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of Transportation
Federal Railroad Administration

Locomotive Crashworthiness Impact Test No.2: Test Procedures, Instrumentation, and Data

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13. ABSTRACT

A full-scale locomotive impact test was performed September 10, 2002. The test involved a SD-45 locomotive, modified to meet AAR Specification S-580, and three trailing loaded hopper cars impacting a stationary log truck at a grade crossing at 50.4 mph.

The locomotive broke through the logs and continued down the track. The 3/8-inch steel sheet covering the short hood of the locomotive was significantly deformed, but the collision posts and anti-climber remained intact. Although no logs hit the windshield of the locomotive, there were high strains on the windshield center-post. The loads measured during the impact on the ATD (test dummy) in the driver's seat showed values well below NHTSA proposed injury criteria.

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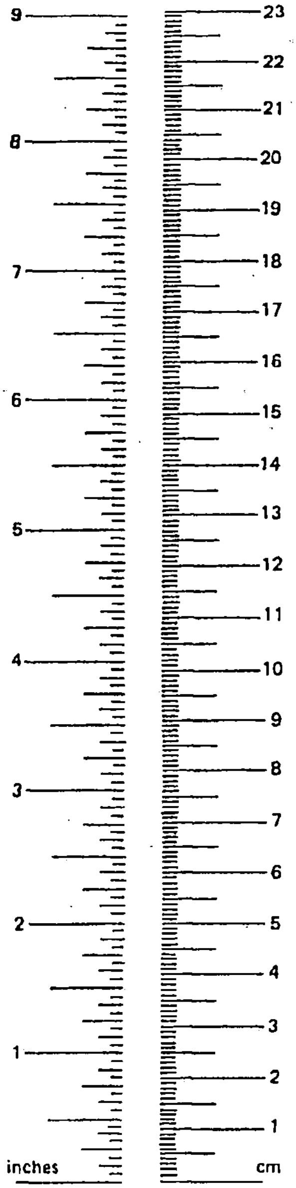
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

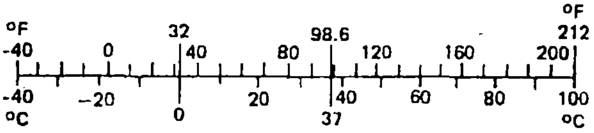
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
		MASS (weight)		
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
		VOLUME		
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	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

* 1 in. = 2.54 cm (exactly)



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
		AREA		
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	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	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius° temperature	9/5 (then add 32	Fahrenheit temperature	°F



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This work was performed as part of the Equipment Safety Research Program sponsored by the Office of Research and Development of the Federal Railroad Administration. John Punwani, Program Manager, and Claire Orth, Division Chief, Equipment and Operating Practices Division, Office of Research and Development, Federal Railroad Administration, supported this effort. Gunars Spons, Federal Railroad Administration Engineering Manager at the Transportation Technology Center, directed and coordinated the activities of all the parties involved in the test. Russell Walker and Mark White, Transportation Technology Center, Inc. implemented the test. Gopal Samavedam, Vice President, Foster Miller, coordinated the technical requirements.

Sharma and Associates designed the cab and modifications to the locomotive, which were carried out by National Rail Equipment.

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Executive Summary

A full-scale locomotive impact test was performed September 10, 2002, at the Federal Railroad Administration's (FRA) Transportation Technology Center (TTC), Pueblo, Colorado. The test involved a SD-45 locomotive, modified to meet Association of American Railroads Specification S-580, and three trailing loaded hopper cars impacting a stationary log truck on a grade crossing at 50.4 mph.

The impact caused a large amount of damage to the sheet steel covering the short hood of the locomotive, which broke through the logs and continued down the track without derailing. The anti-climber and collision posts of the locomotive were undamaged. All of the logs were broken in two and the rear axles of the log trailer were thrown clear of the roadway and railway track. The fuel tank of the locomotive hit the frame extension of tractor/trailer and bent it by about 6-inches at the end. The rear axle of the tractor slid about 6 ½ feet along the railway track as the front axle of the tractor remained at its original location. The semi-truck remained upright throughout the impact.

The test was carried out to evaluate the structural crashworthiness of the locomotive in an impact with a loaded log truck. Strains, displacements, and accelerations were measured on the locomotive and hopper cars during the impact to allow correlation of test results with analytical predictions. Tri-axial accelerometers were mounted on the locomotive floor, on the rear of a collision post to which an event recorder was attached, and on the first and second trailing hopper cars. Longitudinal, lateral, and vertical displacements were measured on each coupler between the locomotive and the first hopper car. The longitudinal force between the locomotive and first hopper car was measured with an instrumented coupler. Strains were measured on the collision posts, the center post of the windshield, and the underframe of the locomotive. An instrumented anthropomorphic test device (ATD) was positioned in the locomotive engineer's seat.

Transportation Technology Center, Inc. carried out the planning and execution of the test. Under separate contracts with the FRA, Sharma & Associates designed the locomotive modifications, National Rail Equipment carried out the modifications, and Foster Miller, Inc. coordinated the technical requirements for the test and performed analytical modeling of the impact.

This report describes the test and presents the measured data. The correlation of the test results with analytical results will be the subject of another report.

Main Results

- The maximum longitudinal acceleration recorded on the floor of the locomotive was 183 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to 11 g.
- The maximum lateral acceleration recorded on the floor of the locomotive was 121 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to 8 g.

- The maximum vertical acceleration recorded on the floor of the locomotive was 108 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to 11 g.
- The maximum longitudinal acceleration recorded on the event recorder was 69 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to 17 g.
- The maximum lateral acceleration recorded on the event recorder was 79 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to 11 g.
- The maximum vertical acceleration recorded on the event recorder was 72 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to 18 g.
- A peak load of 366 kips was recorded in the instrumented coupler between the locomotive and the first hopper car.
- A maximum strain of 1,547 microstrain was measured on the collision posts of the locomotive during the impact.
- A maximum strain of 644 microstrain was measured on the underframe of the locomotive during the impact.
- A maximum strain of 2,995 microstrain was measured on the windshield center post during the impact.
- The maximum chest acceleration was 3 g, which meets the recommended National Highway Transportation Safety Association (NHTSA)[i] criterion of 60 g. NHTSA also recommends a criterion for chest deflection, but that was not measured in this test.
- The peak tension in the neck was 341 N, which meets the recommended NHTSA criterion of 4,170 N.
- The peak compression in the neck was 272 N, which meets the recommended NHTSA criterion of 4,000 N.
- The neck injury criteria, Nij, was 0.05, which meets the recommended NHTSA criterion of 1.
- The Head Injury Criterion (15 msec) was 0.1, which meets the NHTSA criterion of 700.
- The maximum femur load was 0.1 kN, which meets the NHTSA criterion of 10 kN.

[1] Supplement: Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems – II. National Highway Traffic Safety Administration, National Transportation Biomechanics Research Center and Vehicle Research and Test Center, March 2000.

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1.0 INTRODUCTION AND OBJECTIVES

Transportation Technology Center, Inc. (TTCI) performed a full-scale grade crossing impact test September 10, 2002. The test involved an SD-45 locomotive, modified to meet Association of American Railroads (AAR) Specification S-580, and three trailing loaded hopper cars impacting a stationary log truck on a grade crossings at 50.4 mph.

The purpose of the test was to evaluate the structural crashworthiness of the locomotive and to measure strains, accelerations, and displacements during the impact so that computer models of the locomotive and log truck could be validated at a later date. The acceleration levels in the crew compartment of the locomotive were measured as were the head, neck, and chest loads on an anthropomorphic test device (ATD) in the driver's seat of the locomotive.

Acceleration levels on an Event Recorder mounted on the rear of a collision post on the locomotive were also measured.

2.0 DESCRIPTION OF TEST LOCOMOTIVE AND HOPPER CARS

The locomotive used for this test was a modified SD-45, with a cab and nose structure designed by Sharma & Associates, and manufactured by National Rail Equipment to represent a SD-70 MAC front end structure, as Figure 2.1 shows. The locomotive nose and cab were designed to conform to AAR Specification S-580. This locomotive had been used in a previous full-scale impact test in which it and three loaded hopper cars impacted a stationary train of 35 loaded hopper cars at 32 mph.[2]

The following repairs were carried out to the locomotive after the first impact test:

- The pilot plate and snowplow were replaced.
- The damaged hand railing and front steps were removed.
- The lead axle and traction motor were replaced.
- The chains connecting the locomotive trucks to the body were repaired.

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[2] Locomotive Crashworthiness Impact Test No.1: Test Procedures, Instrumentation, and Data. FRA Draft Report. September 2002.

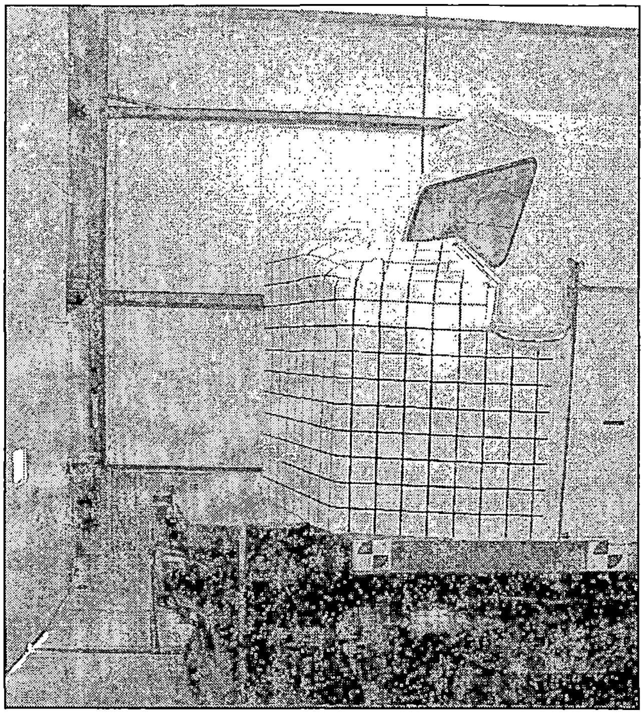

Figure 2.1 Locomotive Nose before Impact Test

A mock console was fitted in the cab of the locomotive, and a driver's seat was mounted on the floor behind the console. The ATD was positioned in the driver's seat as Figure 2.2 shows.

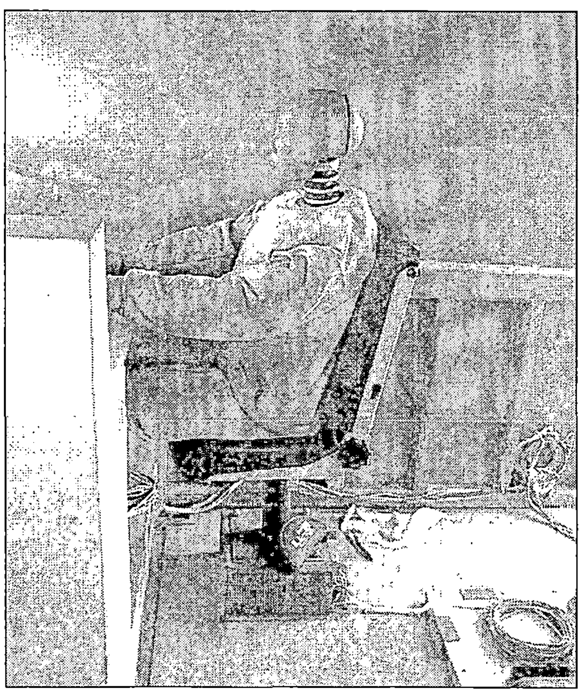

Figure 2.2 ATD in Locomotive Cab

An event recorder was mounted behind one of the collision posts of the locomotive facing rearward, as Figure 2.3 shows. A tri-axial accelerometer was mounted above the event recorder so that it measured the accelerations going into the recorder.

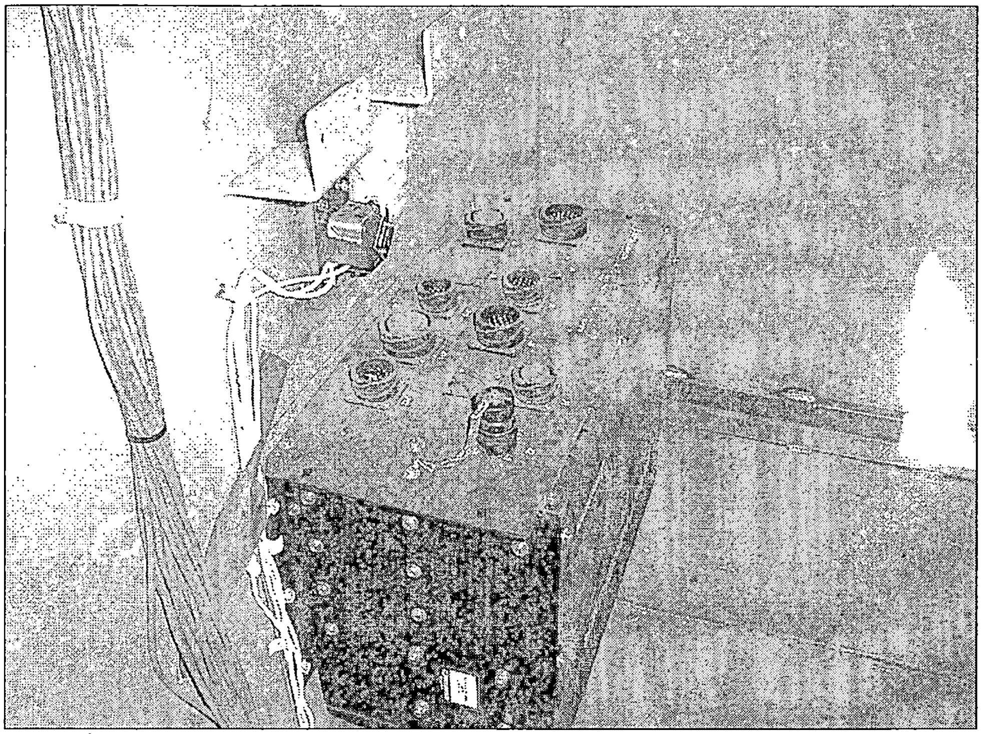

Figure 2.3 Event Recorder and Tri-Axial Accelerometer

The couplers at the impact ends of both the locomotive and the leading stationary hopper had flat plates welded to the front of them with Tape Switches™ mounted on these plates to trigger all the instrumentation on impact.

A strain-gaged coupler was fitted between the locomotive and the first hopper car.

String potentiometers were mounted on brackets at the rear of the locomotive and on the leading end of the first moving hopper car to measure the coupler displacements in each direction. Figure 2.4 shows this arrangement.

Tri-axial accelerometers were mounted in the center of the center sill of the first two hopper cars behind the locomotive.

There was no instrumentation on the stationary log truck.

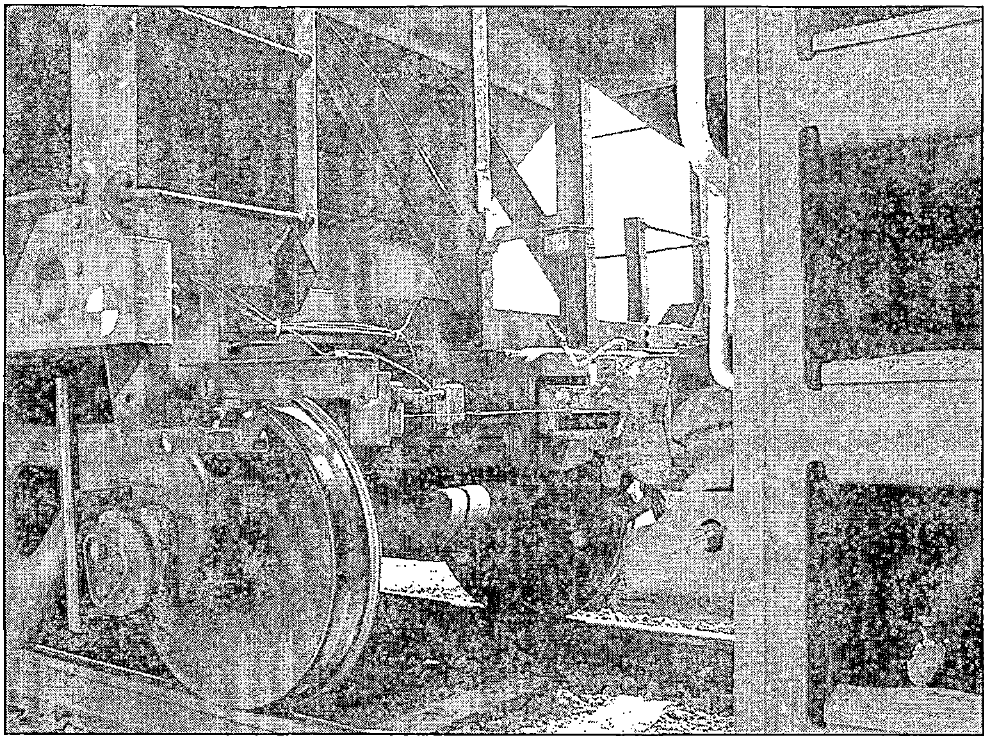

Figure 2.4 String Potentiometers Attached to Couplers

3.0 TEST METHODOLOGY

The test was performed at the FRA's Transportation Technology Center (TTC), Pueblo, Colorado, according to the procedures outlined in the Test Implementation Plan (see Appendix A).

The Impact Test was performed by pushing the moving consist (locomotive and three loaded hopper cars) with another locomotive, releasing it at a pre-determined point and speed, then letting it run along the track to impact the stationary log truck that was positioned at right angles to the track on a grade crossing. The log truck was positioned on the crossing so that the center of the locomotive impacted near to the center of the logs on the trailer.

The release distance and the speed of the moving consist were calculated from a series of speed calibration tests completed before the actual impact test. Simulation calculations were also performed using TOES™ (TTCI's train action model) based on the actual track profile. The target impact speed for the test was 50 mph.

4.0 RESULTS

4.1 Items Measured Before The Test

4.1.1 Lengths

Moving Consist

Length of locomotive over the ends of the anti-climbers = 70 ft
Length of first hopper car over strikers = 47 ft 5 in.
Length of second hopper car over strikers = 46 ft 5 in.
Length of third hopper car over strikers = 51 ft 5 in.

4.1.2 Weights

Moving Consist

Weight of locomotive = 381,769 lb
Weight of first loaded hopper car = 264,414 lb
Weight of second loaded hopper car = 267,439 lb
Weight of third loaded hopper car = 264,684 lb

Total weight = 1,178,306 lb
(Note: The accuracy of the weighbridge is within 50 lb per measurement; i.e. ±100 lb per vehicle or ±400 lb for the total weight)

4.1.3 Weather Conditions

Weather conditions just before the test:

- Temperature = 79°F
- Wind speed = 13 mph from the east

4.1.4 Photograph Taken Before Test

A photograph showing the vehicles, before impact, is shown in Figure 4.1.

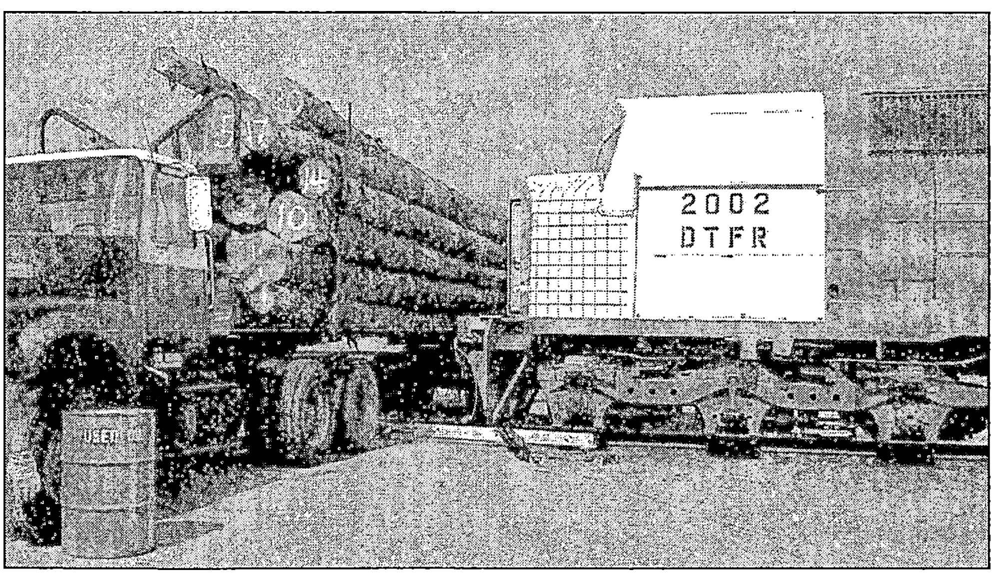

Figure 4.1 Locomotive and Log Trailer before Impact

4.2 Items Measured During the Test

4.2.1 Speed

The test consist, made up of the test locomotive and three loaded hopper cars, was accelerated from the rest by a pusher locomotive and released at a point 1,500 feet from the log trailer on the grade crossing. The speed of the consist just before impact with the log trailer, as measured by the laser based speed trap, was:

Laser 1	73.83 ft/s
Laser 2	73.93 ft/s
Average	73.88 ft/s = 50.37 mph

4.2.2 Strains

The Data Bricks measuring strain were set for a sampling rate of 12,800 Hz, a pre-trigger of 1 s and post-trigger of 4 s. Positive values show tension and negative values show compression.

For the rosette strain gages on the collision post the following convention is used:

Right collision post:	Direction 1 = Vertical
	Direction 2 = Diagonal
	Direction 3 = Longitudinal
Left collision post:	Direction 1 = Longitudinal
	Direction 2 = Diagonal
	Direction 3 = Vertical

Figures 4.2 and 4.3 show the locations of the strain gages on the left and right corner-posts, respectively. The highest magnitude strain measured in the test is shown next to each strain gage.

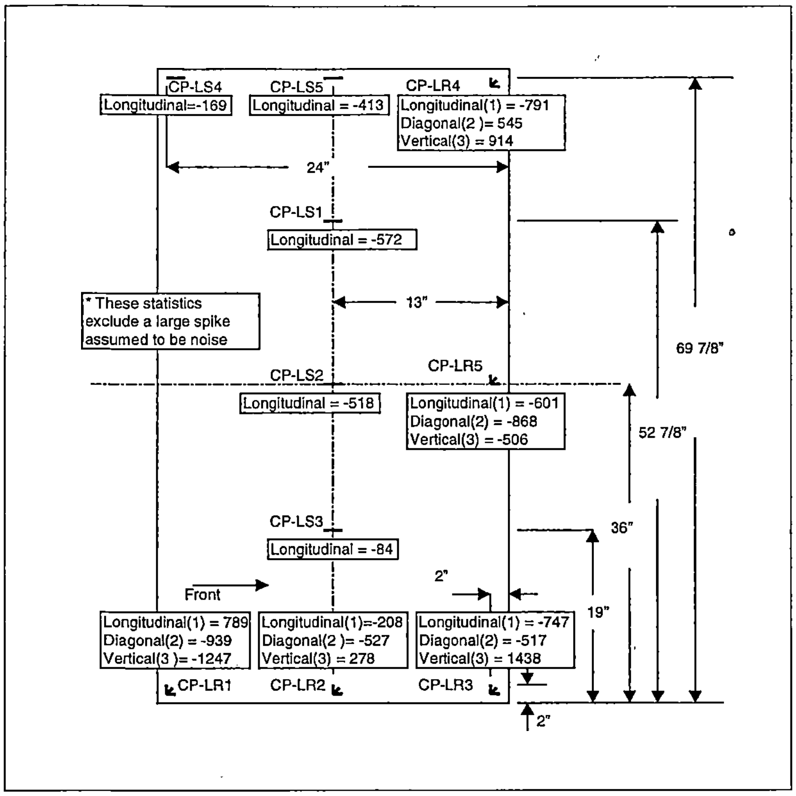

Figure 4.2 Left Collision Post; Location of Strain Gages and Largest Strain

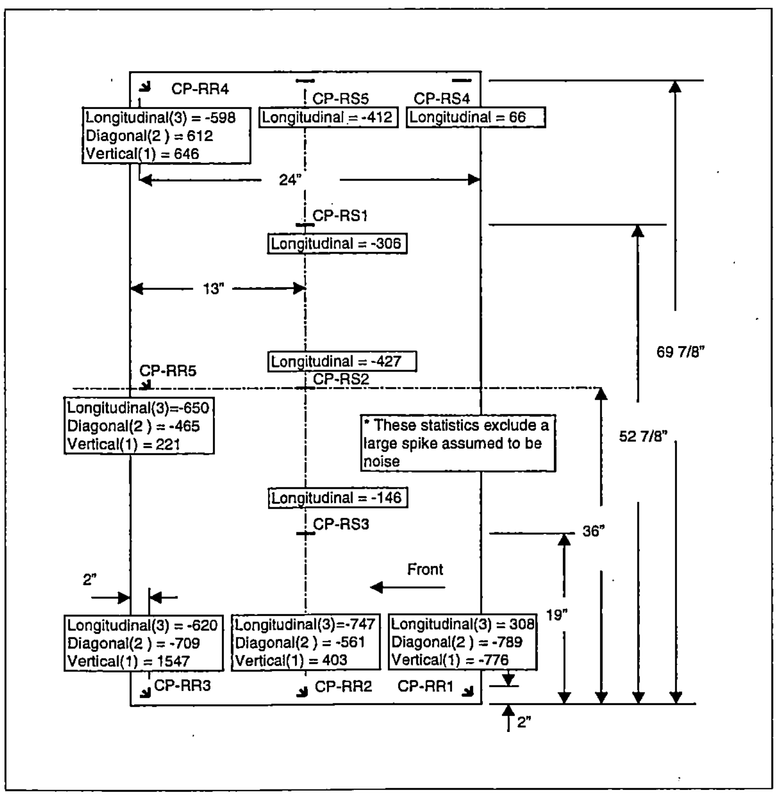

Figure 4.3 Right Collision Post; Location of Strain Gages and Largest Strain

The largest strain on the collision posts was 1,547 microstrain on the vertical leg of the bottom front rosette on the right collision post (channel CP_RR3).

Figure 4.4 shows the locations of the strain gages on the underframe of the locomotive. The highest magnitude strain measured in the test is shown next to each strain gage.

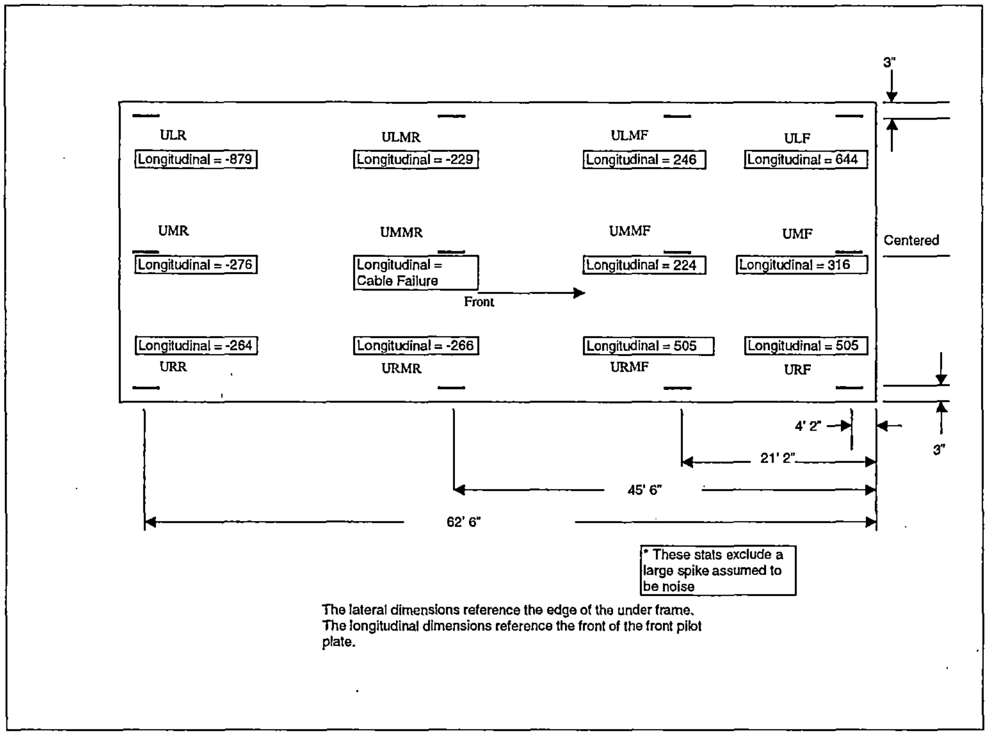

Figure 4.4 Underframe of Locomotive; Location of Strain Gages and Largest Strain

The largest magnitude strain on the underframe was 644 microstrain on the left hand side of the leading row of gages (channel ULF).

Figure 4.5 shows the locations of the strain gages on the window frame of the locomotive. The highest magnitude strain measured in the test is shown next to each strain gage.

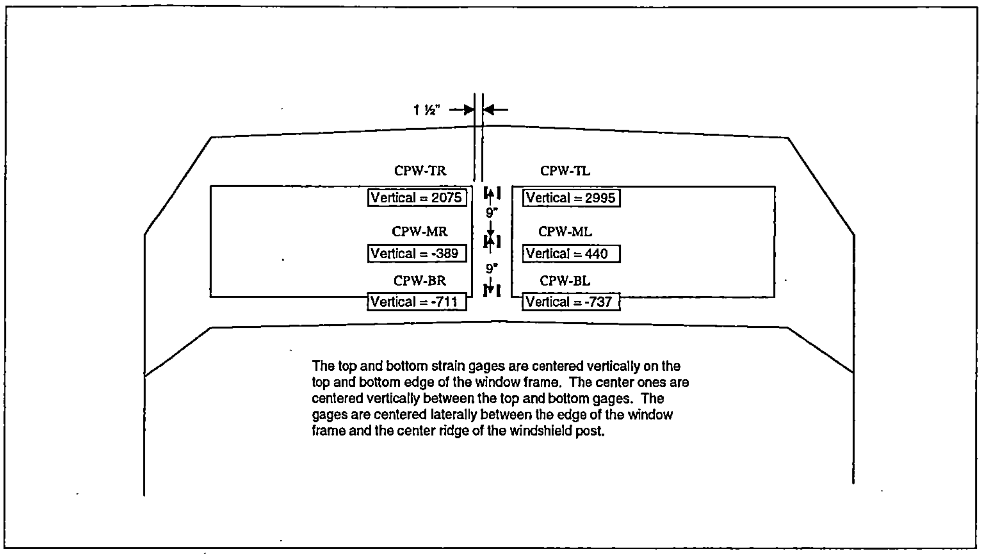

Figure 4.5. Window Frame; Location of Strain Gages and Largest Strain

The largest magnitude strain on the window center post was 2,995 microstrain. This occurred on the top left hand gage (channel CPW_TL).

All the strain-gage time histories are included in Appendix F.

4.2.3 Accelerations

Acceleration channels were sampled at 12,800 Hz. and filtered at 1,735 Hz. Data was digitally filtered with a phase-less 4-pole Butterworth filter as specified in SAE J211. Digital filter frequencies were CFC=1000 Hz (Fc=1,667 Hz), Fc=100 Hz, and Fc=25 Hz. The sign convention for the accelerometers is:

- Longitudinal (x), positive is forward acceleration
- Lateral (y), positive is rightward acceleration
- Vertical (z), positive is downward acceleration

The highest amplitude acceleration at each location is shown in Table 1. These statistics were computed from –0.5s to 3.5s for all locations. Time plots of each channel are shown in:

- Appendix B for 1000 Hz data
- Appendix C for 100 Hz data
- Appendix D for 25 Hz data

The Test Implementation Plan, Appendix A, shows the positions of the individual accelerometers.

Table 1. Largest Amplitude Accelerations at Each Location (g)

Direction	Locomotive Cab Floor	Event Recorder	Bullet Hopper 1	Bullet Hopper 2
X CFC=1000Hz	183.1	68.9	22.7	27.3
X F_c =100	-10.8	17.3	4.2	1.9
X F_c =25	-5.1	-6.2	1.5	-0.9
Y CFC=1000Hz	120.9	79.4	-19.4	-9.2
Y F_c =100	8.3	11.0	1.3	-0.4
Y F_c =25	3.0	1.8	-0.2	-0.1
Z CFC=1000Hz	107.6	71.8	-22.2	15.7
Z F_c =100	10.5	-17.6	-3.3	0.8
Z F_c =25	3.1	-6.2	0.8	0.2

It is apparent that the magnitude of the accelerations is very dependant on the filter frequency. It is suggested that the time plots in the appendices may be used to compare this data with other test or model results.

4.2.4 Displacements

The relative displacements (in each direction) between the locomotive and its trailing-end (B-end) coupler and the first hopper car and its leading-end (A-end) coupler were measured using string potentiometers. The sign convention for the string potentiometers is as follows:

- Locomotive Longitudinal: + = coupler extending, (BL_CBX)
- Locomotive Lateral: + = coupler moving right in pocket (forward facing), (BL_CBY)
- Locomotive Vertical: + = coupler drooping downward, (BL_CBZ)
- Bullet (Moving) Hopper Car 1 Longitudinal: + = coupler extending, (BH1_CAX)
- Bullet (Moving) Hopper Car 1 Lateral: + = coupler moving left in pocket (forward facing), (BH1_CAY)
- Bullet (Moving) Hopper Car 1 Vertical: + = coupler drooping downward, (BH1_CAZ)

The largest amplitude displacements for each channel are shown in Table 2.

Table 2. Largest Amplitude Coupler Displacements (inches)

Direction	Locomotive	Bullet Hopper Car 1
Longitudinal	-1.1	-3.9
Lateral	0.8	-0.6
Vertical	-0.6	-0.7

The coupler on the bullet hopper car 1 bottomed out longitudinally during the impact. Apart from this, there was very little coupler displacement.

Appendix E contains time plots of each displacement channel.

4.2.5 Longitudinal Force In Coupler

The coupler at the leading end of the first moving hopper car was strain gaged and calibrated so that the longitudinal force could be measured. The Data Brick measuring the coupler force was set at a sampling rate of 12,800 Hz. The maximum coupler force measured was 366 kips. The complete time history of the coupler force is shown in Appendix E.

4.2.6 Anthropomorphic Test Device

An ATD was positioned in the locomotive engineer's seat during the test. Tri-axial accelerometers were placed in the head and chest of the ATD, a six-axis load cell measured neck forces, and two uni-axial load cells measured femur loads. All the data was filtered at 1,734 Hz and sampled at 12,800 Hz. The data was digitally filtered with a four-pole Butterworth filter as specified in SAE J211.

The complete time histories of the ATD measurements are presented in Appendix G as:

- Head Accelerations – Unfiltered
- Chest Accelerations – CFC 180 Hz
- Neck Forces – Unfiltered
- Neck Moments – CFC 600 Hz
- Femur Loads – CFC 600 Hz

The magnitude of the vector sum accelerations was computed for the head and chest. Head accelerations were used to compute the Head Injury Criterion (HIC) as described in the document referenced in footnote 2. The neck injury criteria described in document referenced in footnote 1 was computed using the neck loads and moments data. The ATD data is compared to the NHTSA proposed criteria in Table 3.

Table 3. Comparison of ATD Data to NHTSA Proposed Criteria

Criteria	Criteria for Hybrid III Dummy 50% Male	Test Results
Head Criteria (HIC 15 msec)	700	0.1
Neck Criteria: Nij	1.0	0.05
In Position Critical Intercept Values*		
Tension (N)	6806	
Compression (N)	6160	
Flexion (Nm)	310	
Extension (Nm)	135	
Peak Tension (N)	4170	341
Peak Compression (N)	4000	272
Thoracic Criteria		
Chest Acceleration (g)	60	3.0
Chest Deflection	63	Not Measured
Lower Ext. Criteria		
Femur Load (kN)	10.0	0.1

*Values listed, as "In Position Critical Intercept Values" are not criteria per se. They are values specific to the Hybrid III 50% Male dummy and are used in calculating the Nij criteria. A description of these calculations is in reference 1.

All of the test results were considerably below the NHTSA proposed criteria.

4.2.7 Anomalies in Measured Data

The following anomalies occurred with the instrumentation and data acquisition during the test:

- Three strain gages showed some indication of loose electrical connections during the period of data acquisition: CPLR3_2, CPRS4, and URMF.
- The data from string potentiometers TH1_CBY appeared to show the effects of a noisy potentiometer or a loose electrical connection in the wiring.
- The data from the chest x-axis accelerometer showed a possible electrical failure before the end of the data acquisition period.

4.2.8 Photography

The impact between the locomotive led consist and the log truck on the grade crossing was visually recorded with five high-speed film cameras and six video cameras. The camera coverage was selected to provide views of both the left- and right-hand sides of the vehicles, overhead views, an overall view of the impact, and included a video camera in the cab of the locomotive.

The film and video camera positions are shown in Figure 4 of Appendix A.

4.3 Description of Impact Damage

The locomotive struck the log truck at 50.4 mph in the center of the logs. It broke through the logs and continued down the track. The 3/8-inch steel sheet covering the short hood of the locomotive was significantly deformed as a result of the impact with the logs, but the collision posts and anti-climber remained intact. After the logs broke, their outside ends rotated around and into the sides of the locomotive. This action caused significant damage to the handrails and generator compartment doors on the locomotive and destroyed an external brake cylinder. The edge of the locomotive fuel tank hit the end of the semi-truck frame, denting the fuel tank but not rupturing it.

On impact, all of the logs broke at their center. The pendle hitch that connects the rear bogie tongue of the trailer to the log truck frame broke, and the rear bogie of the trailer was knocked away from the railway track. The locomotive caused the semi-truck to rotate on impact with the rear axle moving about 6.5 feet parallel to the track while the front axle stayed in the same position.

Photographs in Figures 4.6 to 4.12 were taken after impact.

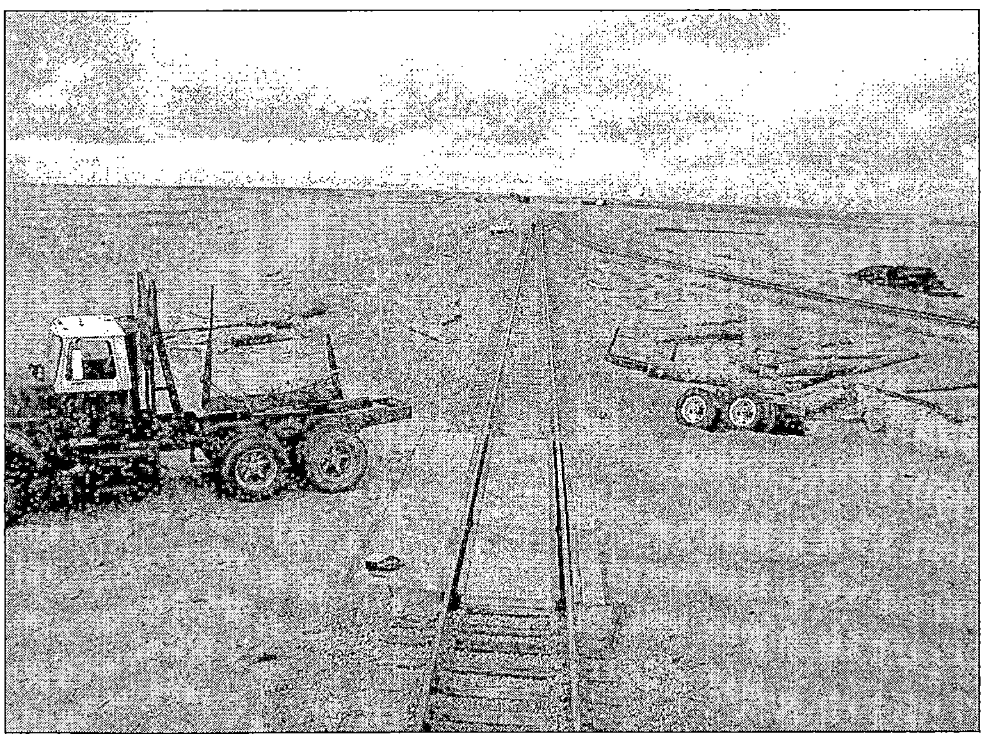

Figure 4.6 Grade Crossing after Impact

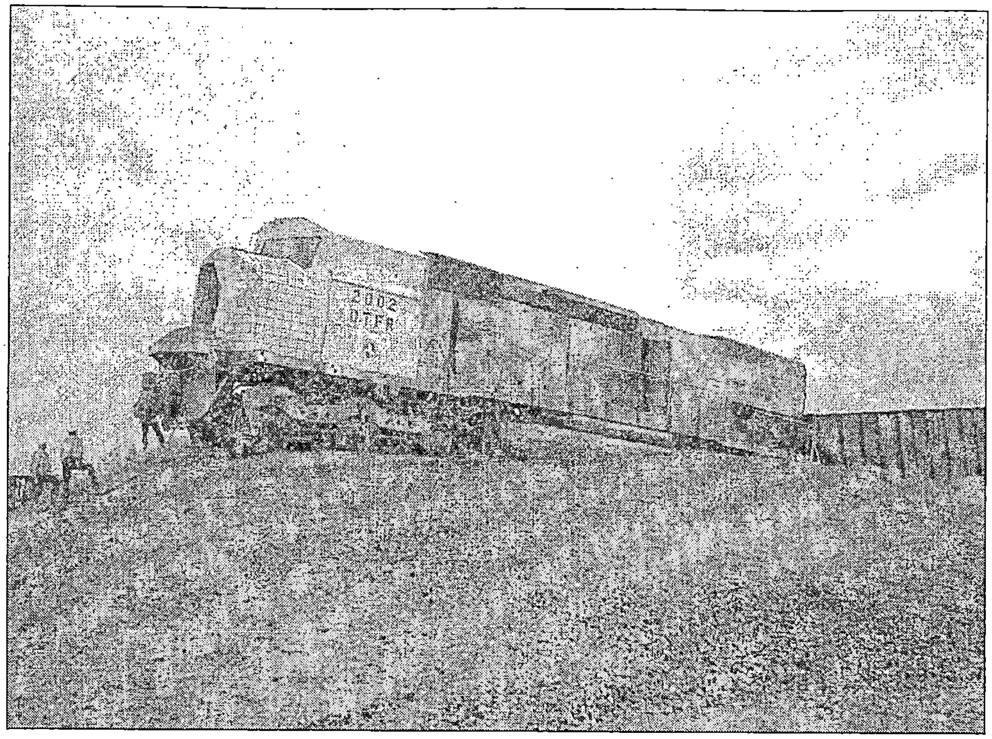

Figure 4.7 Locomotive after Impact

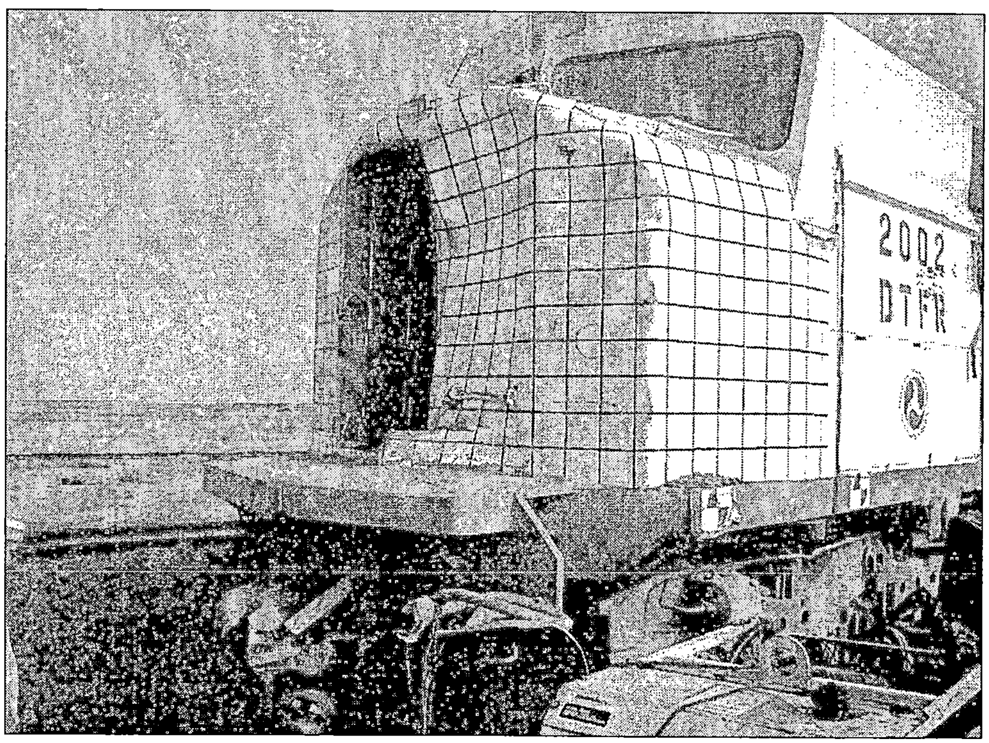

Figure 4.8 Nose of Locomotive after Impact

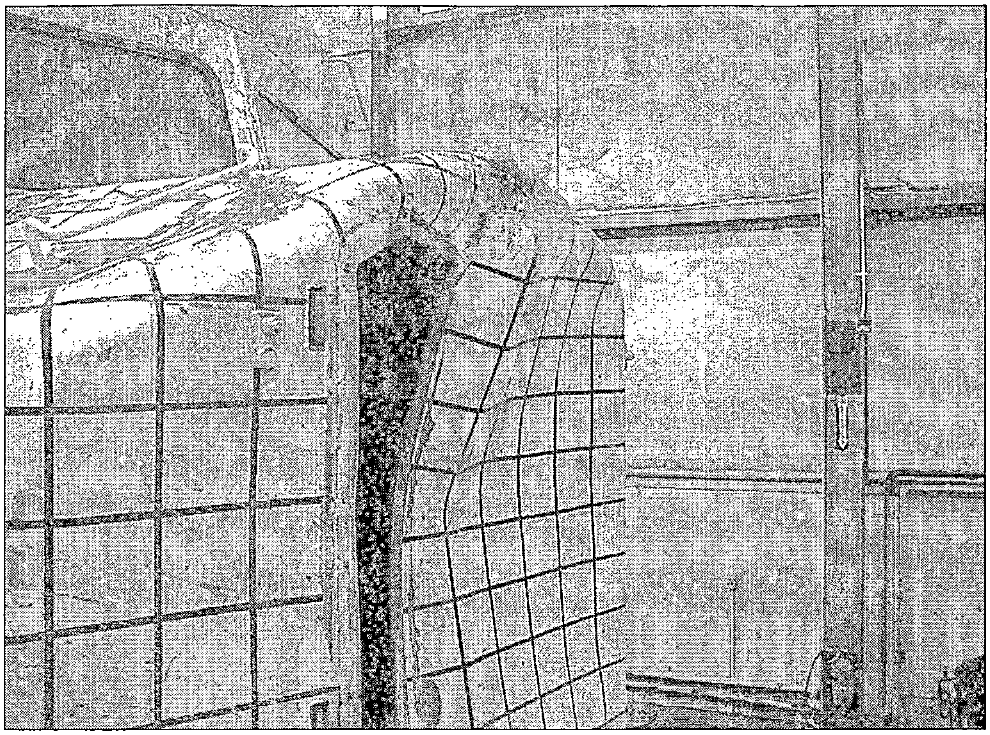

Figure 4.9 Closeup of Locomotive Nose after Impact

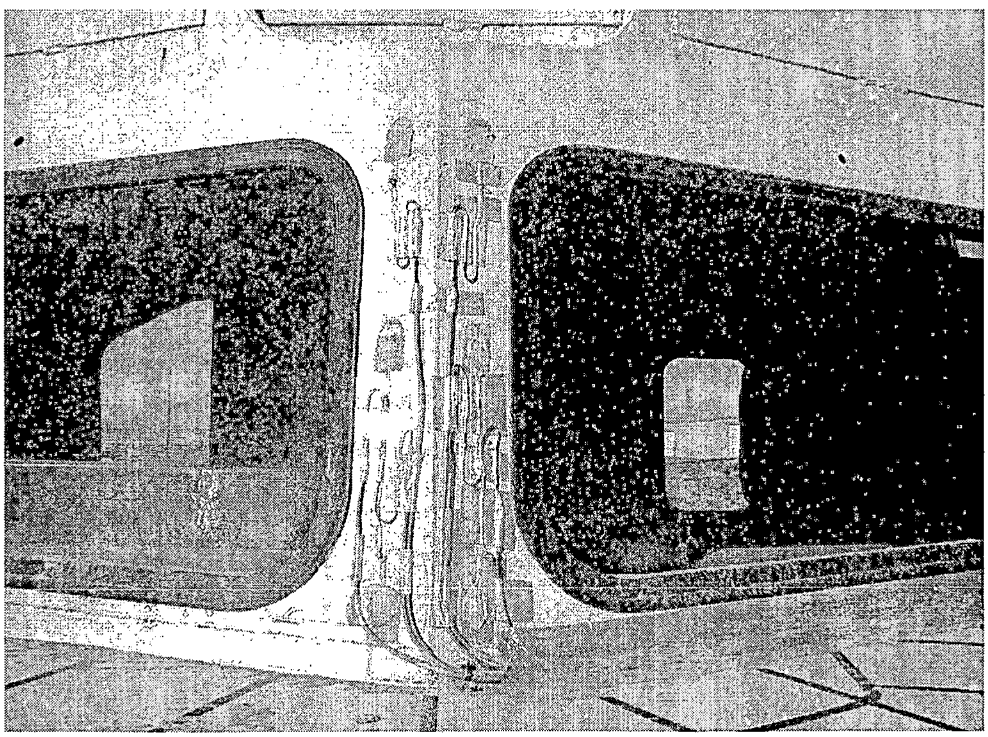

Figure 4.10 Locomotive Windshield after Impact

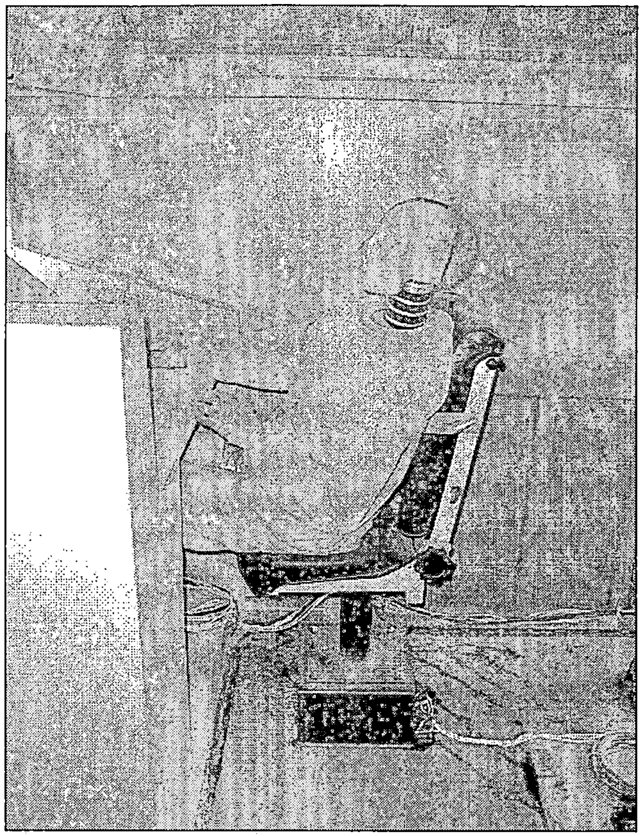

Figure 4.11 ATD after Impact

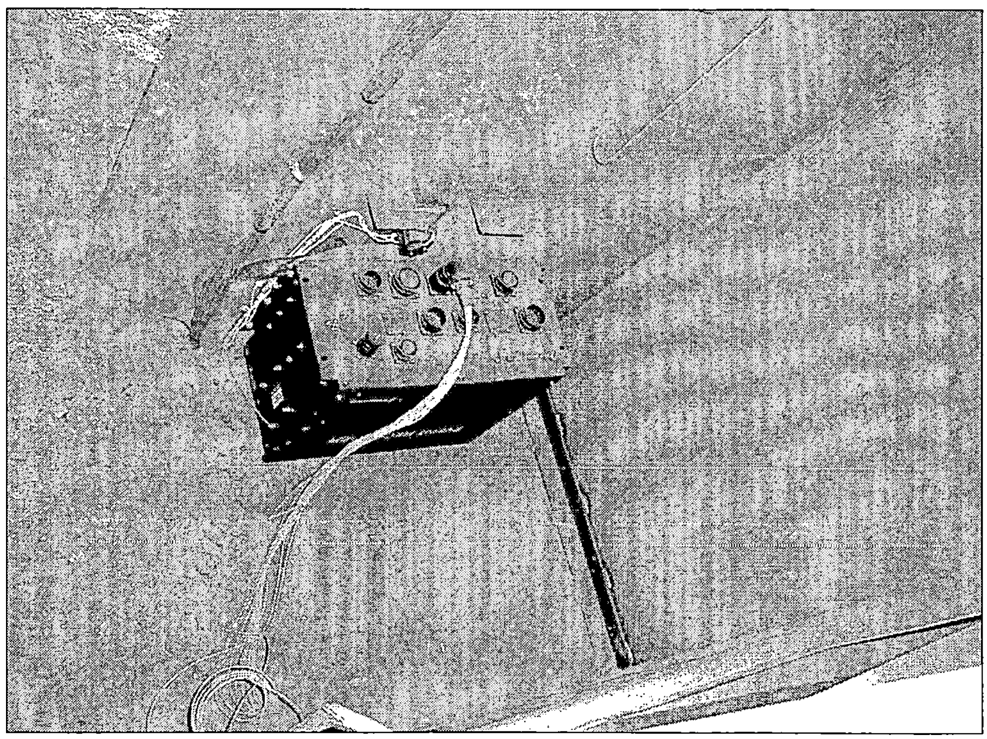

Figure 4.12 Event Recorder after Impact

5.0 DISCUSSION AND CONCLUSIONS

It was expected that during the impact of the locomotive with the log trailer that one or more of the logs would have come over the nose of the locomotive and impacted with the windshield. This would have tested the ability of the windshield post to prevent intrusion into the cab of the locomotive. In the event, there was no damage to the windshield and no intrusion into the cab. The type of wood, the size of the logs, the method of restraining the logs on the trailer, and the speed of the impact could all have an effect on the behavior of the logs.

The video camera in the cab of the locomotive shows that the ATD in the driver's seat hardly moved on impact with the log trailer. The instrumentation in the ATD shows the measurements were considerably below the proposed NHTSA injury criteria.

APPENDIX A

Test Implementation Plan for Locomotive Crashworthiness Testing

TO 137

(Contract No. DTFR53-93-C-00001)

June 2002

Presented by:
Transportation Technology Center, Inc.
55500 DOT Road
P.O. Box 11130
Pueblo, Colorado, USA, 81001

1.0 Purpose

Evaluation of freight locomotive structural crashworthiness by carrying out a series of full-scale impact tests based on historical accidents. Each locomotive will be instrumented to measure material strains and structural accelerations, in sufficient quantity, to allow correlation with analytical predictions. In all cases the acceleration levels in the crew compartment and the dynamic forces transmitted to critical components of the locomotive will be measured. An anthropomorphic test device (ATD) will be positioned in the seat of the locomotive for each test.

2.0 Requirements

Carry out the following full-scale impact tests involving a current AAR Specification S-580 compliant (SD-70 MAC) locomotive pulling three loaded hopper cars at:

1. 30 mph impacting a stationary consist of loaded hopper cars.
2. 50 mph impacting a stationary log truck on a railroad grade crossing.
3. 50 mph impacting a stationary truck/flatbed carrying two steel coils on a railroad grade crossing.

3.0 Test Vehicles and Site

The impact tests will be conducted using a locomotive structure built to comply with AAR Specification S-580 and provided by another contractor.

The loaded hopper cars will be provided by TTCI.

The log truck, trailer and logs will be provided by TTCI.

The flatbed trailer and steel coils will be provided by TTCI.

Test #1 will be conducted on tangent track at TTC.

Test #2 and #3 will be conducted on a grade crossing at TTC.

4.0 Test Method

The impact tests will be performed at TTC by pushing the consist of test locomotive and three loaded hopper cars with another locomotive, to a pre-defined speed and then released allowing the consist to roll along the track and into the stationary consist (Test #1), stationary log truck on a railroad grade crossing (Test #2) or stationary truck/flatbed carrying two steel coils on a railroad grade crossing (Test #3).

The release distance, and the speed of the locomotive at the release point, will be determined from a series of speed calibration runs carried out before each test. A radar speed measuring system will be used for the speed calibration tests. Calculations will be performed using TOES to estimate the speed versus distance for the test

locomotive and freight cars, using the measured track profile. The ambient temperature and wind speed will be measured during the calibration tests and during the actual test. A laser speed trap will be used on the actual test to measure the speed of the test consist just before impact.
On-board instrumentation will record accelerations, displacements and strains at various points on the locomotive and hopper cars during and after the impact. Five high-speed film cameras and six video cameras will be used to record each impact test.

5.0 Measured Items

The weight of the test locomotive and hopper cars, and the position of all the transducers will be measured before each test. The weights of the logs, steel coils and trailers will also be measured before each test. Strains and accelerations will be measured during the test using a battery powered on-board data acquisition system which will provide excitation to the strain gauges and accelerometers, analog anti-aliasing filtering of the signals, analog-to-digital conversion and recording. Data acquisition will be in accordance with SAE J211/1,Instrumentation for Impact Tests (revised March 1995). Data from each channel will be recorded at a sample rate of 12,800 Hz. All data will be synchronized with a time reference applied to all systems simultaneously at the time of impact. The time reference will come from a closure of a tape switch on the front of the impacting cab-car. The following items will be measured during each test :

1. The speed of the test locomotive just before impact using a laser based speed trap
2. Strains at each Collision Post of the locomotive as shown in Figure 1 (5 3-axis rosette and 5 uniaxial strain gauges (longitudinal))(2x20=40 channels).
3. Longitudinal strains on the Under-frame of the Locomotive as shown in Figure 2 (12 uniaxial strain gauges)(12 channels).
4. Longitudinal strains at the Center Post of the Windshield as shown in Figure 3 (3 uniaxial strain gauges (vertical) on either side of centerline)(6 channels).
5. A tri-axial accelerometer on the floor of the cab of the locomotive, near the driver's seat (3 channels). A second tri-axial accelerometer will also be located on the floor of the cab near the driver's seat (3 channels). This accelerometer will be connected to a different Data Brick so that it offers a separate redundant system.
6. Longitudinal strain of coupler between locomotive and first hopper car. (1 channel).
7. The ATD in the driver's seat of the locomotive will include the following instrumentation: (14 channels)
    - Head tri-axial accelerometer
    - Chest tri-axial accelerometer
    - Six-axis upper neck load cell
    - Two single-axis femur load cells

8. A tri-axial accelerometer on the first two hopper cars behind the locomotive (6 channels).
9. Three string potentiometers on each coupler between the locomotive and the first hopper car (6 channels).
10. A tri-axial accelerometer will be mounted on an Event Recorder located in an equipment bay below the locomotive cab.

In addition, the following items will also be measured on each individual test:

Test #1

1. A tri-axial accelerometer on each of the first two stationary hopper cars (6 channels).
2. Three string potentiometers on each coupler between the first two stationary hopper cars (6 channels).

Test #2

1. Targets will be attached to each of the logs on the log trailer and an attempt will be made to color code the logs.

Test #3

1. A tri-axial accelerometer will be mounted in the center of each of the two steel coils (6 channels).

In summary, 106 channels are required for Test #1, 94 channels for Test #2 and 100 channels for Test #3.

For Test #1, this will require a Data Brick on each of the first two hopper cars behind the locomotive (2 Data Bricks), each of the first two stationary hopper cars (2 Data Bricks), and 11 Data Bricks on the locomotive. A total of 15 Data Bricks.
For Test #2, this will require a Data Brick on each of the first two hopper cars behind the locomotive (2 Data Bricks) and 11 Data Bricks on the locomotive. A total of 13

Data Bricks.
For Test #3, this will require a Data Brick on each of the first two hopper cars behind the locomotive (2 Data Bricks) and 11 Data Bricks on the locomotive. A Data Brick will also be required in each steel coil (2 Data Bricks). A total of 15 Data Bricks.
Each Data Brick will be set at a sampling rate of 12,800 Hz and timing of 1 second pre-trigger data collection and 7 seconds of post-trigger data collection.
Five high-speed film cameras and six video cameras will be used to record the impact for each test. A reference signal will be placed on the film so that analysis of the film after the event will give the velocity and displacement of each vehicle during impact. The placement of the high-speed film and video cameras are shown in Figure 4.

6.0 Instrumentation

6.1 Strain measurements, Locomotive

Figures 1, 2 and 3 show the general arrangement of strain gauges on the collision post, underframe and central post of the windshield respectively. Table 1 lists the locations and strain gauge types for the collision post, Table 2 lists the locations and strain gauge types for the underframe and Table 3 lists the locations and strain gauge types for the central post of the windshield.

Table 1 Strain gauge location and type on collision post

Location	Strain Gauge	Channels
SG-CP-RR1	Rosette	1,2,3
SG-CP-RR2	Rosette	4,5,6
SG-CP-RR3	Rosette	7,8,9
SG-CP-RR4	Rosette	10,11,12
SG-CP-RR5	Rosette	13,14,15
SG-CP-RS1	Standard	16
SG-CP-RS2	Standard	17
SG-CP-RS3	Standard	18
SG-CP-RS4	Standard	19
SG-CP-RS5	Standard	20
SG-CP-LR1	Rosette	21,22,23
SG-CP-LR2	Rosette	24,25,26
SG-CP-LR3	Rosette	27,28,29
SG-CP-LR4	Rosette	30,31,32
SG-CP-LR5	Rosette	33,34,35
SG-CP-LS1	Standard	36
SG-CP-LS2	Standard	37
SG-CP-LS3	Standard	38
SG-CP-LS4	Standard	39
SG-CP-LS5	Standard	40

Table 2 Strain gauge location and type on underframe

Location	Strain Gauge	Channel
SG-U-LF	Standard	41
SG-U-MF	Standard	42
SG-U-RF	Standard	43
SG-U-LMF	Standard	44
SG-U-MMF	Standard	45
SG-U-RMF	Standard	46
SG-U-LMR	Standard	47
SG-U-MMR	Standard	48
SG-U-RMR	Standard	49
SG-U-LR	Standard	50
SG-U-MR	Standard	51
SG-U-RR	Standard	52

Table 3 Strain gauge location and type on the central post of the windshield

Location	Strain Gauge	Channel
SG-CPW-TR	Standard	53
SG-CPW-TL	Standard	54
SG-CPW-MR	Standard	55
SG-CPW-ML	Standard	56
SG-CPW-BR	Standard	57
SG-CPW-BL	Standard	58

6.2 Acceleration measurements, Locomotive and Hopper Cars

The gross and flexible motions of the floor of the cab, near the driver's seat, will be measured using a tri-axial accelerometer. The gross and flexible motions of the first two hopper cars behind the locomotive will be measured by a tri-axial accelerometer underneath each car. The gross and flexible motions of the first two stationary hopper cars will also be measured by a tri-axial accelerometer underneath each car.

All the accelerometers are critically damped. The accelerometers will be calibrated prior to installation. The accelerometers posses natural frequencies sufficiently high to meet the requirements of SAE J211/1, *Instrumentation for Impact Test (Revised MAR95)*, Class 1000, which requires that the frequency response is essentially flat to 1000 Hz.

Table 4 lists the accelerometer locations, accelerometer types, and data channels.

Table 4 Locomotive and Hopper Cars accelerometers

Location	Accelerometer	Measurement		Channel	
Locomotive Floor (BL_F1)	Three axis	Longitudinal	X	1	50g
		Lateral	Y	2	50g
		Vertical	Z	3	50g
Locomotive Floor (BL_F2)	Three axis	Longitudinal	X	4	400g
		Lateral	Y	5	200g
		Vertical	Z	6	400g
Event Recorder (BL_R)	Three axis	Longitudinal	X	7	400g
		Lateral	Y	8	200g
		Vertical	Z	9	400g
First moving hopper car (BH1)	Three axis	Longitudinal	X	10	200g
		Lateral	Y	11	50g
		Vertical	Z	12	100g
Second moving hopper car (BH2)	Three axis	Longitudinal	X	13	100g
		Lateral	Y	14	50g
		Vertical	Z	15	50g
First stationary hopper car *	Three axis	Longitudinal	X	16	200g
		Lateral	Y	17	100g
		Vertical	Z	18	100g
Second stationary hopper car*	Three axis	Longitudinal	X	19	200g
		Lateral	Y	20	100g
		Vertical	Z	21	100g

Note: * accelerometers only required for Test #1

6.3 String Potentiometers

Three string potentiometers will be attached to each coupler between the locomotive and first hopper car to measure the displacement of the coupler relative to the car body. (Three string potentiometers will also be attached to each coupler between the first two stationary hopper cars, for Test #1, to measure the displacement of the coupler relative to the car bodies.)

The following code is used to identify each string potentiometer:

Locomotive ,	B end (trailing end)	BL_CB
First Hopper car,	A end (leading end)	BH1_CA

6.4 ATD

The ATD in the driver's seat of the locomotive will include the instrumentation listed in Table 5.

Table 5. ATD Instrumentation

Location	Transducer	Measurement		Channel	
Head (ATDH)	Three axis accel.	Longitudinal	X	1	400g
		Lateral	Y	2	200g
		Vertical	Z	3	200g
Chest (ATDC)	Three axis accel.	Longitudinal	X	4	400g
		Lateral	Y	5	200g
		Vertical	Z	6	200g
Upper neck	Six axis load cell	Longitudinal	X	7	
		Lateral	Y	8	
		Vertical	Z	9	
		Roll		10	
		Pitch		11	
		Yaw		12	
Femur (ATDF)	Two single axis load cells	Longitudinal (L)	X	13	
		Longitudinal (R)	X	14	

6.5 Acceleration measurements, Steel Coils

Tri-axial accelerometers will be mounted in each steel coil for Test #3. Table 6 lists the accelerometer locations, accelerometer types and data channels.

Table 6. Steel Coil Accelerometers

Location	Accelerometer	Measurement		Channel	
Steel coil at front of trailer	Three axis	Longitudinal	X	1	400g
		Lateral	Y	2	200g
		Vertical	Z	3	200g
Steel coil at rear of trailer	Three axis	Longitudinal	X	4	400g
		Lateral	Y	5	200g
		Vertical	Z	6	200g

6.6 High-Speed and Real-Time Photography

Five high-speed film cameras and six video cameras will document the impact test. The position of the film and video cameras is shown in Figure 4. One video camera will be located in the cab of the locomotive. All the cameras are equipped with sights that allow the photographer to view the expected image. The final siting of cameras will be carried out at the time of camera setup. Adjustments will be made, if necessary, to achieve the optimum views.

A 100 Hz reference signal will be placed on the film so that accurate frame speed can be determined for film analysis. An electronic signal generator provides the calibrated 100-Hz pulse train to light emitting diodes (LEDs) in the high-speed cameras. Illumination of the LEDs exposes a small red dot on the edge of the film, outside the normal field of view. During film analysis, the precise film speed is determined from the number of frames and fractions thereof that pass between two adjacent LED marks. Battery powered on-board lights will illuminate the on-board camera view. Battery packs use 30- v NiCad batteries.

Color negative film for the ground-based cameras will be Kodak 16-mm 7246, ISO 250, for daylight on 100-ft spools. Film speed will be pushed in processing if necessary to compensate for light conditions at test time

Targets will be placed on the vehicles and the ground to facilitate post-test film analysis to determine speed and displacement during the test. The targets are divided into four quadrants with adjacent colors contrasting to provide good visibility. At least three targets will be placed on each side of each vehicle and the ground. During film analysis, the longitudinal and vertical coordinates of the targets are determined from projections on a film analyzer on a frame-by-frame basis. The distances between the targets, which are known from pre-test measurements, provide distance reference information for the film analysis. The differences in locations between vehicle-mounted targets and ground-based targets quantify the motion of the vehicle during the test. By taking the position differences between vehicle-mounted and ground-based targets, the effects of film registration jitter in the high-speed cameras are minimized. The 100-Hz LED reference marks provide an accurate time base for the film analysis. Test vehicle position is determined directly as indicated above, and vehicle speed is determined by dividing displacement between adjacent frames by the time difference between the adjacent frames. If necessary, smoothing is applied to the displacement and speed data to compensate for digitization and other uncertainties.

The ground-based cameras will be started simultaneously from a central relay box triggered manually. The cameras will run at the determined nominal speed of 300-500 frames per second for about eight seconds before the100-ft film is entirely exposed. The appropriate nominal speed will be defined prior to the test.

6.6 Data Acquisition

Up to fifteen, 8-channel battery-powered on-board data acquisition systems will provide excitation to the strain gauges, accelerometers and displacement transducers, analog anti-aliasing filtering of the signals, analog-to-digital conversion, and recording on the locomotive.

Data acquisition will be in compliance with SAE J211. Data from each channel will be recorded at 12,800 Hz. Parallel redundant systems will be used for all accelerometer channels. Data recorded on the fifteen Data Bricks will be synchronized with a time reference applied to all systems simultaneously at the time of impact. The time reference will come from closure of the tape switches on the front of the test vehicle. The data acquisition systems are GMH Engineering Data Brick Model II. Each Data Brick is ruggedized for shock loading up to at least 100 g. On-board battery power will be provided by GMH Engineering 1.7 A-HR 14.4 volt NiCad Packs. Tape Switches, Inc., model 1201-131-A tape switches will provide event markers.

Software in the Data Brick will be used to determine zero levels and calibration factors rather than relying on set gains and expecting no zero drift. The Data Bricks will be set to record 1 seconds of pre-trigger data and 7 seconds of post-trigger data.

6.7 Speed Trap

A dual channel speed trap will accurately measure the impact speed of the locomotive when it is within 0.5 meter impact point. The speed trap is a GMH Engineering Model 400, 4 Interval Precision Speed Trap with an accuracy of 0.1%. Passage of a rod affixed to the vehicle will interrupt laser beams a fixed and known distance apart. The first interruption starts a precision counter, and the second interruption stops the counter. Speed is calculated from distance and time. Tentatively, the rod will be attached at the aft-end of the third moving hopper car. Final rod location will be determined prior to installation.

7.0 Test Procedure

- Strain gauges, accelerometers and displacement transducers will be attached to the locomotive, hopper cars and steel coils as described above.
- Speed calibration runs will be carried out using the test consist, comprising the test locomotive and three hopper cars. The test consist will be pushed by a locomotive and then the power switched off at a pre-determined point before the impact point. The speed of the consist will be measured as the consist passes the impact point, using a radar gun. Having passed the impact point, the test consist will be stopped by the pushing locomotive. A calibration chart of speed versus distance will be produced from these tests and compared with simulation results using TOES. The speed of release will be determined from these tests.
- The Data Bricks will be mounted on the locomotive and hopper cars. The transducers will be connected to the data acquisition system and tested.
- The film and video cameras will be set up.
- The weight of the locomotive, hopper cars, log truck and steel coil truck, will be measured just prior to each test.
- All instruments will be calibrated and a zero reading carried out.
- A trial low speed soft impact (less than 1 mph) of the test consist will be carried out to confirm all the instruments work properly.
- The instruments will be re-calibrated, the Tape Switches replaced and the test consist pulled back.
- The test consist will be pushed by a locomotive and released at the appropriate distance from the stationary hopper cars, or road trailer, triggering the cameras just before impact.

- The instrumentation will be triggered on impact.
- Visual inspection of all the vehicles will be carried out after impact. Still photographs will be taken.
- The data will be downloaded onto lap-top computers from the on-board data acquisition system.

A checklist based on the above tasks will be signed by key personnel as each task is completed.

8.0 Data Analysis

8.1 Data Post-Processing

Each data channel will be offset adjusted in post-processing. The procedure is to average the data collected just prior to the test locomotive's impact with the first hopper car and subtract the offset from the entire data set for each channel. It is expected that between 0.05 and 1.0 second of pre-impact data will be averaged to determine the offsets. The precise duration of the averaging period cannot be determined with certainty until the data are reviewed. The offset adjustment procedure assures that the data plotted and analyzed contains impact-related accelerations and strains but not electronic offsets or steady biases in the data. The post-test offset adjustment is independent of, and in addition to, the pre-test offset adjustment made by the data acquisition system.
Plots of all data channels recorded and combinations of data channels will be produced as described below. Post-test filtering of the data will be accomplished with a two-pass phaseless four-pole digital filter algorithm consistent with the requirements of SAE J211. In the filtering process, data are first filtered in the forward direction with a two-pole filter. The first pass of the filtering process introduces a phase lag in the data. In the next pass, the data are filtered in the reverse direction with the same filter. Because the data are filtered in the reverse direction, a phase lead is introduced into the data. The phase lead of the reverse-direction filtering cancels the phase lag from the forward-direction filtering. The net effect is to filter the data without a change in phase with a four-pole filter.

8.2 Data Presentation

Every channel as recorded (raw data) will be plotted against time (where time = 0 is defined as the impact of the locomotive with the hopper cars or road trailer).
The acceleration records during the impacts will be plotted against time. The longitudinal acceleration will be integrated and the derived velocity plotted against time. The strain gauge time histories will be presented. The displacement time histories will be presented. All data recorded by the Data Bricks, the derived values mentioned above, and plotted time histories will be presented to the FRA in digital form on a CD.
The film from each high speed camera will be analyzed frame by frame and the velocity during the impact calculated. A 100 Hz reference signal will be placed on the film so that accurate frame speed can be determined for film analysis. An electronic signal generator provides the calibrated 100-Hz pulse train to light emitting diodes (LEDs) in the high-speed cameras. Illumination of the LEDs exposes a small red dot on the edge of the film, outside the normal field of view

During film analysis, the precise film speed is determined from the number of frames and fractions thereof that pass between two adjacent LED marks.
All the data output described in this section will be presented in a report and submitted to the FRA. The report will also contain general information about the crash test and describe how it was conducted.

9.0 Safety

All Transportation Technology Center, Inc. (TTCI) safety rules will be observed during the preparation and performance of the crash tests. All personnel participating in the tests will be required to comply with these rules when visiting the TTC, including wearing appropriate personal protective equipment. A safety briefing for all test personnel and visitors will be held prior to testing.

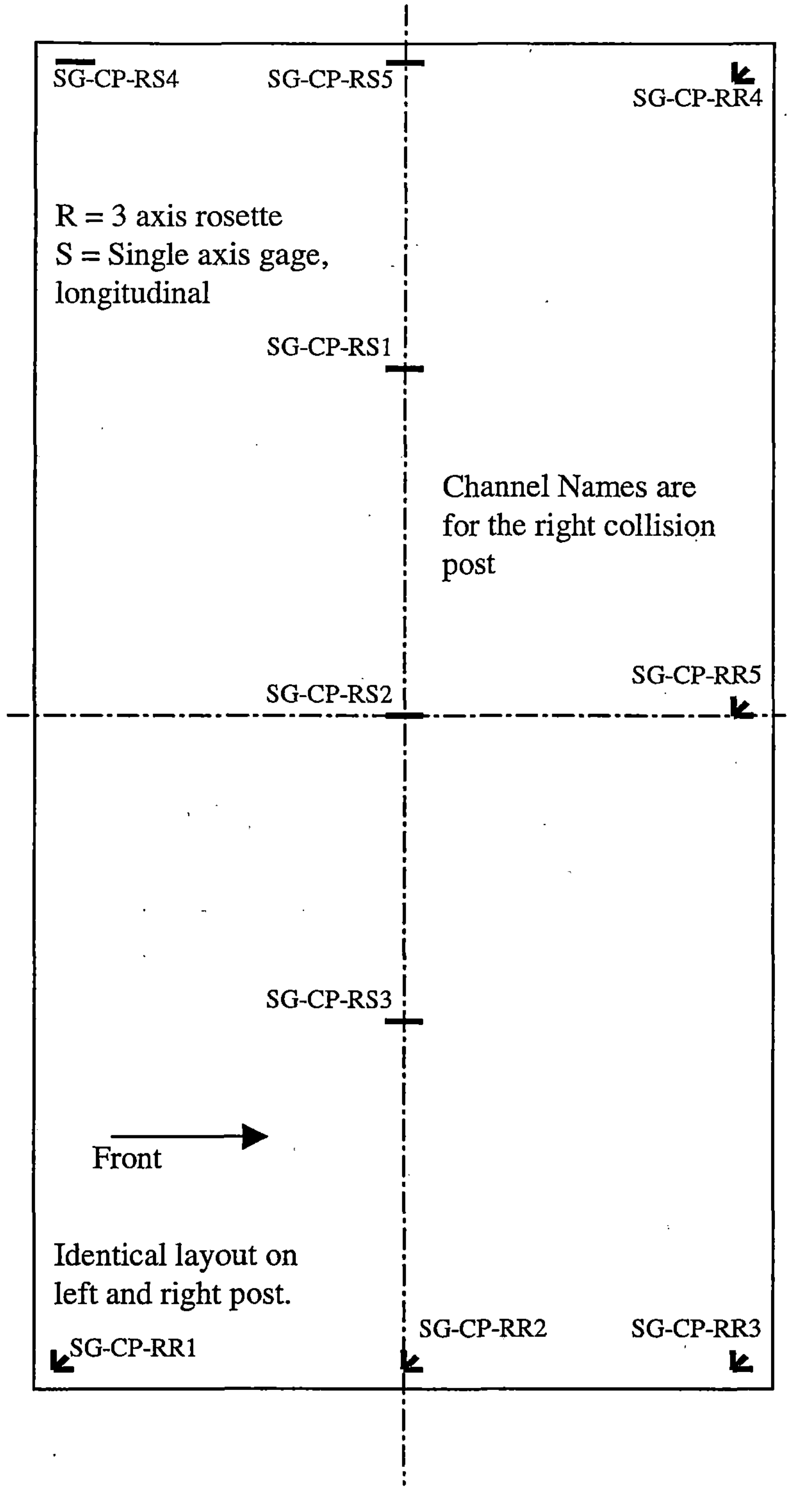

Figure 1. Location of strain gauges on the collision post

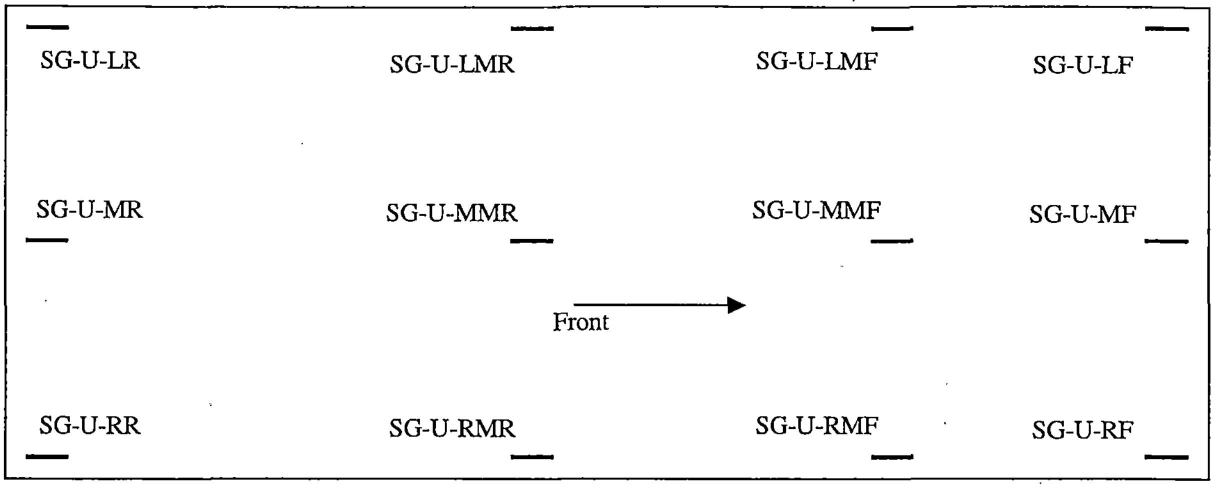

Figure 2. Location of strain gauges on locomotive under-frame

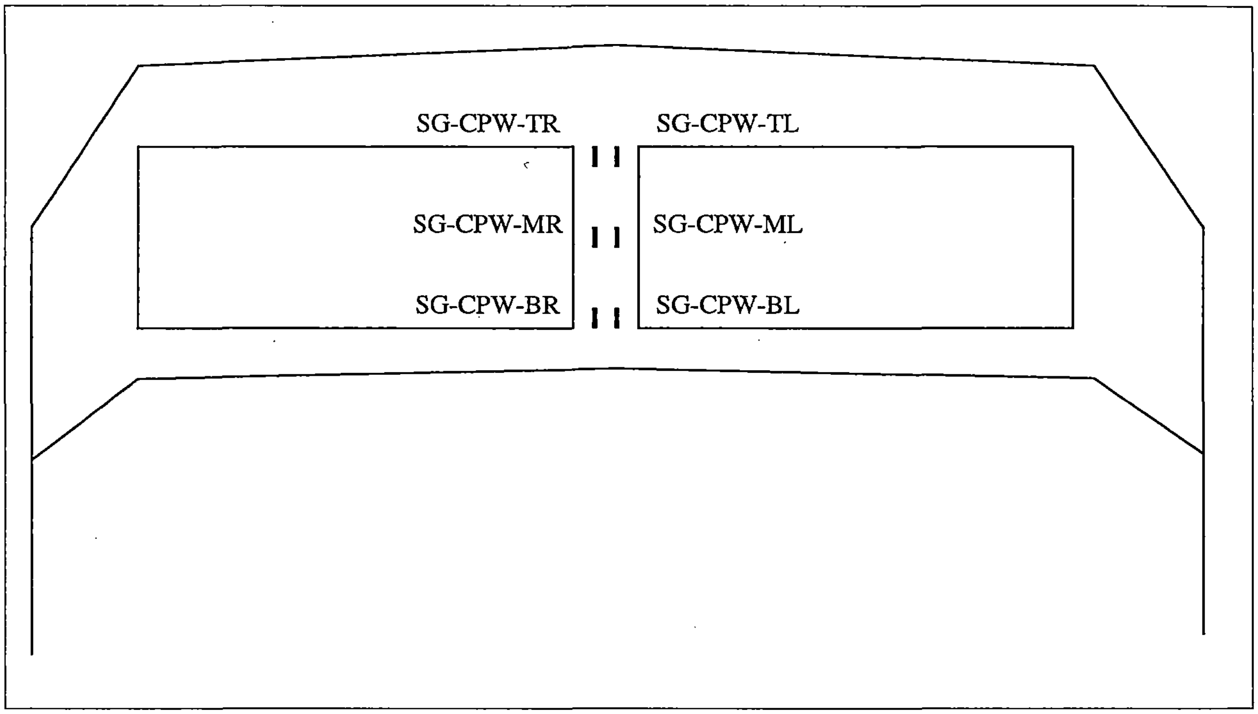

Figure 3. Location of strain gauges on windshield post

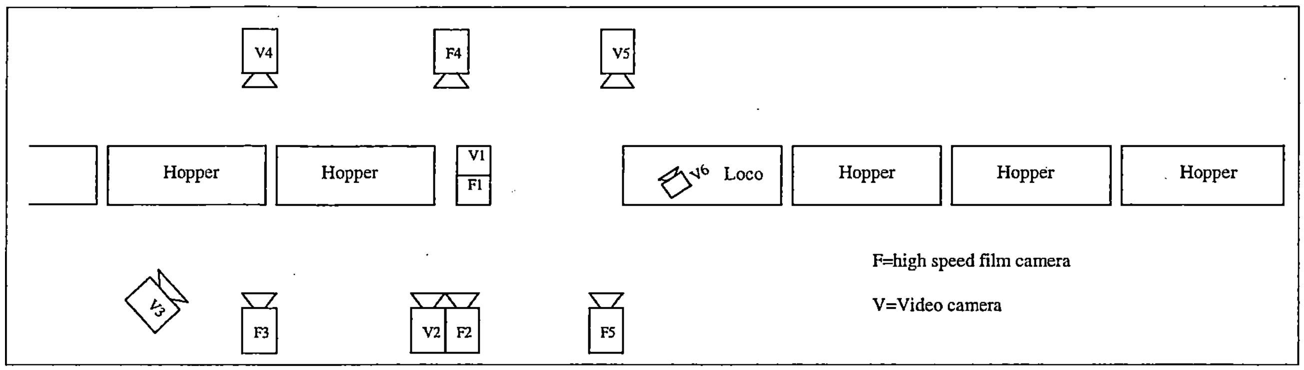

Figure 4. Location of cameras

APPENDIX B

Acceleration Data, CFC = 1000 Hz

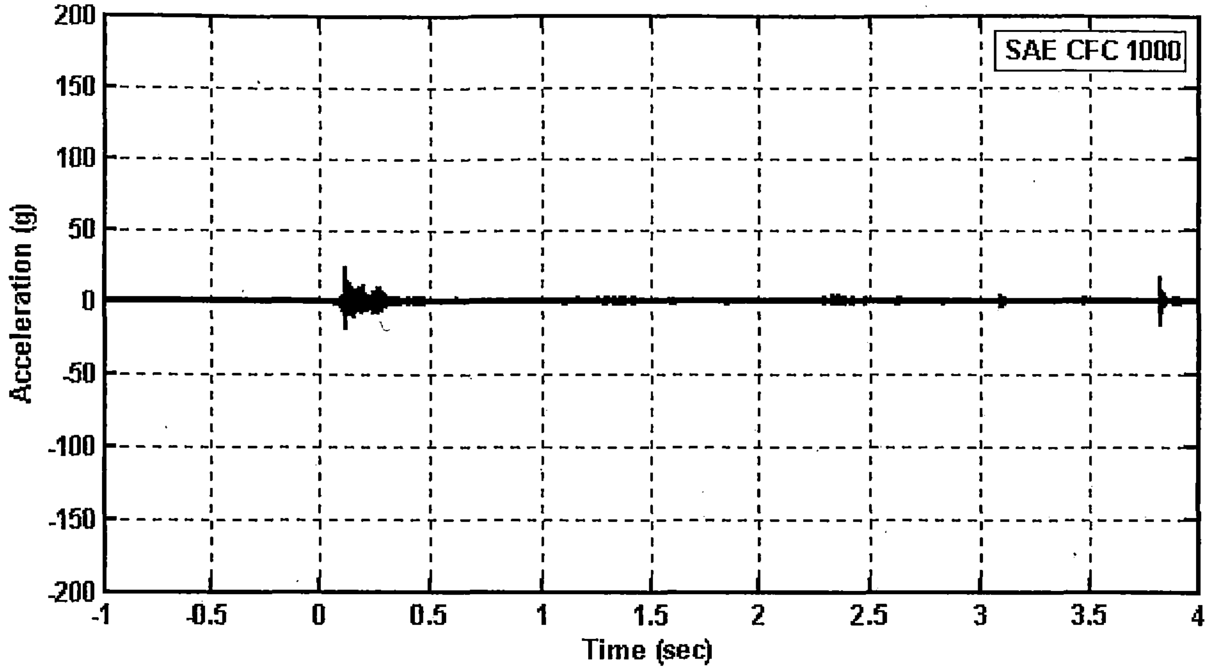

Figure B1. Bullet hopper 1, longitudinal acceleration
Channel Name: BH1_CGX

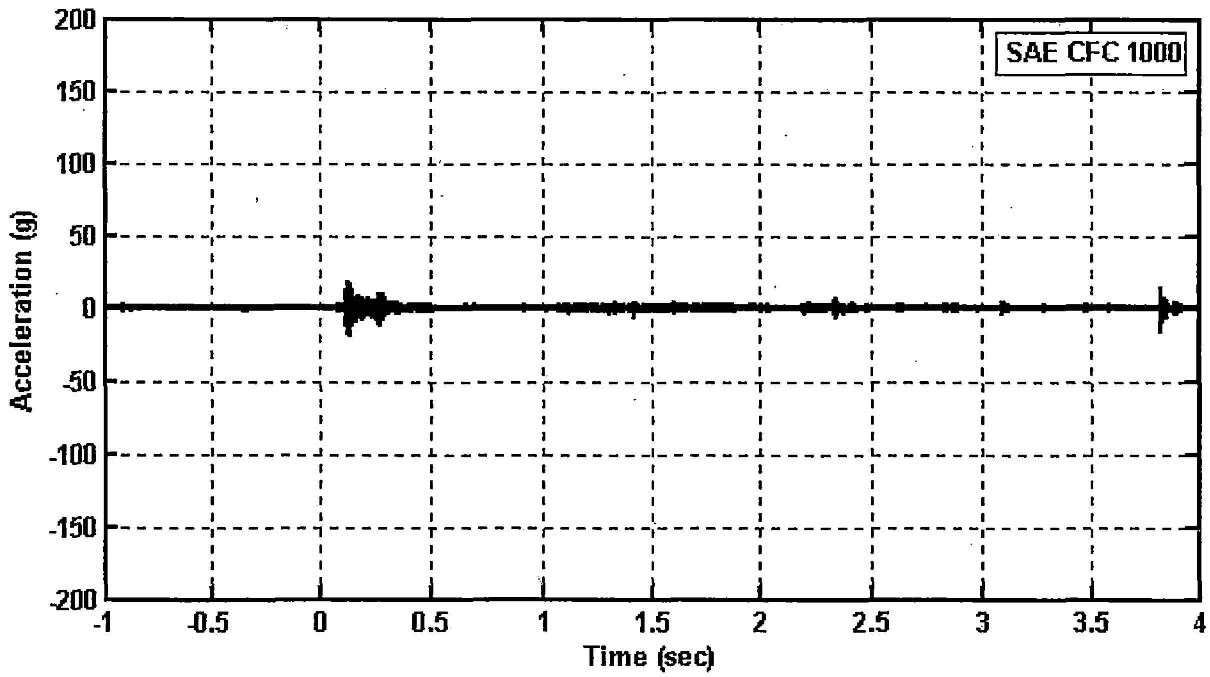

Figure B2. Bullet hopper 1, lateral acceleration
Channel Name: BH1_CGY

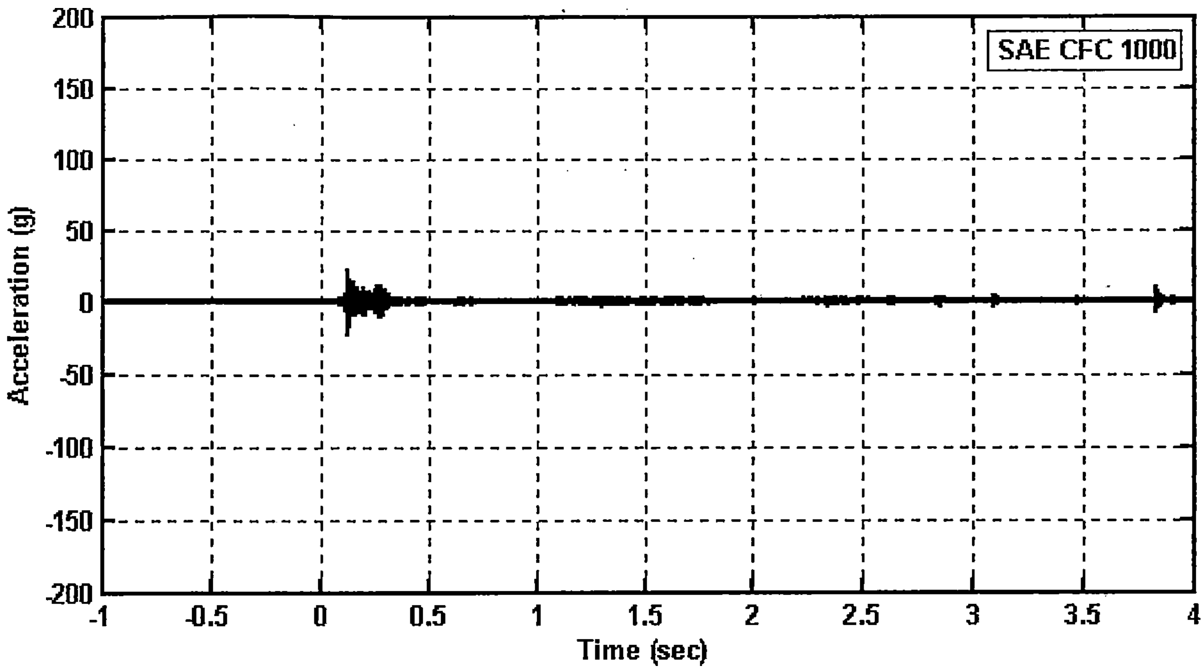

Figure B3. Bullet hopper 1, vertical acceleration
Channel Name: BH1_CGZ

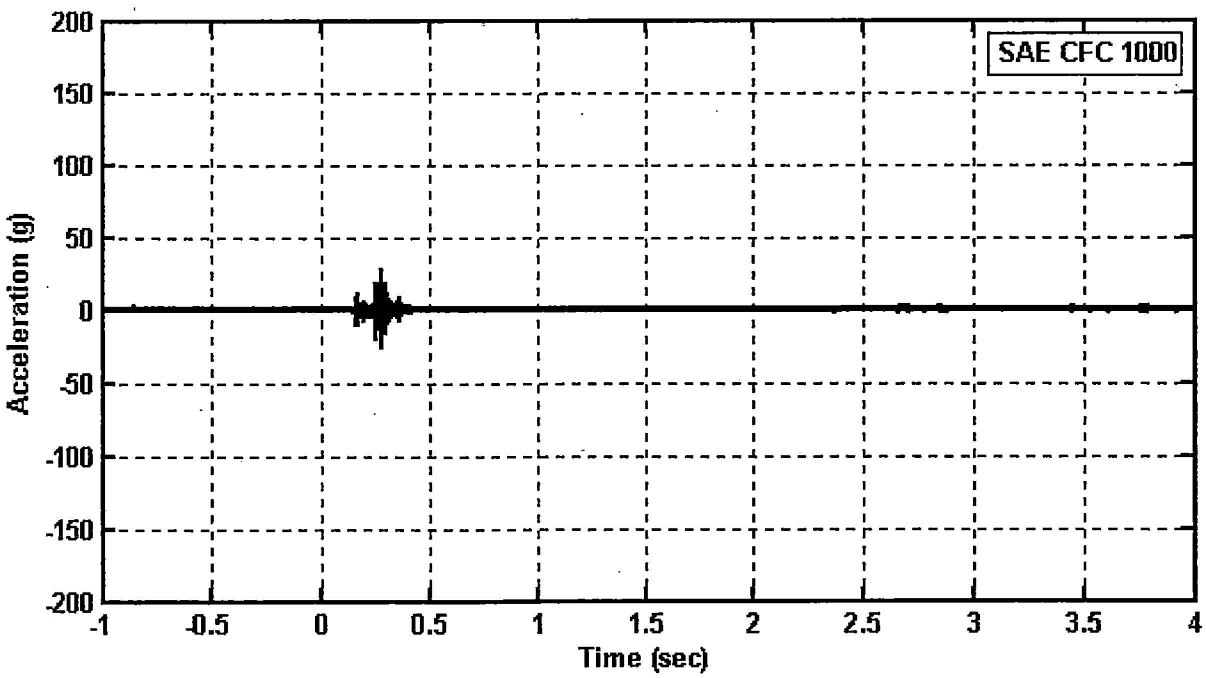

Figure B4. Bullet hopper 2, longitudinal acceleration
Channel Name: BH2_CGX

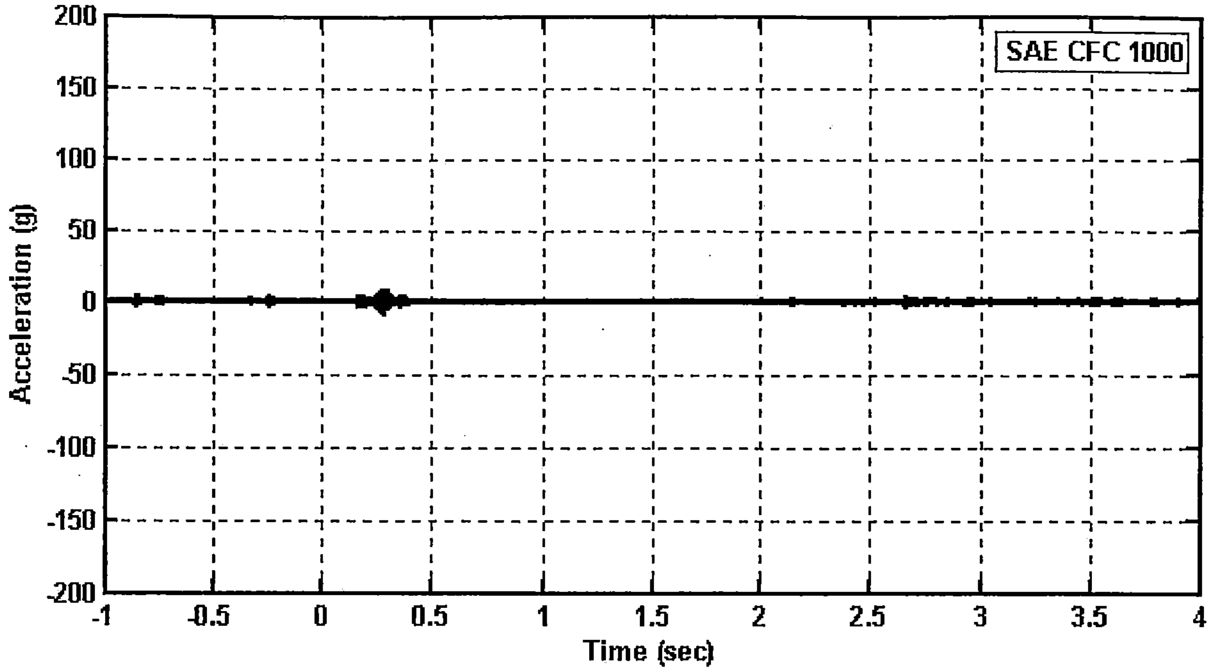

Figure B5. Bullet hopper 2, lateral acceleration
Channel Name: BH2_CGY

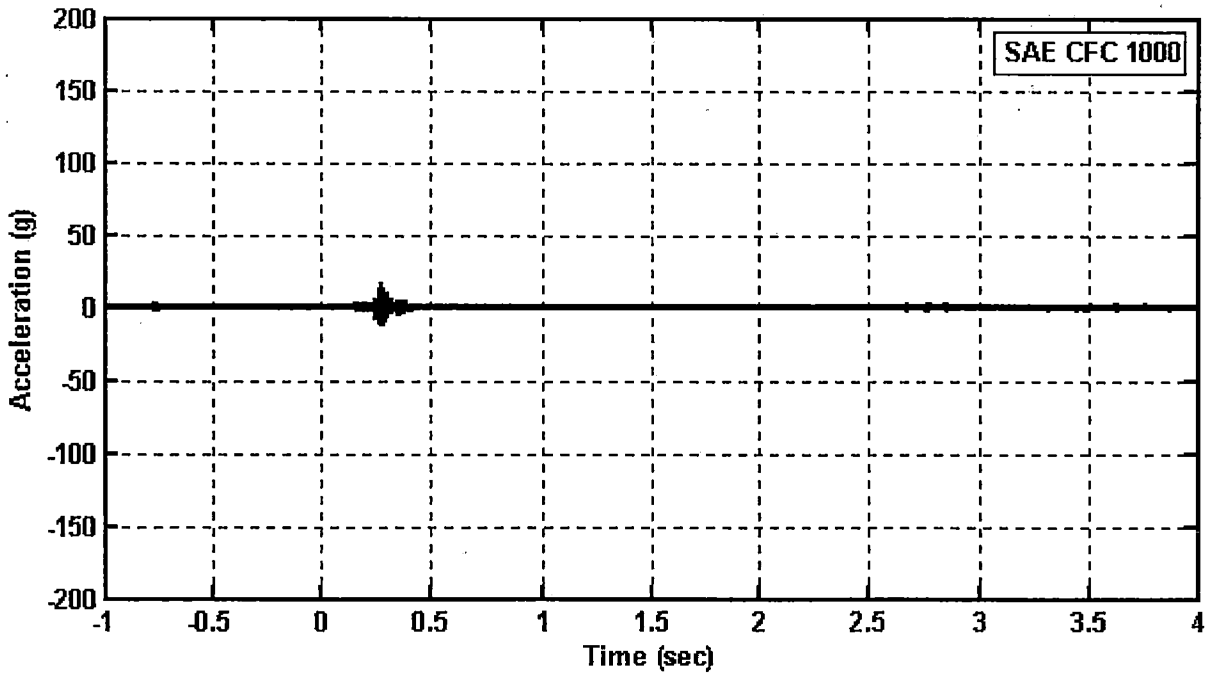

Figure B6. Bullet hopper 2, vertical acceleration
Channel Name: BH2_CGZ

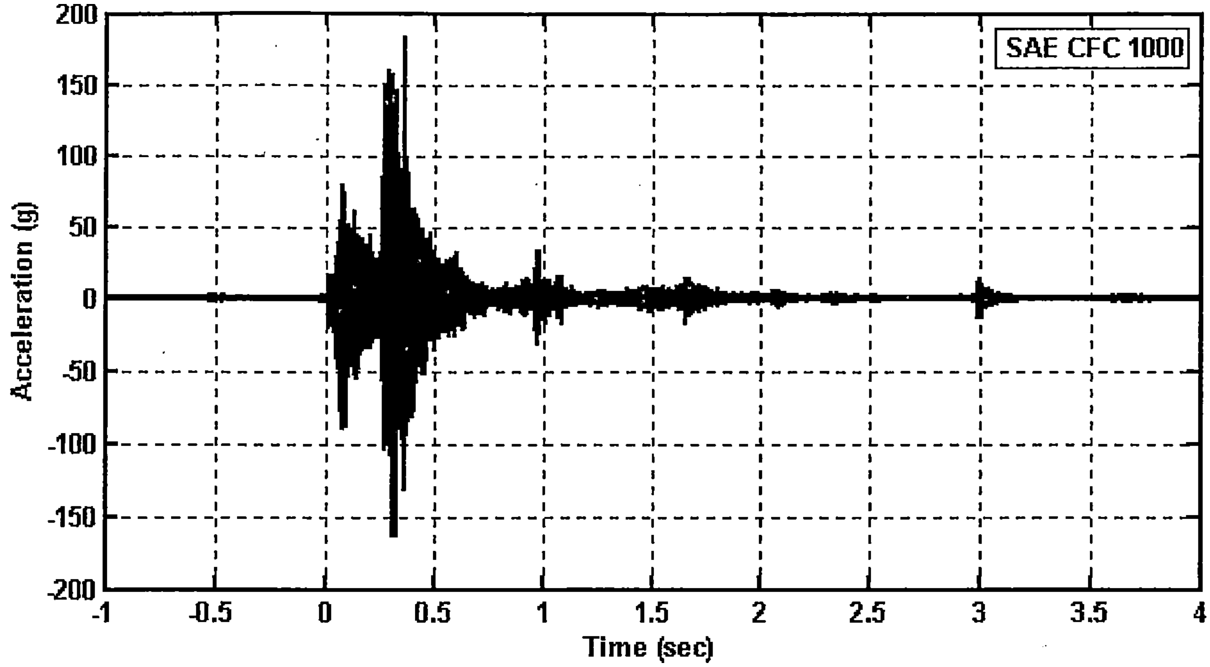

Figure B7. Locomotive floor, location 1, longitudinal acceleration
Channel Name: BL_F1X

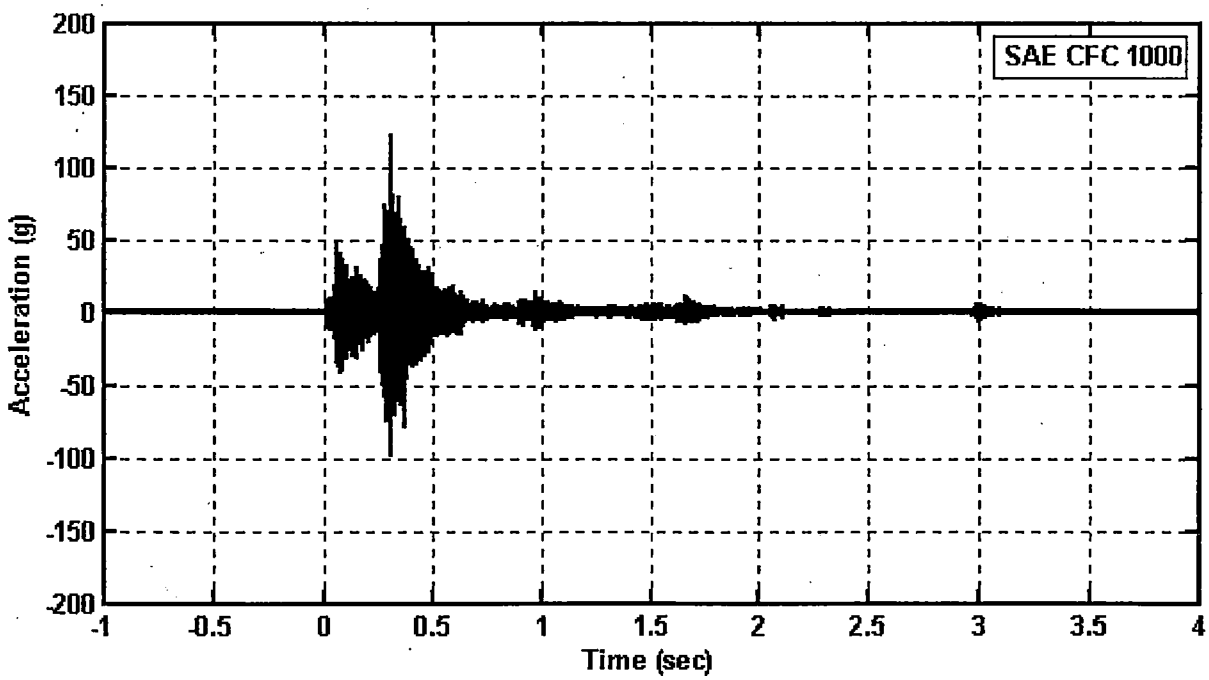

Figure B8. Locomotive floor, location 1, lateral acceleration
Channel Name: BL_F1Y

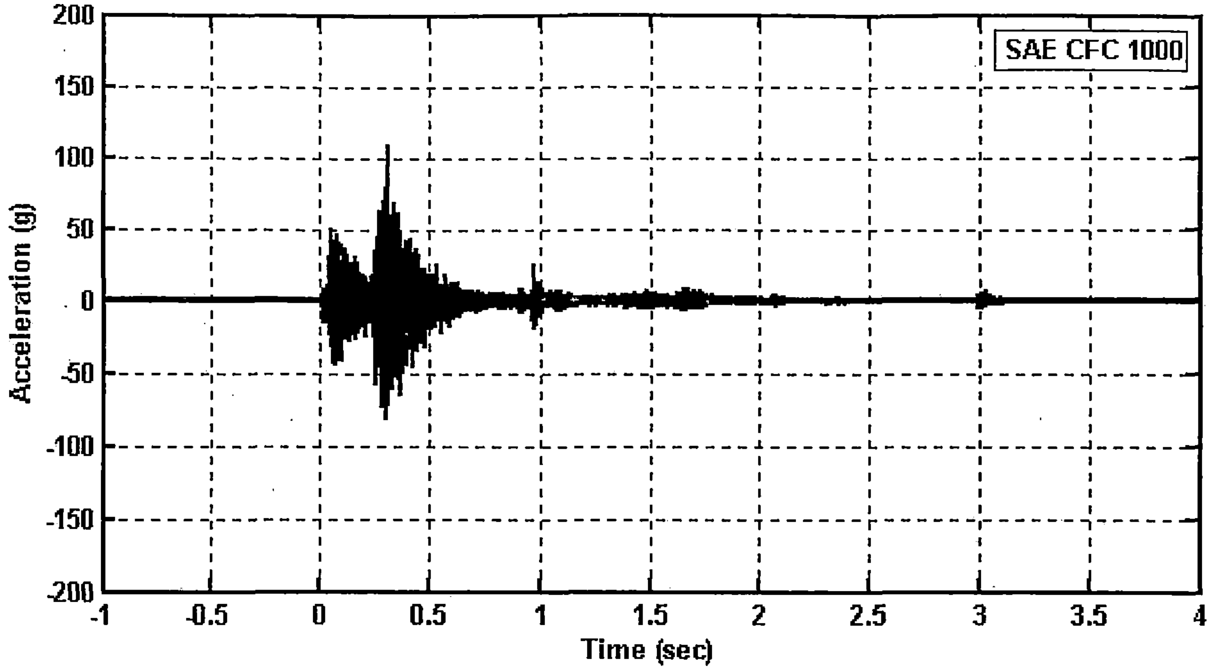

Figure B9. Locomotive floor, location 1, vertical acceleration
Channel Name: BL_F1Z

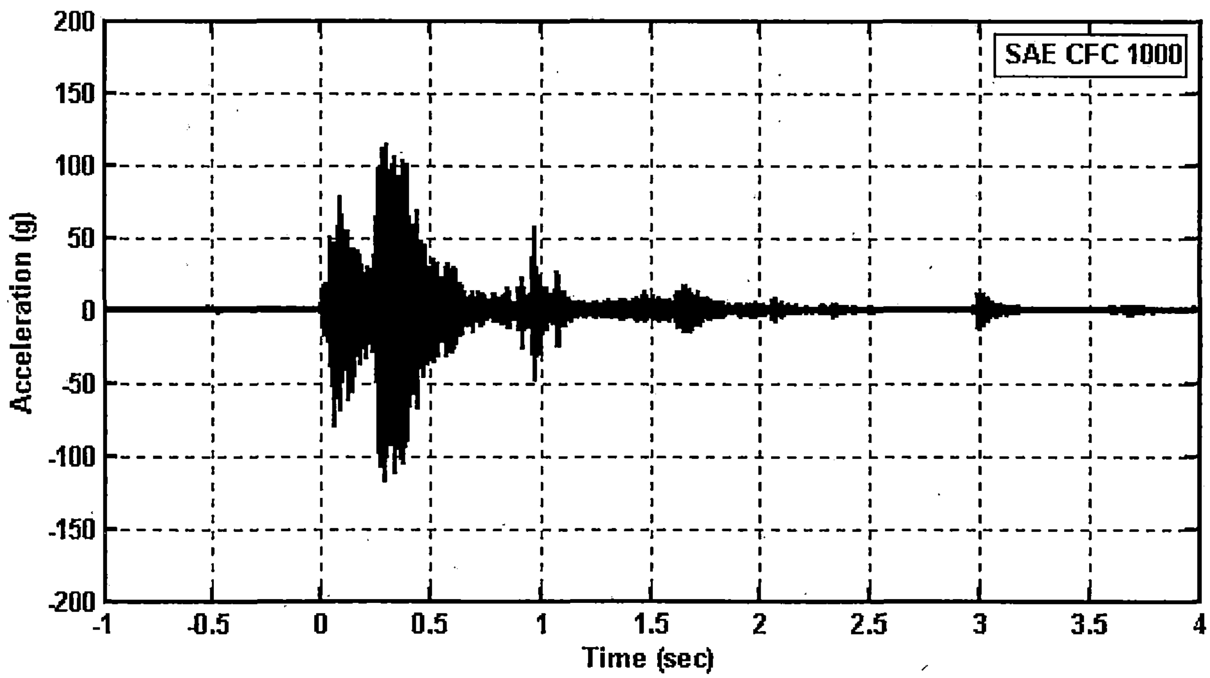

Figure B10. Locomotive floor, location 2, longitudinal acceleration
Channel Name: BL_F2X

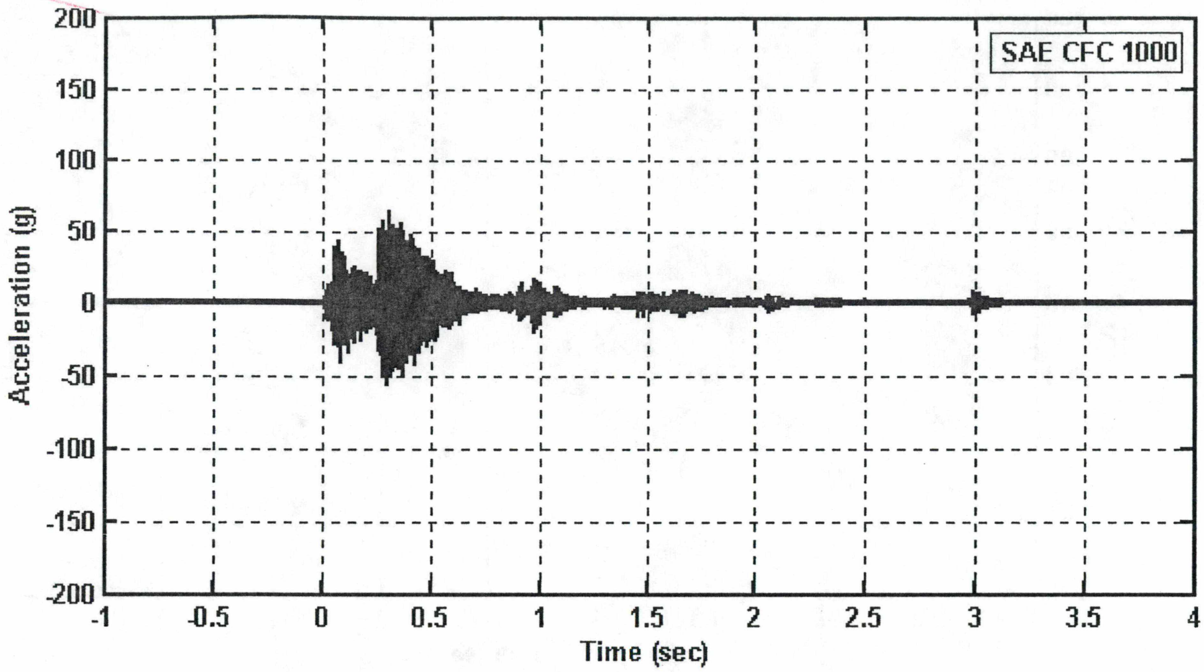

Figure B11. Locomotive floor, location 2, lateral acceleration
Channel Name: BL_F2Y

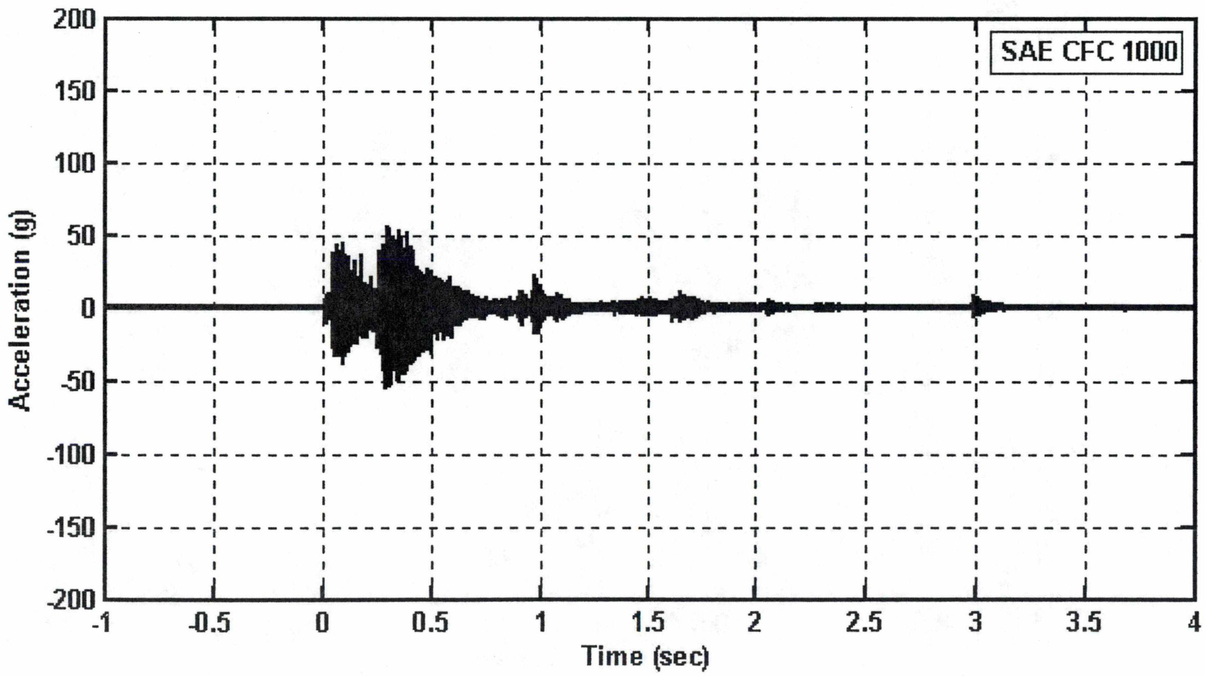

Figure B12. Locomotive floor, location 2, vertical acceleration
Channel Name: BL_F2Z

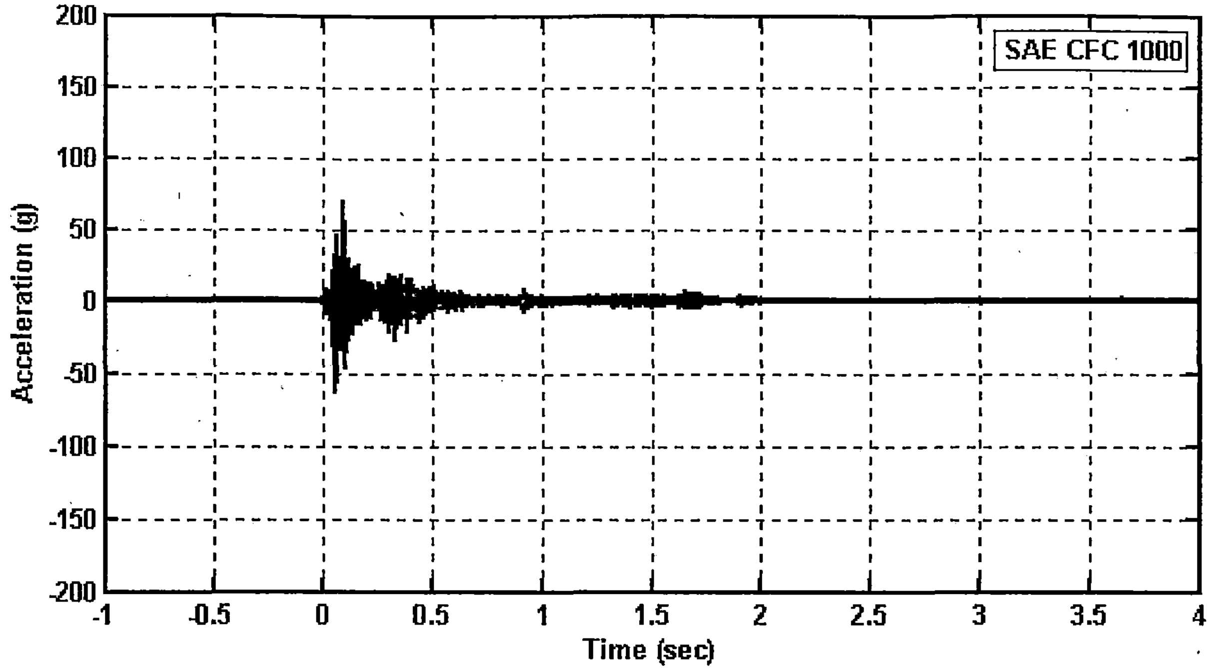

Figure B13. Locomotive event recorder, longitudinal acceleration
Channel Name: BL_RX

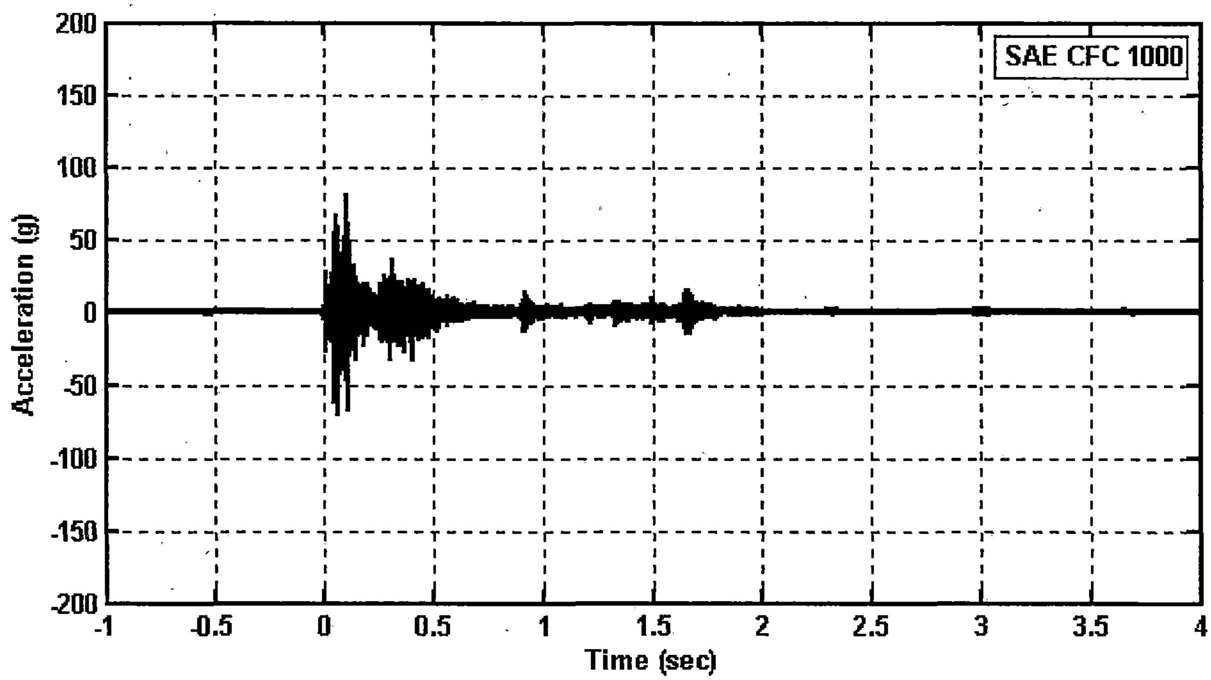

Figure B14. Locomotive event recorder, lateral acceleration
Channel Name: BL_RY

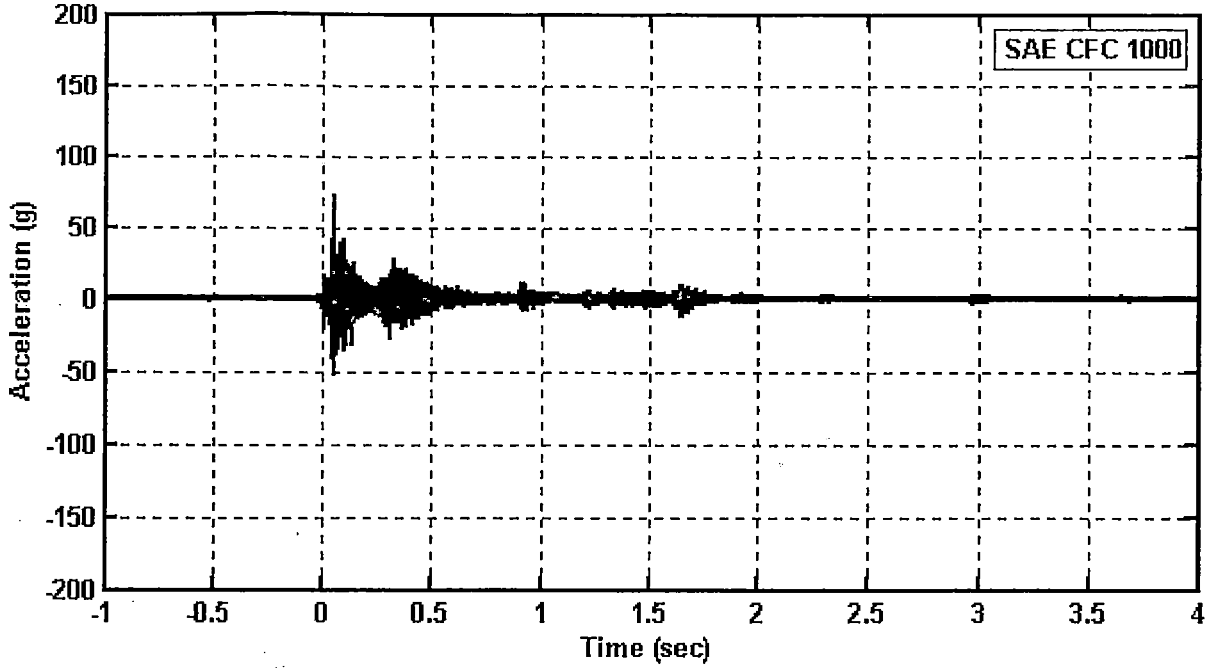

Figure B15. Locomotive event recorder, vertical acceleration
Channel Name: BL_RZ

APPENDIX C

Acceleration Data, Fc = 100 Hz

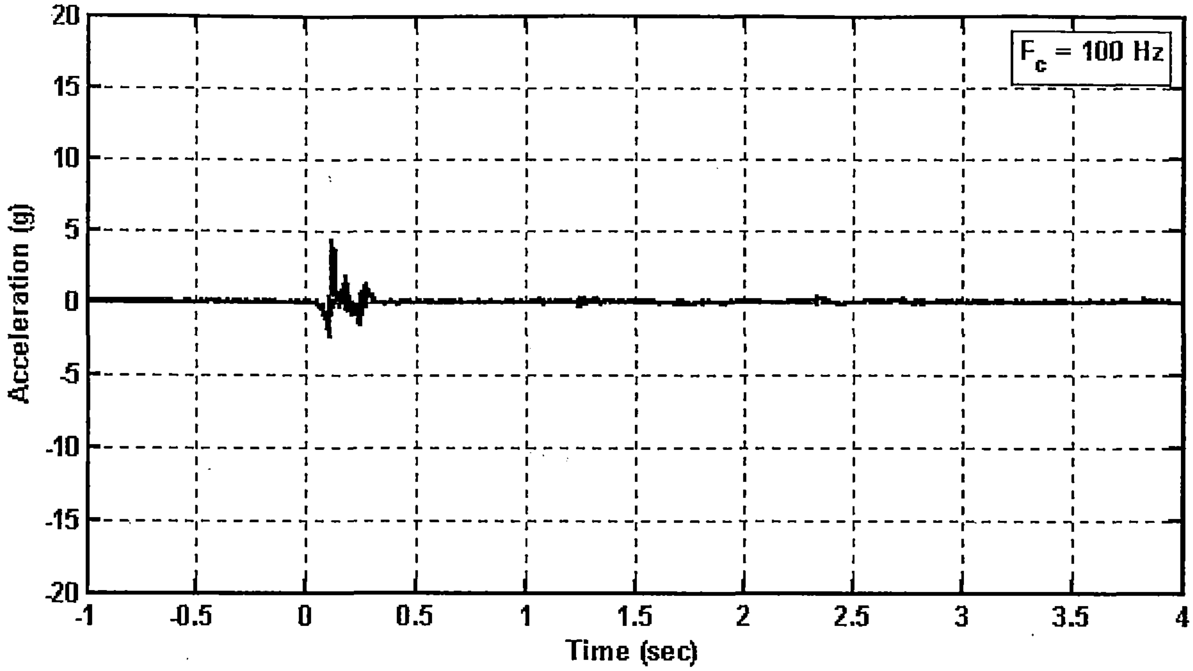

Figure C1. Bullet hopper 1, longitudinal acceleration
Channel Name: BH1_CGX

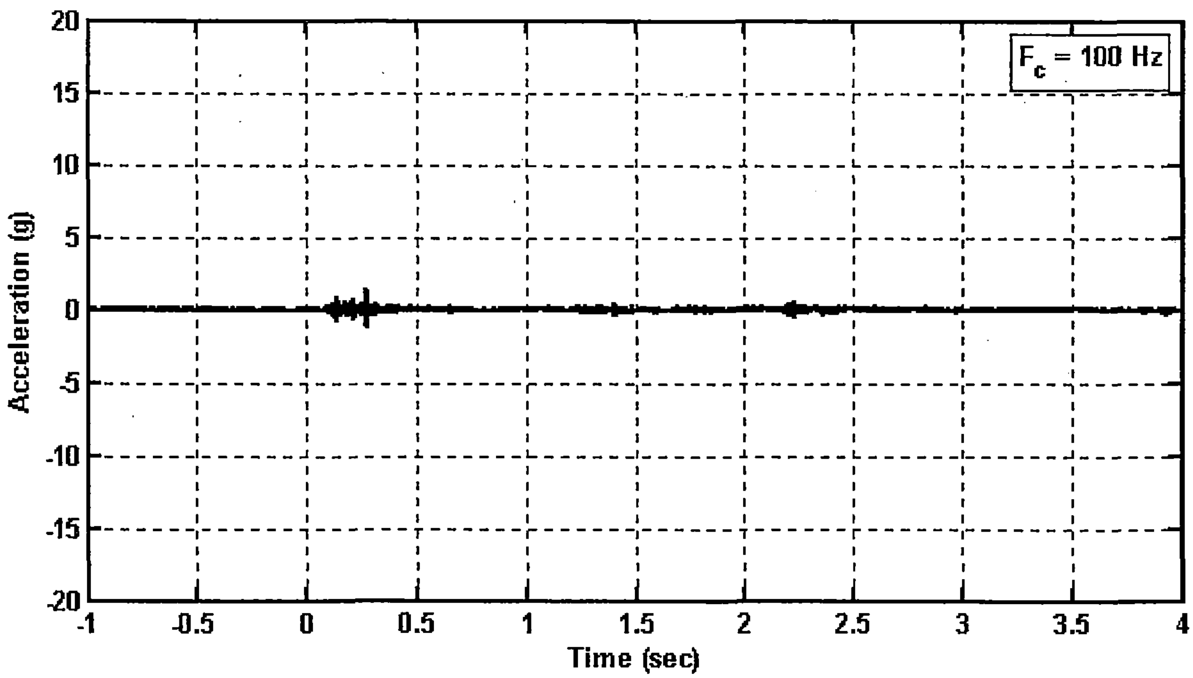

Figure C2. Bullet hopper 1, lateral acceleration
Channel Name: BH1_CGY

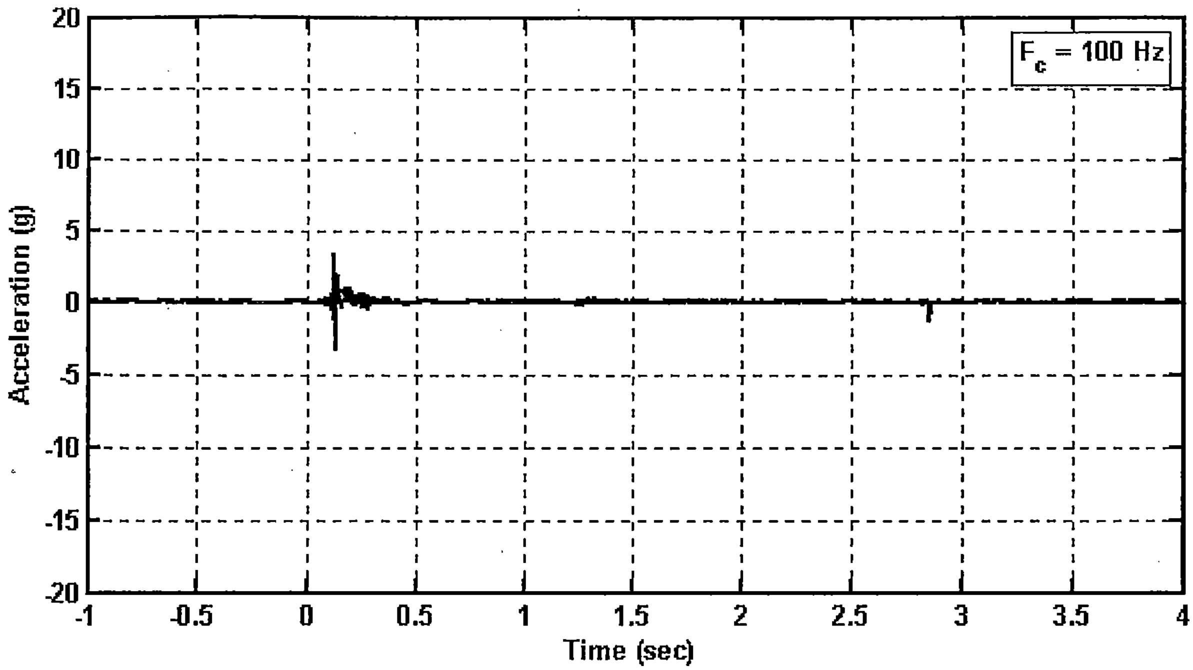

Figure C3. Bullet hopper 1, vertical acceleration
Channel Name: BH1_CGZ

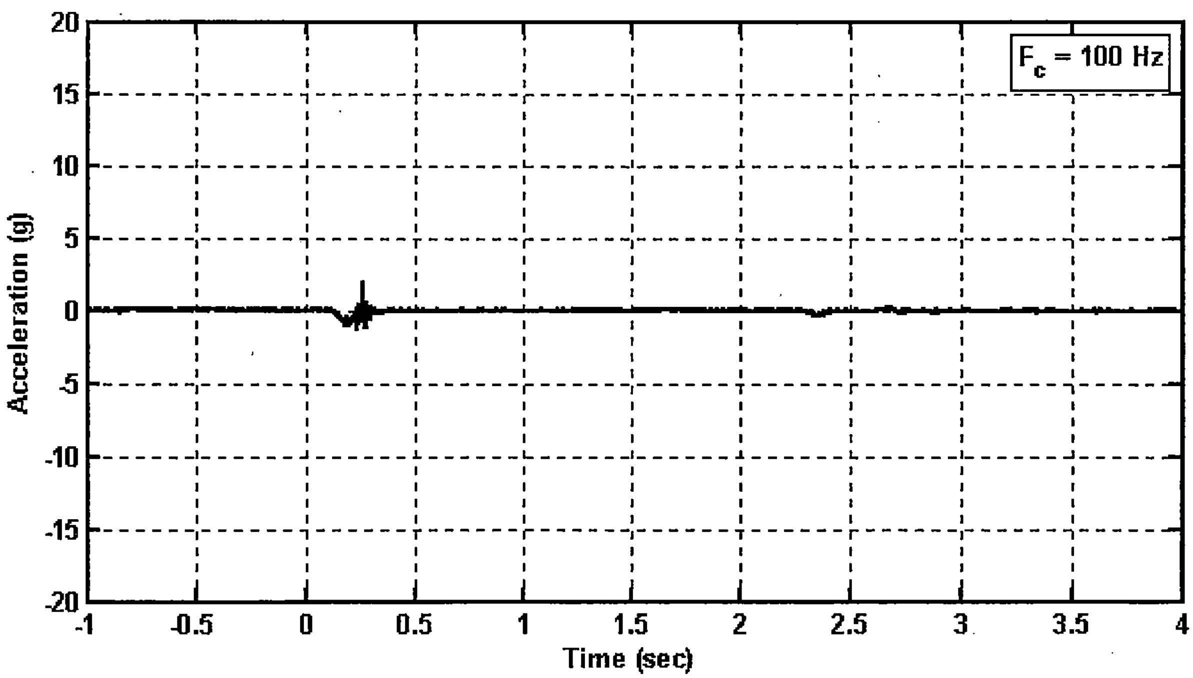

Figure C4. Bullet hopper 2, longitudinal acceleration
Channel Name: BH2_CGX

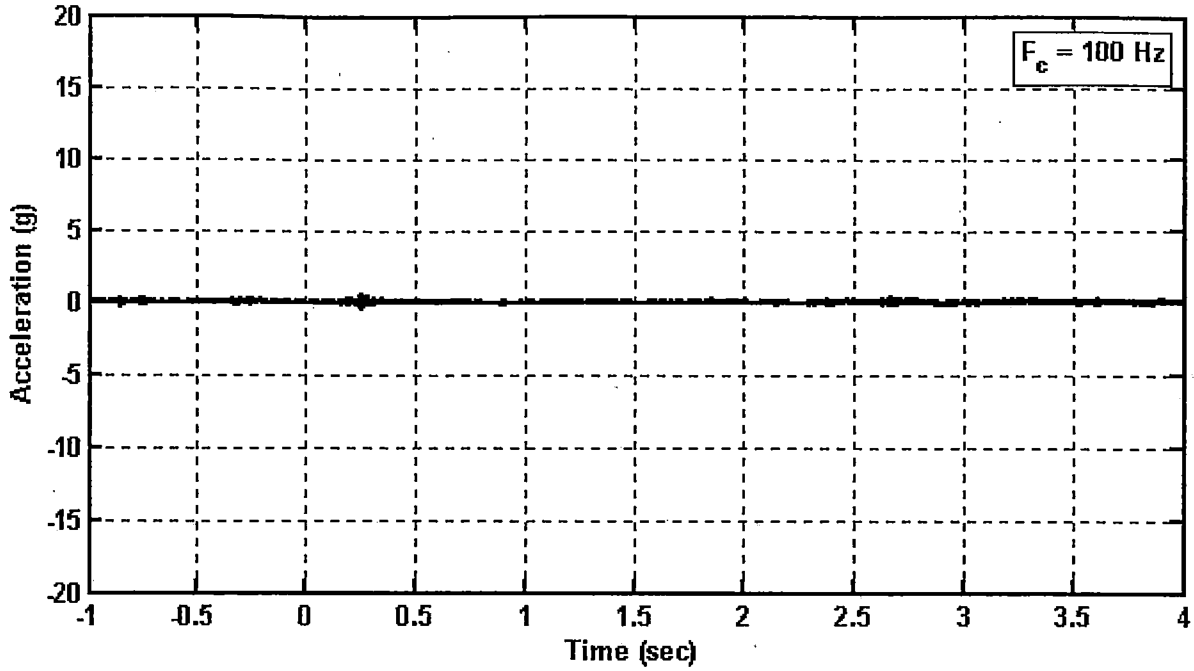

Figure C5. Bullet hopper 2, lateral acceleration
Channel Name: BH2_CGY

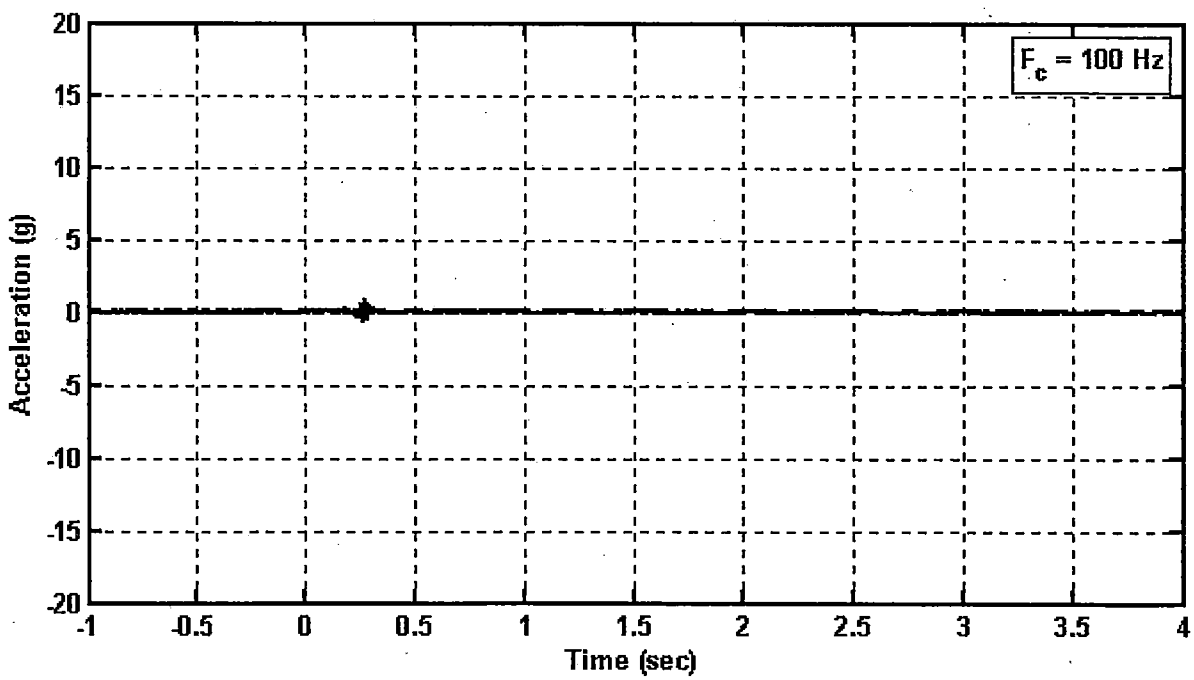

Figure C6. Bullet hopper 2, vertical acceleration
Channel Name: BH2_CGZ

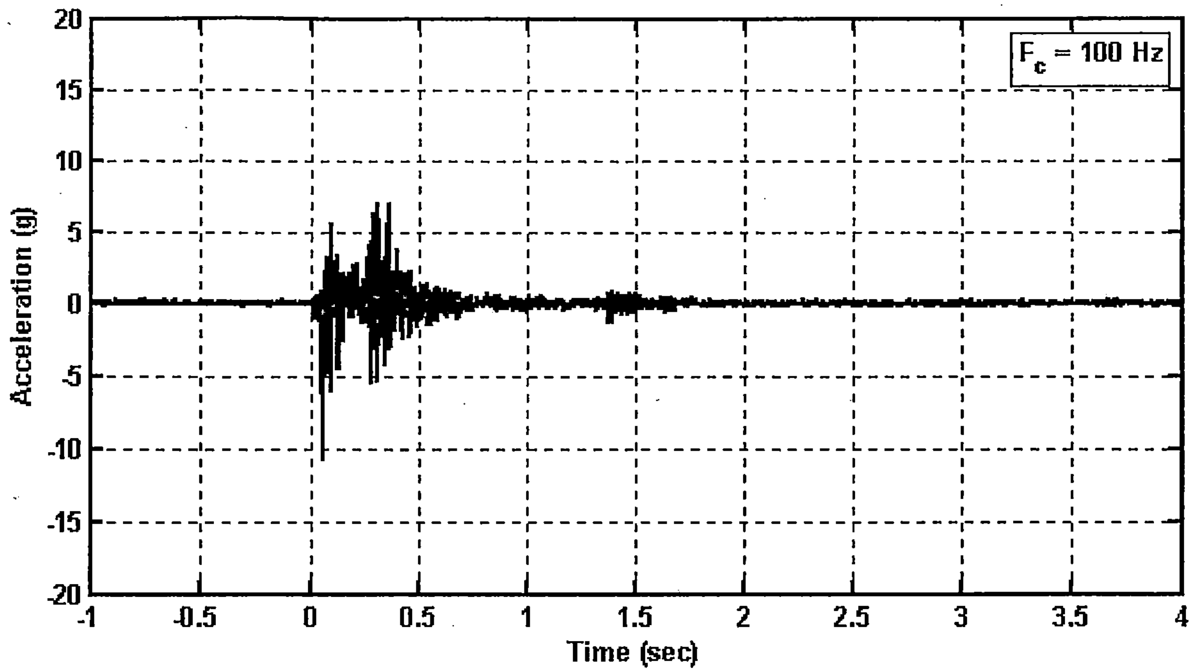

Figure C7. Locomotive floor, location 1, longitudinal acceleration
Channel Name: BL_F1X

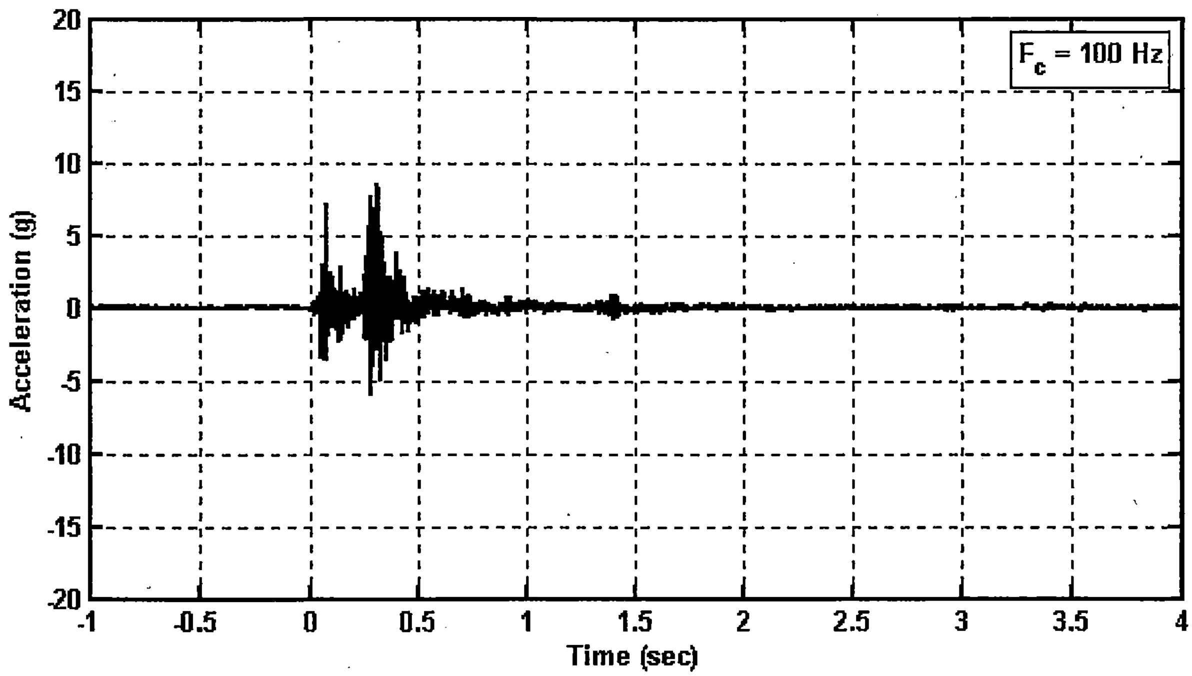

Figure C8. Locomotive floor, location 1, lateral acceleration
Channel Name: BL_F1Y

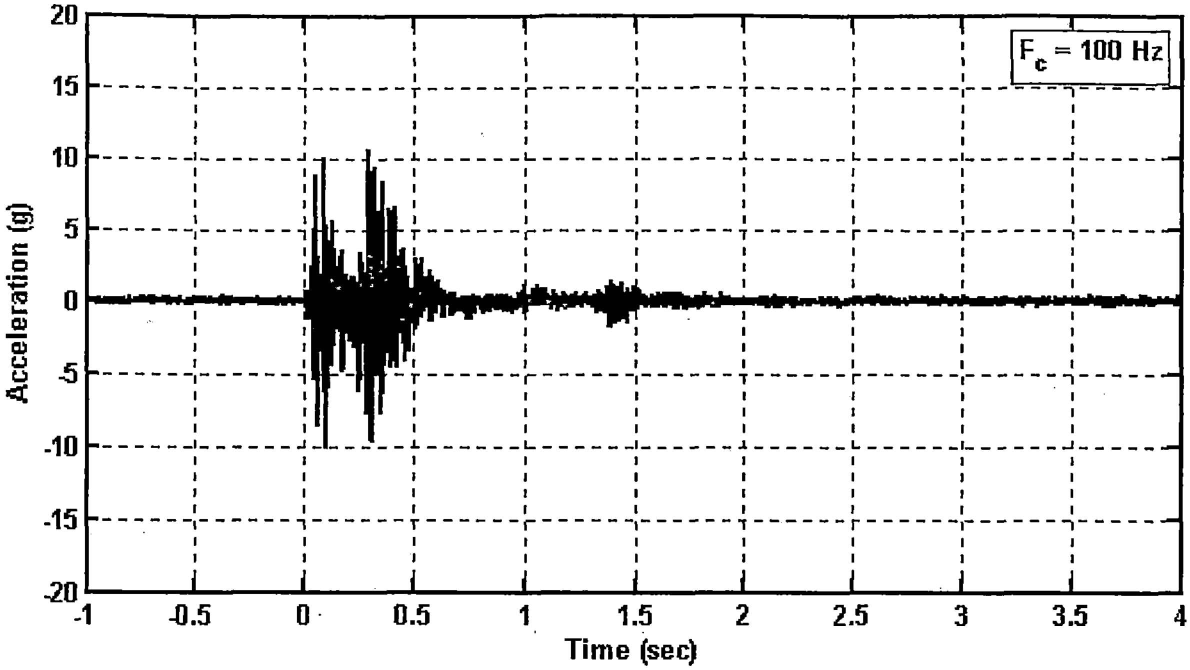

Figure C9. Locomotive floor, location 1, vertical acceleration
Channel Name: BL_F1Z

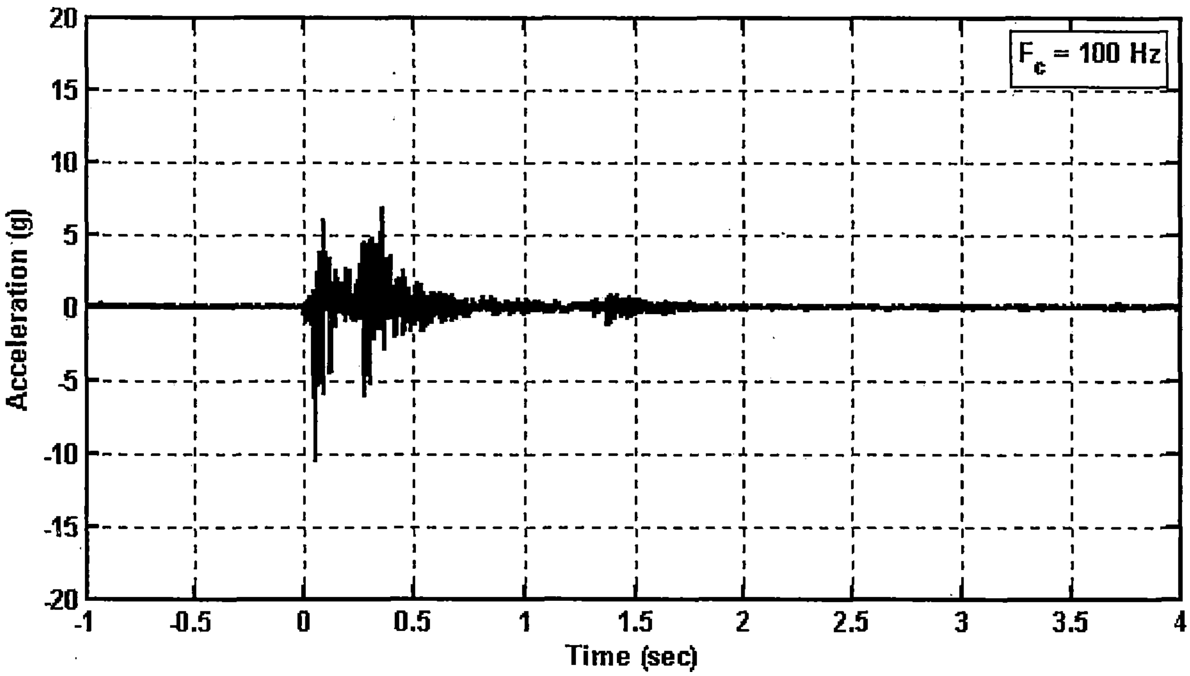

Figure C10. Locomotive floor, location 2, longitudinal acceleration
Channel Name: BL_F2X

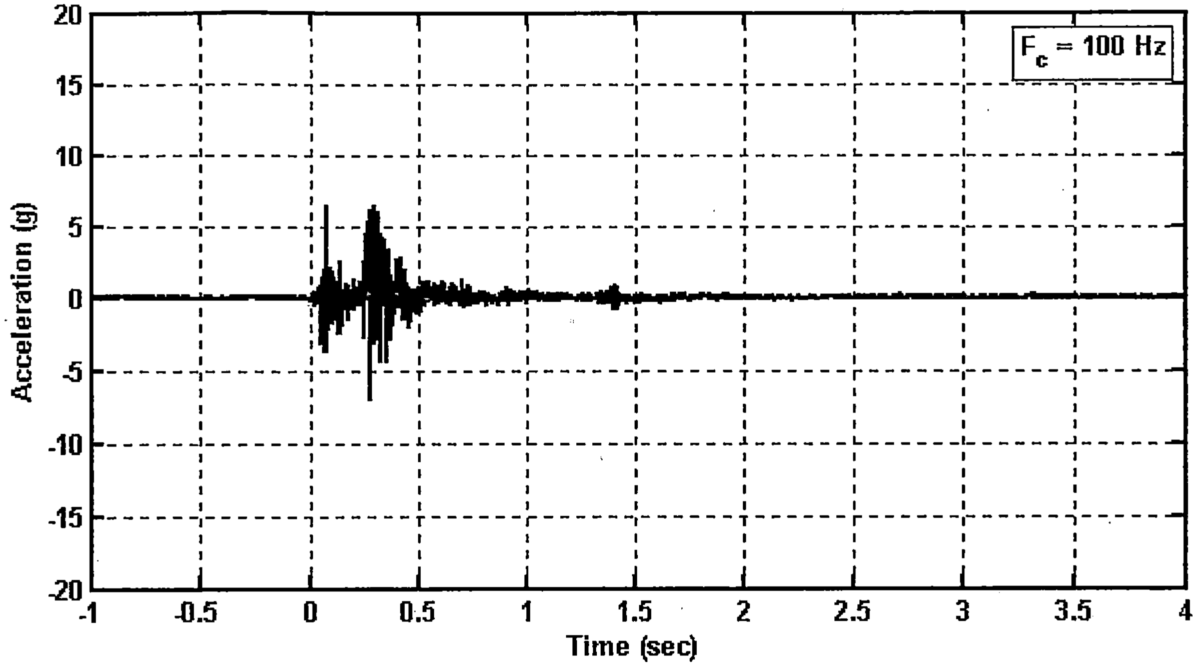

Figure C11. Locomotive floor, location 2, lateral acceleration
Channel Name: BL_F2Y

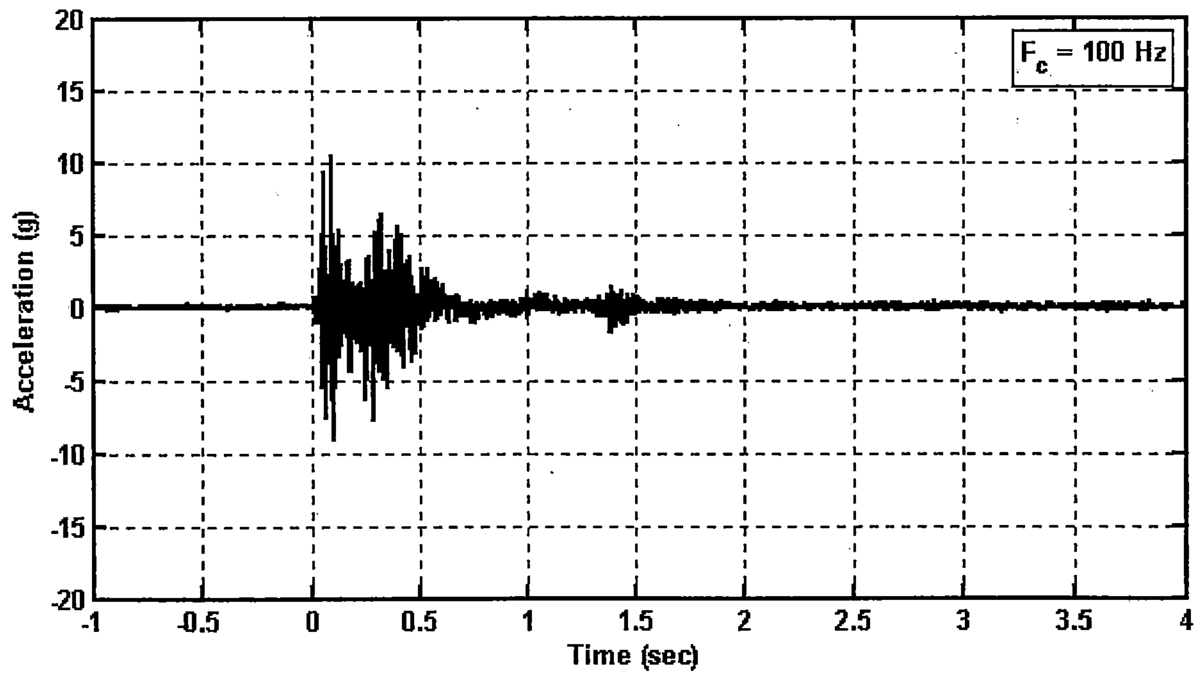

Figure C12. Locomotive floor, location 2, vertical acceleration
Channel Name: BL_F2Z

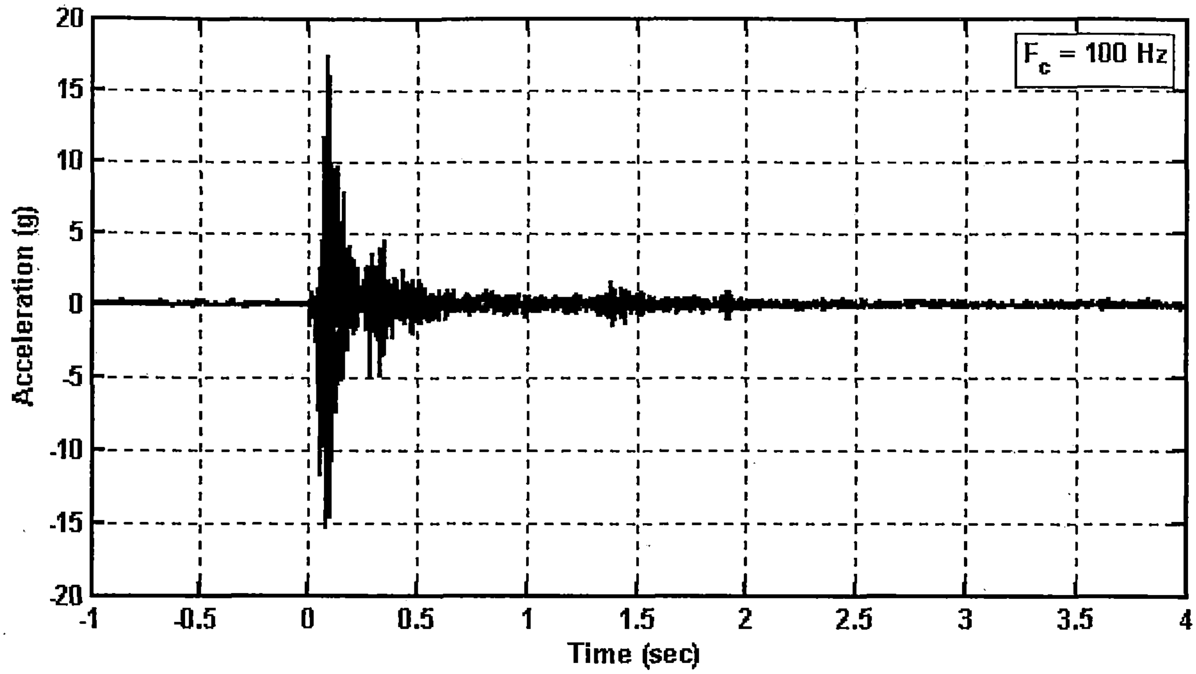

Figure C13. Locomotive event recorder, longitudinal acceleration
Channel Name: BL_RX

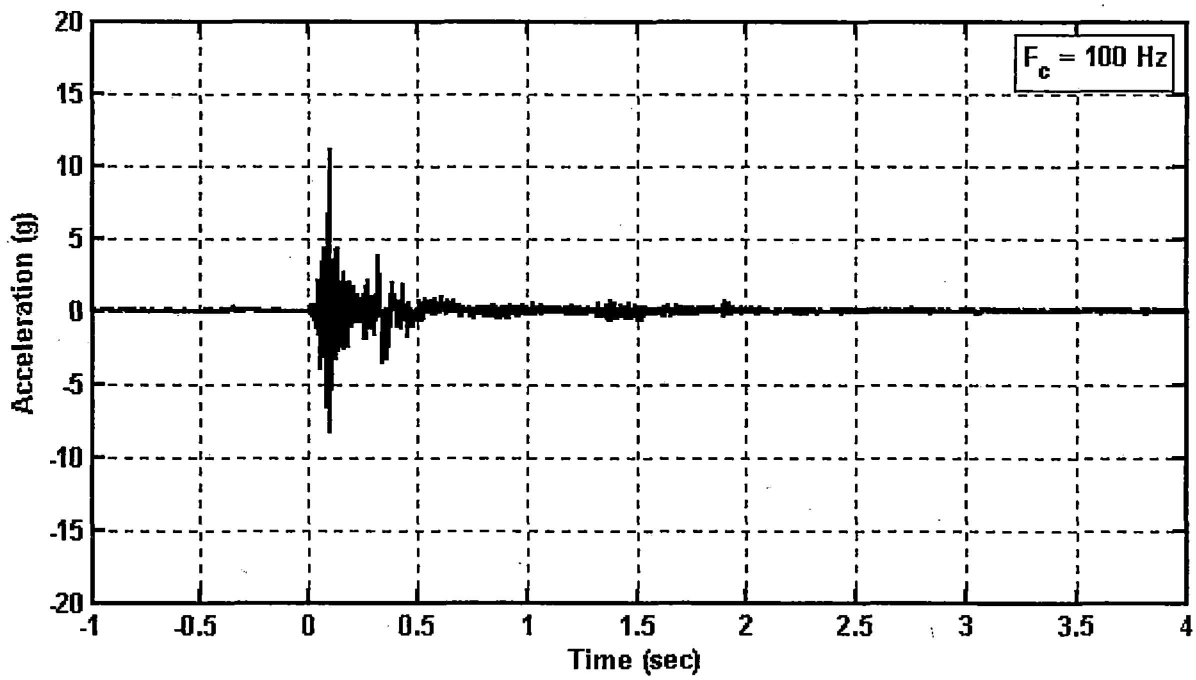

Figure C14. Locomotive event recorder, lateral acceleration
Channel Name: BL_RY

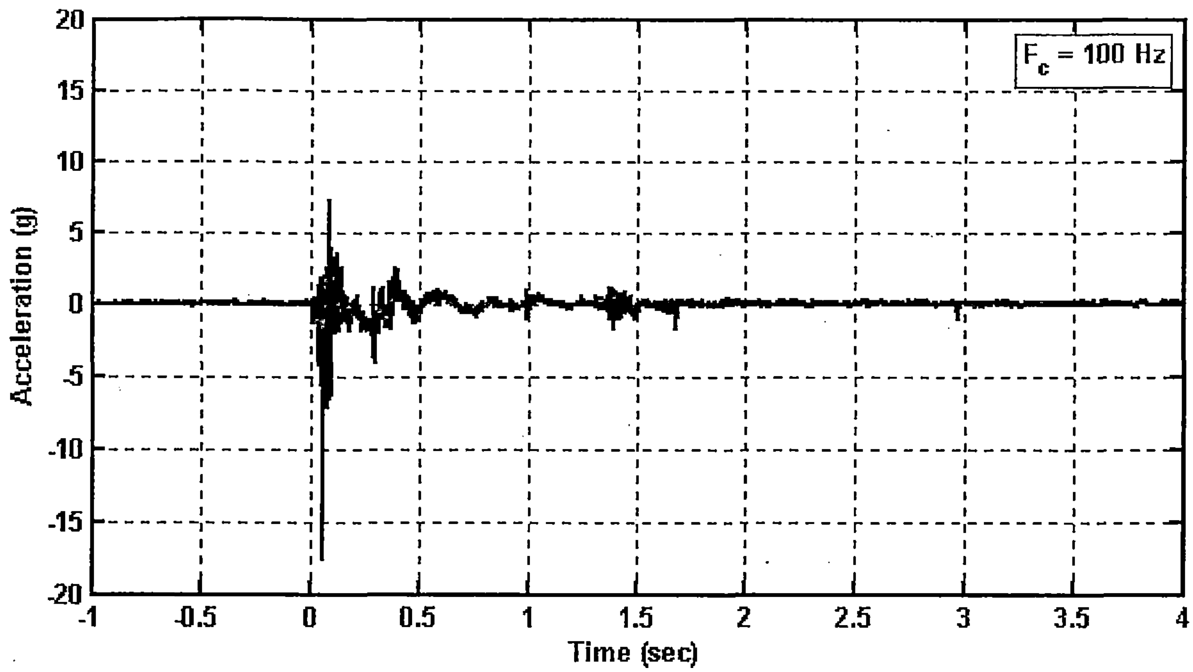

Figure C15. Locomotive event recorder, vertical acceleration
Channel Name: BL_RZ

APPENDIX D

Acceleration Data, Fc = 25 Hz

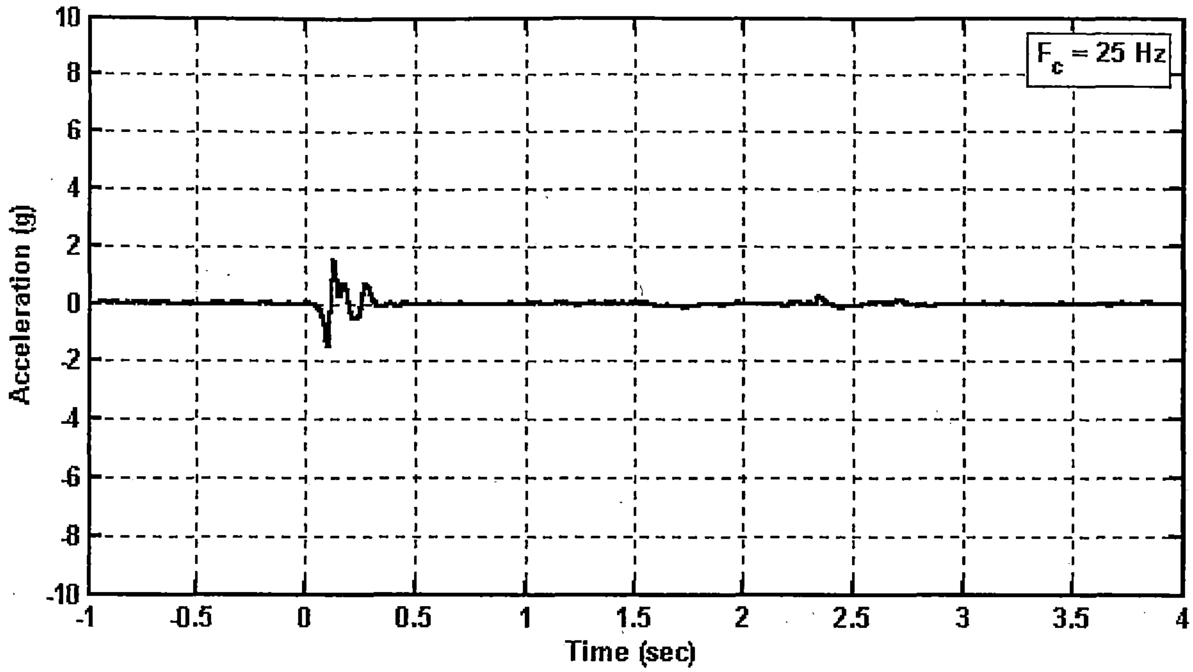

Figure D1. Bullet hopper 1, longitudinal acceleration
Channel Name: BH1_CGX

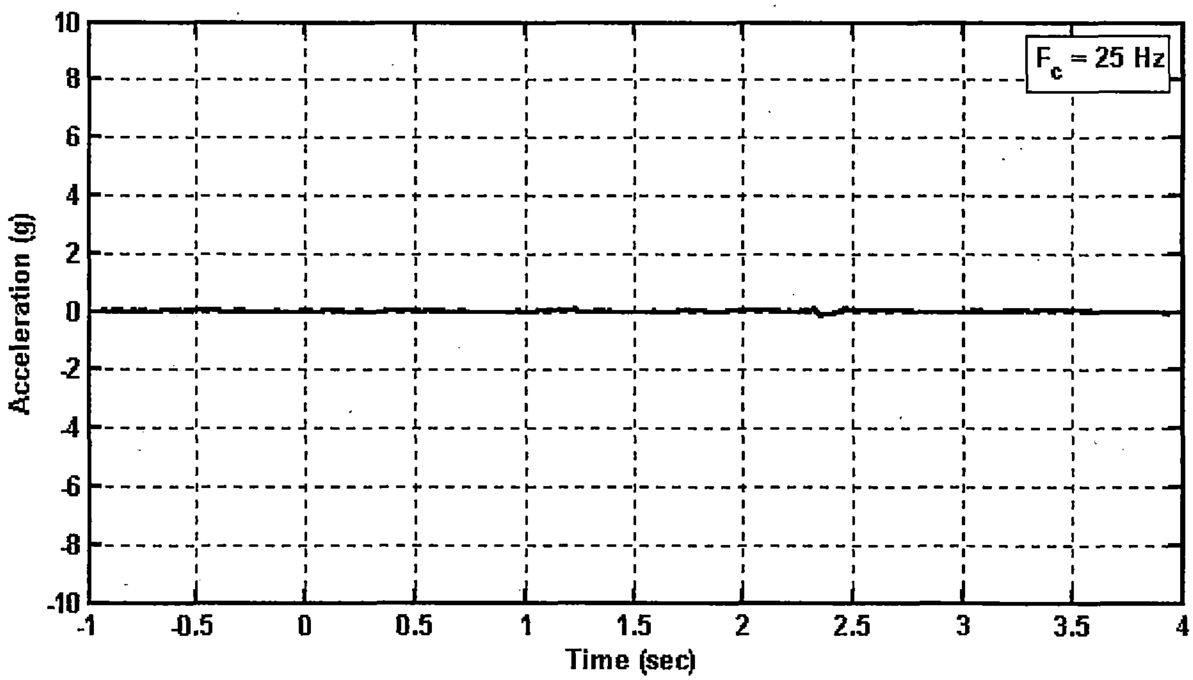

Figure D2. Bullet hopper 1, lateral acceleration
Channel Name: BH1_CGY

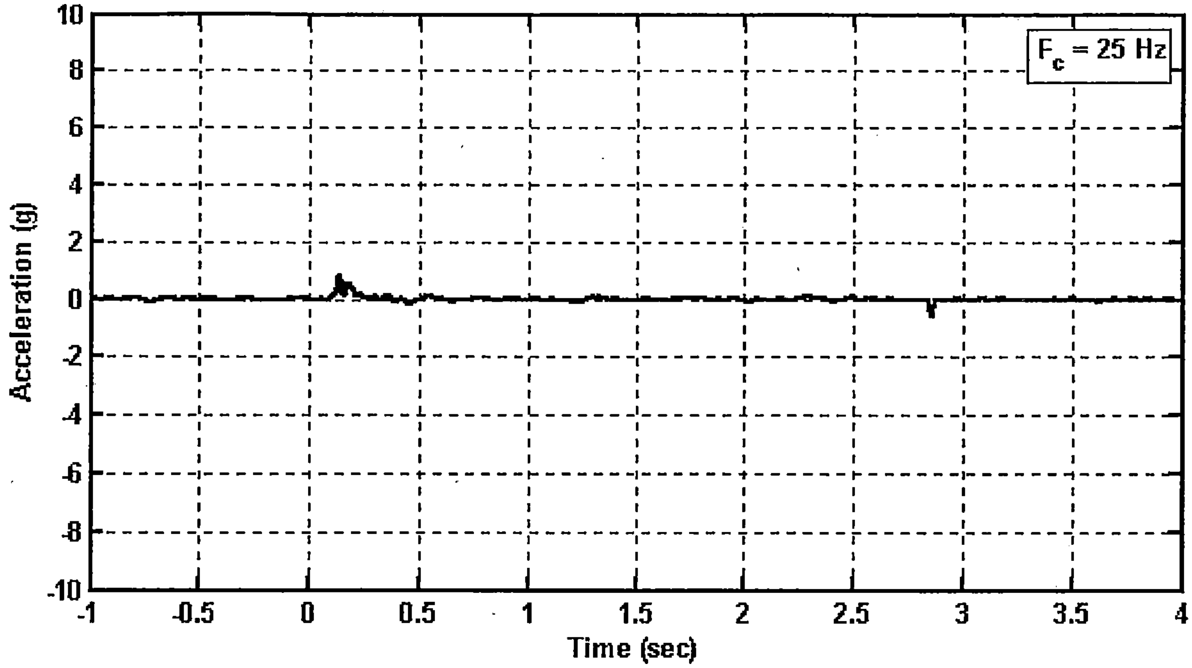

Figure D3. Bullet hopper 1, vertical acceleration
Channel Name: BH1_CGZ

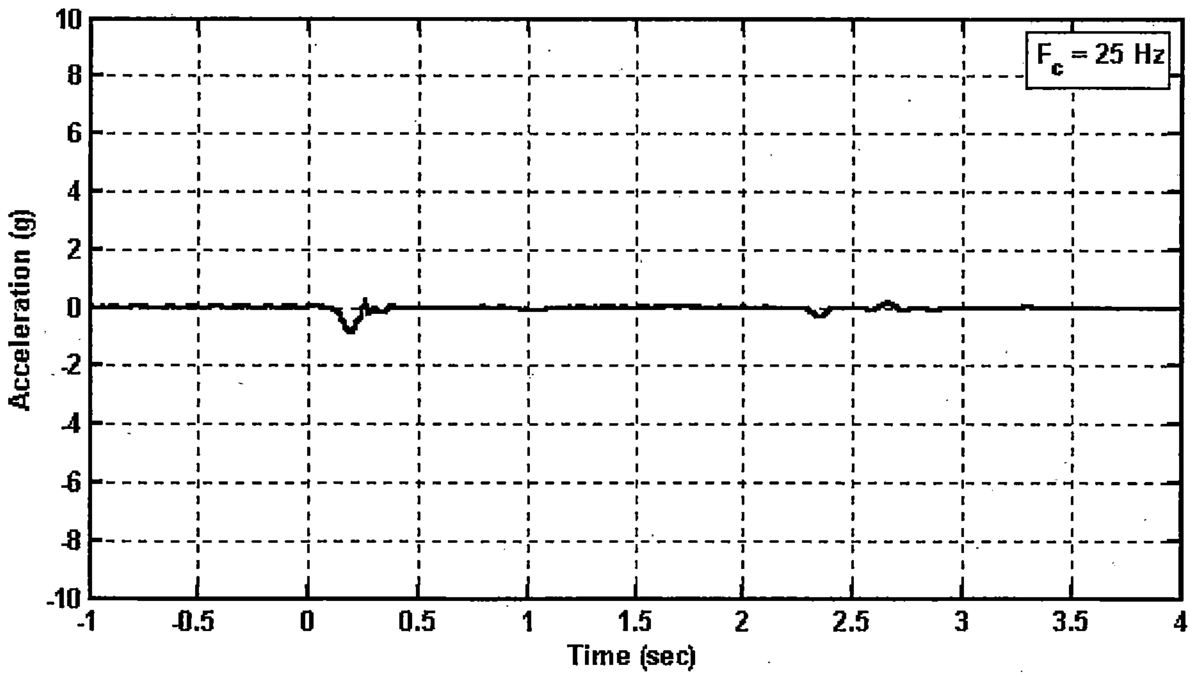

Figure D4. Bullet hopper 2, longitudinal acceleration
Channel Name: BH2_CGX

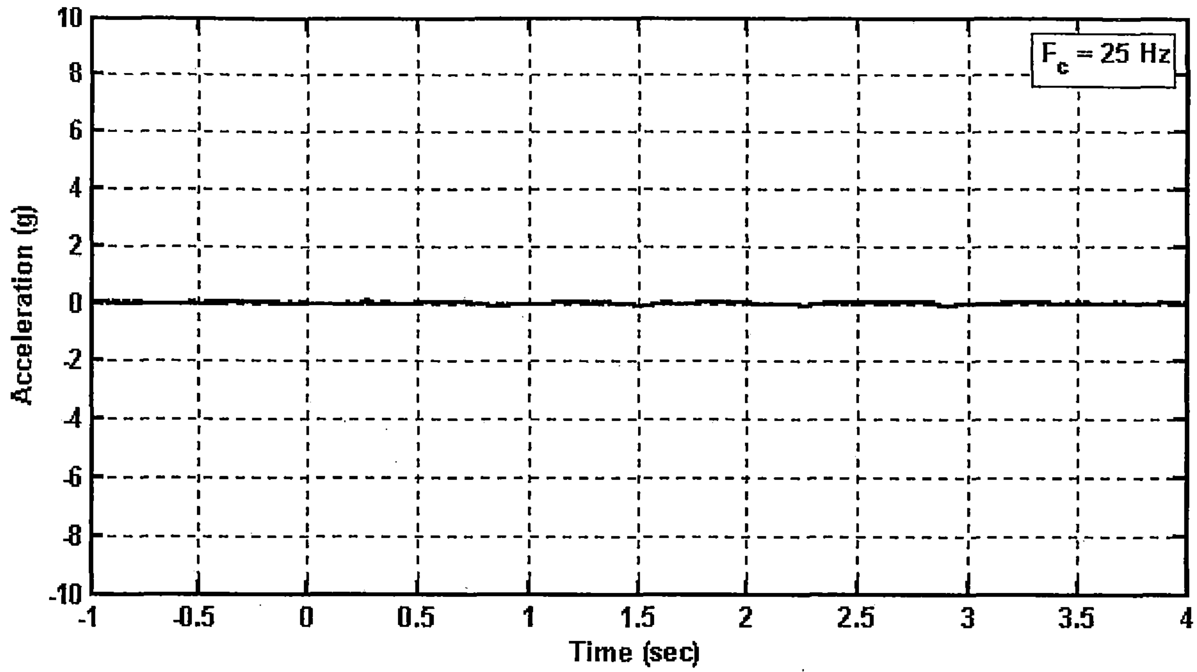

Figure D5. Bullet hopper 2, lateral acceleration
Channel Name: BH2_CGY

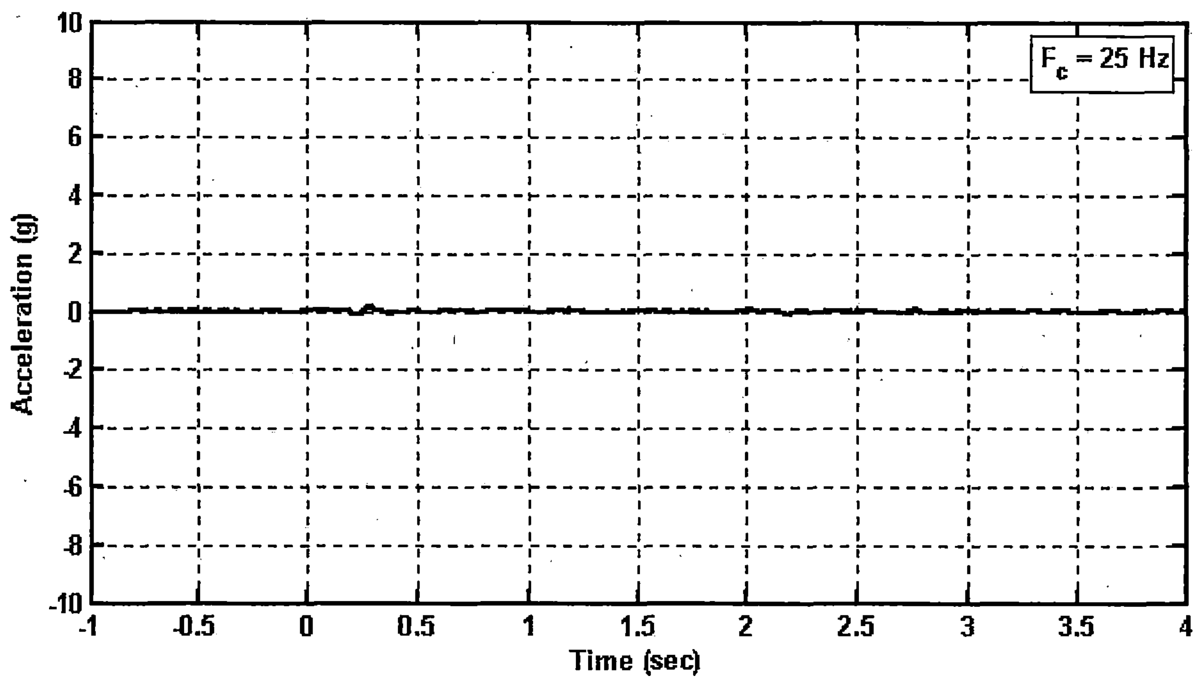

Figure D6. Bullet hopper 2, vertical acceleration
Channel Name: BH2_CGZ

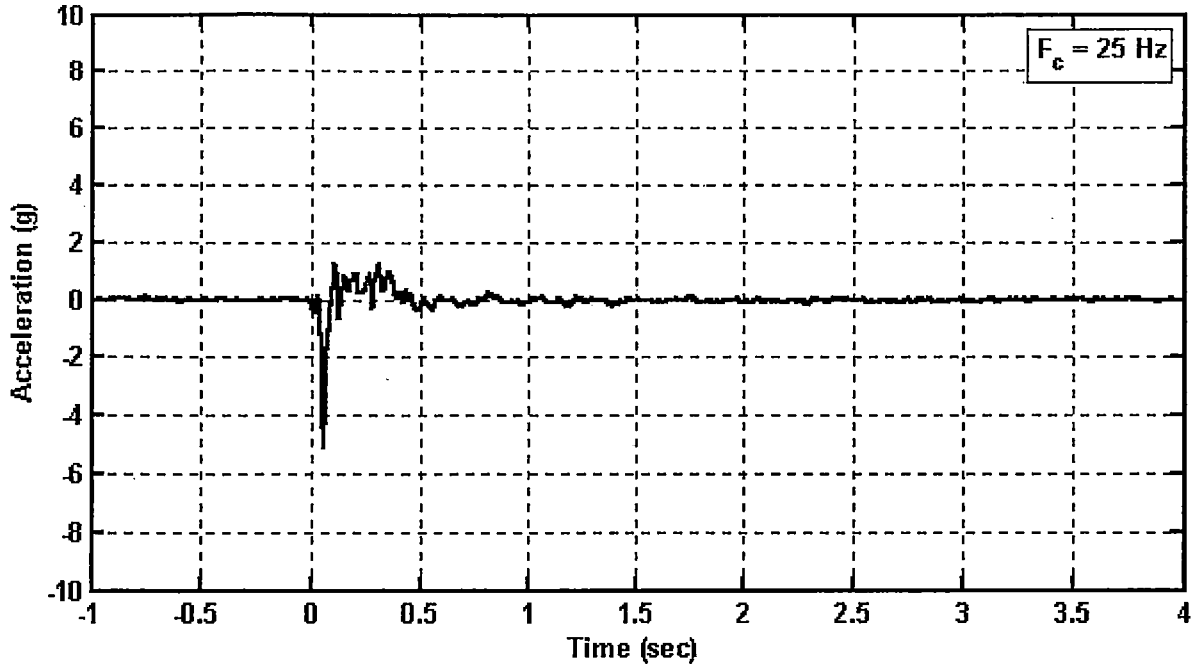

Figure D7. Locomotive floor, location 1, longitudinal acceleration
Channel Name: BL_F1X

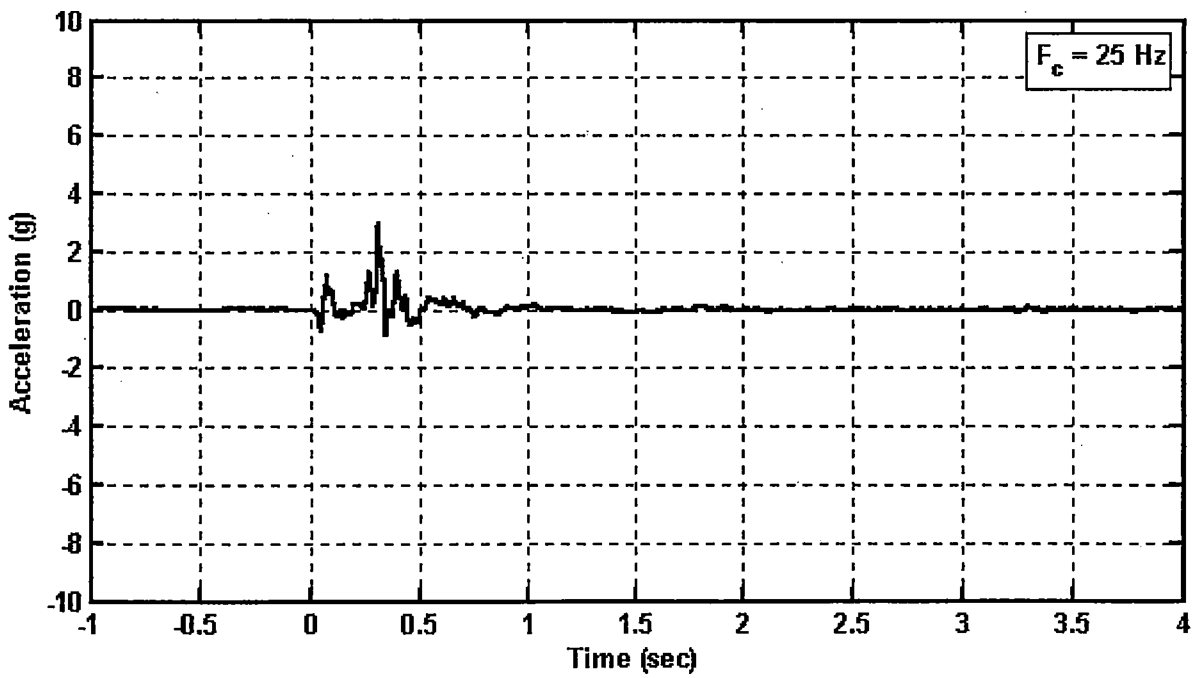

Figure D8. Locomotive floor, location 1, lateral acceleration
Channel Name: BL_F1Y

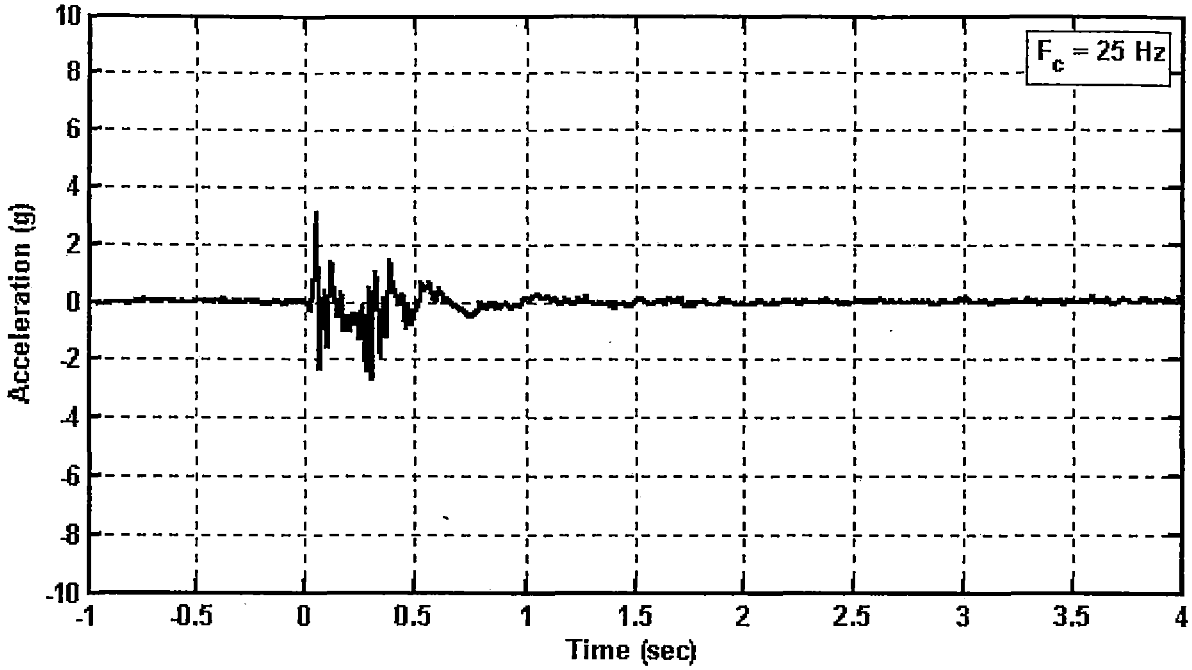

Figure D9. Locomotive floor, location 1, vertical acceleration
Channel Name: BL_F1Z

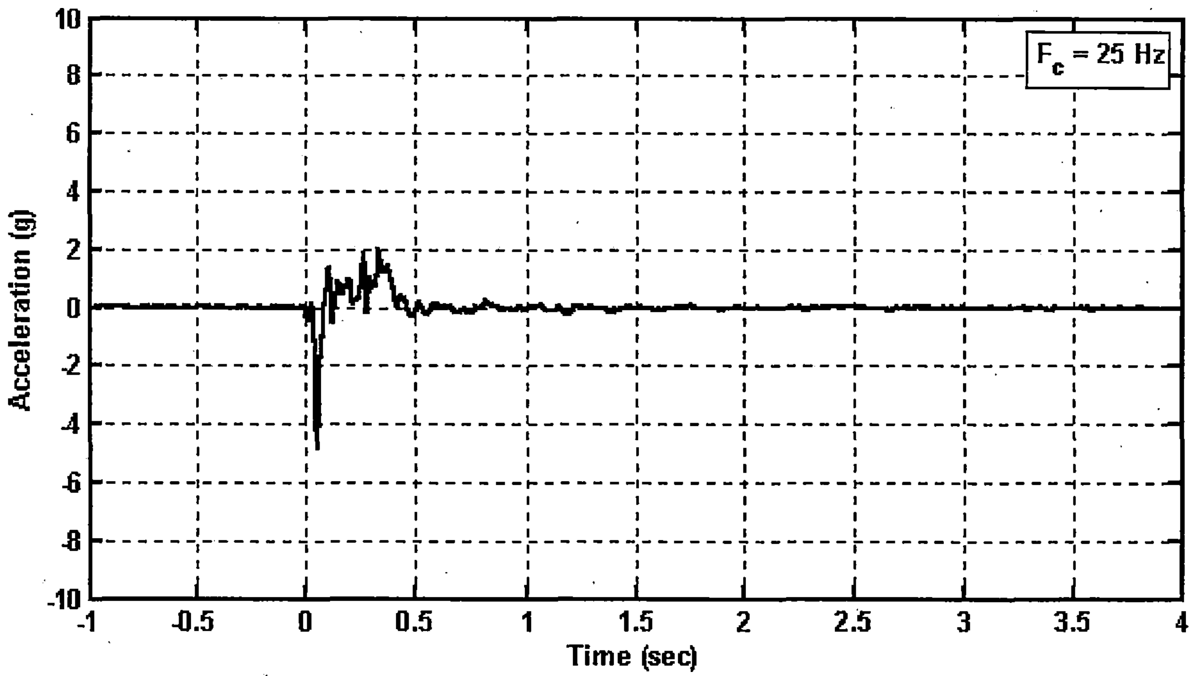

Figure D10. Locomotive floor, location 2, longitudinal acceleration
Channel Name: BL_F2X

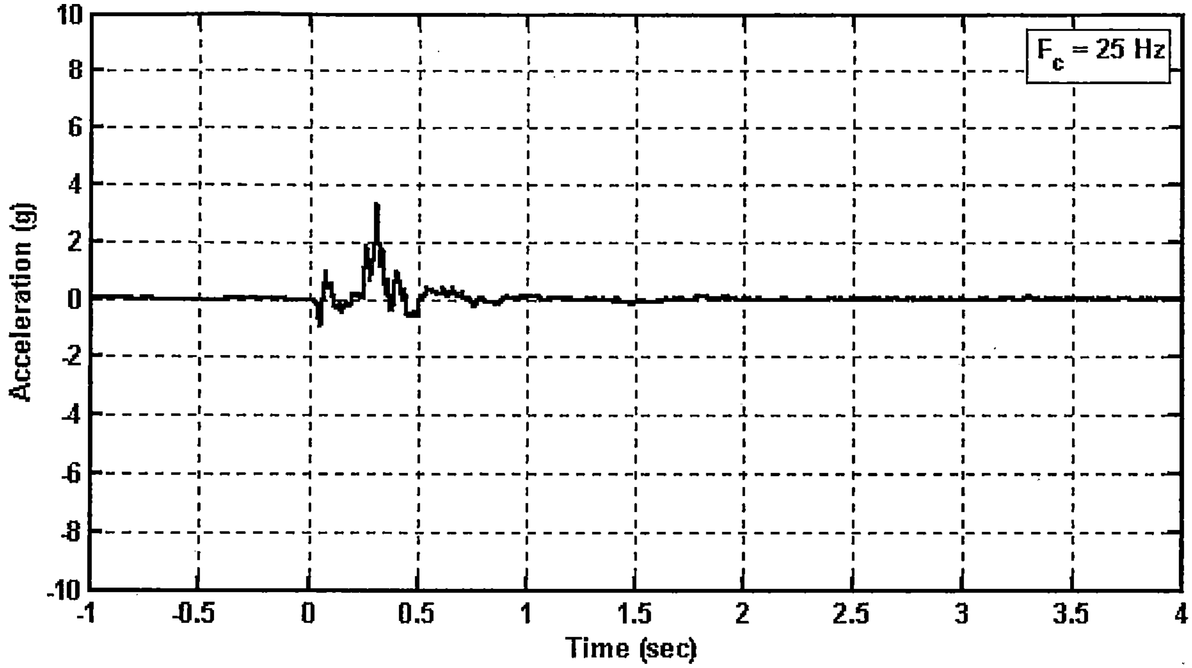

Figure D11. Locomotive floor, location 2, lateral acceleration
Channel Name: BL_F2Y

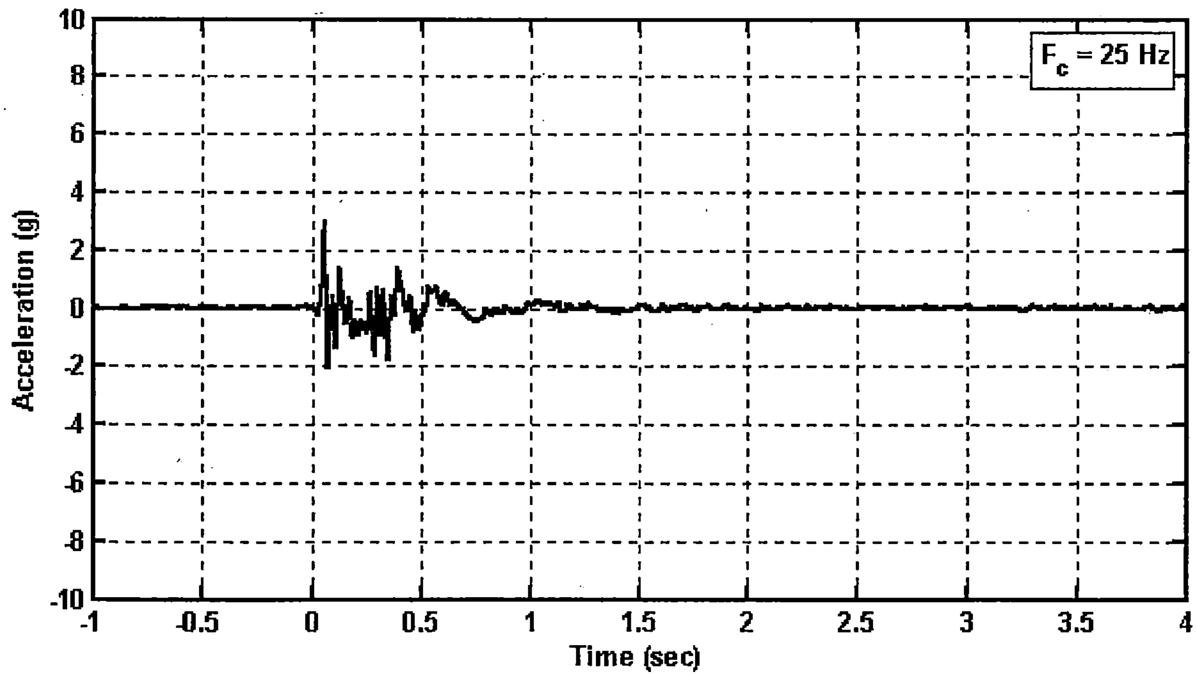

Figure D12. Locomotive floor, location 2, vertical acceleration
Channel Name: BL_F2Z

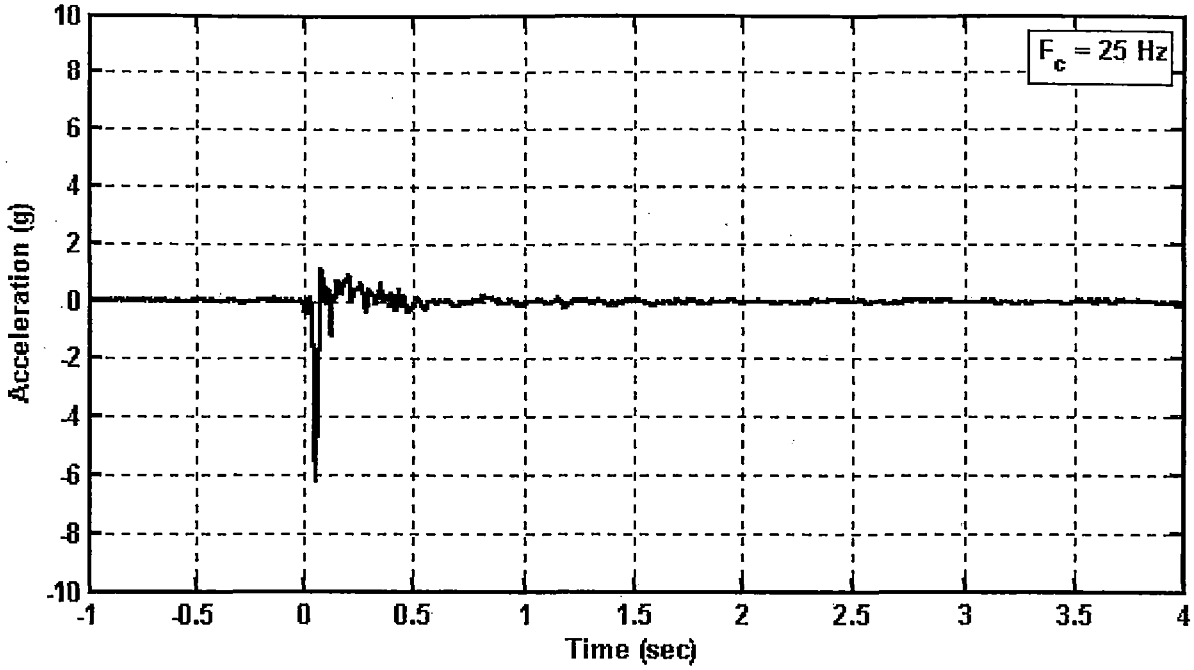

Figure D13. Locomotive event recorder, longitudinal acceleration
Channel Name: BL_RX

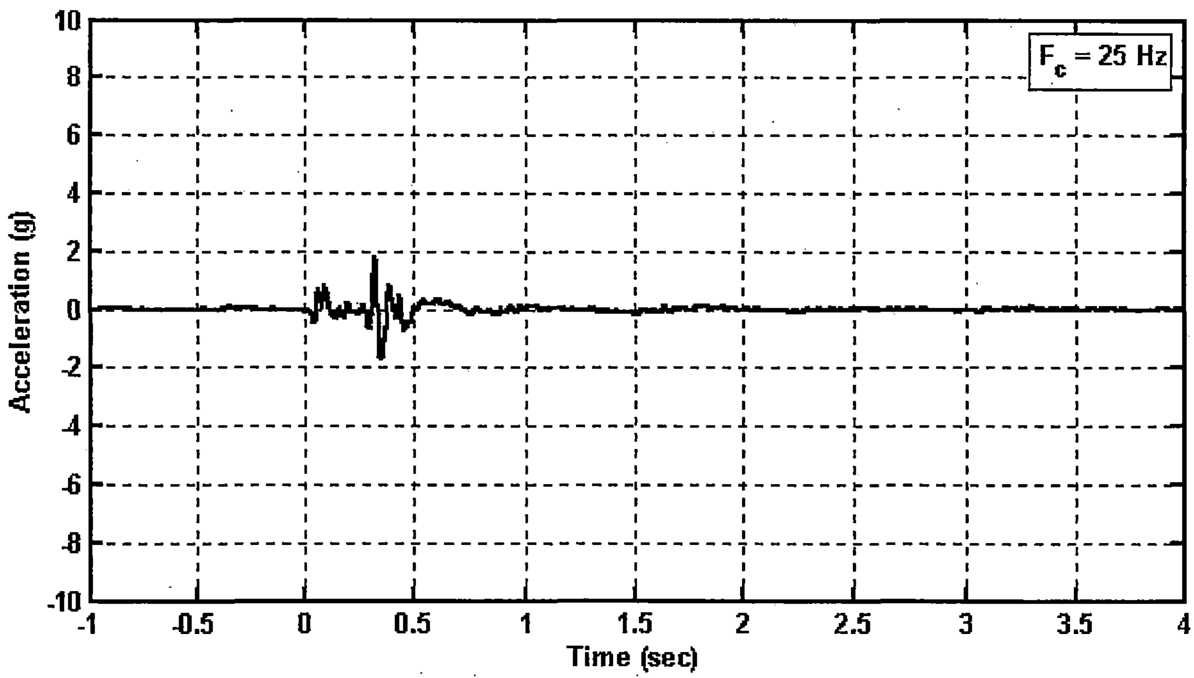

Figure D14. Locomotive event recorder, lateral acceleration
Channel Name: BL_RY

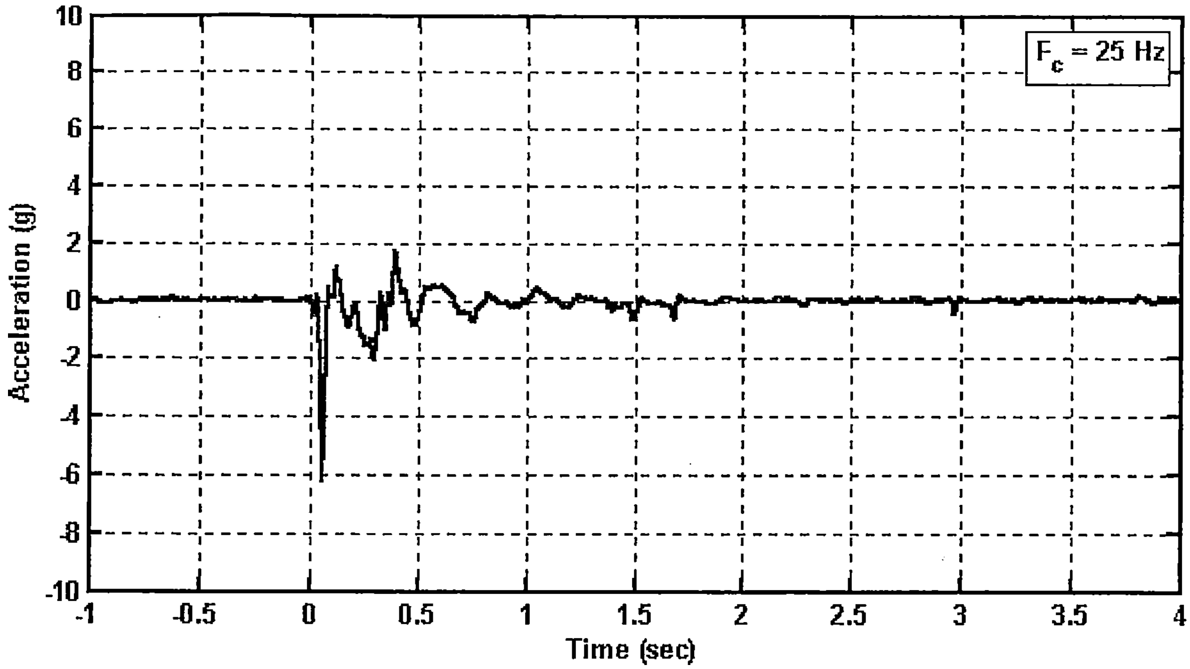

Figure D15. Locomotive event recorder, vertical acceleration
Channel Name: BL_RZ

APPENDIX E

Displacement and Coupler Force Data

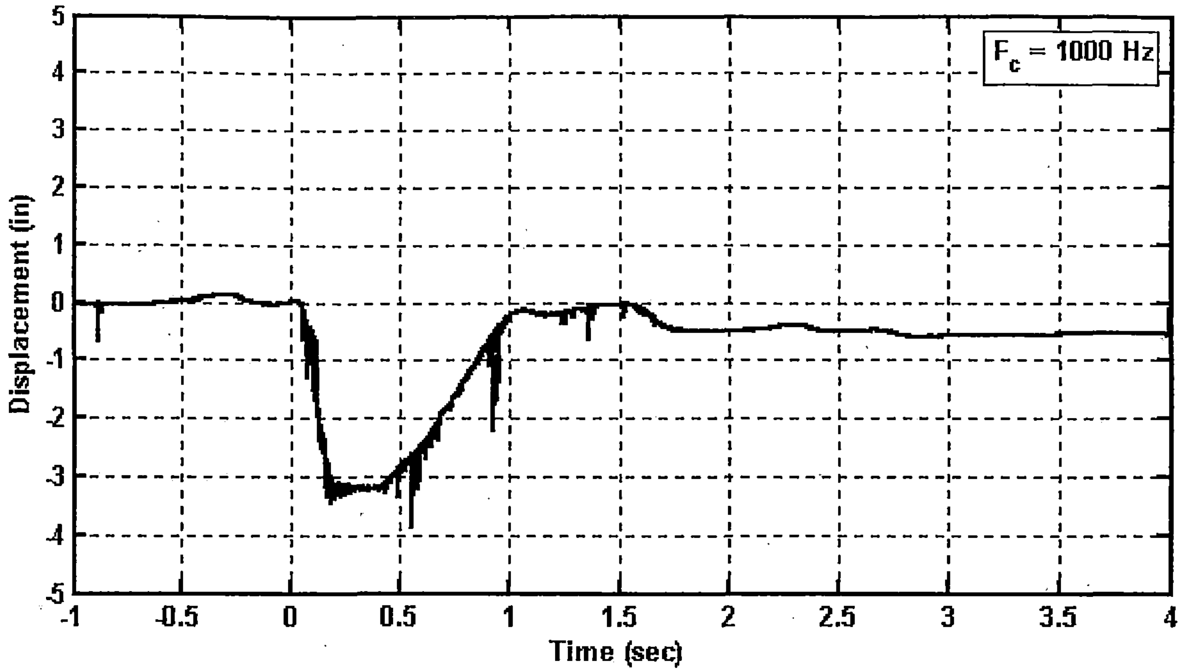

Figure E1. Bullet hopper 1, longitudinal coupler displacement
Channel Name: BH1_CAX

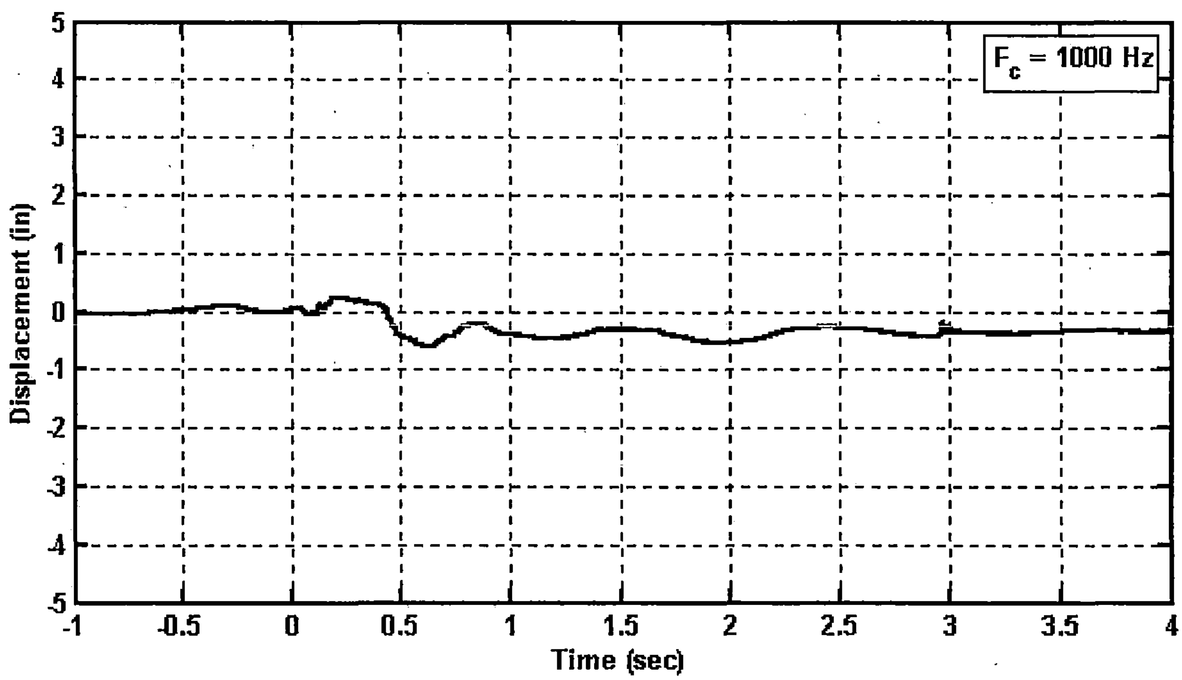

Figure E2. Bullet hopper 1, lateral coupler displacement
Channel Name: BH1_CAY

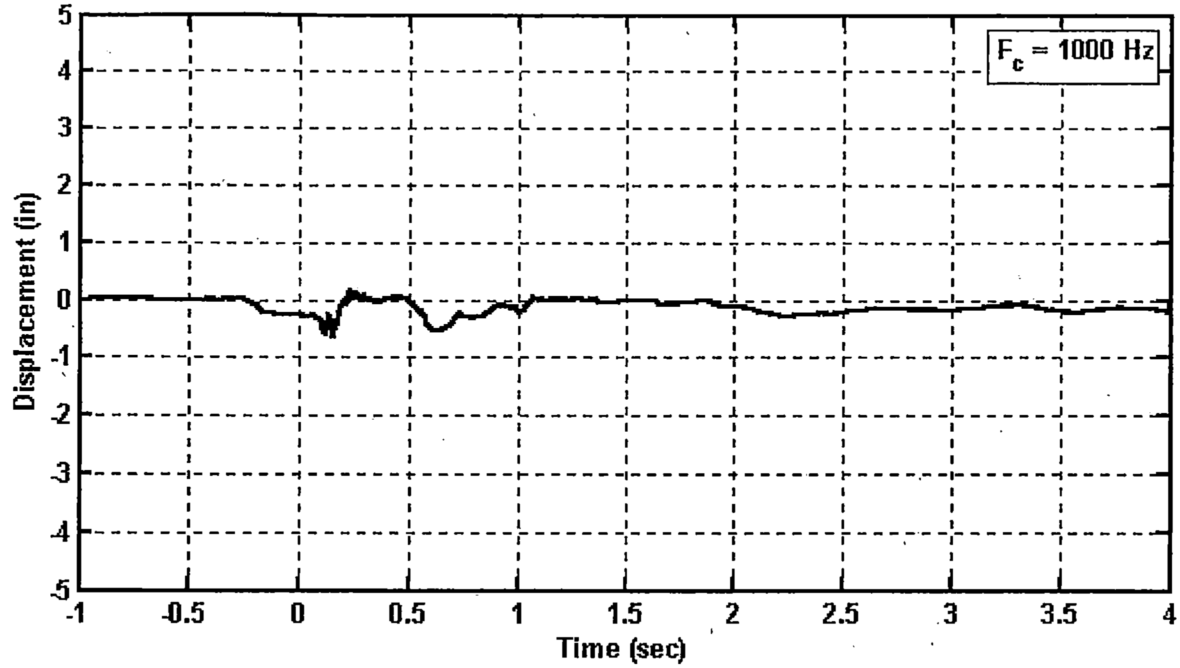

Figure E3. Bullet hopper 1, verical coupler displacement
Channel Name: BH1_CAZ

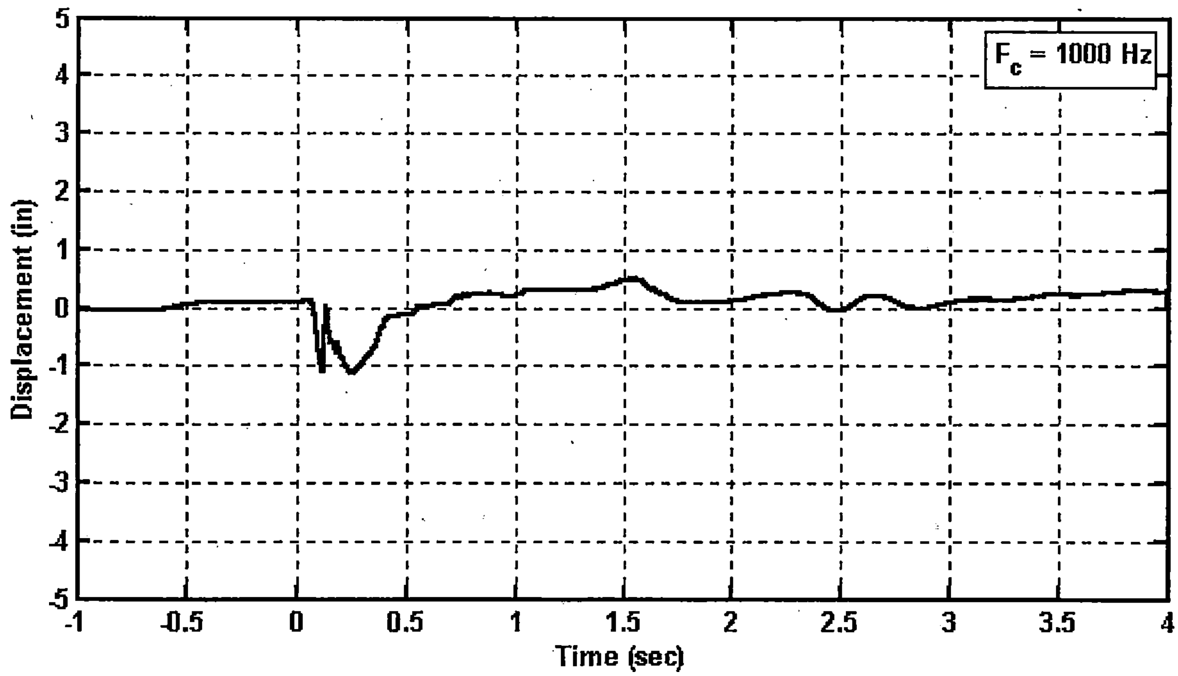

Figure E4. Locomotive, longitudinal coupler displacement
Channel Name: BL_CBX

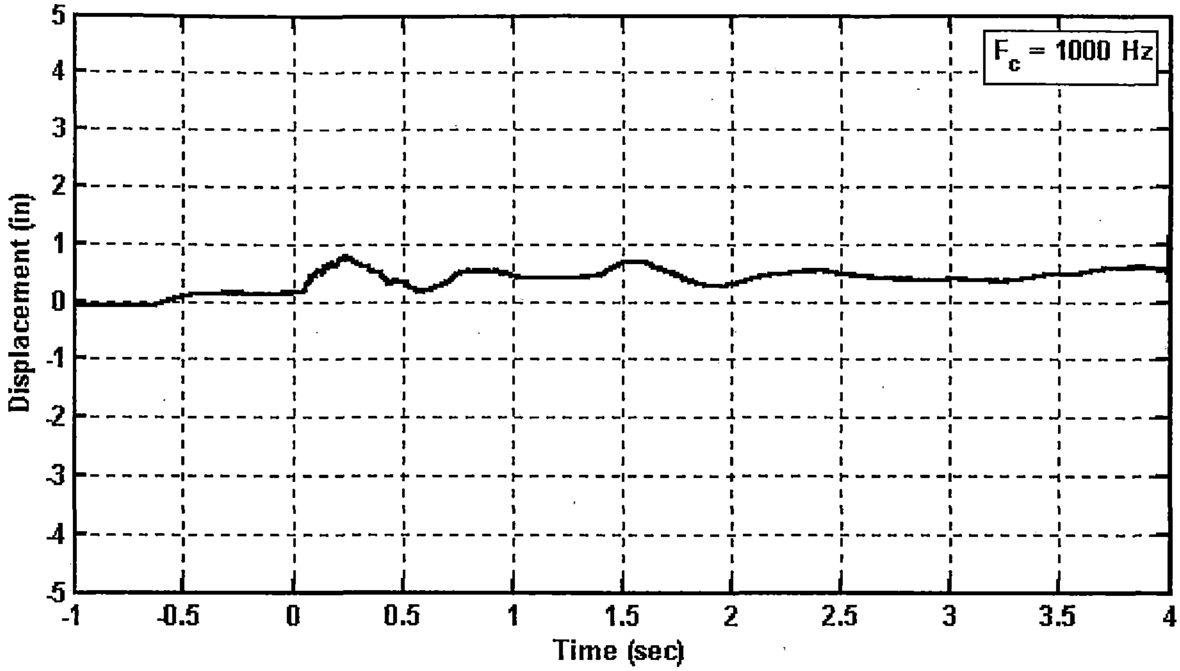

Figure E5. Locomotive, lateral coupler displacement
Channel Name: BL_CBY

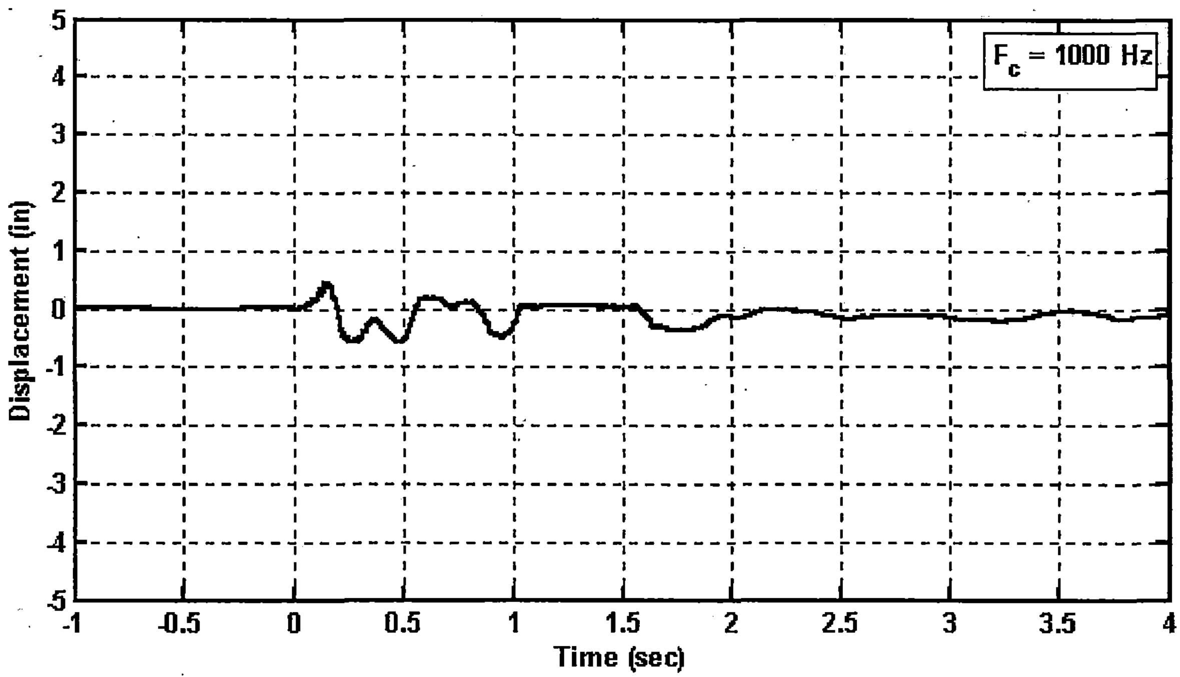

Figure E6. Locomotive, verical coupler displacement
Channel Name: BL_CBZ

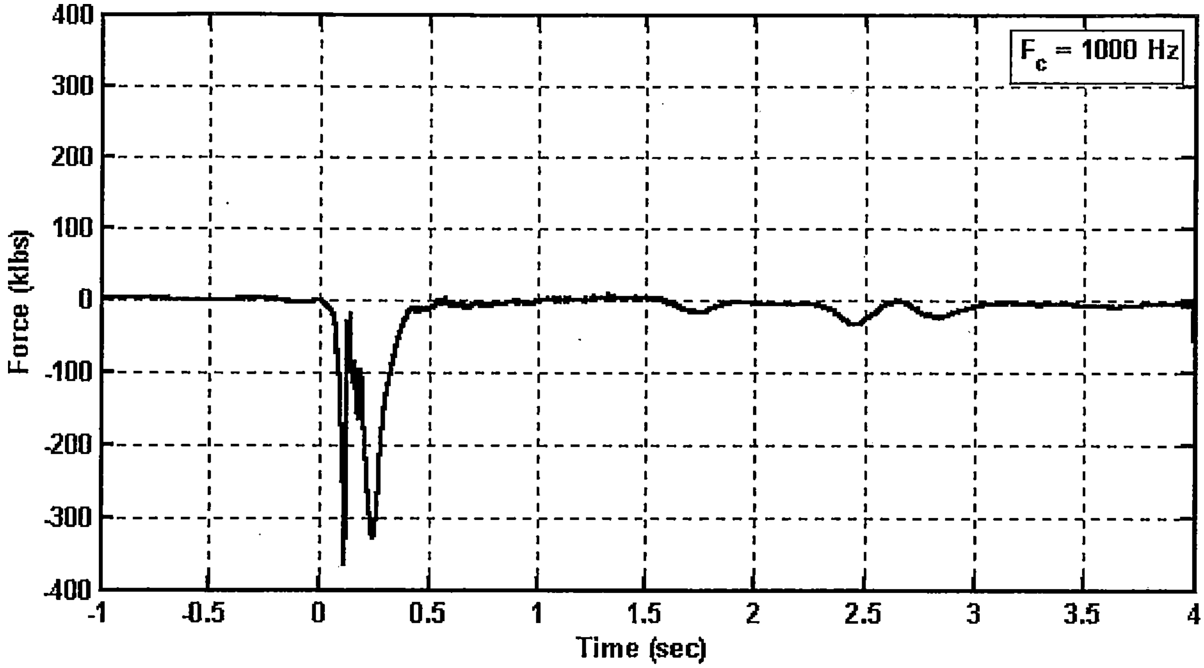

Figure E7. Bullet hopper 1, leading coupler force
Channel Name: BH1_CLoad

APPENDIX F

Strain Data

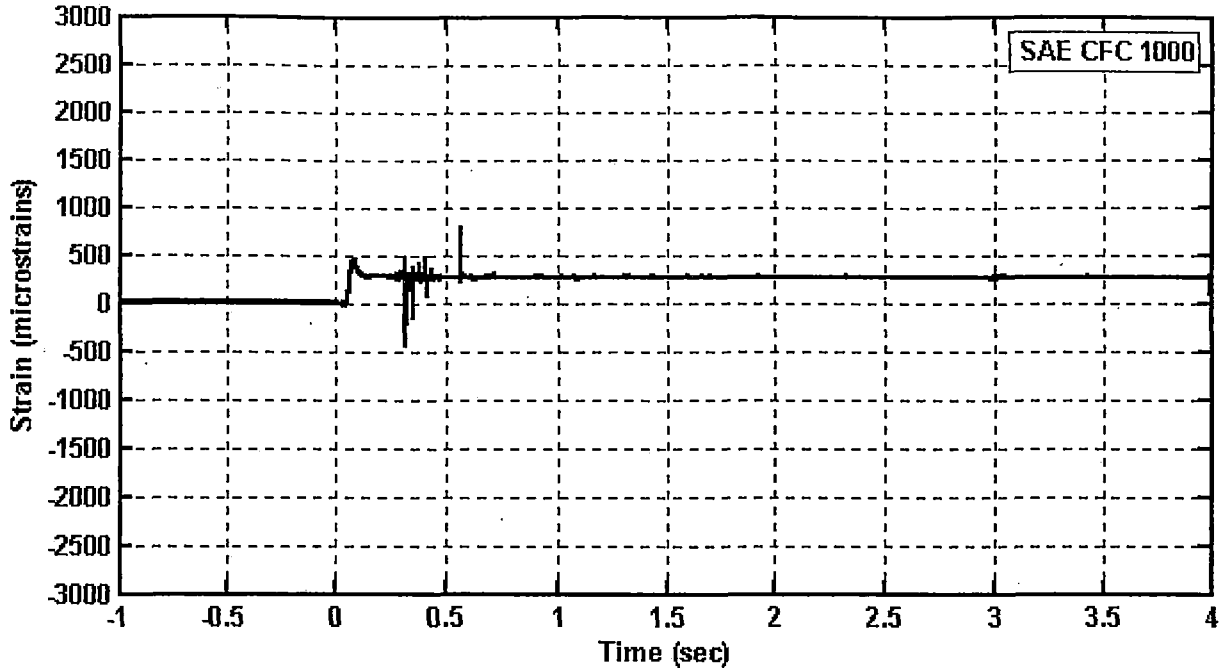

Figure F1. Strain on left collision post, bottom rear rosette, longitudinal element
Channel Name: CPLR1_1

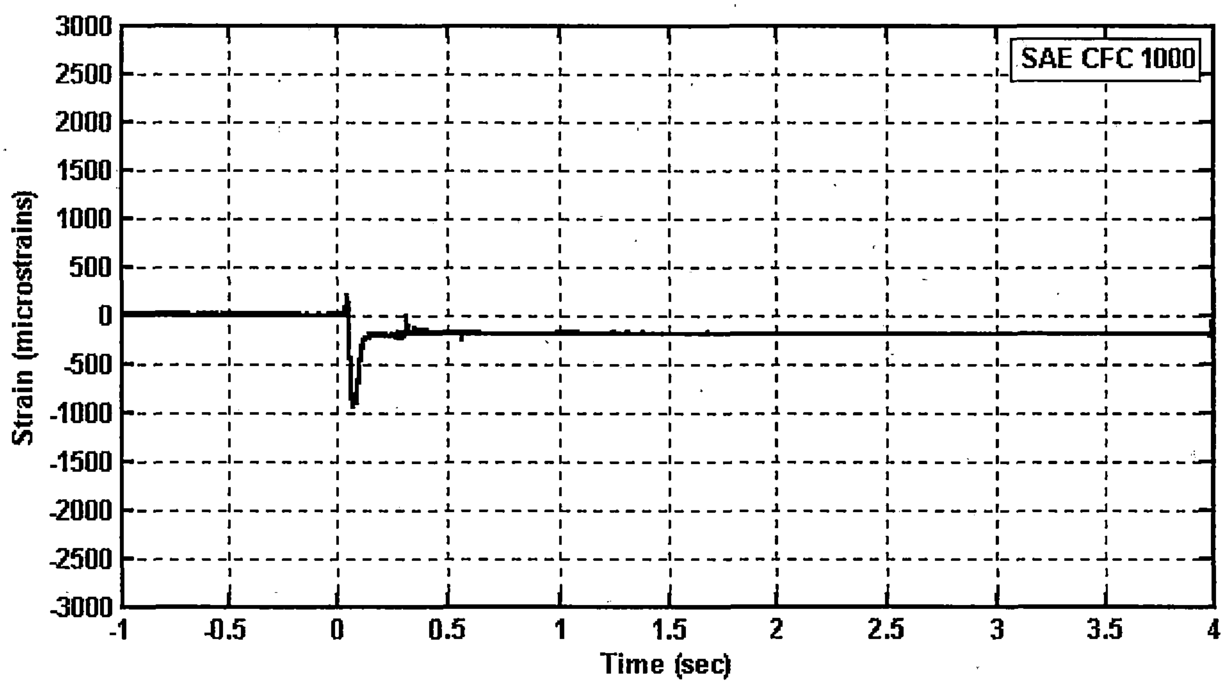

Figure F2. Strain on left collision post, bottom rear rosette, diagonal element
Channel Name: CPLR1_2

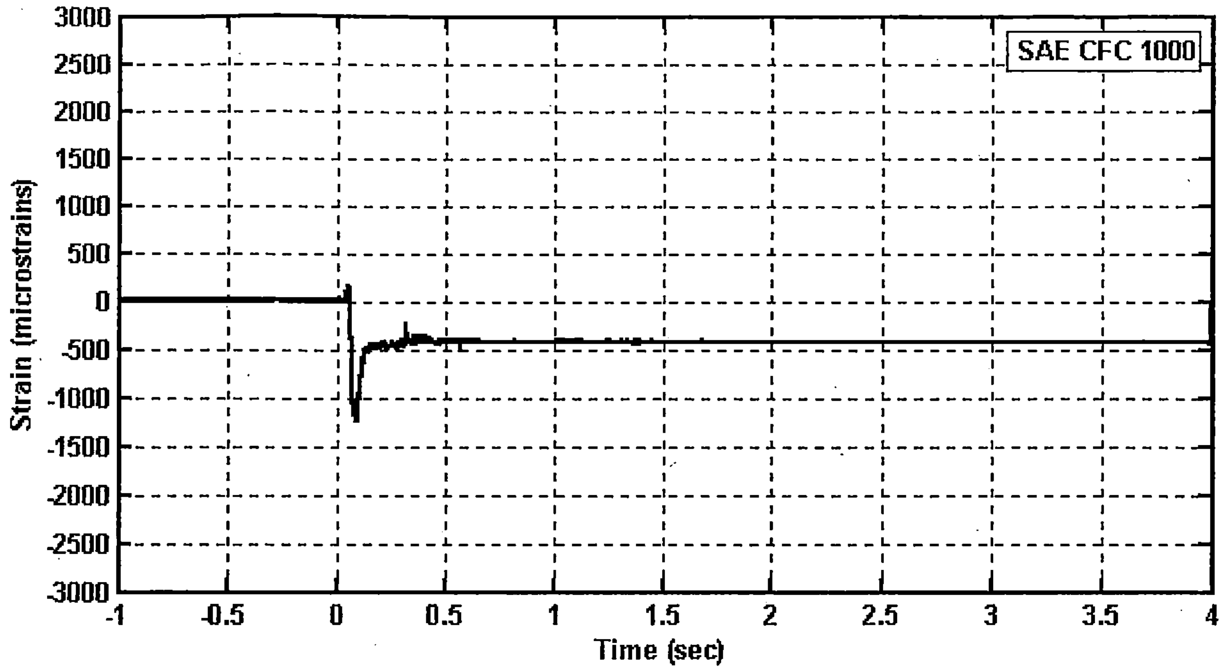

Figure F3. Strain on left collision post, bottom rear rosette, vertical element
Channel Name: CPLR1_3

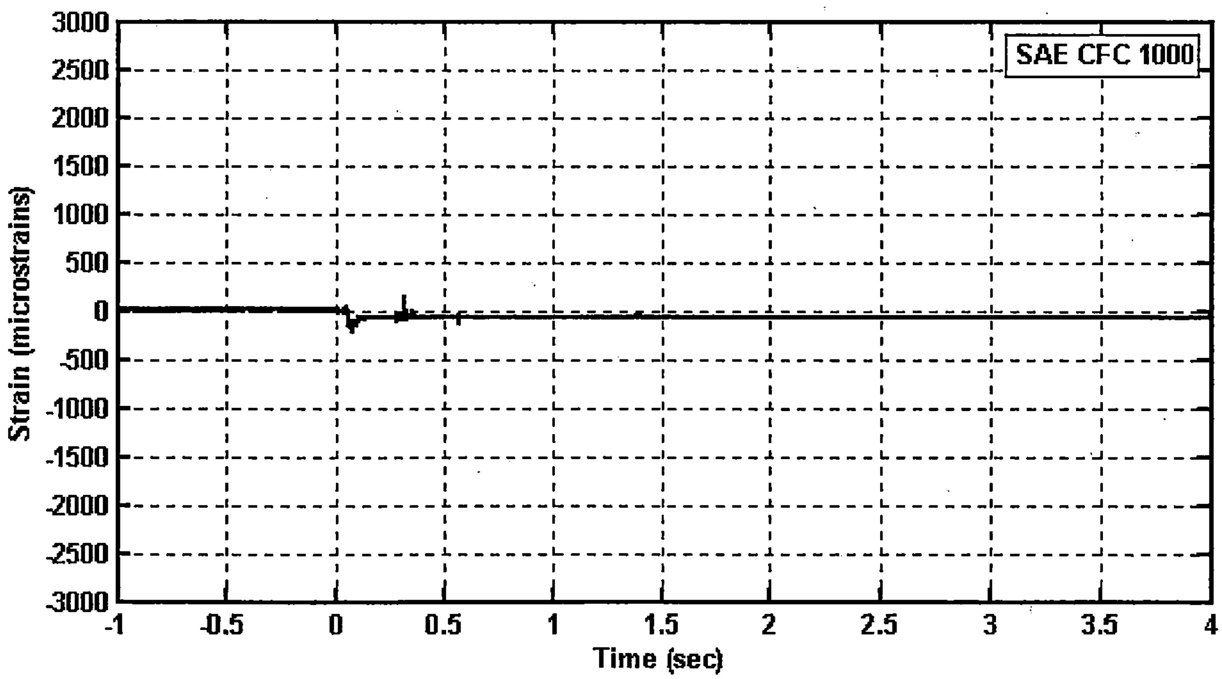

Figure F4. Strain on left collision post, bottom center rosette, longitudinal element
Channel Name: CPLR2_1

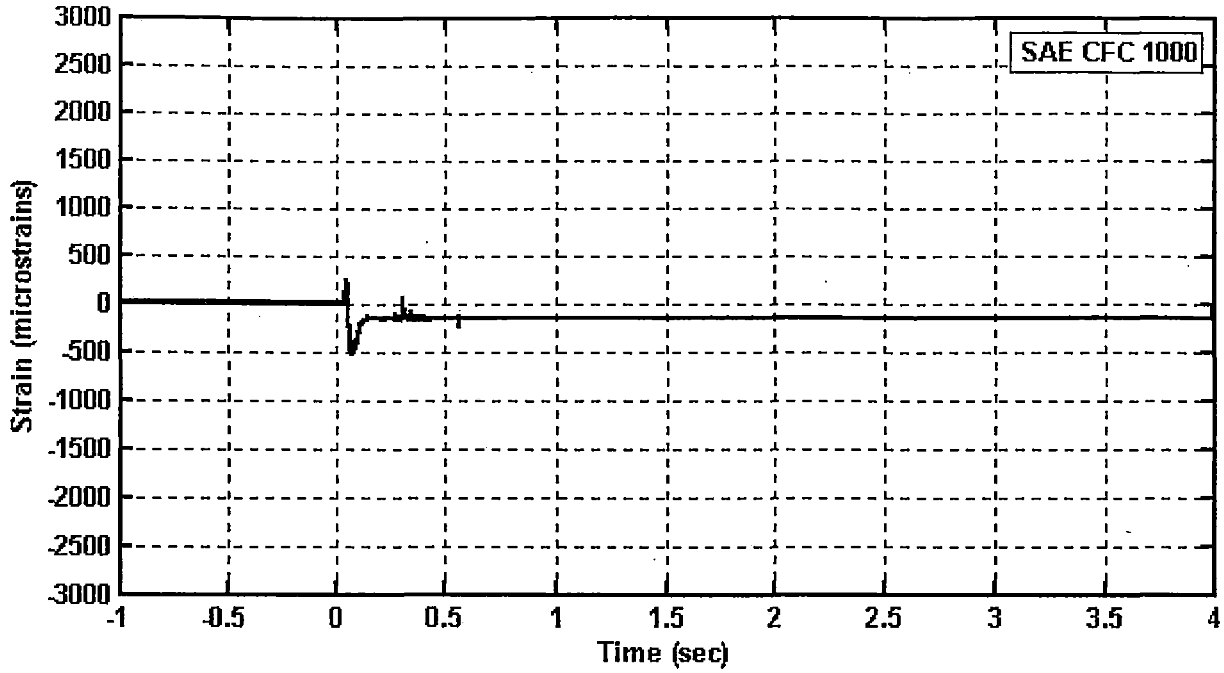

Figure F5. Strain on left collision post, bottom center rosette, diagonal element
Channel Name: CPLR2_2

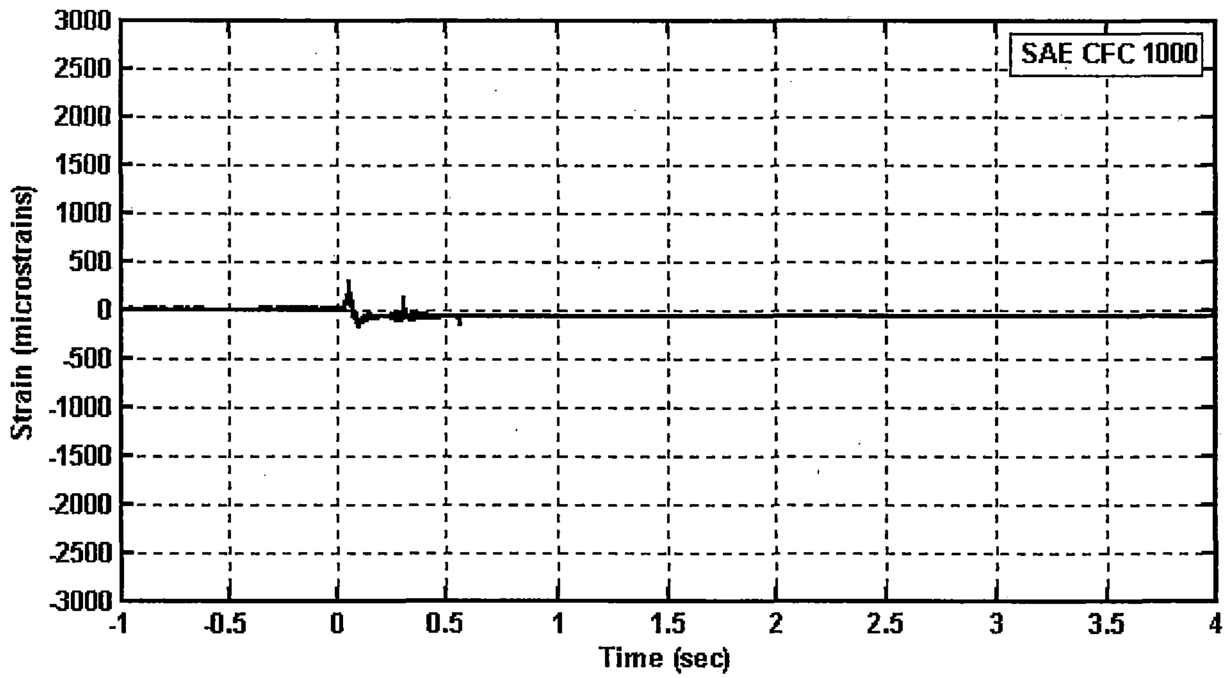

Figure F6. Strain on left collision post, bottom center rosette, vertical element
Channel Name: CPLR2_3

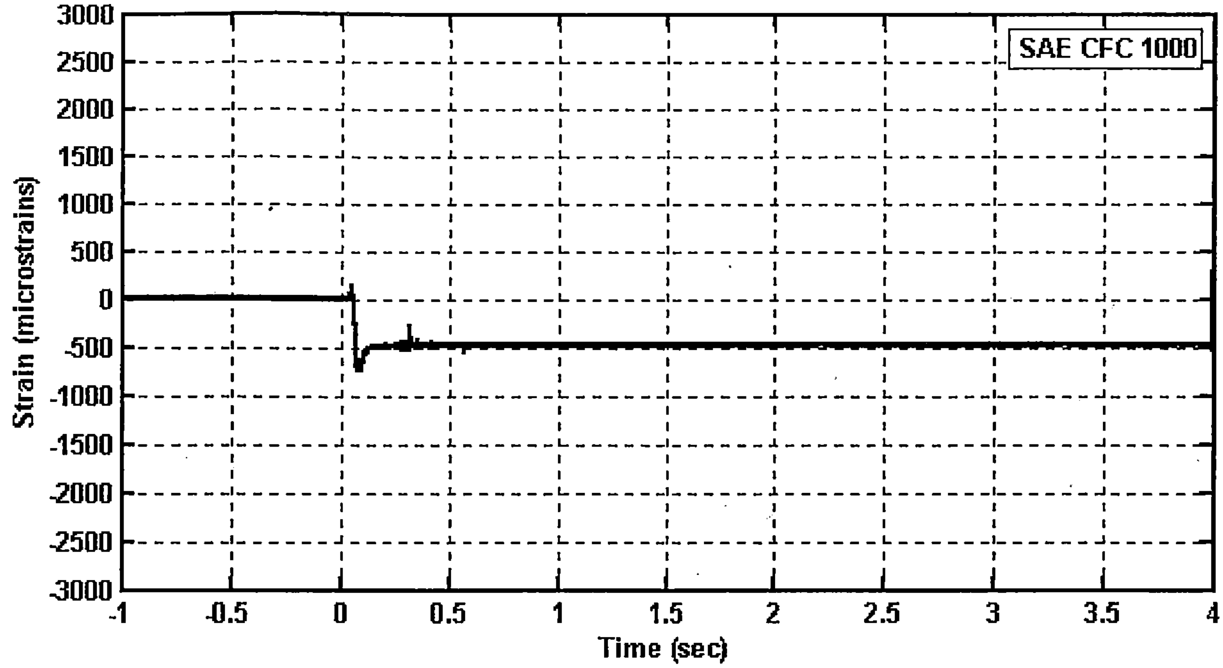

Figure F7. Strain on left collision post, bottom front rosette, longitudinal element
Channel Name: CPLR3_1

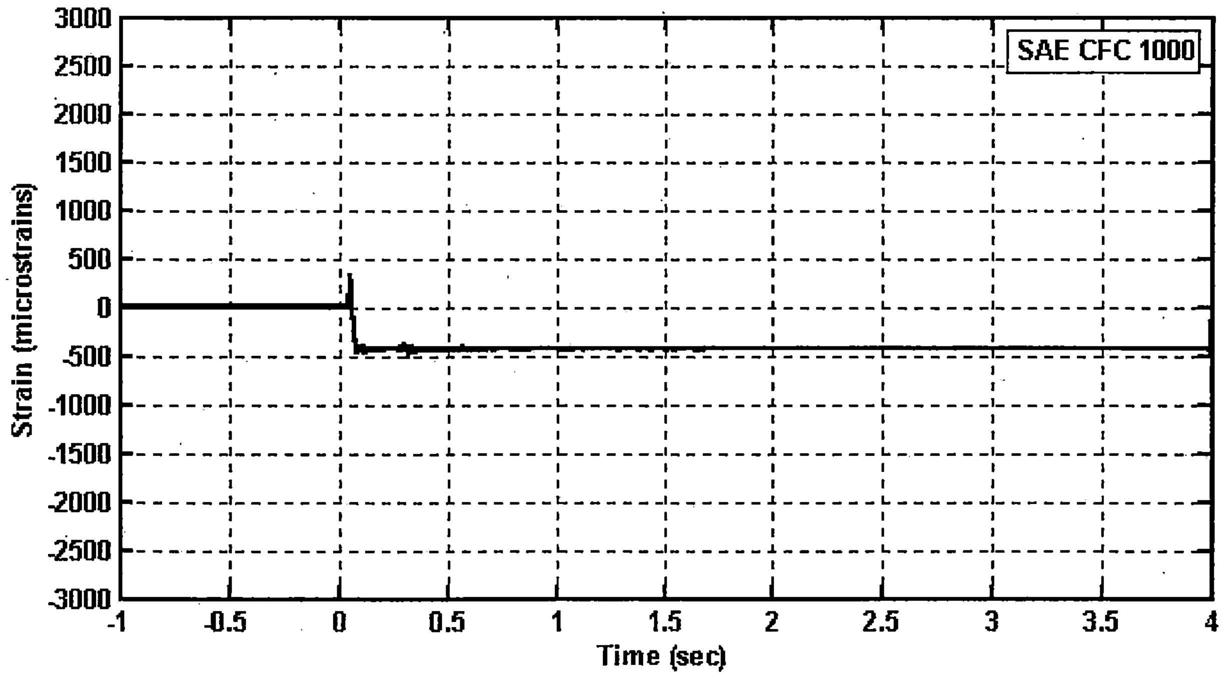

Figure F8. Strain on left collision post, bottom front rosette, diagonal element
Channel Name: CPLR3_2

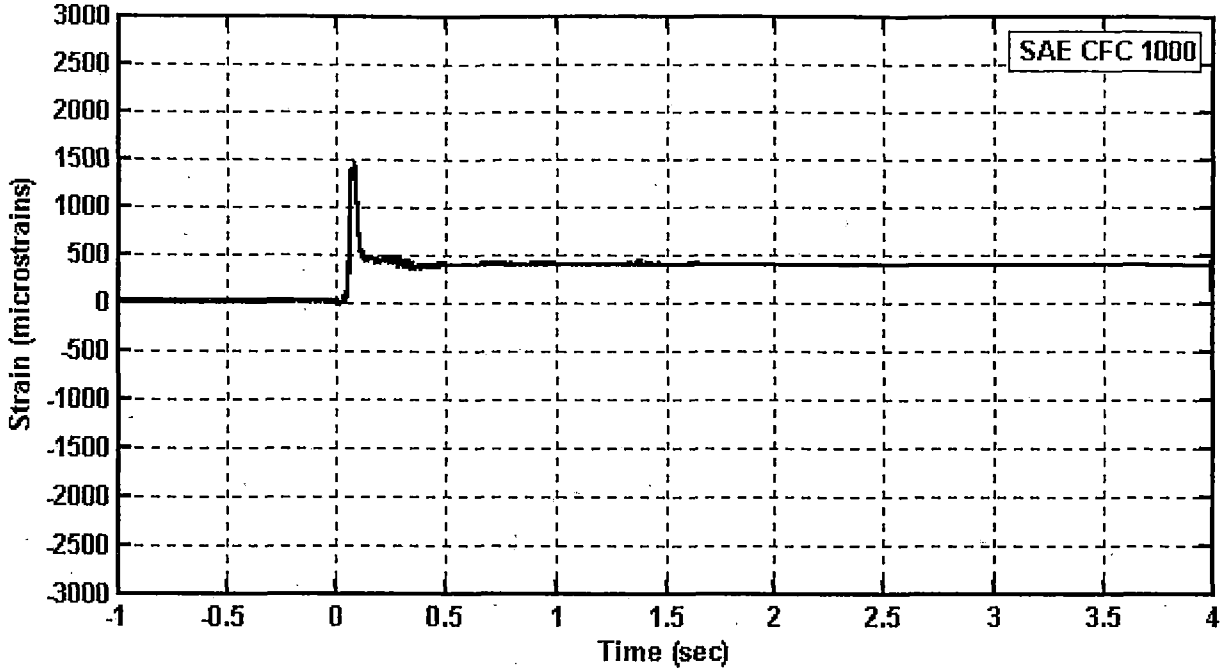

Figure F9. Strain on left collision post, bottom front rosette, vertical element
Channel Name: CPLR3_3

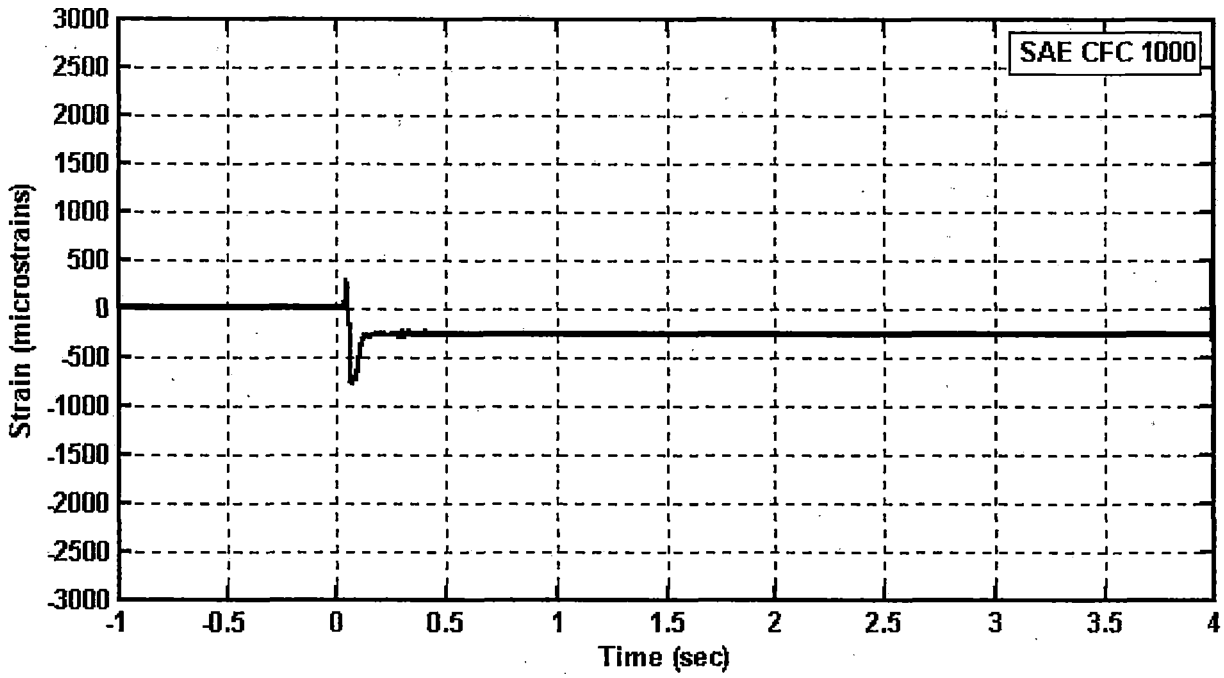

Figure F10. Strain on left collision post, top front rosette, longitudinal element
Channel Name: CPLR4_1

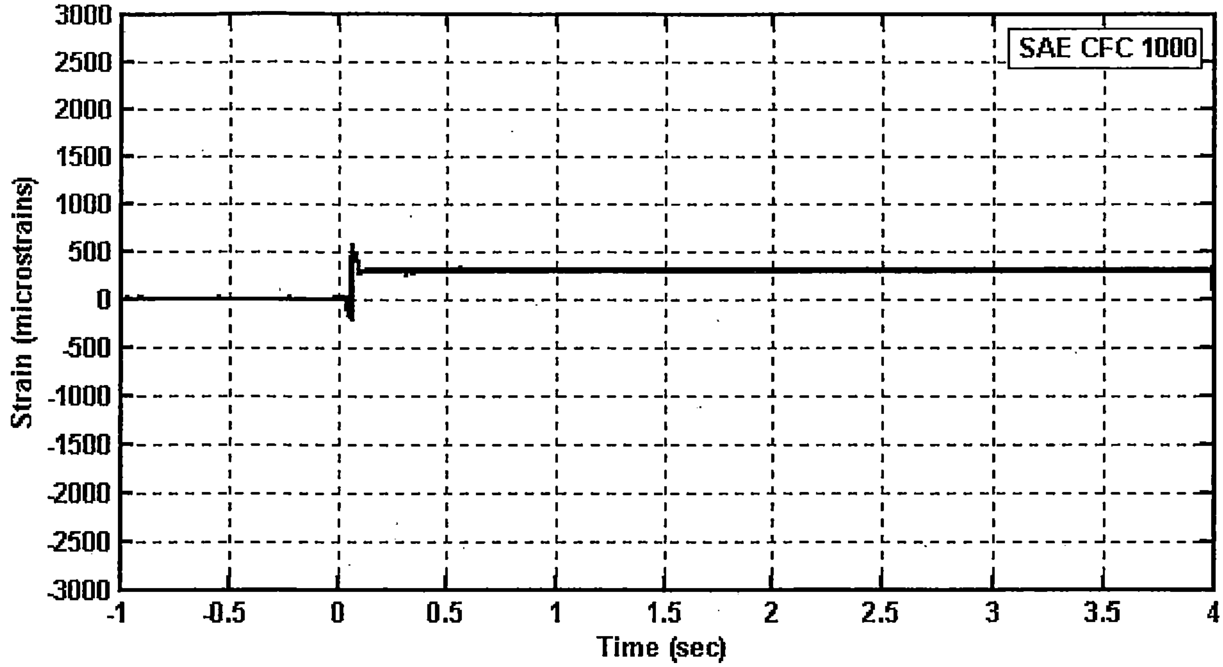

Figure F11. Strain on left collision post, top front rosette, diagonal element
Channel Name: CPLR4_2

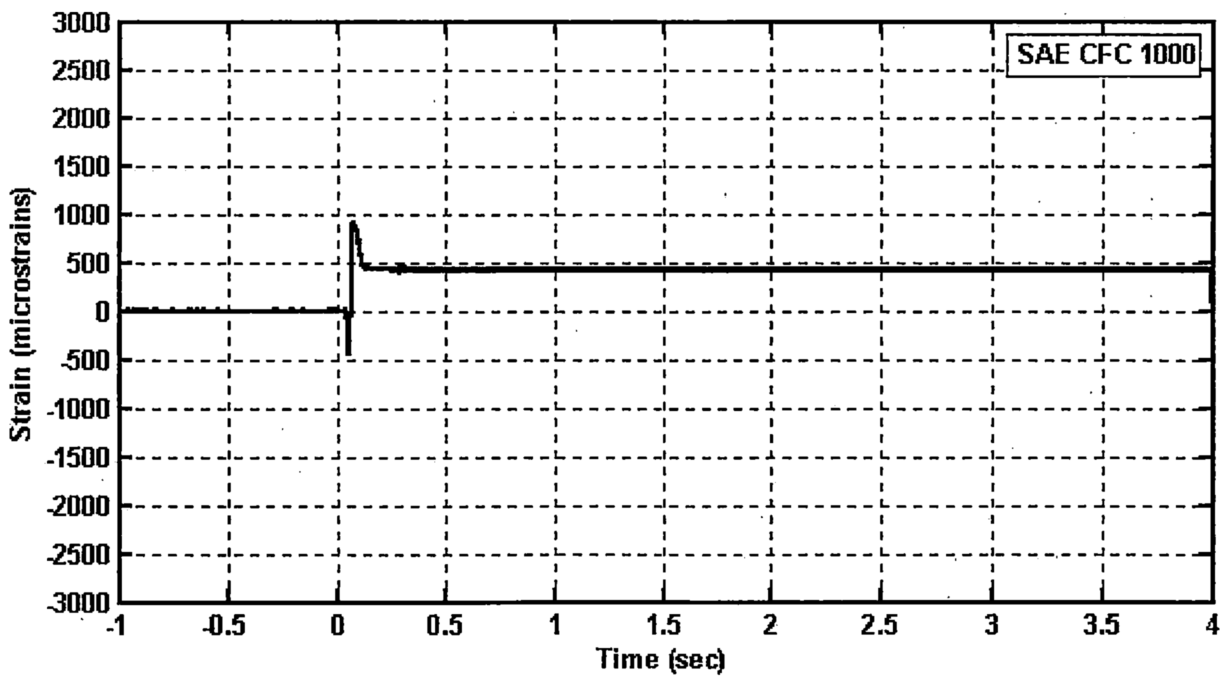

Figure F12. Strain on left collision post, top front rosette, vertical element
Channel Name: CPLR4_3

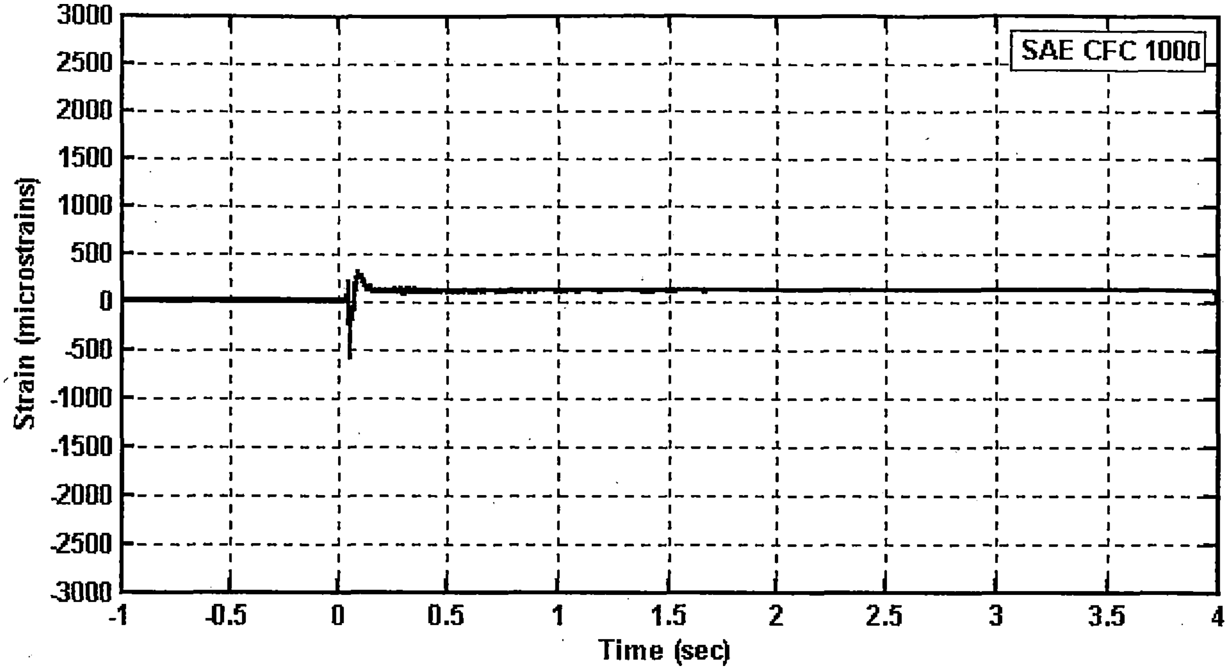

Figure F13. Strain on left collision post, middle front rosette, longitudinal element
Channel Name: CPLR5_1

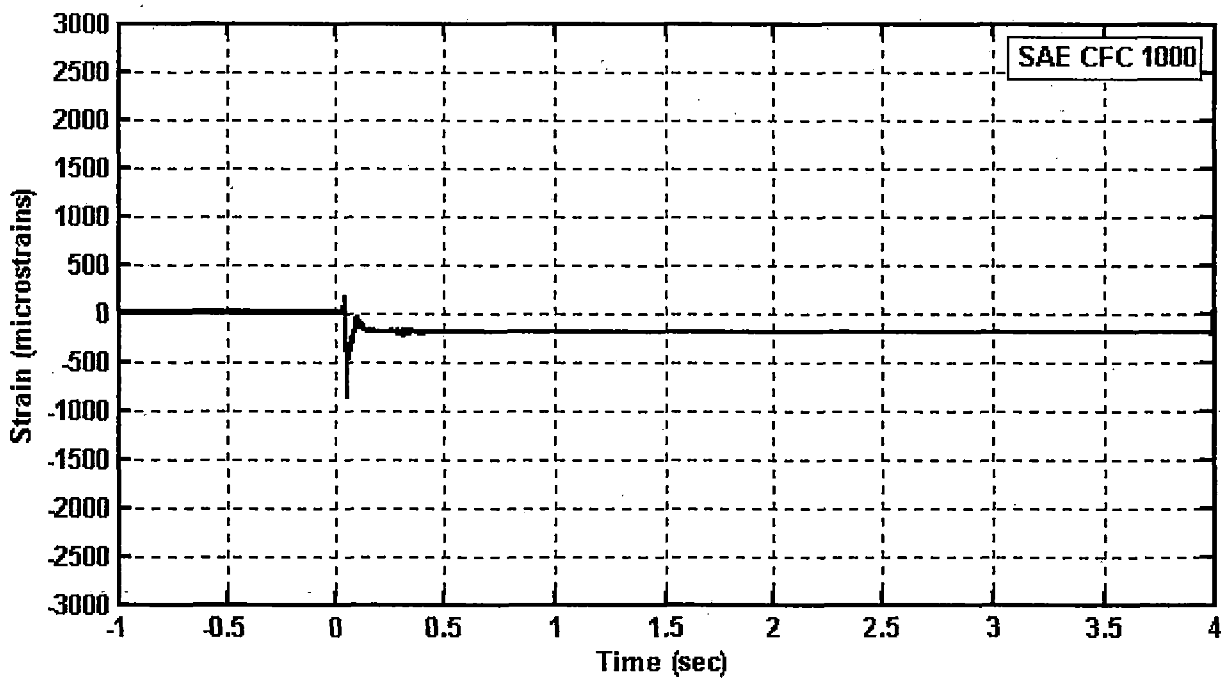

Figure F14. Strain on left collision post, middle front rosette, diagonal element
Channel Name: CPLR5_2

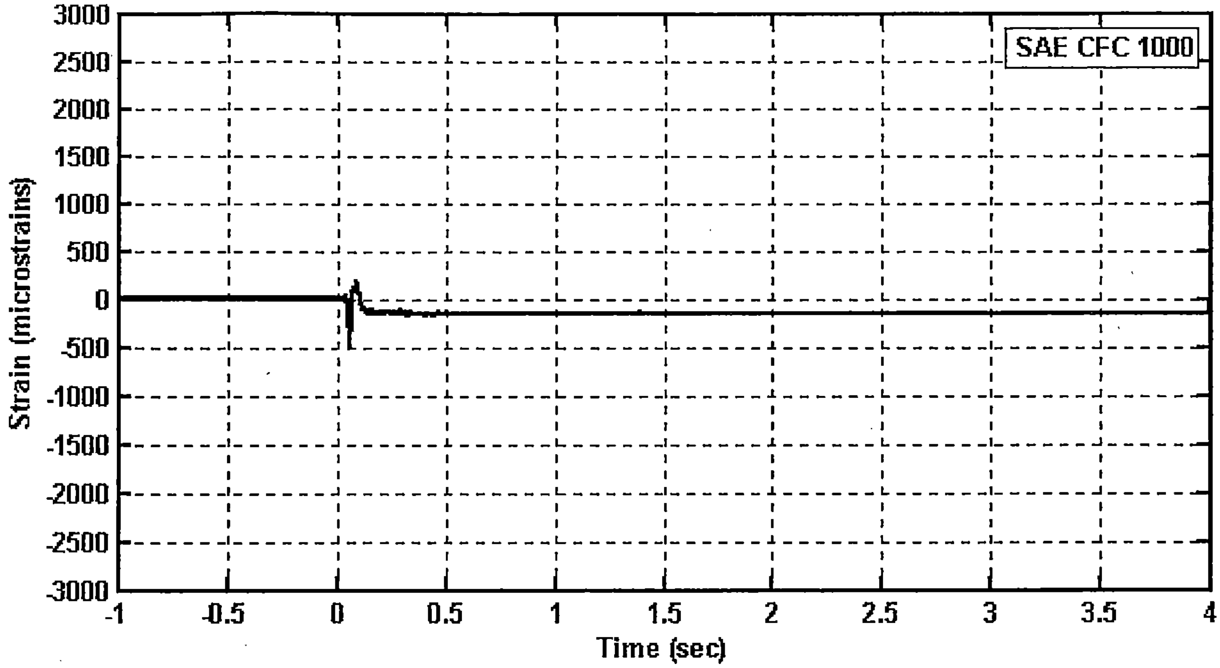

Figure F15. Strain on left collision post, middle front rosette, vertical element
Channel Name: CPLR5_3

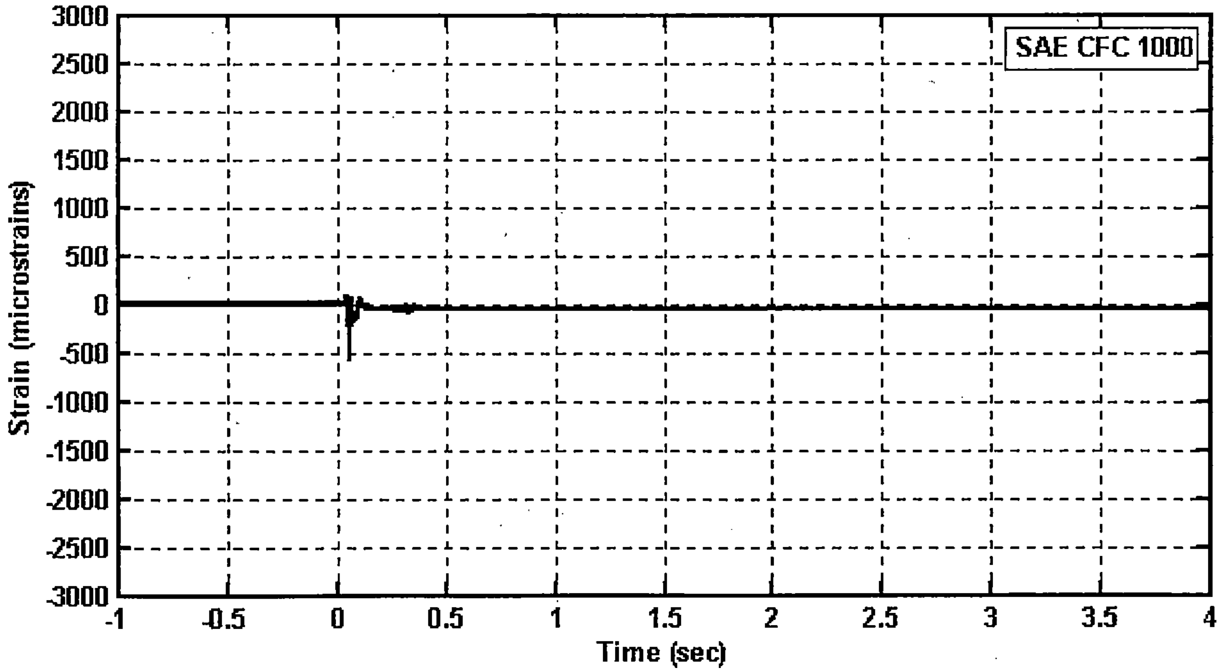

Figure F16. Longitudinal strain on left collision post, center, 3/4 up from bottom edge
Channel Name: CPLS1

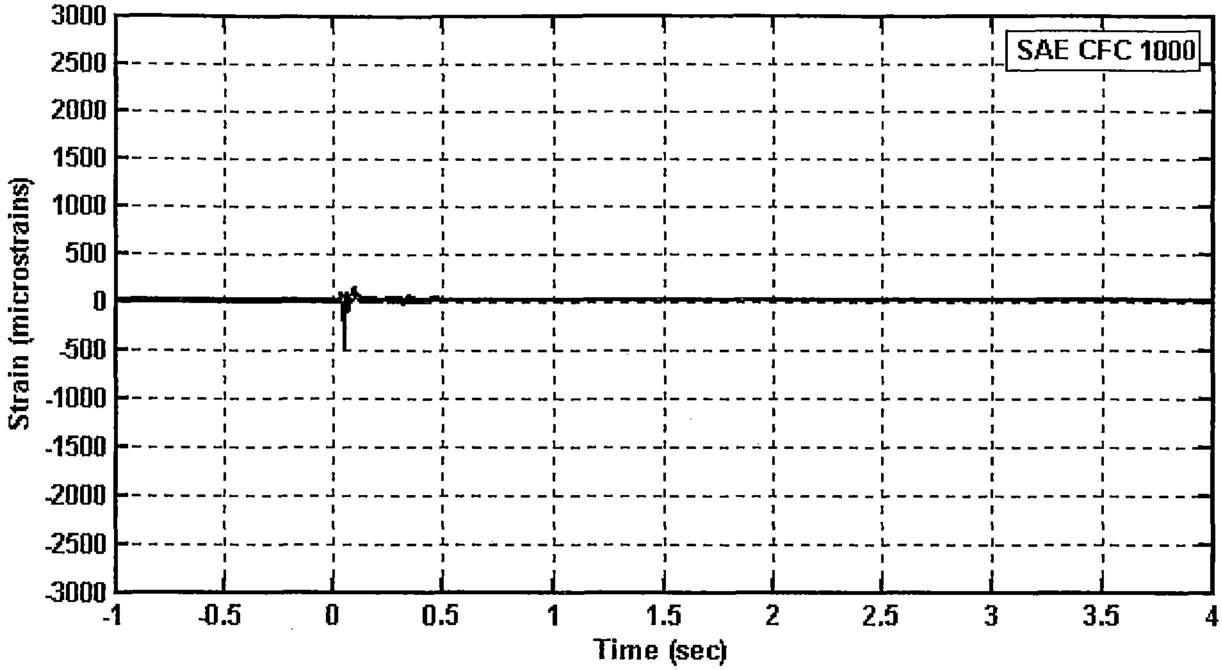

Figure F17. Longitudinal strain on left collision post, center, 1/2 up from bottom edge
Channel Name: CPLS2

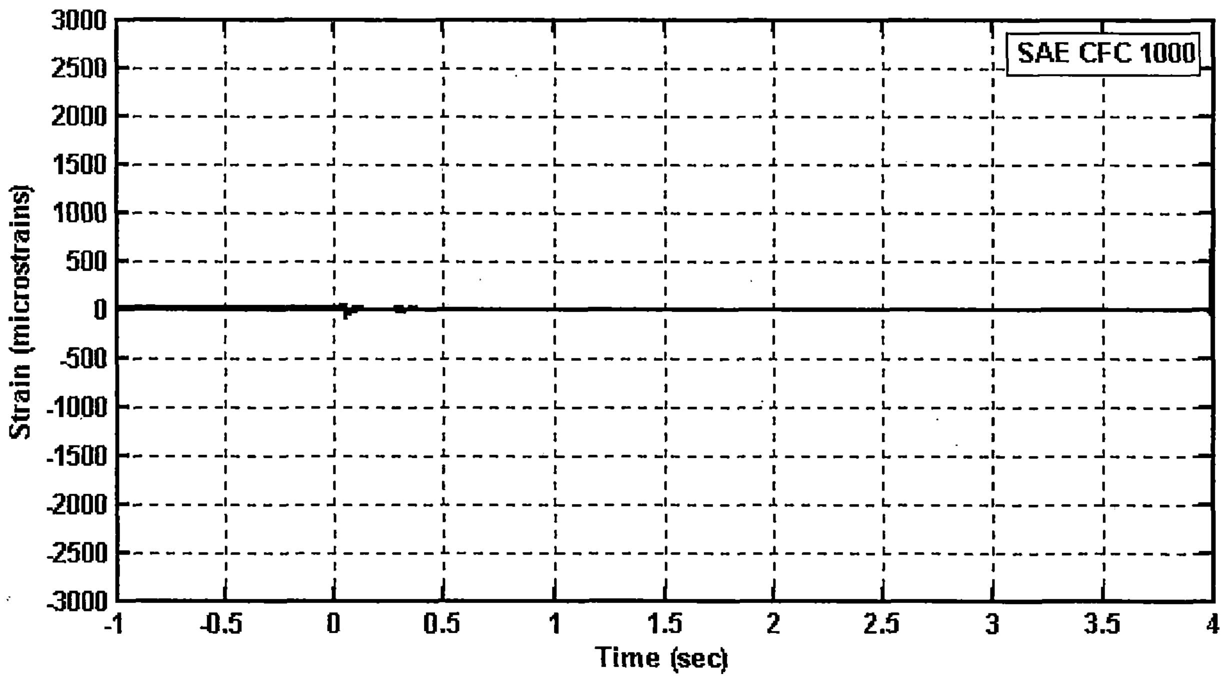

Figure F18. Longitudinal strain on left collision post, center, 1/4 up from bottom edge
Channel Name: CPLS3

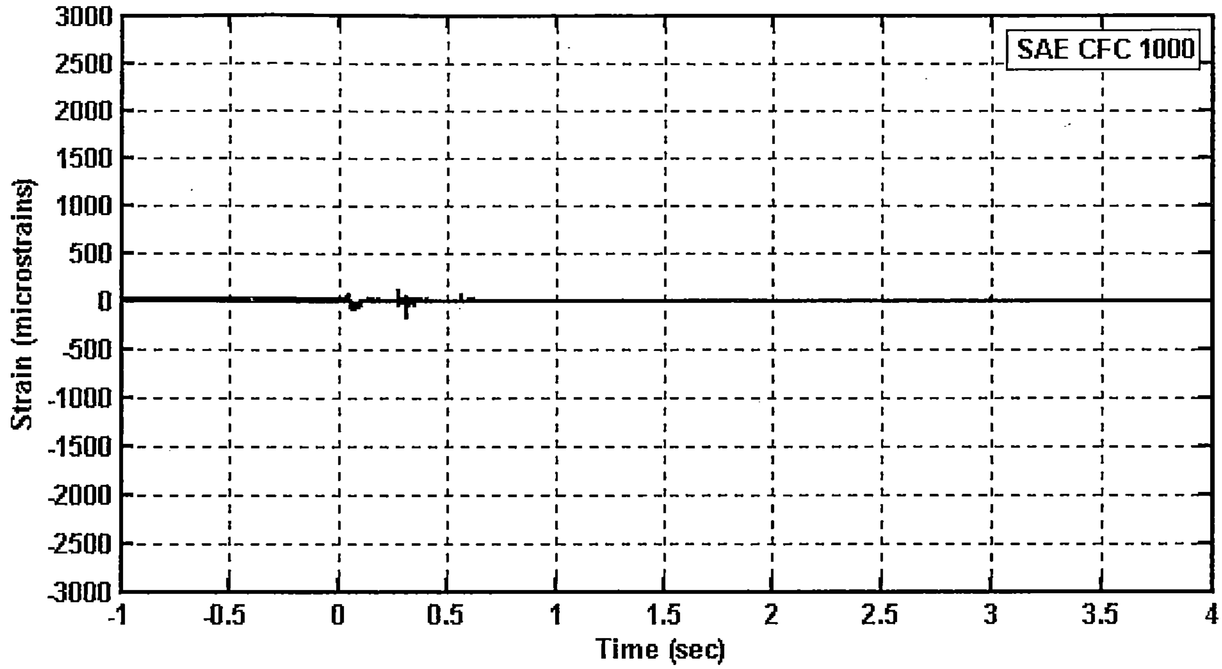

Figure F19. Longitudinal strain on left collision post, top rear corner
Channel Name: CPLS4

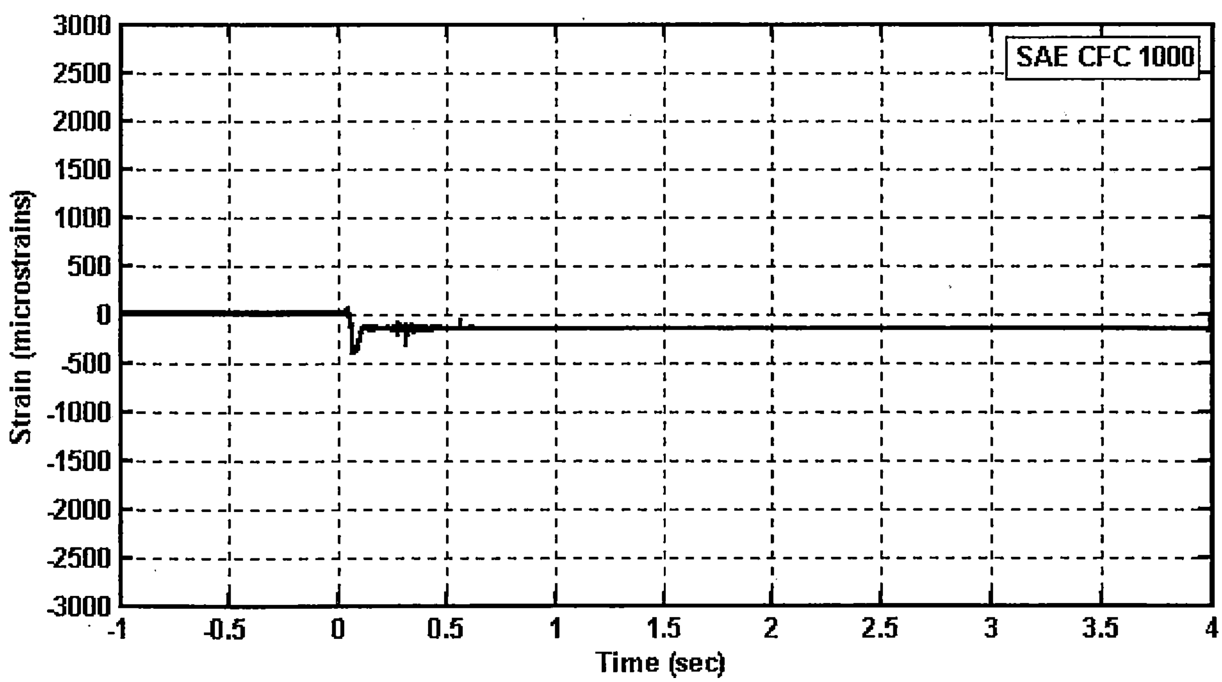

Figure F20. Longitudinal strain on left collision post, centered longitudinally, top edge
Channel Name: CPLS5

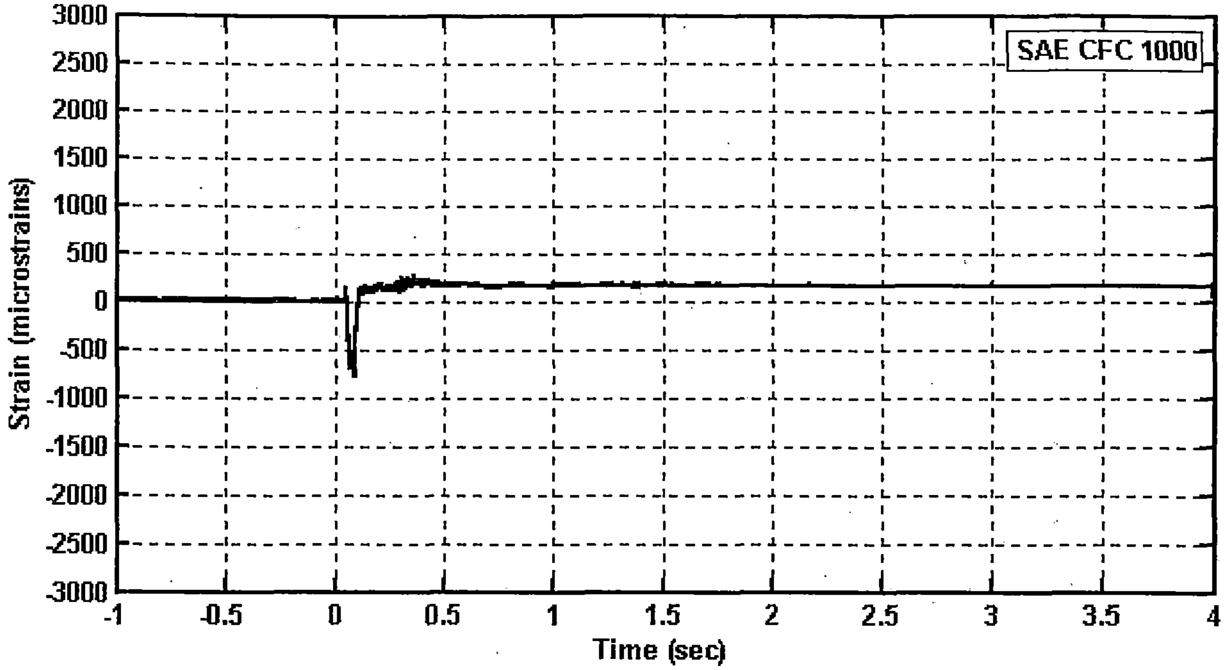

Figure F21. Strain on right collision post, bottom rear rosette, vertical element
Channel Name: CPRR1_1

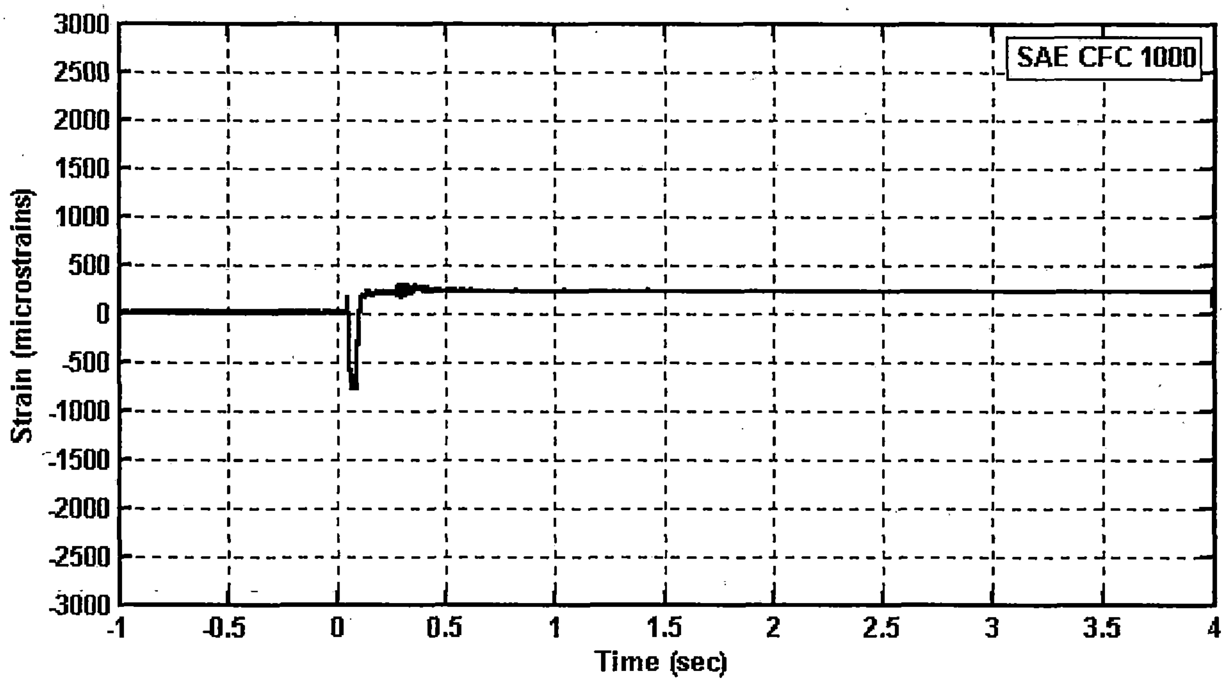

Figure F22. Strain on right collision post, bottom rear rosette, diagonal element
Channel Name: CPRR1_2

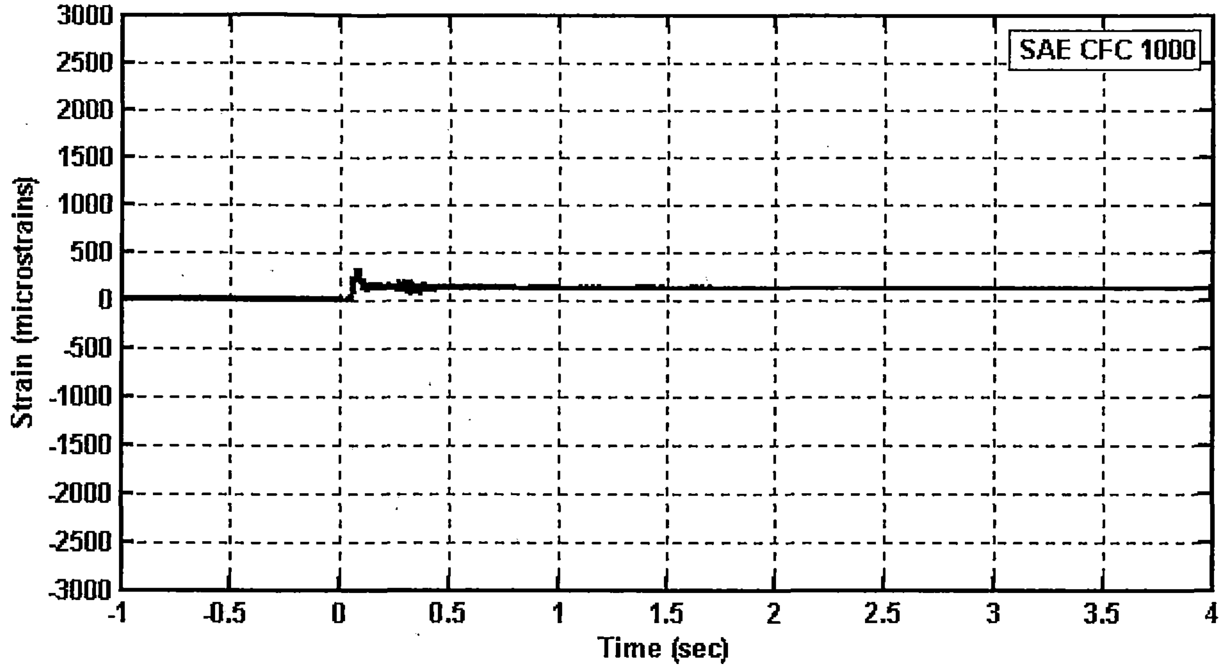

Figure F23. Strain on right collision post, bottom rear rosette, longitudinal element
Channel Name: CPRR1_3

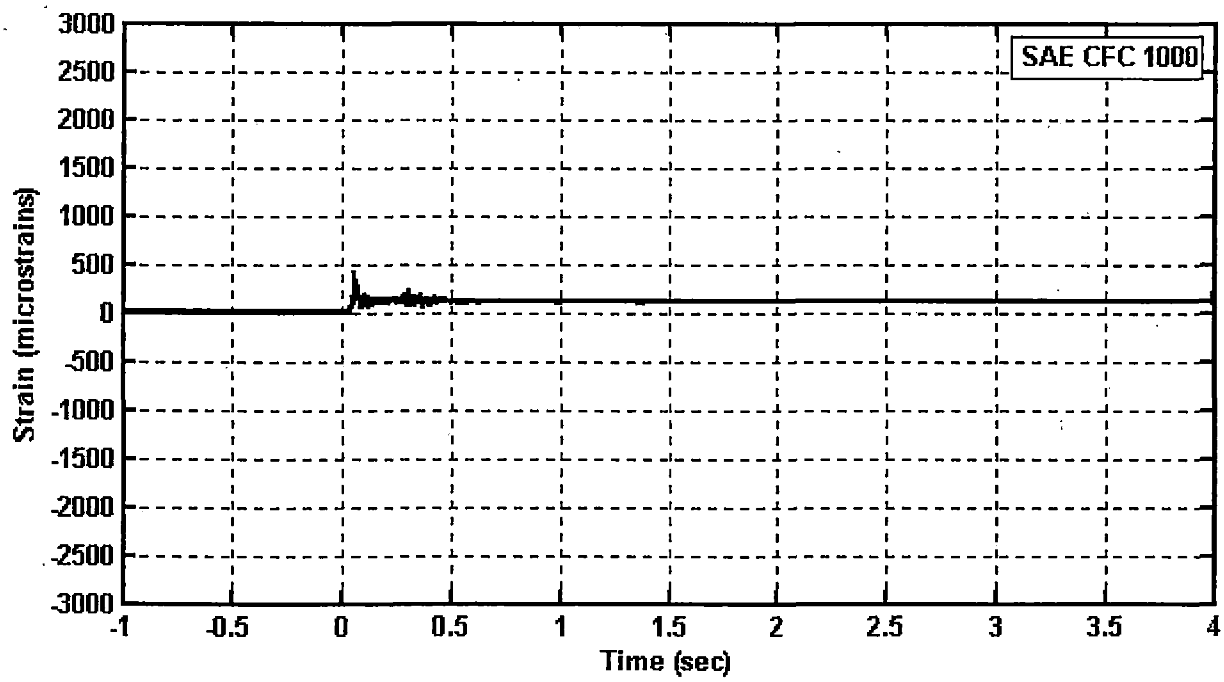

Figure F24. Strain on right collision post, bottom center rosette, vertical element
Channel Name: CPRR2_1

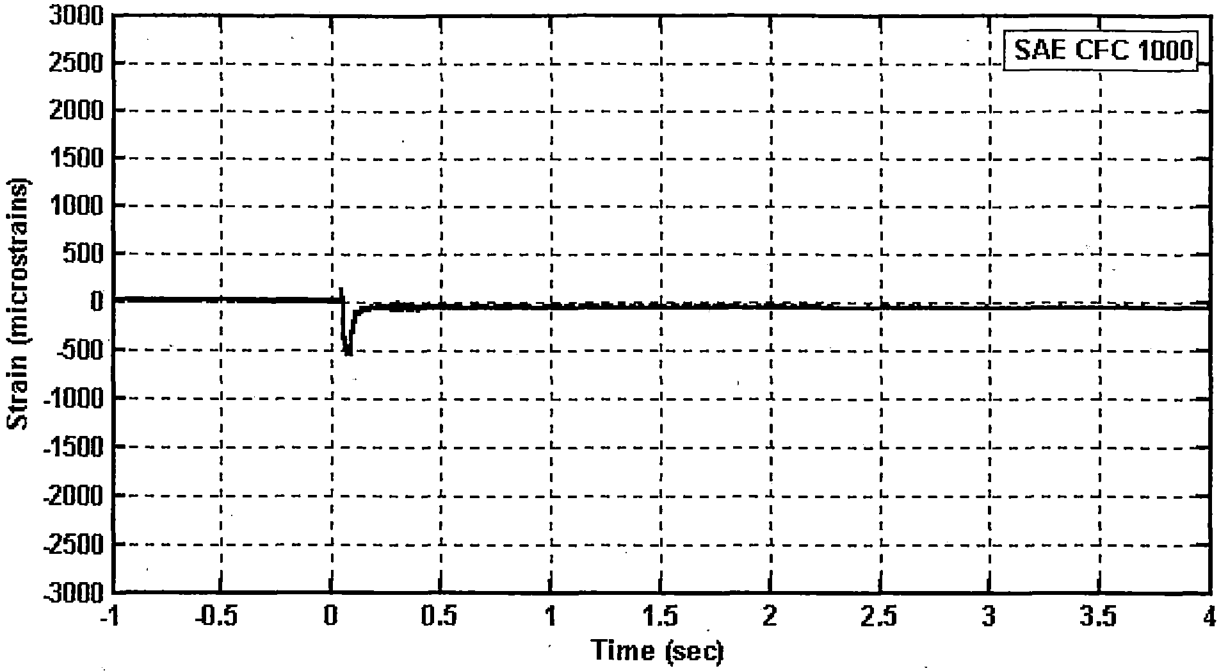

Figure F25. Strain on right collision post, bottom center rosette, diagonal element
Channel Name: CPRR2_2

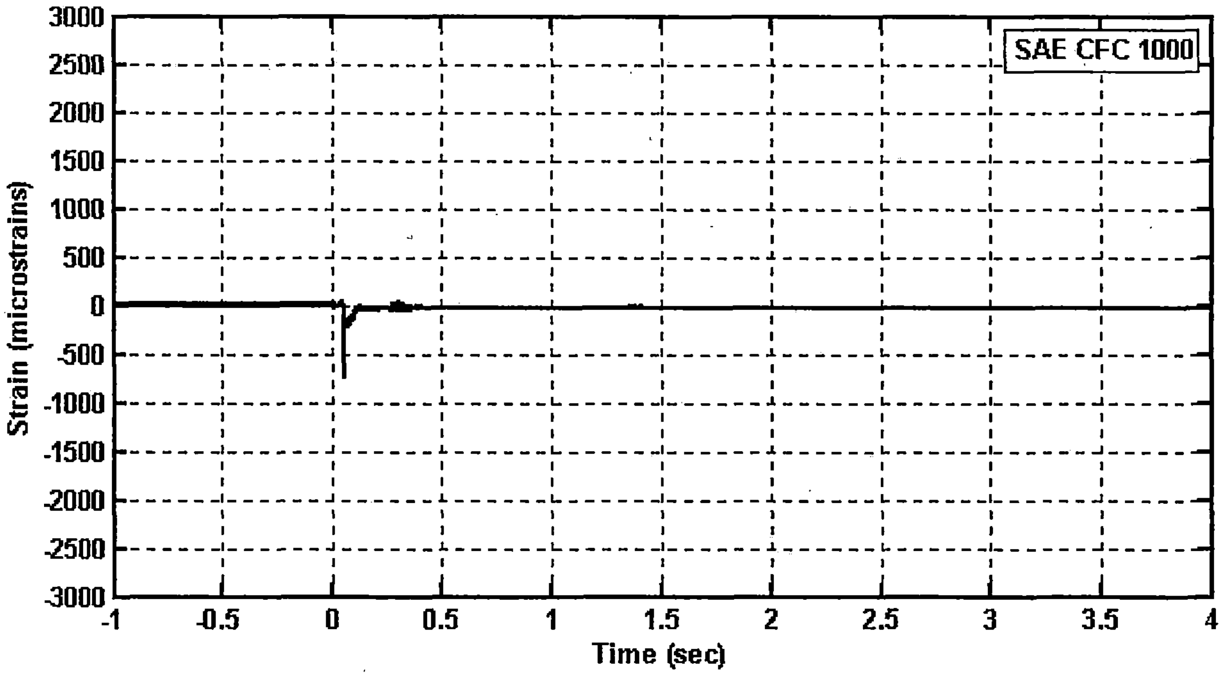

Figure F26. Strain on right collision post, bottom center rosette, longitudinal element
Channel Name: CPRR2_3

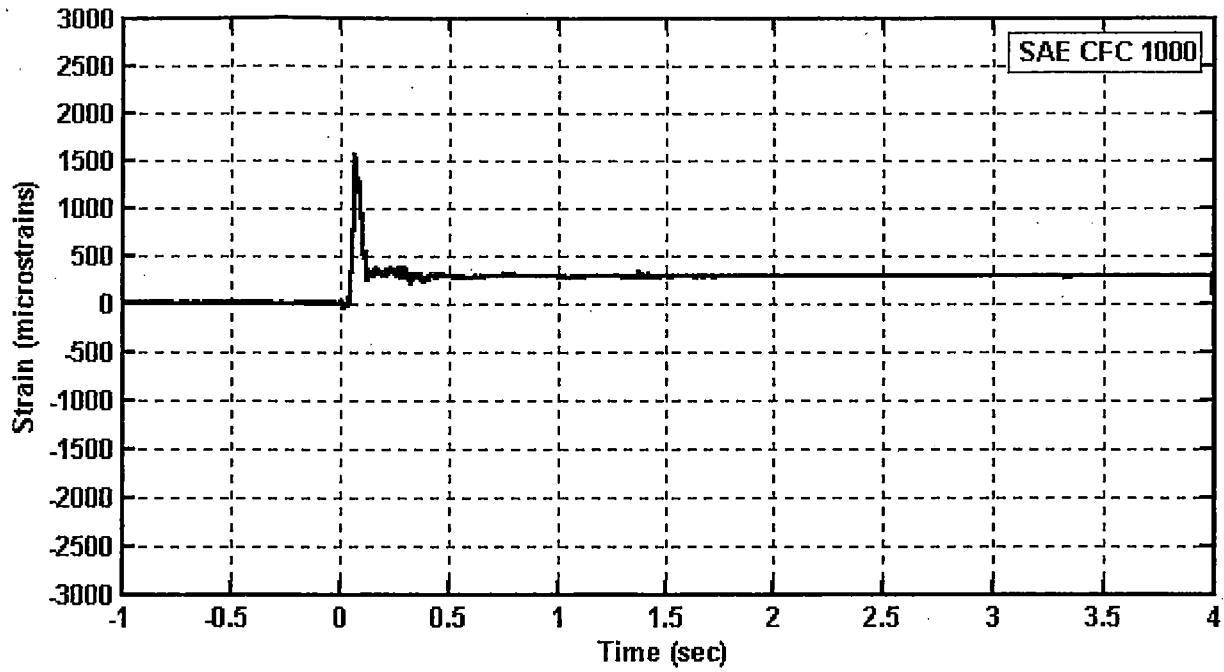

Figure F27. Strain on right collision post, bottom front rosette, vertical element
Channel Name: CPRR3_1

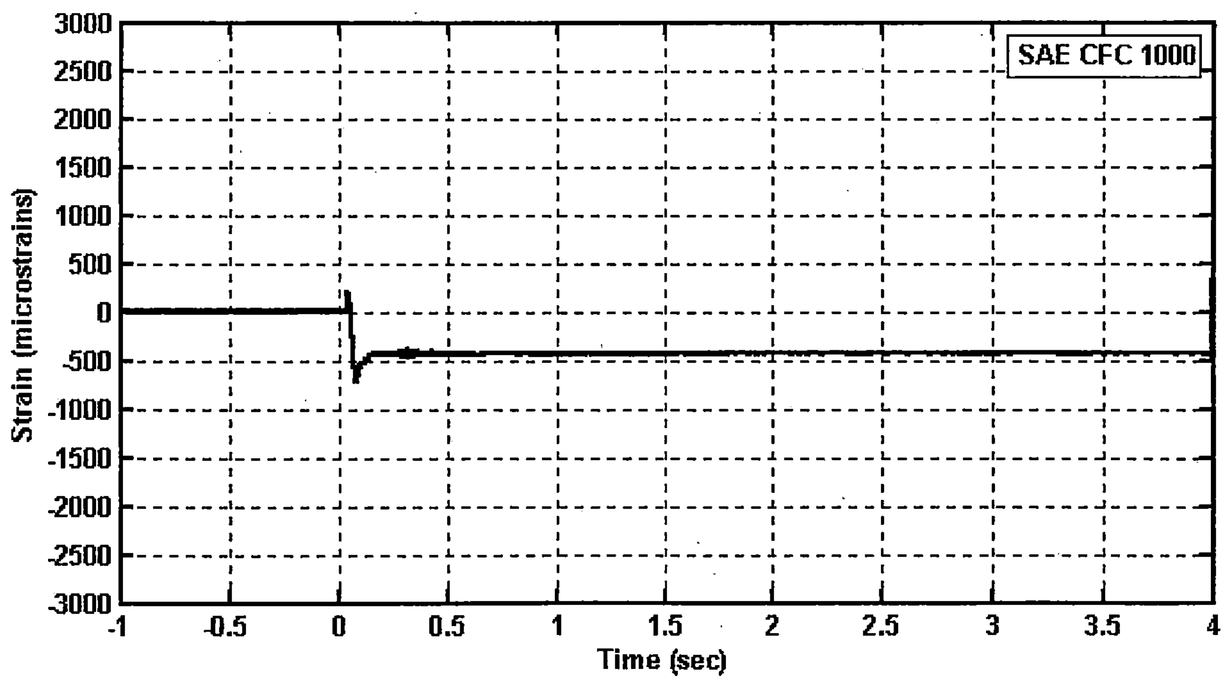

Figure F28. Strain on right collision post, bottom front rosette, diagonal element
Channel Name: CPRR3_2

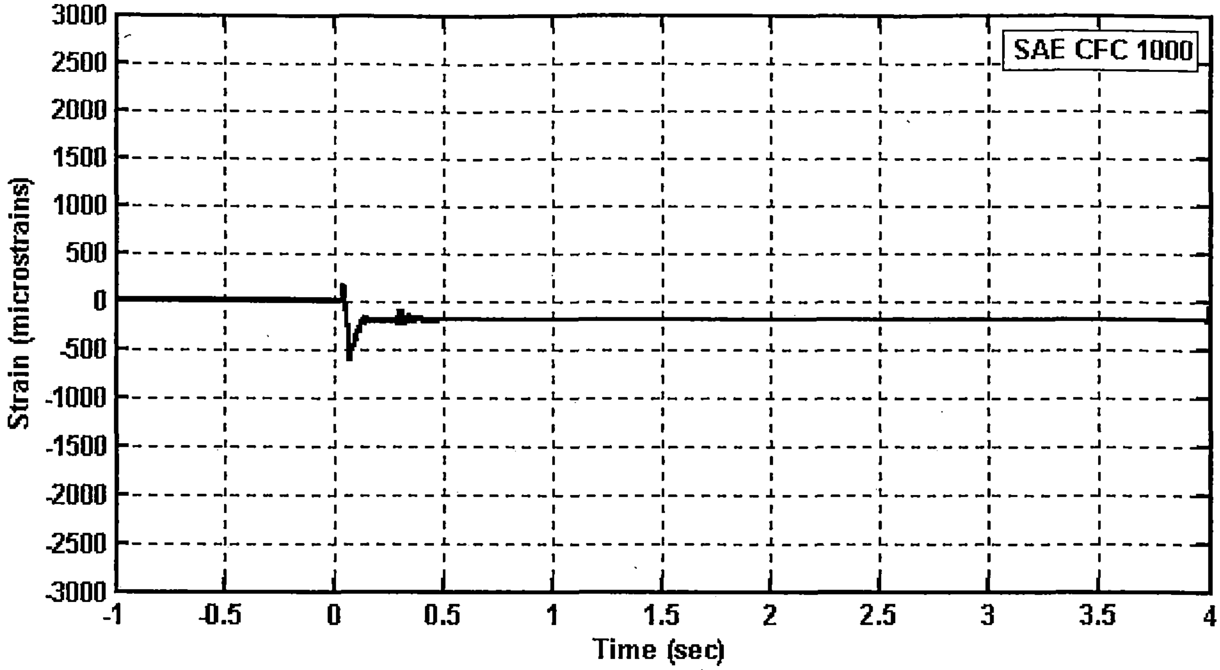

Figure F29. Strain on right collision post, bottom front rosette, longitudinal element
Channel Name: CPRR3_3

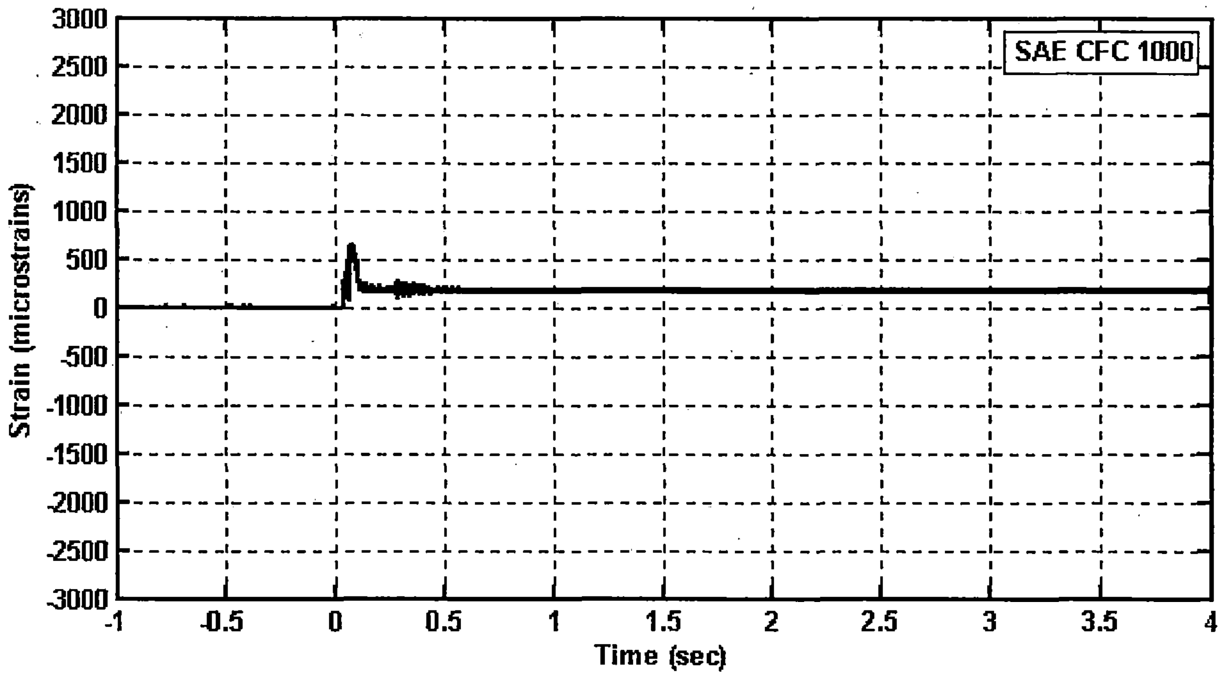

Figure F30. Strain on right collision post, top front rosette, vertical element
Channel Name: CPRR4_1

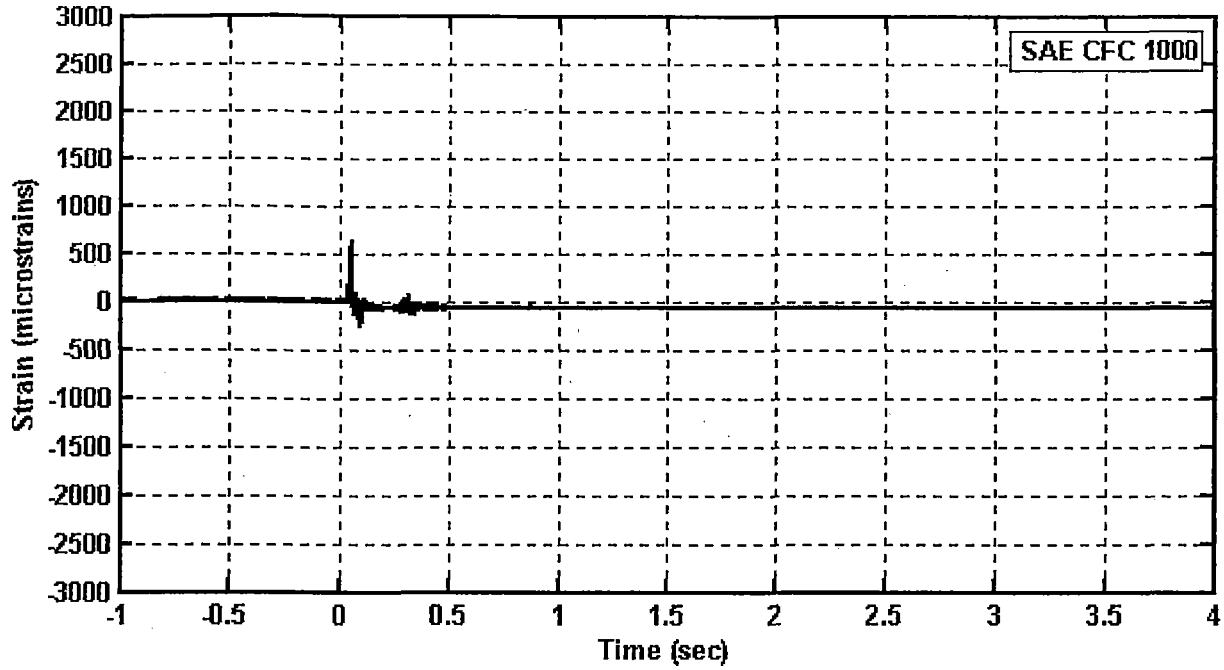

Figure F31. Strain on right collision post, top front rosette, diagonal element
Channel Name: CPRR4_2

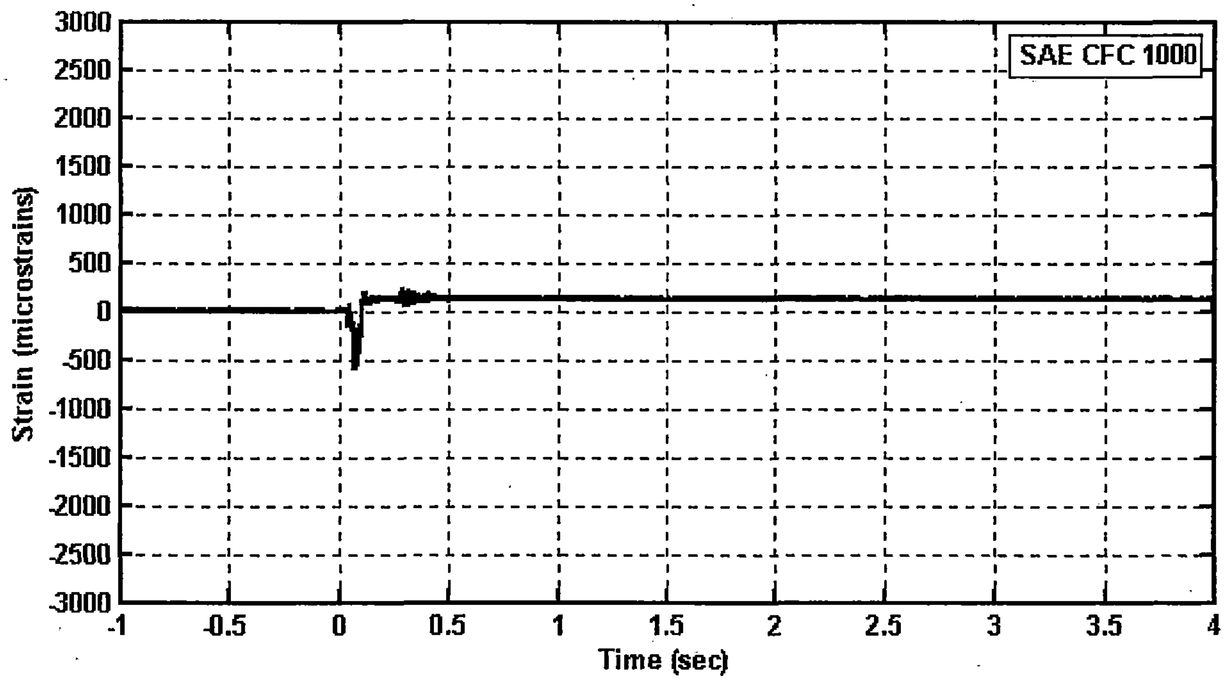

Figure F32. Strain on right collision post, top front rosette, longitudinal element
Channel Name: CPRR4_3

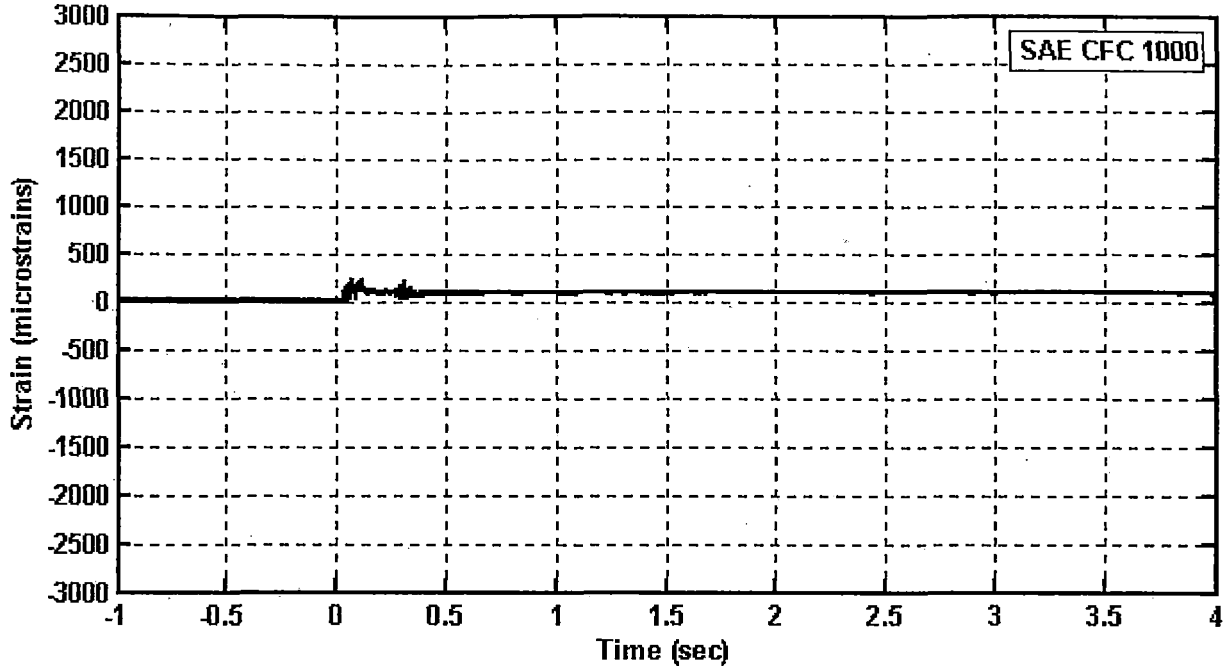

Figure F33. Strain on right collision post, middle front rosette, vertical element
Channel Name: CPRR5_1

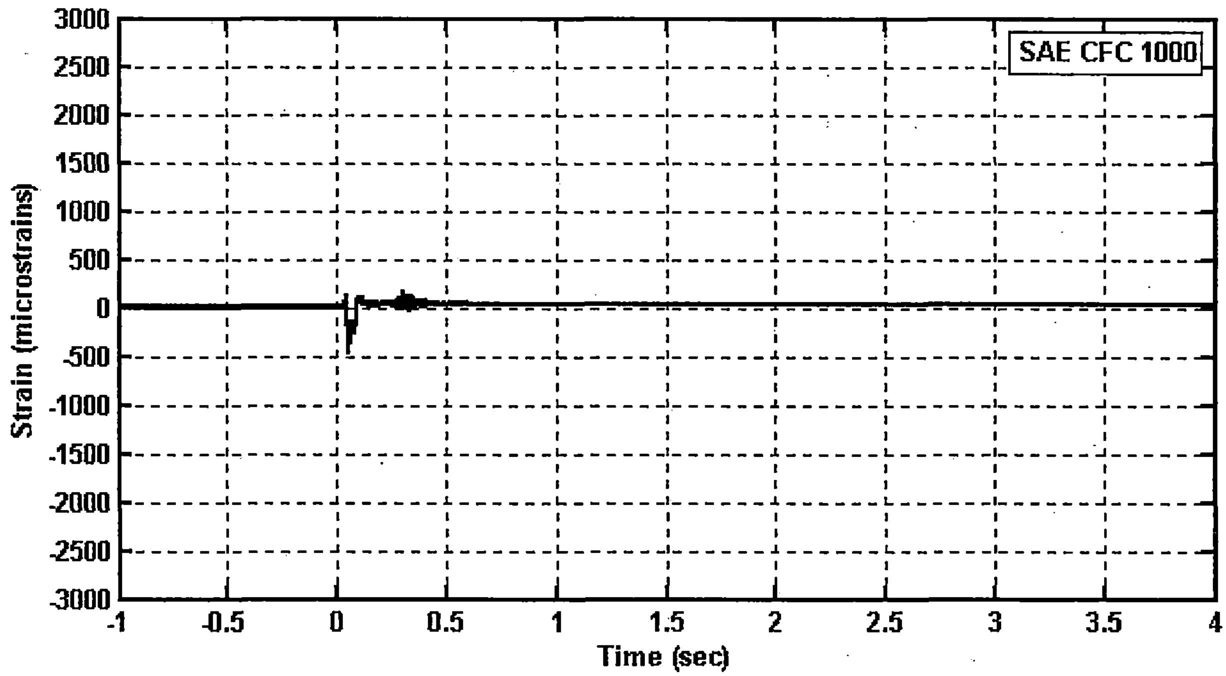

Figure F34. Strain on right collision post, middle front rosette, diagonal element
Channel Name: CPRR5_2

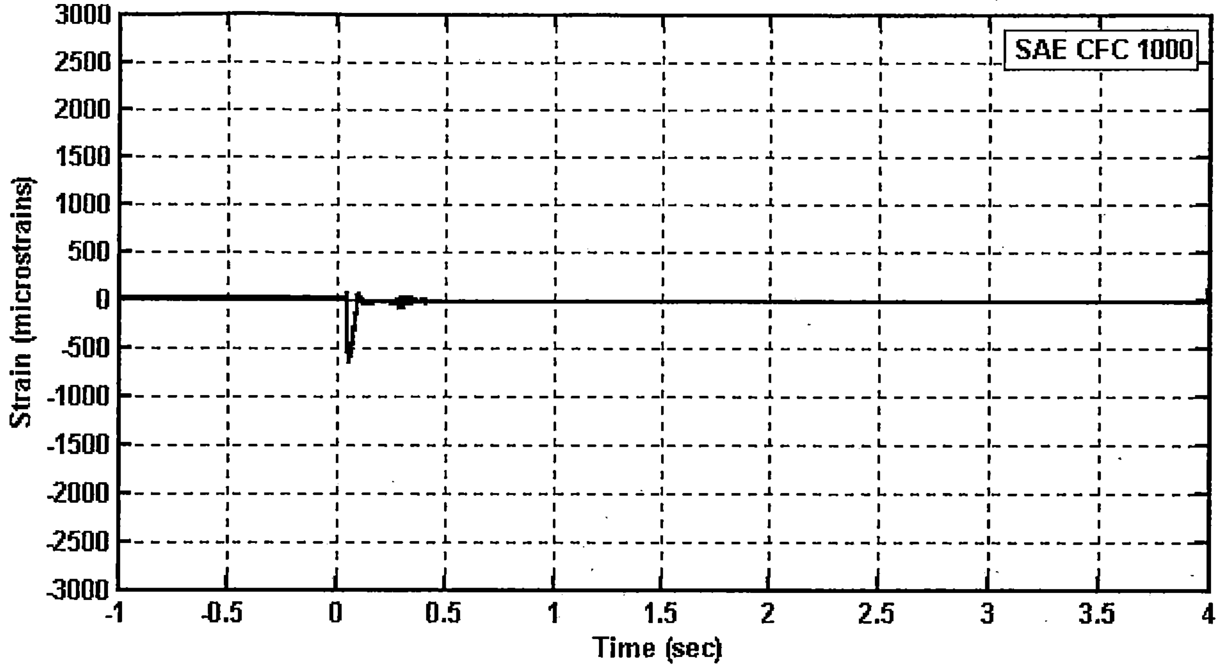

Figure F35. Strain on right collision post, middle front rosette, longitudinal element
Channel Name: CPRR5_3

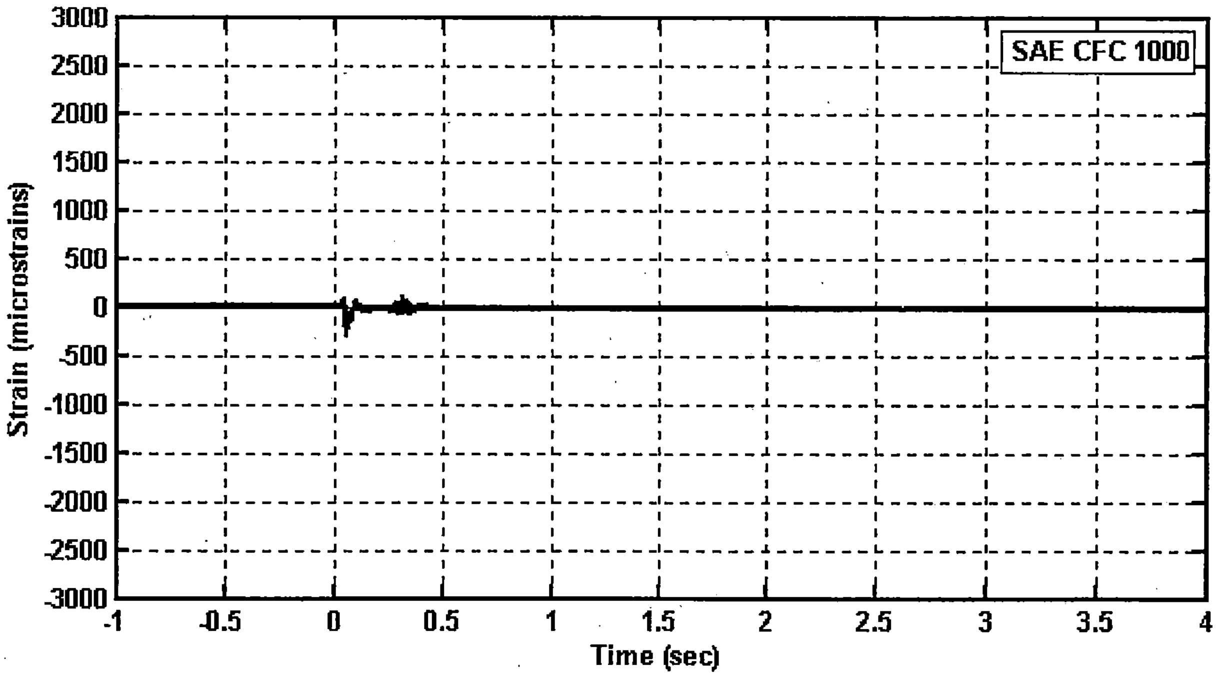

Figure F36. Longitudinal strain on right collision post, center, 3/4 up from bottom edge
Channel Name: CPRS1

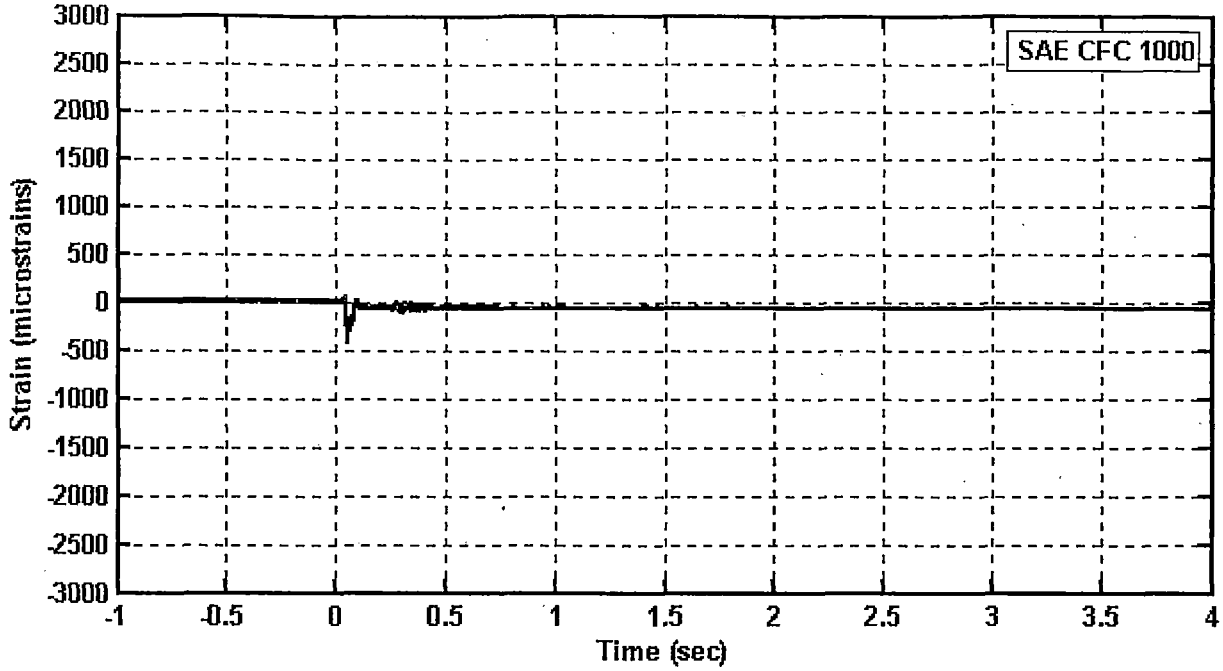

Figure F37. Longitudinal strain on right collision post, center, 1/2 up from bottom edge
Channel Name: CPRS2

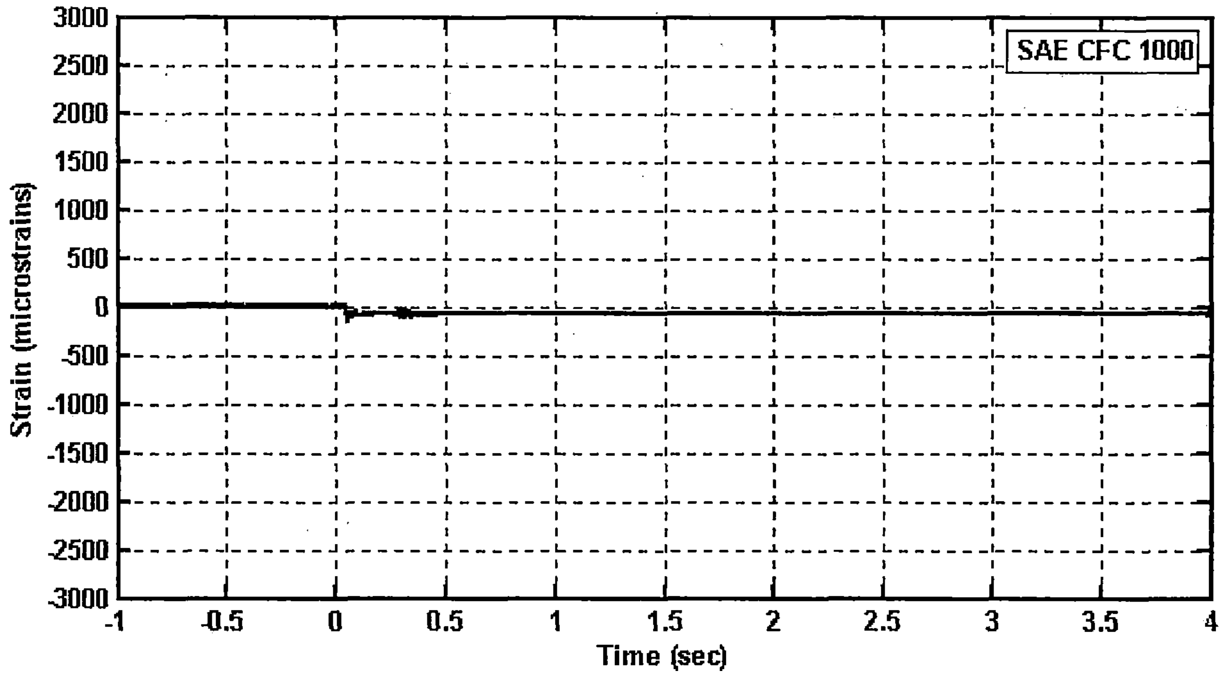

Figure F38. Longitudinal strain on right collision post, center, 1/4 up from bottom edge
Channel Name: CPRS3

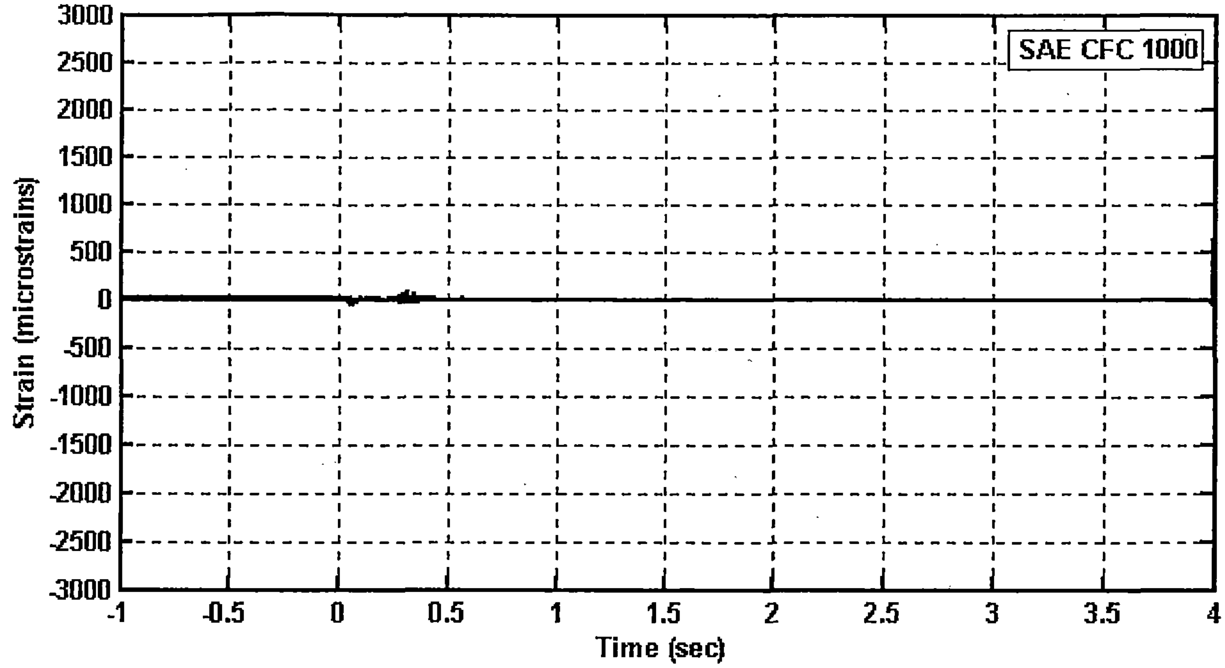

Figure F39. Longitudinal strain on right collision post, top rear corner
Channel Name: CPRS4

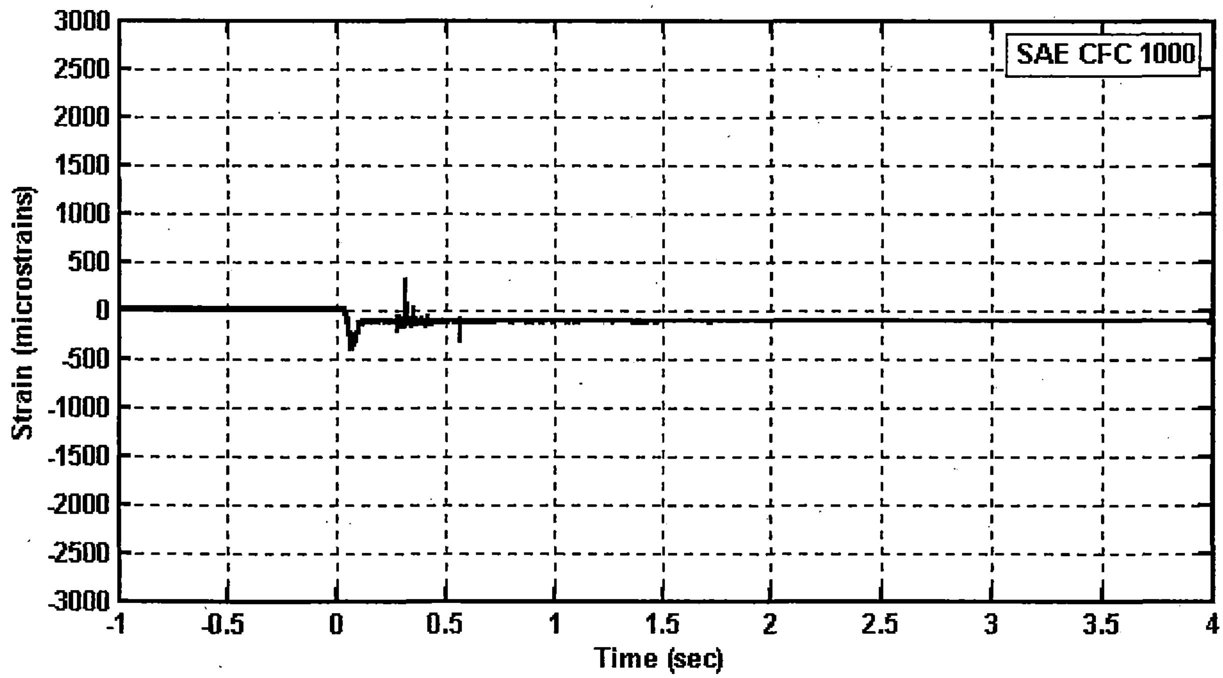

Figure F40. Longitudinal strain on right collision post, centered longitudinally, top edge
Channel Name: CPRS5

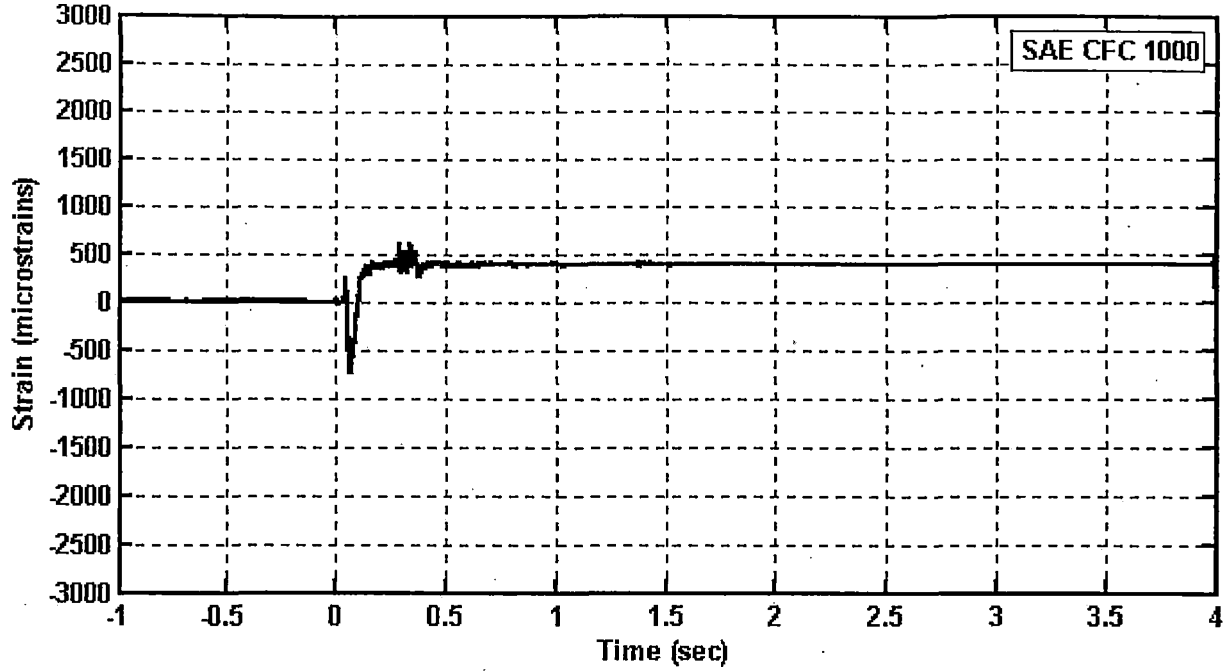

Figure F41. Vertical strain on windshield post, bottom edge of windshield, left side
Channel Name: CPWBL

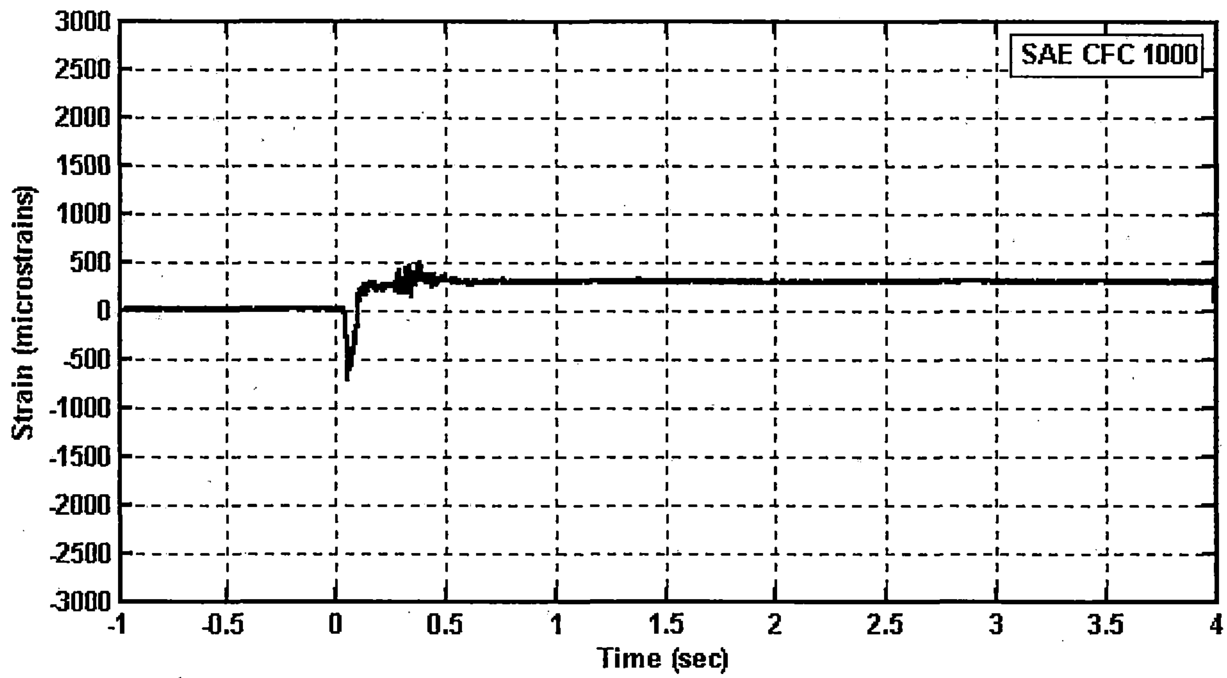

Figure F42. Vertical strain on windshield post, bottom edge of windshield, right side
Channel Name: CPWBR

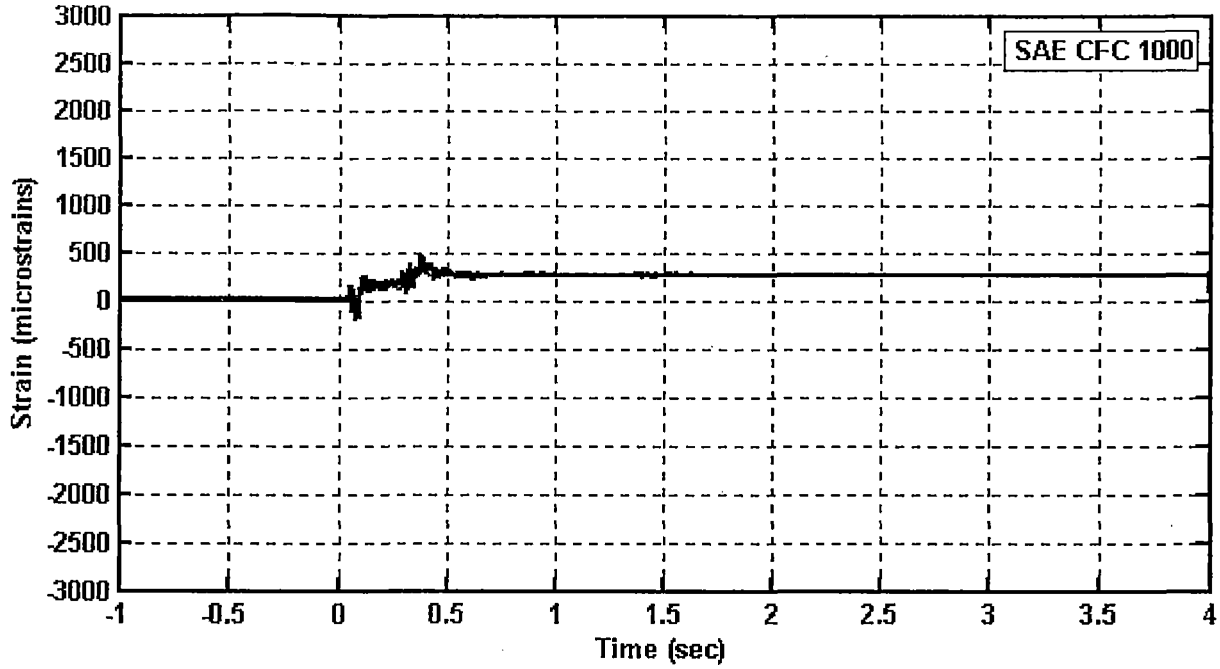

Figure F43. Vertical strain on windshield post, middle of windshield, left side
Channel Name: CPWML

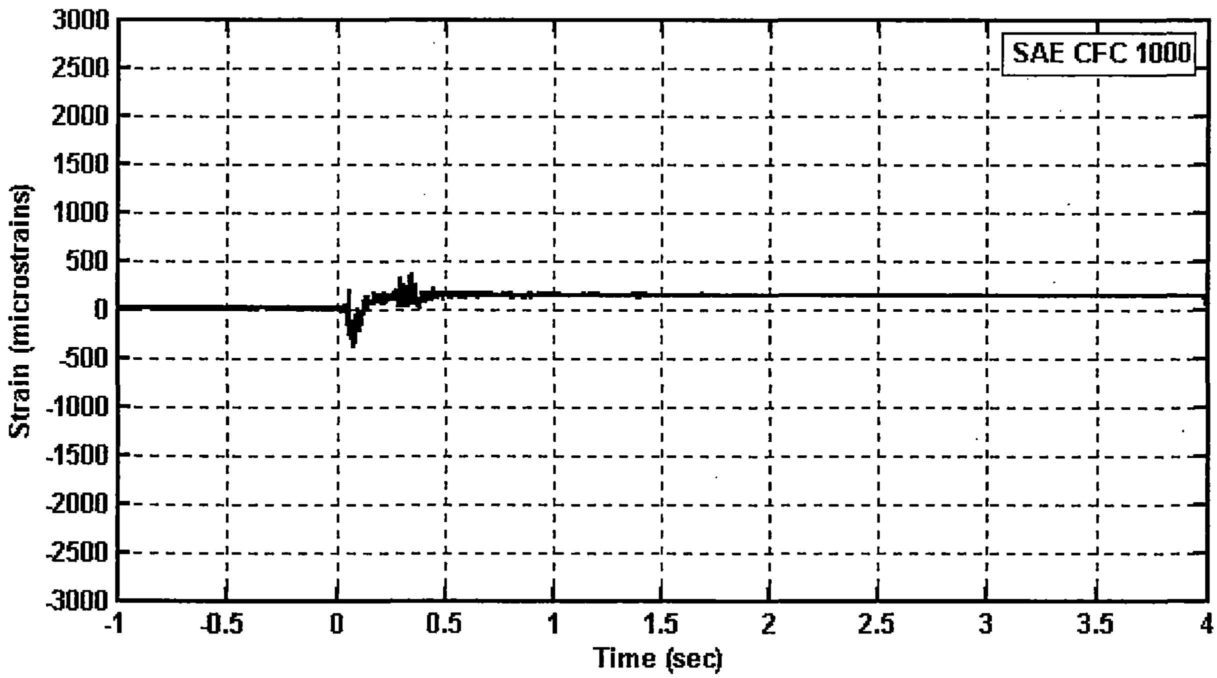

Figure F44. Vertical strain on windshield post, middle of windshield, right side
Channel Name: CPWMR

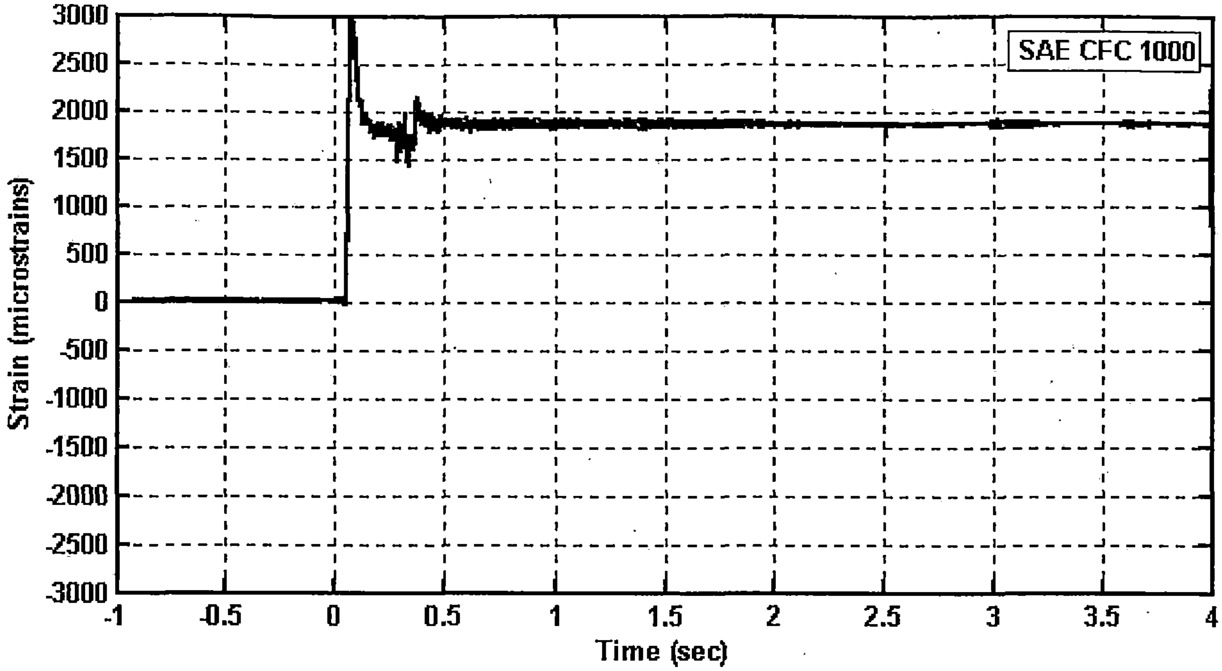

Figure F45. Vertical strain on windshield post, top edge of windshield, left side
Channel Name: CPWTL

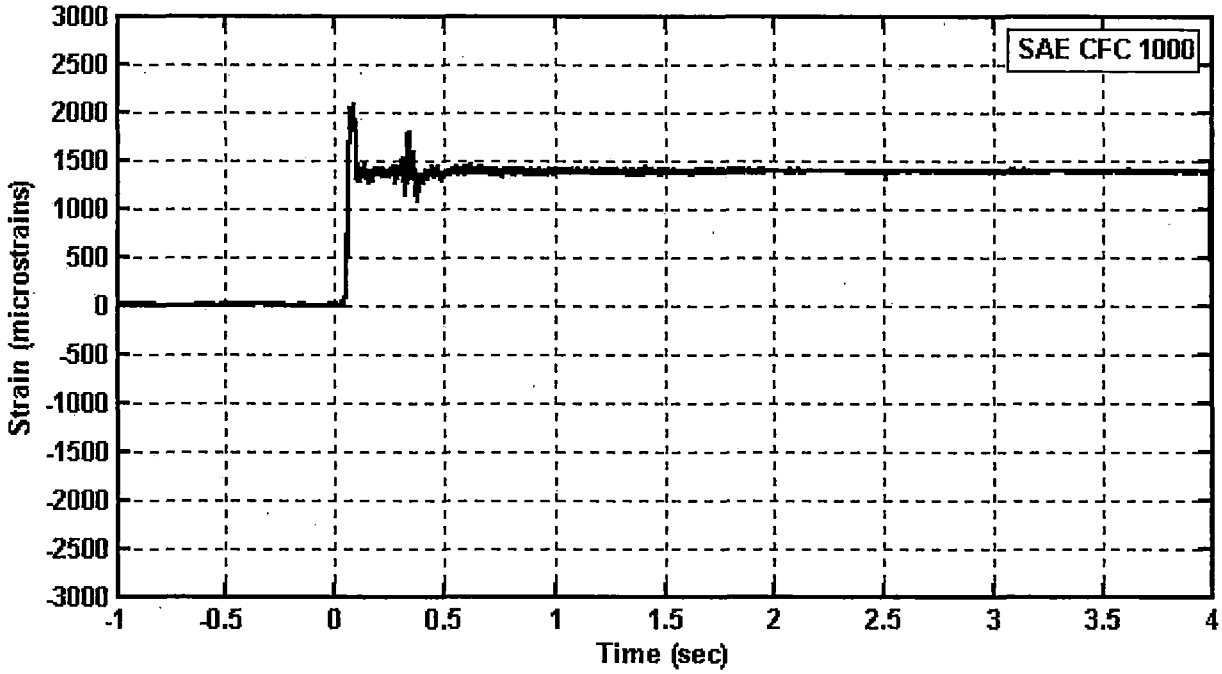

Figure F46. Vertical strain on windshield post, top edge of windshield, right side
Channel Name: CPWTR

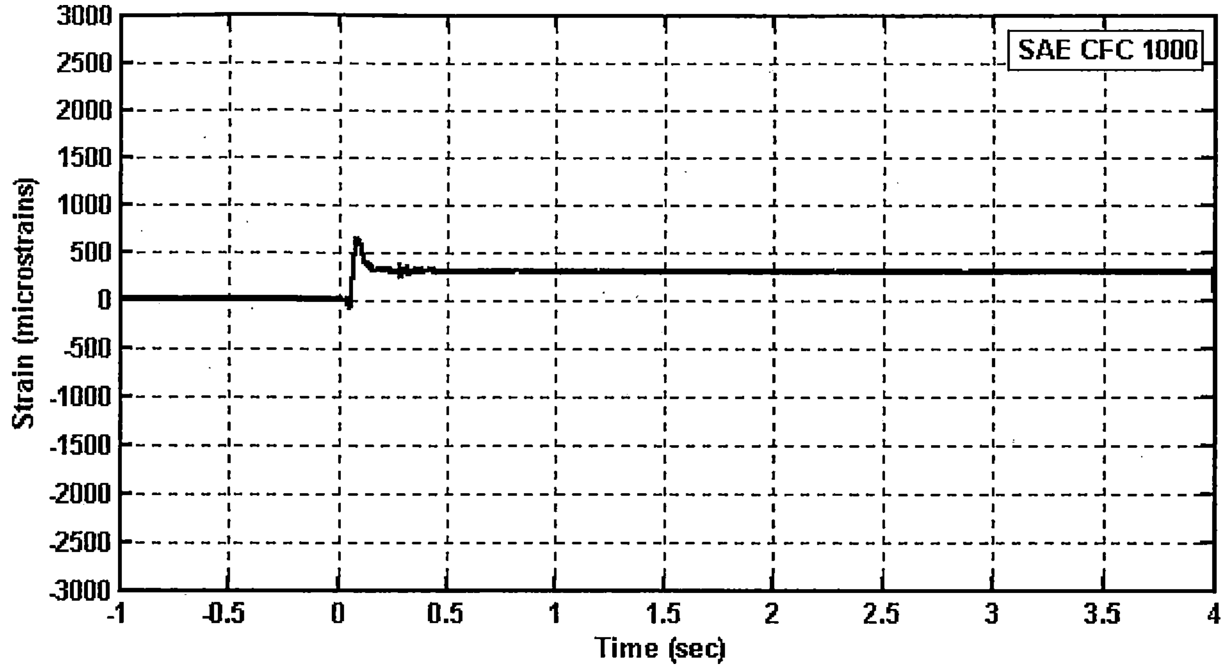

Figure F47. Longitudinal strain on underframe, about even with the leading axle, left side
Channel Name: ULF

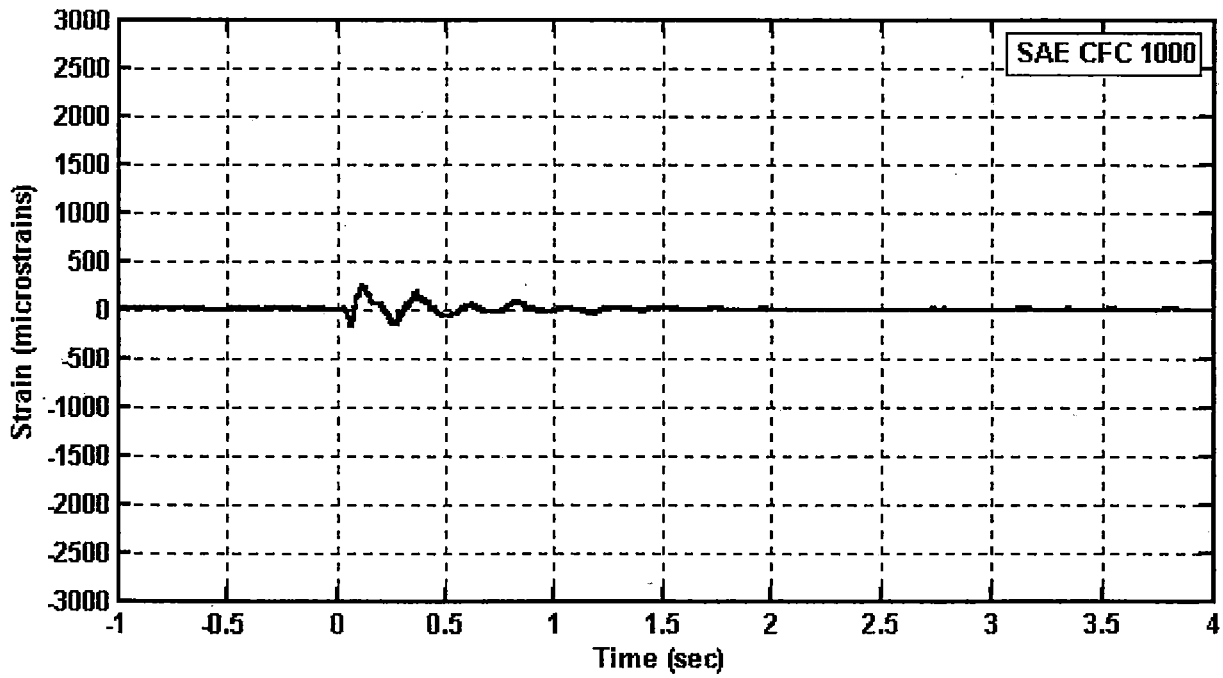

Figure F48. Longitudinal strain on underframe, just in front of the fuel tank, left side
Channel Name: ULMF

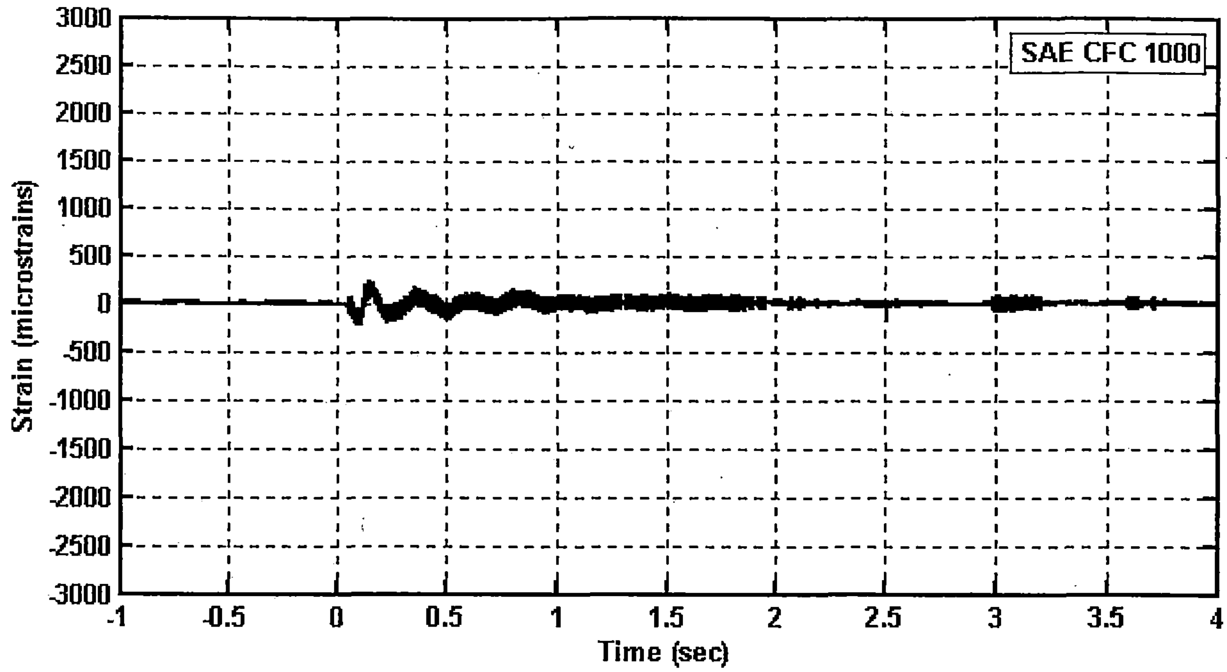

Figure F49. Longitudinal strain on underframe, just behind the fuel tank, left side
Channel Name: ULMR

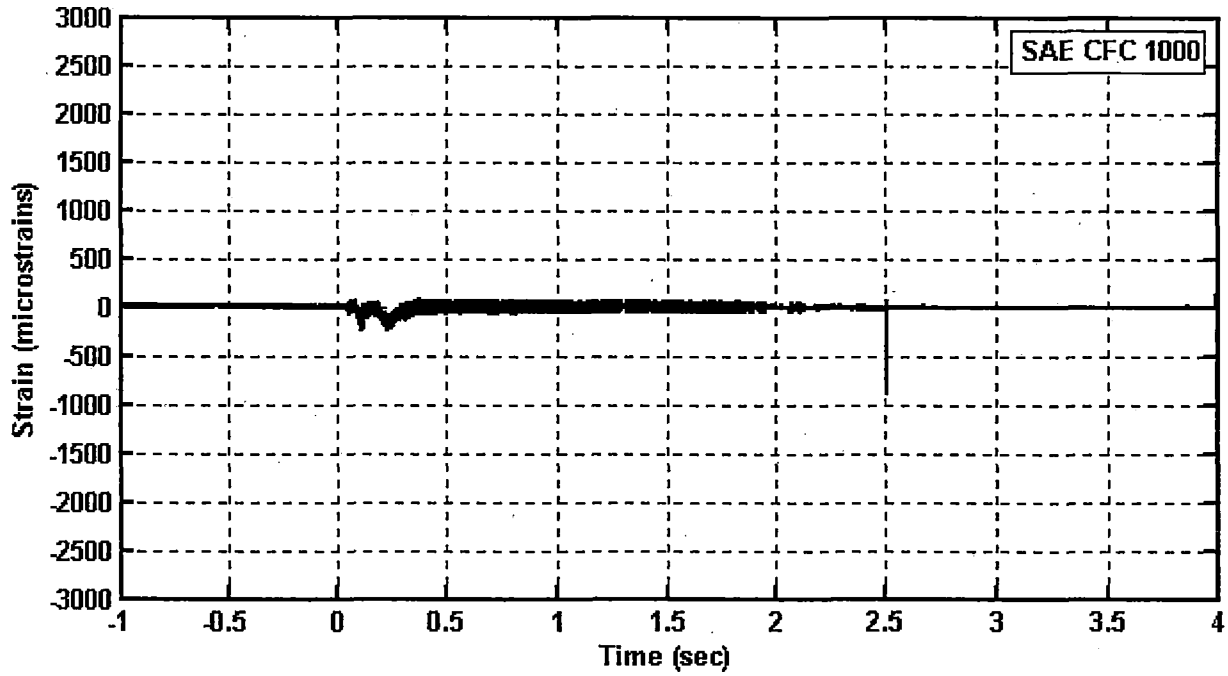

Figure F50. Longitudinal strain on underframe, about even with the trailing axle, left side
Channel Name: ULR

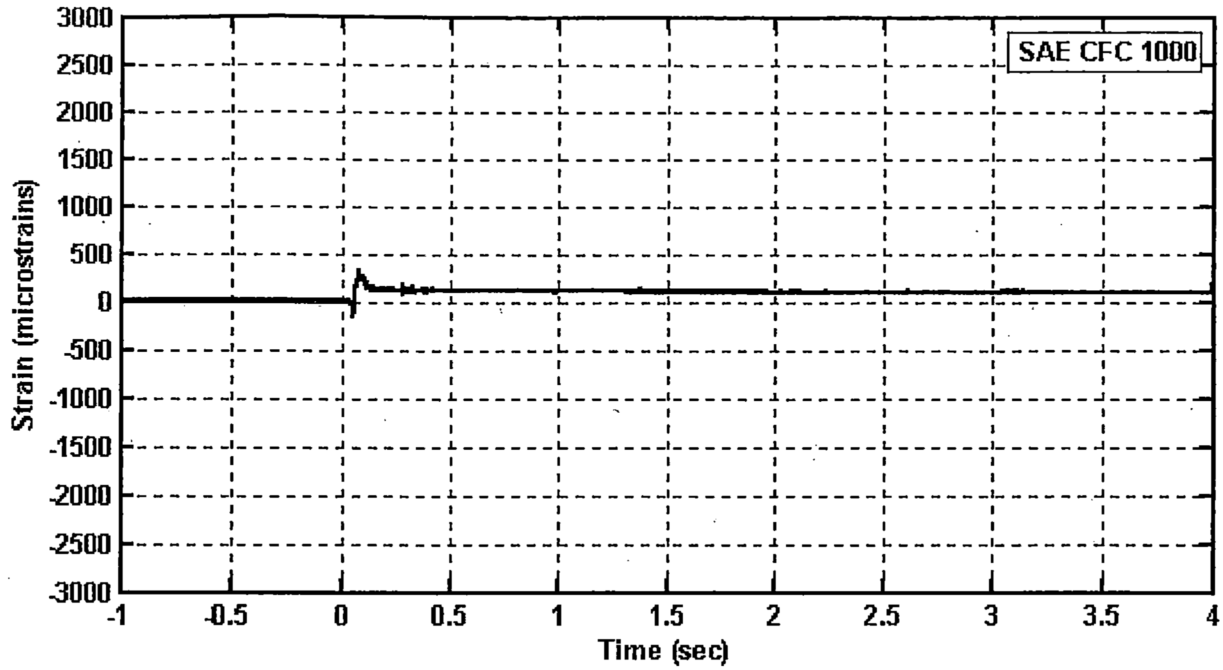

Figure F51. Longitudinal strain on underframe, about even with the leading axle, center
Channel Name: UMF

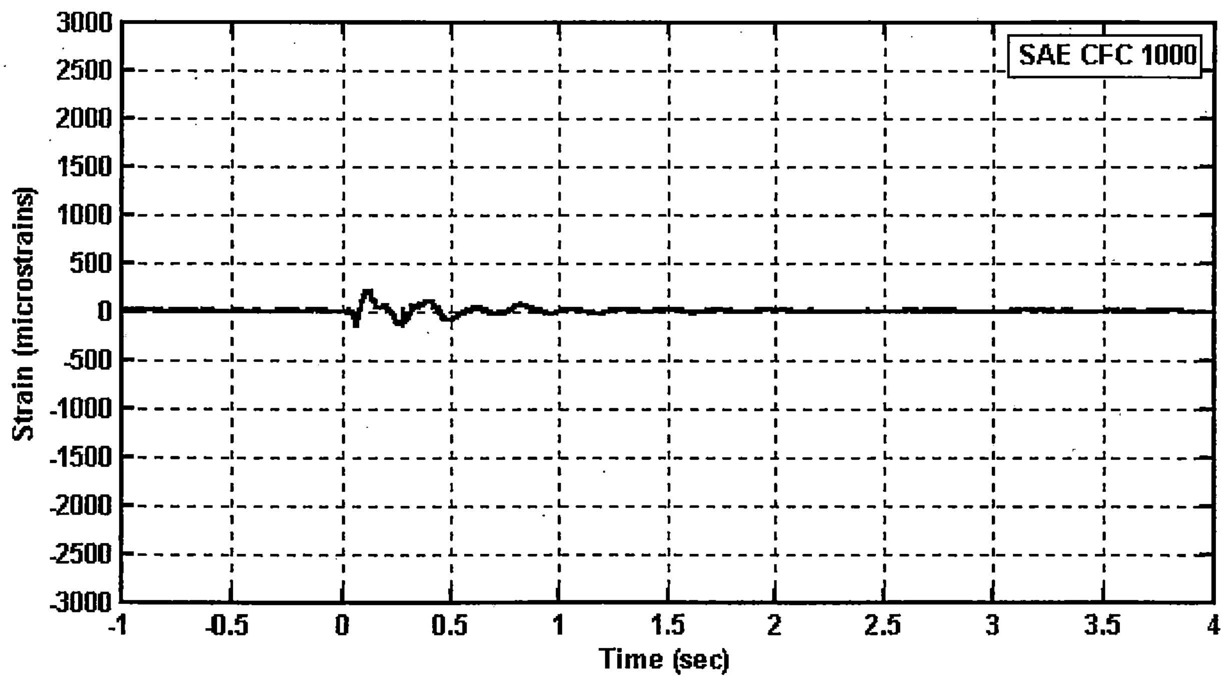

Figure F52. Longitudinal strain on underframe, just in front of the fuel tank, center
Channel Name: UMMF

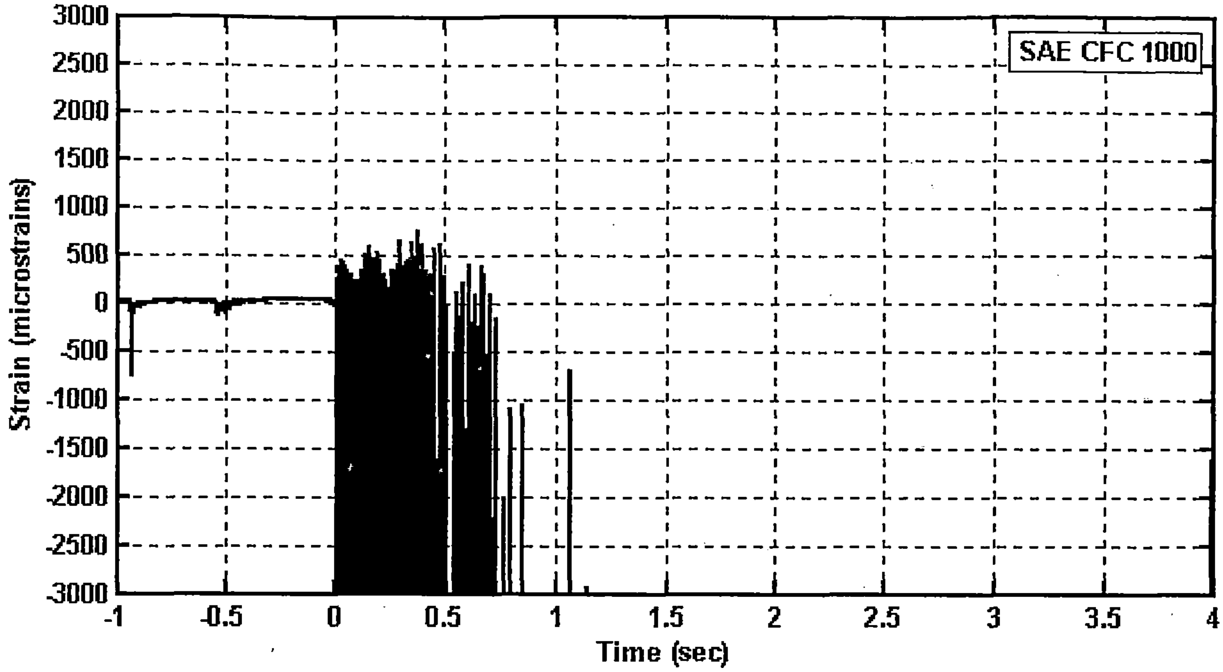

Figure F53. Longitudinal strain on underframe, just behind the fuel tank, center
Channel Name: UMMR

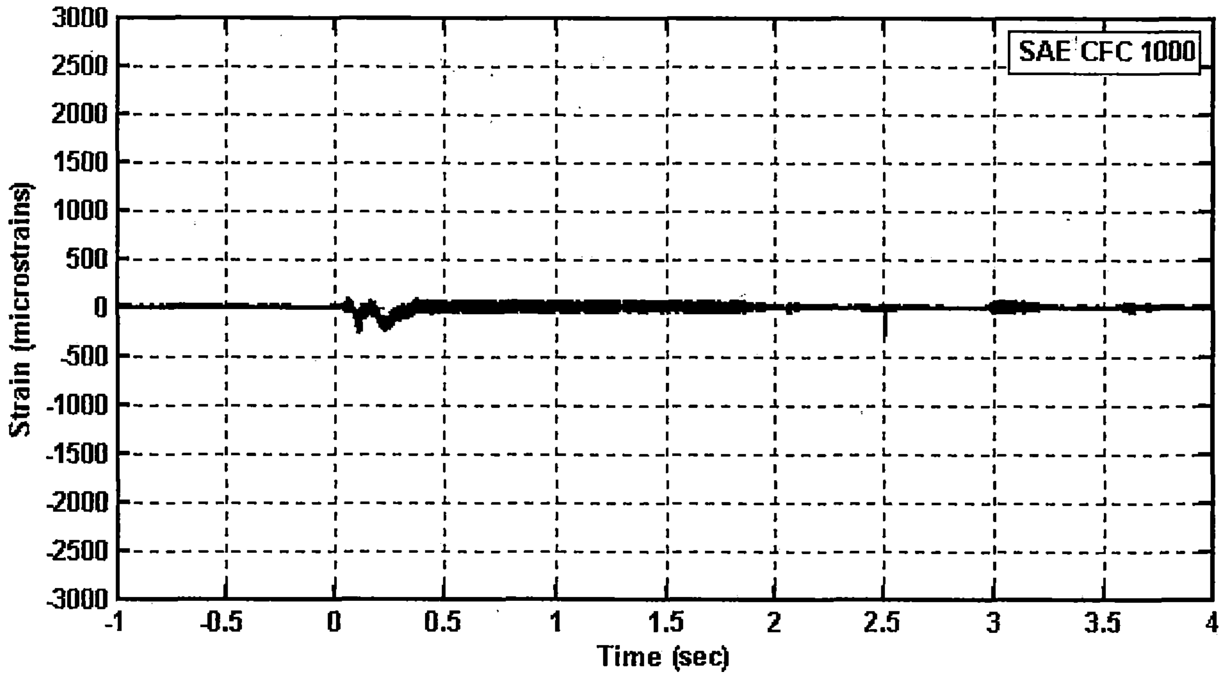

Figure F54. Longitudinal strain on underframe, about even with the trailing axle, center
Channel Name: UMR

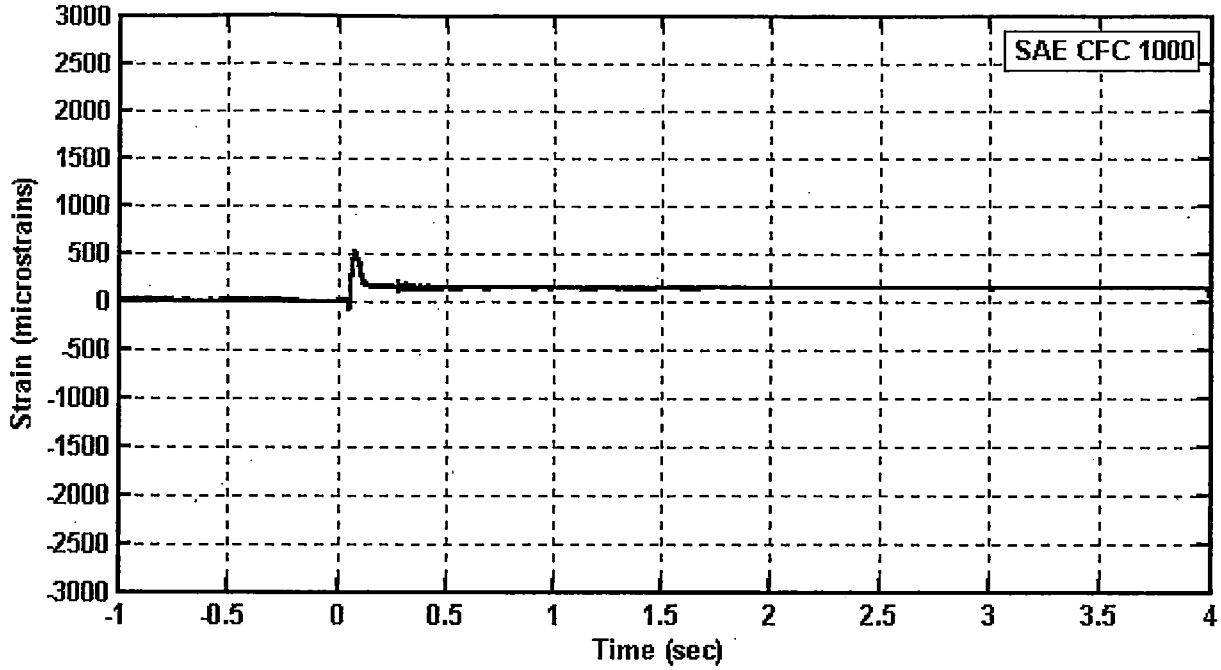

Figure F55. Longitudinal strain on underframe, about even with the leading axle, right side
Channel Name: URF

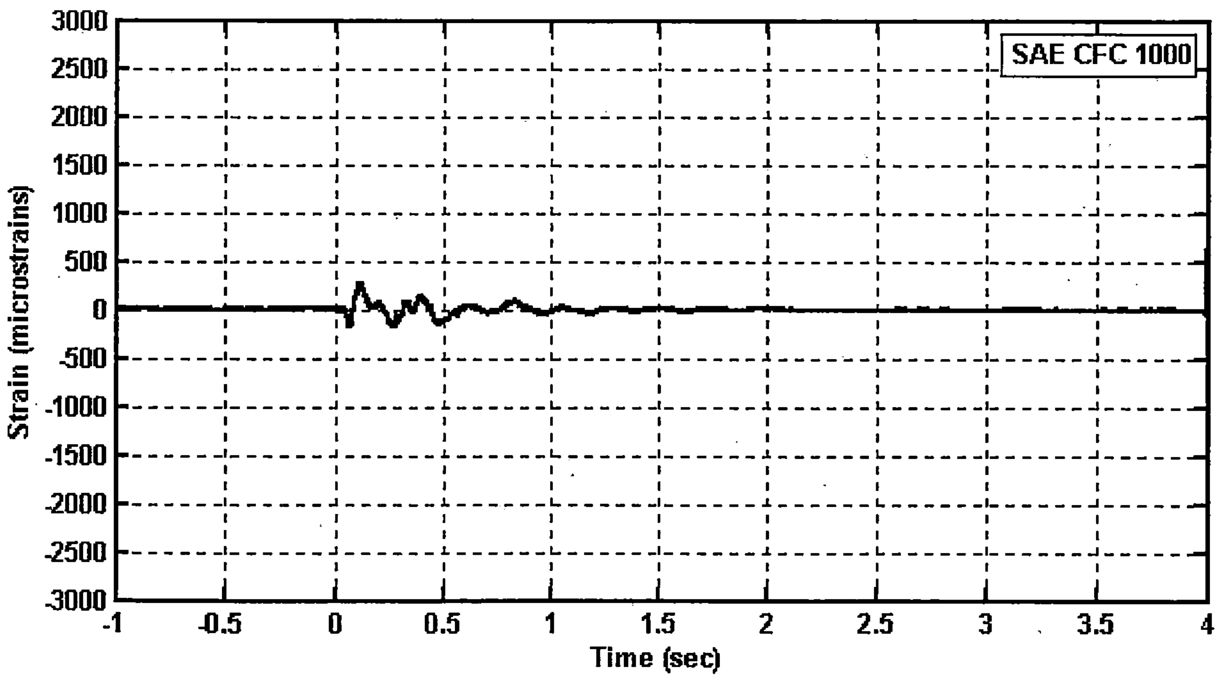

Figure F56. Longitudinal strain on underframe, just in front of the fuel tank, right side
Channel Name: URMF

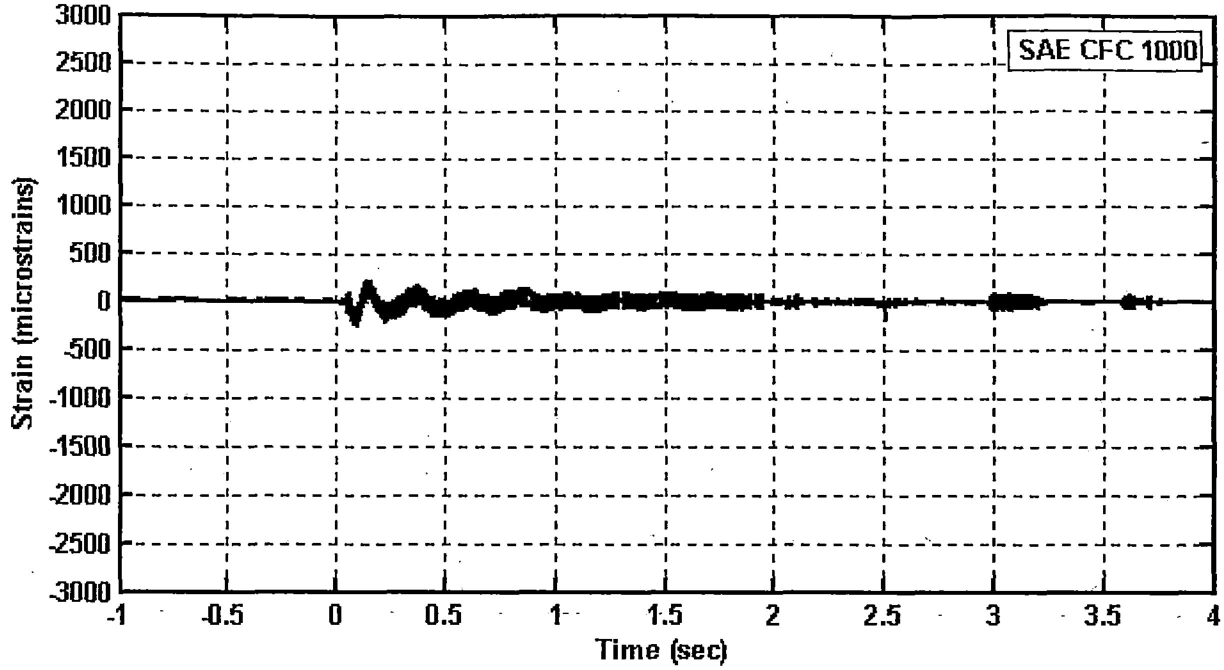

Figure F57. Longitudinal strain on underframe, just behind the fuel tank, right side
Channel Name: URMR

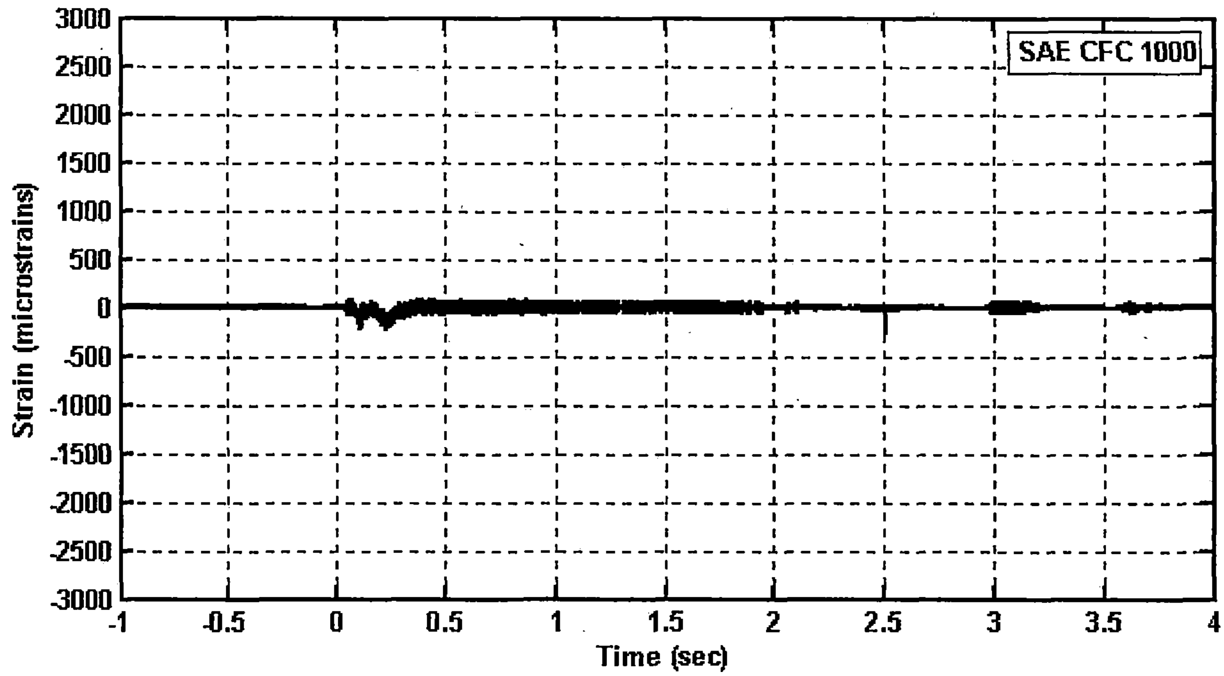

Figure F58. Longitudinal strain on underframe, about even with the trailing axle, right side
Channel Name: URR

APPENDIX G

Anthropomorphic Test Device (ATD) Data

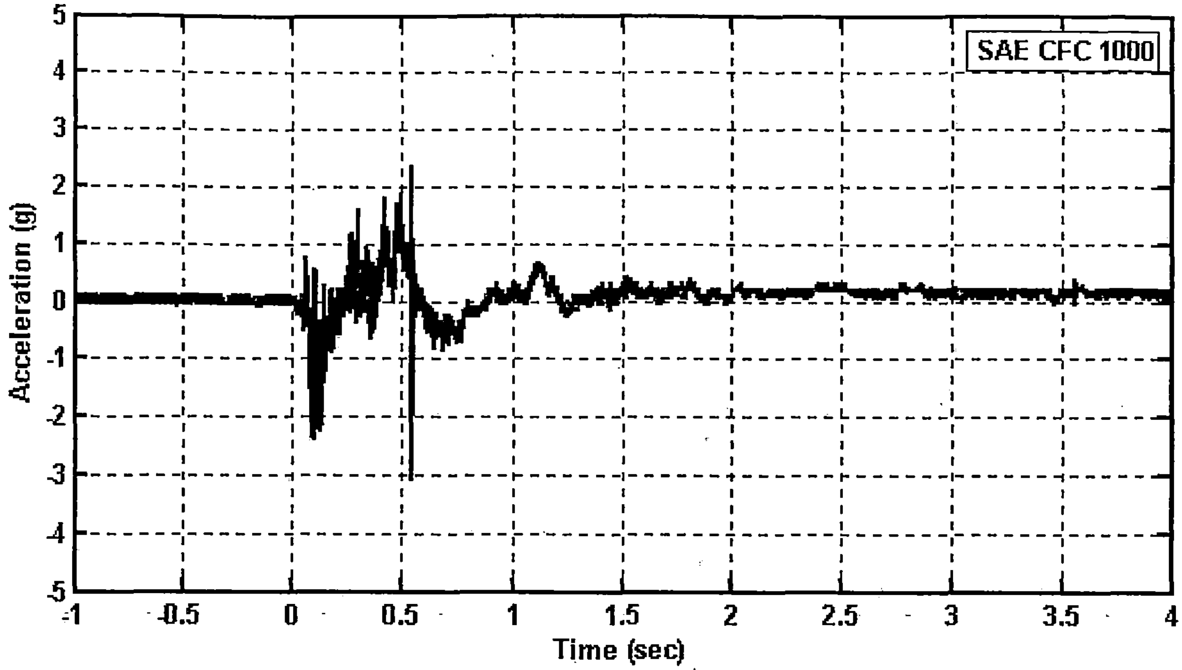

Figure G1. Anthropomorphic test device, chest acceleration, x direction
Channel Name: ATDC_X

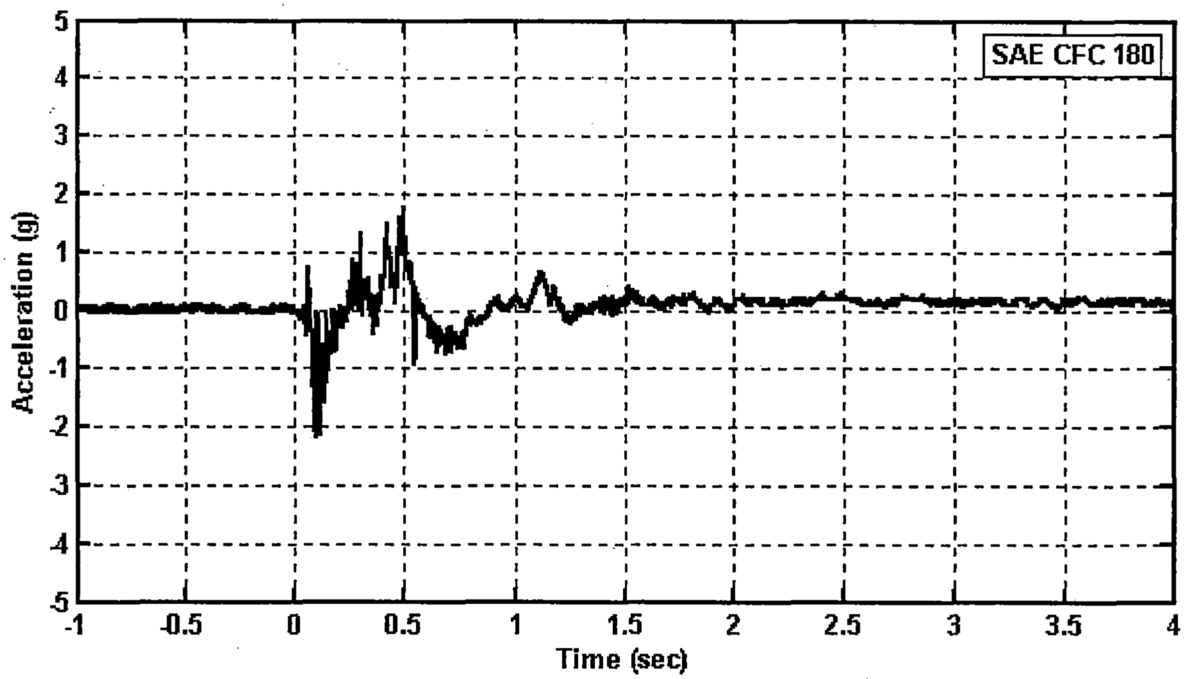

Figure G2. Anthropomorphic test device, chest acceleration, x direction
Channel Name: ATDC_X

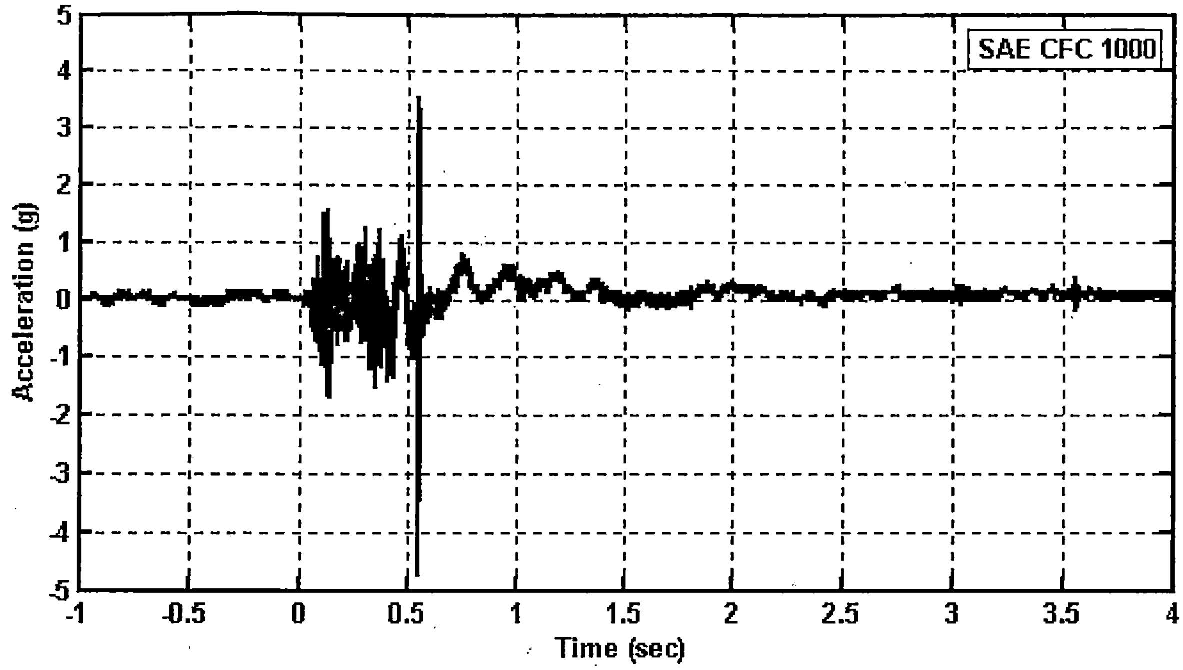

Figure G3. Anthropomorphic test device, chest acceleration, y direction
Channel Name: ATDC_Y

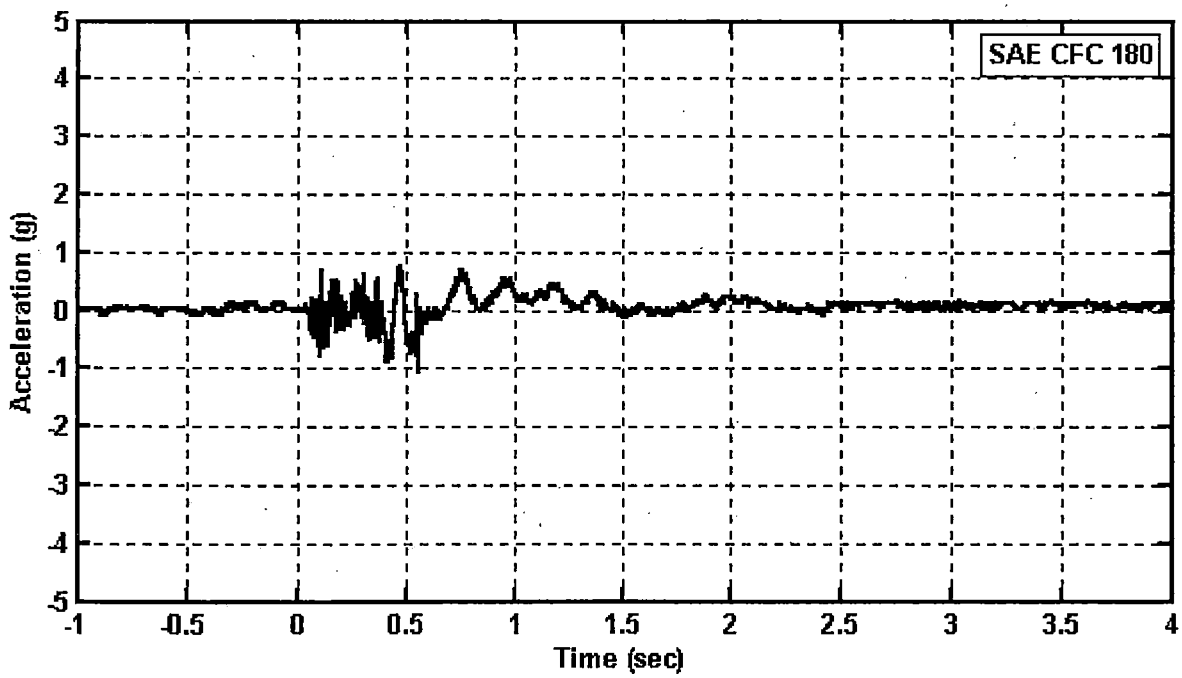

Figure G4. Anthropomorphic test device, chest acceleration, y direction
Channel Name: ATDC_Y

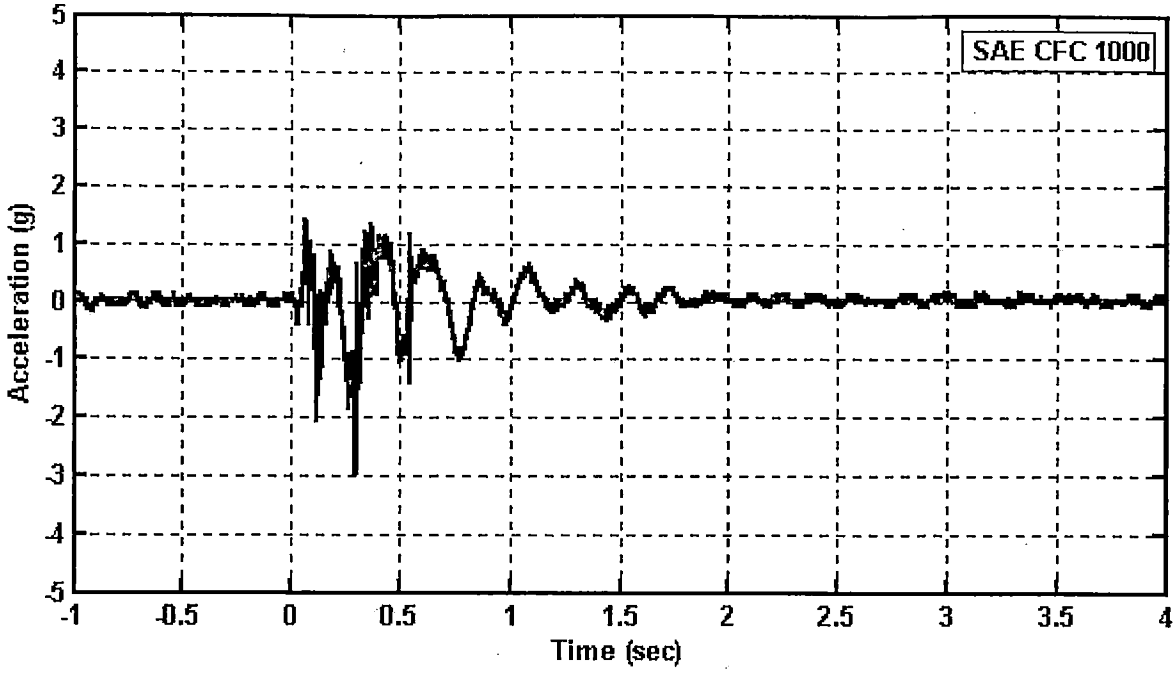

Figure G5. Anthropomorphic test device, chest acceleration, z direction
Channel Name: ATDC_Z

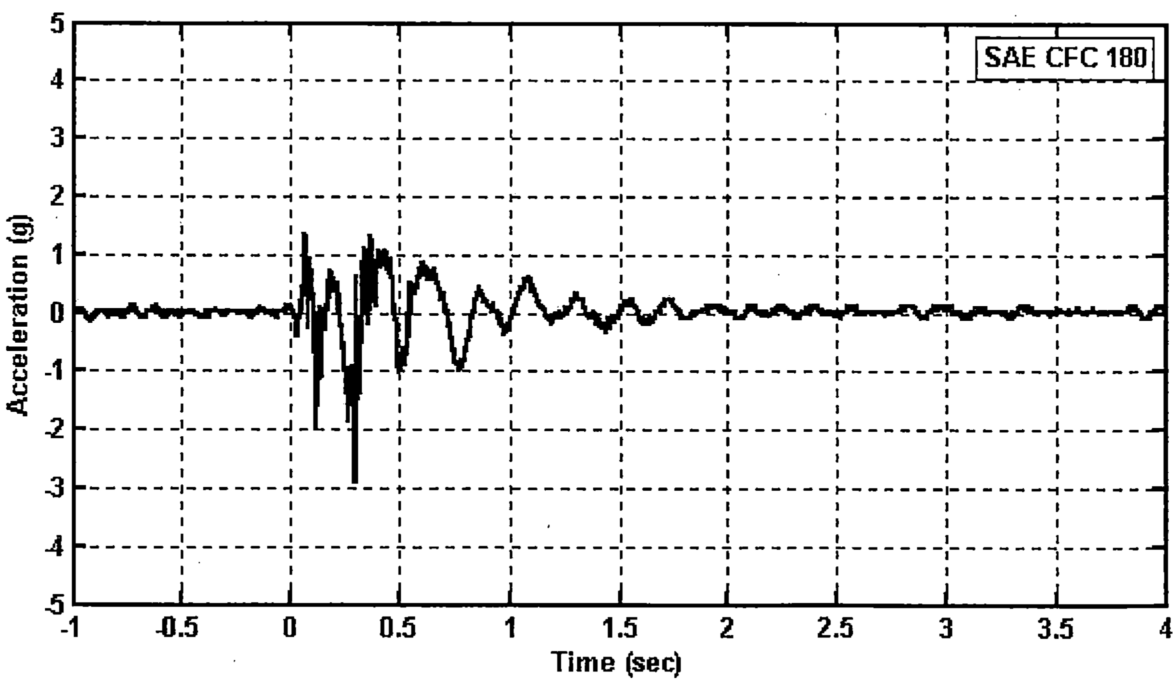

Figure G6. Anthropomorphic test device, chest acceleration, z direction
Channel Name: ATDC_Z

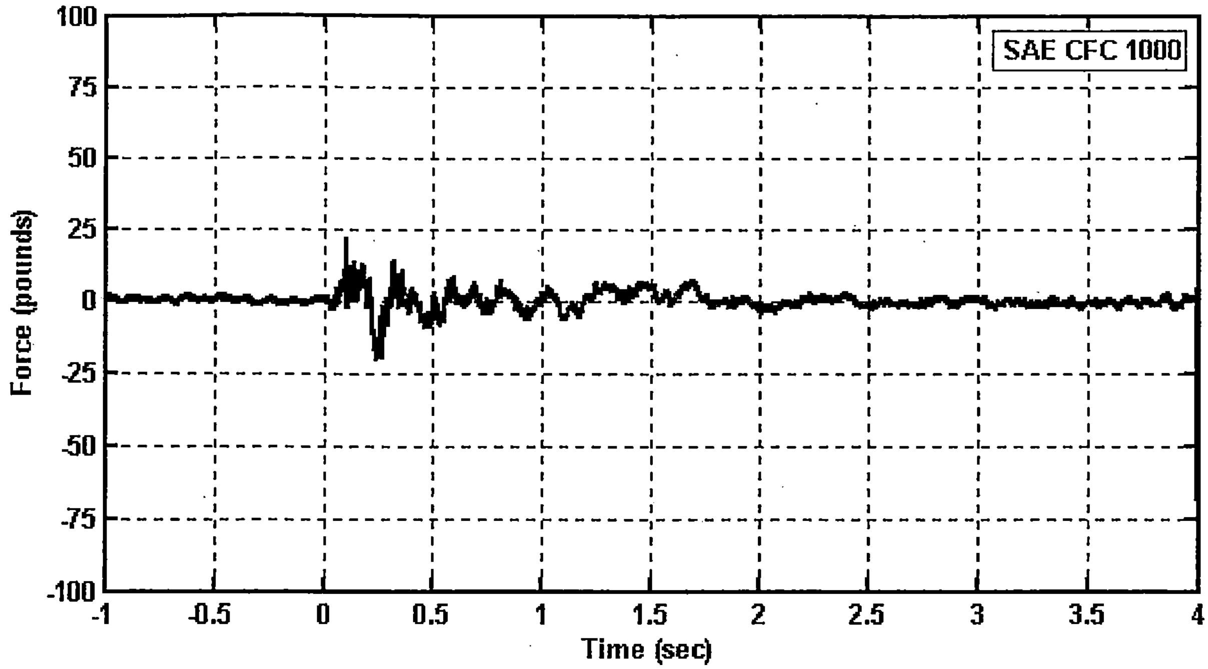

Figure G7. Anthropomorphic test device, left femur load
Channel Name: ATDF_L

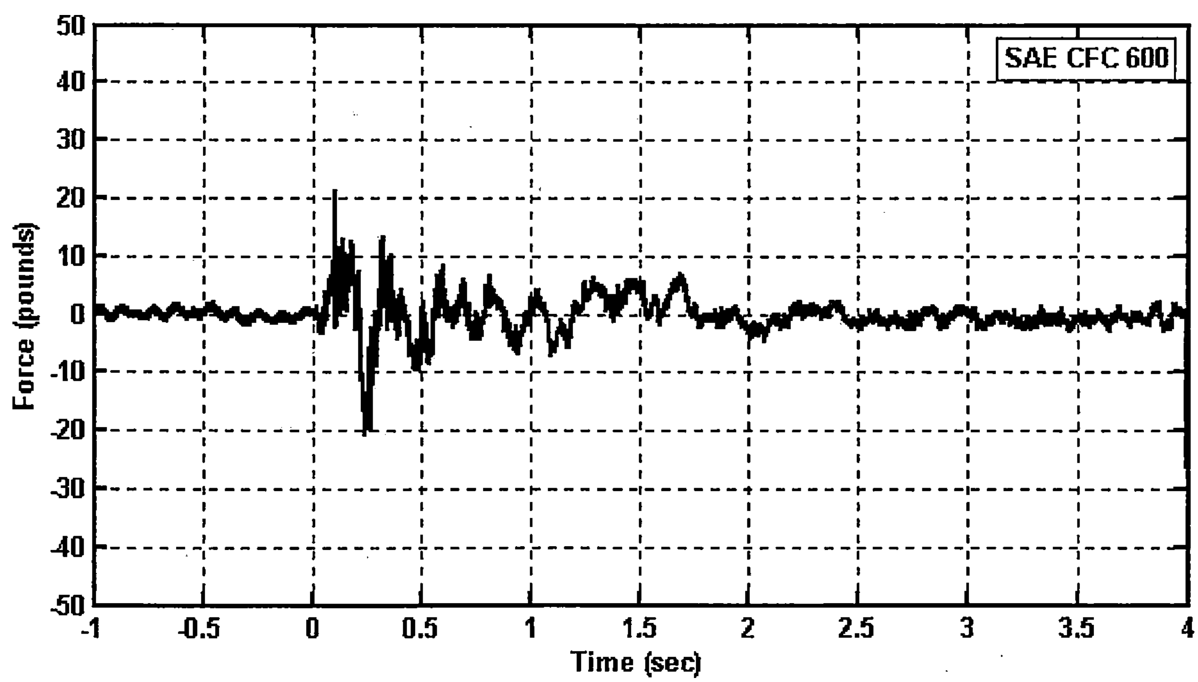

Figure G8. Anthropomorphic test device, left femur load
Channel Name: ATDF_L

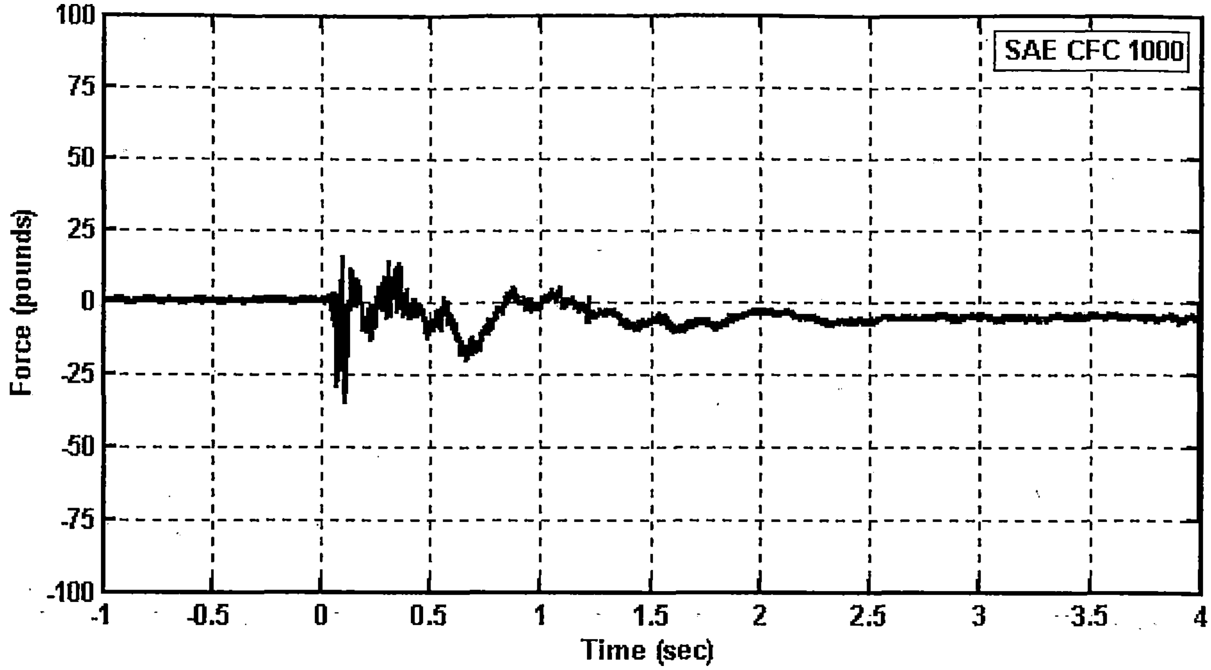

Figure G9. Anthropomorphic test device, right femur load
Channel Name: ATDF_R

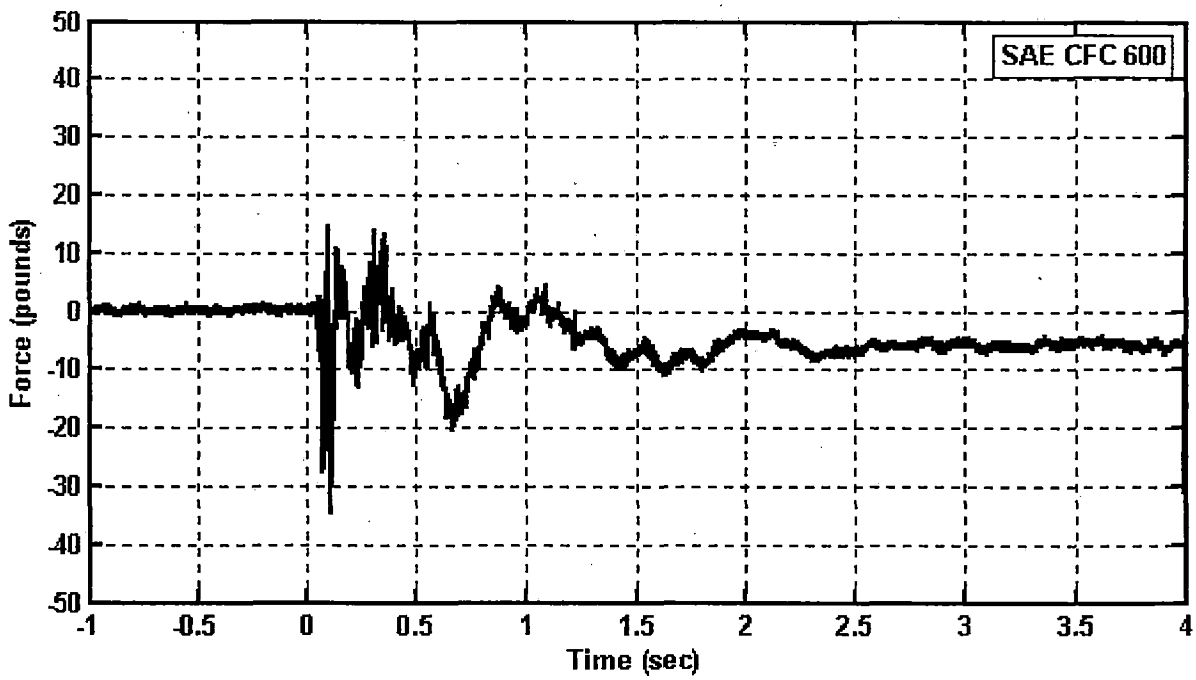

Figure G10. Anthropomorphic test device, right femur load
Channel Name: ATDF_R

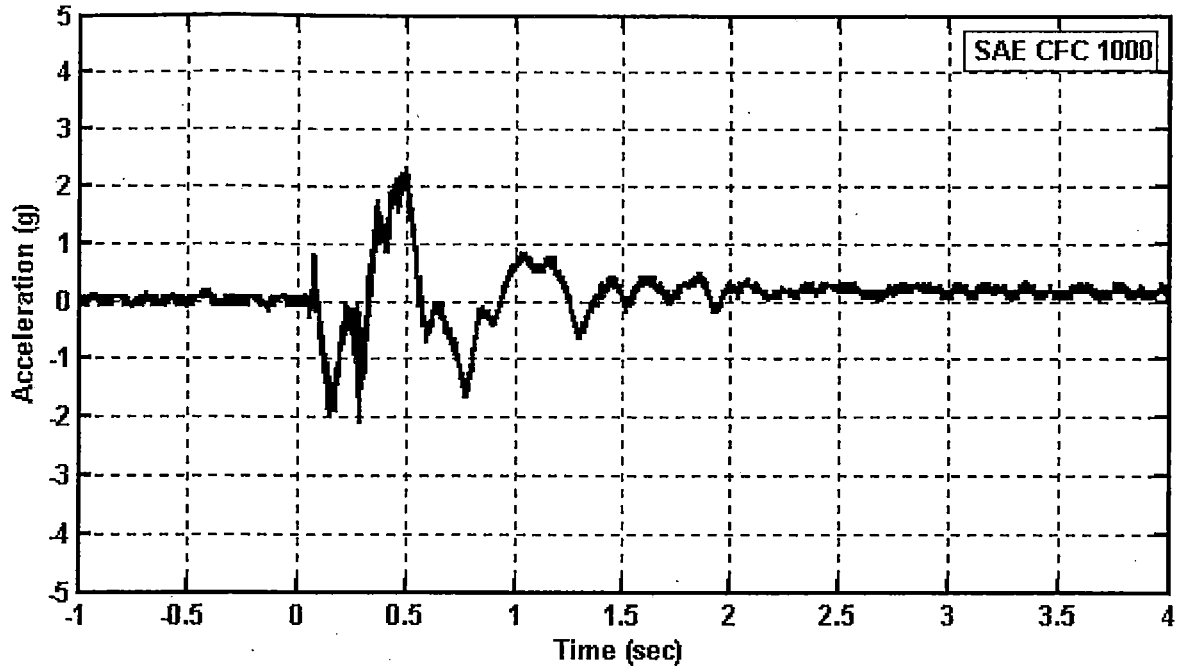

Figure G11. Anthropomorphic test device, head acceleration, x direction
Channel Name: ATDH_X

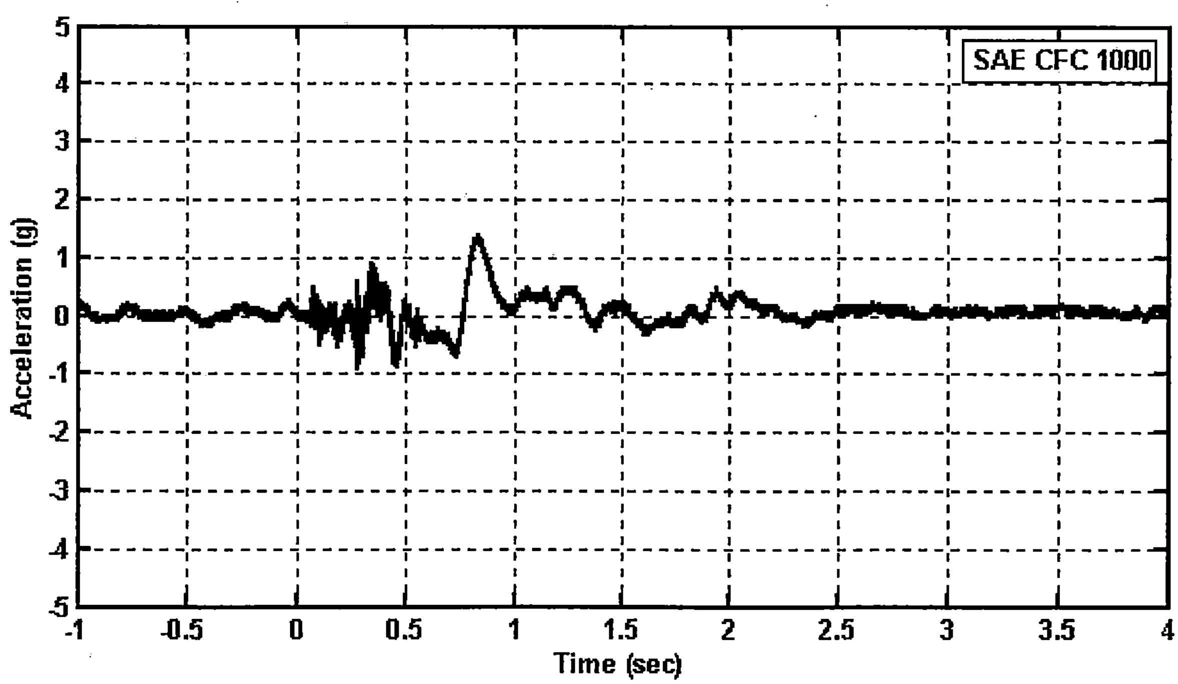

Figure G12. Anthropomorphic test device, head acceleration, y direction
Channel Name: ATDH_Y

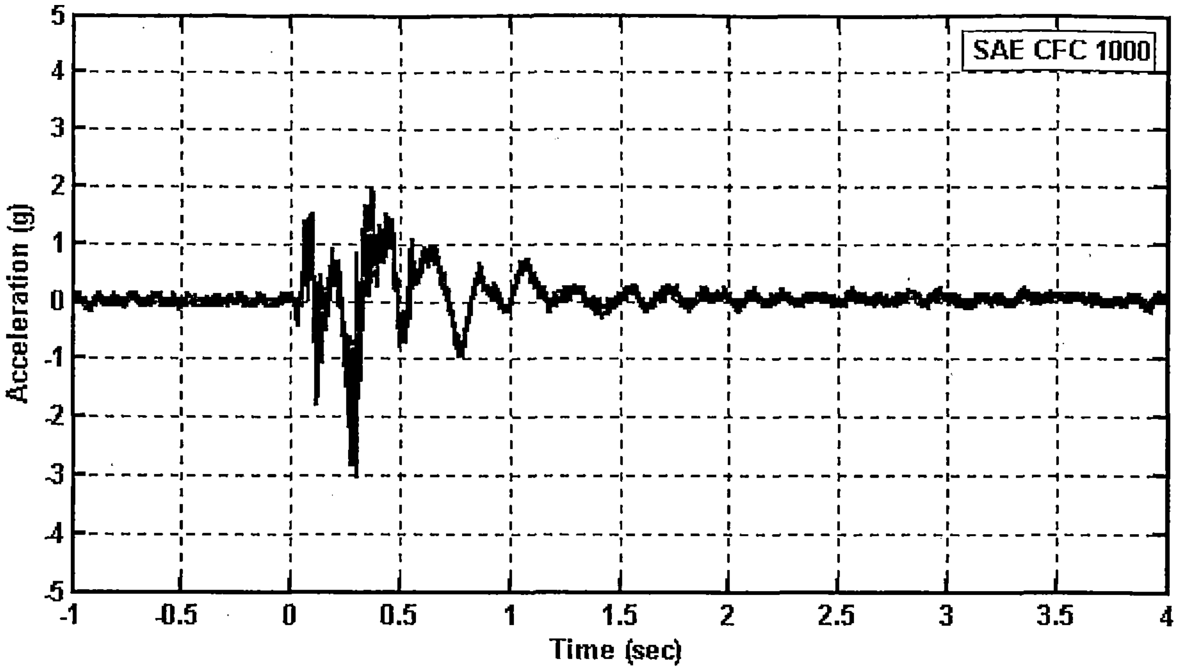

Figure G13. Anthropomorphic test device, head acceleration, z direction
Channel Name: ATDH_Z