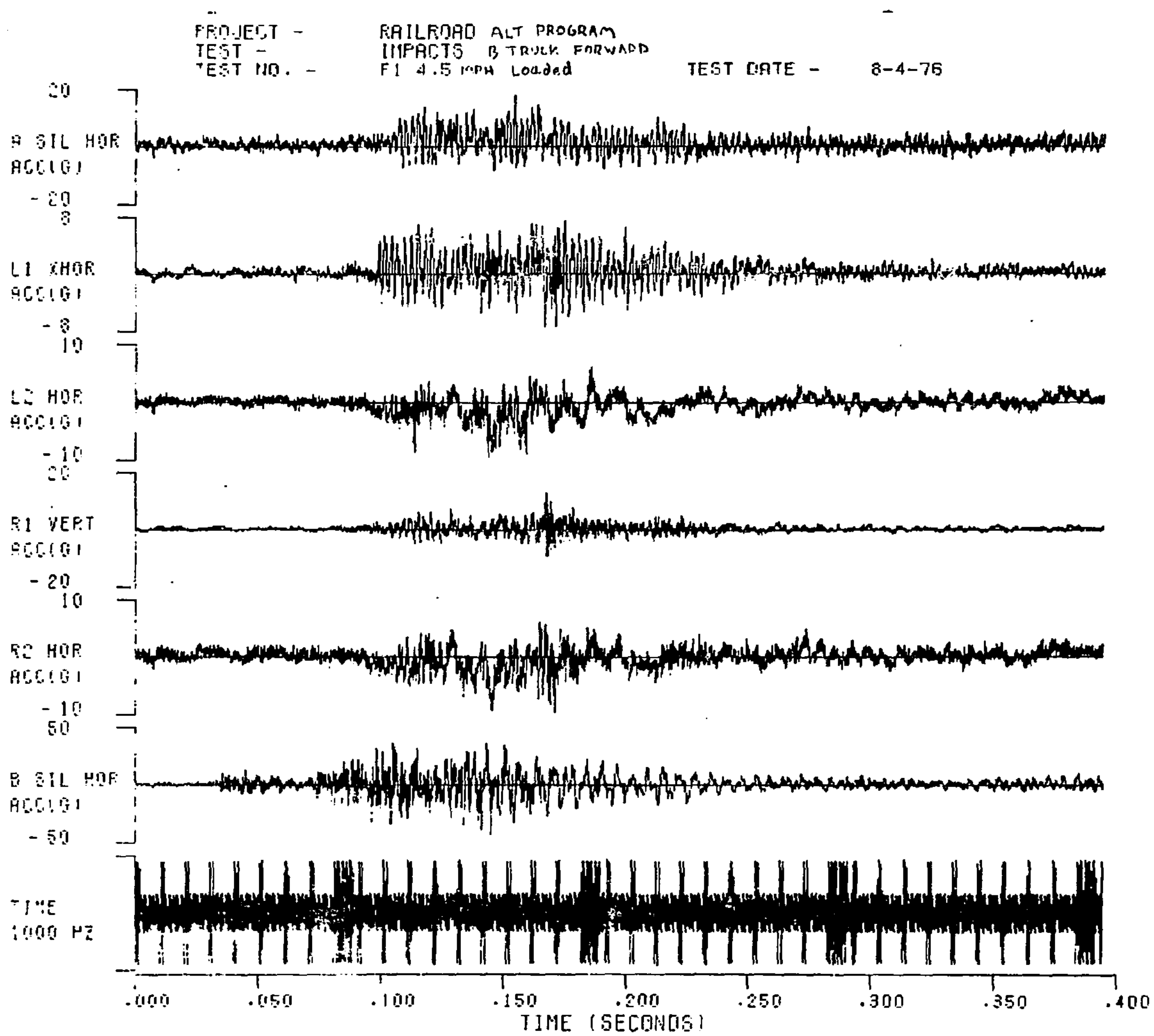


FIGURE B-1-1 COUPLING IMPACT SHOCK UNFILTERED ACCELERATIONS

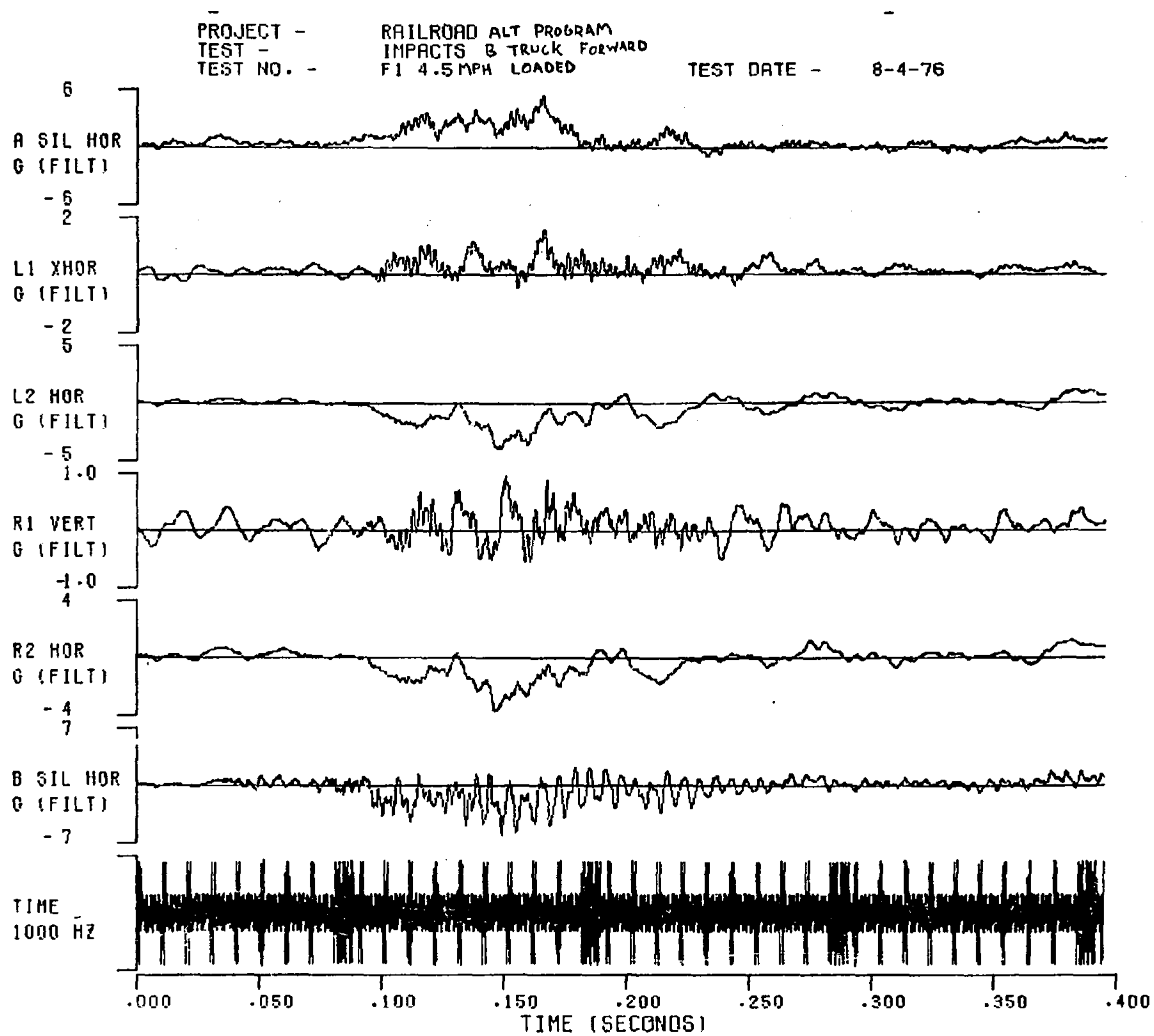


FIGURE B-1-2 COUPLING IMPACT SHOCK ACCELERATIONS FILTERED @ 30 HZ

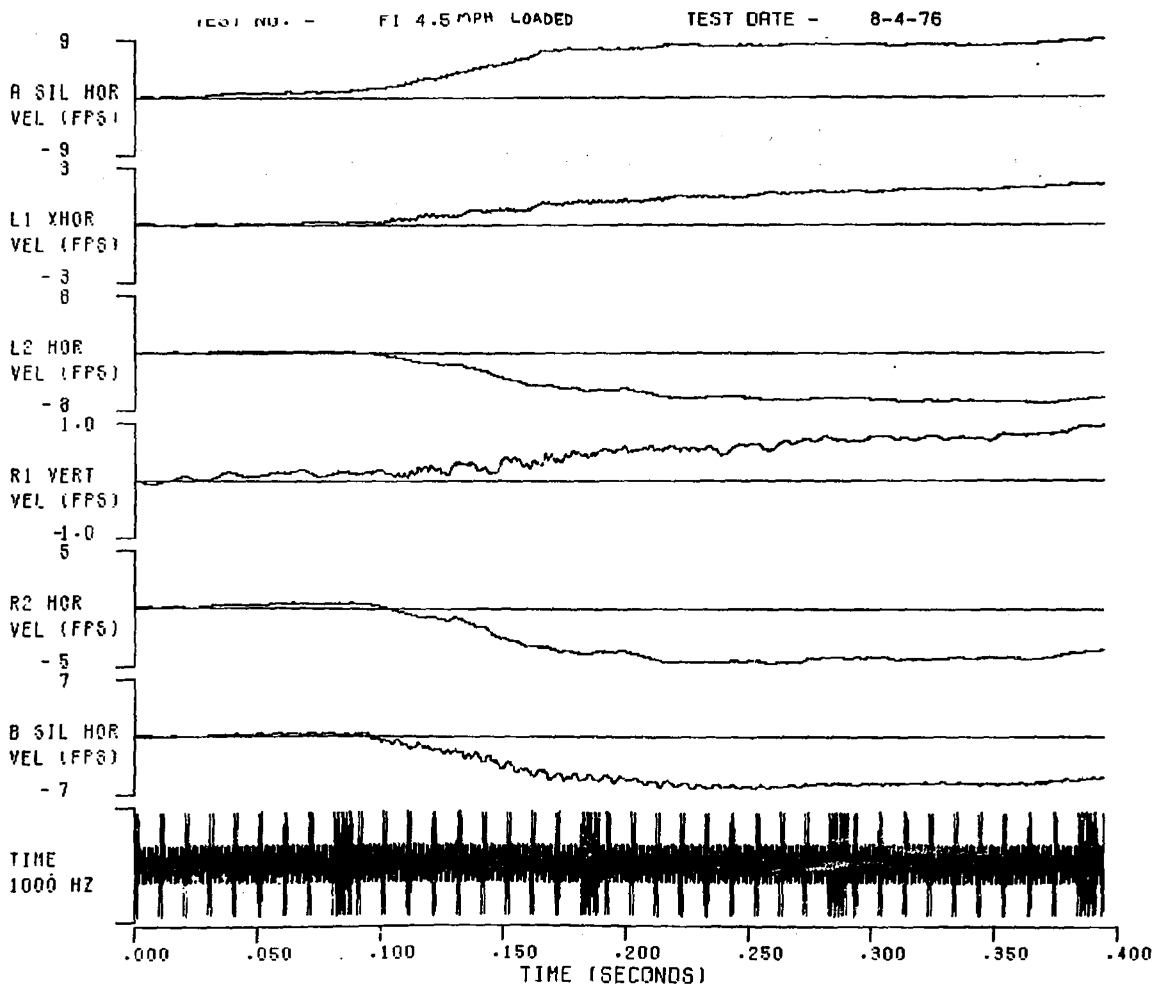


FIGURE B-1-3 COUPLING IMPACT SHOCK VELOCITY CHANGE

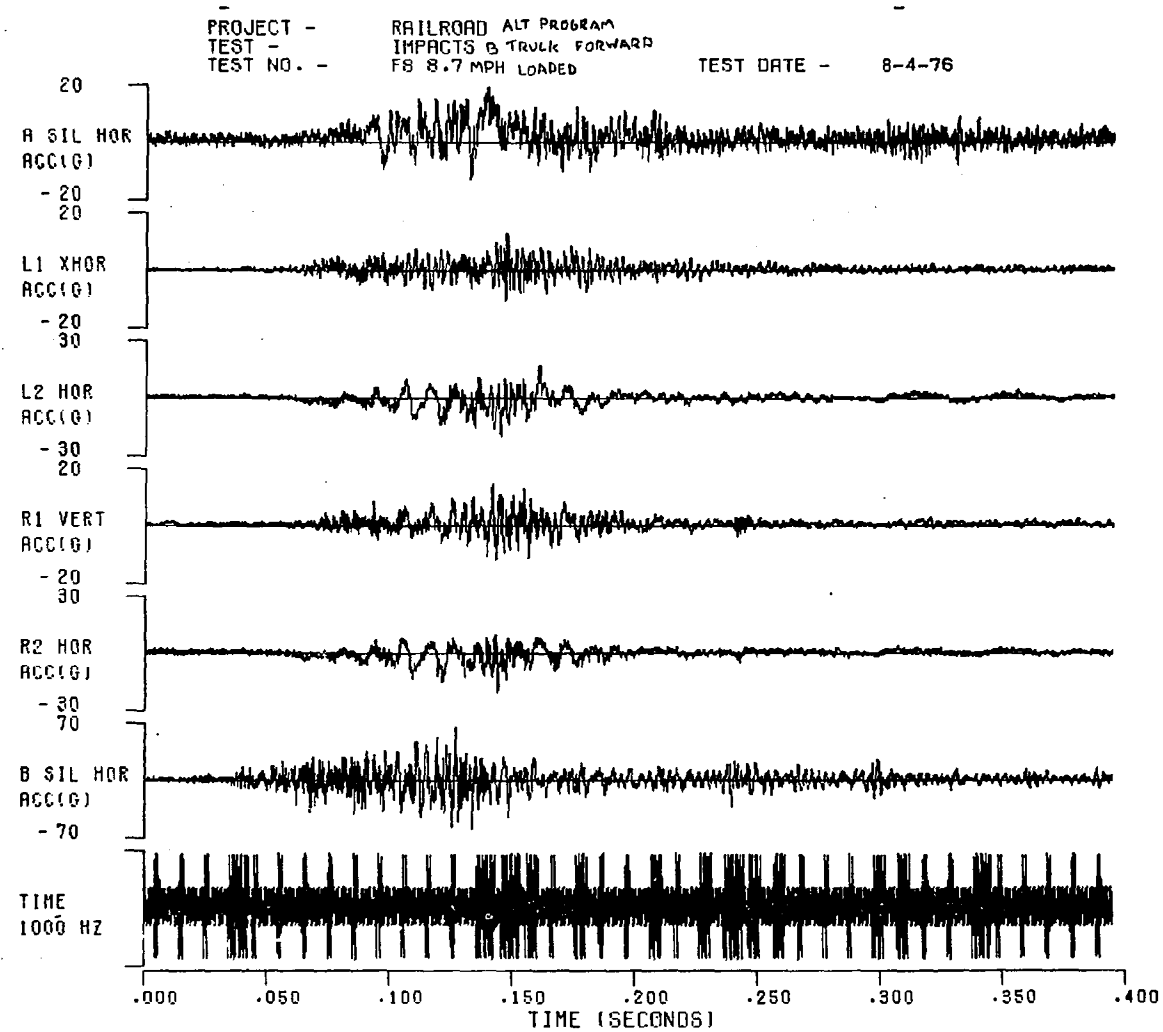


FIGURE B-2-1 COUPLING IMPACT SHOCK UNFILTERED ACCELERATIONS

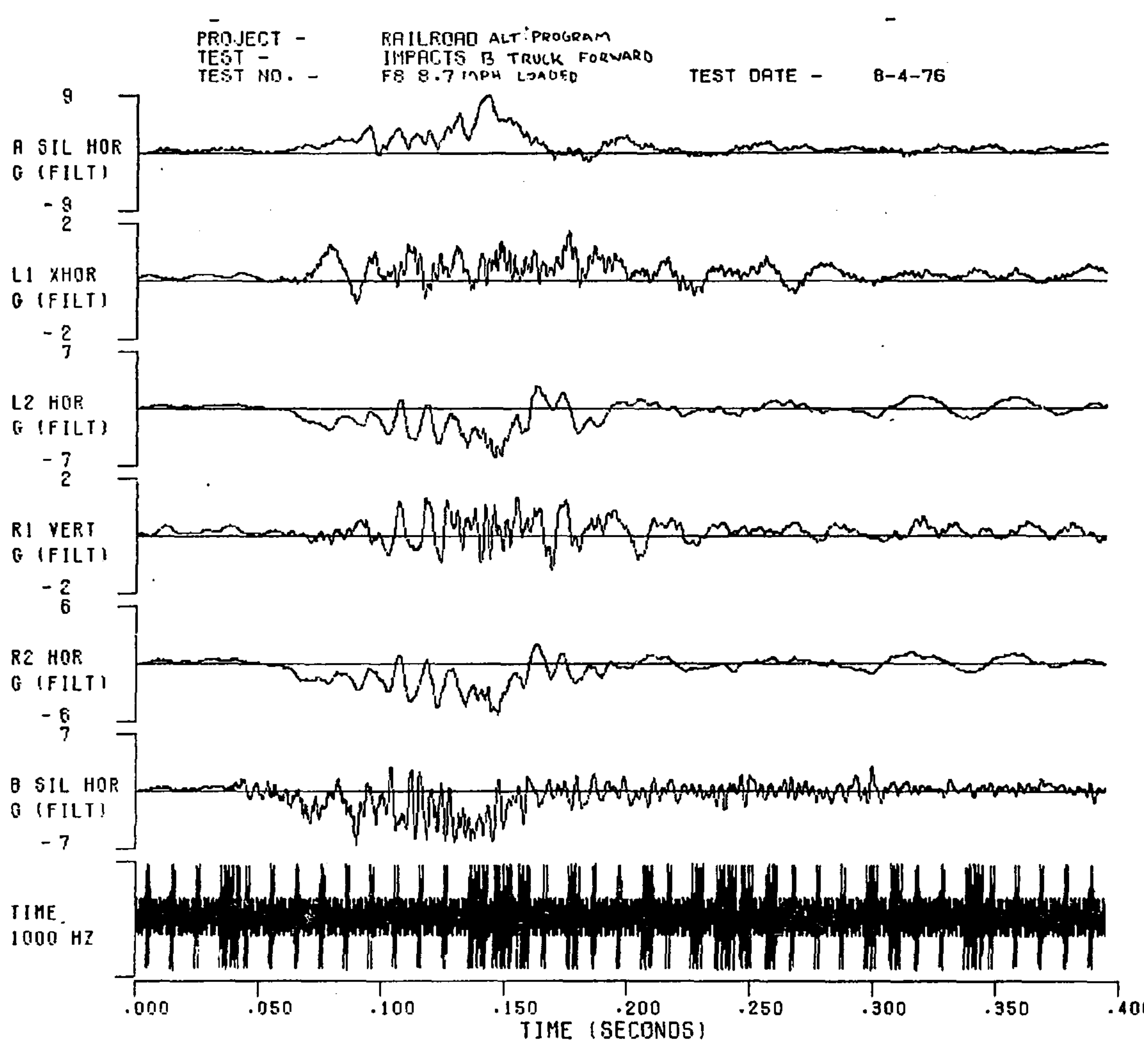


FIGURE B-2-2 COUPLING IMPACT SHOCK ACCELERATIONS FILTERED @ 30 HZ

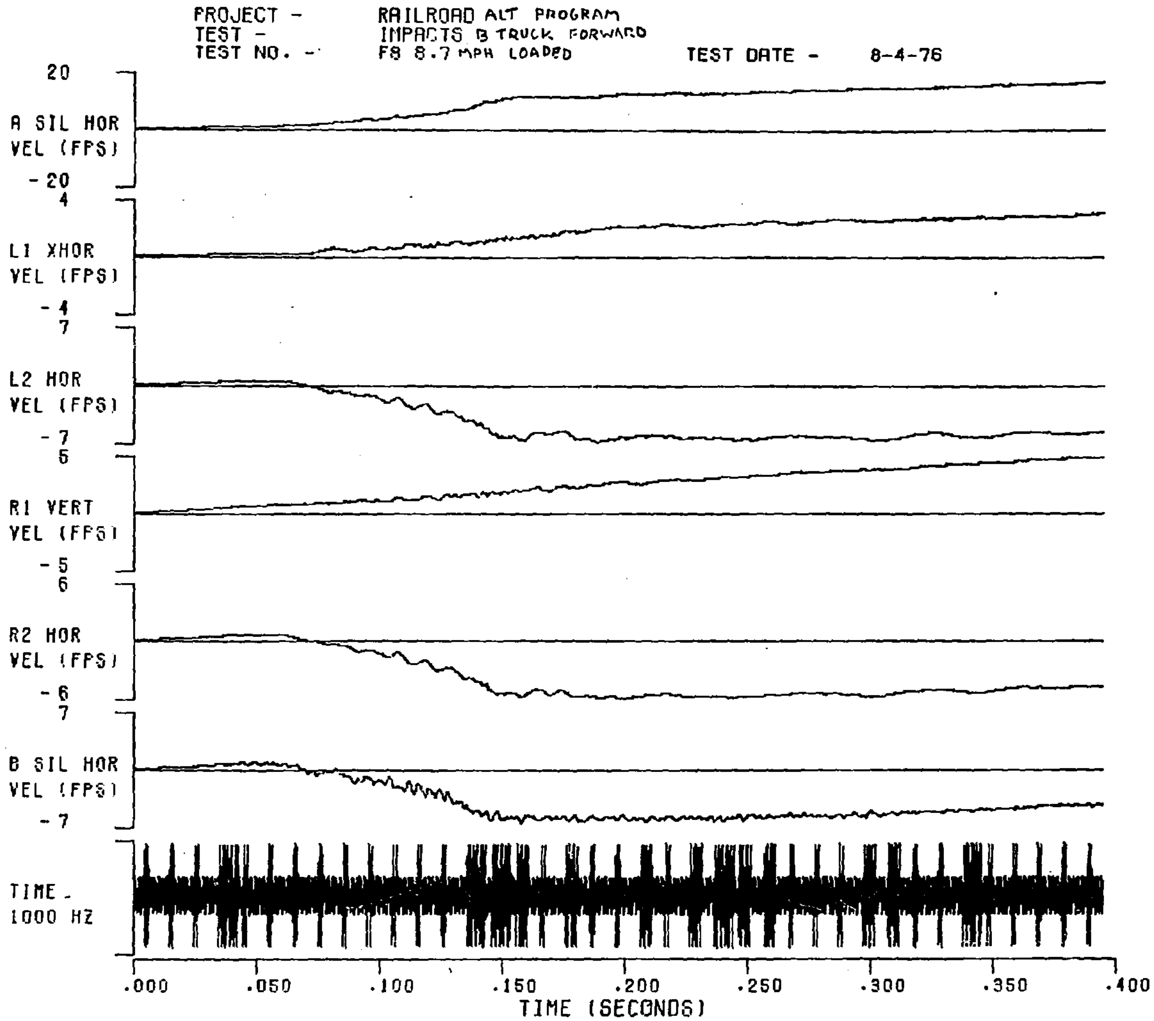


FIGURE B-2-3 COUPLING IMPACT SHOCK VELOCITY CHANGE

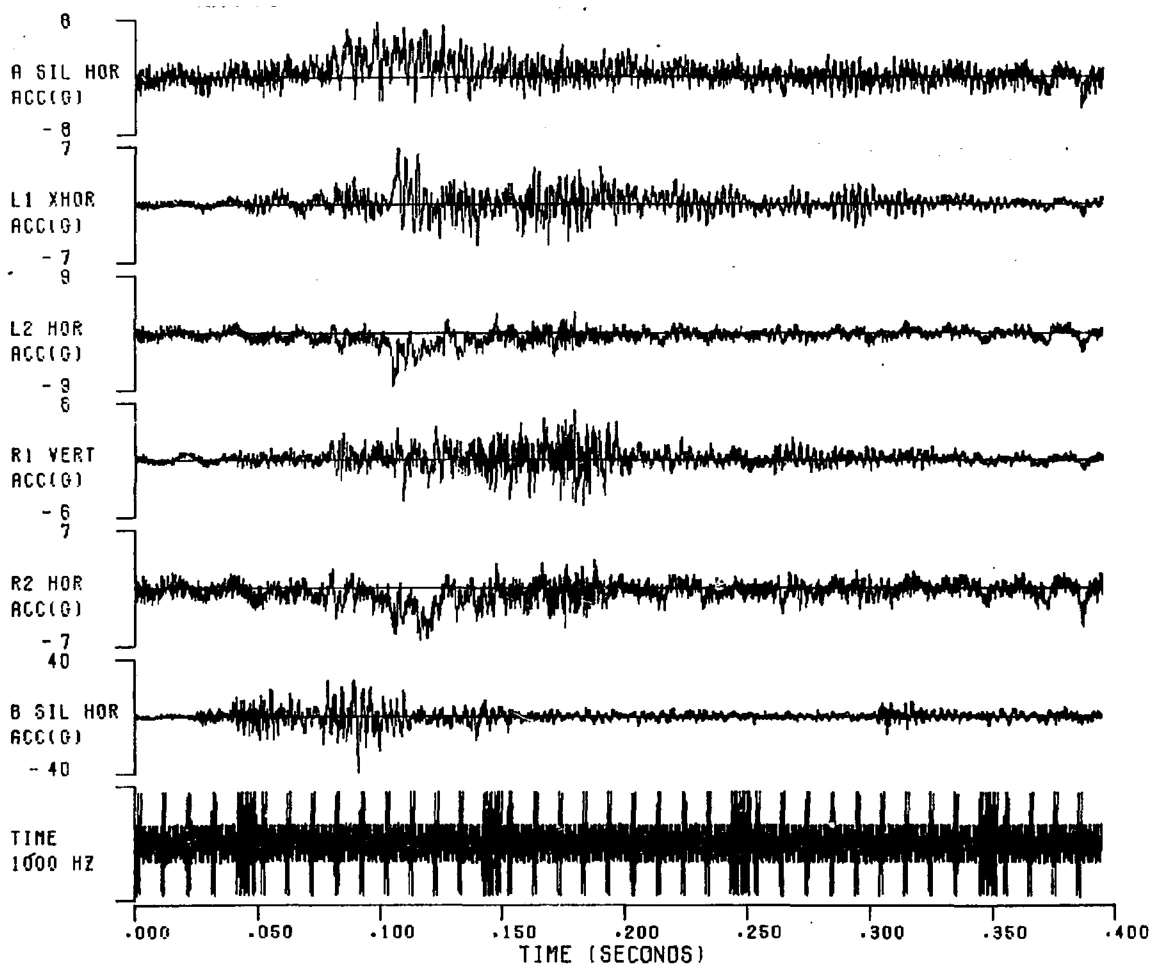


FIGURE B-3-1 COUPLING IMPACTS UNFILTERED ACCELERATIONS

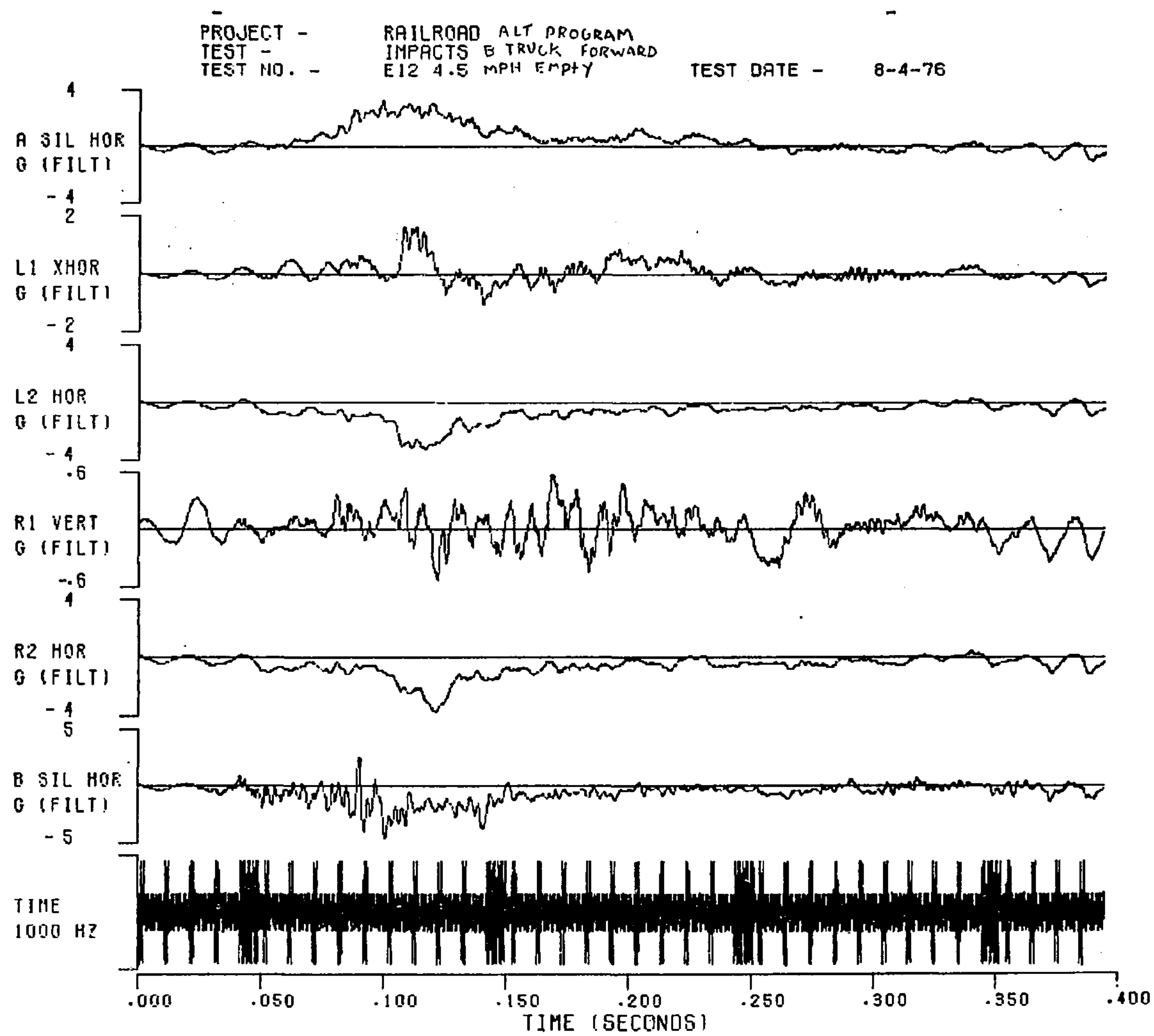


FIGURE B-3-2 COUPLING IMPACT SHOCK ACCELERATIONS FILTERED @ 30 HZ

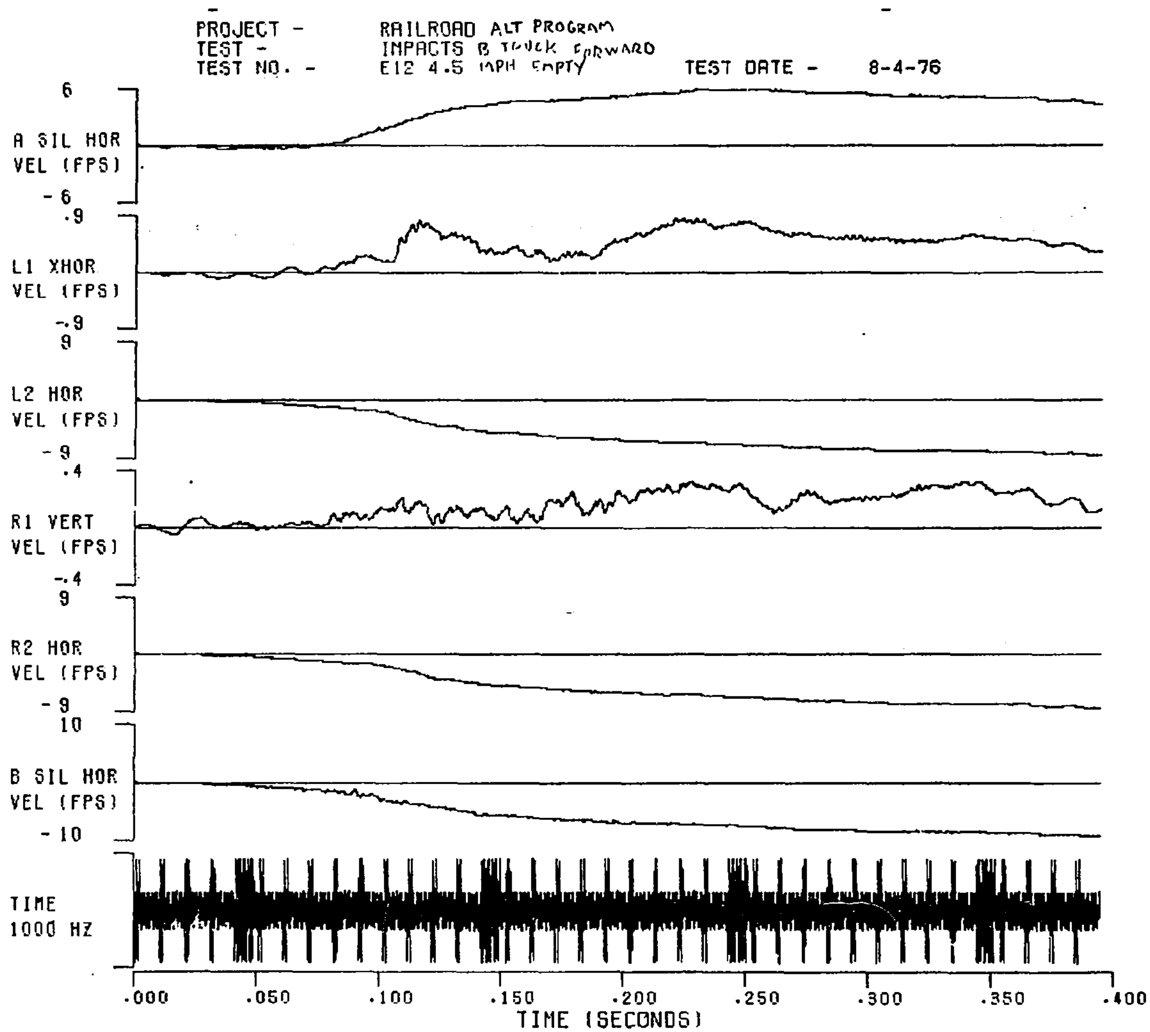


FIGURE B-3-3 COUPLING IMPACT SHOCK VELOCITY CHANGE

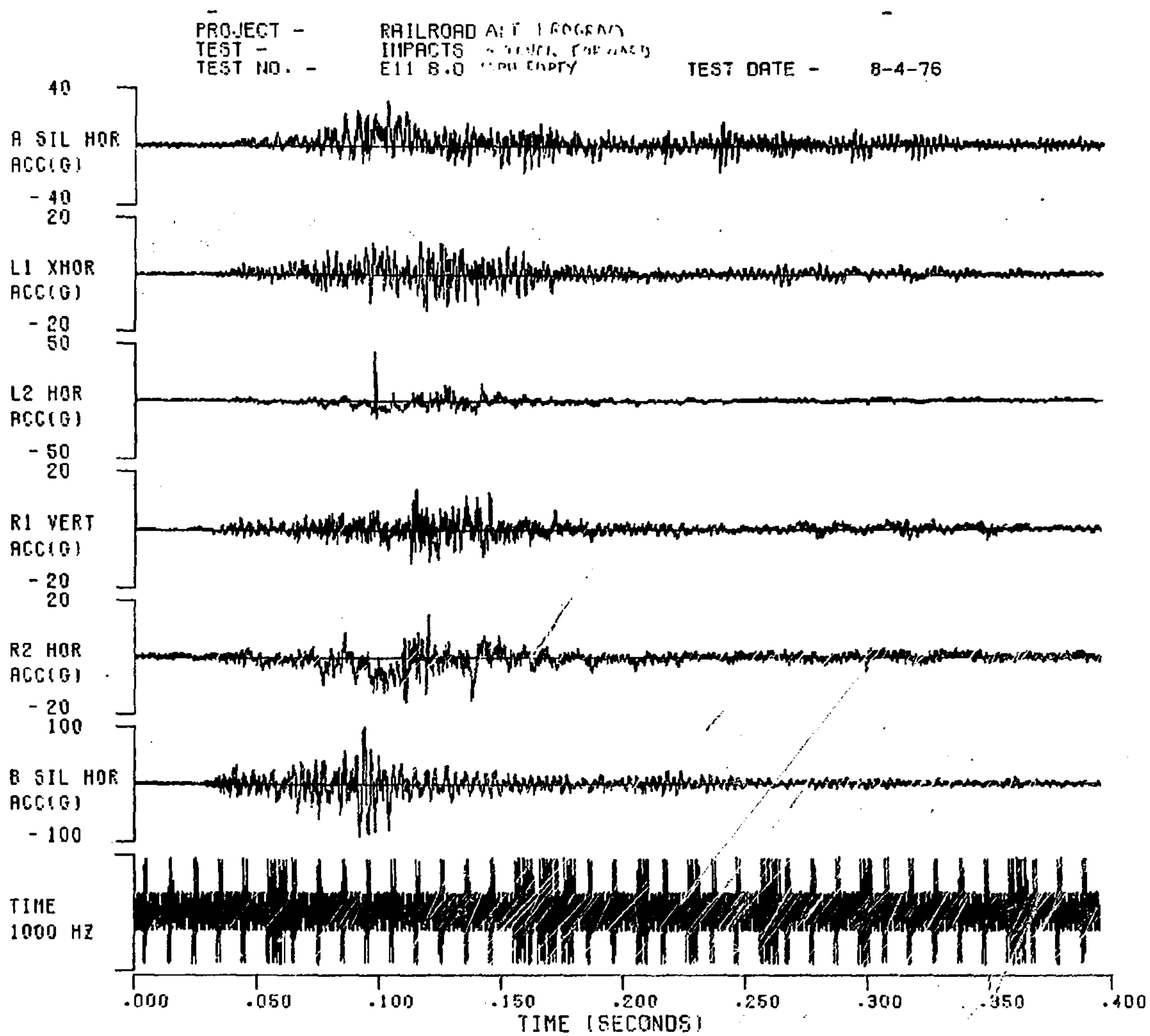


FIGURE B-3-4 COUPLING IMPACT SHOCK UNFILTERED ACCELERATIONS

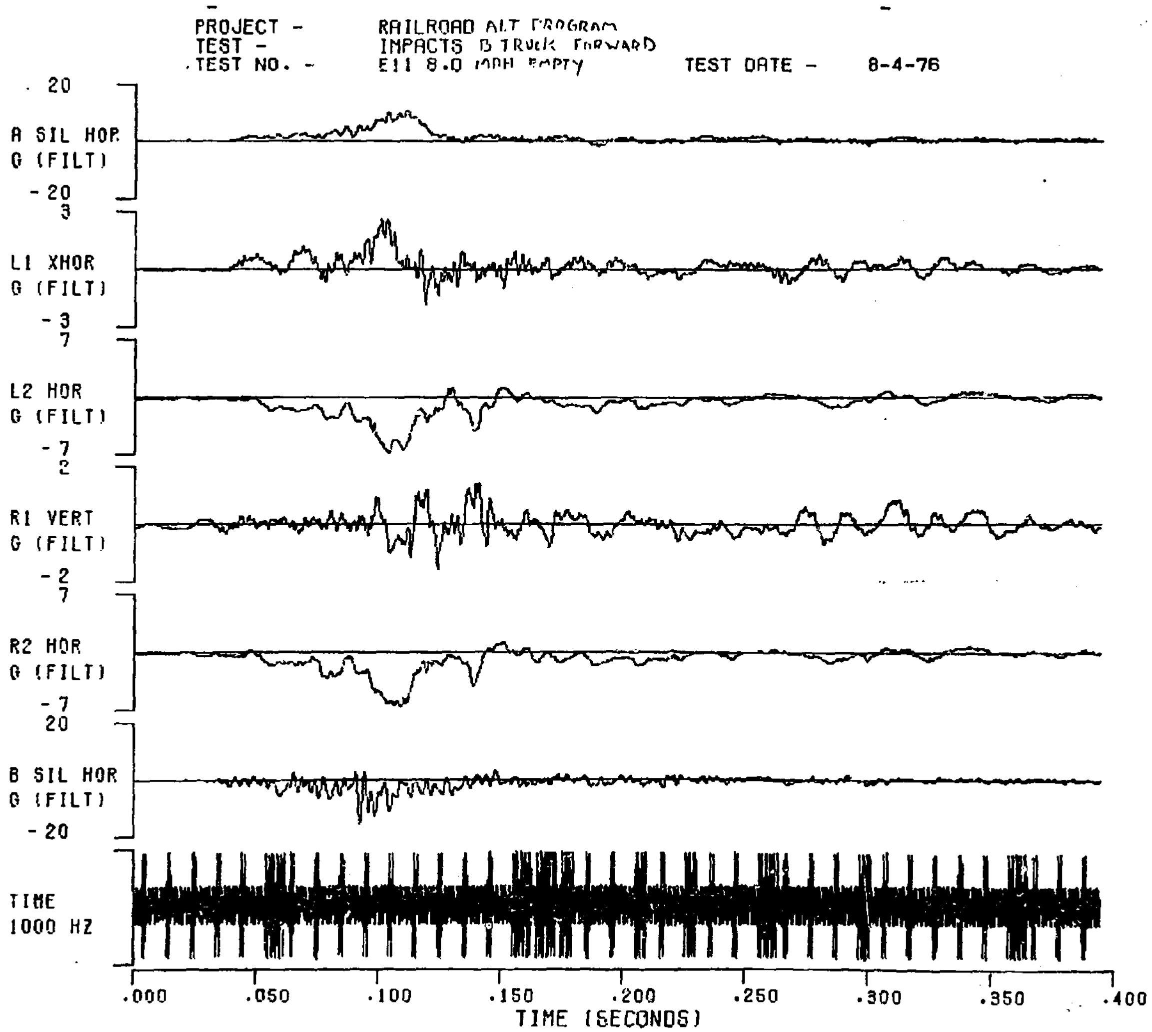


FIGURE B-3-5 COUPLING IMPACT SHOCK ACCELERATIONS FILTERED @ 30 HZ

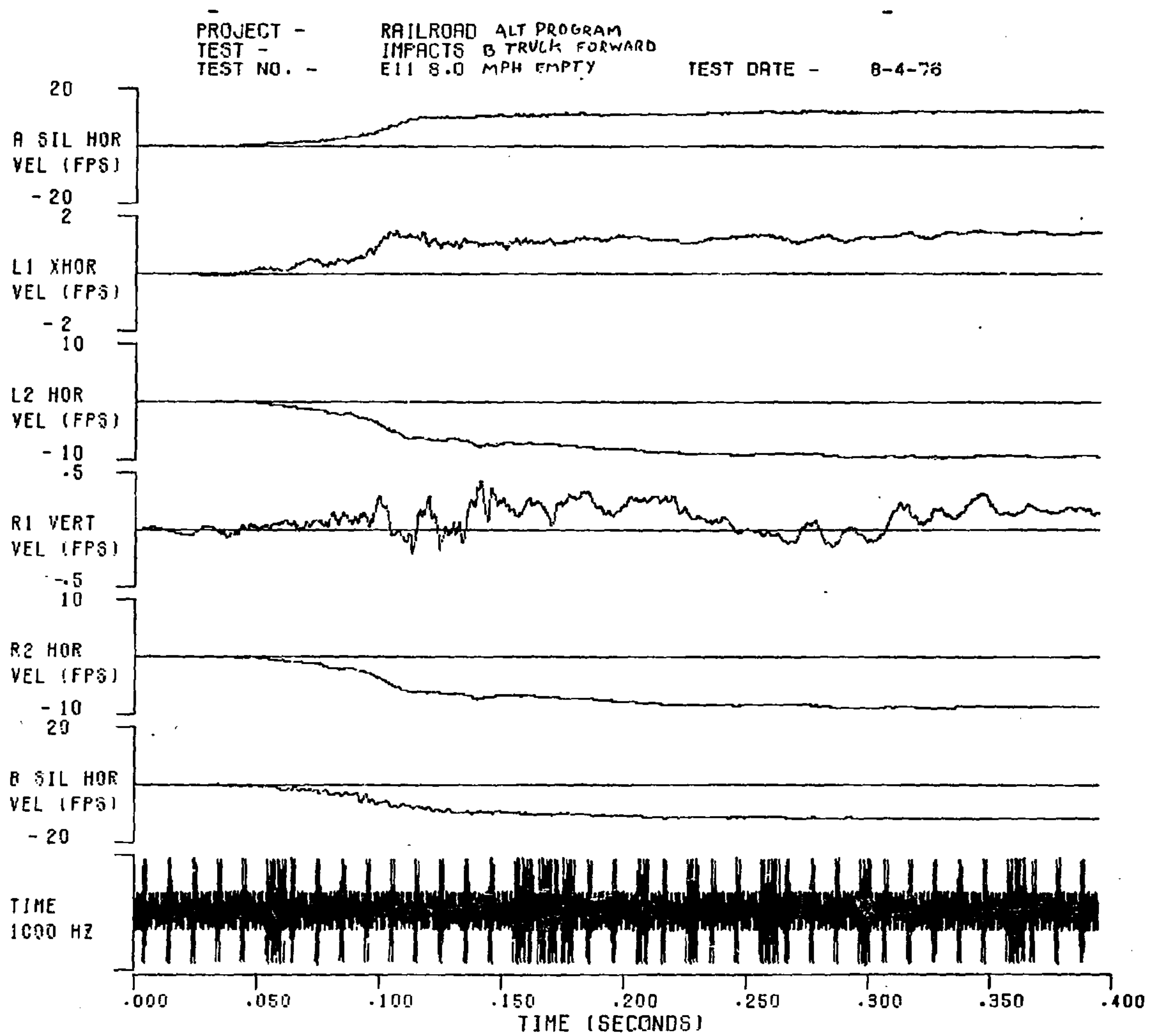


FIGURE B-3-6 COUPLING IMPACT SHOCK VELOCITY CHANGE

APPENDIX C

TRACK CHARACTERIZATION ACCELERATION DATA

C - 1 This appendix contains a sampling of the most significant track characterization data. The entire track characterization data are contained on seven reels of magnetic tape each of 1/2 hour playing time at a playback speed of 15 inches per second.

C - 2 Accelerations were measured at the following six locations during the track characterization tests:

a. A end sill vertical acceleration

b. L1 wheel horizontal cross axial acceleration

c. L2 wheel vertical acceleration

d. R1 wheel horizontal axial (along track) acceleration

e. R2 wheel vertical acceleration

f. B end sill vertical acceleration

C - 3 This appendix contains acceleration versus time records for each of these six locations for the following events:

a. Typical smooth track near marker 11

b. Typical smooth track near marker 19

c. Rough track near marker 70

d. Rough track near marker 58

e. Switch near marker 5

f. One Inch Shims at 45 mph

g. One Inch Shims at 55 mph

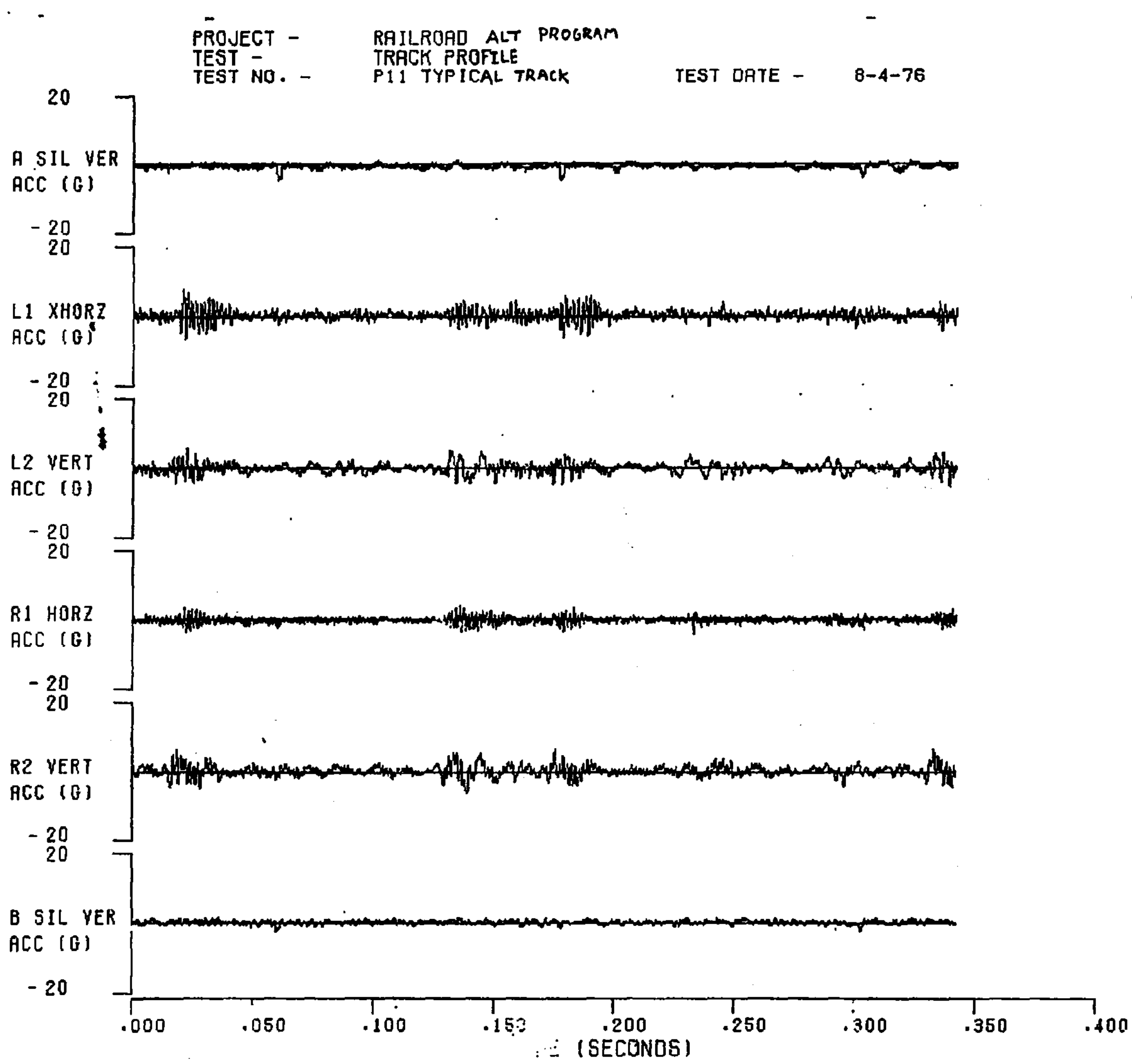


FIGURE C-1 TRACK CHARACTERIZATION ACCELERATION DATA TYPICAL SMOOTH TRACK NEAR MARKER 11

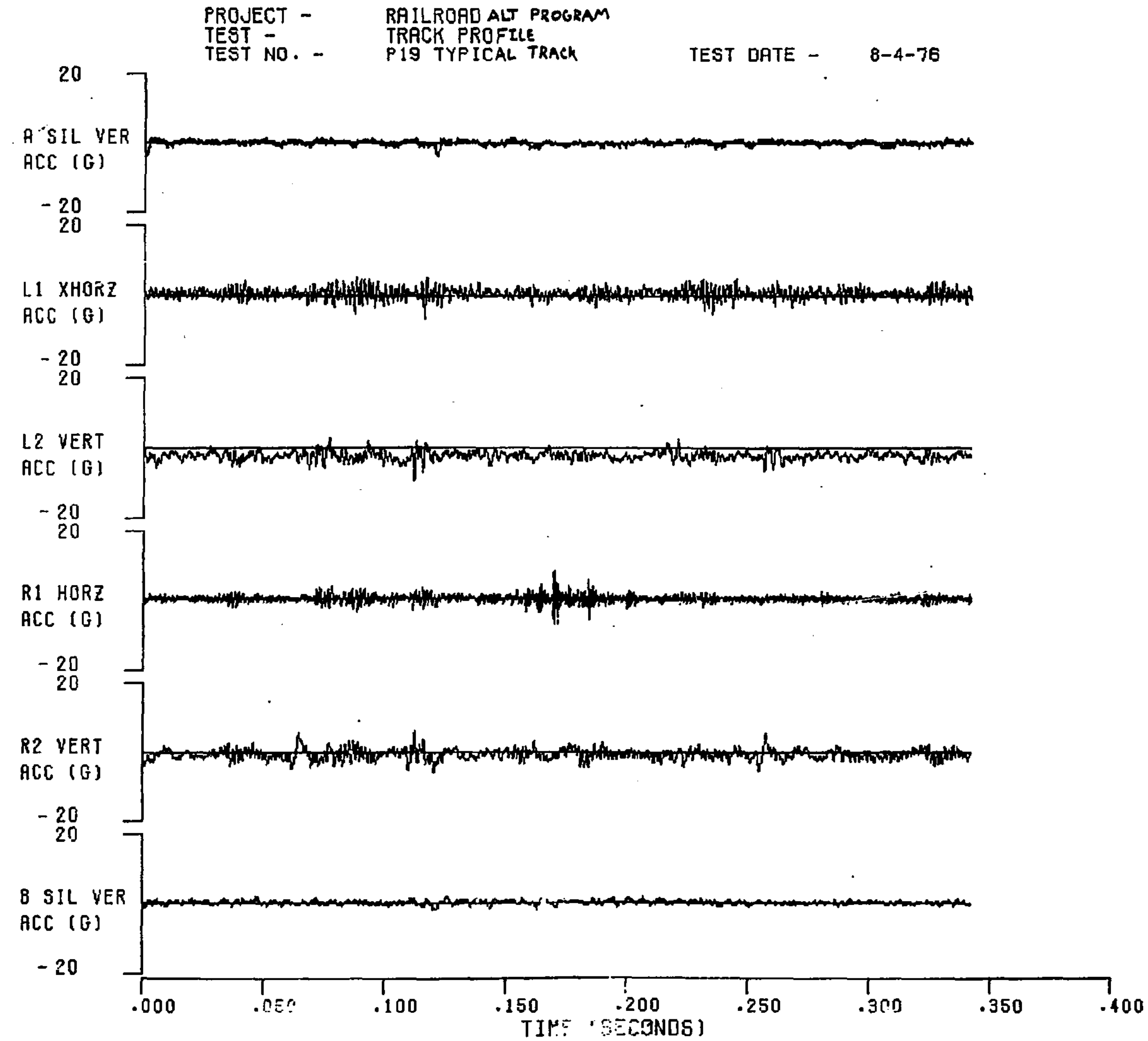


FIGURE C-2 TRACK CHARACTERIZATION ACCELERATION DATA TYPICAL SMOOTH TRACK NEAR MARKER 19

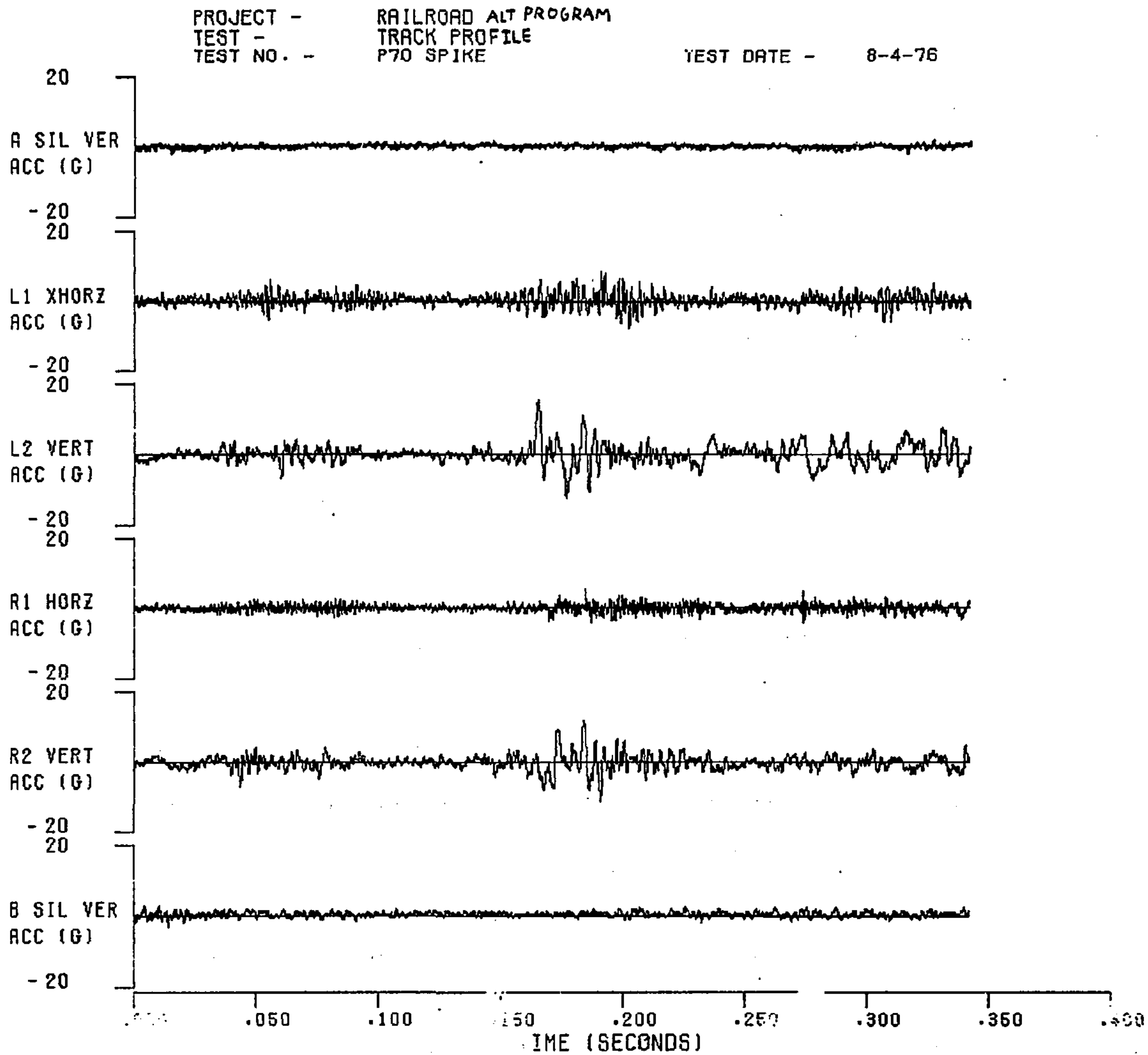


FIGURE C-3 TRACK CHARACTERIZATION ACCELERATION DATA ROUGH TRACK NEAR MARKER 70

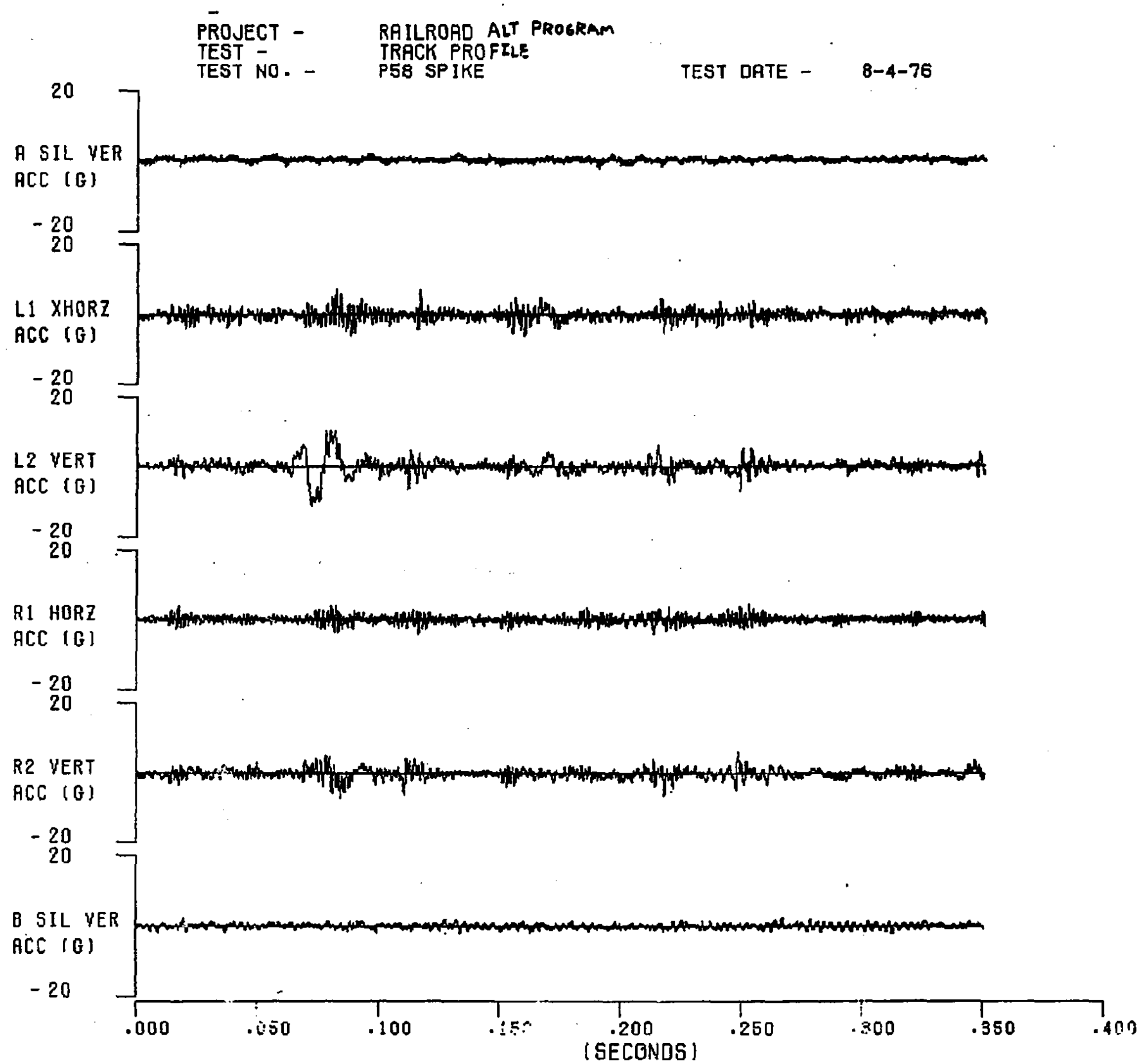


FIGURE C-4 TRACK CHARACTERIZATION ACCELERATION DATA ROUGH TRACK NEAR MARKER 58

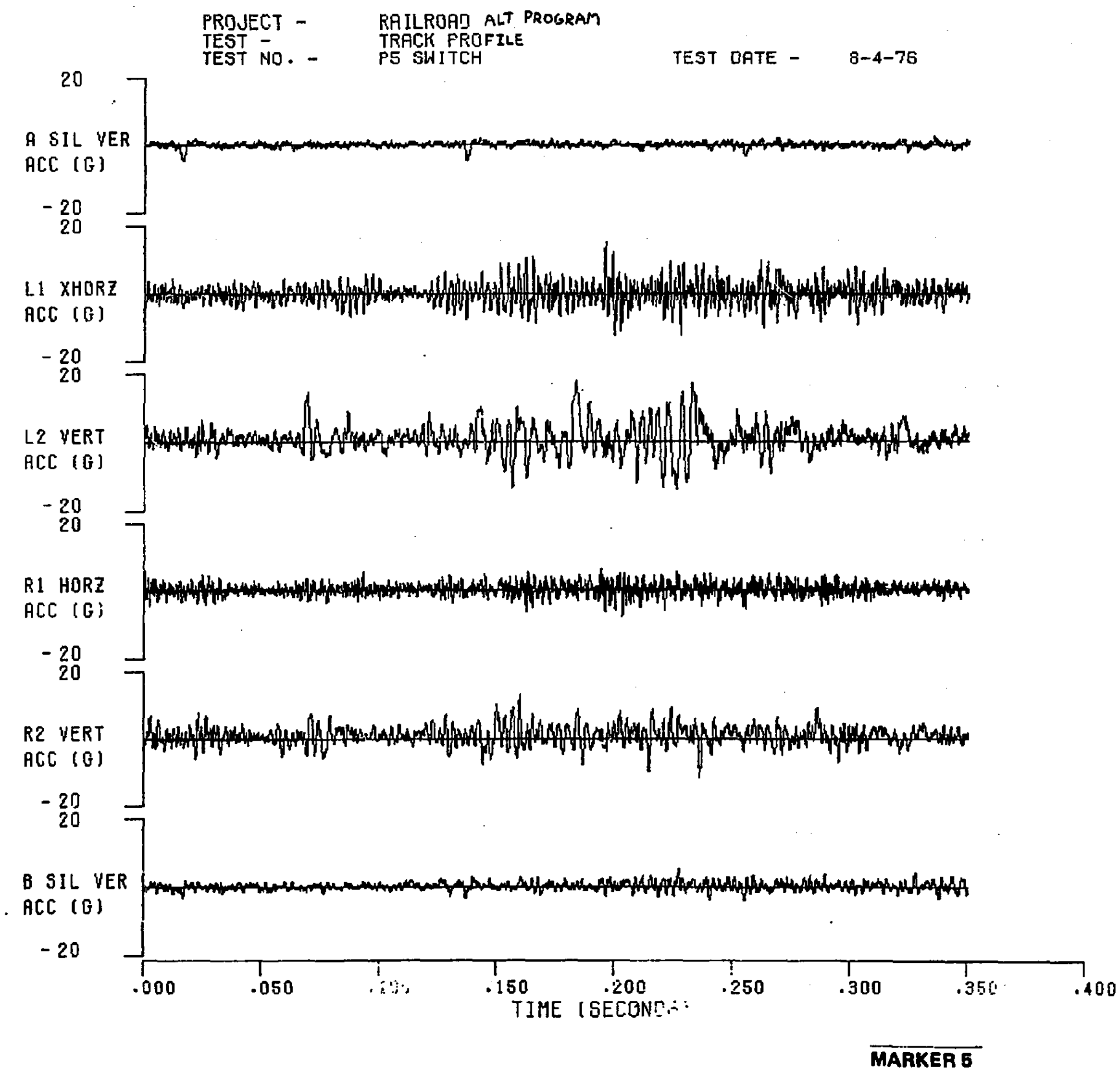


FIGURE C-5 TRACK CHARACTERIZATION ACCELERATION DATA SWITCH NEAR

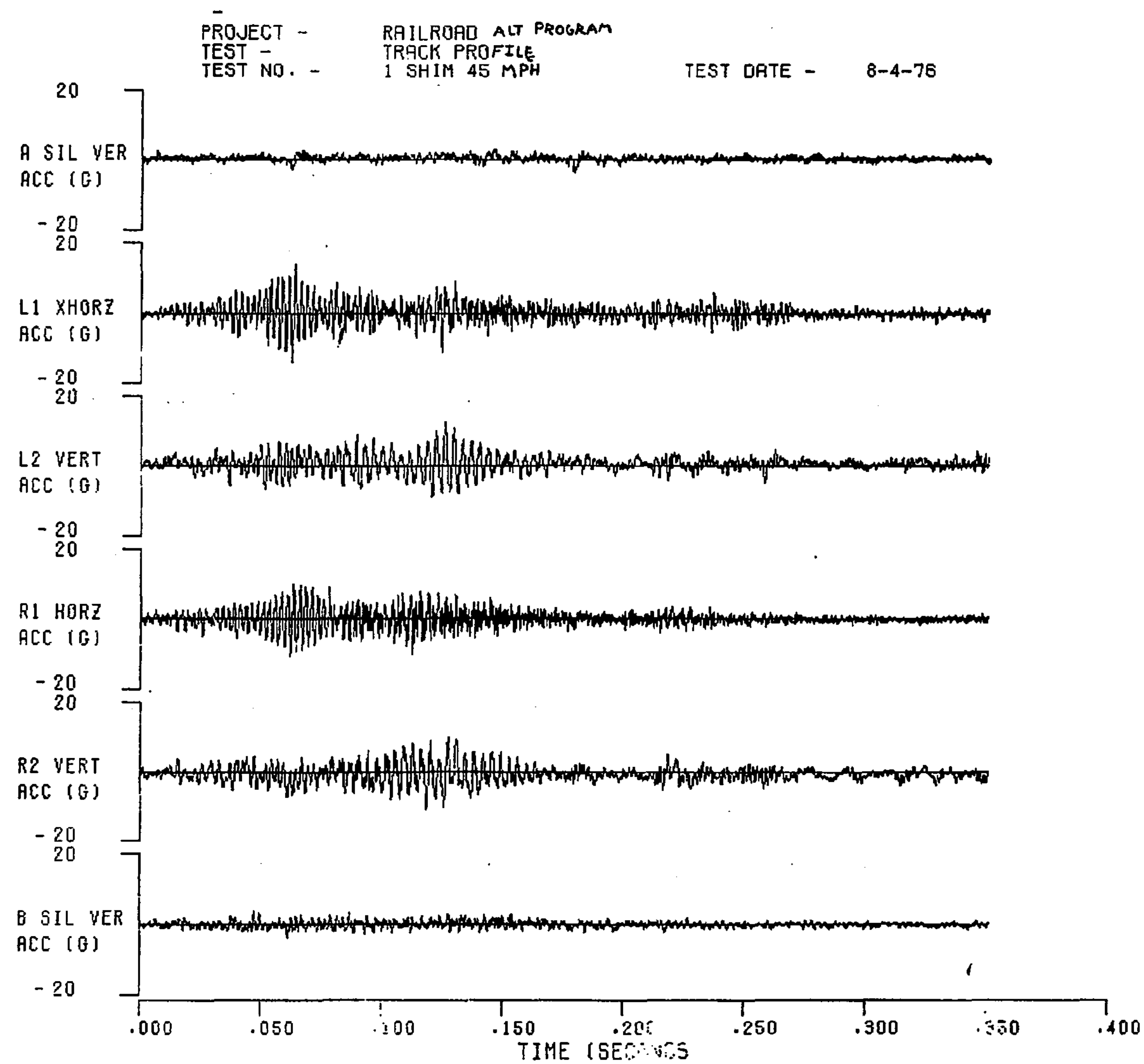


FIGURE C-6 TRACK CHARACTERIZATION ACCELERATION DATA ONE INCH SHIMS AT 45 MPH

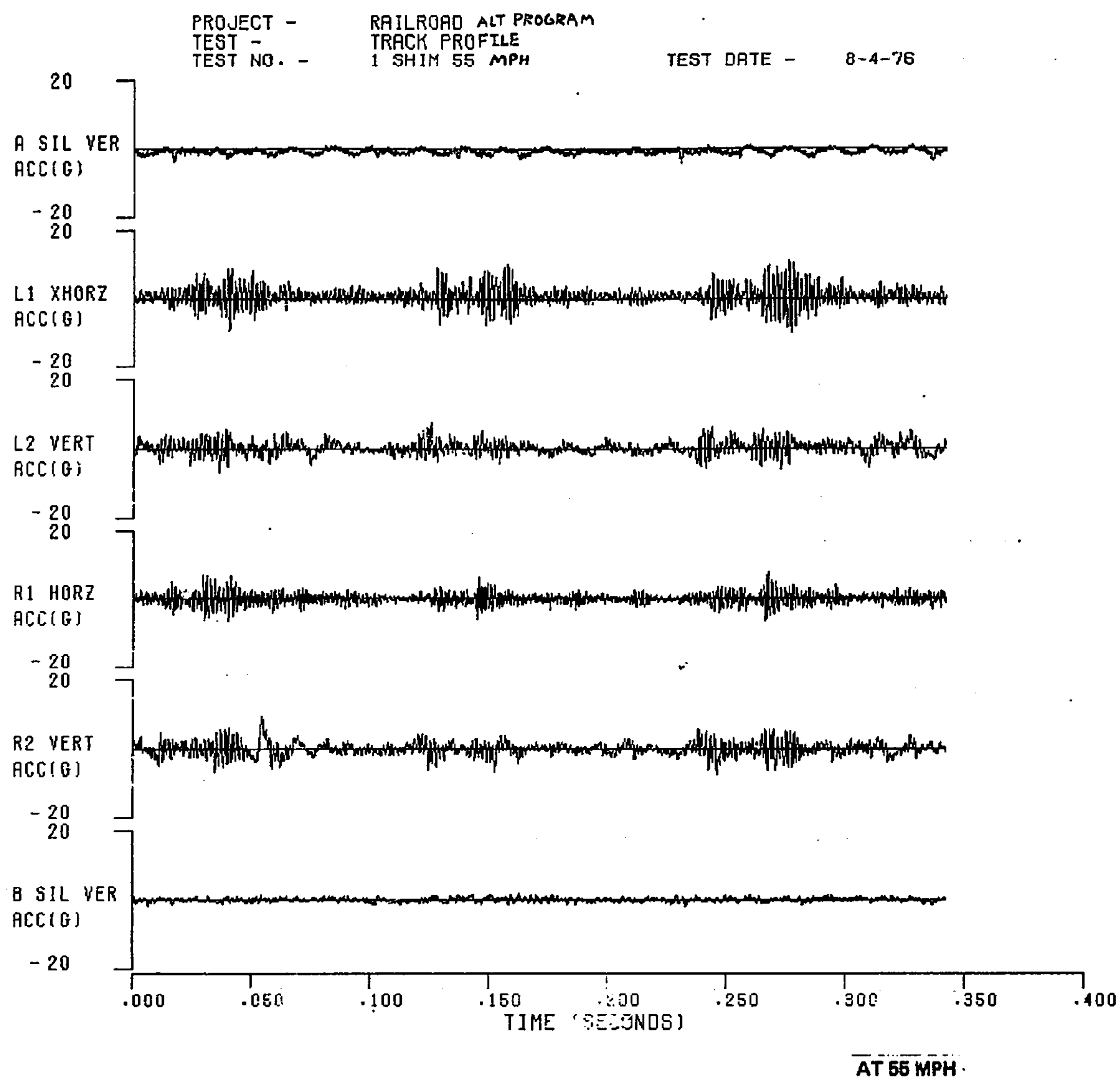


FIGURE C-7 TRACK CHARACTERIZATION ACCELERATION DATA ONE INCH SHIMS

APPENDIX D

TRACK CHARACTERIZATION MOTION DATA

D - 1 This appendix contains records of motion (acceleration, velocity and displacement) in the vertical direction of the end sill or the sideframe of the tank car taken during the track characterization tests. Records are given for motion due to the following:

a. Sideframe motion riding over smooth track

b. Sideframe motion due to track irregularity

c. Sideframe motion passing over track irregularity

d. Leading end sill motion due to passing over a switch at 55 mph

e. Sideframe motion due to passing over a switch at 45 mph

f. Sideframe motion passing over switch near station 5

g. Sideframe motion due to passing over a switch at 55 mph

h. Leading end sill motion due to 3/4" shims at 45 mph

i. Leading end sill motion due to passing over 3/4" shims at 55 mph

j. Sideframe motion due to passing over 3/4" shims at 45 mph

k. Sideframe motion passing over 3/4" shims at 45 mph

l. Trailing end sill motion passing over 3/4" shims at 45 mph

m. Trailing end sill motion passing over 3/4" shims at 55 mph

n. Trailing end sill motion due to passing over 3/4" shims at 55 mph

o. Leading end sill motion passing through 1" shim section at 55 mph

p. Leading end sill motion due to passing over 1" shims at 55 mph

q. Sideframe motion due to passing over 1" shims at 55 mph

r. Trailing end sill motion due to passing over 1" shims at 55 mph

D - 2 The velocity and displacement were obtained by integration and double integration of the acceleration records.

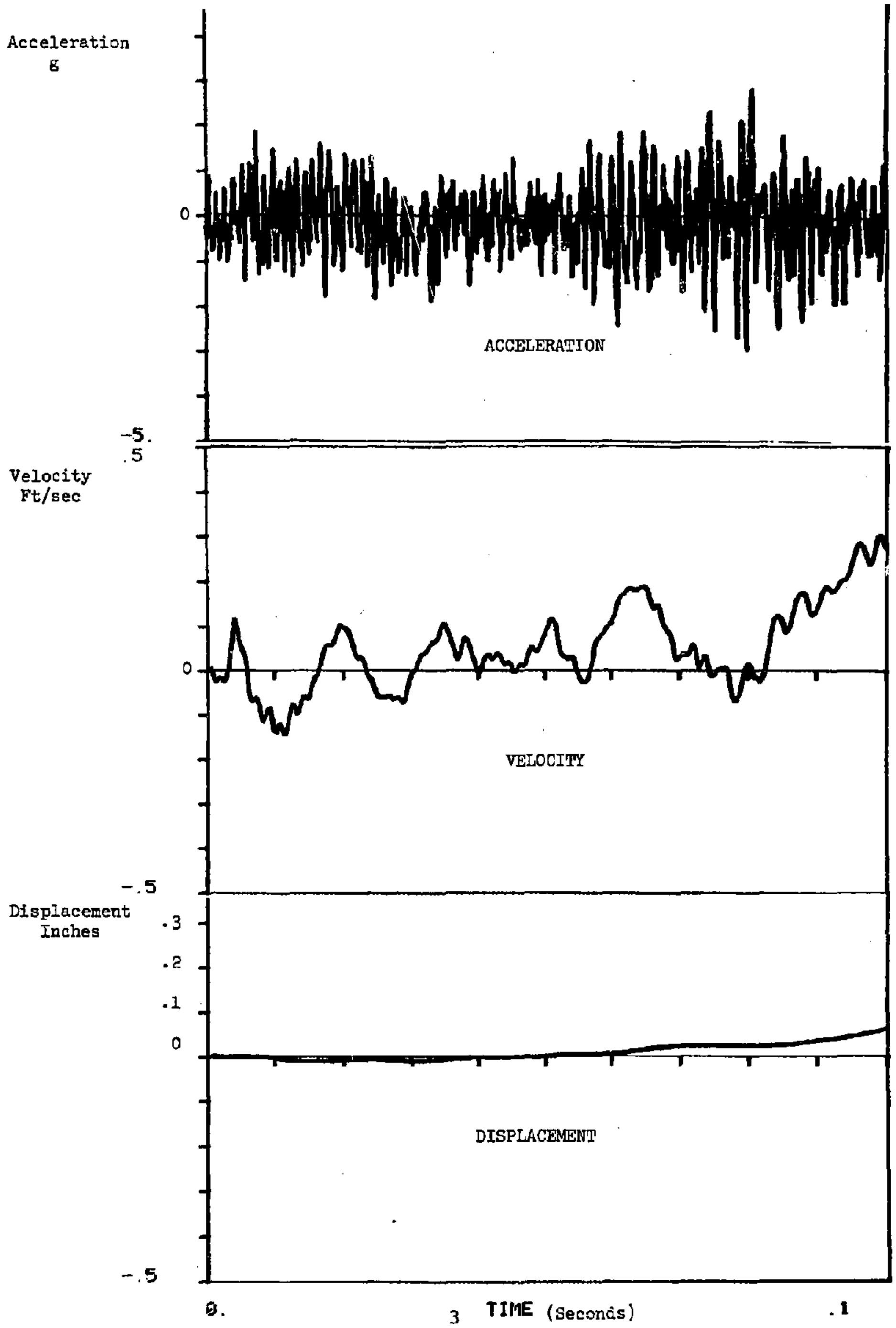


FIGURE D-1. SIDEFRAME MOTION RIDING OVER SMOOTH TRACK

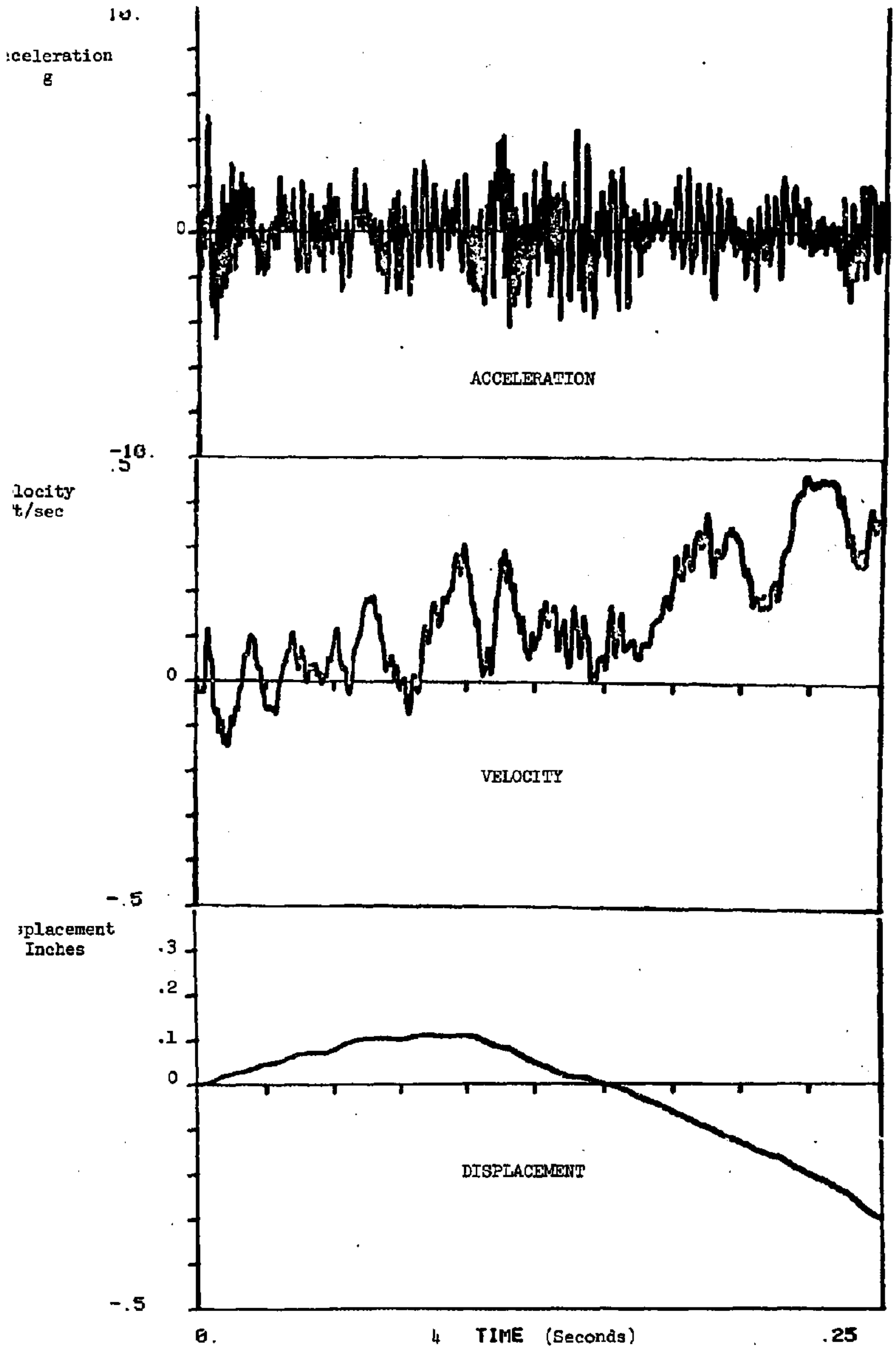


FIGURE D-2. SIDEFRAME MOTION DUE TO TRACK IRREGULARITY

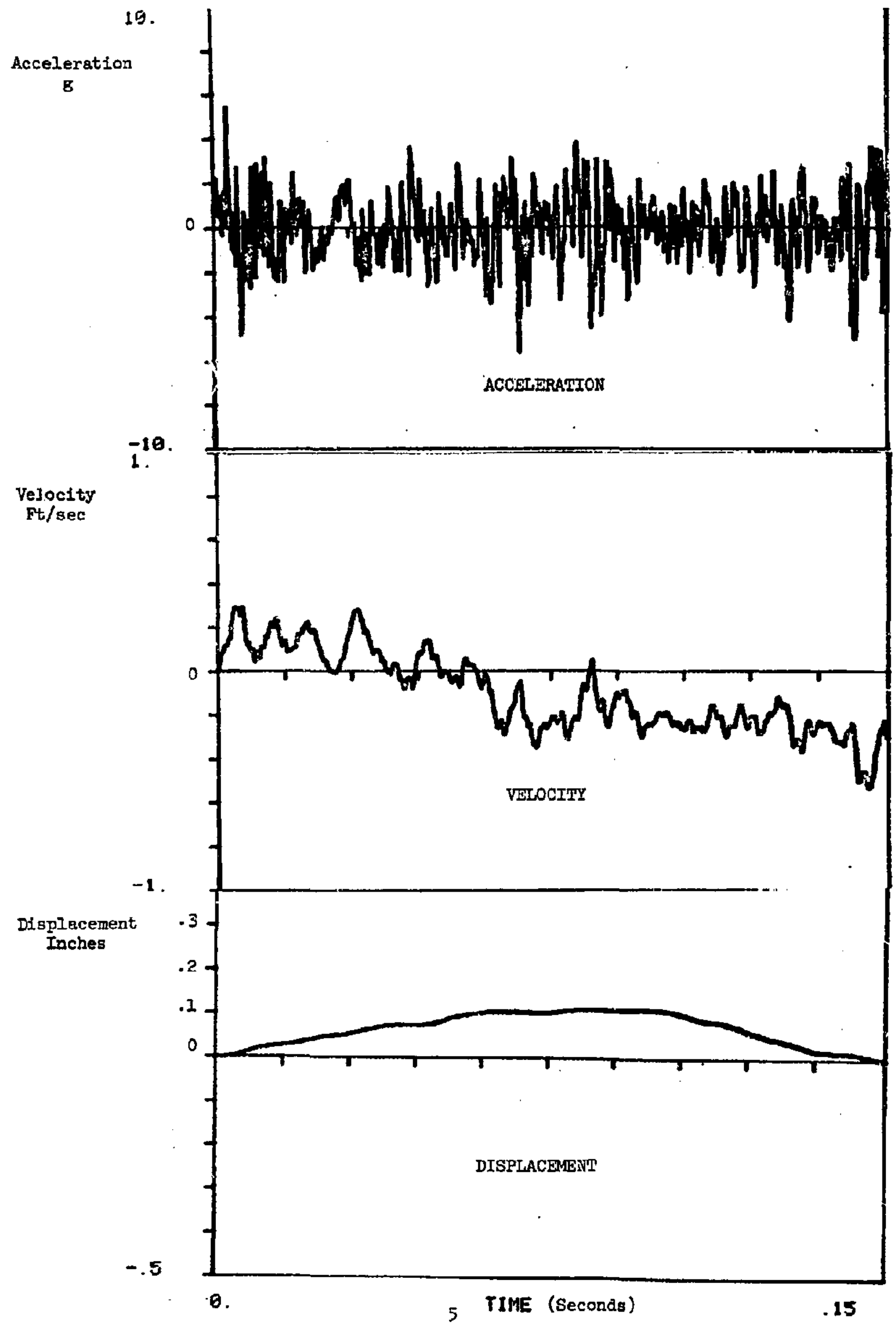


FIGURE D-3. SIDEFRAME MOTION PASSING OVER TRACK IRREGULARITY

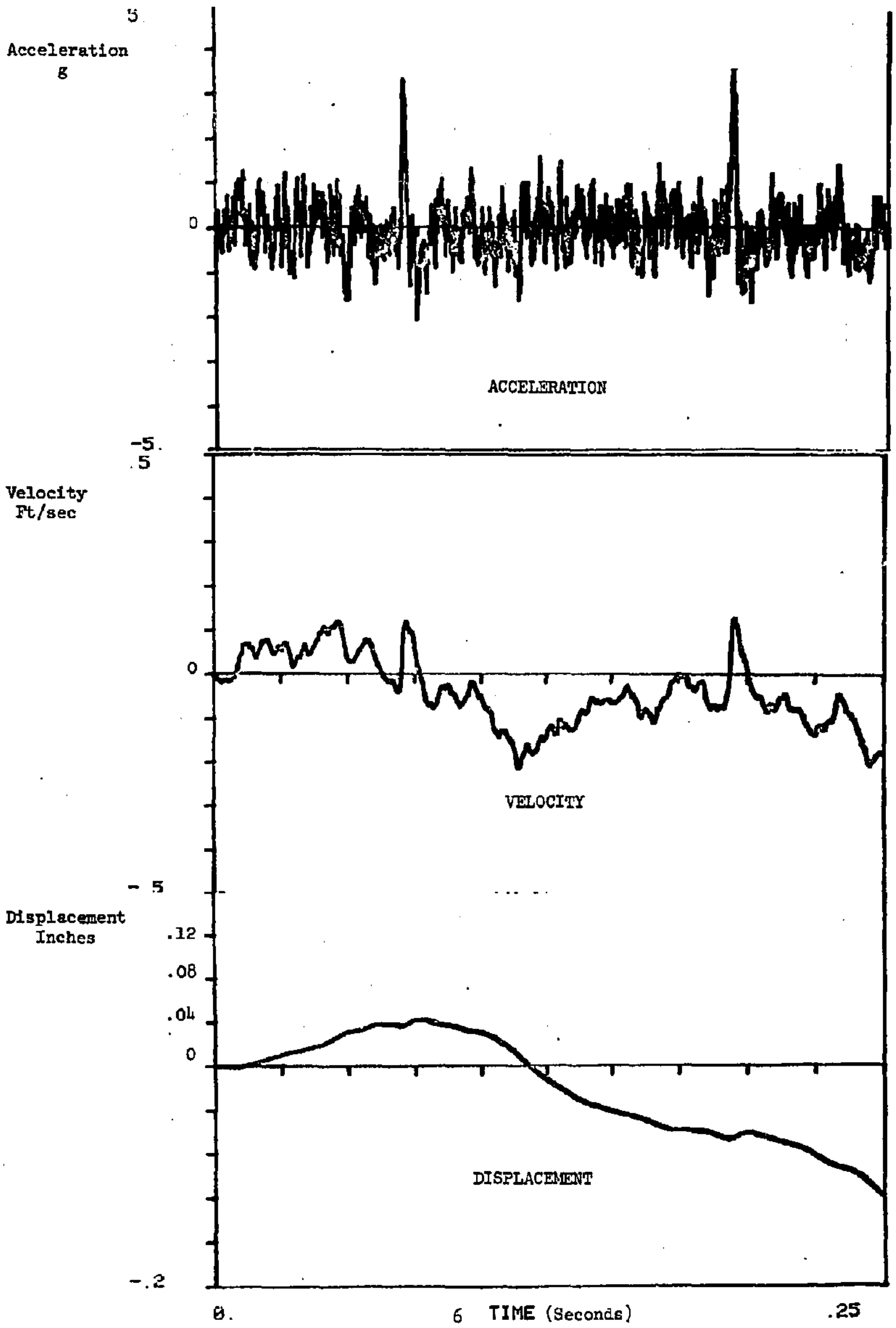


FIGURE D-4. LEADING END SILL MOTION DUE TO PASSING OVER A SWITCH AT 55 MPH

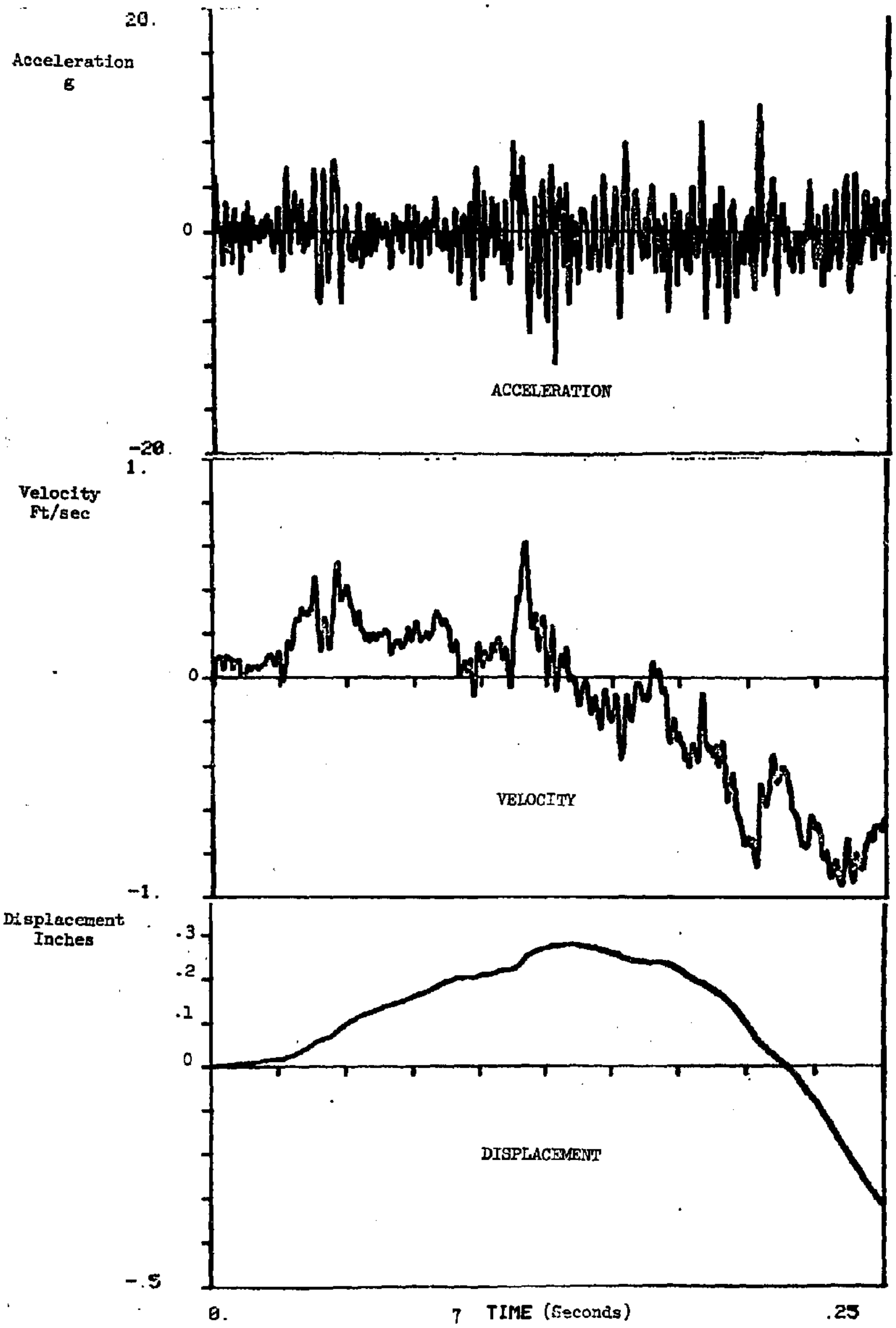


FIGURE D-5. SIDEFRAME MOTION DUE TO PASSING OVER A SWITCH AT 45 MPH

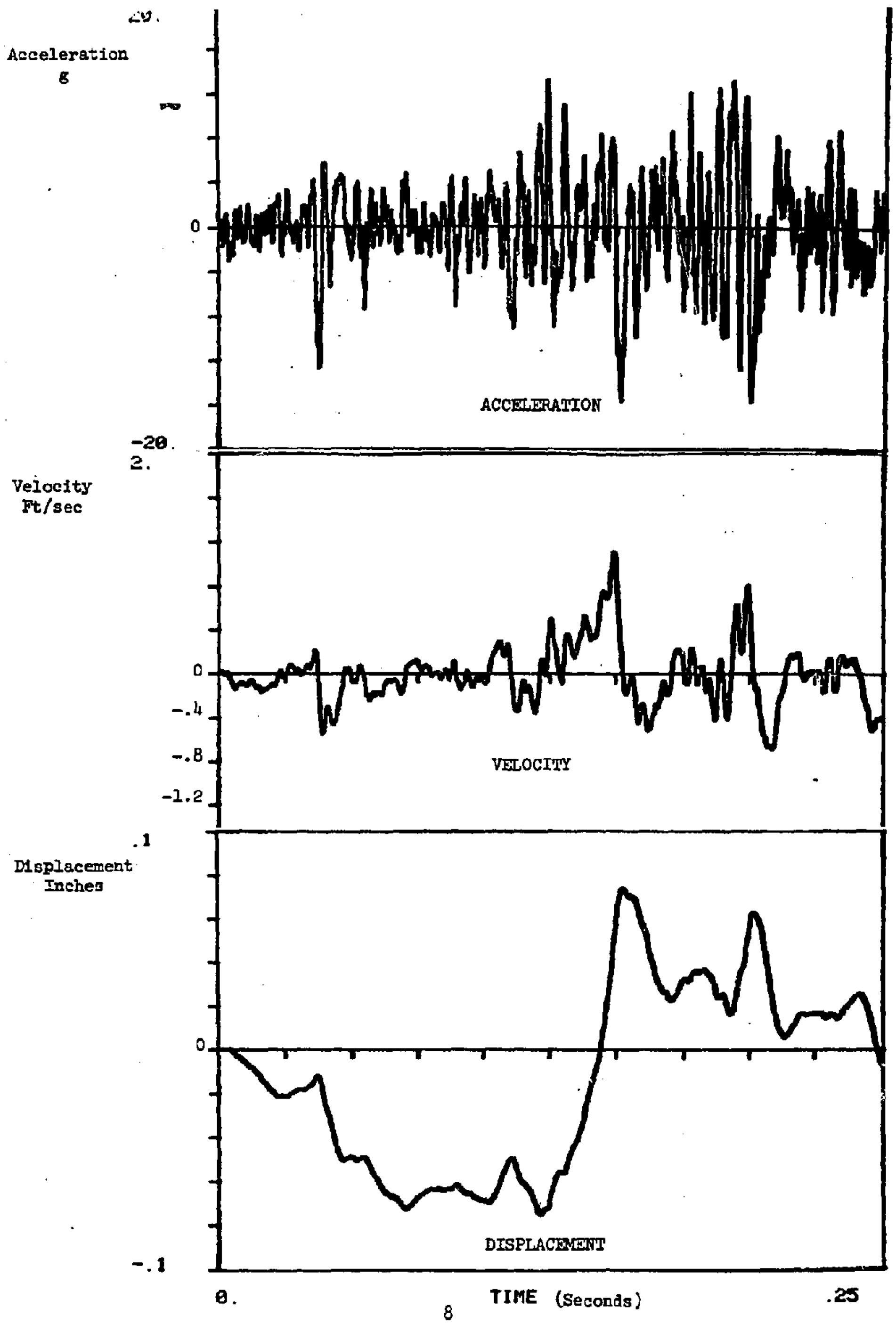


FIGURE D-6. SIDEFRAME MOTION PASSING OVER A SWITCH NEAR STATION 5

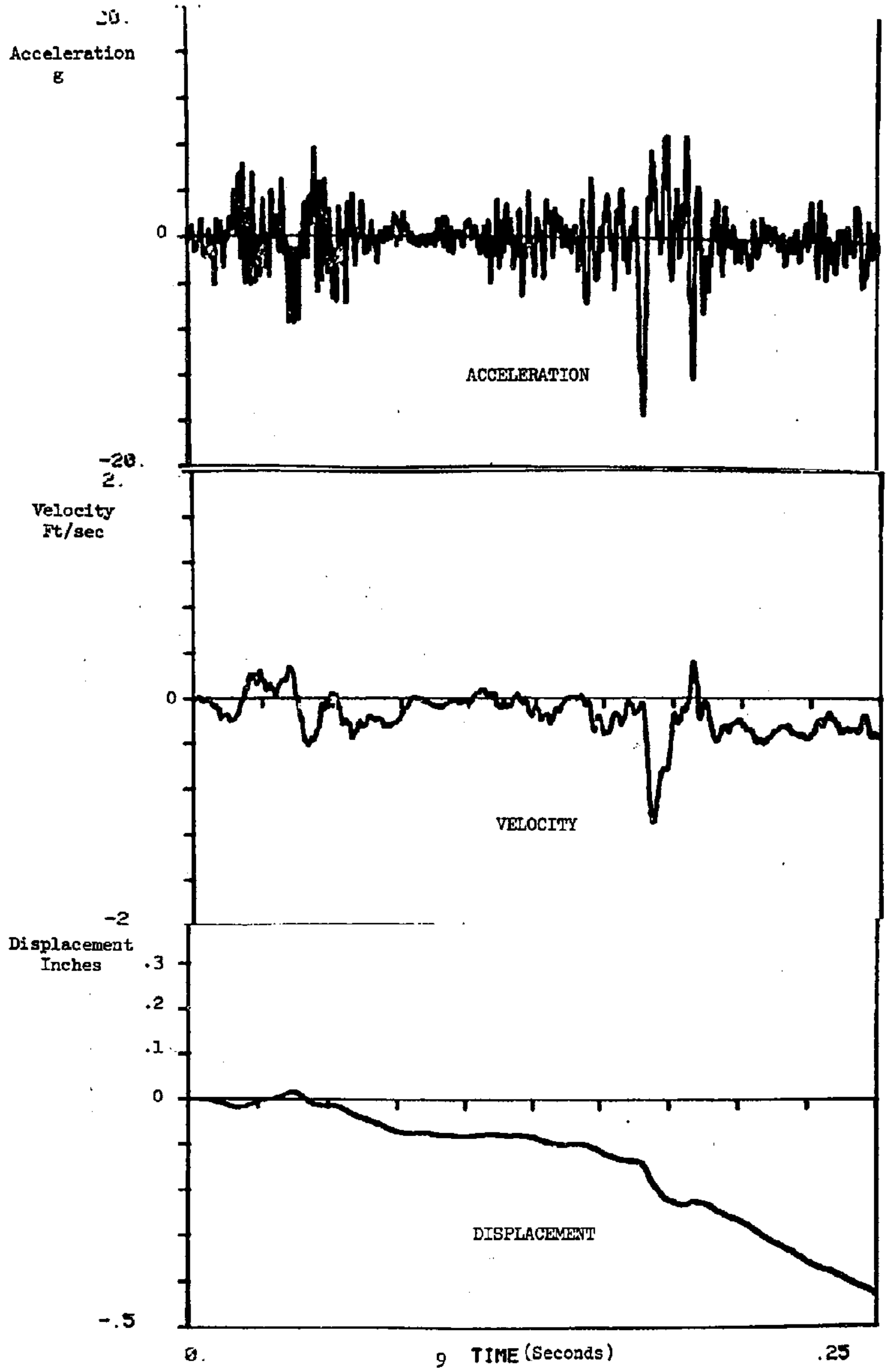


FIGURE D-7. SIDEFRAME MOTION DUE TO PASSING OVER A SWITCH AT 55 MPH

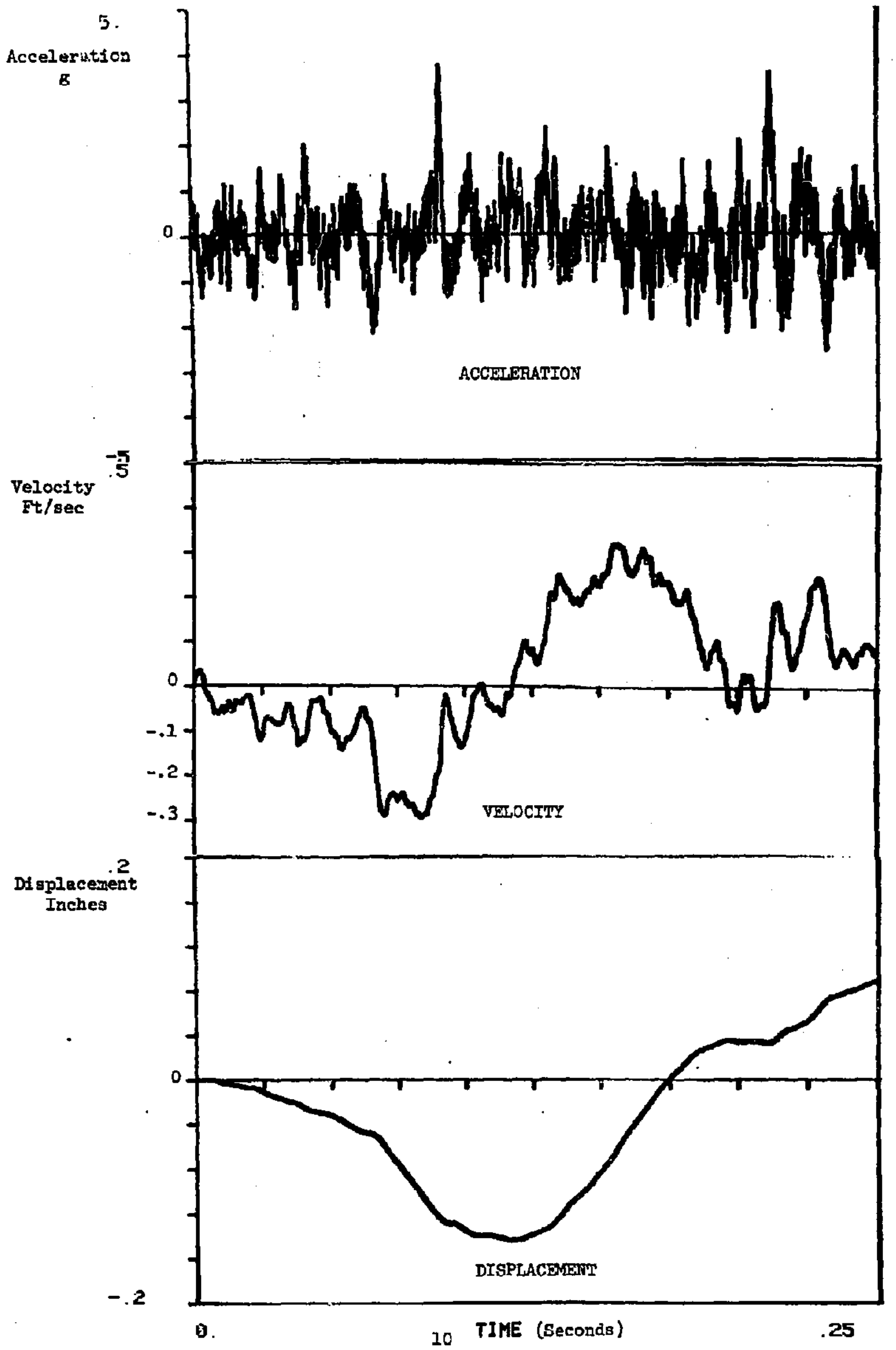


FIGURE D-8. LEADING END SILL MOTION DUE TO 3/4" SHIMS AT 45 MPH

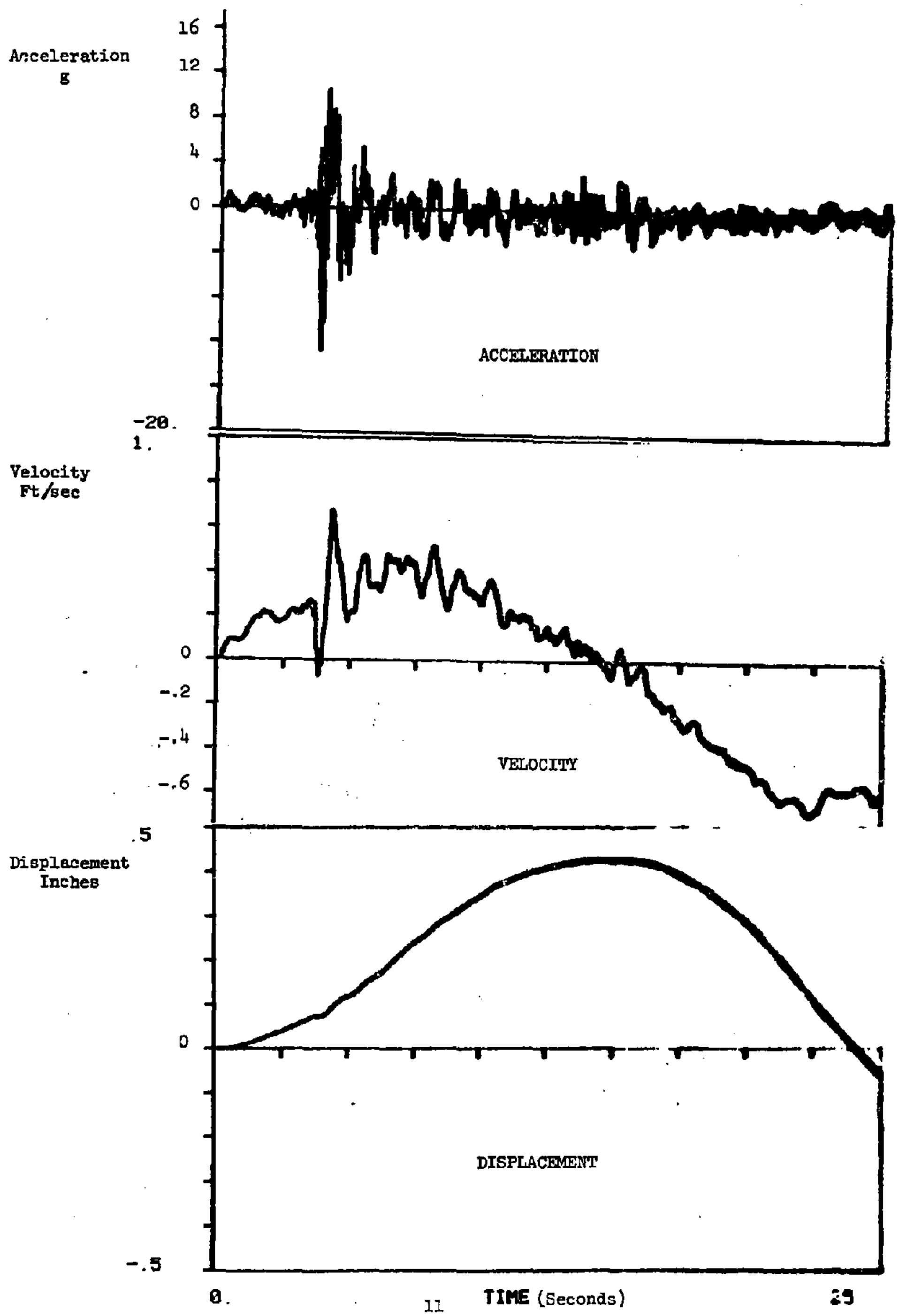


FIGURE D-9. LEADING END SILL MOTION DUE TO PASSING OVER 3/4" SHIMS AT 55 MPH

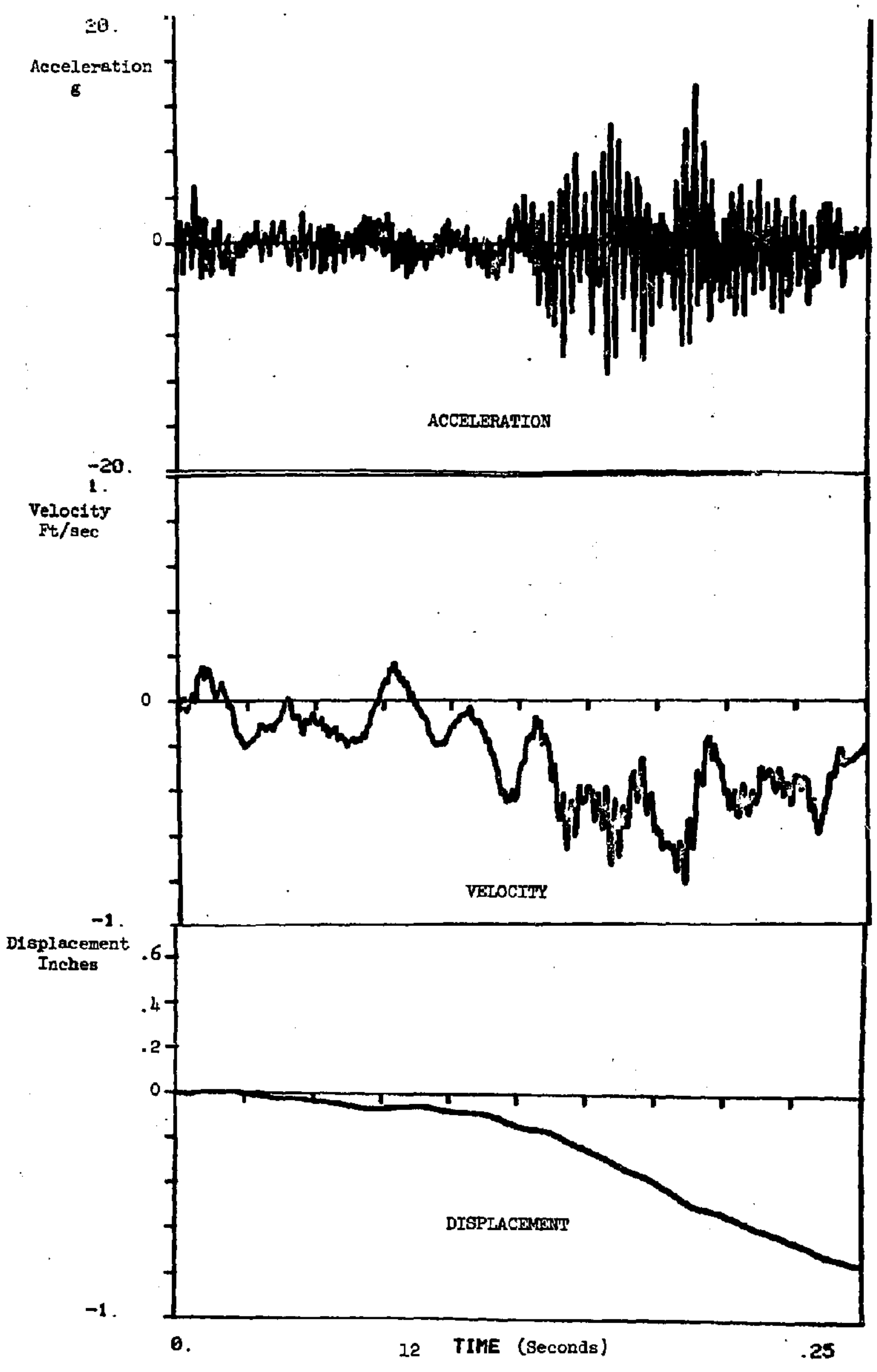


FIGURE D-10. SIDEFRAME MOTION DUE TO PASSING OVER 3/4" SHIM AT 45 MPH

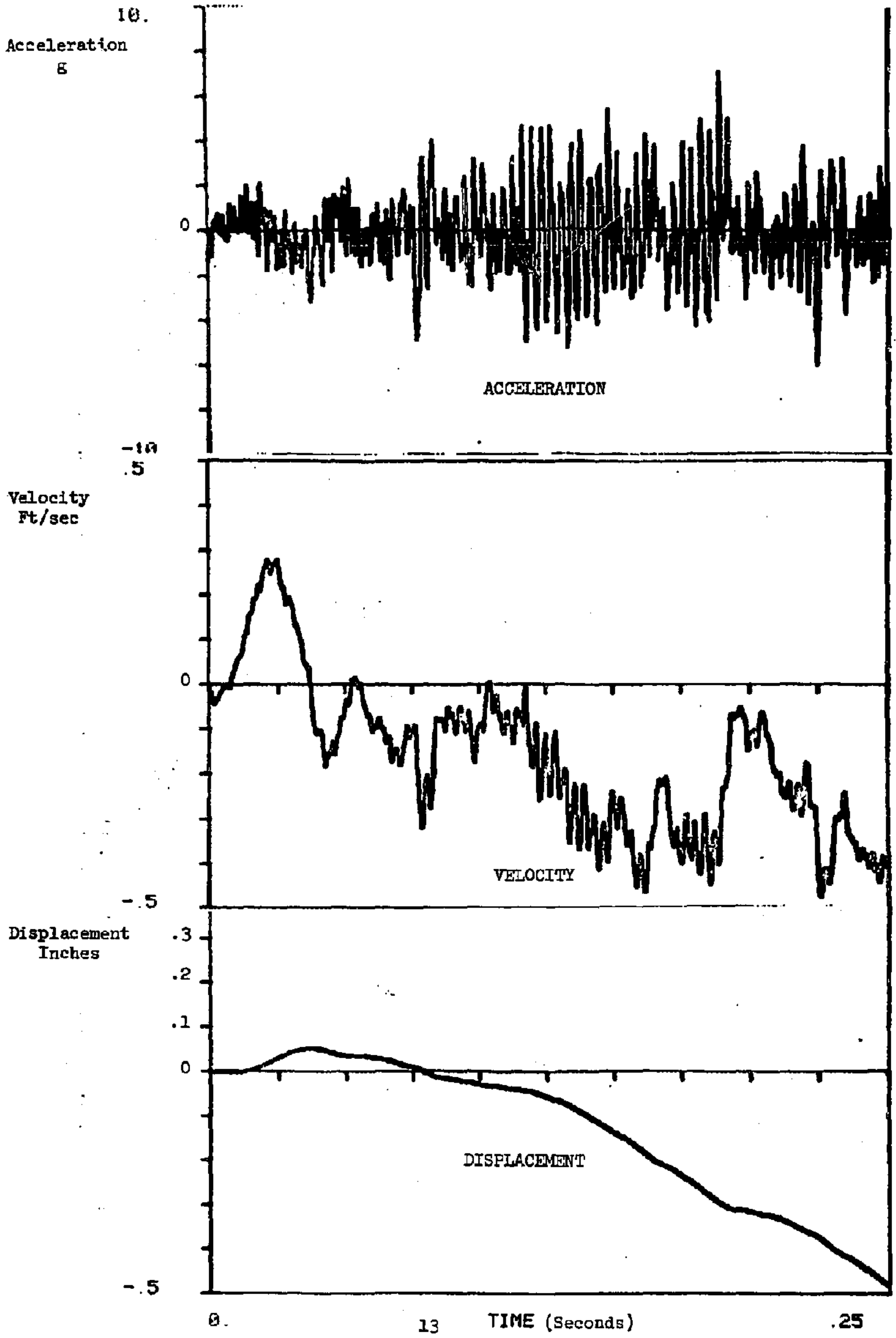


FIGURE D-11. SIDEFRAME MOTION PASSING OVER 3/4" SHIMS AT 45 MPH

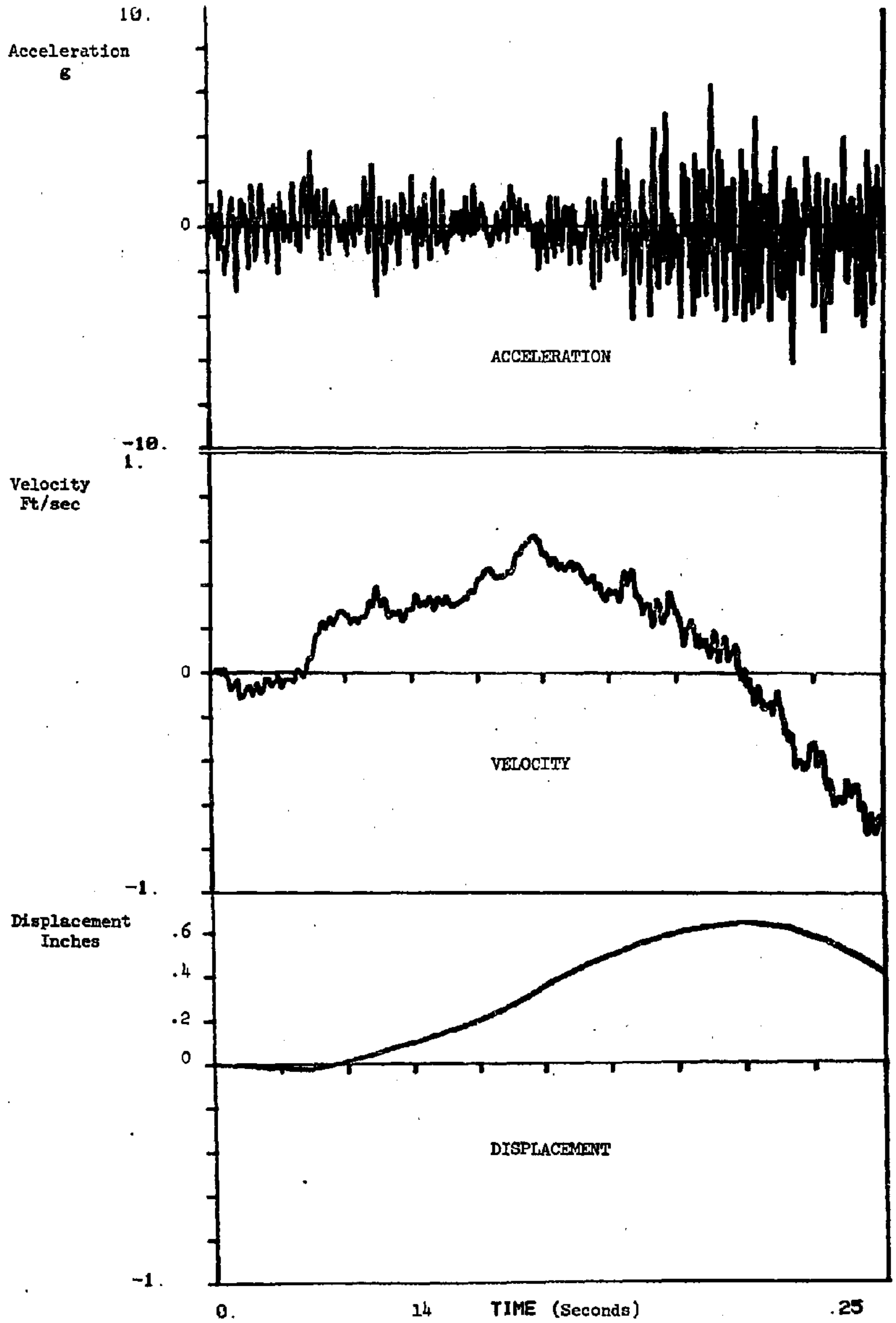


FIGURE D-12. TRAILING END SILL MOTION PASSING OVER 3/4" SHIMS AT 45 MPH

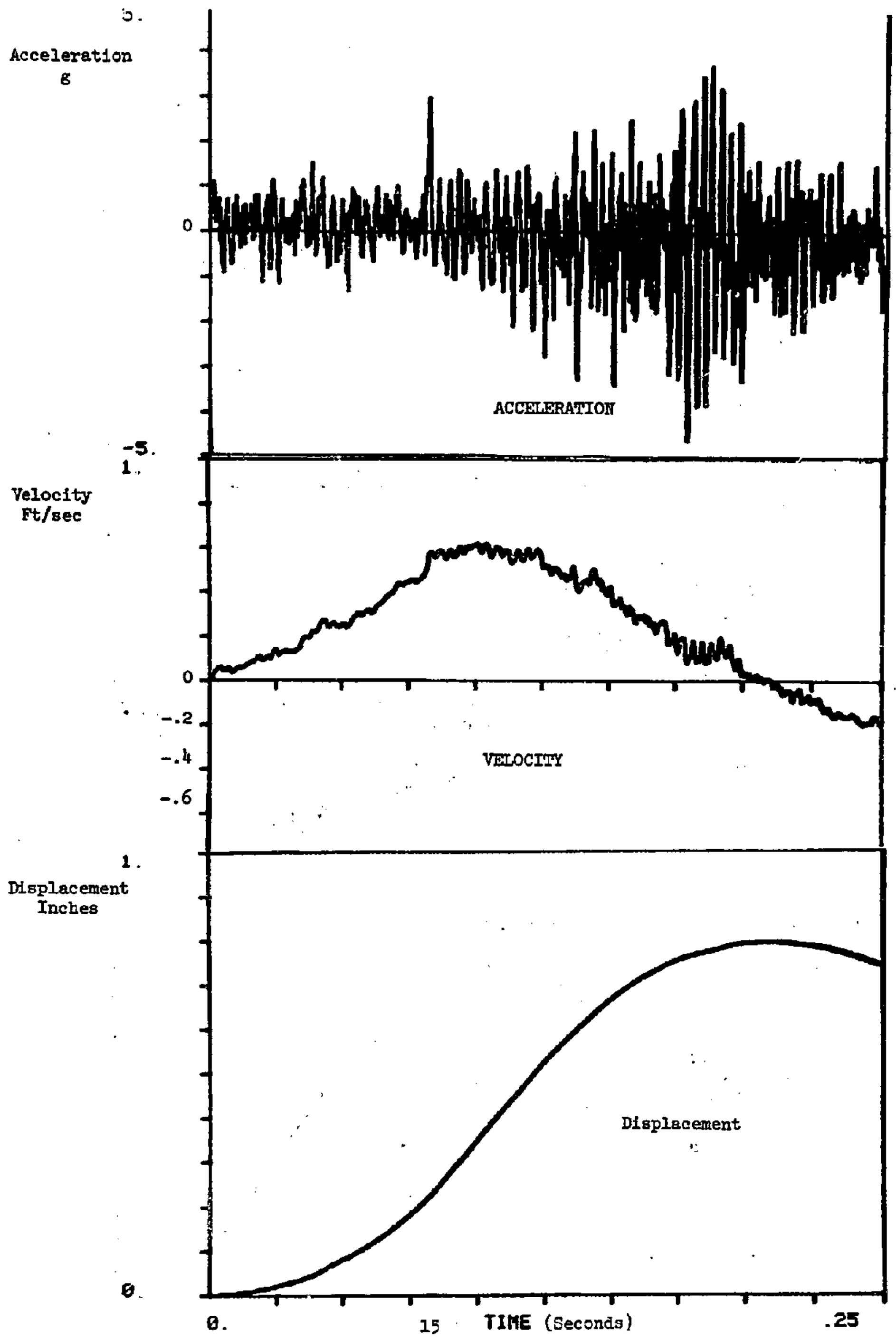


FIGURE D-13. TRAILING END SILL MOTION PASSING OVER 3/4" SHIM AT 55 MPH

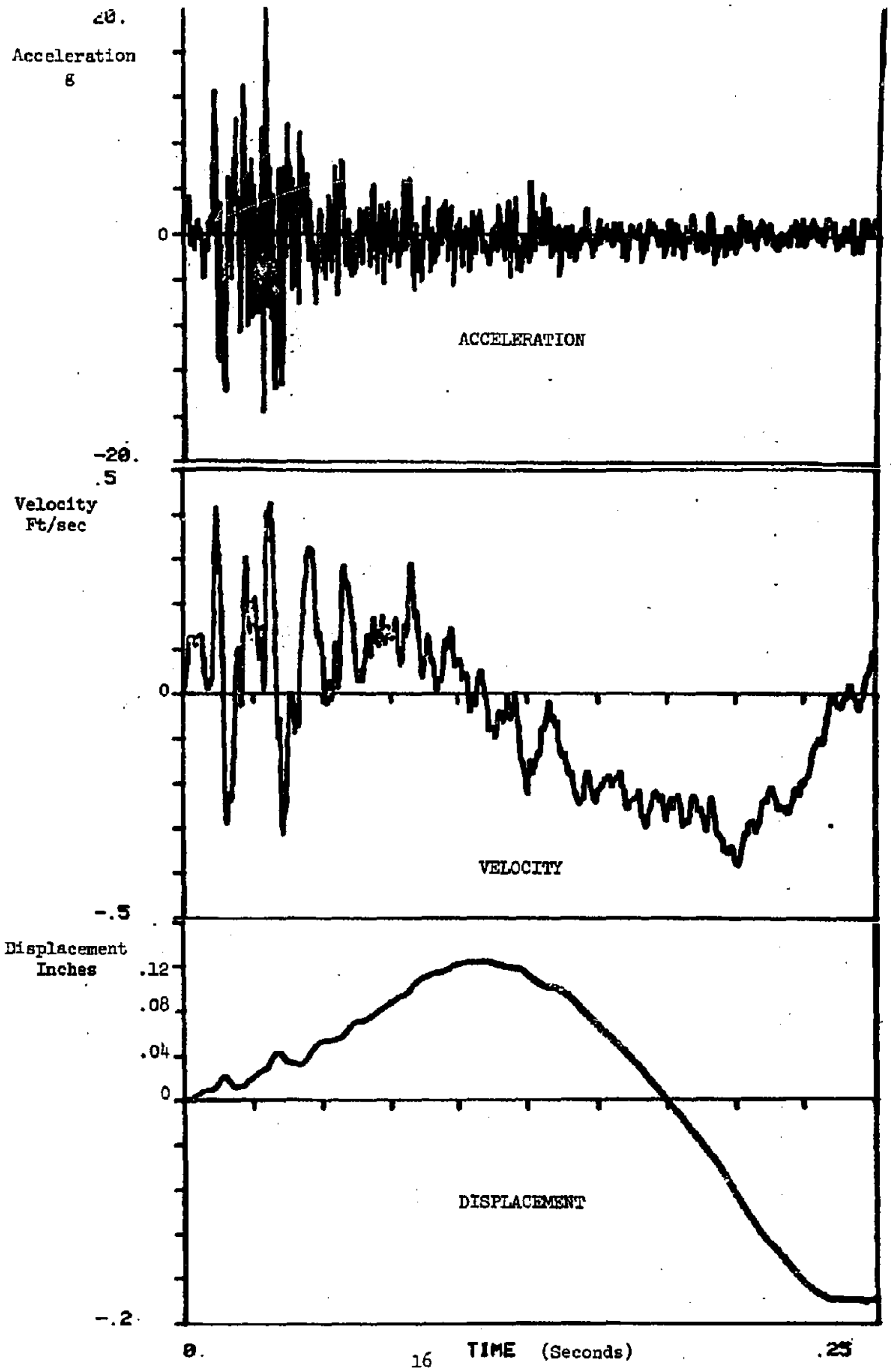


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FIGURE D-14. TRAILING END SILL MOTION DUE TO PASSING OVER 3/4" SHIMS AT 55 MPH

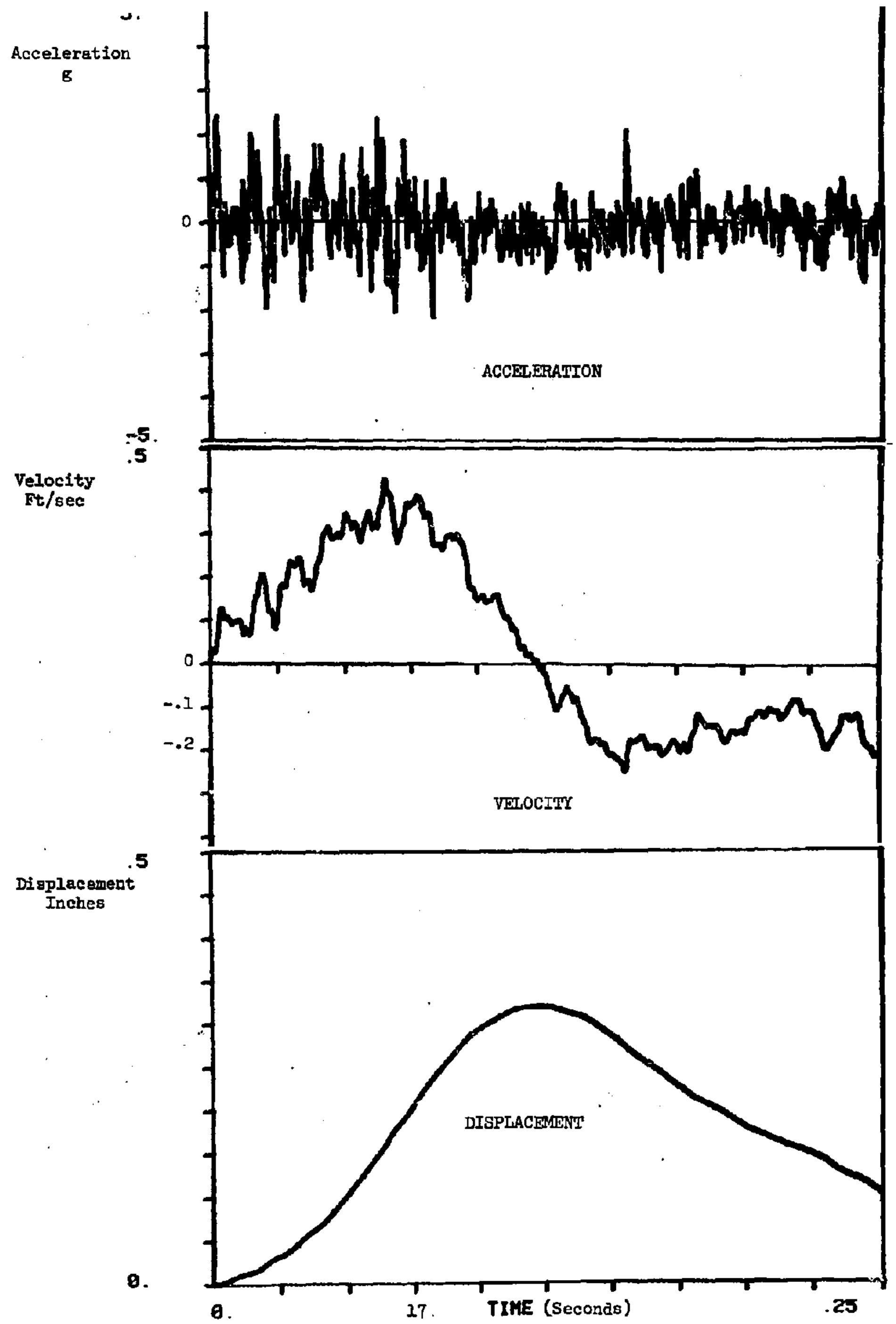

FIGURE D-15. LEADING END SILL MOTION PASSING THROUGH 1" SHIM SECTION AT 55 MPH

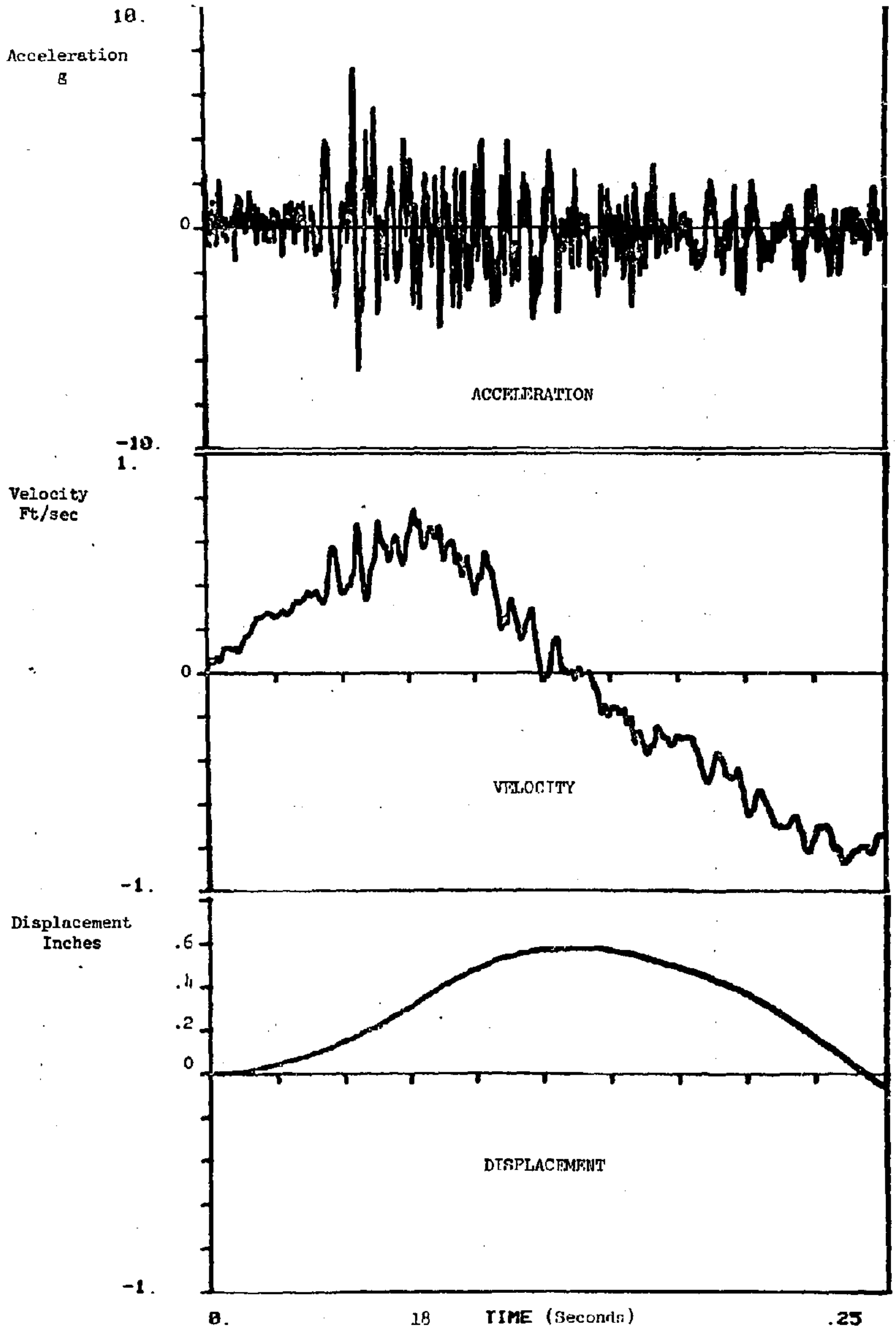

FIGURE D-16. LEADING END SILL MOTION DUE TO PASSING OVER 1" SHIMS AT 55 MPH

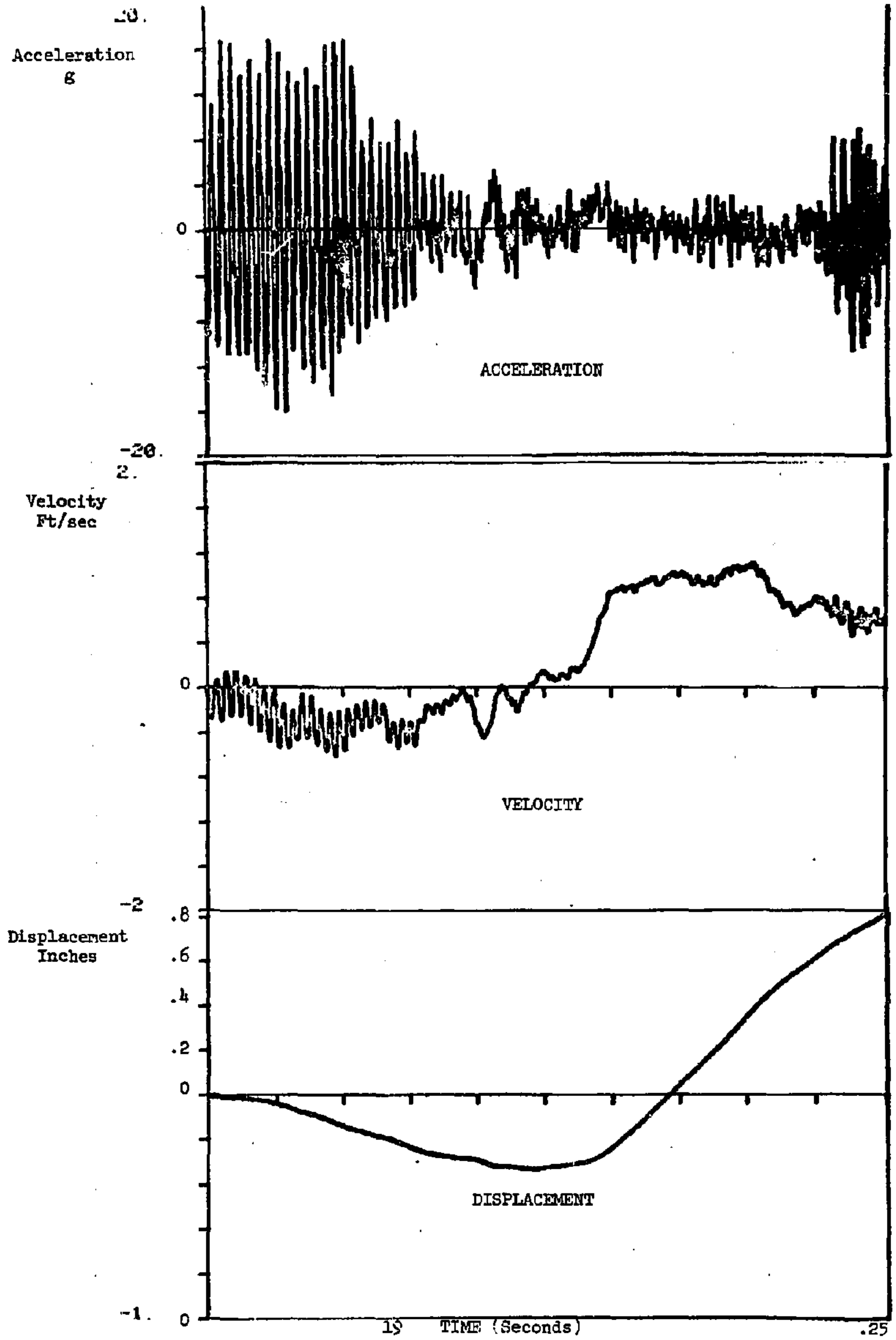

FIGURE D-17. SIDEFRAME MOTION DUE TO PASSING OVER 1" SHIMS AT 55 MPH

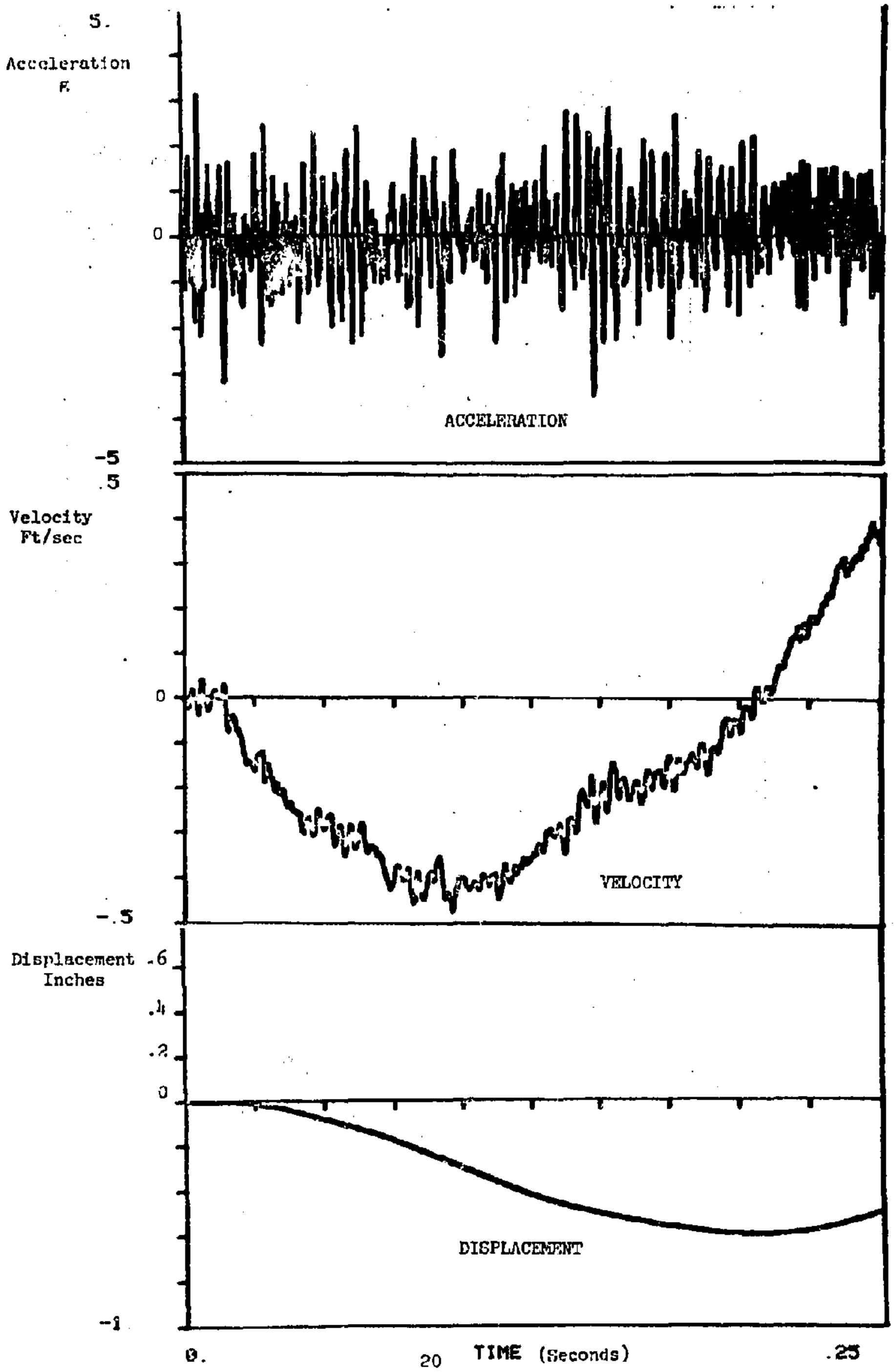

FIGURE D-18. TRAILING END SILL MOTION DUE TO PASSING OVER 1" SHIMS AT 55 MPH

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