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Federal Railroad Administration

Locomotive Crashworthiness Impact Test No.3: Test Procedures, Instrumentation and Data

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Draft Report

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13. ABSTRACT

A full-scale impact test of a locomotive crashing into a highway trucking rig (tractor and trailer) loaded with two steel coils was conducted on a grade crossing at the FRA's Transportation Technology Center (TTC) on December 18, 2002. This was the third of a series of locomotive crashworthiness tests conducted under Task Order 137. The rearmost steel coil was aligned with the right side collision post of the locomotive. An anthropomorphic test device (ATD, or test dummy) was placed seated on the floor in the nose of the locomotive, facing rearward with it's back against the interior door. The impact speed was approximately 58 miles per hour.

On impact, the trucking rig was thrown clear of the track and destroyed. The chains holding the coils on the trailer broke free and the rear coil struck the collision post, shearing the post just above the weld between it and the underframe. The coil continued into the cab destroying the windshield, control console, and cab floor. The ATD sustained severe damage including damage to the head, neck, left shoulder attachment, and skin.

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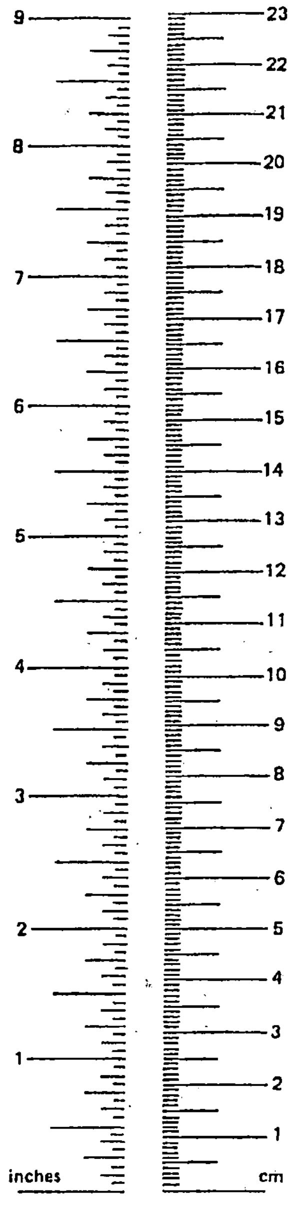
298-102

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

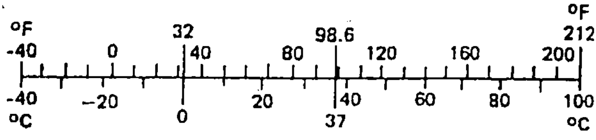
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	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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Sharma and Associates designed the cab and modifications to the locomotive, which were carried out by National Rail Equipment. Cinemac Productions and GMH Engineering contracted with TTCI to provide filming and instrumentation services, respectively.

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Executive Summary

A full-scale impact test of a locomotive test train crashing into a highway trucking rig (tractor and trailer) loaded with two steel coils was conducted December 18, 2002, on a grade crossing at the Federal Railroad Administration's (FRA) Transportation Technology Center (TTC) Pueblo, Colorado . The test involved a SD-45 locomotive, modified to meet AAR Specification S-580, and two trailing loaded hopper cars traveling 58 mph.

On impact, the trucking rig was thrown clear of the track and destroyed. The chains holding the coils on the trailer broke free, and the rear coil struck the collision post, shearing the post just above the weld between it and the underframe. The coil continued into the cab destroying the windshield, control console, and cab floor. The anthropomorphic test device (ATD) sustained severe damage including damage to the head, neck, left shoulder attachment, and skin.

The test was carried out to evaluate the structural crashworthiness of the locomotive in an impact with a steel coil. 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, on the trailing hopper cars, and at the center of gravity of each of the steel coils. 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 ATD was placed and positoned on the floor in the nose of the locomotive, facing rearward with its back against the interior door.

Transportation Technology Center, Inc. (TTCI) 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 -508 g. when filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to -158 g.
- The maximum lateral acceleration recorded on the floor of the locomotive was -257 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to -62 g.

- The maximum vertical acceleration recorded on the floor of the locomotive was 505 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to 206 g.
- The maximum longitudinal acceleration recorded on the event recorder was -507 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to -306 g.
- The maximum lateral acceleration recorded on the event recorder was 262 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to 78 g.
- The maximum vertical acceleration recorded on the event recorder was 434 g. When filtered to a corner frequency (Fc) of 100 Hz, the peak acceleration was reduced to 51 g.
- A peak load of 452 kips was recorded in the instrumented coupler between the locomotive and the first hopper car.
- Strain amplitudes on the collision post of the locomotive were above the saturation level (about 5000 micro-strain) during the impact.
- A peak strain of –891 micro-strain was measured on the underframe of the locomotive during the impact.
- Strain amplitudes on the windshield center post of the locomotive were above the saturation level (about 5000 micro-strain) during the impact.
- The measurements on the ATD were difficult to analyze due to instrumentation cable damage early in the impact. The intrusion of the coil into the space occupied by the ATD and the resulting physical damage to the ATD demonstrate that the impact would have resulted in a fatality for a crew-member in that location and position.

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1.0 INTRODUCTION AND OBJECTIVES

A full-scale impact test of a locomotive test train crashing into a highway trucking rig (tractor and trailer) loaded with two steel coils was conducted December 18, 2002, on a grade crossing at the Federal Railroad Administration's (FRA) Transportation Technology Center (TTC) Pueblo, Colorado. The test involved a SD-45 locomotive, modified to meet AAR Specification S-580, and two trailing loaded hopper cars traveling 58 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 truck could be validated at a later date. The acceleration levels in the crew compartment of the locomotive were measured as well as the head, neck, and chest accelerations on an anthropomorphic test device (ATD) placed in the nose section of the locomotive.

Acceleration levels were measured with an event recorder mounted on the rear of a collision post on the locomotive.

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 1 shows. The locomotive nose and cab were designed to conform to AAR Specification S-580. This locomotive had been used in two previous full-scale impact tests at TTC:

1. An impact into a stationary train of 35 loaded hopper cars at 32 mph
2. An impact into a log truck on a grade crossing at 50.4 mph

The following repairs were completed on 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

After the second impact test, the following repairs were completed on the locomotive:

- The bracing between the pilot plate and the underframe on the right side was repaired
- The sheet steel on the front of the short hood was replaced.
- The four bolster springs on the lead truck were replaced

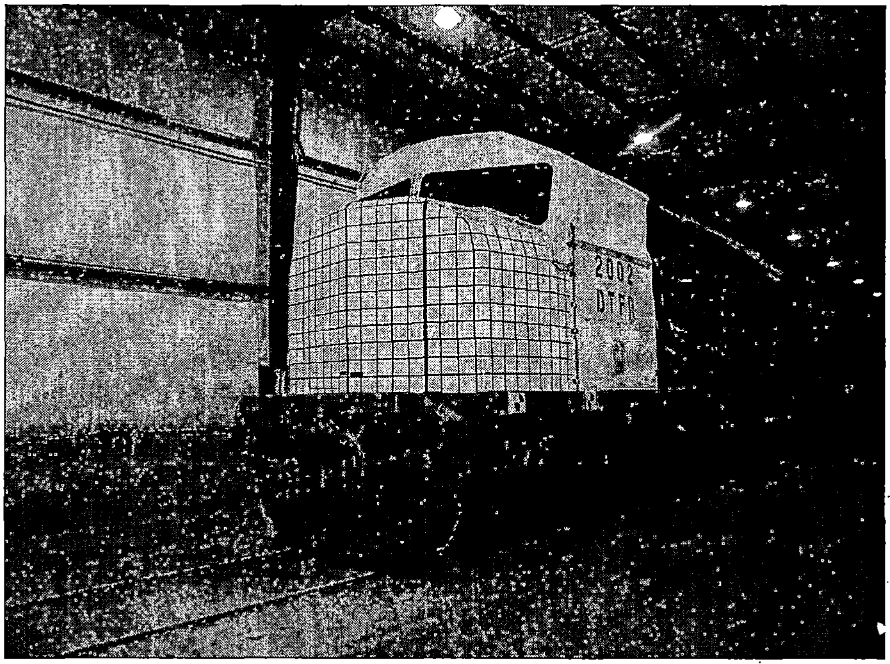

Figure 1. Locomotive Nose before Impact

The first two tests in this series (References 1 and 2) utilized an ATD in the engineer's seat of the locomotive. It was recognized at the time of these tests that in the event of an impending accident the locomotive engineer may choose to take up a different position in the cab that would offer more protection than is available in the engineer's seat. At the suggestion of the Brotherhood of Locomotive Engineers, the ATD was placed in a seating position on the floor facing rearward in the nose of the locomotive with its back against the interior door. There was no room for its legs in the nose because its pelvis is fixed in a normal seated position. Figure 2 shows the ATD in place in the cab.

An event recorder was mounted behind one of the collision posts of the locomotive facing rearward as shown in Figure 3. A tri-axial accelerometer was mounted above the event recorder so that it measured the accelerations going into the recorder.

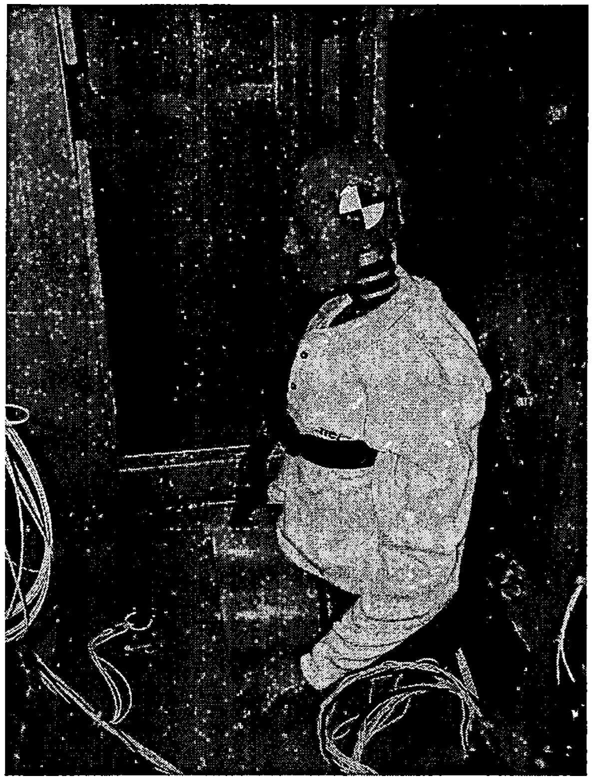

Figure 2. ATD in the Nose of the Locomotive

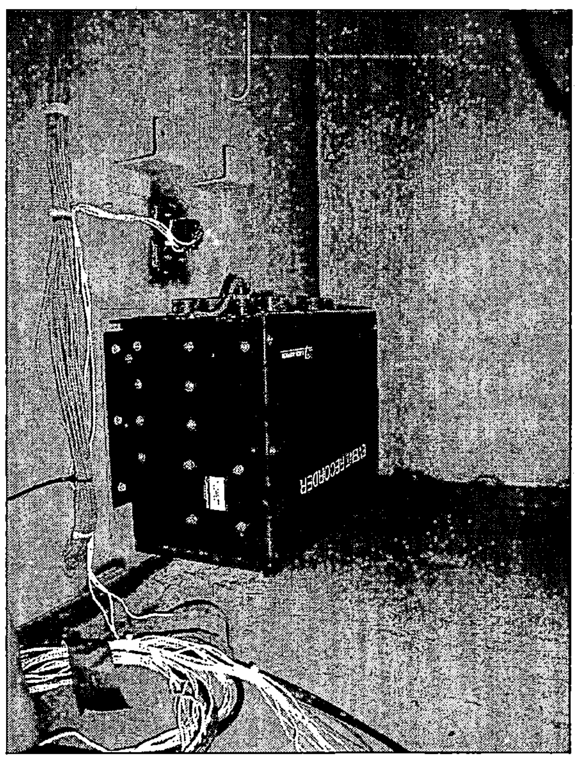

Figure 3. Event Recorder and Tri-Axial Accelerometer

Tape Switches™ were mounted to the front of the locomotive and to the trailer in order to trigger all the instrumentation on impact, as Figure 4 shows.

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

String potentiometers (aka as string pots) were mounted on brackets at the rear of the locomotive and on the leading end of the first moving hopper car in order to measure the coupler displacements in each direction (see Figure 5).

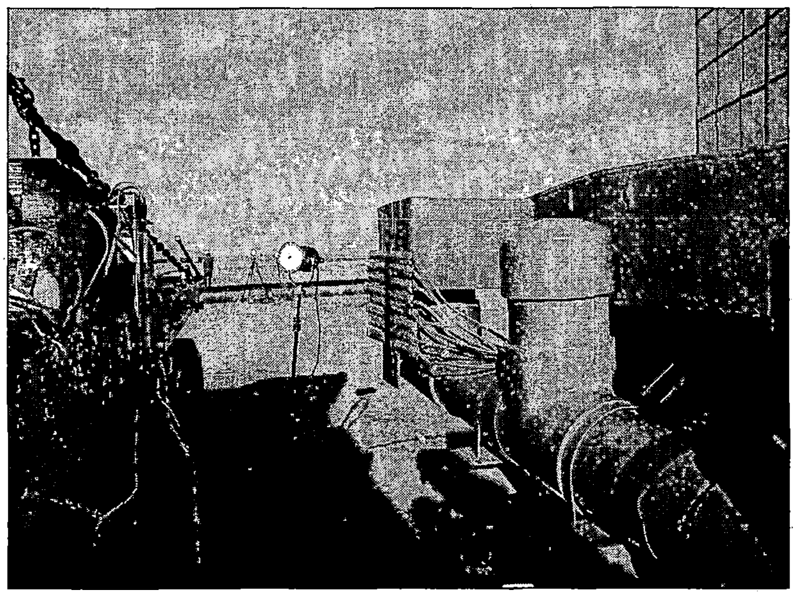

Figure 4. Tape Switches™ on Locomotive and Trailer

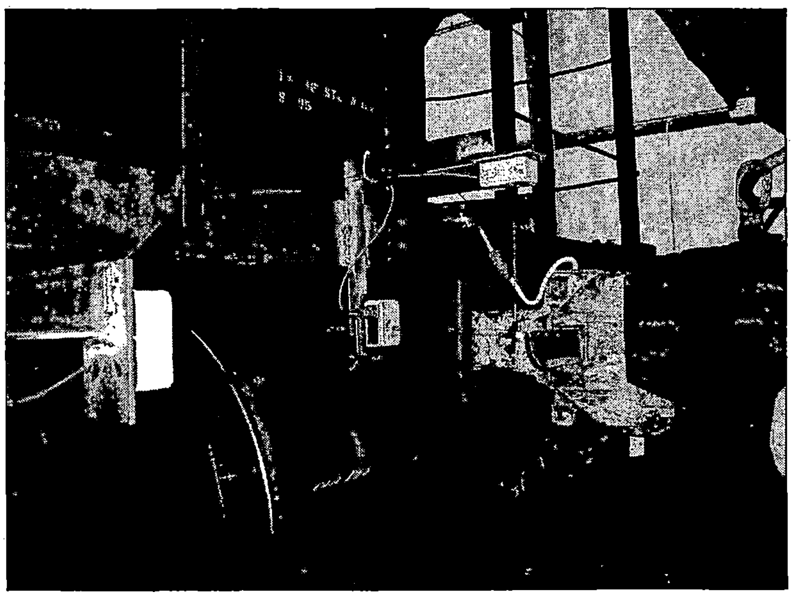

Figure 5. Stringpots and Instrumented Coupler on Hopper Car

Tri-axial accelerometers were mounted in the center of the center sill of the two hopper cars behind the locomotive, as Figure 6 shows.

Figure 6. Accelerometers on the Second Trailing Hopper Car

Each steel coil was attached to the deck of the trailer with two 3/8-inch chains. The center of the rear coil was aligned with the right collision post of the locomotive. The rear coil weighed 35,000 pounds, and the front coil weighed 20,500 pounds. Figure 7 shows the trucking rig and mounted coils positioned on the crossing. Figure 8 shows the instrumentation inside of the rear coil. Both coils were instrumented with longitudinal, lateral, and vertical accelerometers at their center of gravity (CG) locations.

The rear coil was elevated with a pallet about 6 inches off the deck of the trailer. This allowed the coil to contact the short hood/collision post without first contacting the anti-climber.

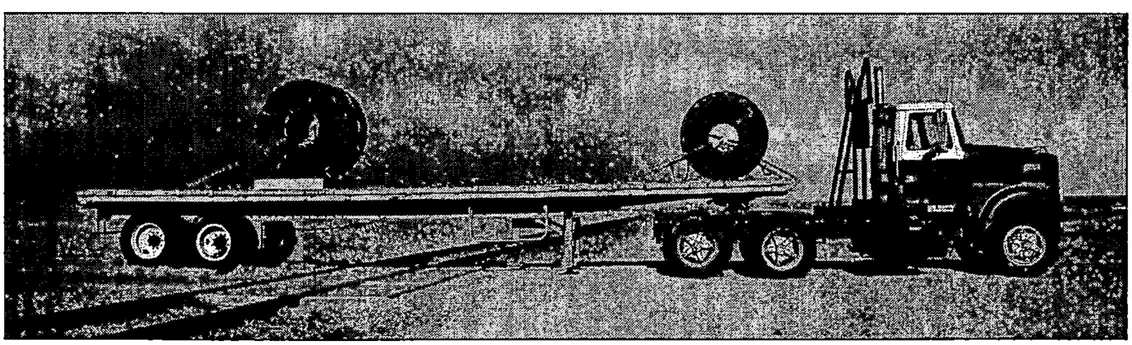

Figure 7. Target Vehicle viewed from the South —Locomotive Approached from the North

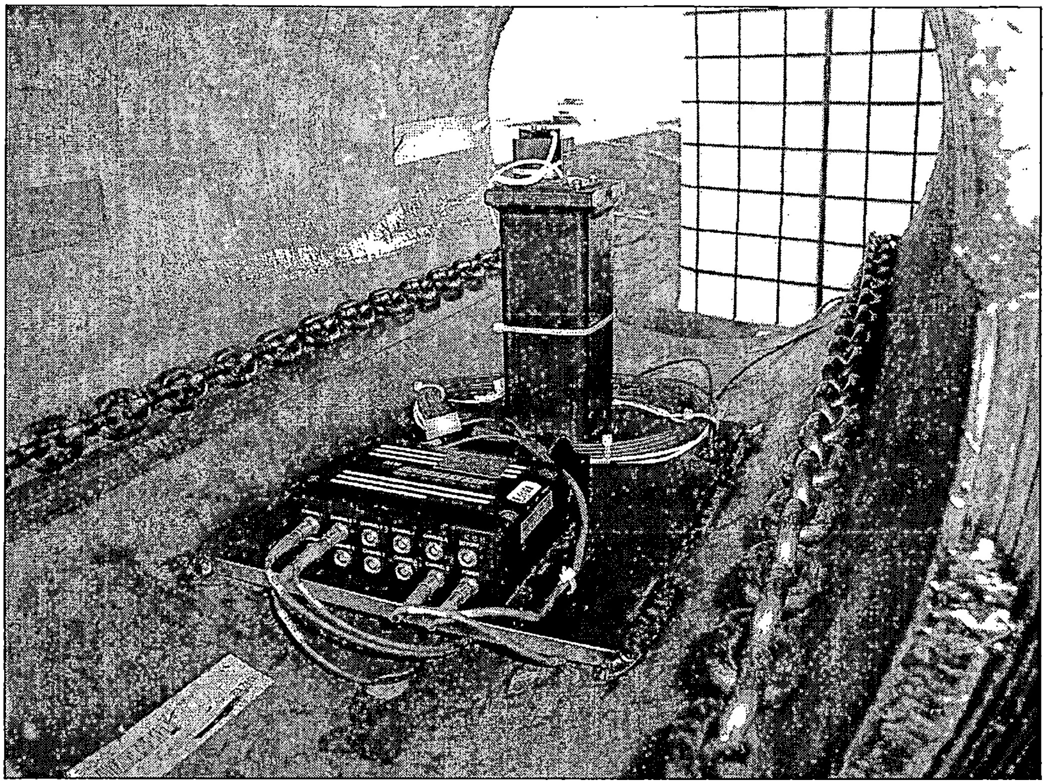

Figure 8. Instrumentation Package inside the Steel Coil

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 for the test, included as Appendix A of this report.

The impact test was performed by pushing the moving consist (locomotive and two 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 trucking rig, which was positioned at right angles to the track on a grade crossing. The rig was positioned on the crossing so that the center of the rear steel coil was aligned with the right collision post of the locomotive.

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 60 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 = 51 ft 11 in.
Length of second hopper car over strikers = 46 ft

4.1.2 Weights

Moving Consist

Weight of locomotive = 380,796 lb
Weight of first loaded hopper car = 264,684 lb
Weight of second loaded hopper car = 265,801 lb

Total weight = 911,281 lb
(Note: The accuracy of the weighbridge is within 50 lb per measurement or 100 lb per vehicle, 300lb for the total weight)

4.1.3 Weather Conditions

Weather conditions just before the test:

- Temperature = 40°F
- Wind speed = 9.8 mph from the east

4.1.4 Photographs Taken Before Test

Figures 9 and 10 show the vehicles before impact.

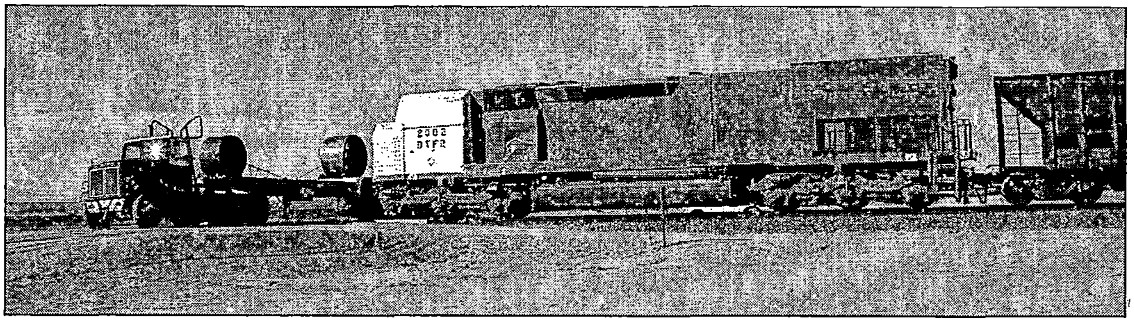

Figure 9. Locomotive and Trucking Rig at the Impact Point

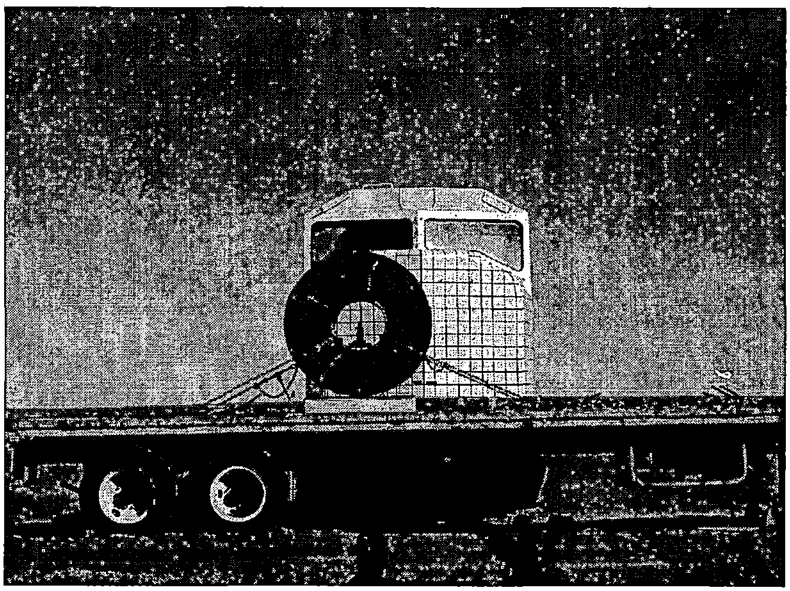

Figure 10. View of the Locomotive and Coil Showing the Alignment

4.2 Items Measured During the Test

4.2.1 Speed

The test train, made up of the test locomotive and two loaded hopper cars, was accelerated by a pusher locomotive and released at a point 2,700 feet from the trucking rig on the grade crossing. The laser-based speed trap was prematurely triggered by a piece of debris before the trigger arm passed the lasers preventing the unit from recording train speed. A handheld radar gun showed a speed of 58.0 mph. A radar speed sensor was installed on the locomotive. An average of its speed data, 100 feet before impact, was 58.1 mph.

4.2.2 Strains

Data Bricks measuring strain were set for a sampling rate of 12,800 Hz, a pre-trigger of 1 s and a 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 was 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 11 and 12 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.

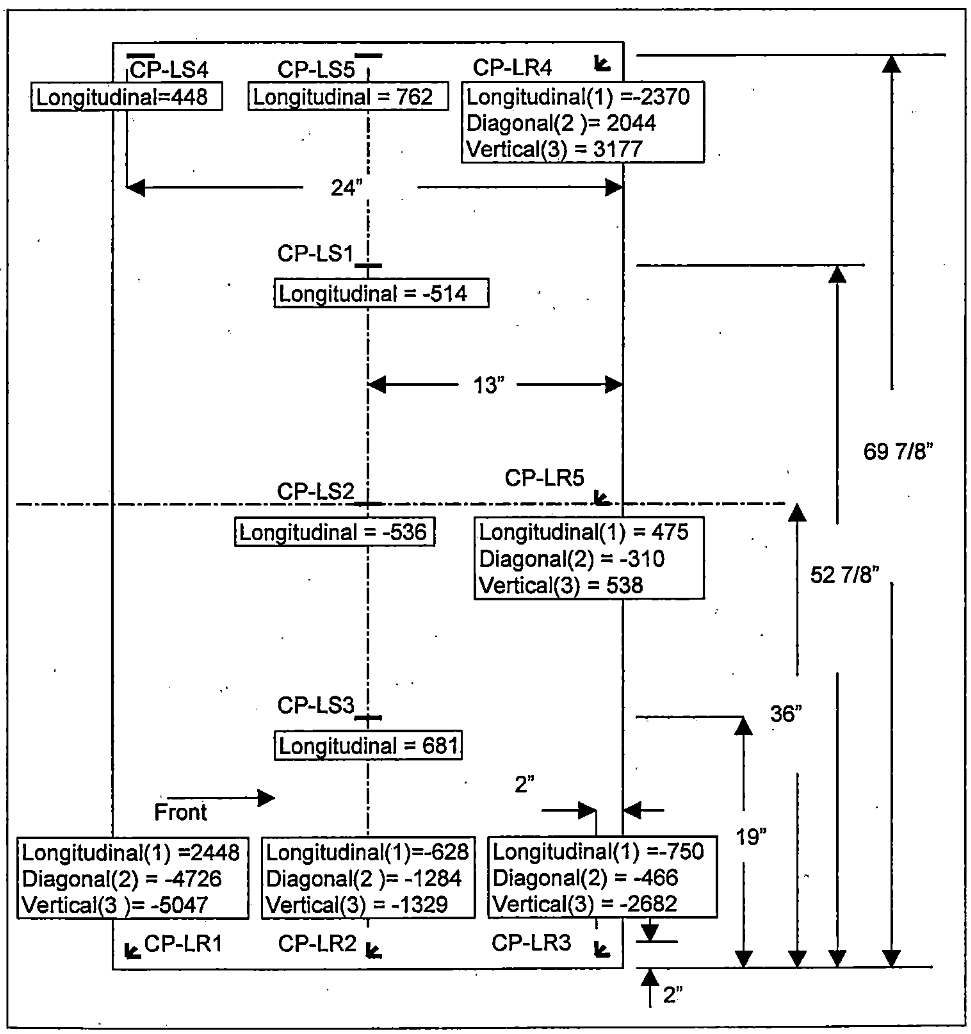

Figure 11. Diagram showing Micro-strains on the Left Collision Post

The left collision post, which was not hit directly by the steel coil, had very high strains, especially on the bottom rear rosette. The strain on the vertical leg of the bottom rear rosette saturated at -5047 micro-strain about 100 milliseconds after impact. The strain on the diagonal element of the bottom rear rosette was saturated at –4726 micro-strain from 100 milliseconds after impact to 200 milliseconds after impact. There were cable failures on channels CPLR3_2 and CPLR5_2 about 190 milliseconds after impact.

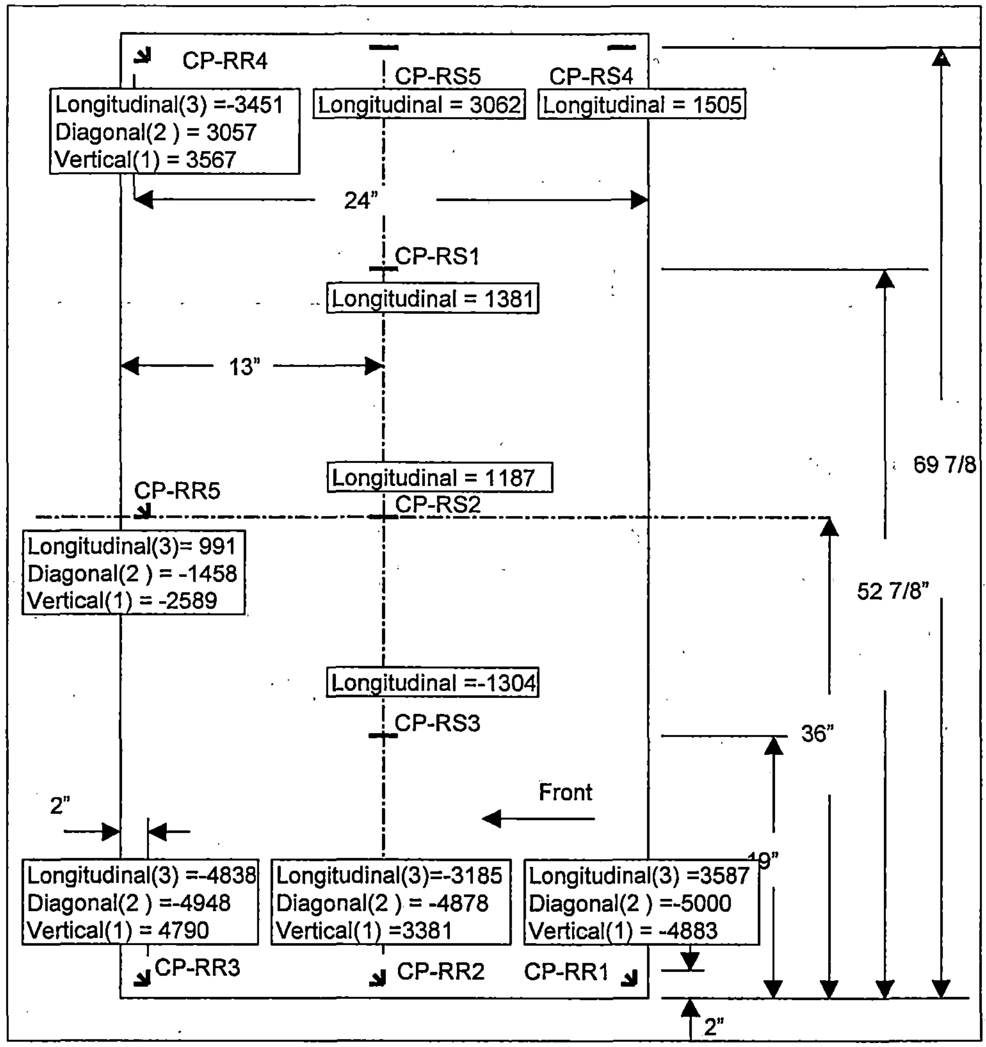

Figure 12. Diagram showing Micro-strains on the Right Collision Post

The right collision post also showed very high strains, with the post itself shearing along the bottom edge just above the weld. The elements of the rosettes on the bottom edge of the collision post all had data peaks about 73 milliseconds after impact, and many of the channels had considerable offsets after that time. In some cases, the spikes were only about 1 millisecond in duration. It appears that the frequency of phenomenon responsible for this data was at or above the upper limit of the frequency response of the measurement system (CFC 1000 Hz). Nearly all of the cables on the right collision post failed at some point between 100 and 200 milliseconds after impact. The following channels appeared to saturate:

- CPRR1_1 at –4883 micro-strain
- CPRR1_2 at –5000 micro-strain
- CPRR2_2 at –4878 micro-strain
- CPRR3_1 at +4790 micro-strain
- CPRR3_2 at –4948 micro-strain
- CPRR3_3 at –4838 micro-strain

Figure 13 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.

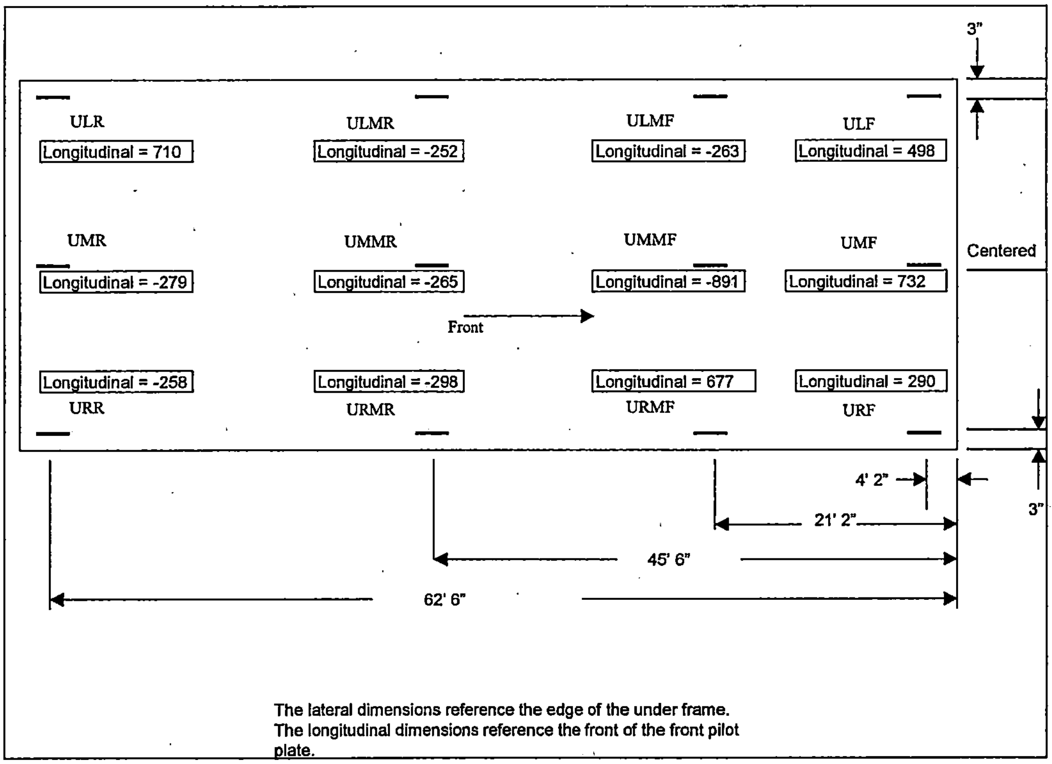

Figure 13. Underframe of the Locomotive with the Highest Amplitude Strain for Each Gage

The largest magnitude strain on the underframe was -891 micro-strain, which was on the center gage just in front of the fuel tank. (channel UMMF).

Figure 14 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.

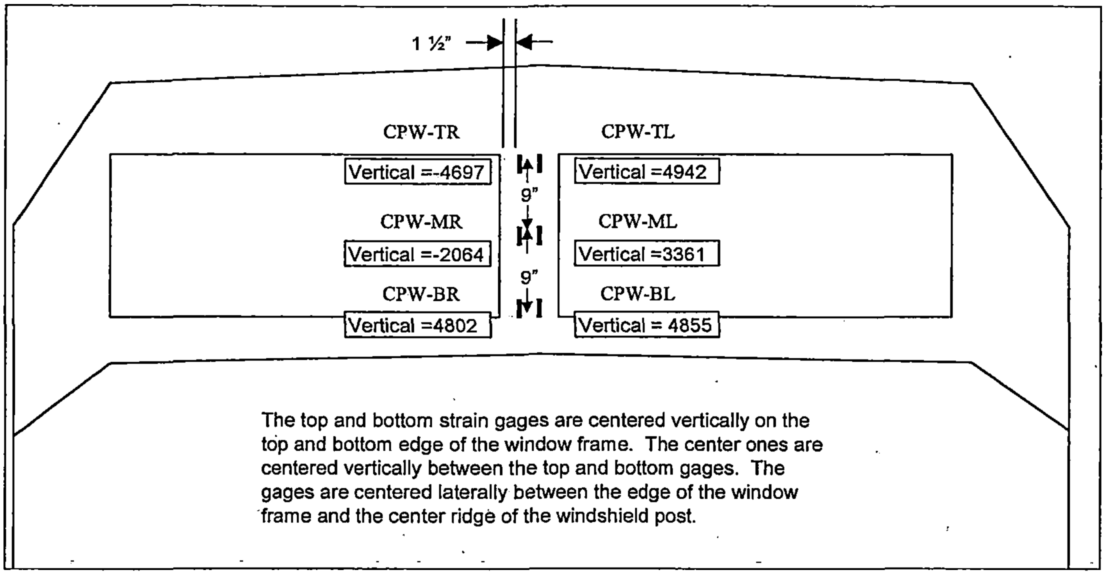

Figure 14. Windshield Center Post with Location of Strain Gages and Highest Amplitude Strain

Three of the windshield strain gages saturated were:

- CPWBL saturated at 4855 micro-strain
- CPWTL saturated at 4942 micro-strain at one point in the data and –4753 micro-strain at another point
- CPWTR saturated at 4697 micro-strain

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

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 Appendix C of SAE J211. Digital filter frequencies were CFC=1000 Hz (Fc=1,667Hz), Fc=100 Hz, and Fc=25 Hz. The sign convention for the accelerometers is:

- Longitudinal, positive is forward acceleration
- Lateral, positive is rightward acceleration
- Vertical, positive is downward acceleration

The highest amplitude acceleration at each location is shown in Table 1. Time plots of each channel are shown in:

- Appendix C for 1000 Hz data
- Appendix D for 100 Hz data
- Appendix E 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

Direction	Loco. Floor Near ATD (g)	Event Recorder (g)	Lead Bullet Hopper (g)	Trail Bullet Hopper (g)	Rear Steel Coil (g)	Front Steel Coil (g)
X CFC=1000 Hz	-508	-507	128	-55	452	249
X F_c =100	-158	-306	17	3	197	75
X F_c =25	-62	-95	7	1	58	30
Y CFC=1000 Hz	-257	-262	51	35	253	-270
Y F_c =100	-62	78	6	4	74	-160
Y F_c =25	-25	28	2	1	17	-14
Z CFC=1000Hz	505	434	36	22	446	174
Z F_c =100	206	52	2	-2	44	-19
Z F_c =25	50.3	-17	1	0	7	-9

It is apparent that the magnitude of the accelerations is very dependent on the filter frequency. Please consider that the event showing the largest peak at one of the higher frequencies does not necessarily correspond to the event showing the higher peak at one of the lower frequencies. 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)

Table 2 shows the largest amplitude displacements for each channel.

Table 2. Largest Amplitude Coupler Displacements (ins)

Direction	Locomotive (in)	Lead Bullet Hopper (in)
Longitudinal	-1.8	-3.67
Lateral	1.4	-1.48
Vertical	-1.3	0.9

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

Time plots of each displacement channel are presented in Appendix F.

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 452 kips in compression. The complete time history of the coupler force is shown in Appendix F.

4.2.6 Anthropomorphic Test Device

An ATD was placed in a seated position on the floor in the nose of the locomotive, facing rearward with its back against the interior door. Tri-axial accelerometers were placed in the head and chest of the ATD, a six-axis load cell measured neck forces, and vertical and lateral accelerometers were placed in the pelvis. All the data was filtered at 1,734 Hz and sampled at 12,800 Hz. The data was digitally filtered with a 4-pole Butterworth filter, as specified in SAE J211.

The time histories of the ATD measurements from 0 to 130 milliseconds after impact are presented in Appendix G as follows.

- 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 Reference 2. The neck injury criteria described in Reference 1 was computed using the neck loads and moments data. The ATD instrumentation cables were damaged some time between 115 and 130 milliseconds after impact. The nature of the transducers used in the ATD make it difficult to precisely determine the time when the cables broke. The data provided in Table 3 is up to 115 milliseconds after impact.

Table 3. Comparison of ATD Data to NHTSA Proposed Criteria for the First 115 msec after Impact

Criteria	Criteria for Hybrid III Dummy 50% Male	Test Results (up to 115 msec)
Head Criteria (HIC 15msec)	700	389
Neck Criteria: Nij	1.0	0.42
In Position Critical Intercept Values		
Tension (N)	6806	
Compression (N)	6160	
Flexion (Nm)	310	
Extension (Nm)	135	
Peak Tension (N)	4170	1848
Peak Compression (N)	4000	404
Thoracic Criteria		
Chest Acceleration (g)	60	**68**
Chest Deflection	63	Not measured
Lower Ext. Criteria		
Femur Load (kN)	10.0	Not measured

The chest acceleration exceeded the criteria, but all other values were valid for the first 115 milliseconds after impact. The highest amplitude pelvis acceleration was –46 g in the longitudinal direction and –26 g in the vertical direction. There are no defined criteria for pelvis measurements, but they are included for comparison of test and model predictions. There was significant damage to the ATD, described in subsection 4.6, that apparently occurred beyond 115 milliseconds after impact. The extent of the physical damage to the ATD demonstrates that the data up to 115 milliseconds after impact significantly understates the severity of the collision.

4.2.7 Anomalies in Measured Data

The amount of damage to the locomotive during this test made data acquisition very difficult. The following anomalies occurred with the instrumentation and data acquisition during the test:

- Most of the strain-gage channels were affected by saturation and cable failures. Gages with saturation are noted in the results section. Statistics for channels that suffered cable failure are only computed until just before the cable failure.

- The floor accelerometers behind the engineer's seat saturated on impact. The cables for the floor accelerometers near the ATD failed at about 200 milliseconds. The cables for the accelerometers near the event recorder failed at about 180 milliseconds.
- The power cable for the Data Brick in the front steel coil failed at about 300 milliseconds. The instrumentation cables in the rear steel coil failed at about 400 milliseconds. Both of these failures are attributed to the action of the tie down chains breaking.
- The y-axis string pot on the locomotive coupler failed about 1.2 seconds after impact, probably due to a piece of debris cutting the string.
- The cables for all of the ATD channels were severed during the impact. The data looks good for the first 115 to 130 milliseconds after impact. The data after that point is unreliable.
- The speed trap was prematurely triggered, and its speed data was unreliable. Speed from handheld and onboard radar sensors was used instead.

The instrumentation report supplied by GMH engineering is provided in Appendix H. It describes the anomalies above as well as the test setup.

4.2.8 Photography

The impact between the locomotive led consist and the trucking rig on the grade crossing was 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. The high-speed camera for the west side overall view failed to run properly.

4.3 Description of Impact Damage

The locomotive struck the rear portion of the trucking rig at 58 mph. The semi-truck and trailer were destroyed. On impact, the trailer remained attached to the tractor and was thrown to the left side of the track, with the trailer bogie breaking free and remaining on the right side of the track. The tractor was spun back into the train, and was struck by the leading hopper car as the train proceeded past it. In total, the rig spun 270 degrees and came to rest facing the direction of train travel about 85 feet down the track and 31 feet to the left of the track centerline. The trailer bogie was thrown about 70 feet down the track and came to rest about 27 feet to the right of track centerline. The chains attaching the front steel coil to the trailer broke on impact, and the coil, which weighed about 20,500 pounds, fell onto the crossing with very little longitudinal or lateral movement, about 9 ½ feet from the center of the track. Figure 15 shows the rig after the impact.

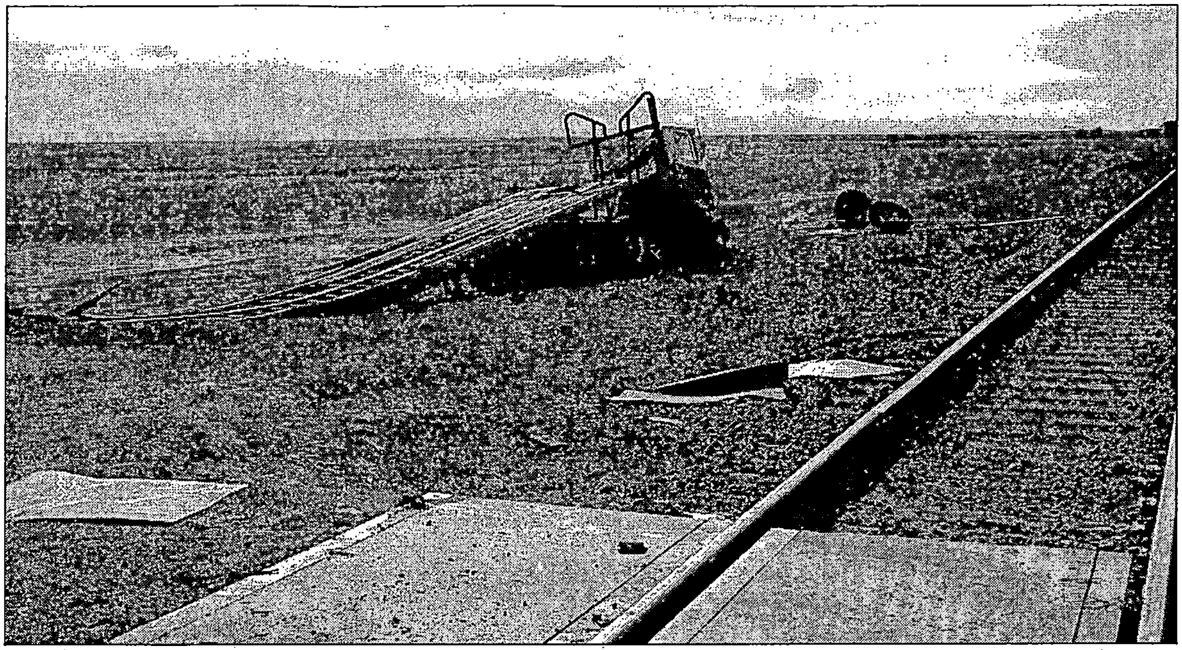

Figure 15. Trucking Rig as seen from the Impact Point

The rear steel coil, which weighed 35,000 pounds, was aligned with the right collision post of the locomotive. The coil was elevated about 6 inches above the deck of the trailer so that it would contact the short hood before contacting any other part of the locomotive. On impact, the chains holding the coil on the trailer broke free and the coil struck the collision post, shearing the post just above the weld between it and the underframe. The coil continued into the cab destroying the windshield, control console, and cab floor. The coil came to rest on the underframe of the locomotive, about ½ way into the cab longitudinally, and rode there until the locomotive hit the ballast pile at the end of the diversion track, when it rolled out to the right side of the track. Figure 16 shows the locomotive cab, and Figure 17 shows where the collision post had been welded to the underframe.

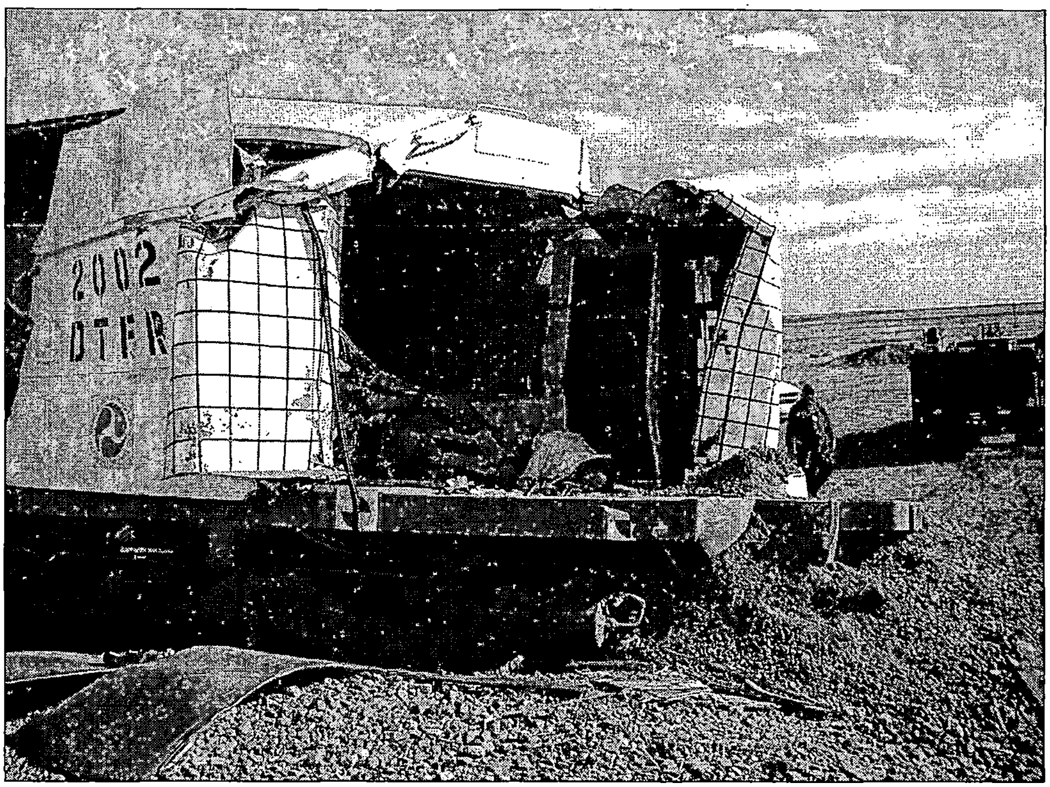

Figure 16. Locomotive after Impact

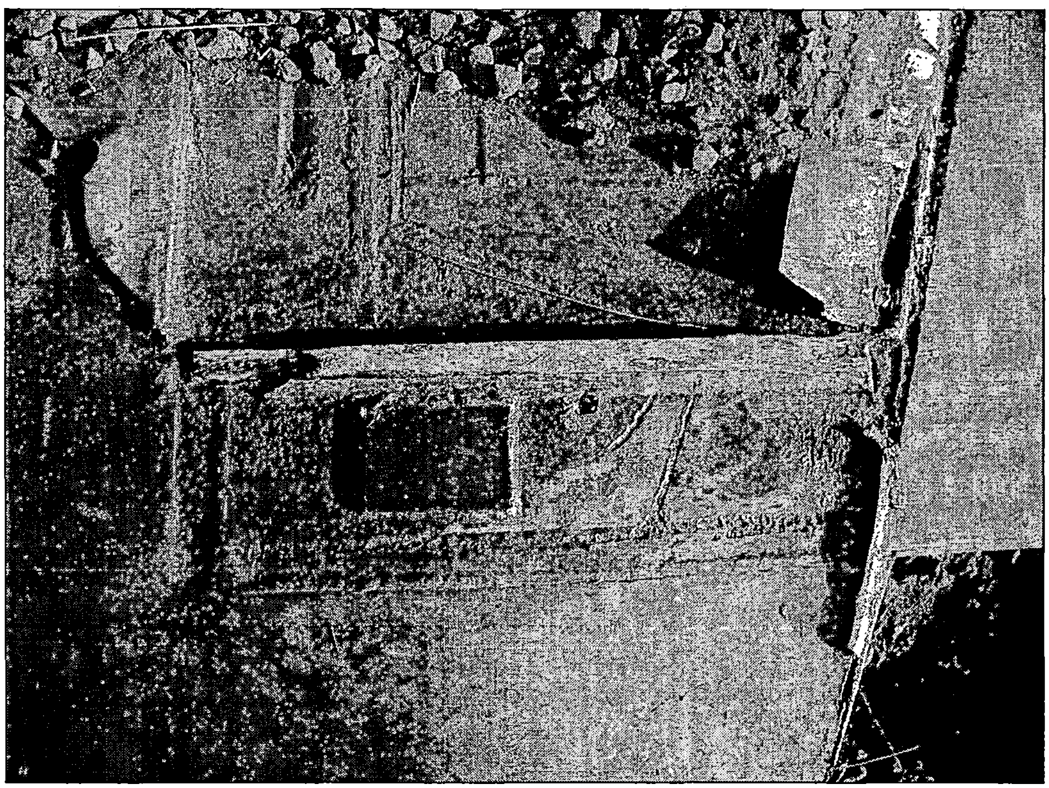

Figure 17. Remains of the Right Collision Post Weld showing Shear Failure of the Post

The event recorder (Figure 18) was mounted just behind the right collision post. It sustained considerable physical damage. After the test, the recorder was removed and sent to Bach-Simpson for analyzing and data recovery. They reported that the hardened memory module inside the unit sustained only minor damage and that the data was intact.

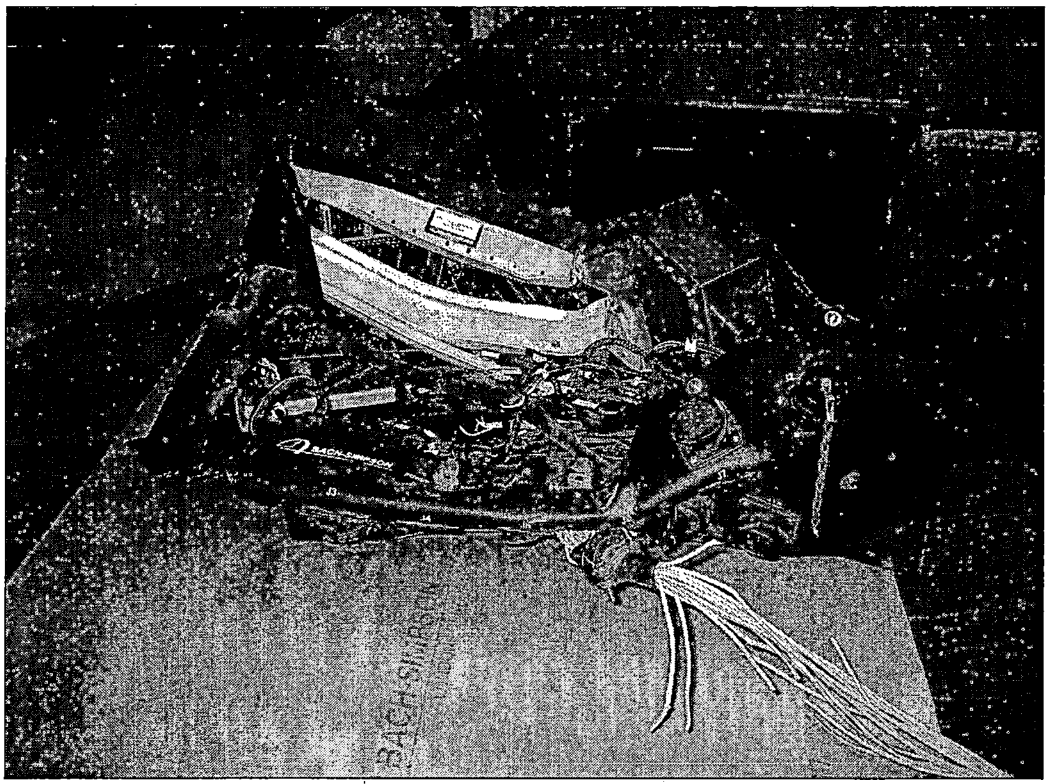

Figure 18. The Event Recorder Inside the Locomotive After the Test

The ATD suffered extensive damage during the test. The attachment for the left shoulder was broken. The weights inside the head of the ATD, used to adjust the mass-moment of inertia, broke loose from their mounts. The neck sensor was slightly damaged. Two of the ribs de-laminated. The sternum and shoulder blades were damaged. The skin on the head, torso, arms, and pelvis sustained cuts and abrasions. The extent of the physical damage to the ATD demonstrates that data up to 115 milliseconds after impact significantly understates the severity of the collision. The intrusion of the coil into the space occupied by the ATD and the resulting physical damage to it demonstrates that the impact would have resulted in a fatality for a crew member in that location and position. Figure 19 shows the ATD after the test.

Figure 19. ATD after Impact

The interior of the cab also suffered extensive damage. Both sections of the windshield were broken out. The cab floor was buckled on the right side and torn apart on the left side. The control console was destroyed and the remains were pushed back into the engineer's seat. Figures 20 and 21 show the interior of the locomotive cab after impact.

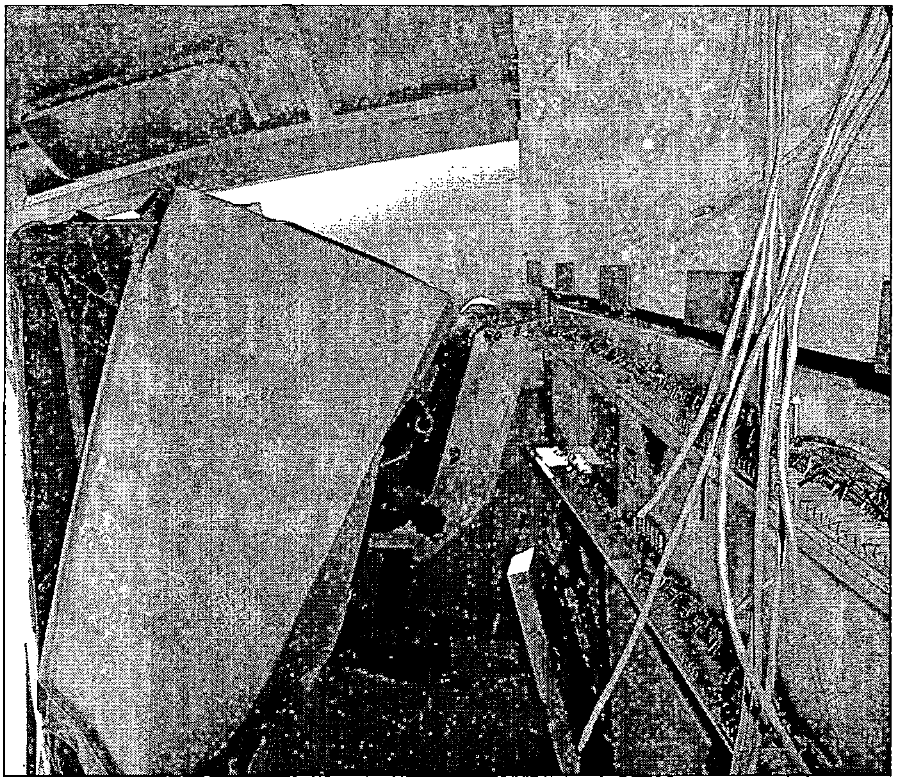

Figure 20. Engineer's Seat and Control Console after Impact

Figure 21. Left Side of the Cab after Impact

5.0 DISCUSSION AND CONCLUSIONS

The objective of this test was to test the strength of the collision post to its limit and that objective was met. The right collision post sheared just above the weld between it and the underframe, allowing the coil to enter the cab. The ATD, which was placed in the nose of the locomotive with its back against the interior door, was severely damaged. Visual documentation was obtained from a variety of views; however, the film camera placed on the west side for the overall view failed. The measurements and video will allow comparison of test performance to analytical models.

References

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

2. Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems, Supplement II. National Highway Traffic Safety Administration. March 2000.

APPENDIX A

Test Implementation Plan for Locomotive Crashworthiness Testing

TO 137

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

June 2002

Presented by:
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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.

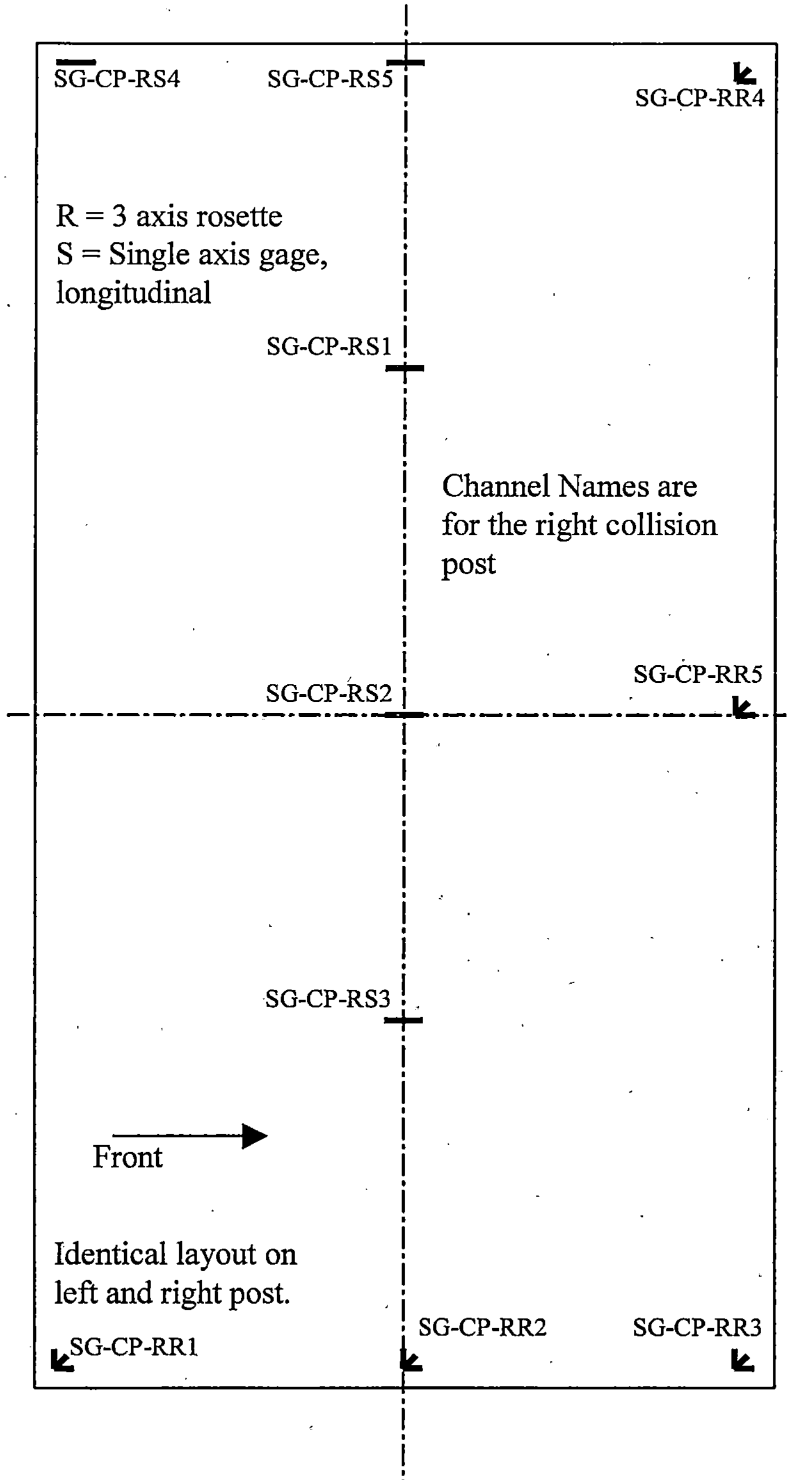

Figure 1. Location of strain gauges on the collision post

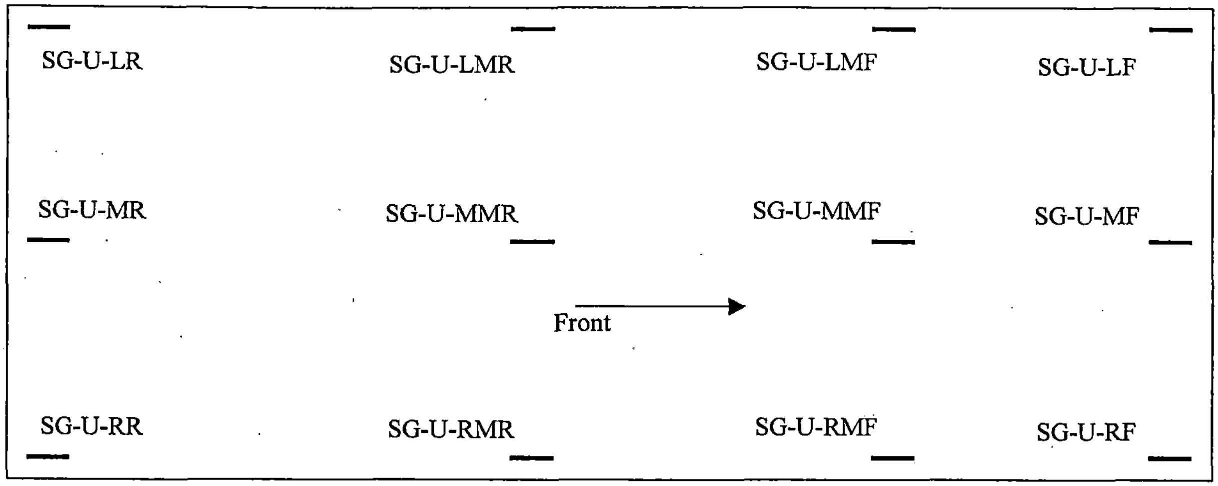

Figure 2. Location of strain gauges on locomotive under-frame

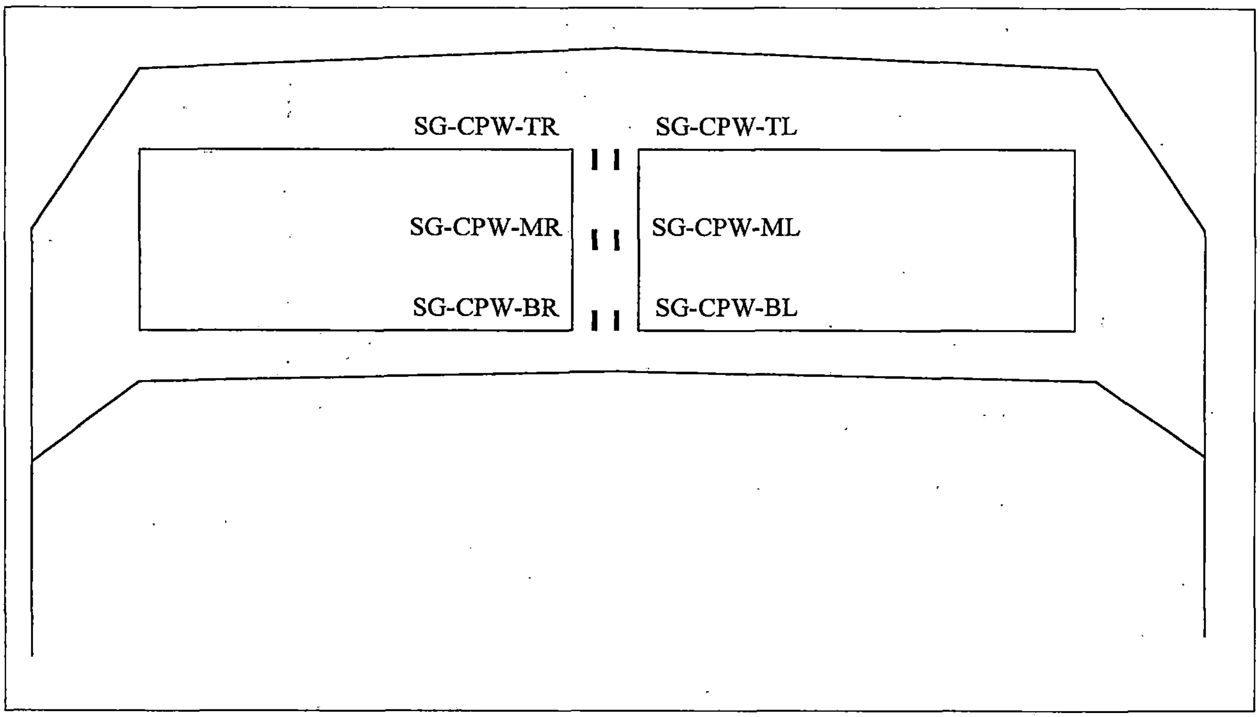

Figure 3. Location of strain gauges on windshield post

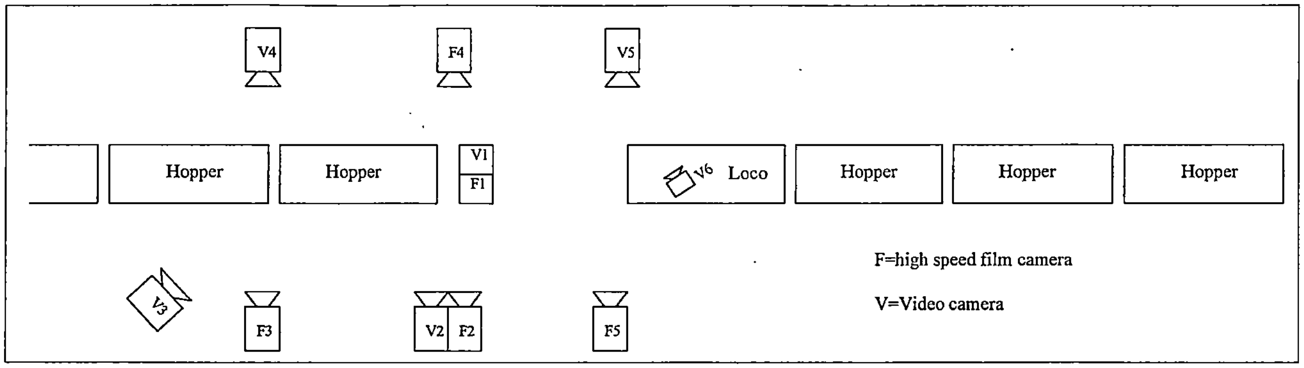

Figure 4. Location of cameras

APPENDIX B

Strain Data

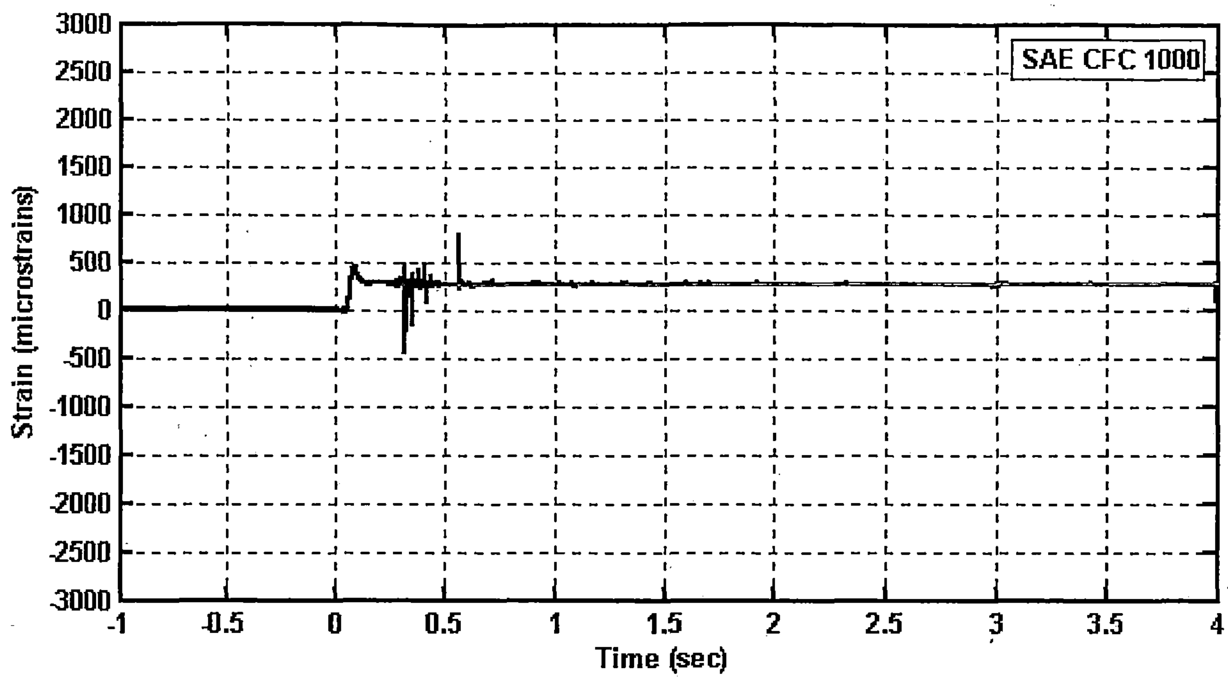

Figure F1. Strain on left collision post, bottom rear rosette, longitudinal element
Channel Name: CPLR1_1

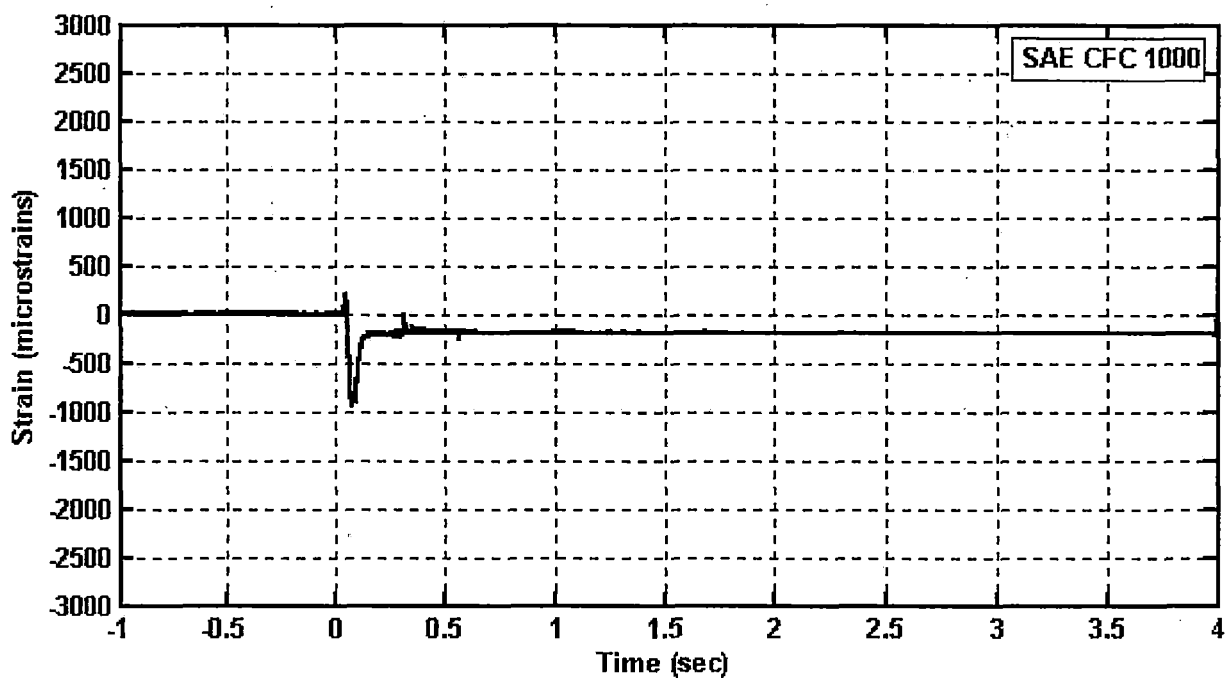

Figure F2. Strain on left collision post, bottom rear rosette, diagonal element
Channel Name: CPLR1_2

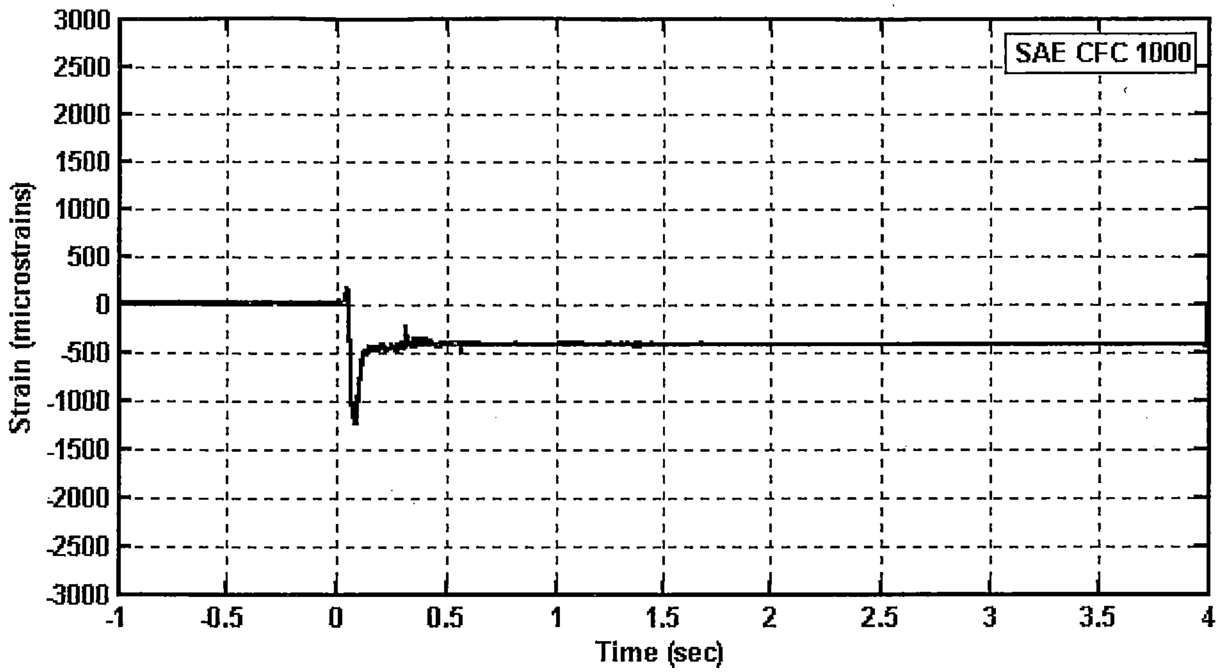

Figure F3. Strain on left collision post, bottom rear rosette, vertical element
Channel Name: CPLR1_3

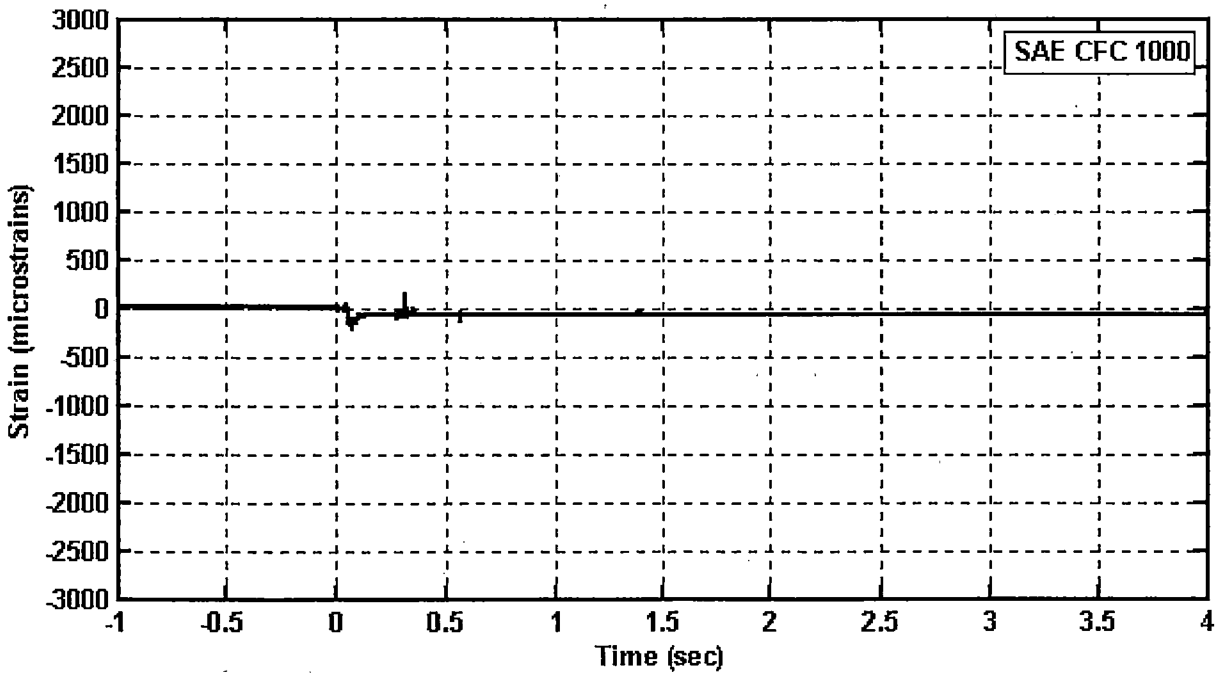

Figure F4. Strain on left collision post, bottom center rosette, longitudinal element
Channel Name: CPLR2_1

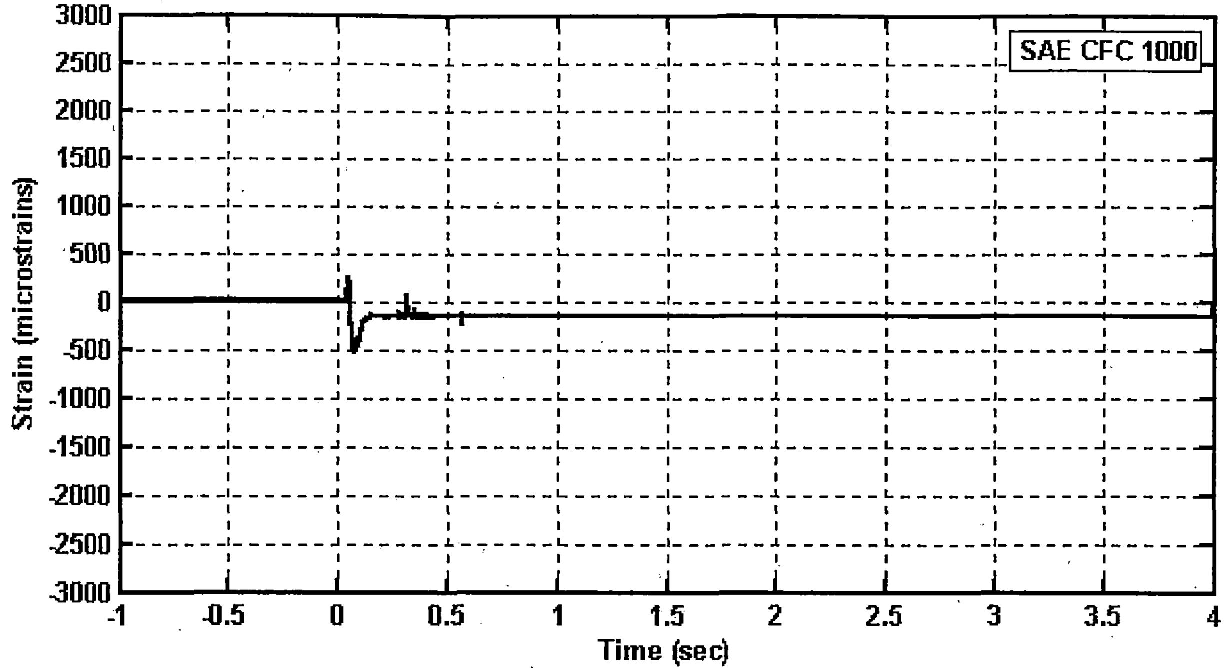

Figure F5. Strain on left collision post, bottom center rosette, diagonal element
Channel Name: CPLR2_2

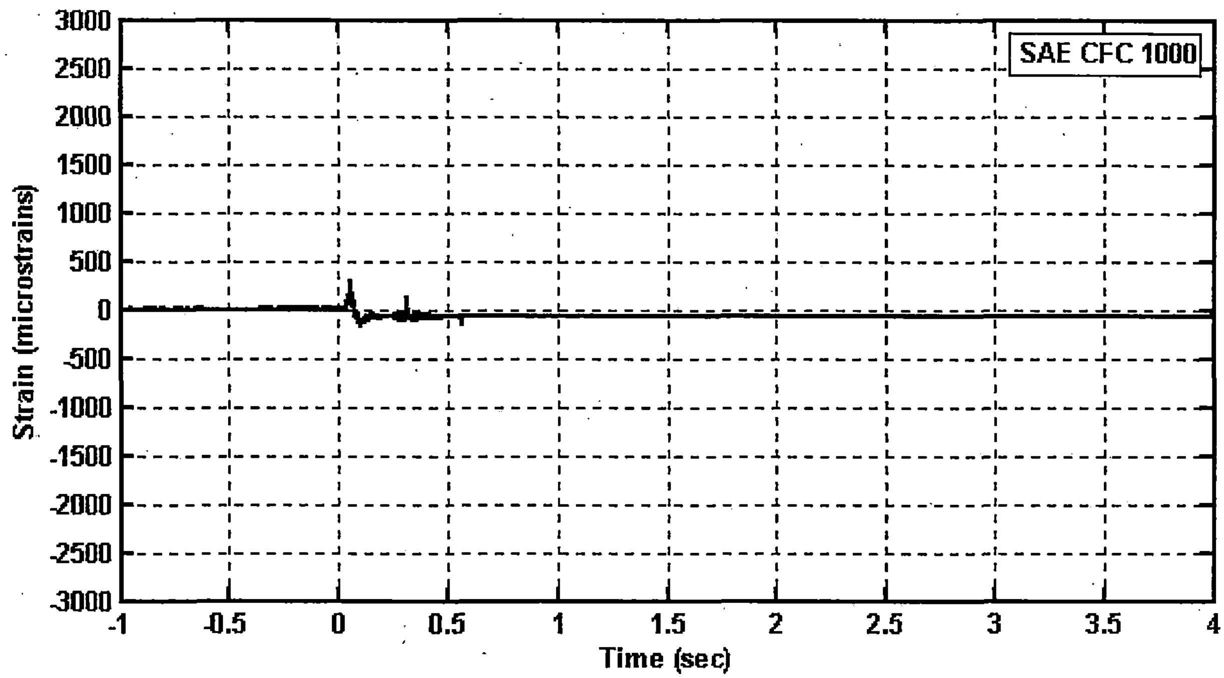

Figure F6. Strain on left collision post, bottom center rosette, vertical element
Channel Name: CPLR2_3

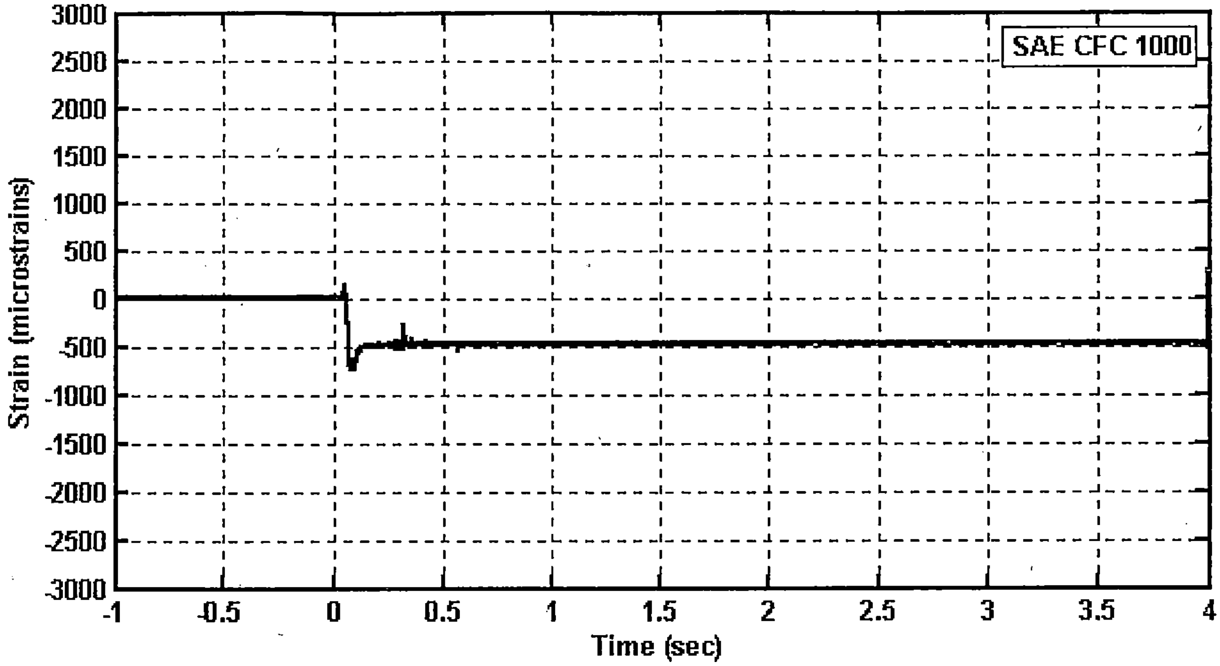

Figure F7. Strain on left collision post, bottom front rosette, longitudinal element
Channel Name: CPLR3_1

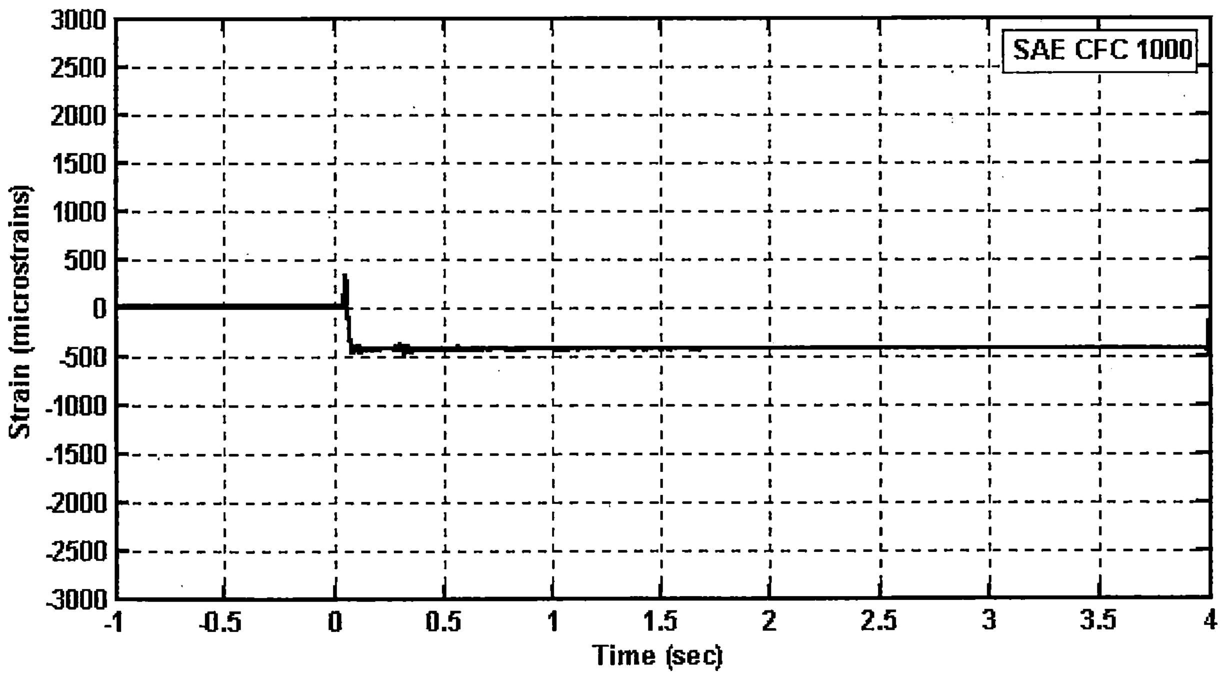

Figure F8. Strain on left collision post, bottom front rosette, diagonal element
Channel Name: CPLR3_2

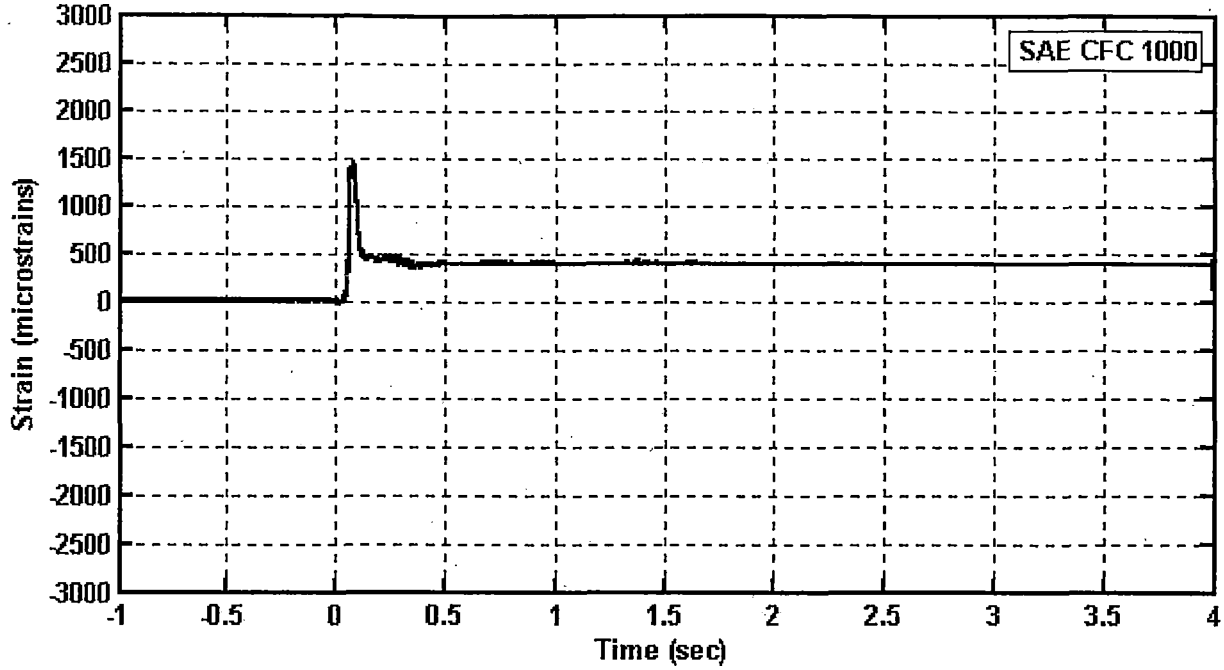

Figure F9. Strain on left collision post, bottom front rosette, vertical element
Channel Name: CPLR3_3

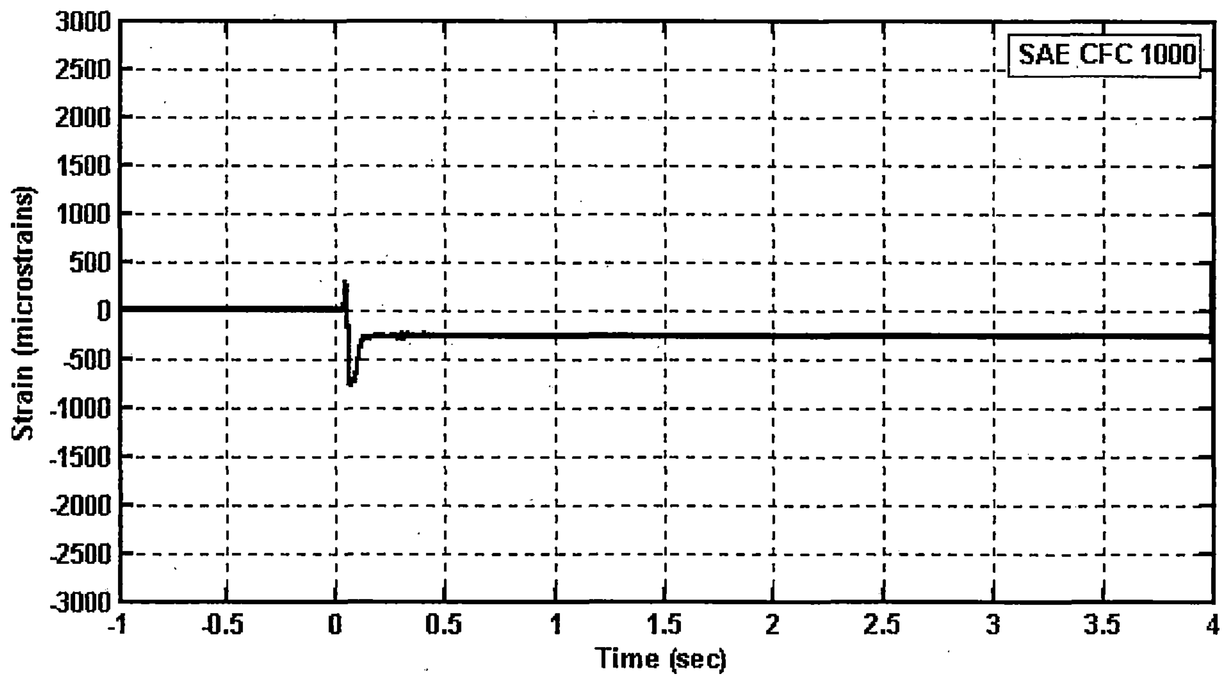

Figure F10. Strain on left collision post, top front rosette, longitudinal element
Channel Name: CPLR4_1

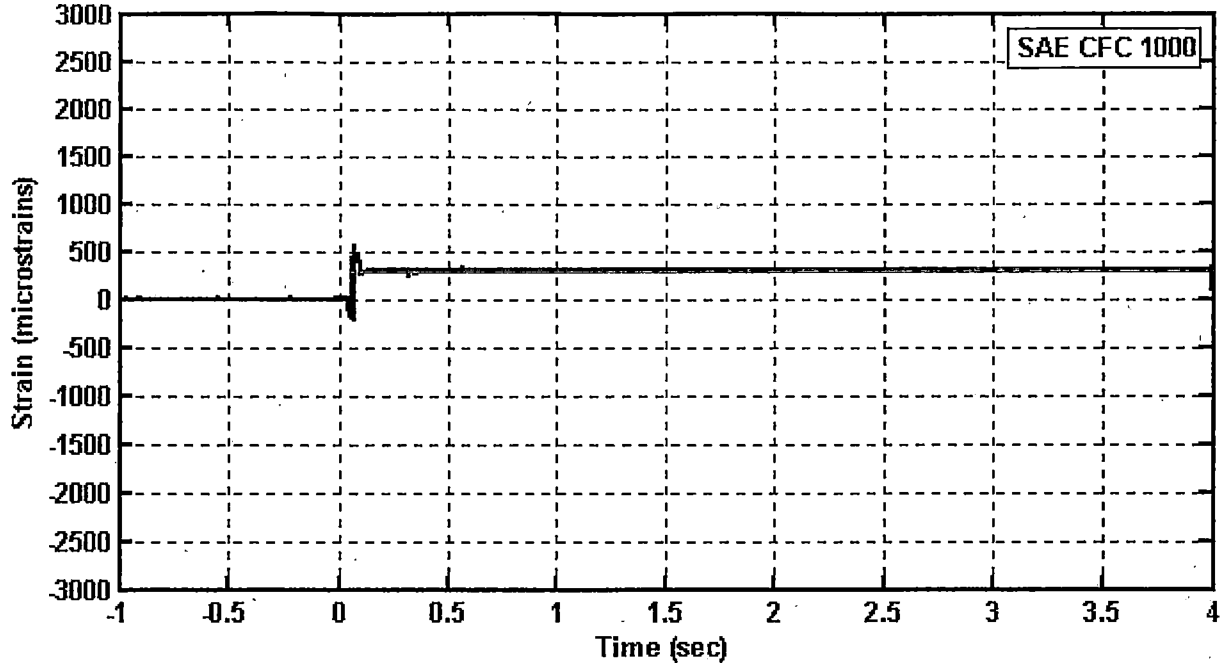

Figure F11. Strain on left collision post, top front rosette, diagonal element
Channel Name: CPLR4_2

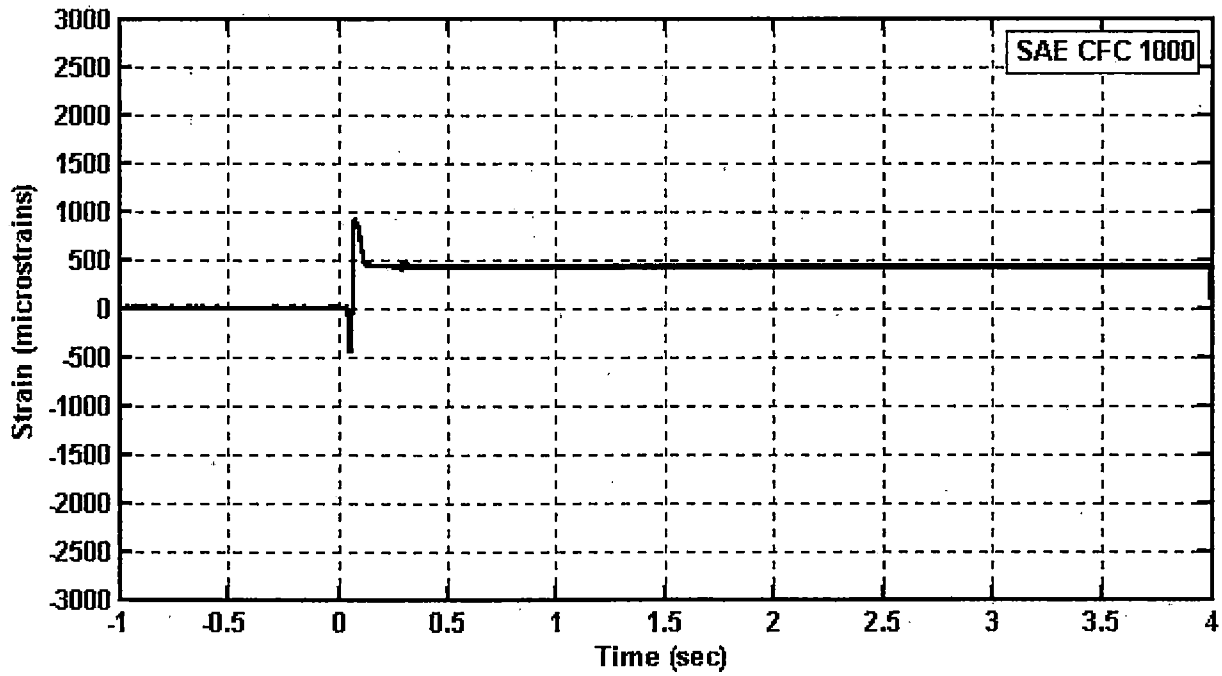

Figure F12. Strain on left collision post, top front rosette, vertical element
Channel Name: CPLR4_3

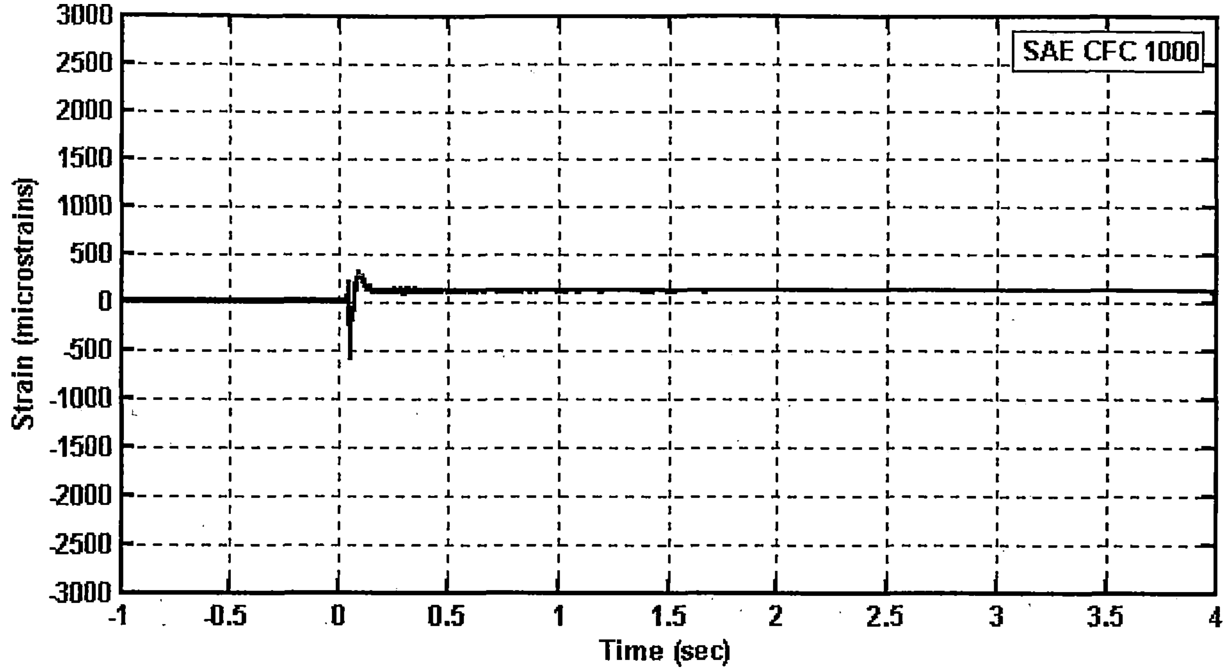

Figure F13. Strain on left collision post, middle front rosette, longitudinal element
Channel Name: CPLR5_1

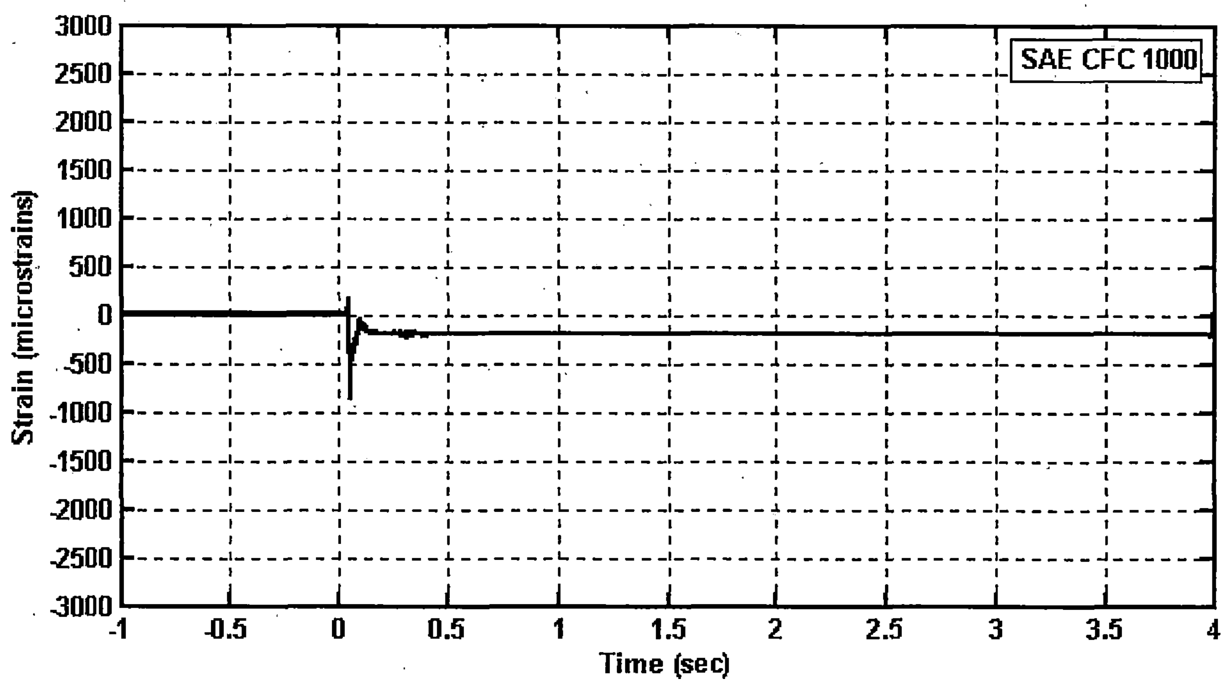

Figure F14. Strain on left collision post, middle front rosette, diagonal element
Channel Name: CPLR5_2

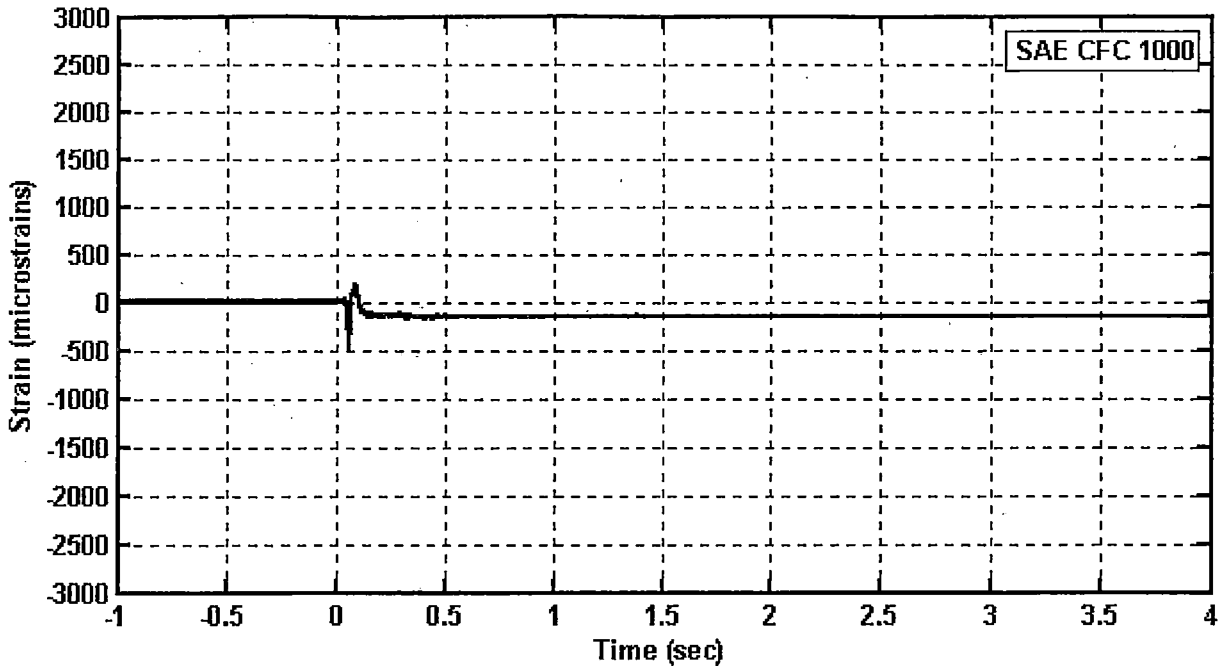

Figure F15. Strain on left collision post, middle front rosette, vertical element
Channel Name: CPLR5_3

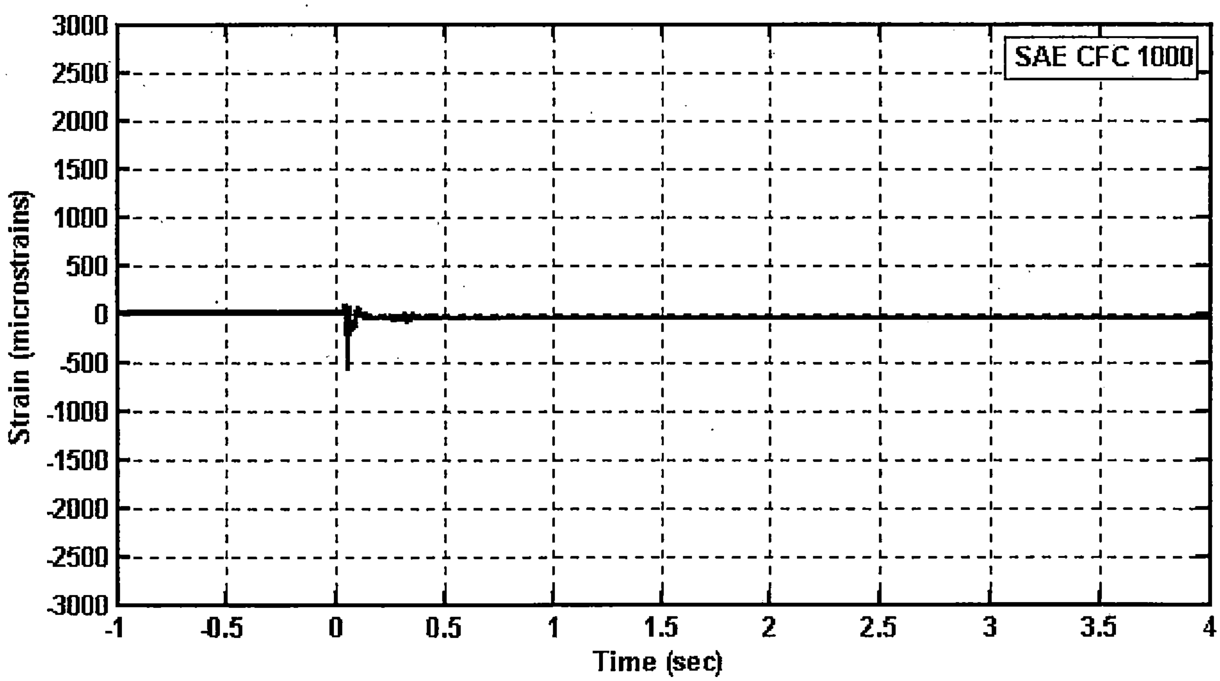

Figure F16. Longitudinal strain on left collision post, center, 3/4 up from bottom edge
Channel Name: CPLS1

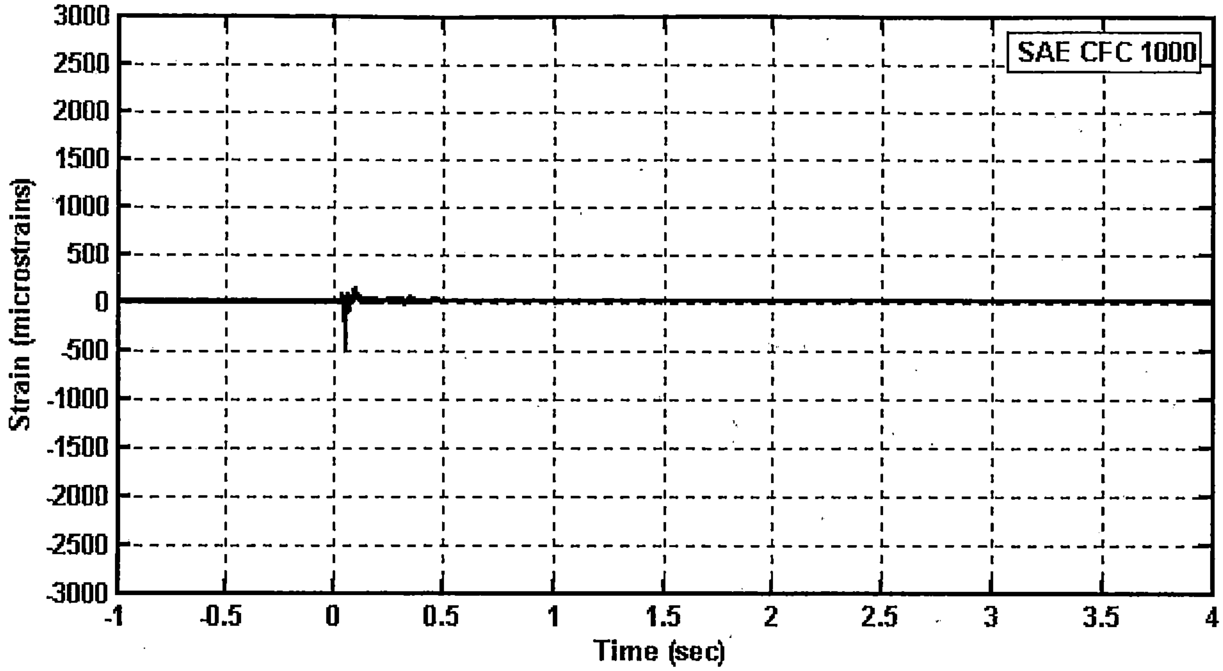

Figure F17. Longitudinal strain on left collision post, center, 1/2 up from bottom edge
Channel Name: CPLS2

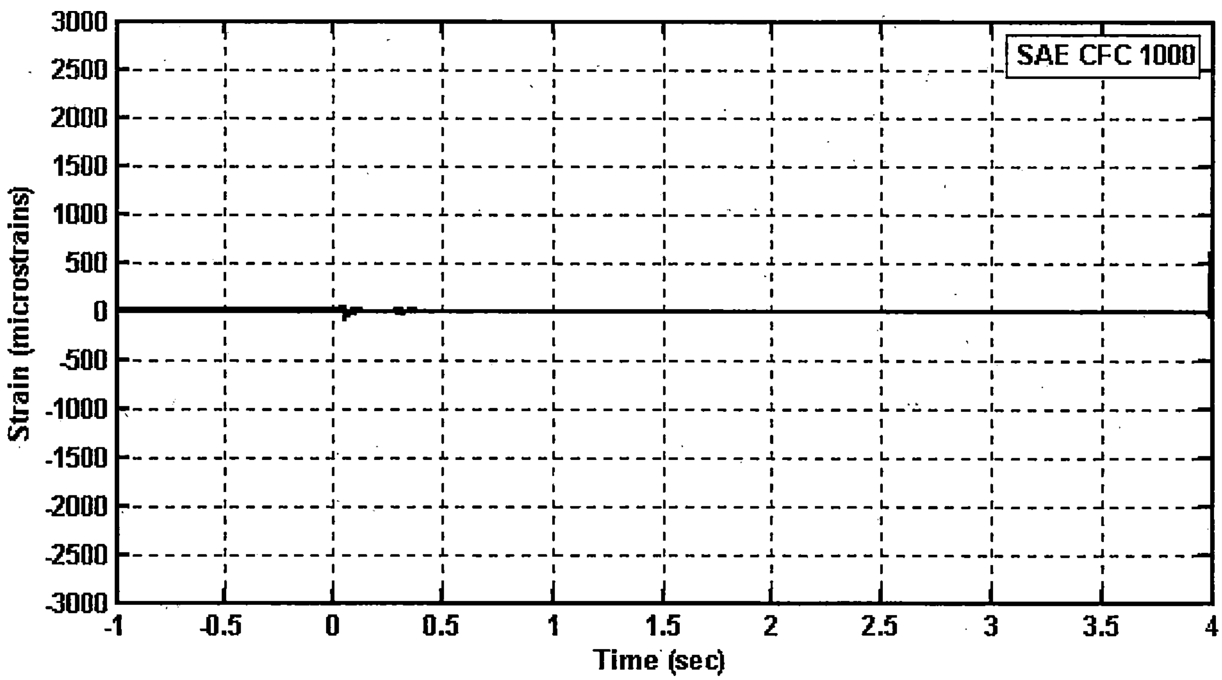

Figure F18. Longitudinal strain on left collision post, center, 1/4 up from bottom edge
Channel Name: CPLS3

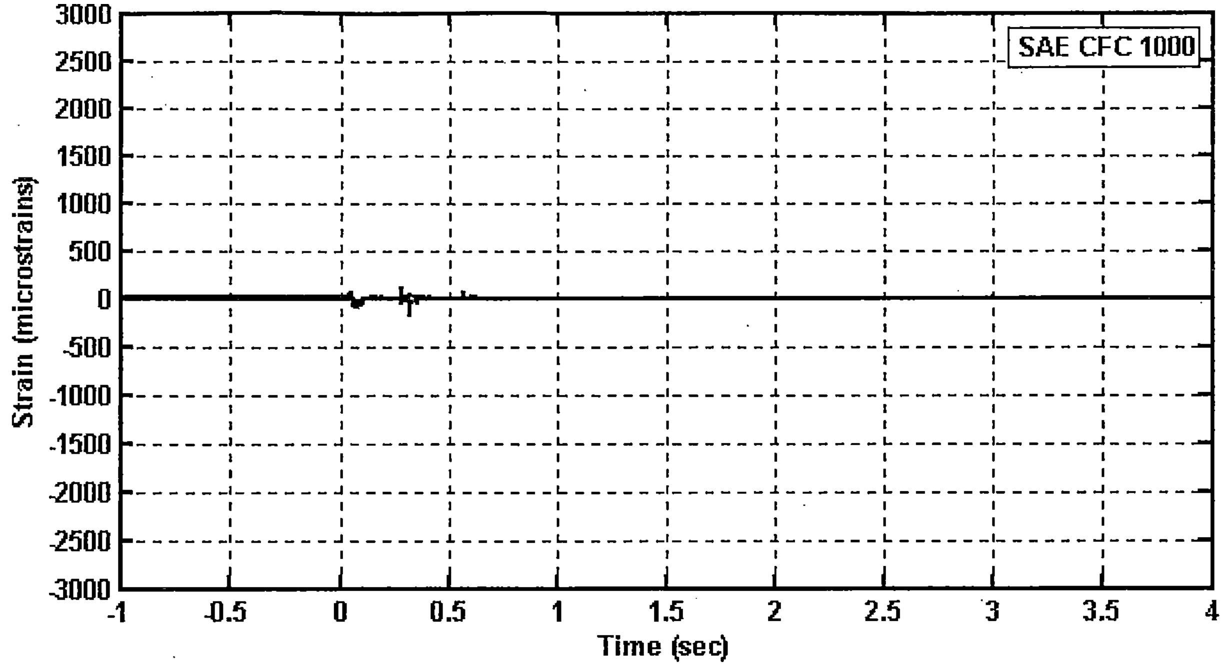

Figure F19. Longitudinal strain on left collision post, top rear corner
Channel Name: CPLS4

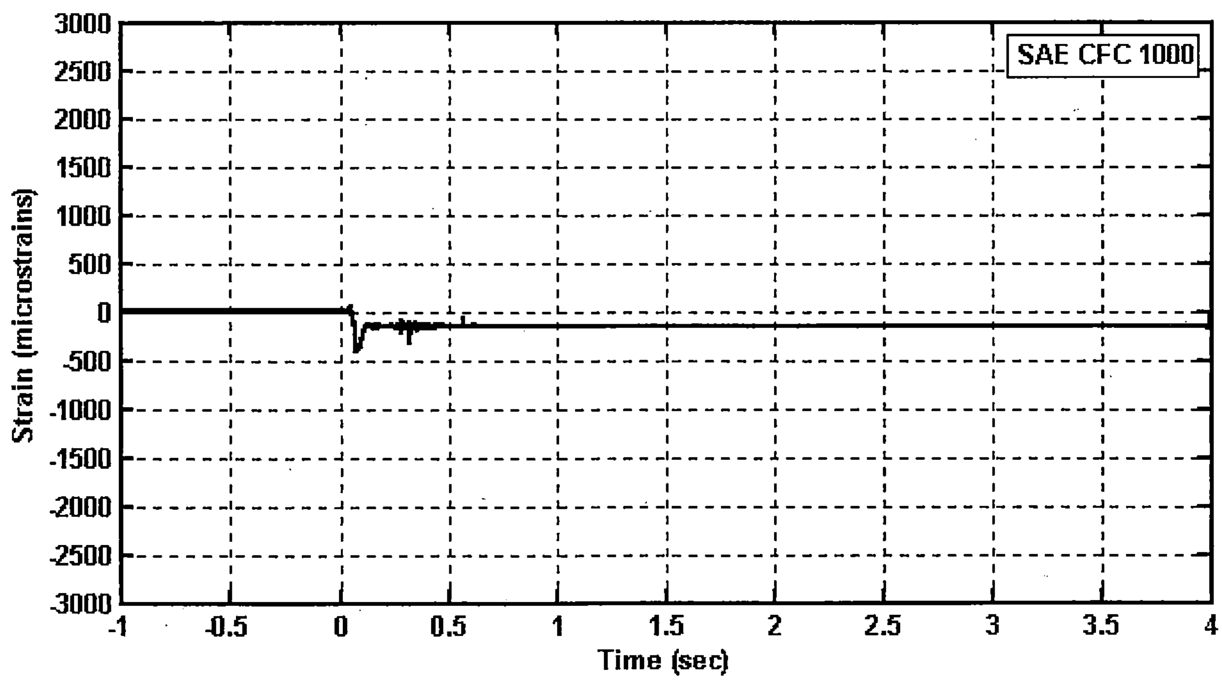

Figure F20. Longitudinal strain on left collision post, centered longitudinally, top edge
Channel Name: CPLS5

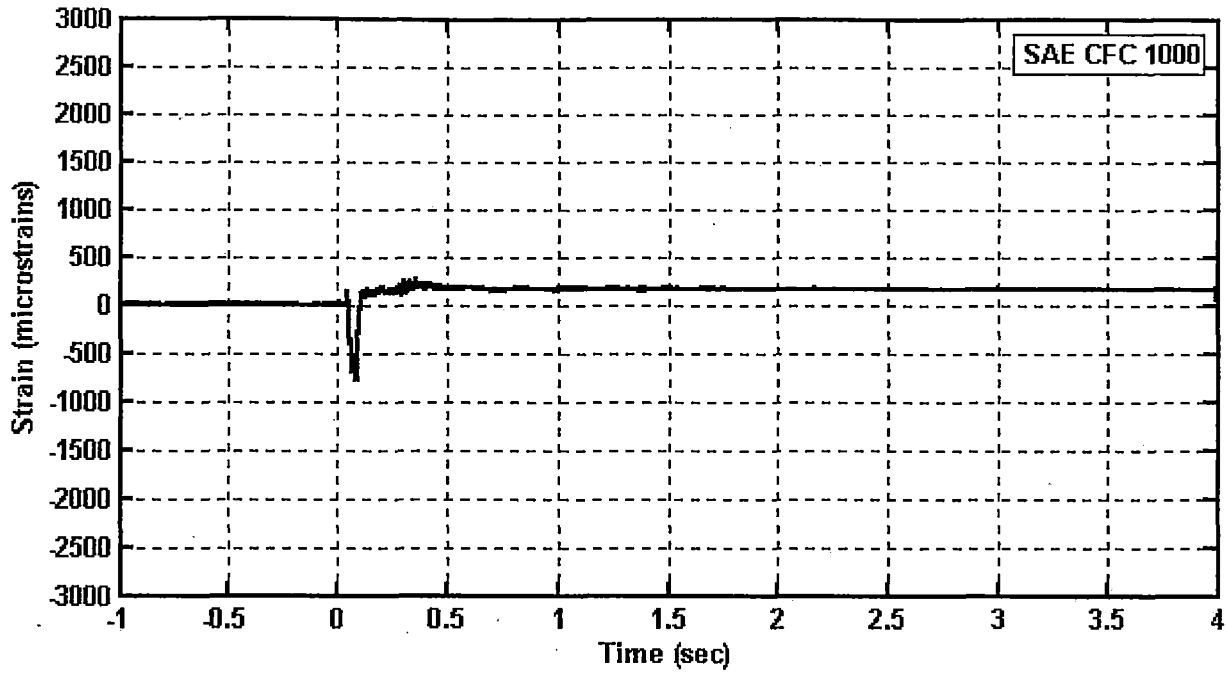

Figure F21. Strain on right collision post, bottom rear rosette, vertical element
Channel Name: CPRR1_1

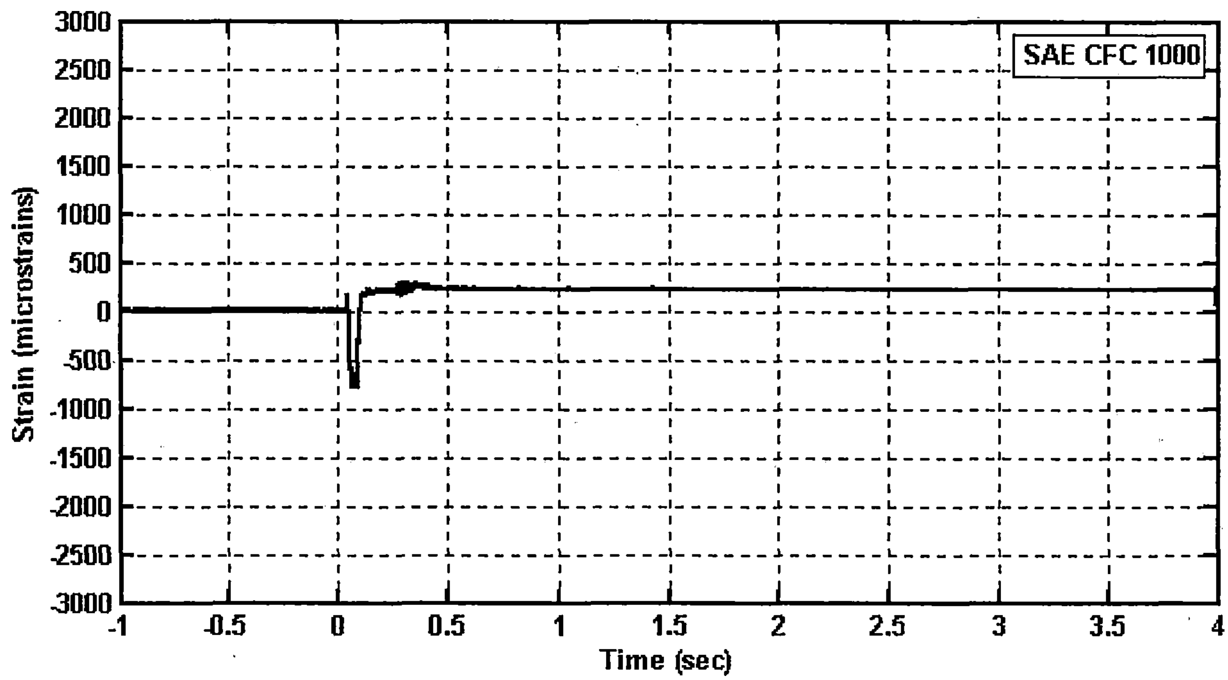

Figure F22. Strain on right collision post, bottom rear rosette, diagonal element
Channel Name: CPRR1_2

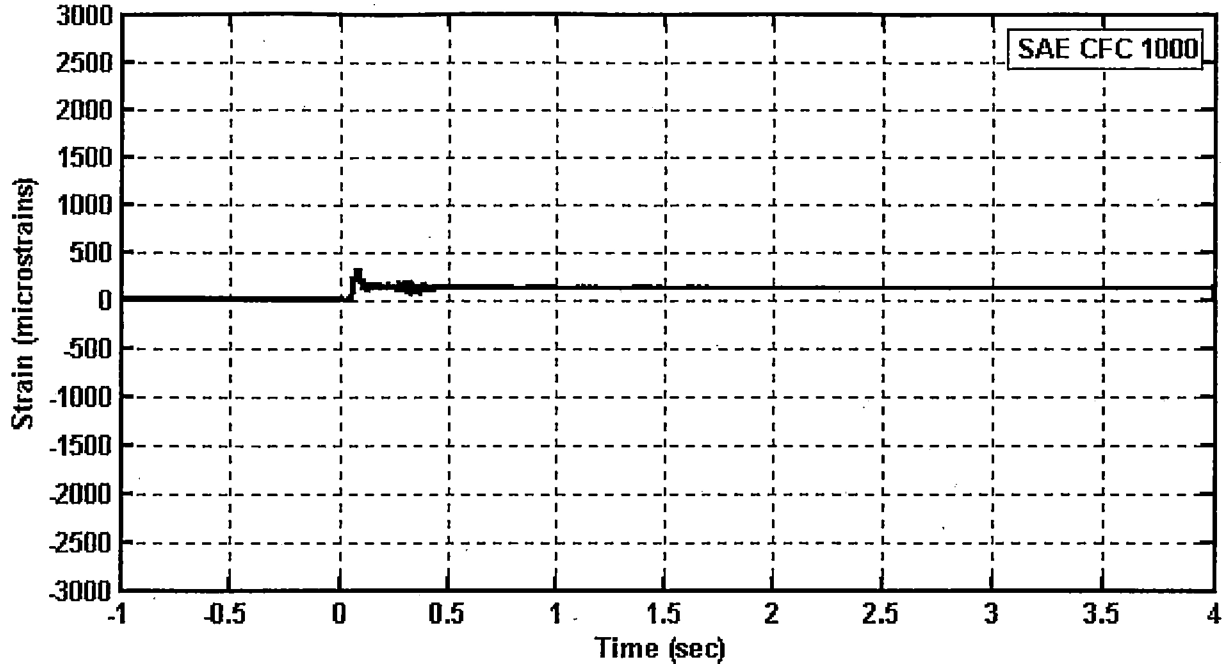

Figure F23. Strain on right collision post, bottom rear rosette, longitudinal element
Channel Name: CPRR1_3

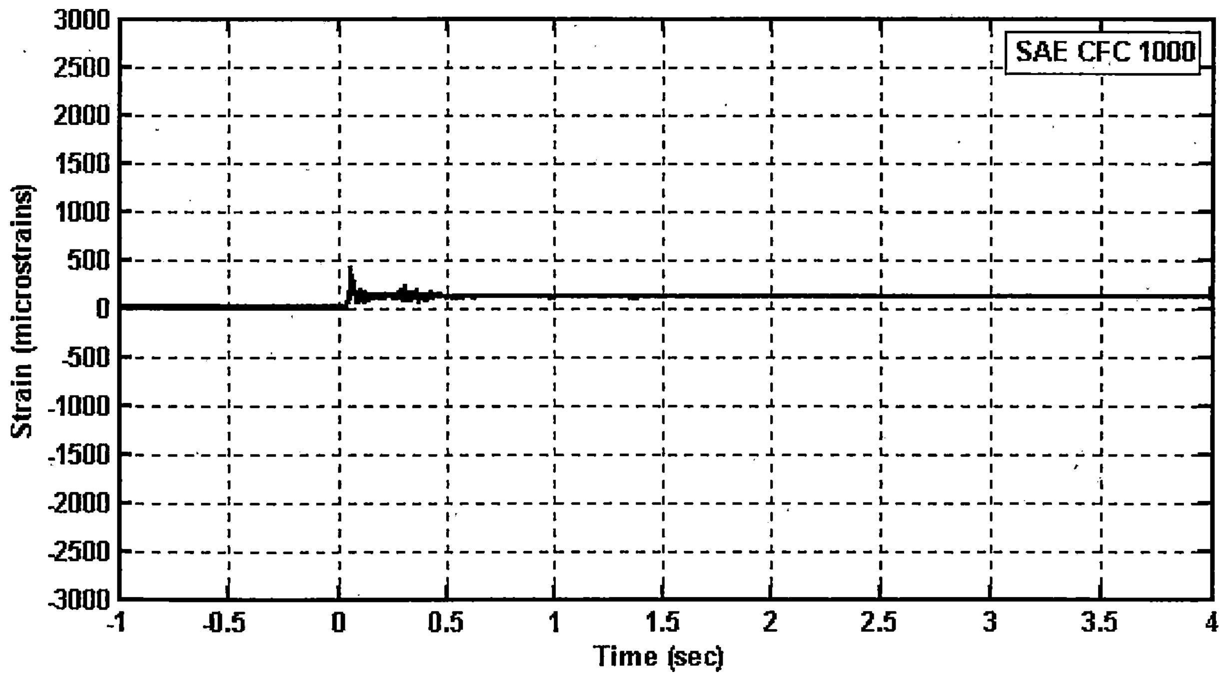

Figure F24. Strain on right collision post, bottom center rosette, vertical element
Channel Name: CPRR2_1

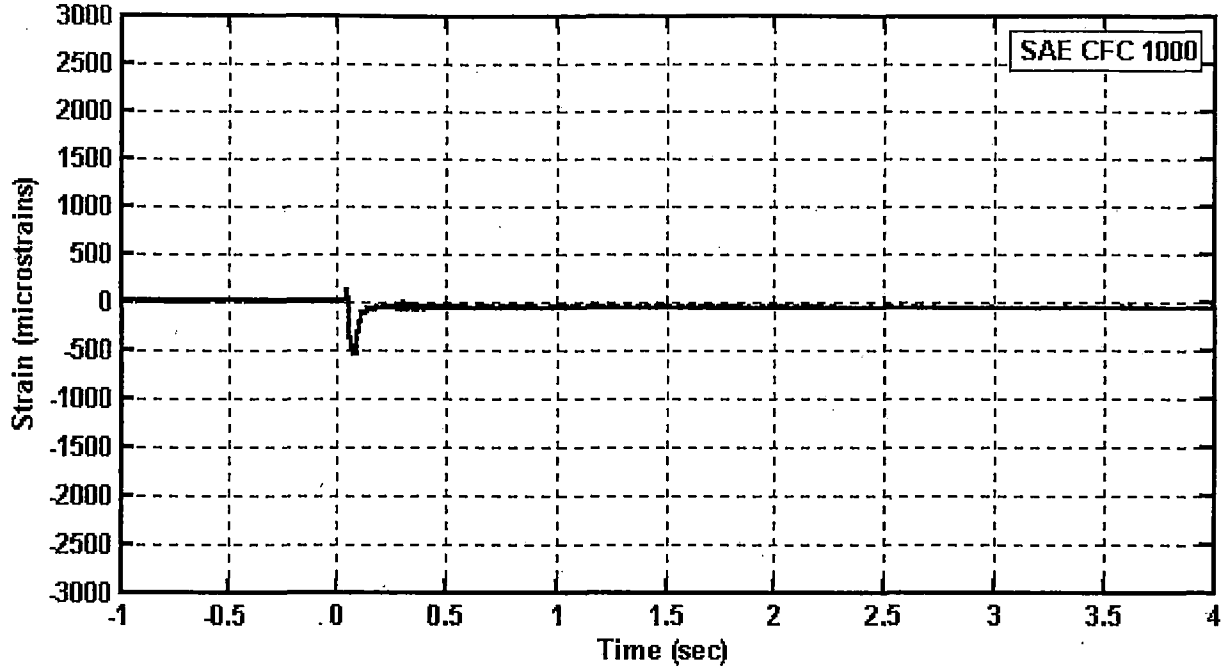

Figure F25. Strain on right collision post, bottom center rosette, diagonal element
Channel Name: CPRR2_2

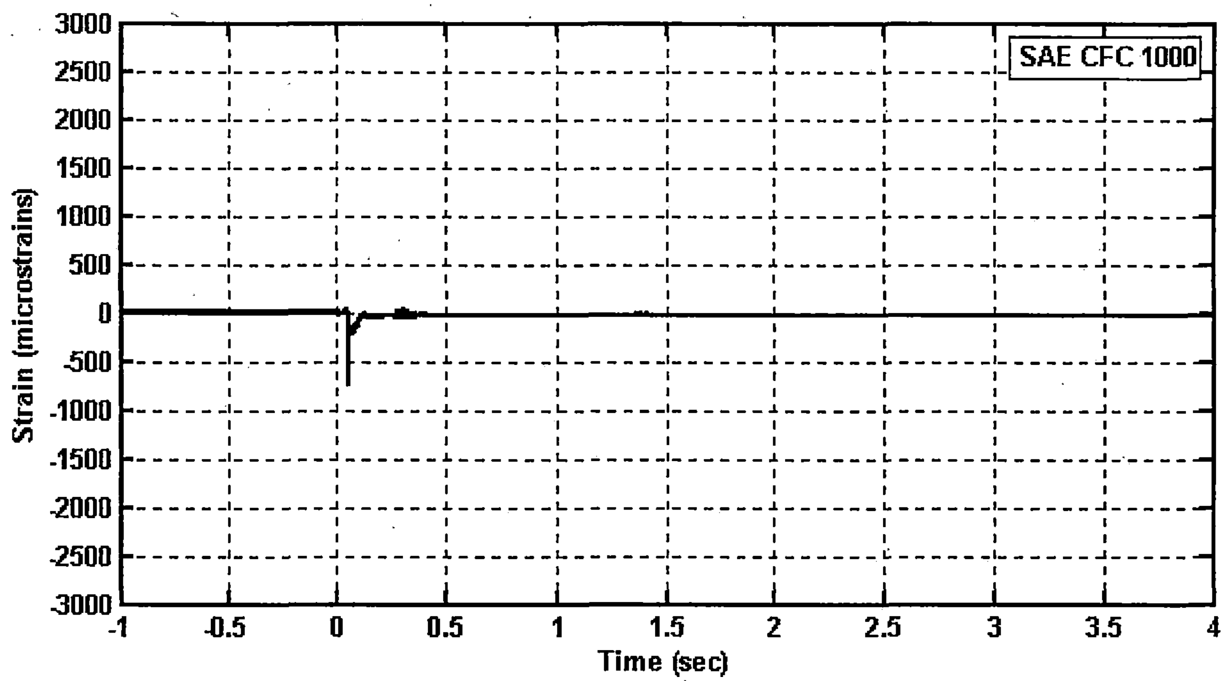

Figure F26. Strain on right collision post, bottom center rosette, longitudinal element
Channel Name: CPRR2_3

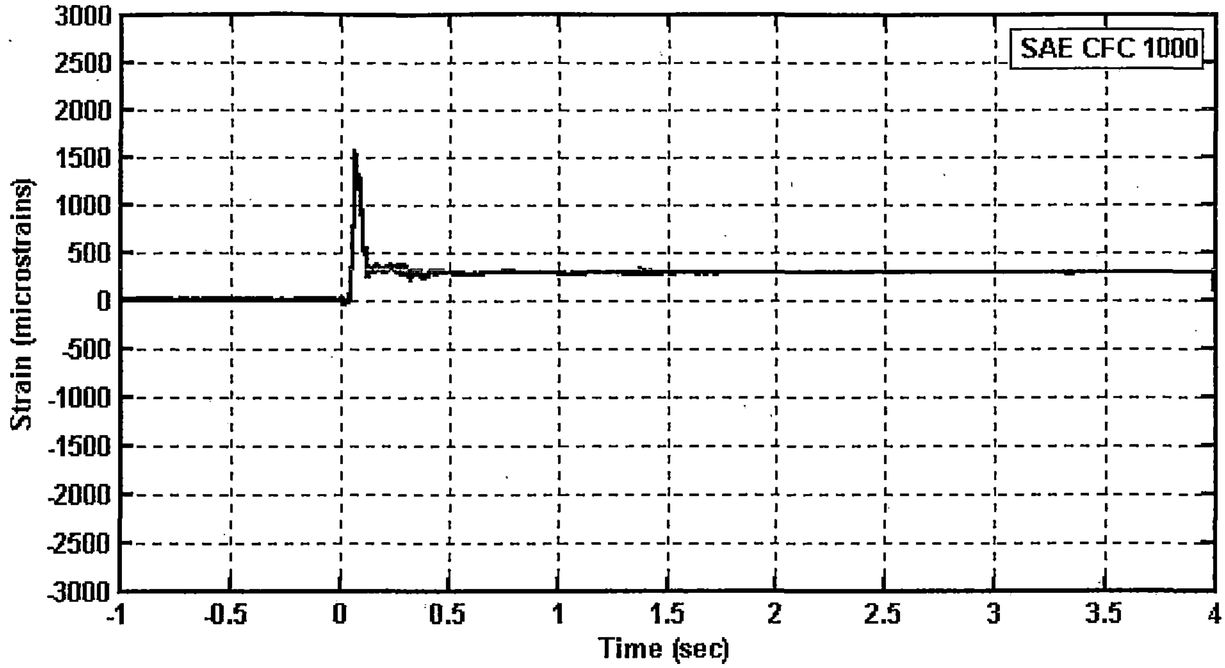

Figure F27. Strain on right collision post, bottom front rosette, vertical element
Channel Name: CPRR3_1

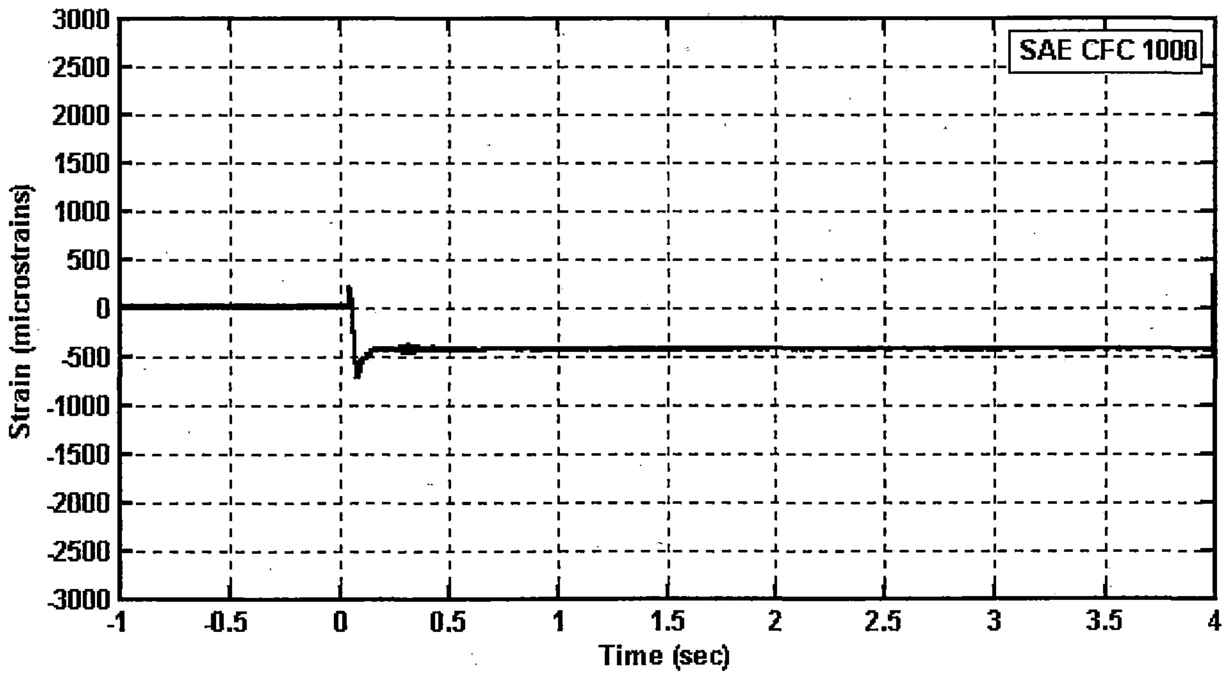

Figure F28. Strain on right collision post, bottom front rosette, diagonal element
Channel Name: CPRR3_2

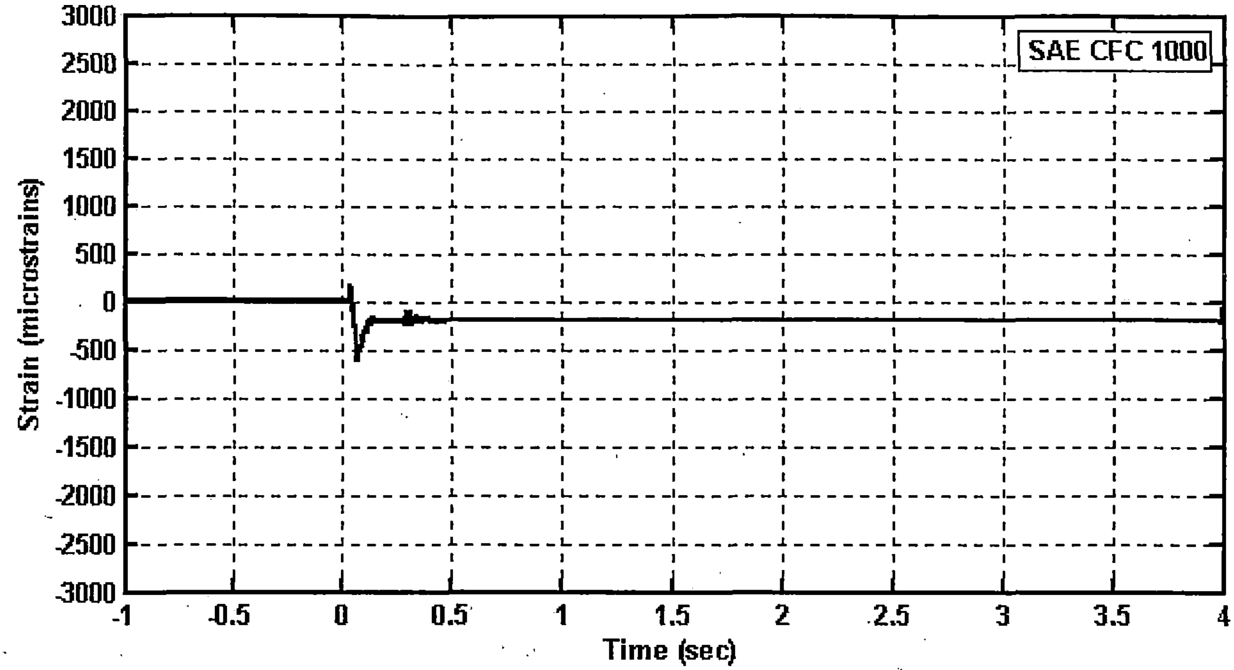

Figure F29. Strain on right collision post, bottom front rosette, longitudinal element
Channel Name: CPRR3_3

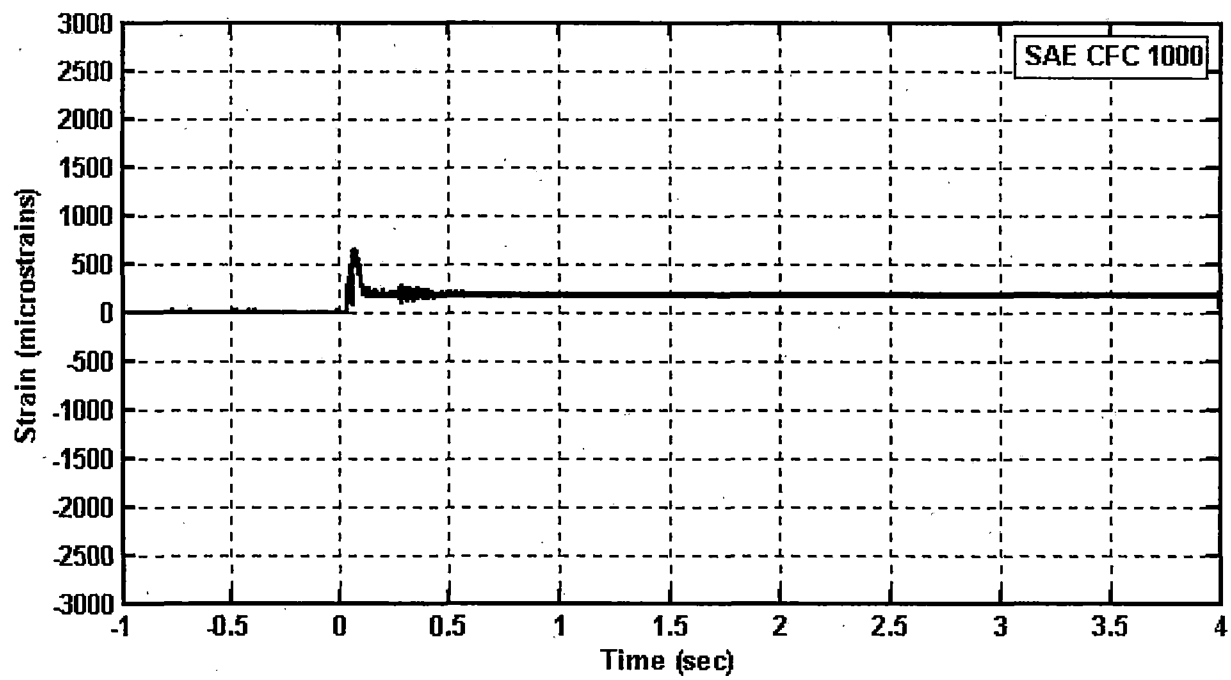

Figure F30. Strain on right collision post, top front rosette, vertical element
Channel Name: CPRR4_1

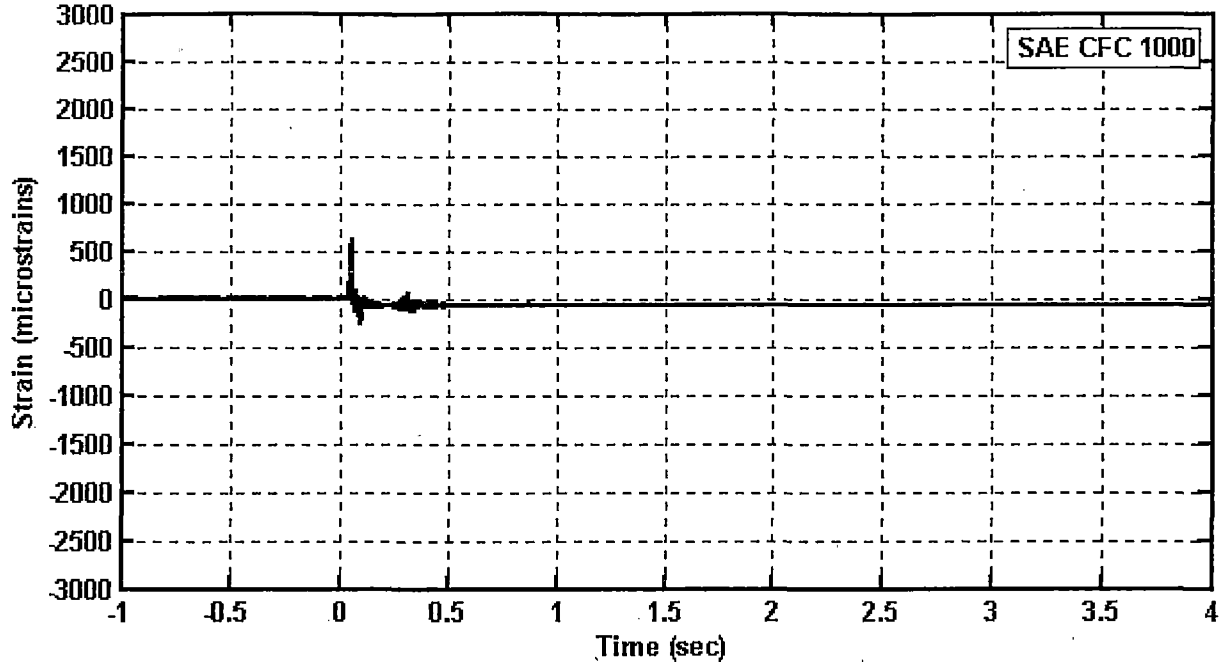

Figure F31. Strain on right collision post, top front rosette, diagonal element
Channel Name: CPRR4_2

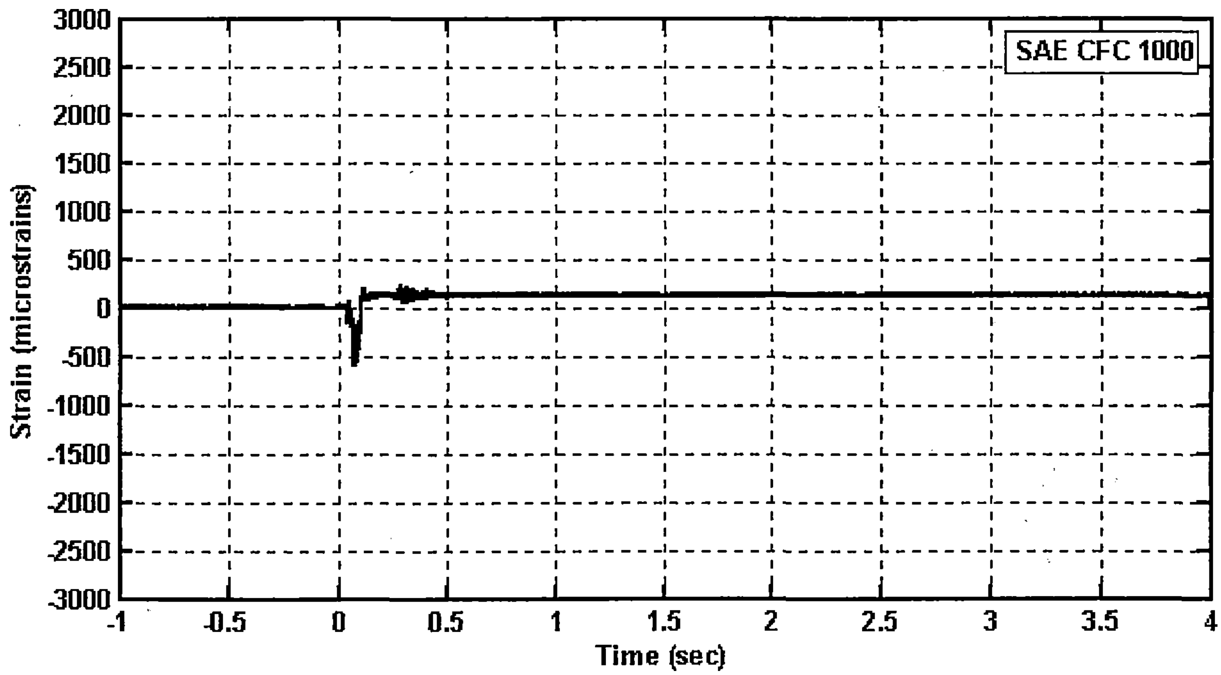

Figure F32. Strain on right collision post, top front rosette, longitudinal element
Channel Name: CPRR4_3

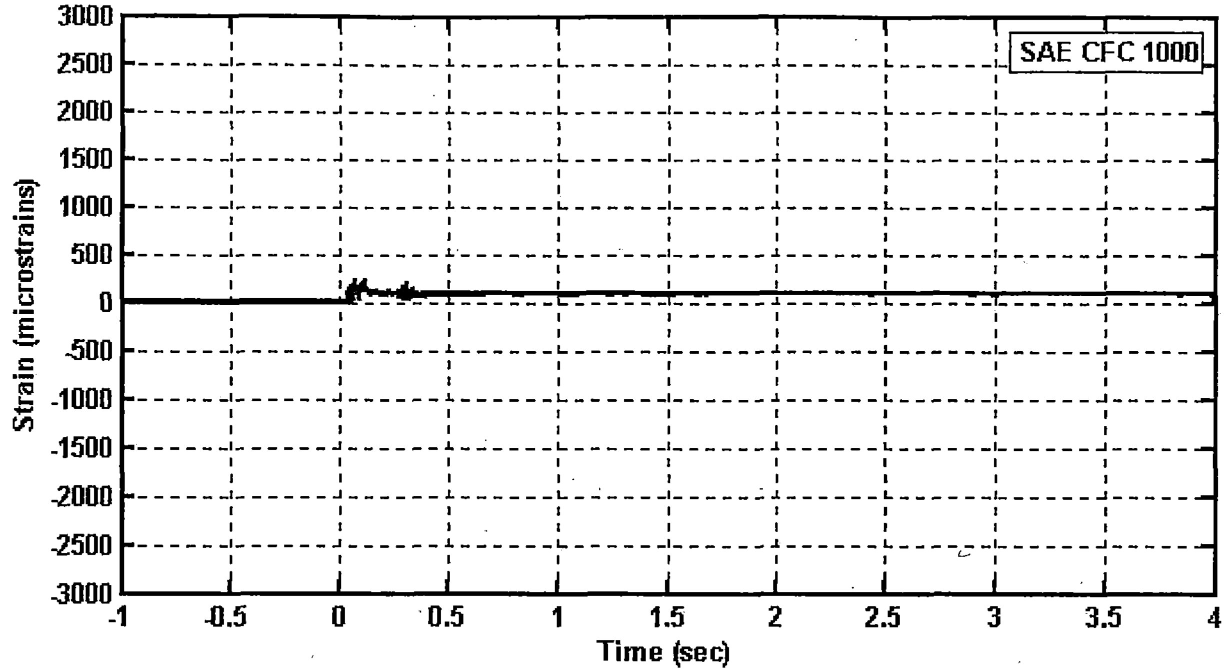

Figure F33. Strain on right collision post, middle front rosette, vertical element
Channel Name: CPRR5_1

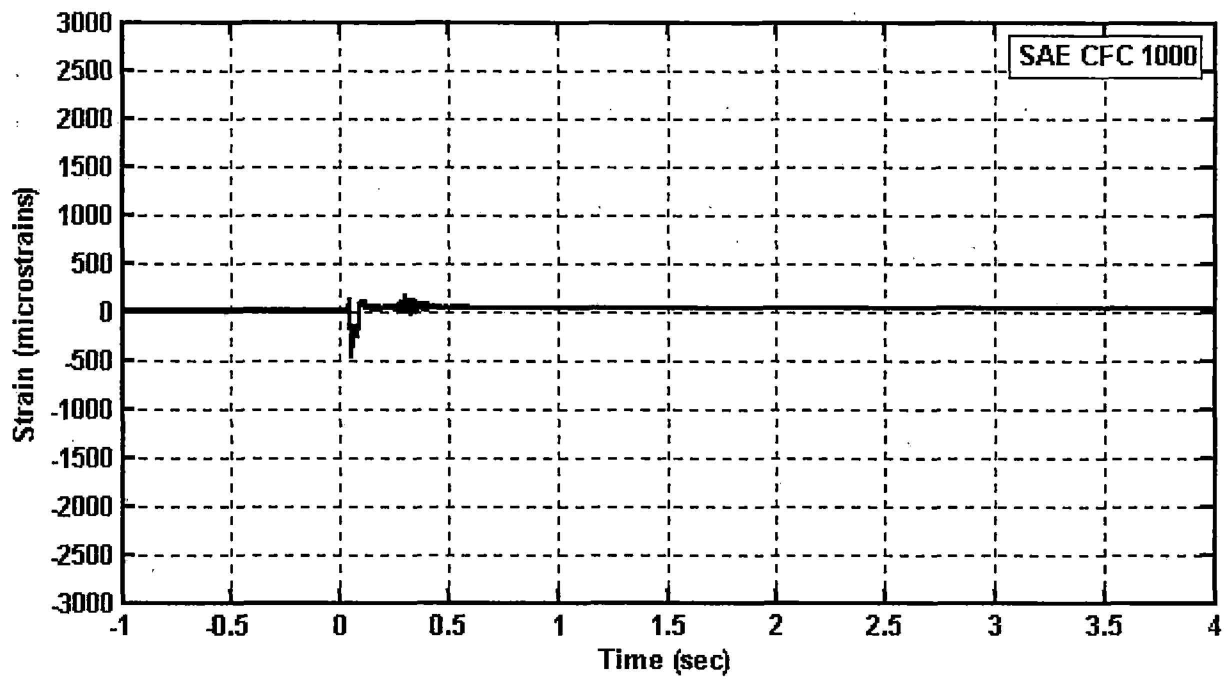

Figure F34. Strain on right collision post, middle front rosette, diagonal element
Channel Name: CPRR5_2

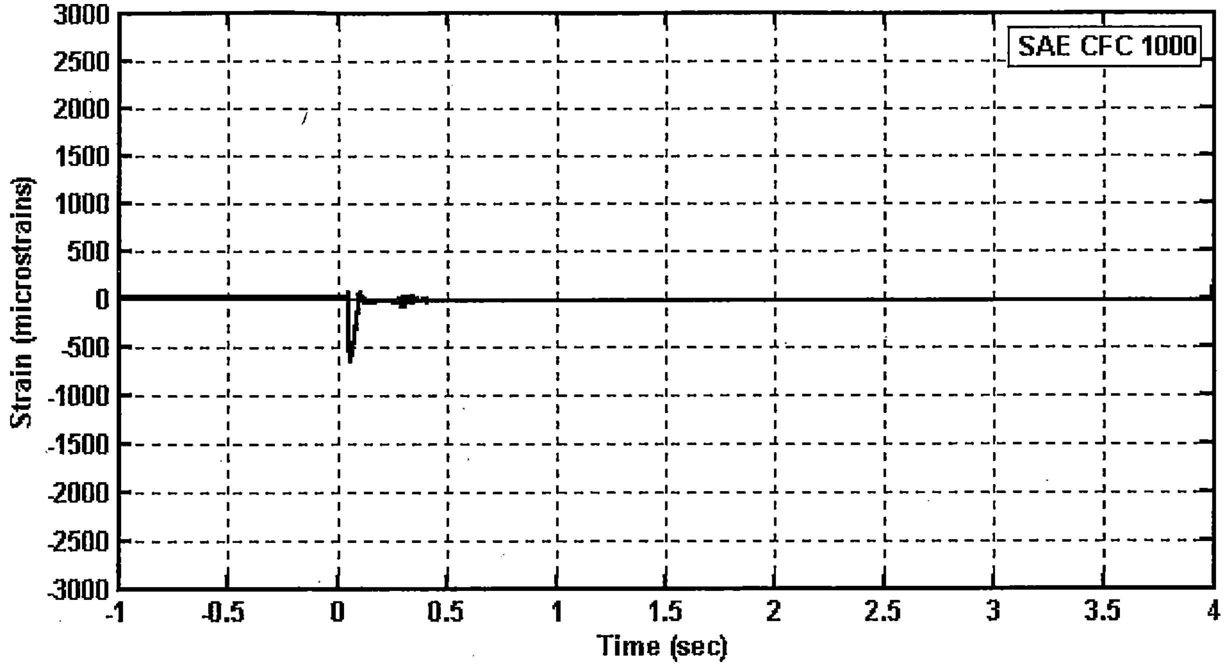

Figure F35. Strain on right collision post, middle front rosette, longitudinal element
Channel Name: CPRR5_3

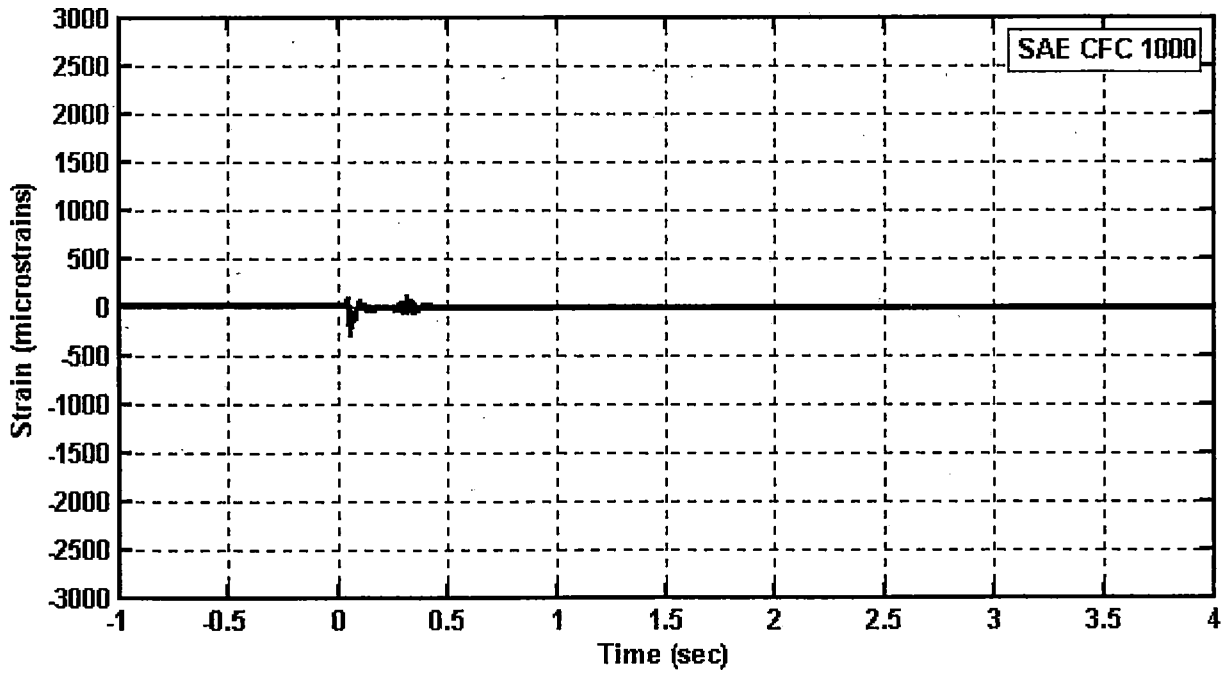

Figure F36. Longitudinal strain on right collision post, center, 3/4 up from bottom edge
Channel Name: CPRS1

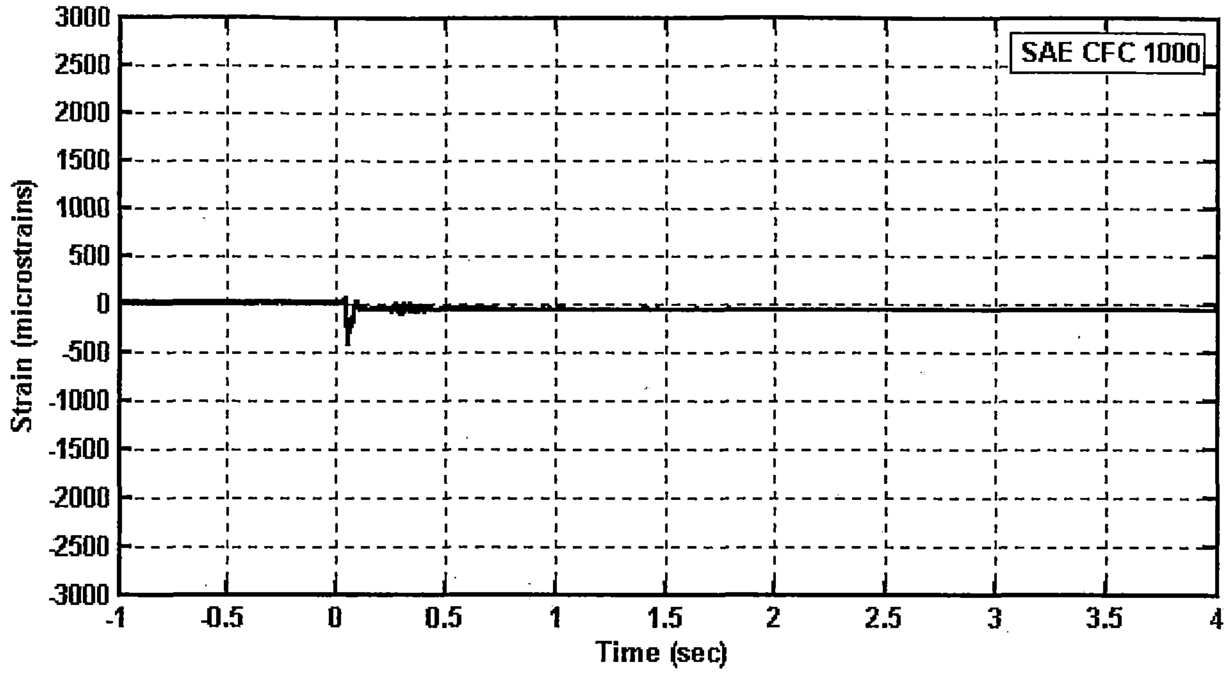

Figure F37. Longitudinal strain on right collision post, center, 1/2 up from bottom edge
Channel Name: CPRS2

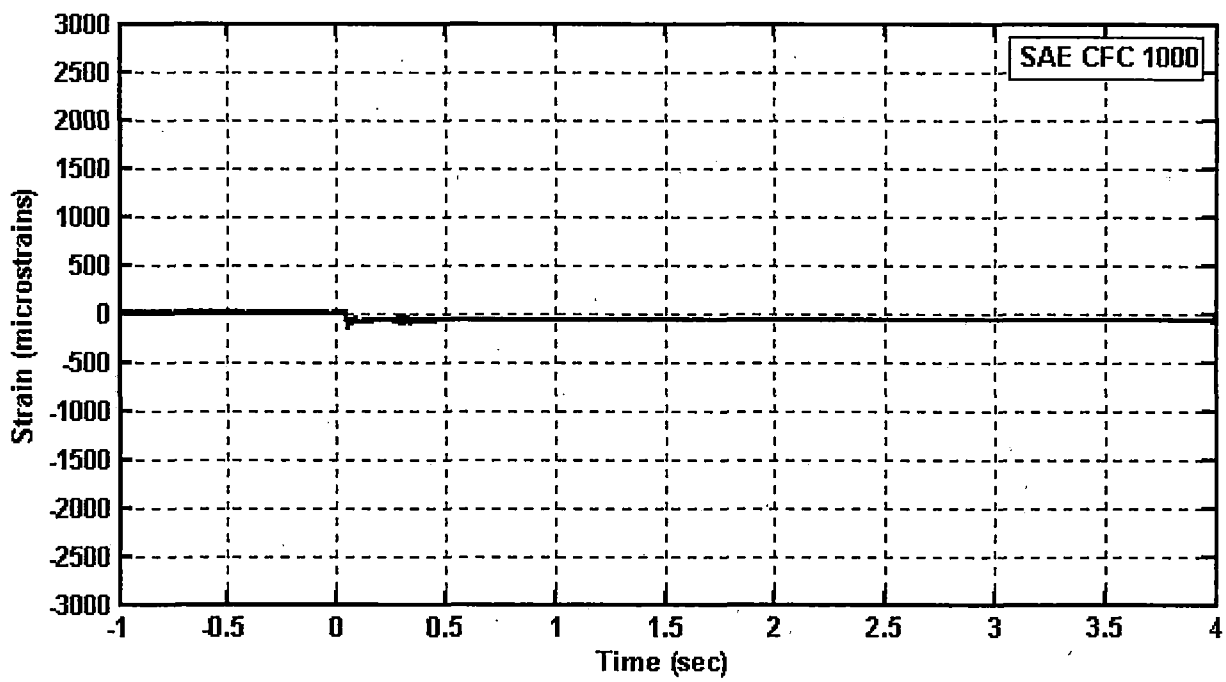

Figure F38. Longitudinal strain on right collision post, center, 1/4 up from bottom edge
Channel Name: CPRS3

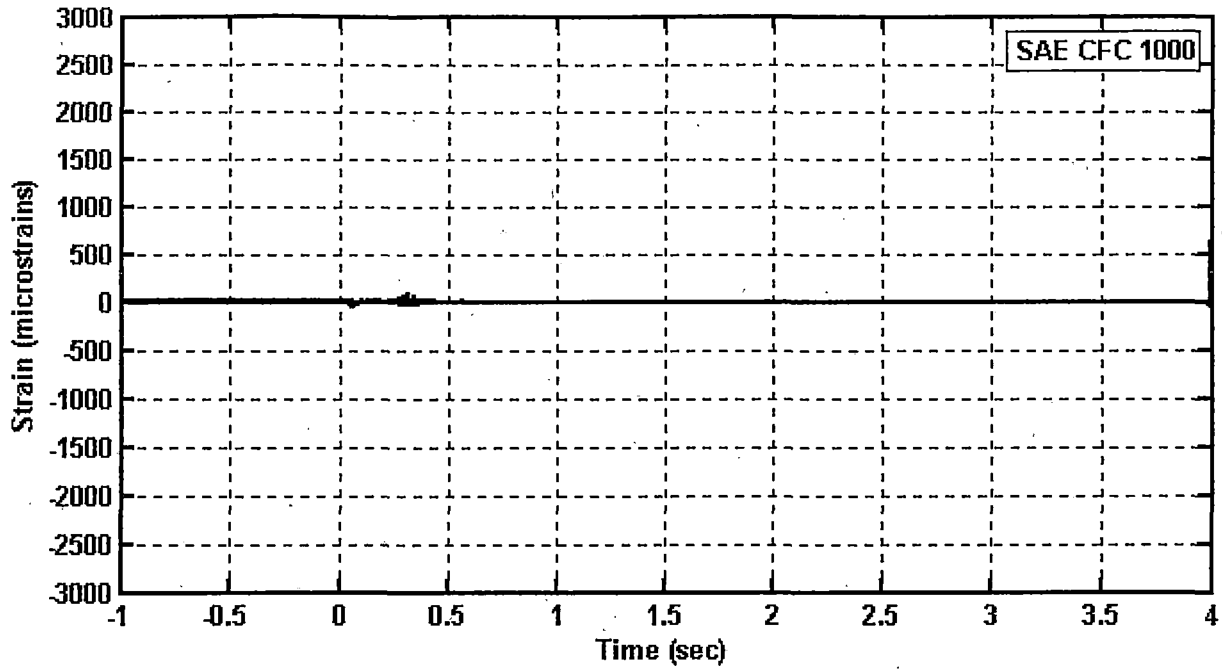

Figure F39. Longitudinal strain on right collision post, top rear corner
Channel Name: CPRS4

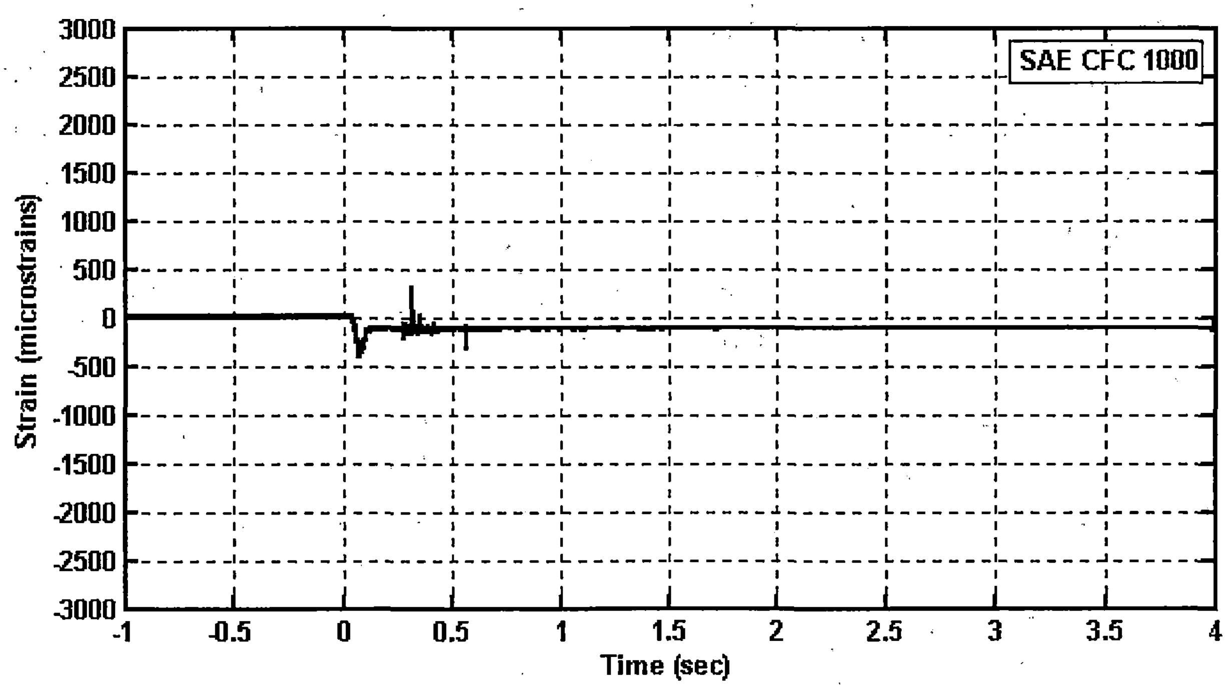

Figure F40. Longitudinal strain on right collision post, centered longitudinally, top edge
Channel Name: CPRS5

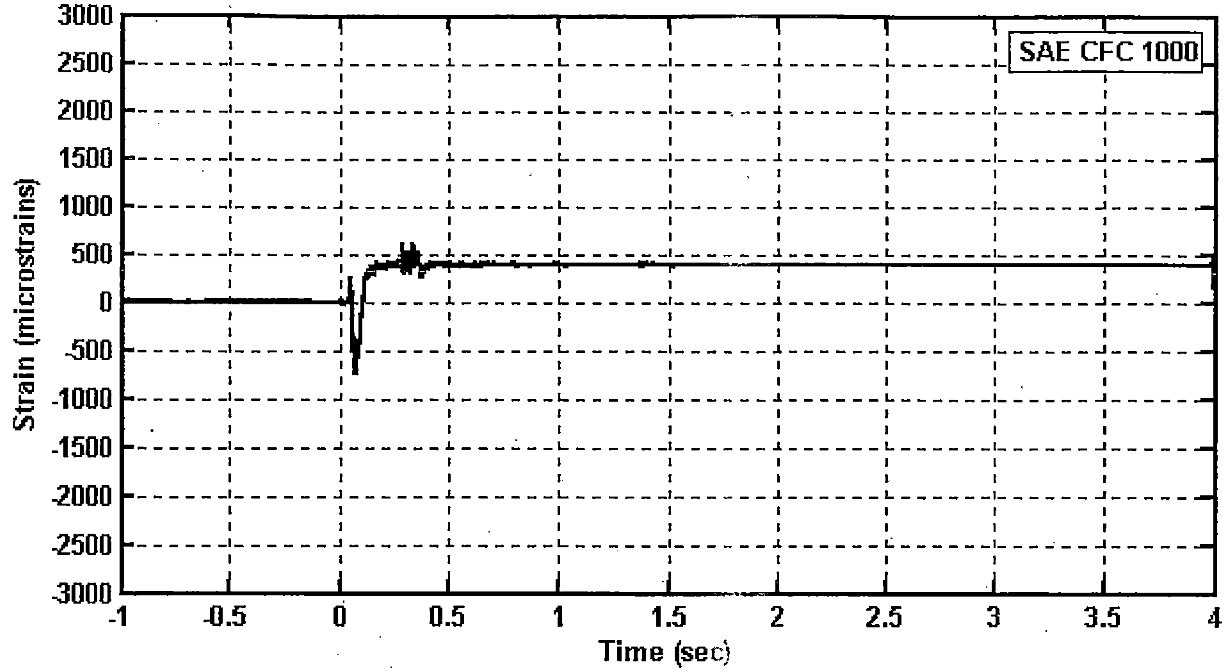

Figure F41. Vertical strain on windshield post, bottom edge of windshield, left side
Channel Name: CPWBL

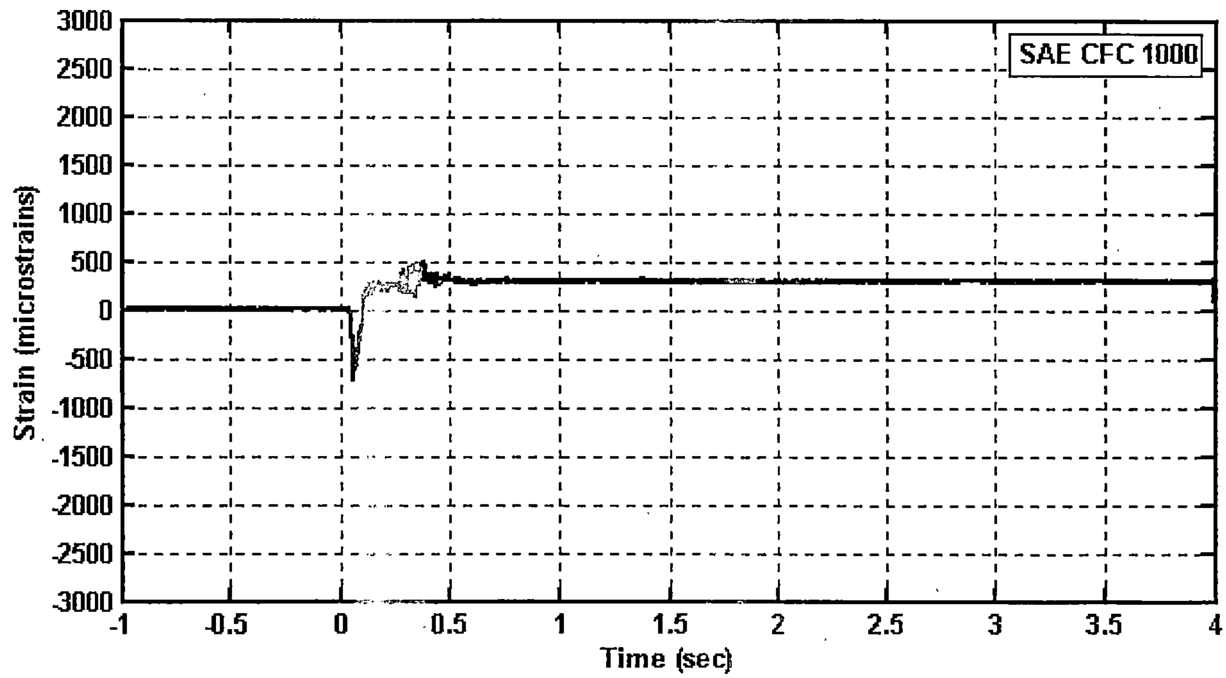

Figure F42. Vertic strain on windshield post, bottom edge of windshield, right side
Channel Name: CPWBR

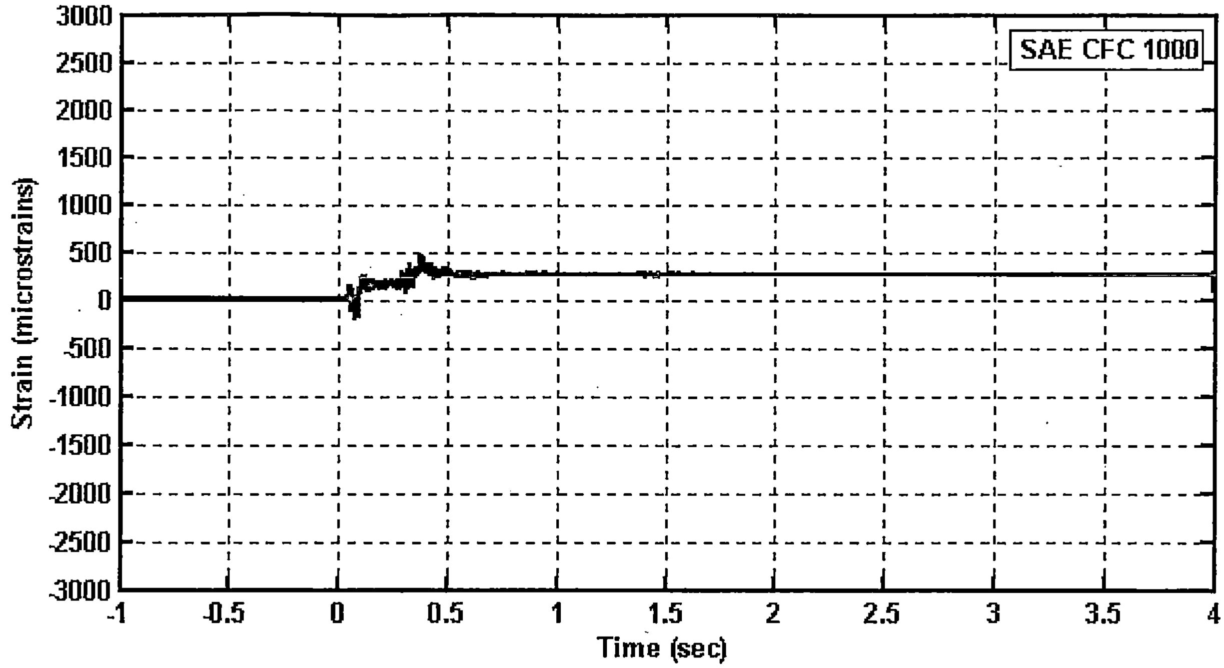

Figure F43. Vertical strain on windshield post, middle of windshield, left side
Channel Name: CPWML

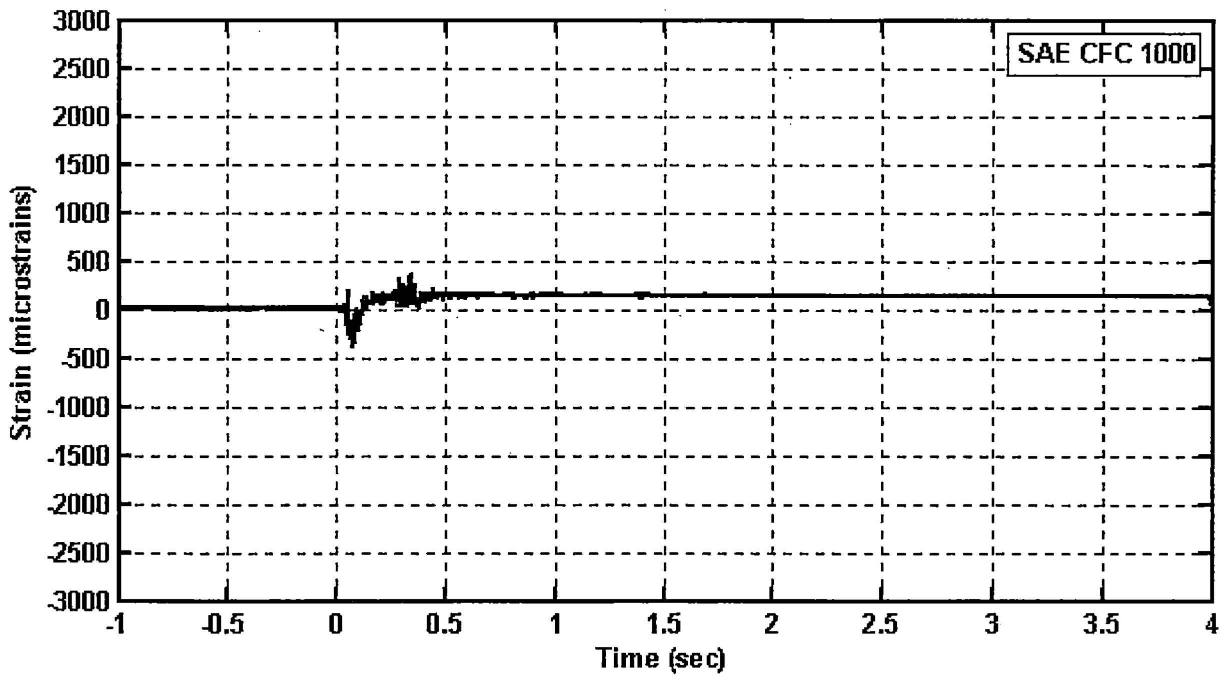

Figure F44. Vertical strain on windshield post, middle of windshield, right side
Channel Name: CPWMR

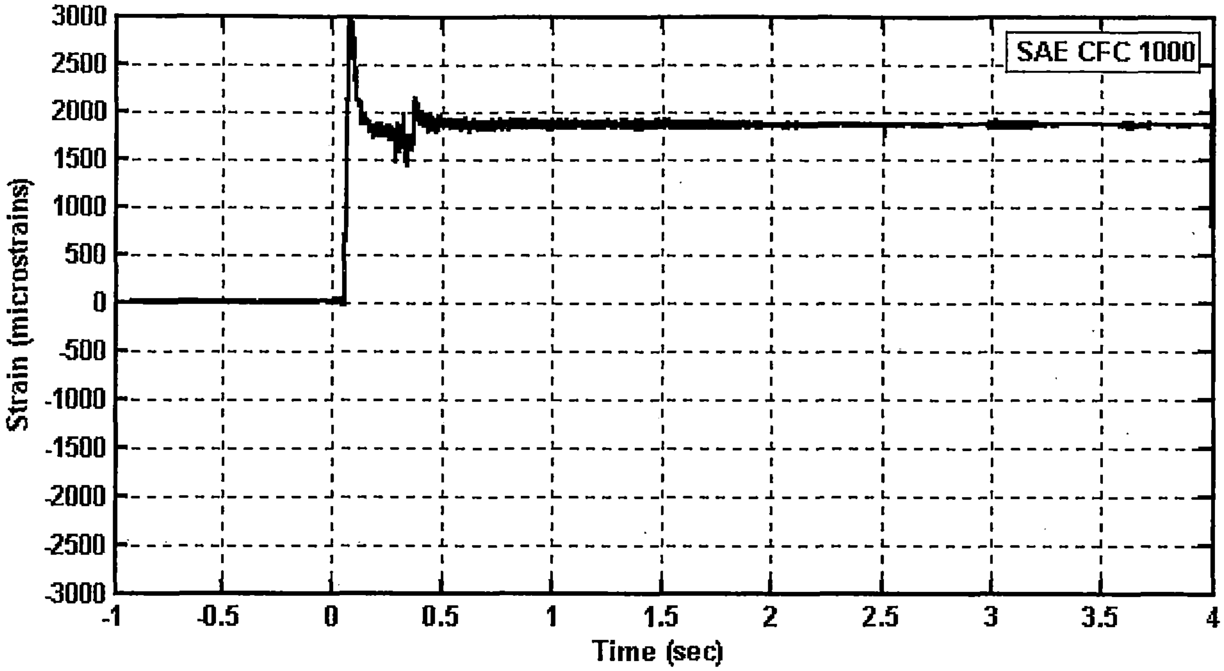

Figure F45. Vertical strain on windshield post, top edge of windshield, left side
Channel Name: CPWTL

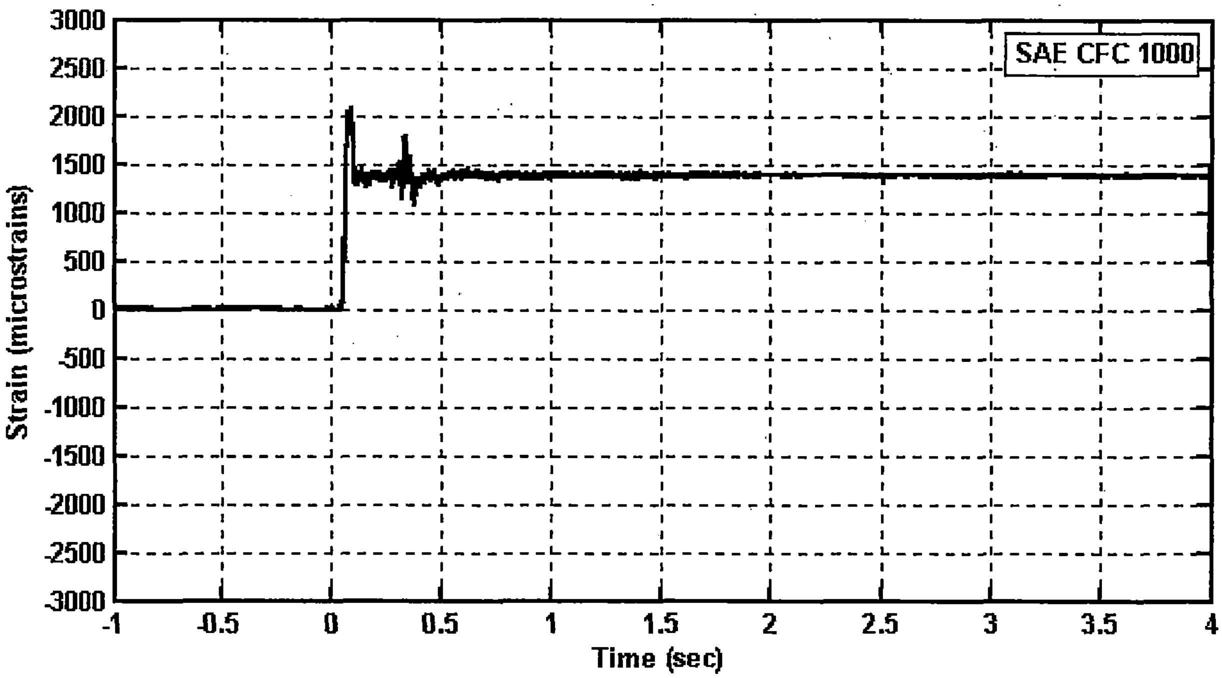

Figure F46. Vertical strain on windshield post, top edge of windshield, right side
Channel Name: CPWTR

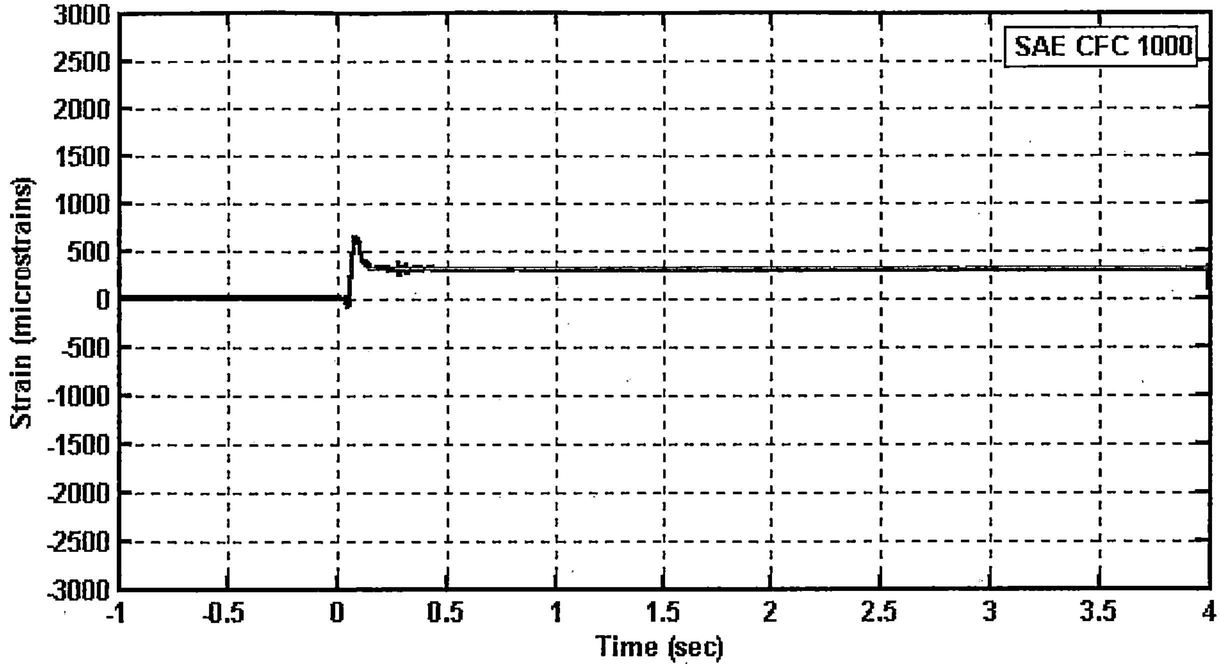

Figure F47. Longitudinal strain on underframe, about even with the leading axle, left side
Channel Name: ULF

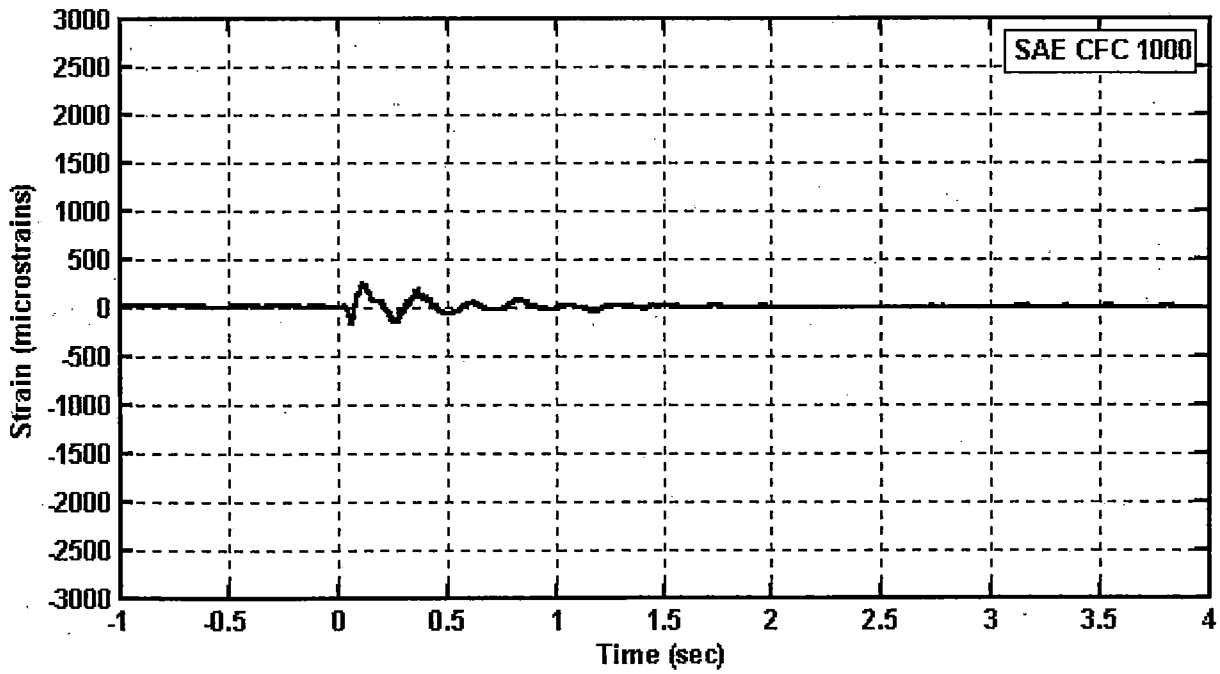

Figure F48. Longitudinal strain on underframe, just in front of the fuel tank, left side
Channel Name: ULMF

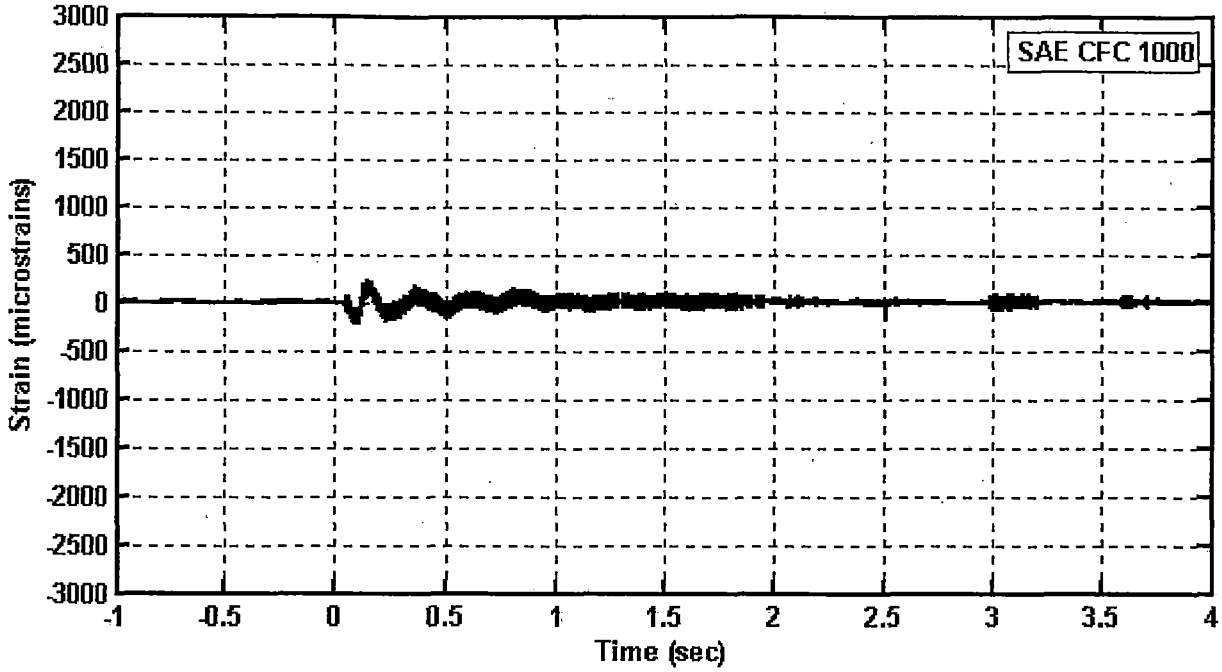

Figure F49. Longitudinal strain on underframe, just behind the fuel tank, left side
Channel Name: ULMR

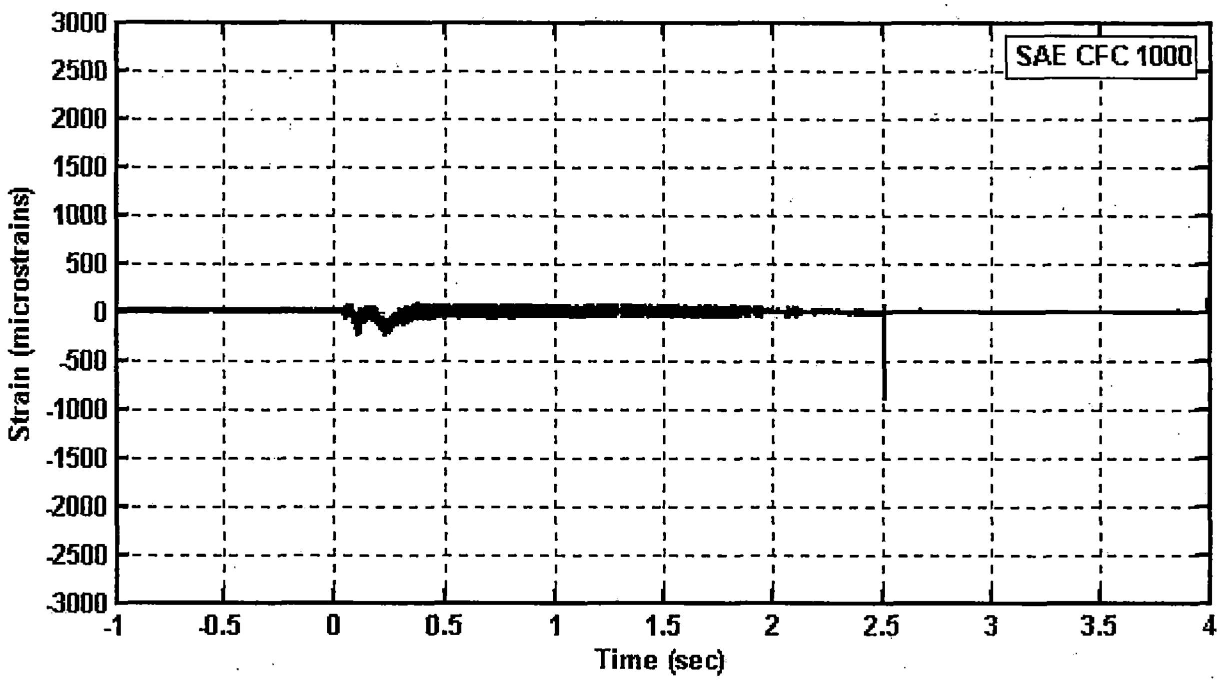

Figure F50. Longitudinal strain on underframe, about even with the trailing axle, left side
Channel Name: ULR

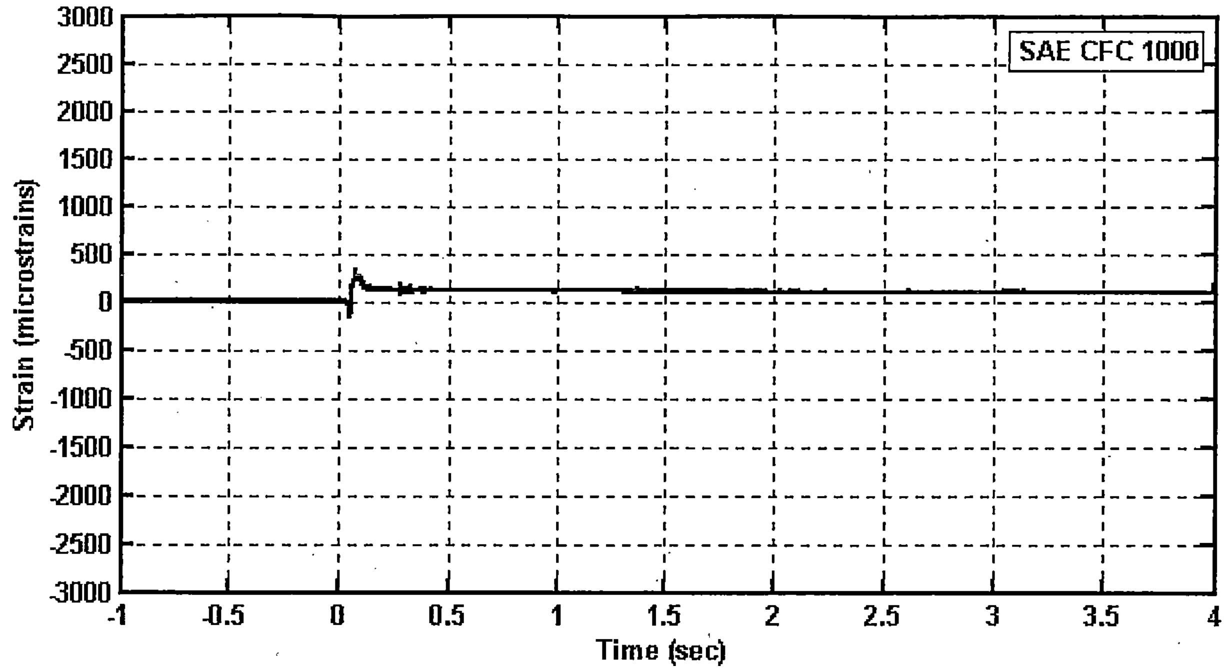

Figure F51. Longitudinal strain on underframe, about even with the leading axle, center
Channel Name: UMF

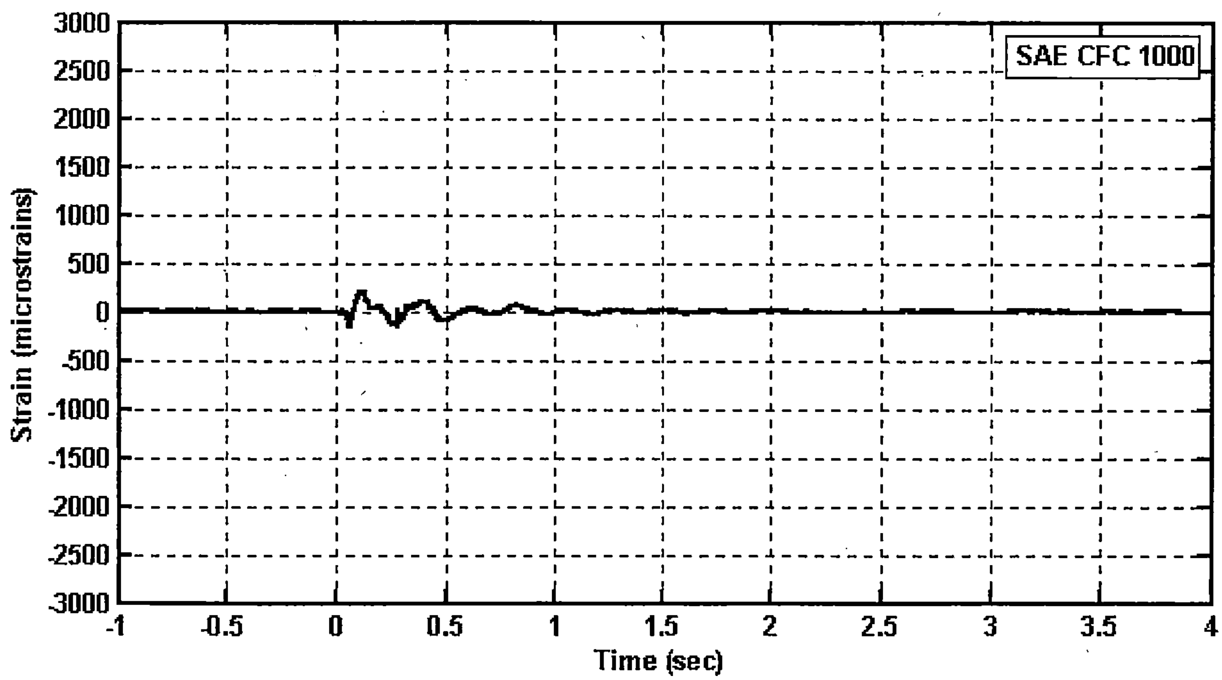

Figure F52. Longitudinal strain on underframe, just in front of the fuel tank, center
Channel Name: UMMF

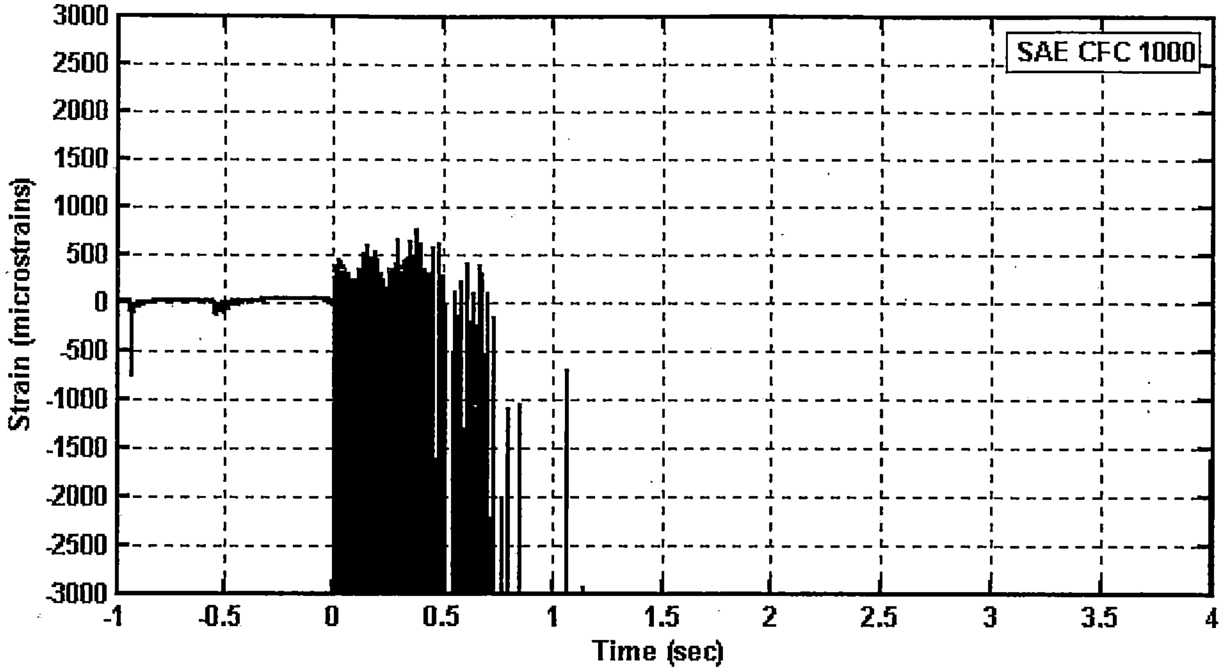

Figure F53. Longitudinal strain on underframe, just behind the fuel tank, center
Channel Name: UMMR

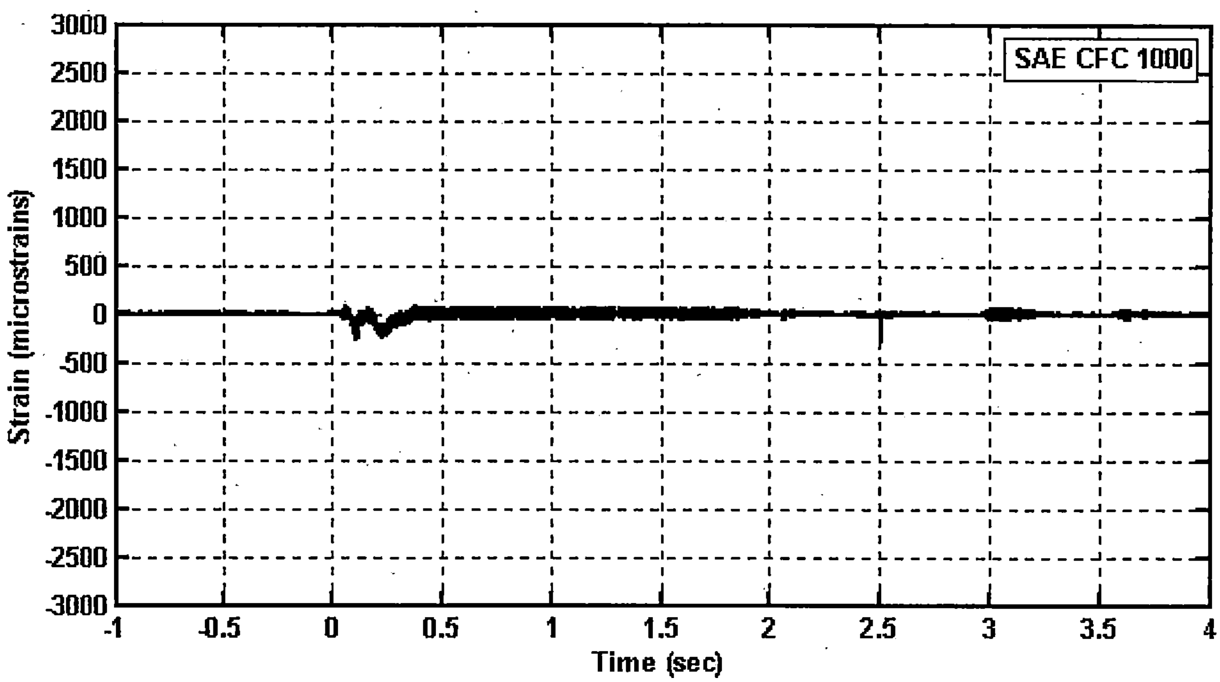

Figure F54. Longitudinal strain on underframe, about even with the trailing axle, center
Channel Name: UMR

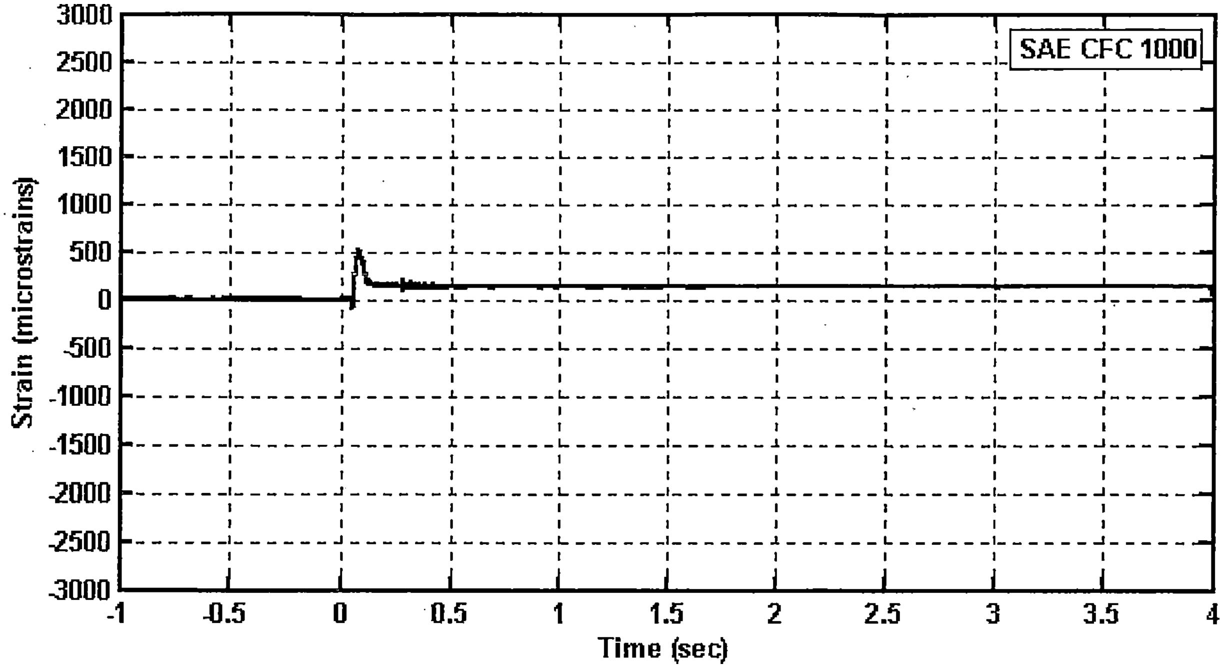

Figure F55. Longitudinal strain on underframe, about even with the leading axle, right side
Channel Name: URF

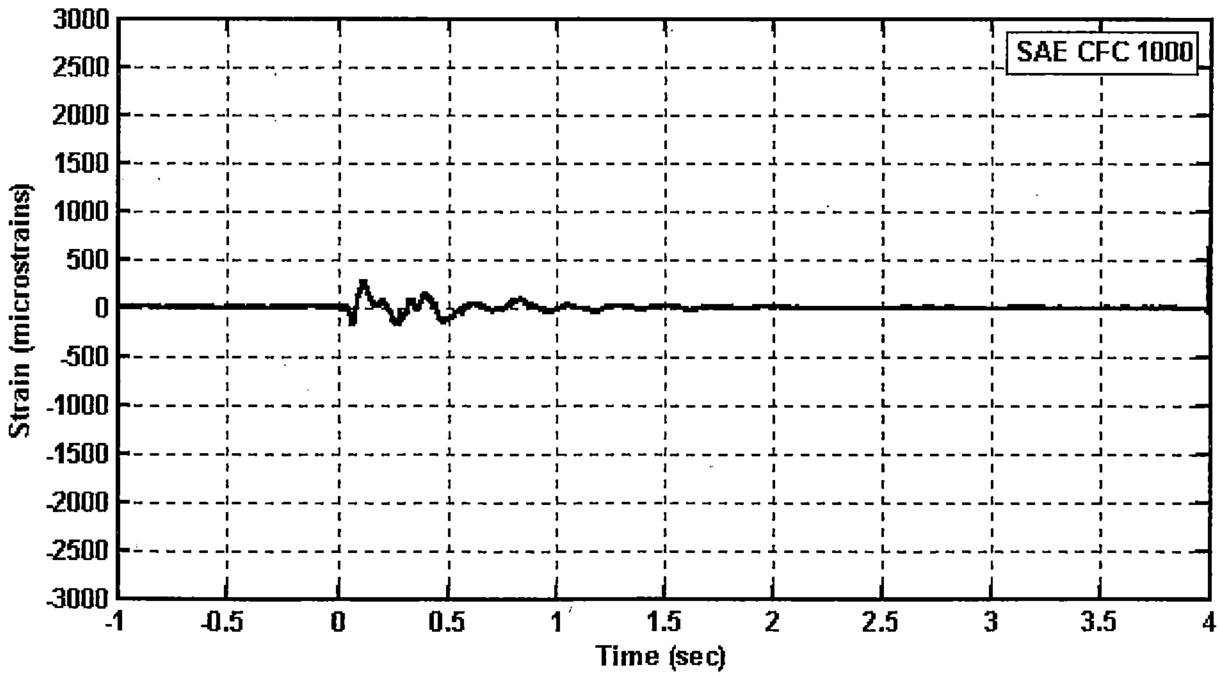

Figure F56. Longitudinal strain on underframe, just in front of the fuel tank, right side
Channel Name: URMF

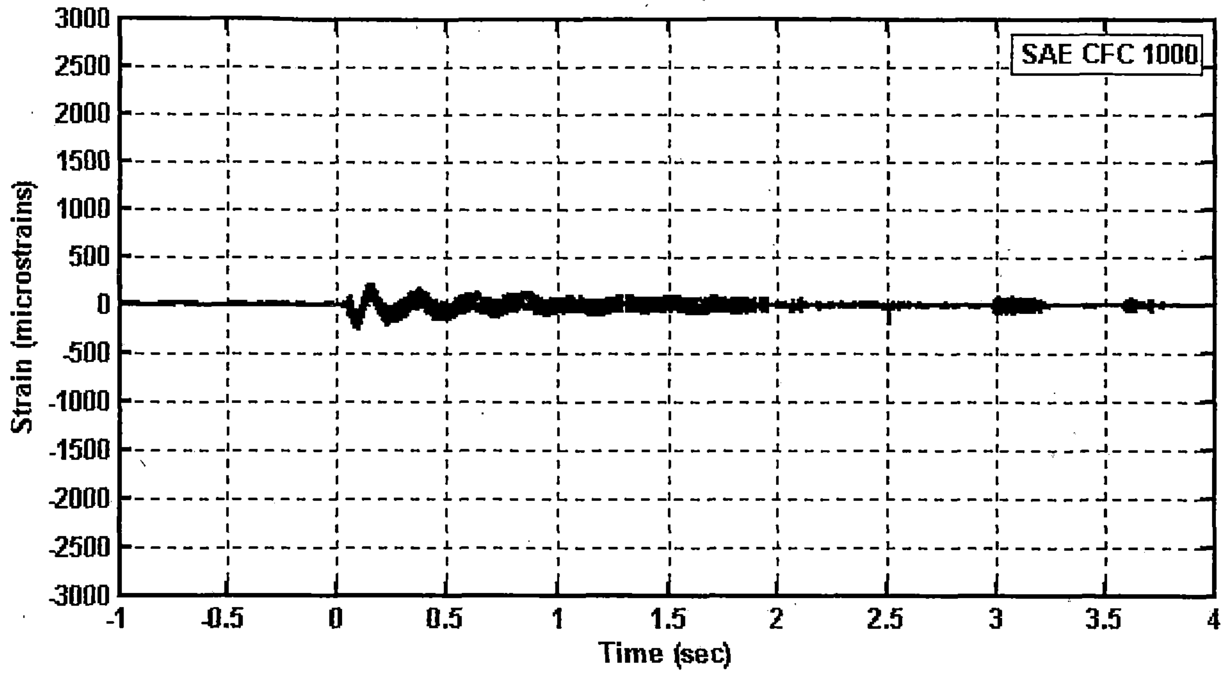

Figure F57. Longitudinal strain on underframe, just behind the fuel tank, right side
Channel Name: URMR

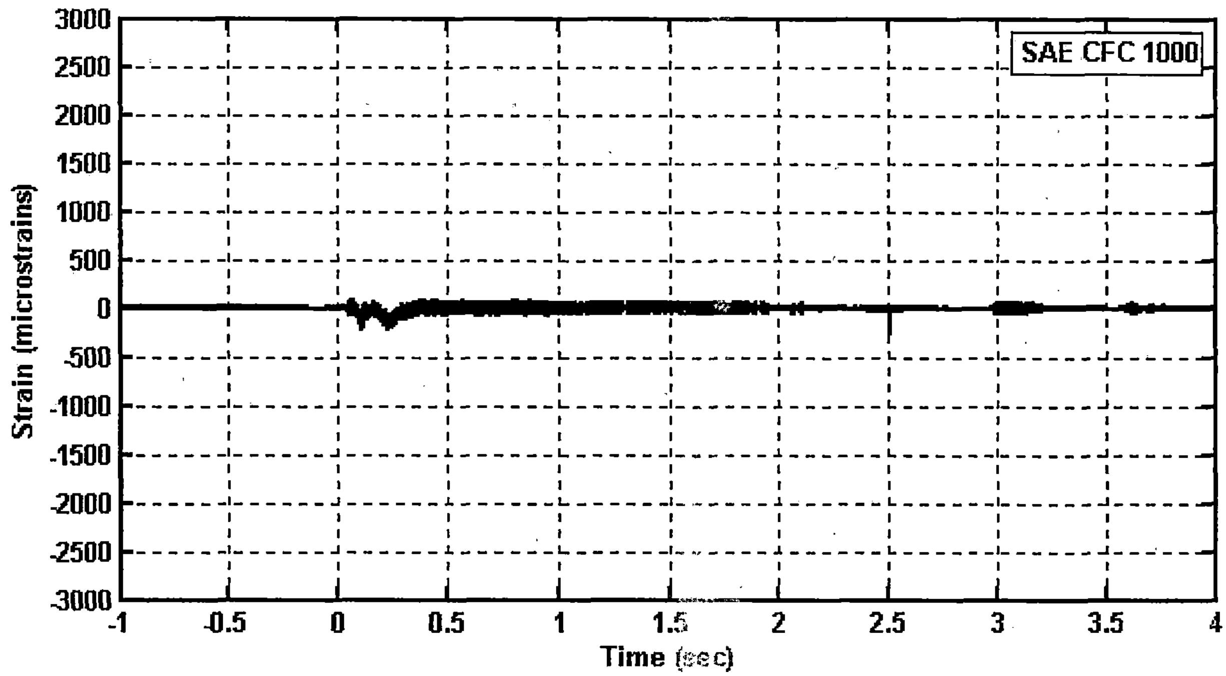

Figure F58. Longitudinal strain on underframe, about even with the trailing axle, right side
Channel Name: URR

APPENDIX C

Acceleration Data, CFC = 1000 Hz

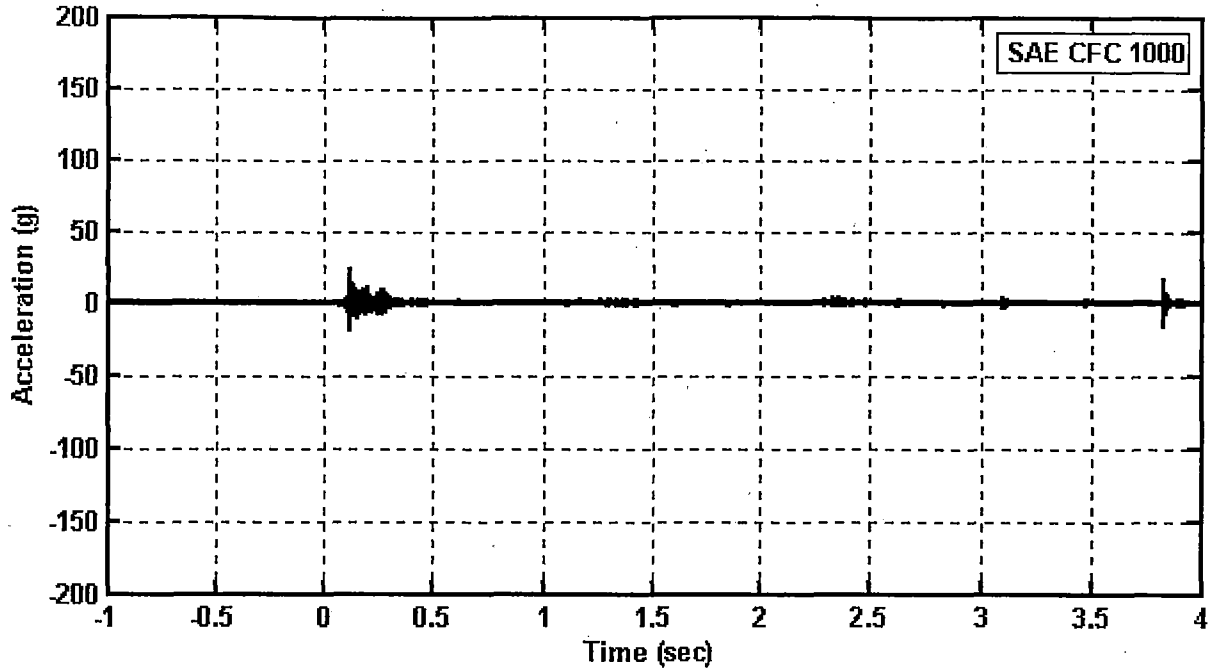

Figure B1. Bullet hopper 1, longitudinal acceleration
Channel Name: BH1_CGX

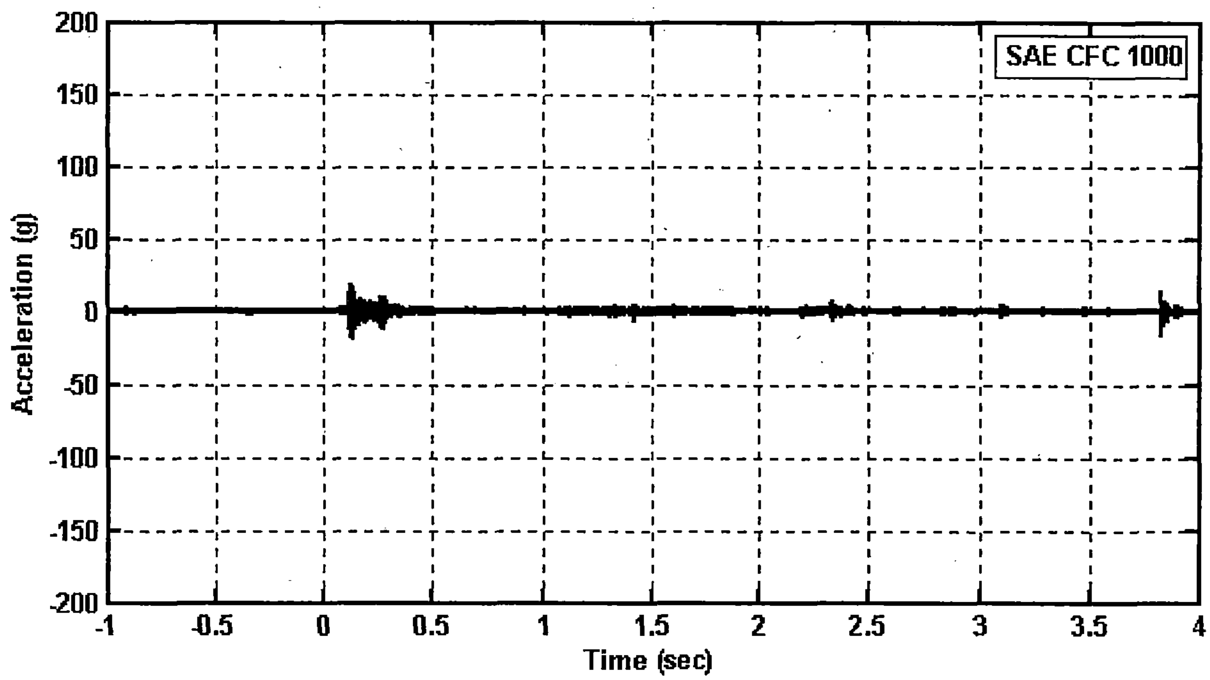

Figure B2. Bullet hopper 1, lateral acceleration
Channel Name: BH1_CGY

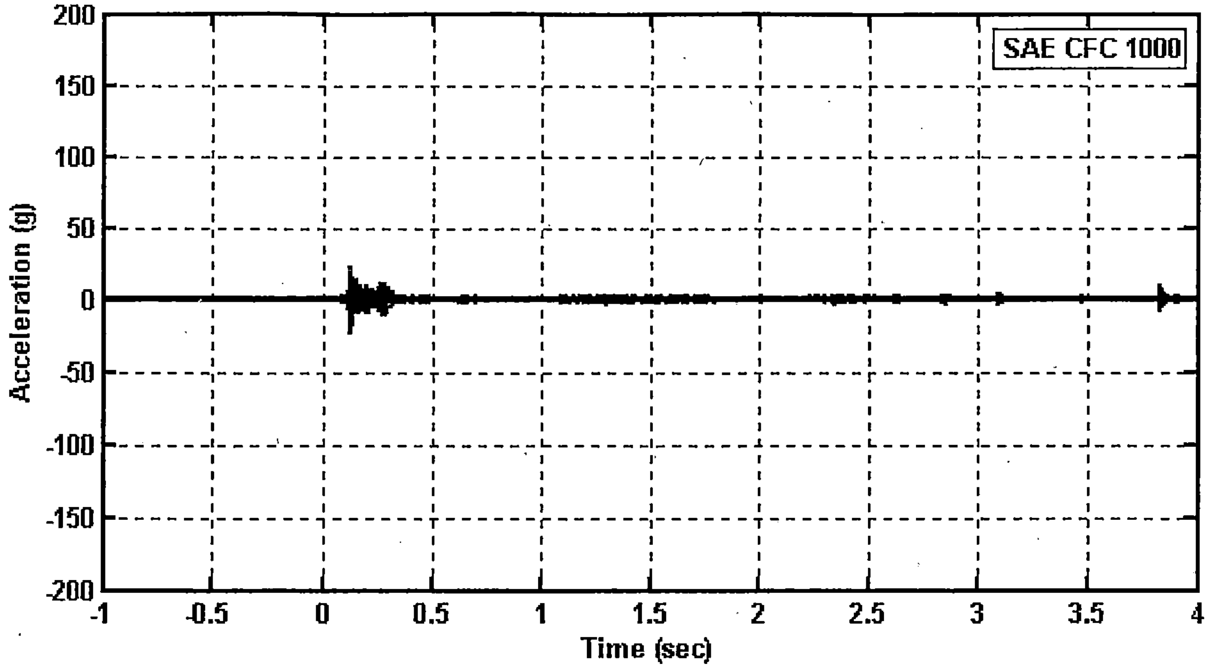

Figure B3. Bullet hopper 1, vertical acceleration
Channel Name: BH1_CGZ

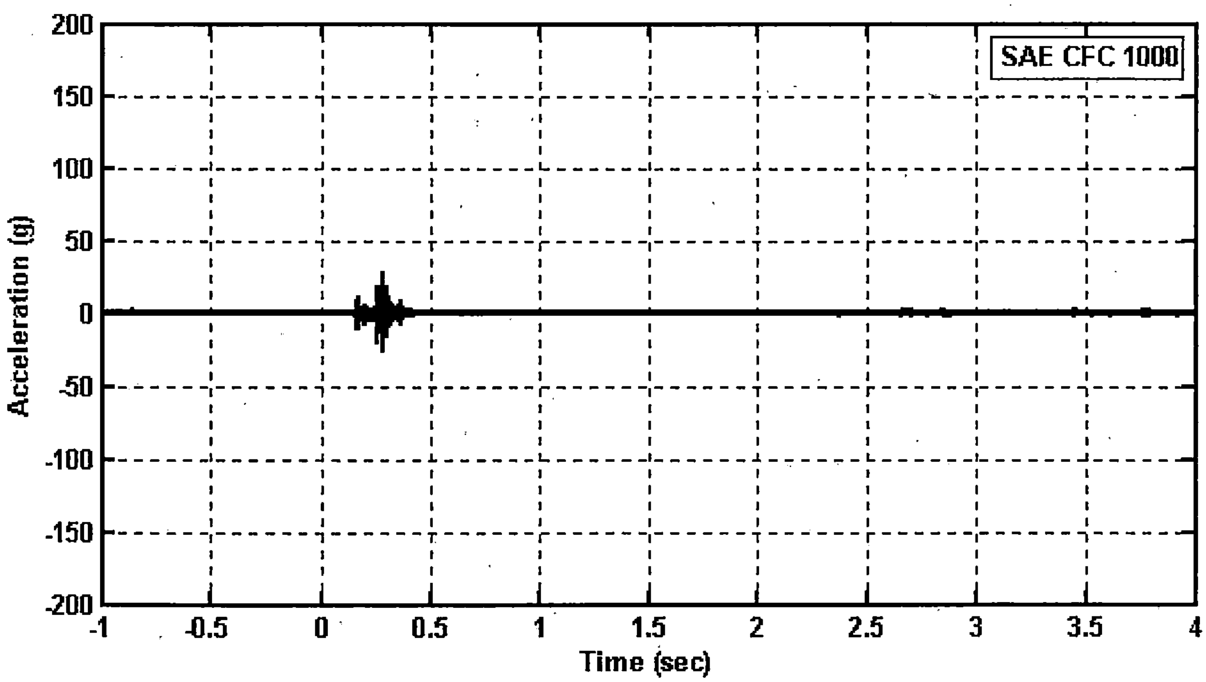

Figure B4. Bullet hopper 2, longitudinal acceleration
Channel Name: BH2_CGX

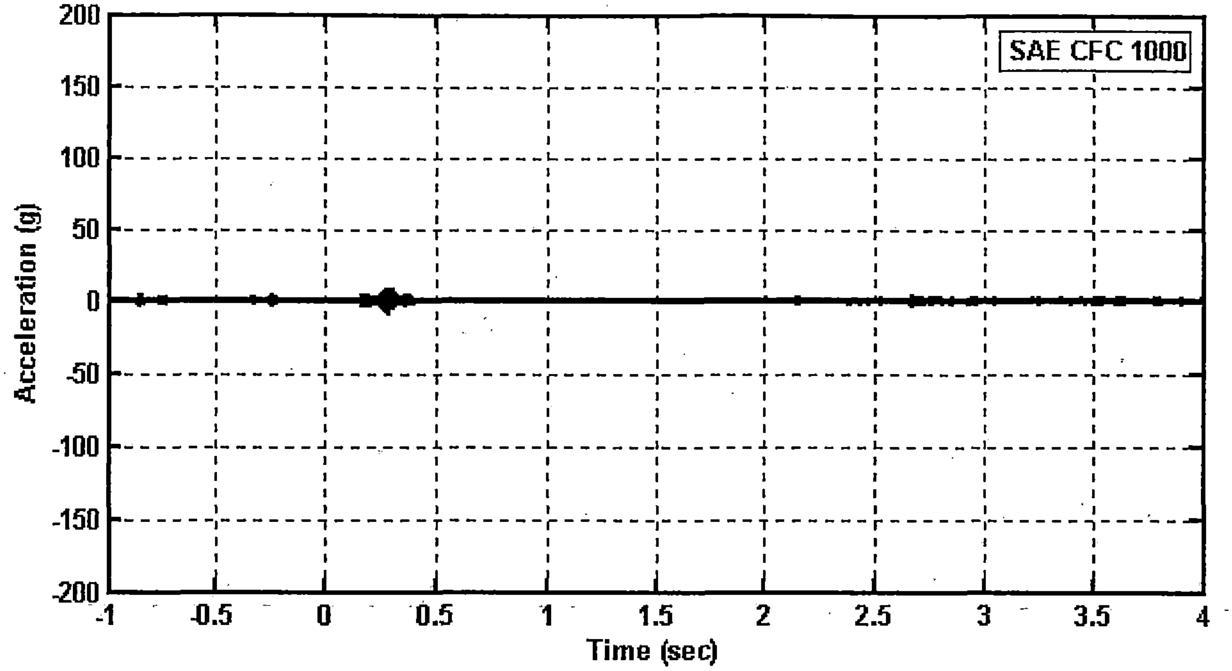

Figure B5. Bullet hopper 2, lateral acceleration
Channel Name: BH2_CGY

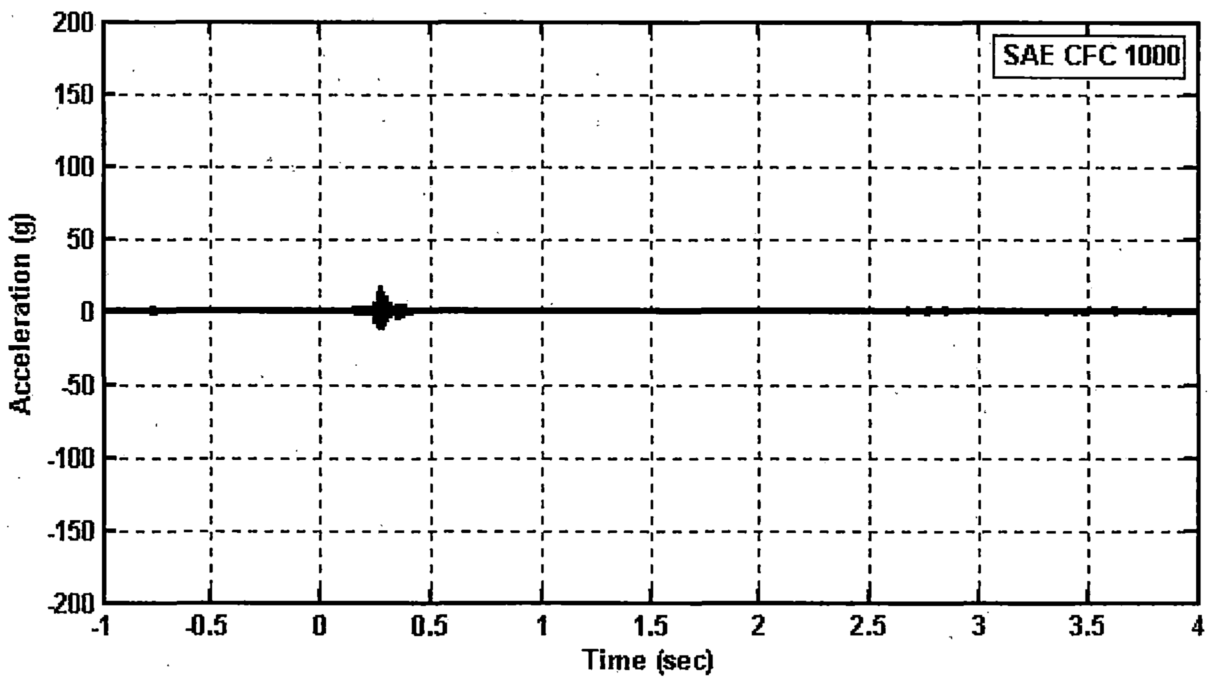

Figure B6. Bullet hopper 2, vertical acceleration
Channel Name: BH2_CGZ

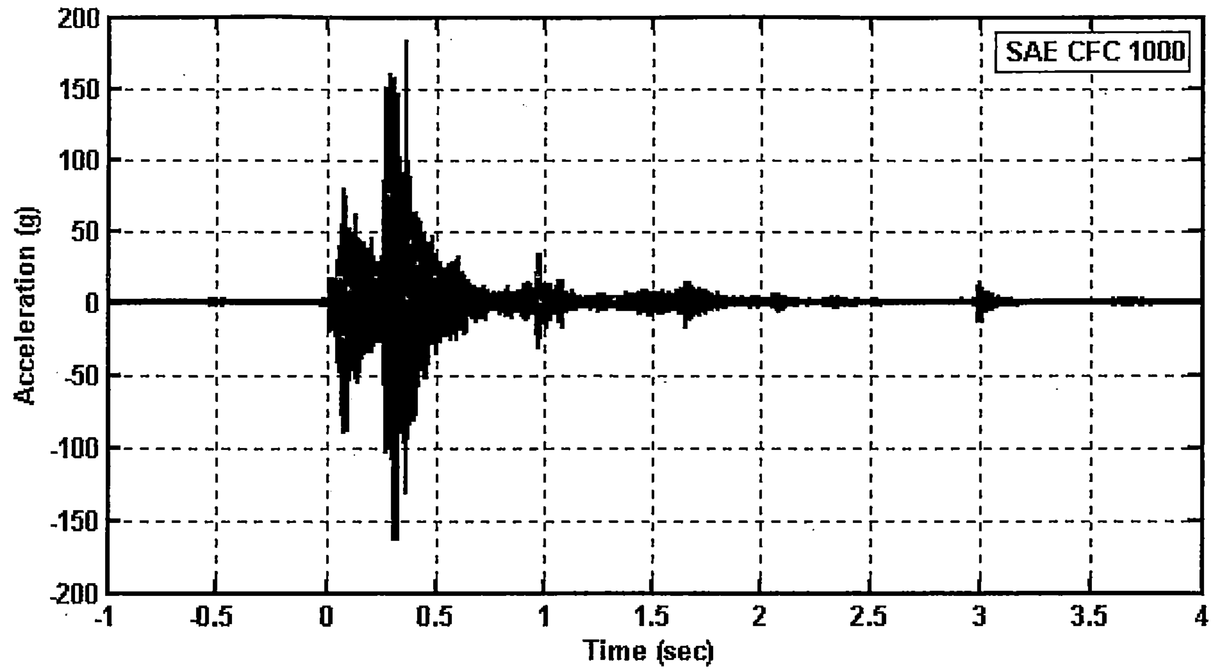

Figure B7. Locomotive floor, location 1, longitudinal acceleration
Channel Name: BL_F1X

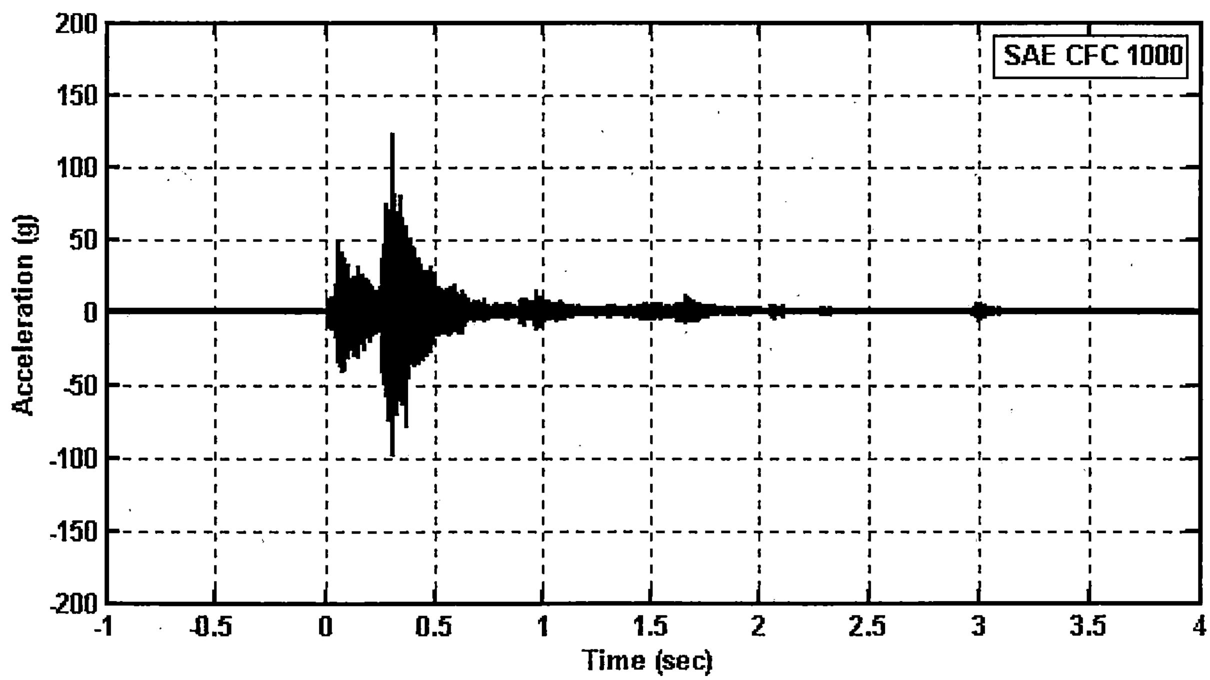

Figure B8. Locomotive floor, location 1, lateral acceleration
Channel Name: BL_F1Y

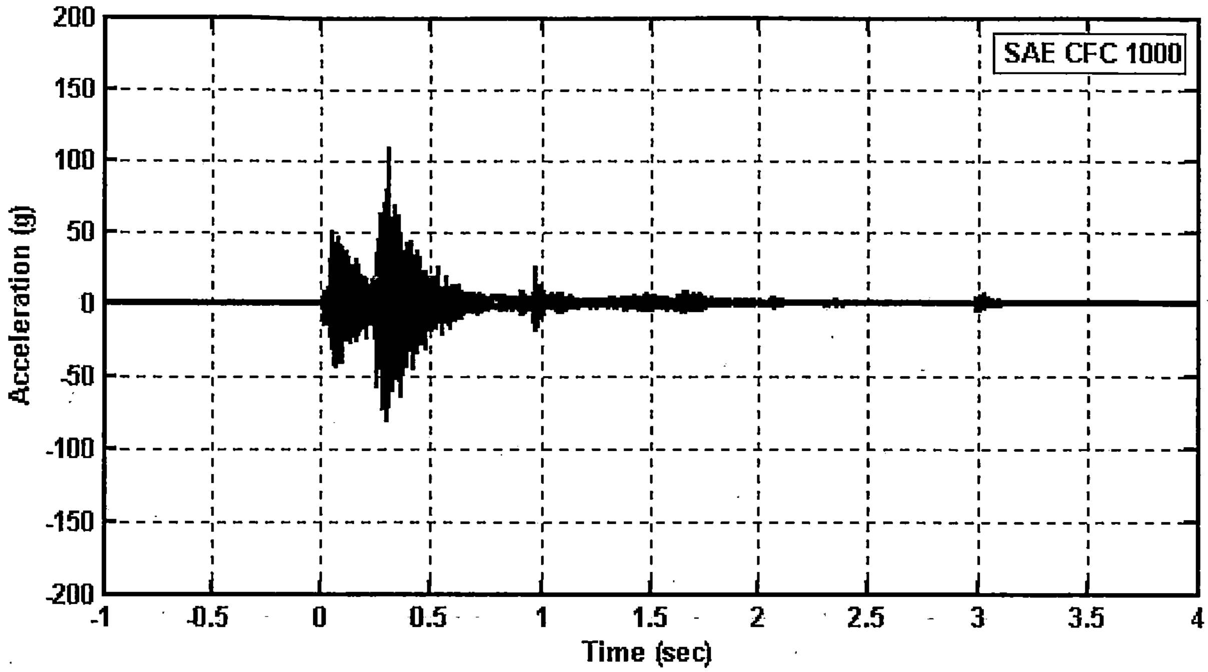

Figure B9. Locomotive floor, location 1, vertical acceleration
Channel Name: BL_F1Z

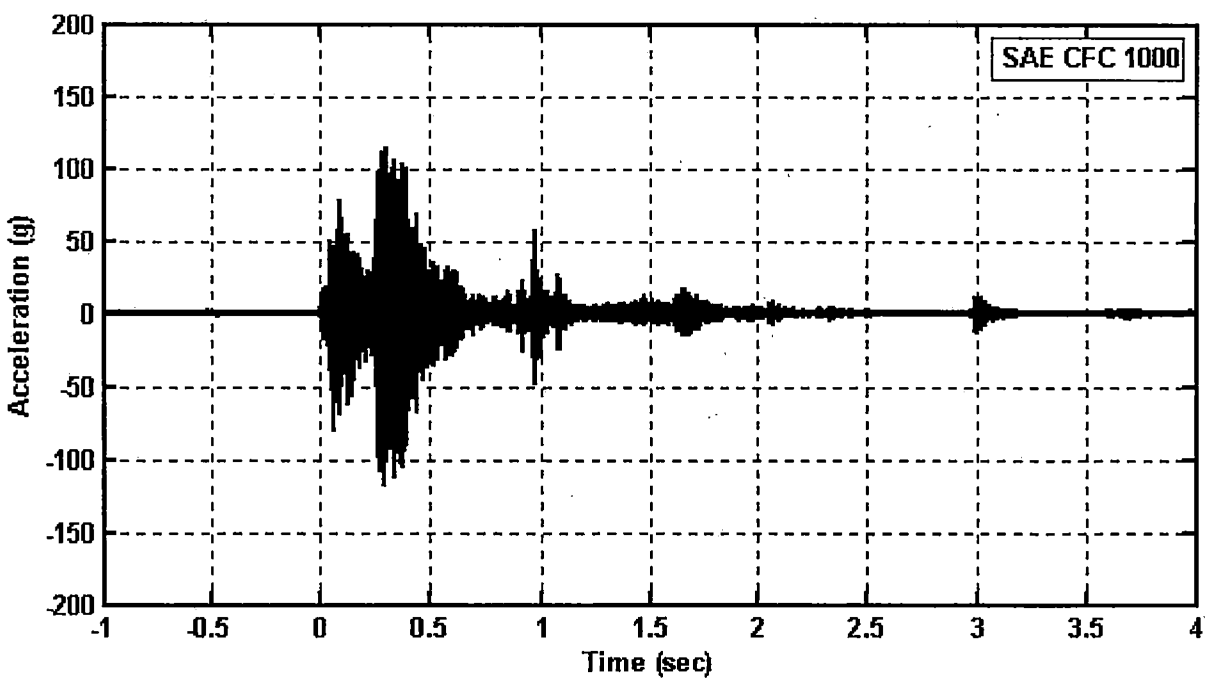

Figure B10. Locomotive floor, location 2, longitudinal acceleration
Channel Name: BL_F2X

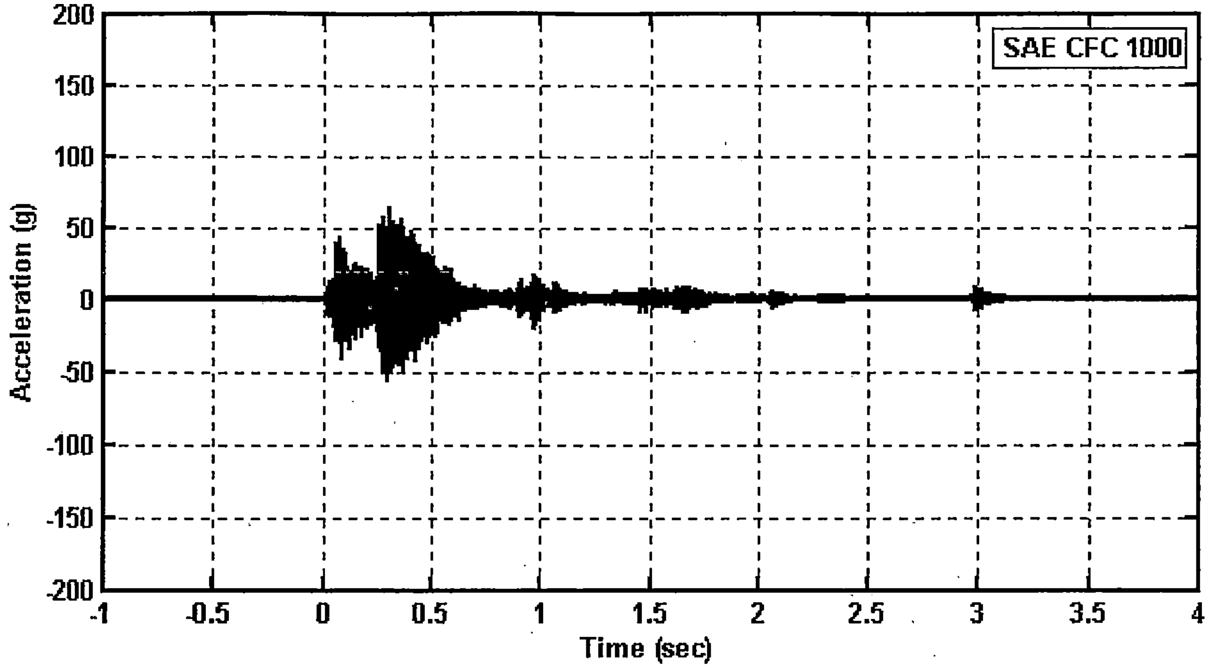

Figure B11. Locomotive floor, location 2, lateral acceleration
Channel Name: BL_F2Y

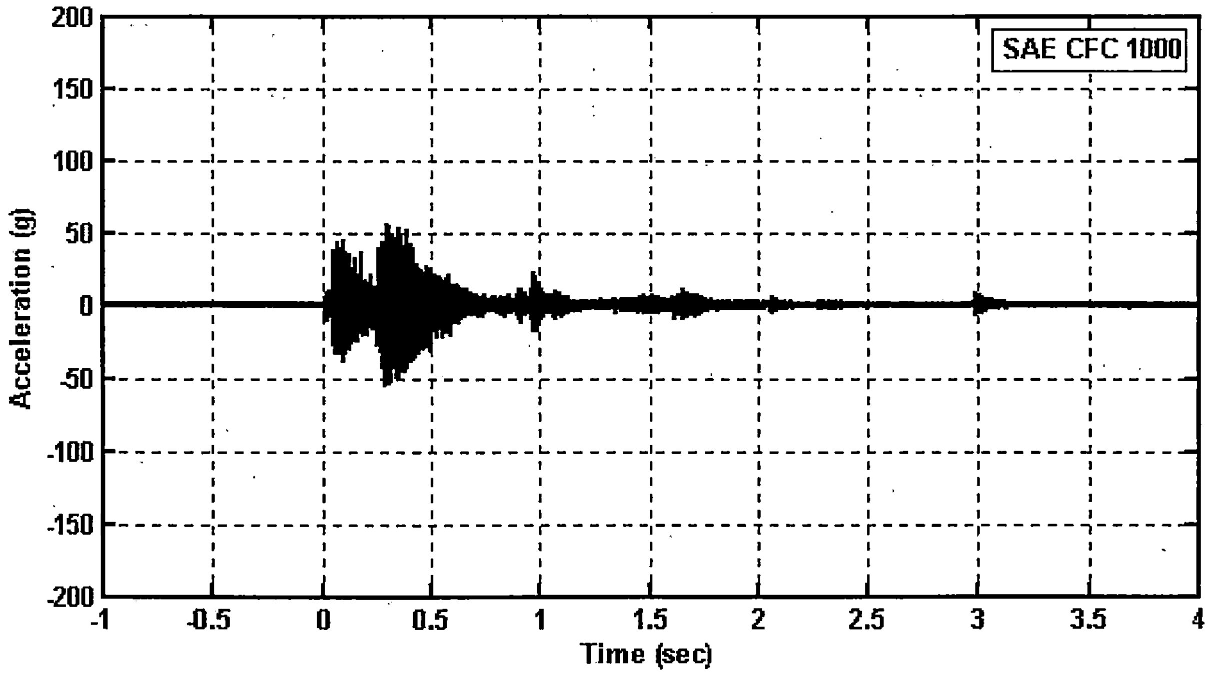

Figure B12. Locomotive floor, location 2, vertical acceleration
Channel Name: BL_F2Z

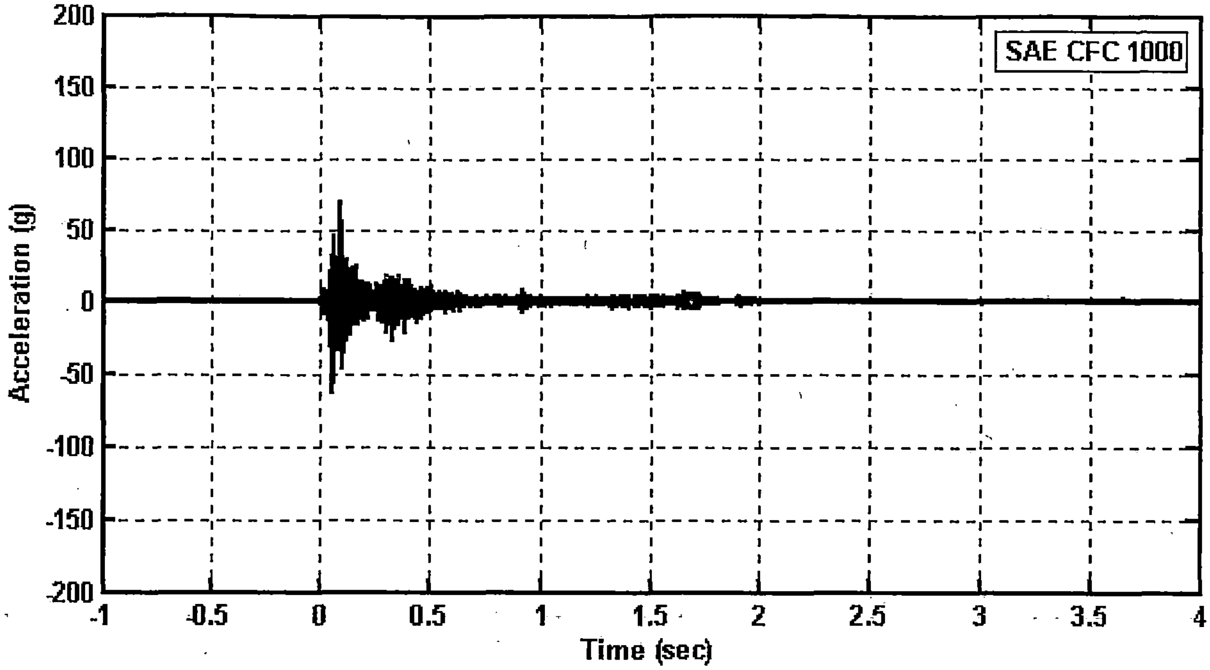

Figure B13. Locomotive event recorder, longitudinal acceleration
Channel Name: BL_RX

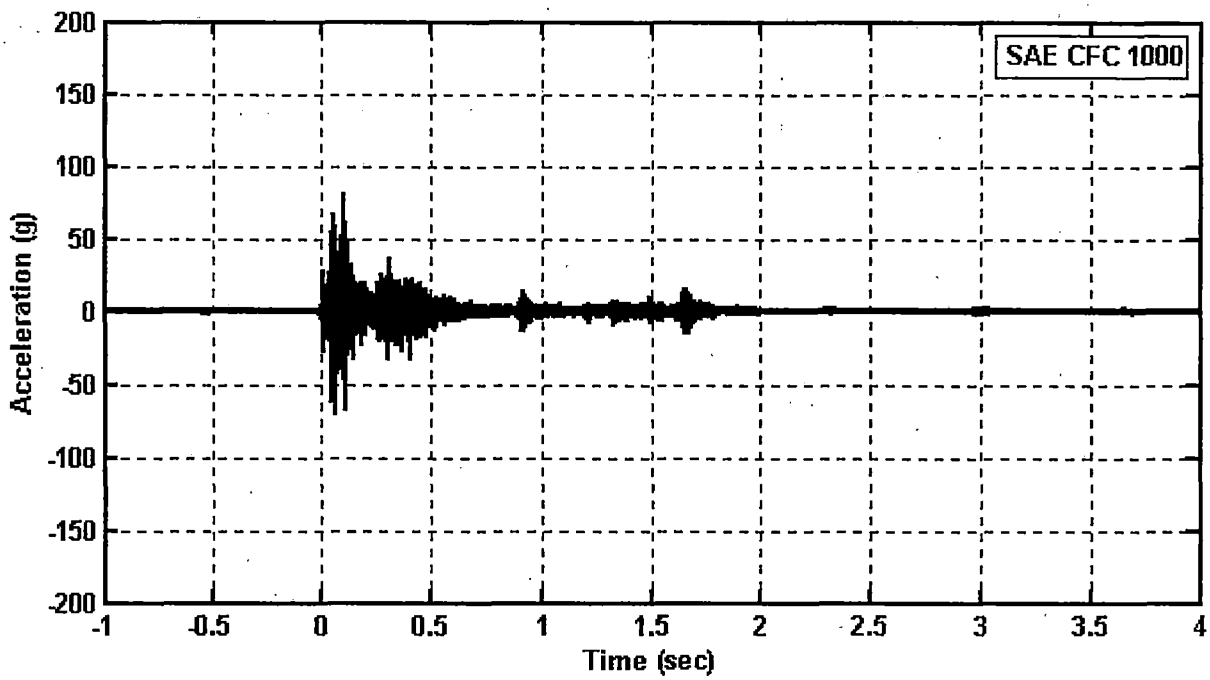

Figure B14. Locomotive event recorder, lateral acceleration
Channel Name: BL_RY

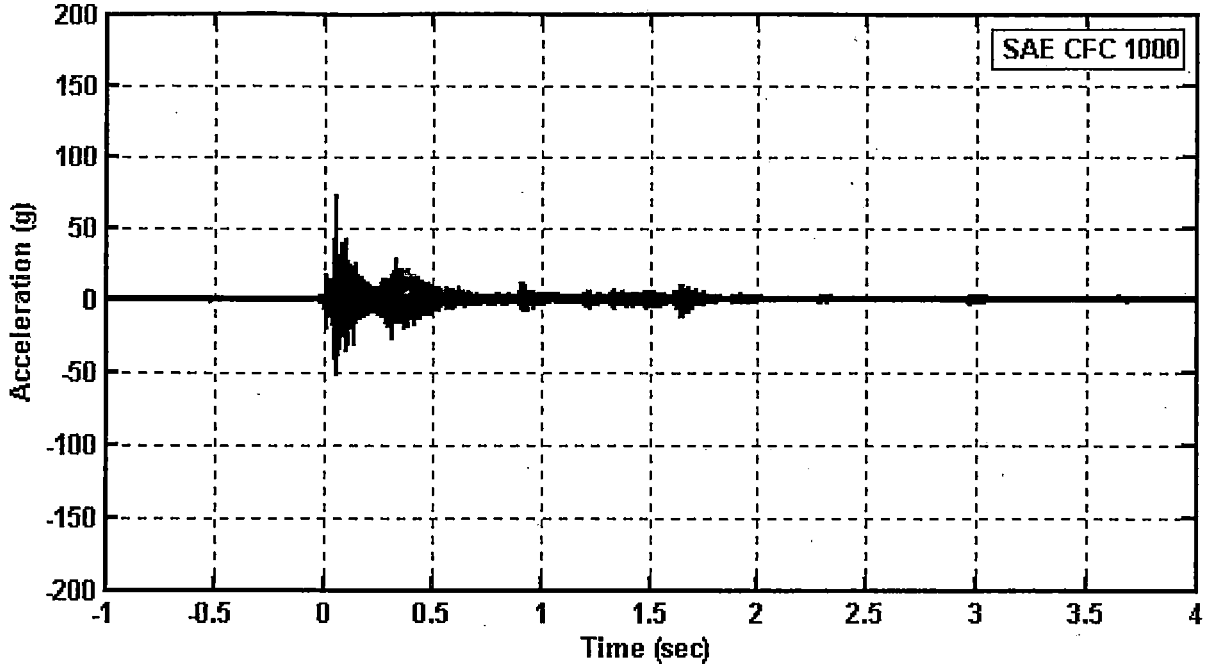

Figure B15. Locomotive event recorder, vertical acceleration
Channel Name: BL_RZ

APPENDIX D

Acceleration Data, Fc = 100 Hz

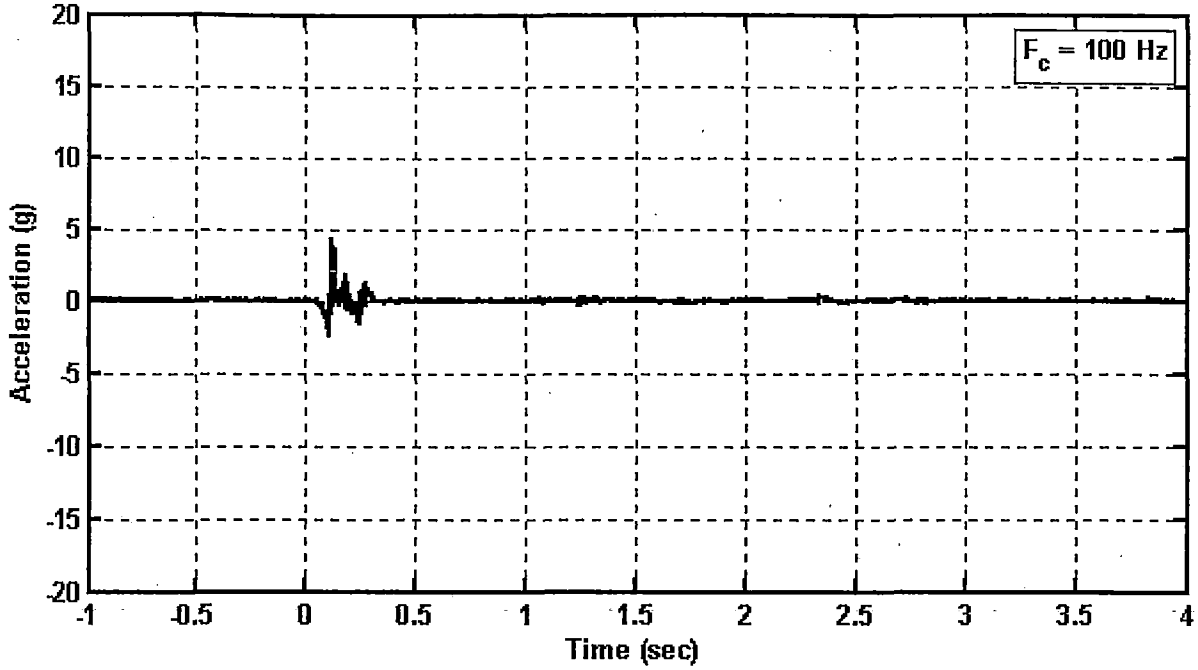

Figure C1. Bullet hopper 1, longitudinal acceleration
Channel Name: BH1_CGX

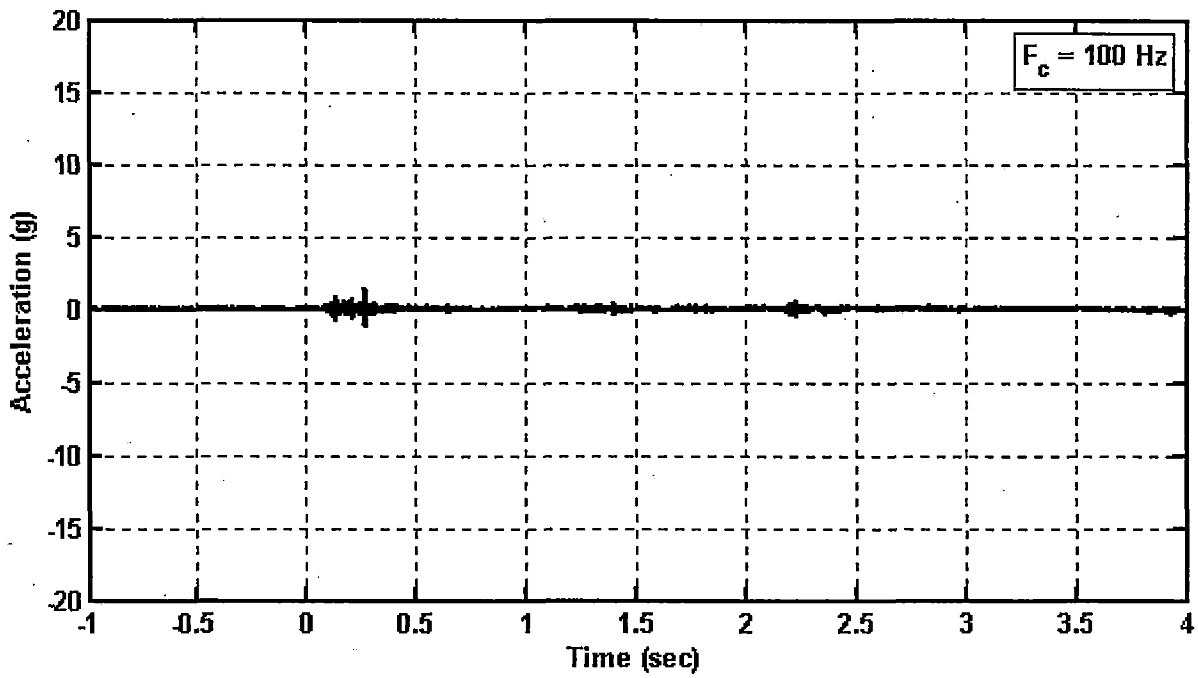

Figure C2. Bullet hopper 1, lateral acceleration
Channel Name: BH1_CGY

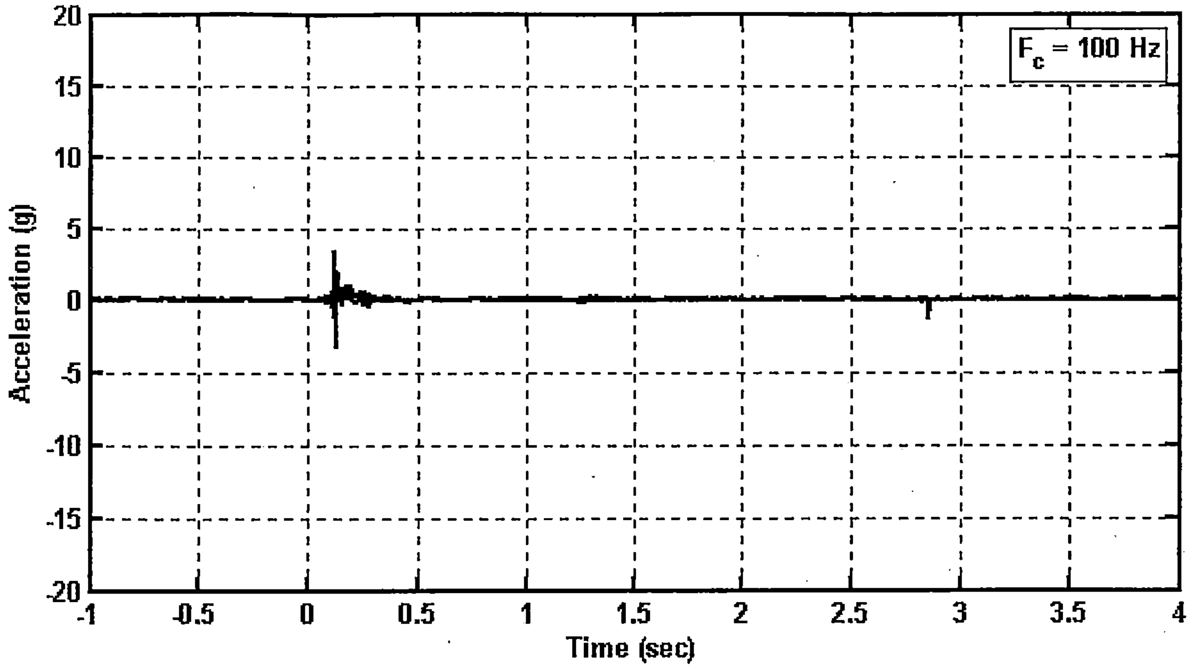

Figure C3. Bullet hopper 1, vertical acceleration
Channel Name: BH1_CGZ

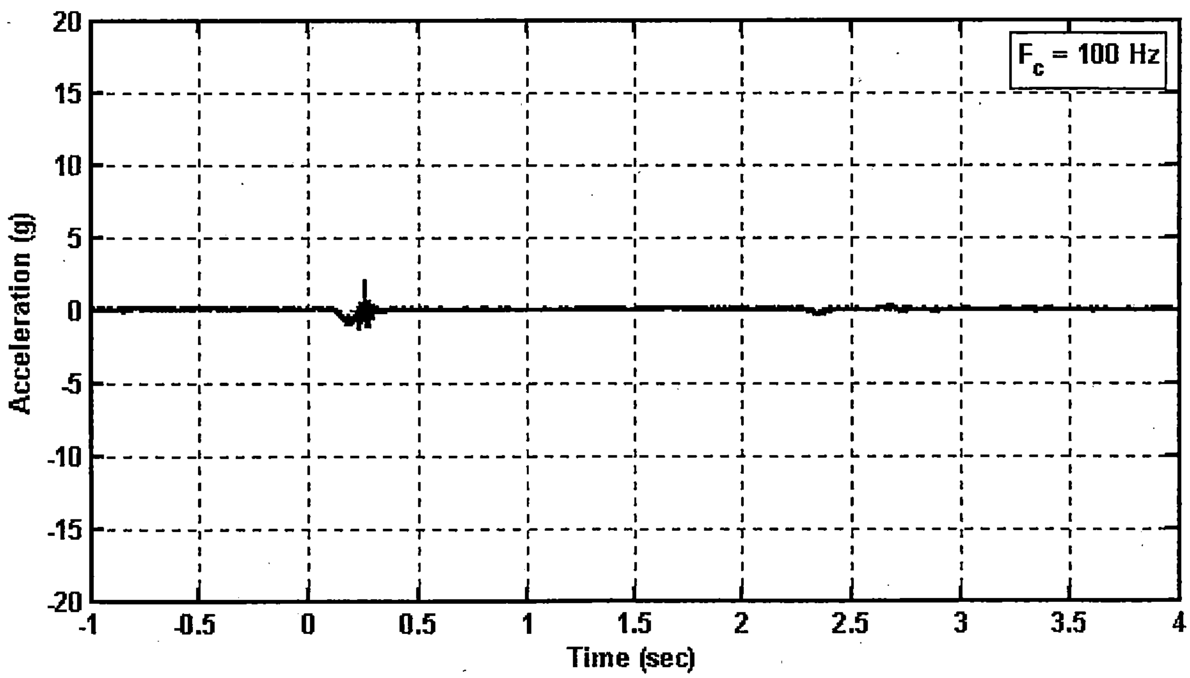

Figure C4. Bullet hopper 2, longitudinal acceleration
Channel Name: BH2_CGX

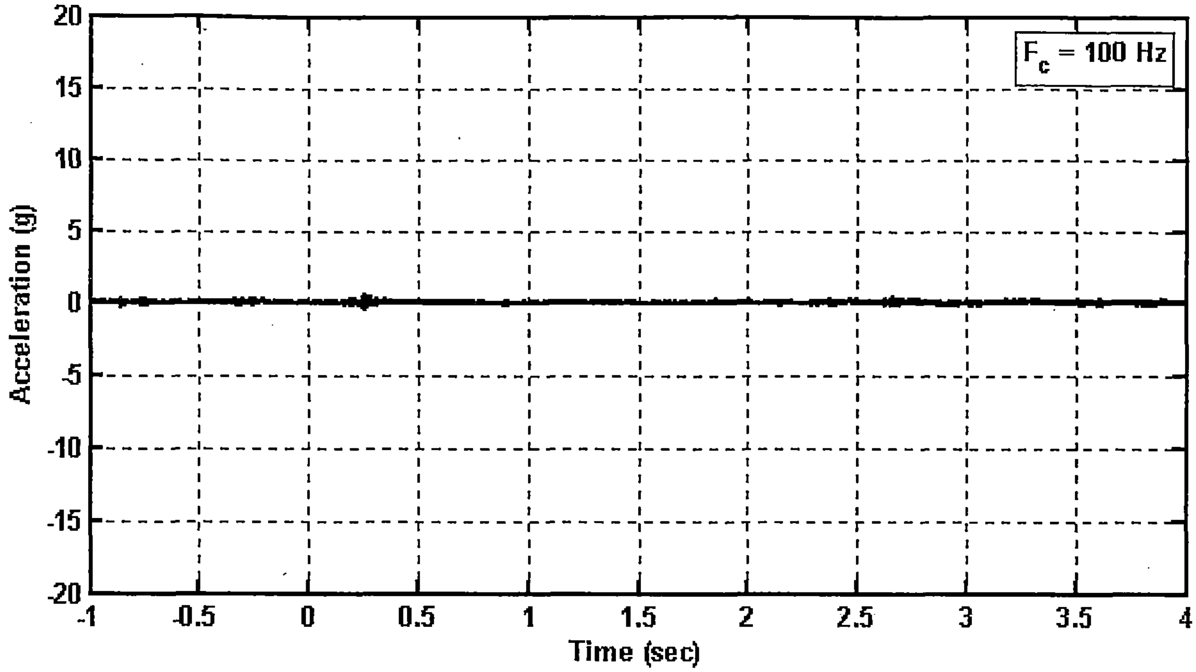

Figure C5. Bullet hopper 2, lateral acceleration
Channel Name: BH2_CGY

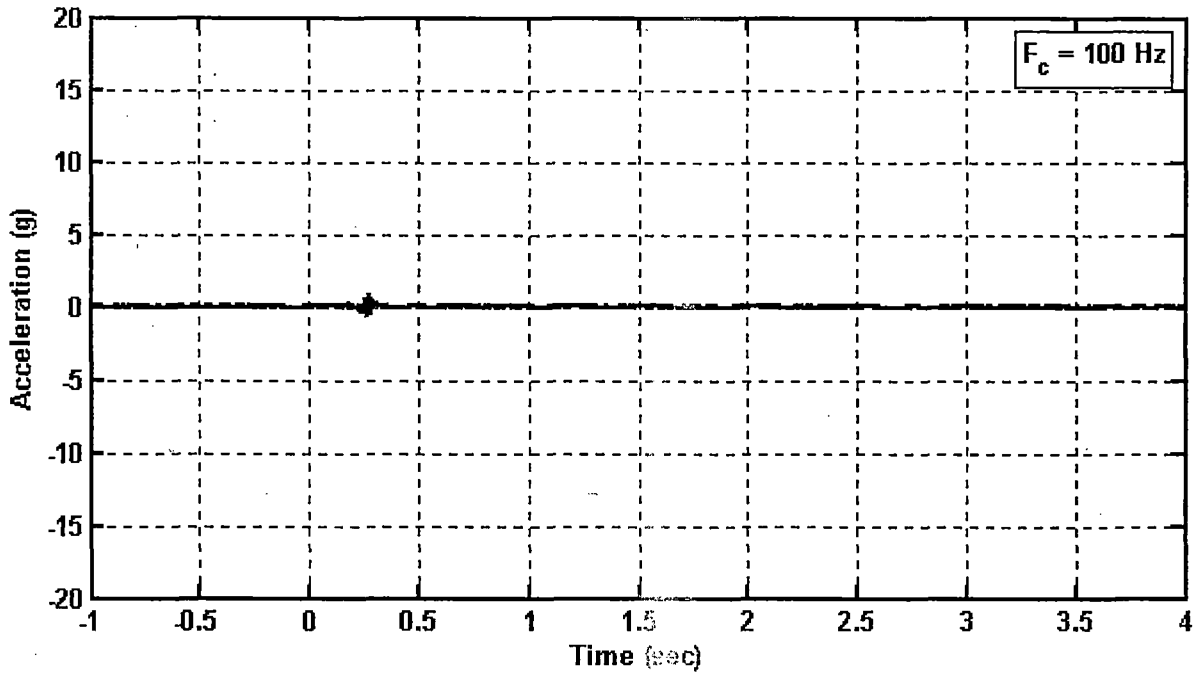

Figure C6. Bullet hopper 2, vertical acceleration
Channel Name: BH2_CGZ

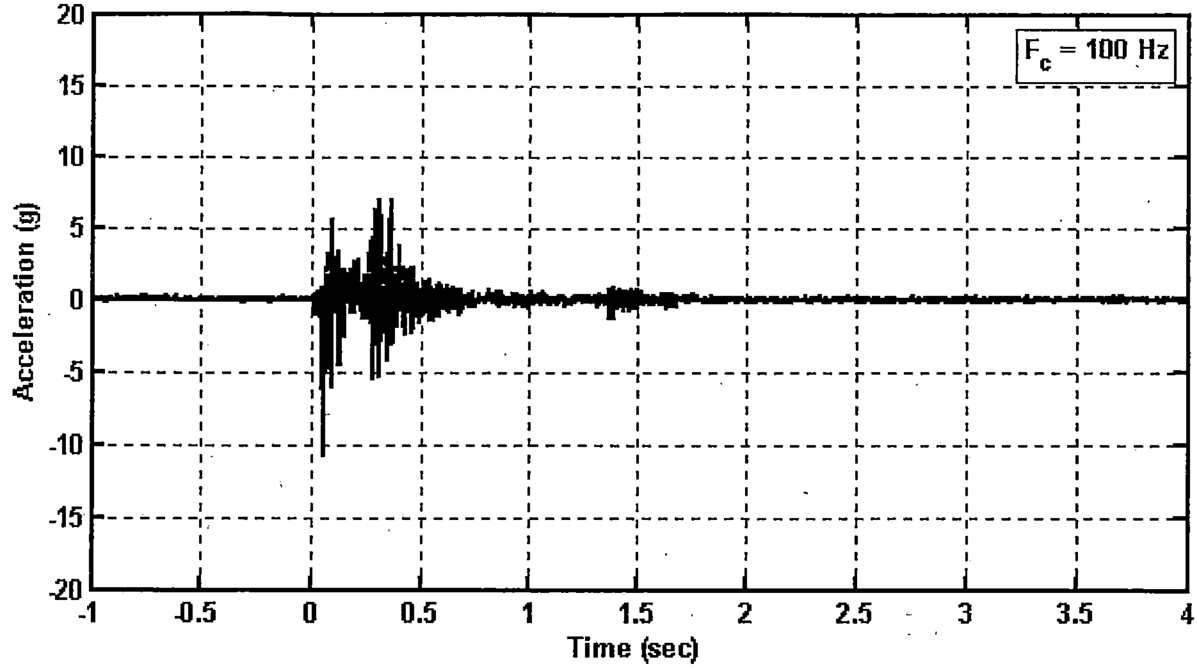

Figure C7. Locomotive floor, location 1, longitudinal acceleration
Channel Name: BL_F1X

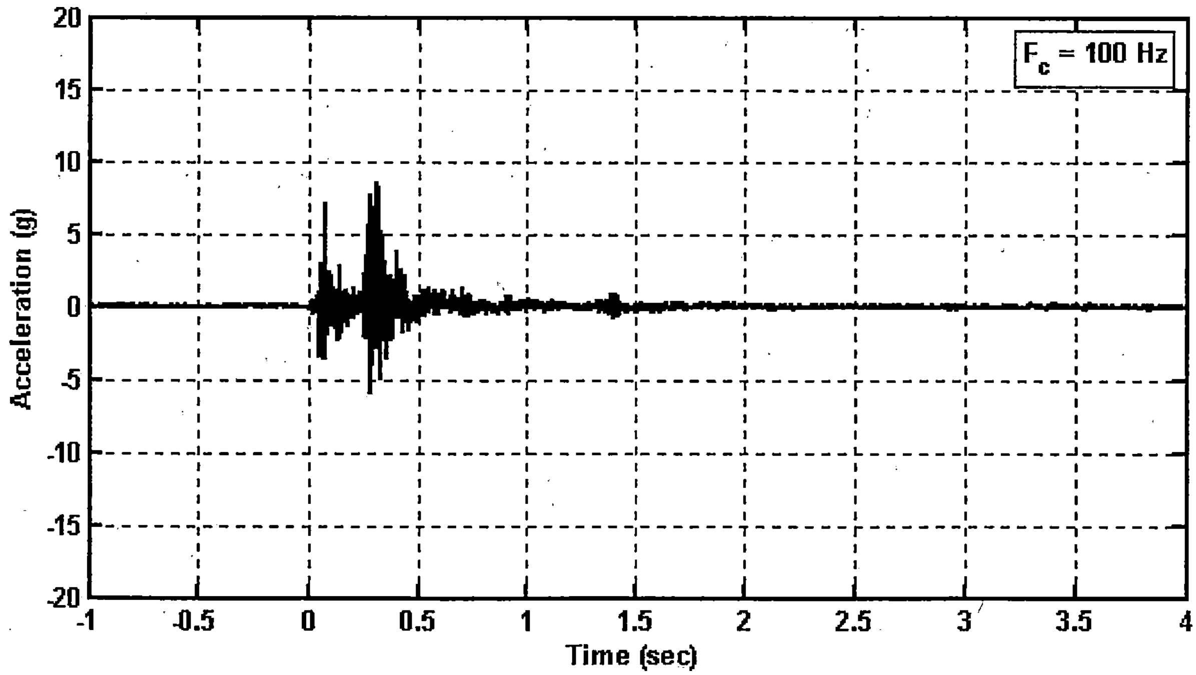

Figure C8. Locomotive floor, location 1, lateral acceleration
Channel Name: BL_F1Y

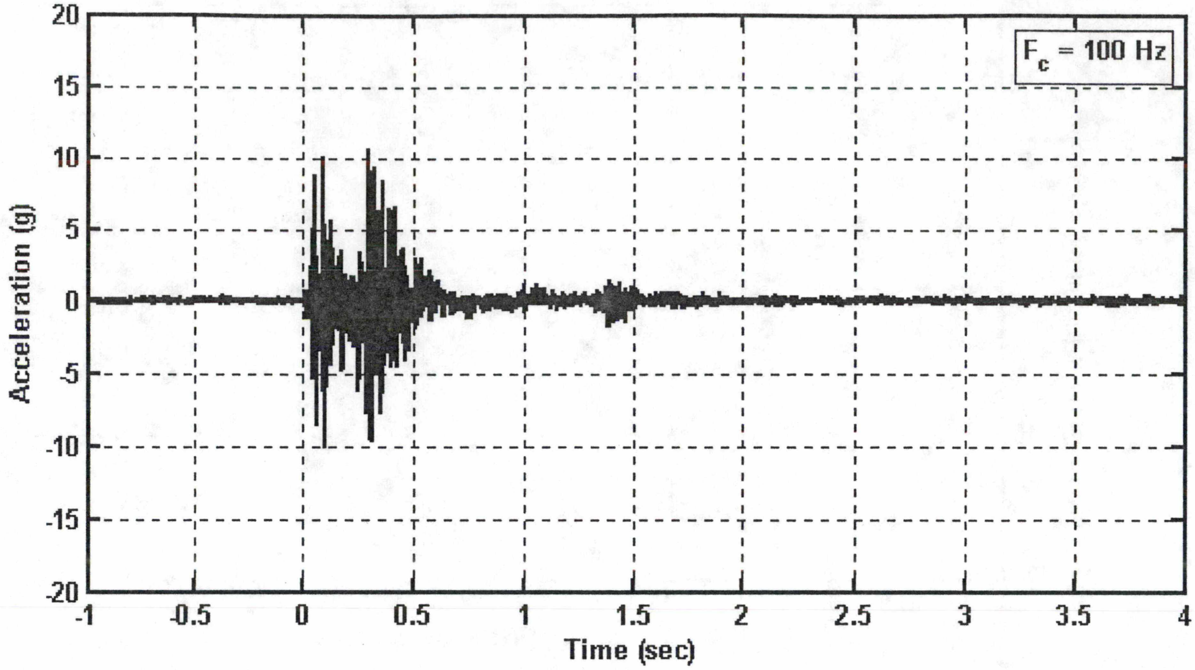

Figure C9. Locomotive floor, location 1, vertical acceleration
Channel Name: BL_F1Z

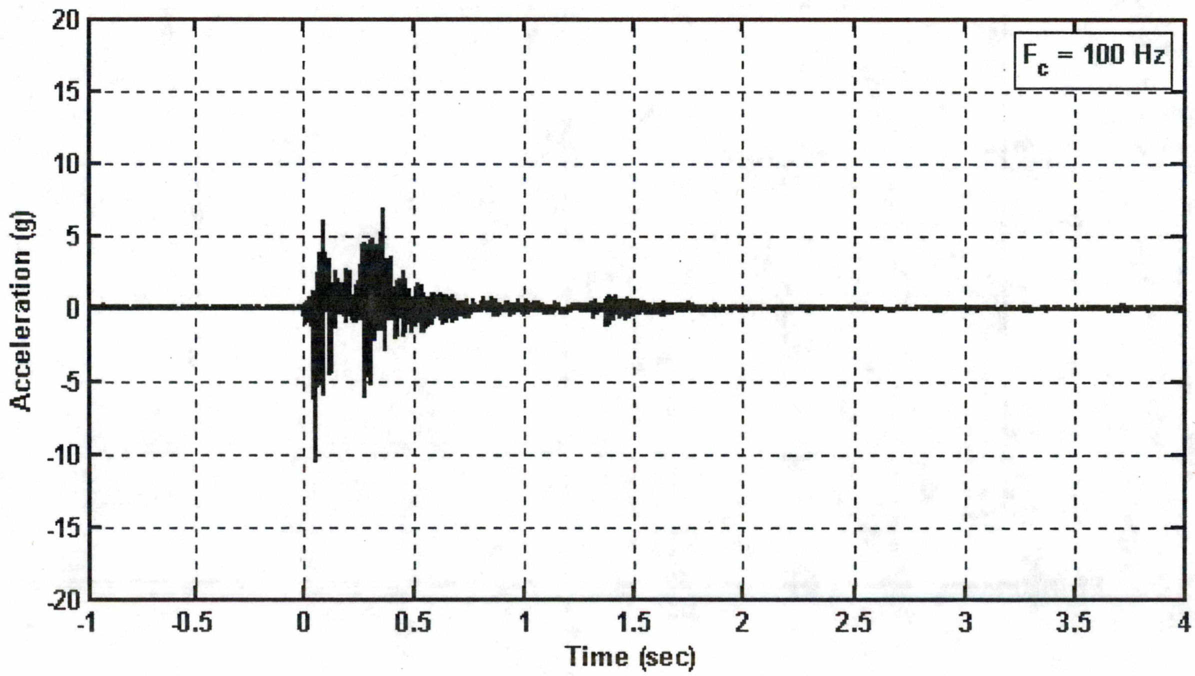

Figure C10. Locomotive floor, location 2, longitudinal acceleration
Channel Name: BL_F2X

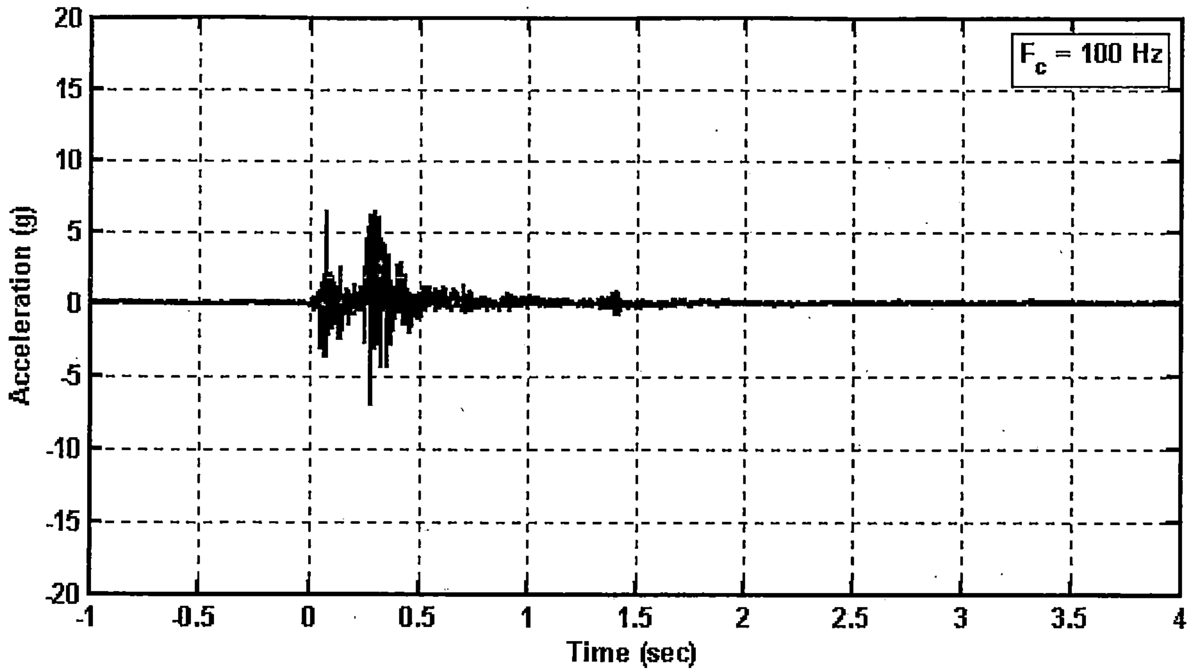

Figure C11. Locomotive floor, location 2, lateral acceleration
Channel Name: BL_F2Y

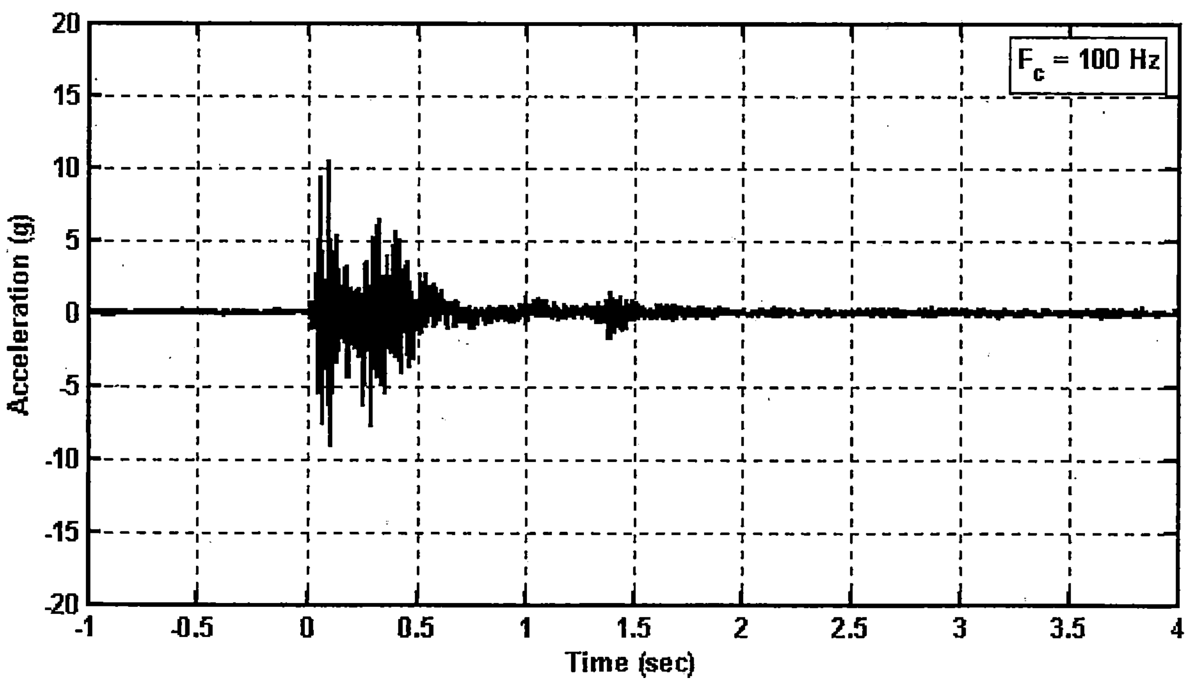

Figure C12. Locomotive floor, location 2, vertical acceleration
Channel Name: BL_F2Z

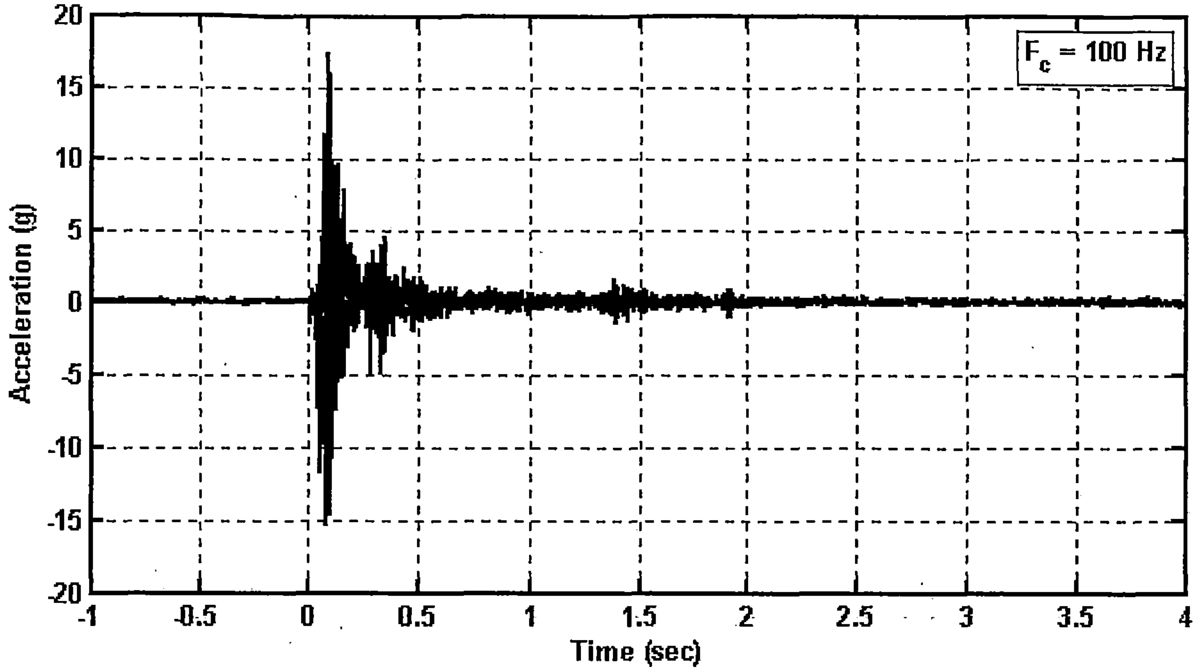

Figure C13. Locomotive event recorder, longitudinal acceleration
Channel Name: BL_RX

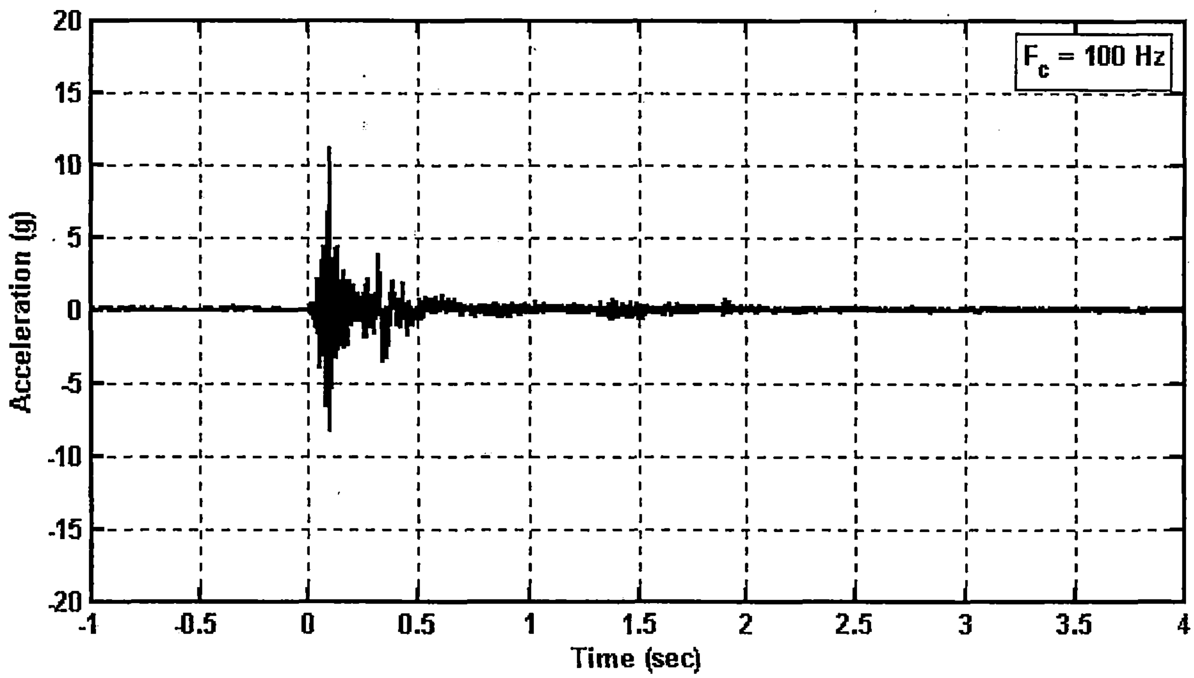

Figure C14. Locomotive event recorder, lateral acceleration
Channel Name: BL_RY

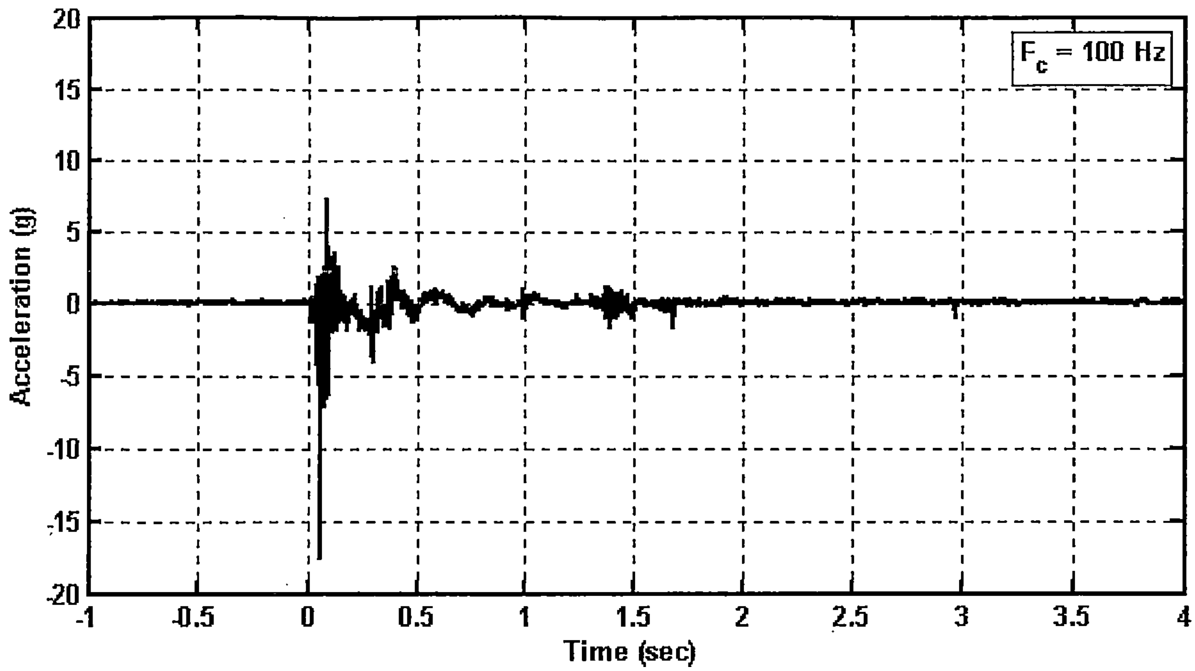

Figure C15. Locomotive event recorder, vertical acceleration
Channel Name: BL_RZ

APPENDIX E

Acceleration Data, Fc = 25 Hz

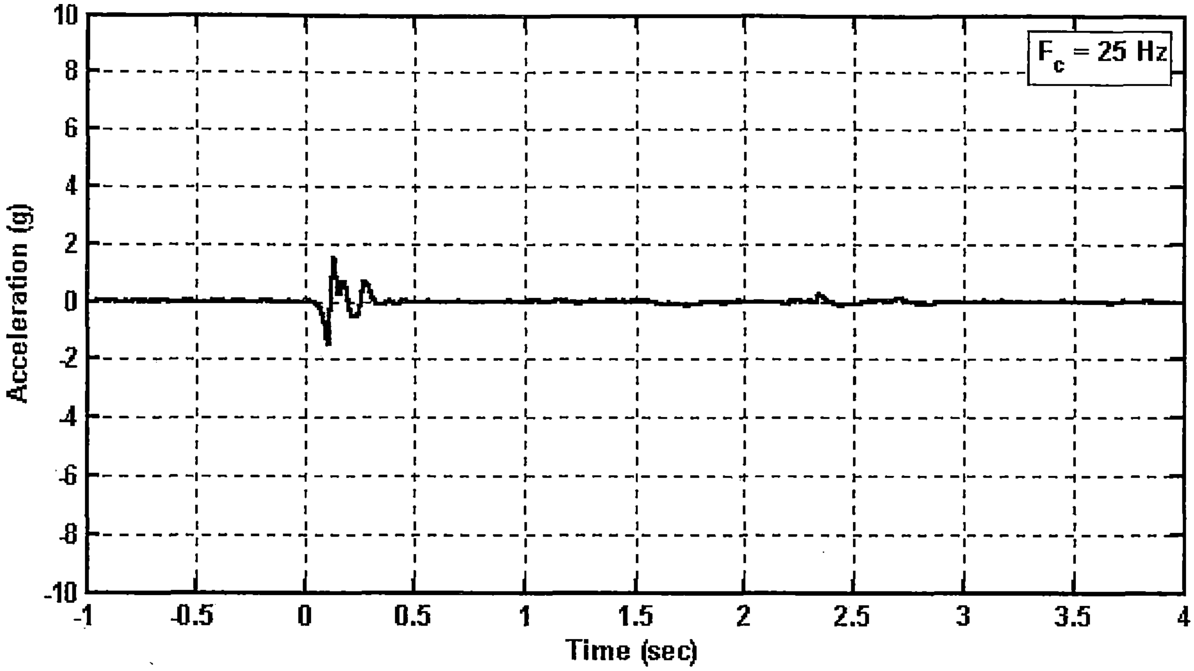

Figure D1. Bullet hopper 1, longitudinal acceleration
Channel Name: BH1_CGX

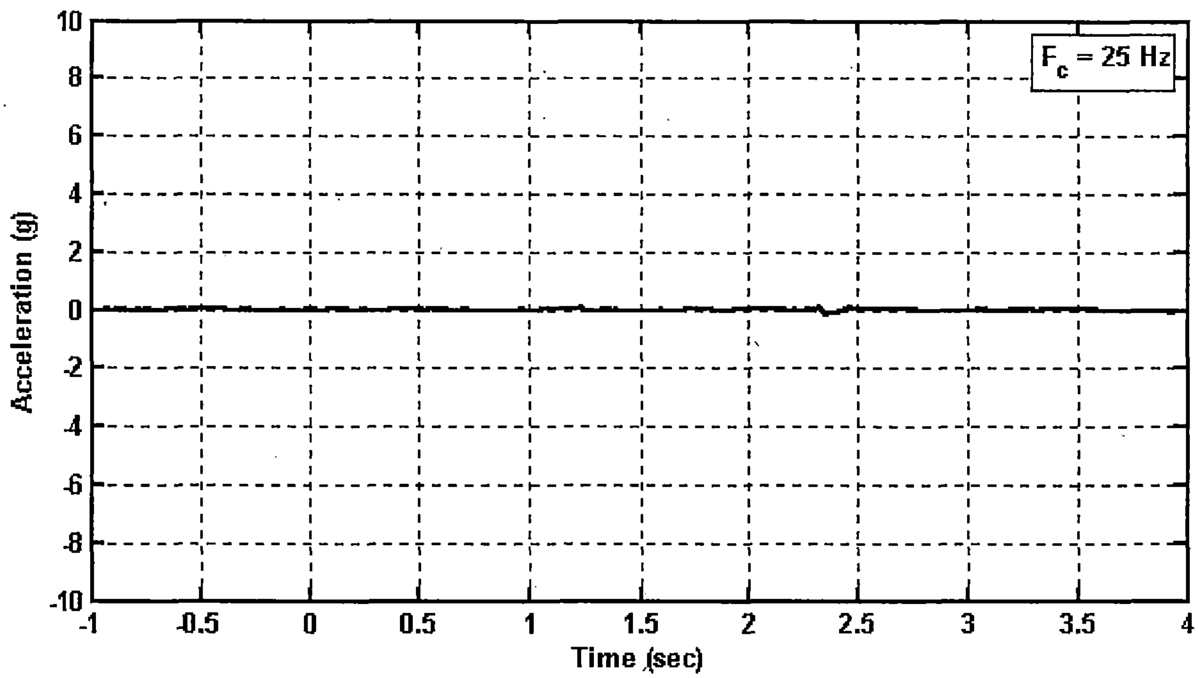

Figure D2. Bullet hopper 1, lateral acceleration
Channel Name: BH1_CGY

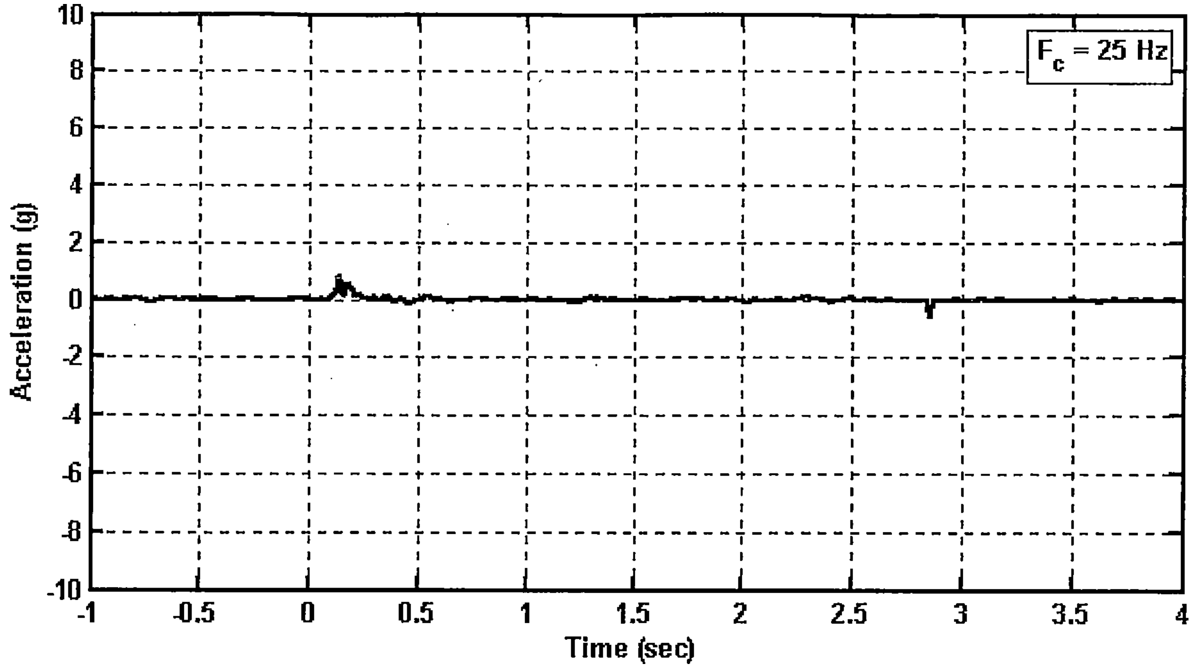

Figure D3. Bullet hopper 1, vertical acceleration
Channel Name: BH1_CGZ

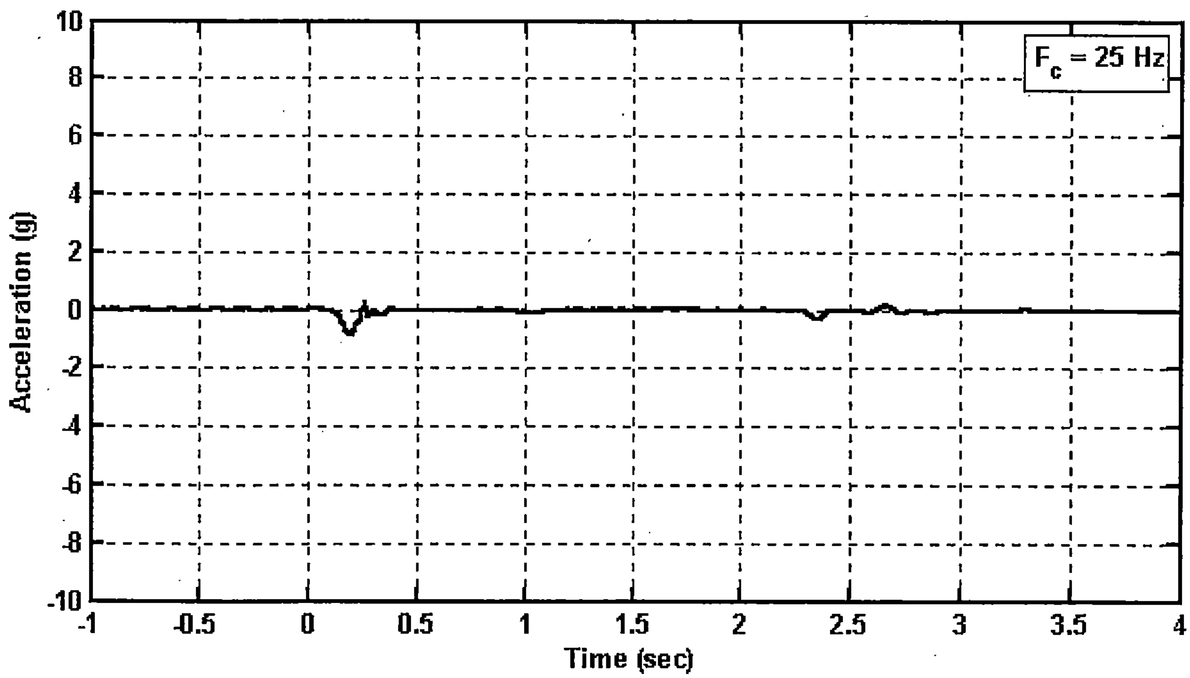

Figure D4. Bullet hopper 2, longitudinal acceleration
Channel Name: BH2_CGX

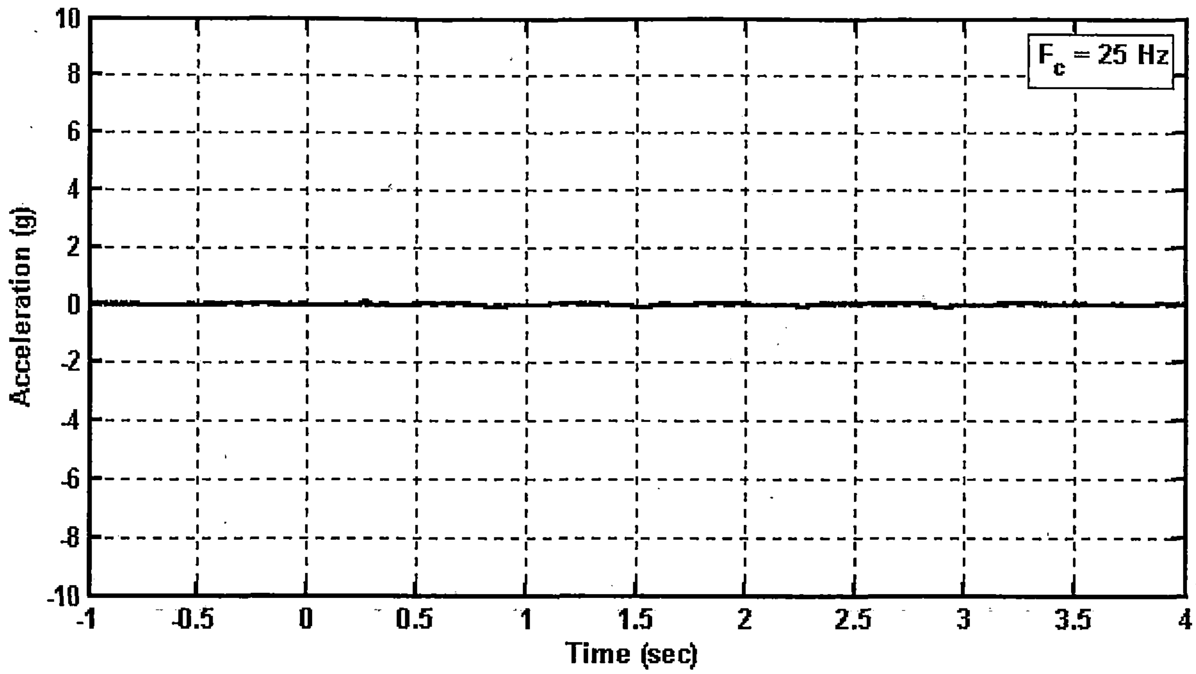

Figure D5. Bullet hopper 2, lateral acceleration
Channel Name: BH2_CGY

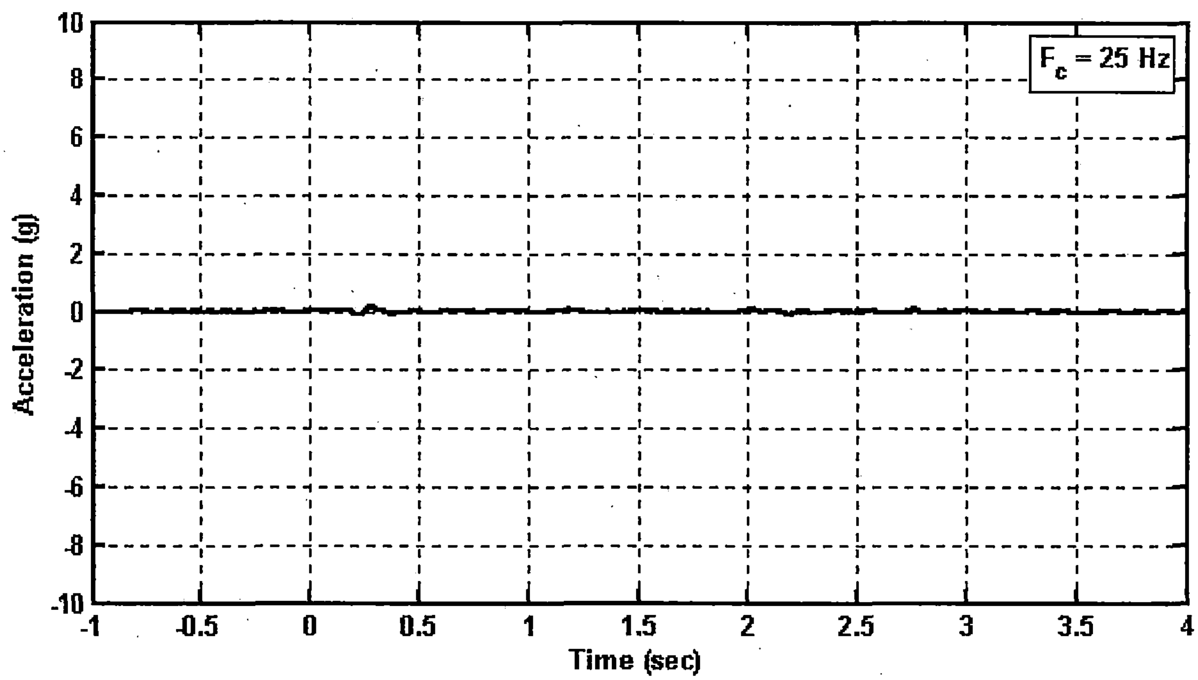

Figure D6. Bullet hopper 2, vertical acceleration
Channel Name: BH2_CGZ

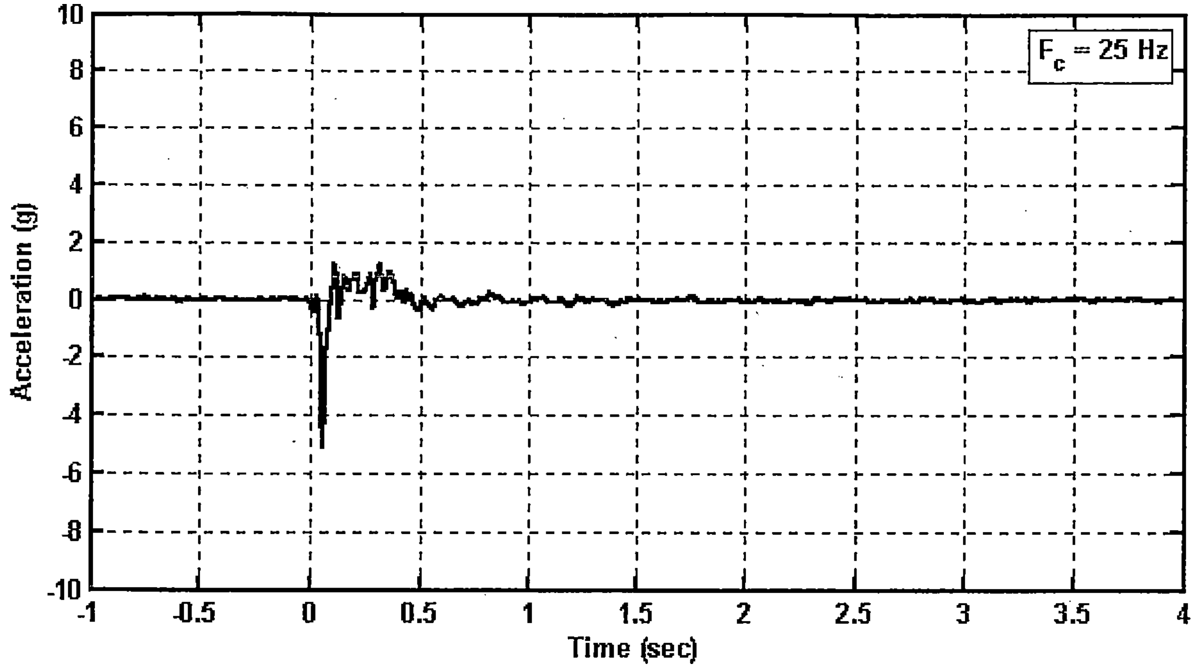

Figure D7. Locomotive floor, location 1, longitudinal acceleration
Channel Name: BL_F1X

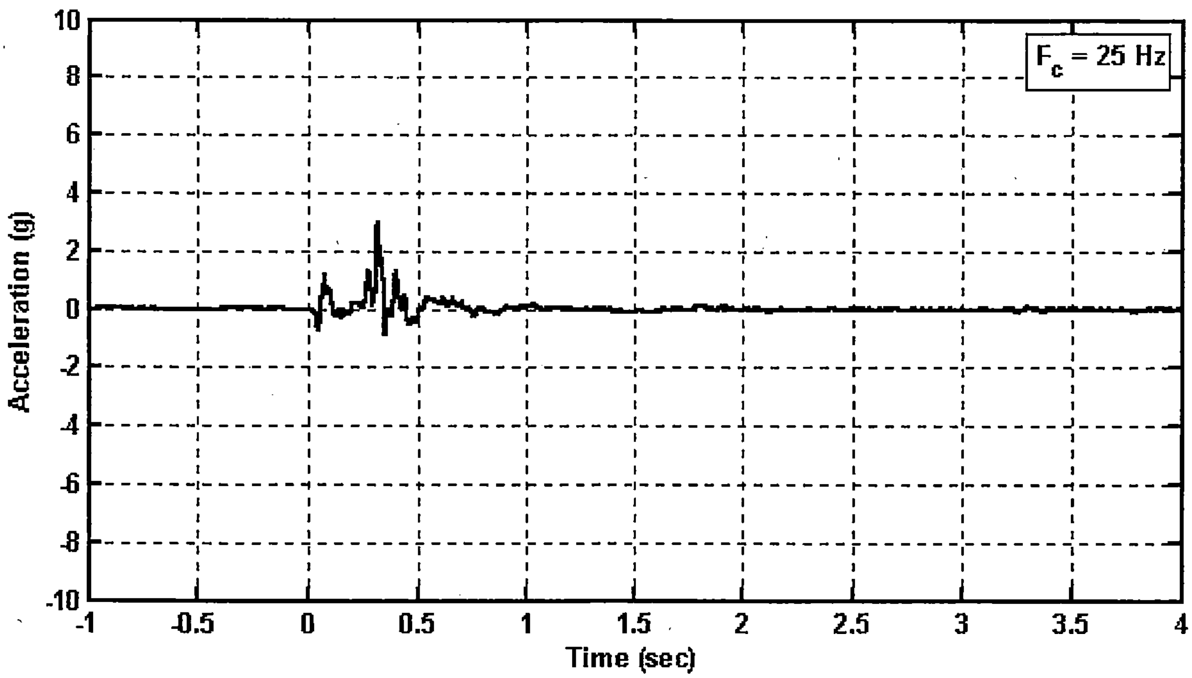

Figure D8. Locomotive floor, location 1, lateral acceleration
Channel Name: BL_F1Y

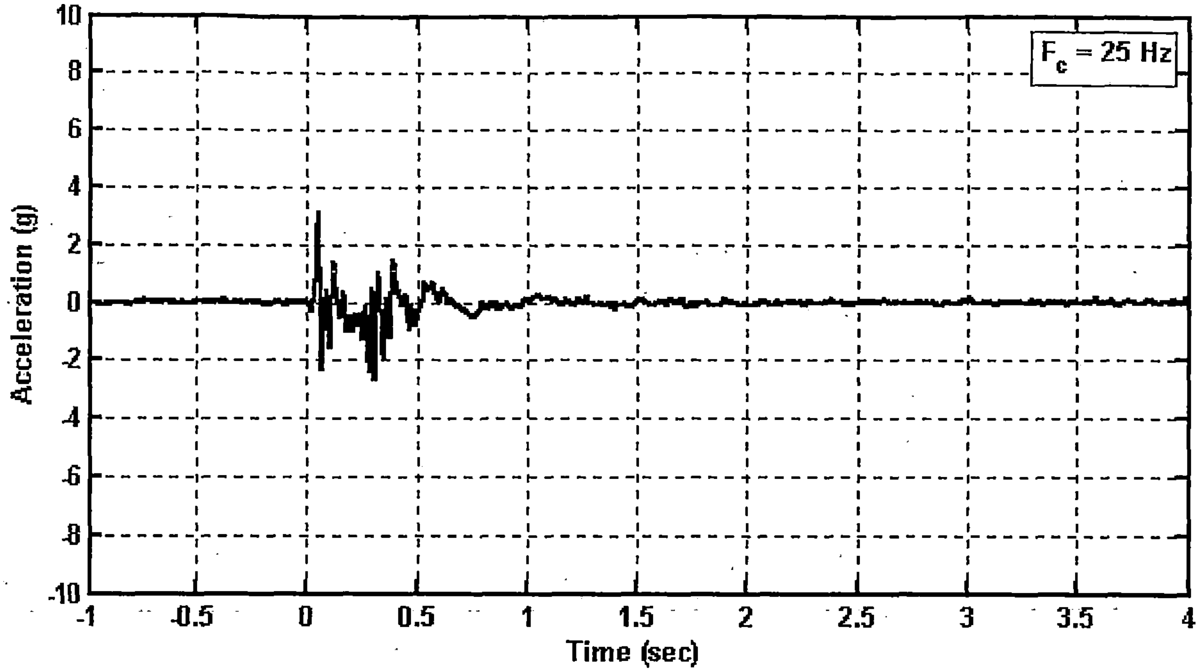

Figure D9. Locomotive floor, location 1, vertical acceleration
Channel Name: BL_F1Z

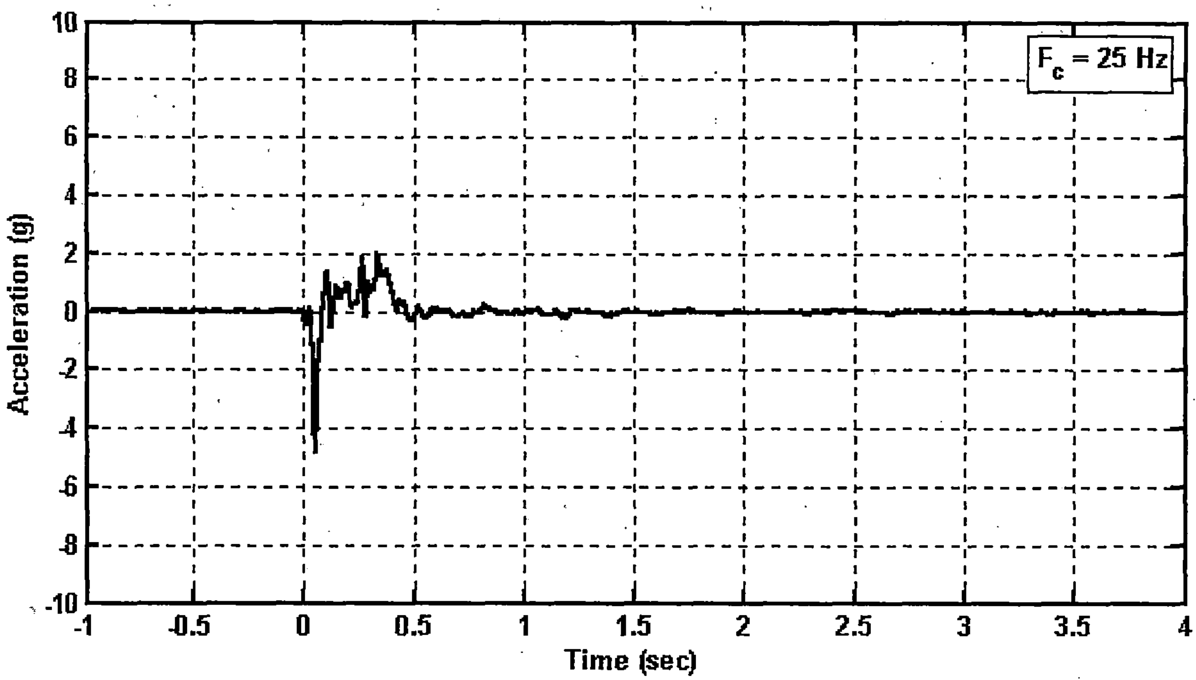

Figure D10. Locomotive floor, location 2, longitudinal acceleration
Channel Name: BL_F2X

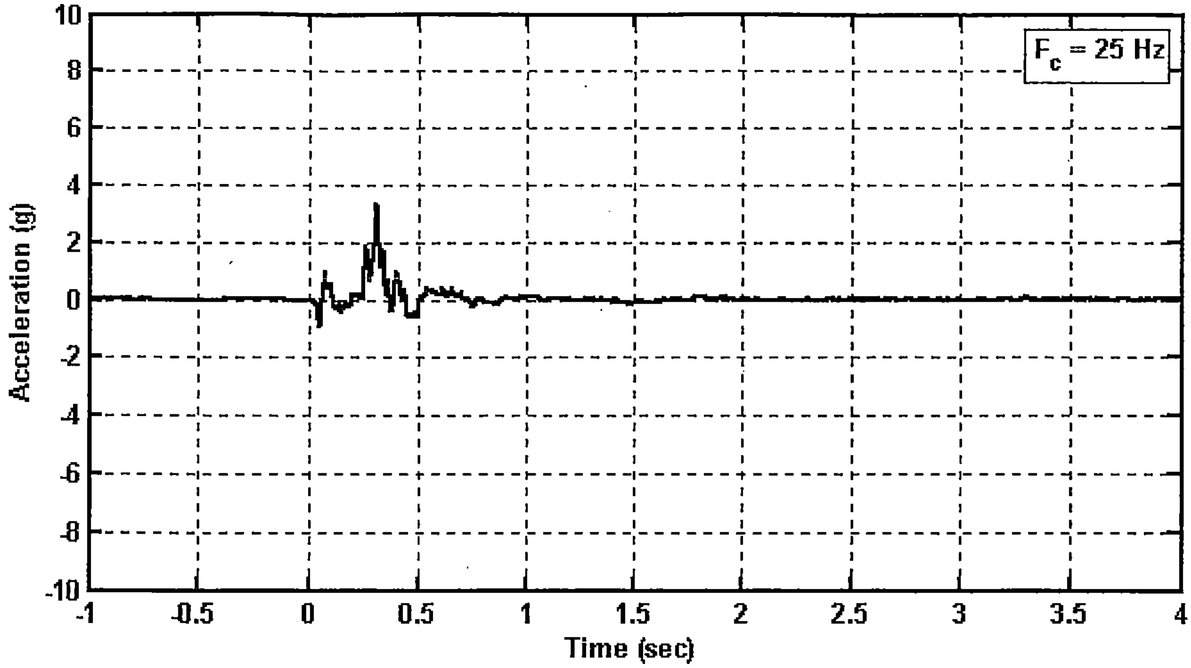

Figure D11. Locomotive floor, location 2, lateral acceleration
Channel Name: BL_F2Y

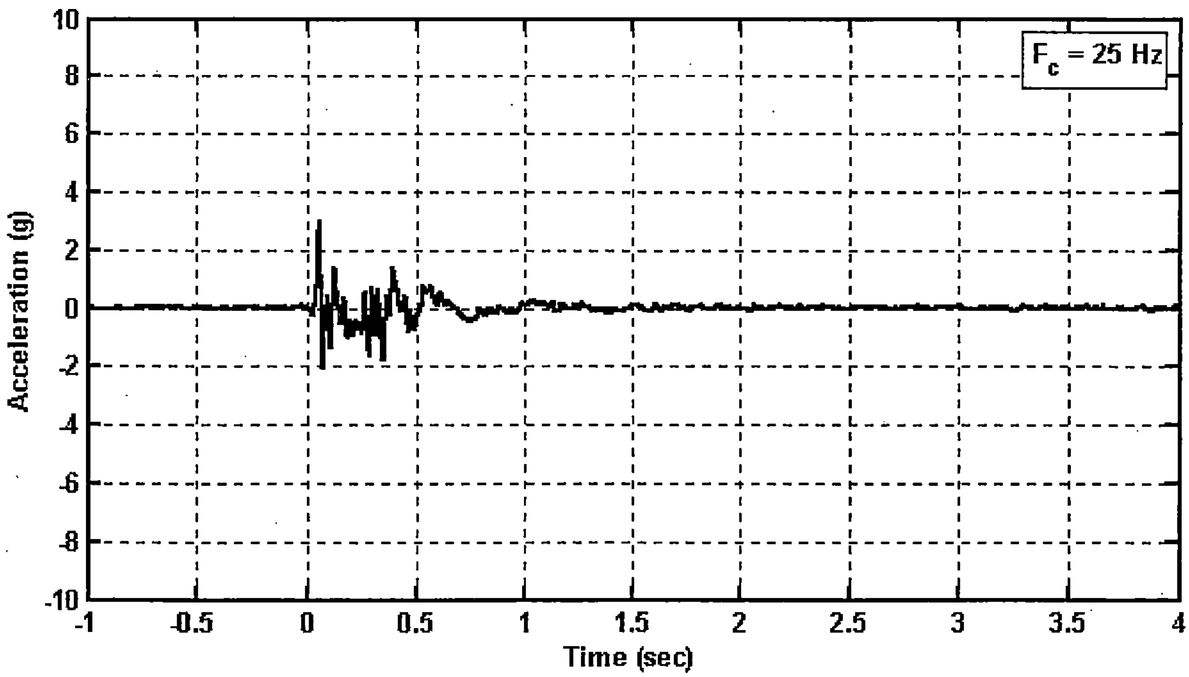

Figure D12. Locomotive floor, location 2, vertical acceleration
Channel Name: BL_F2Z

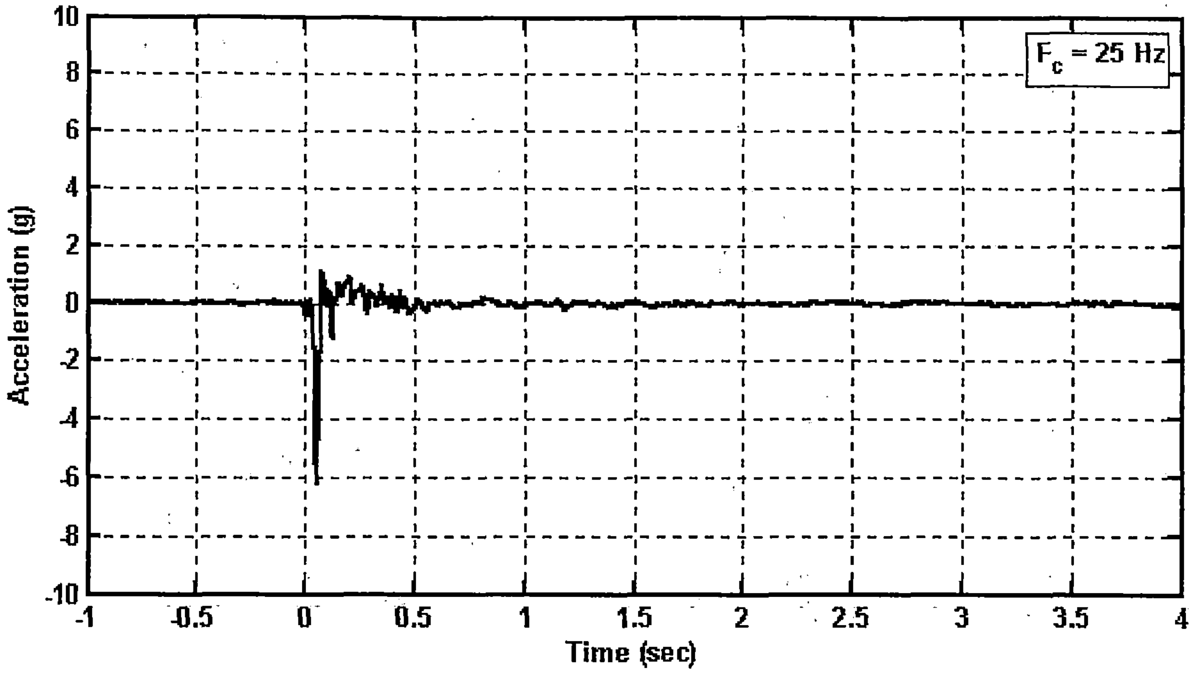

Figure D13. Locomotive event recorder, longitudinal acceleration
Channel Name: BL_RX

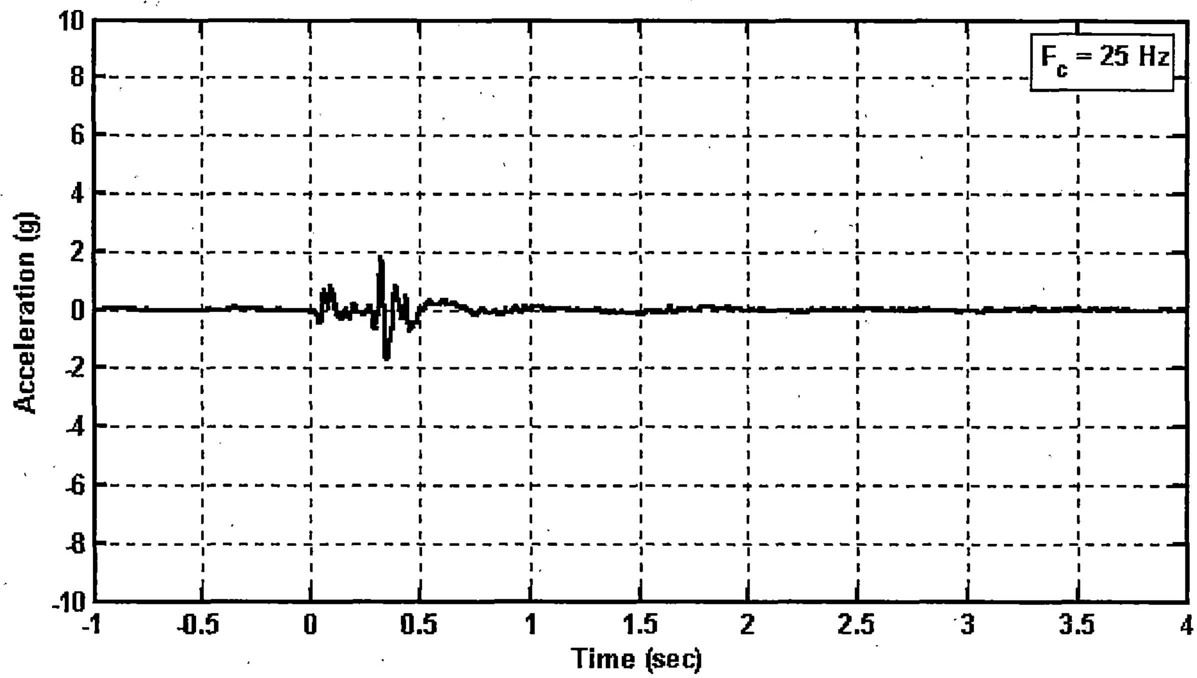

Figure D14. Locomotive event recorder, lateral acceleration
Channel Name: BL_RY

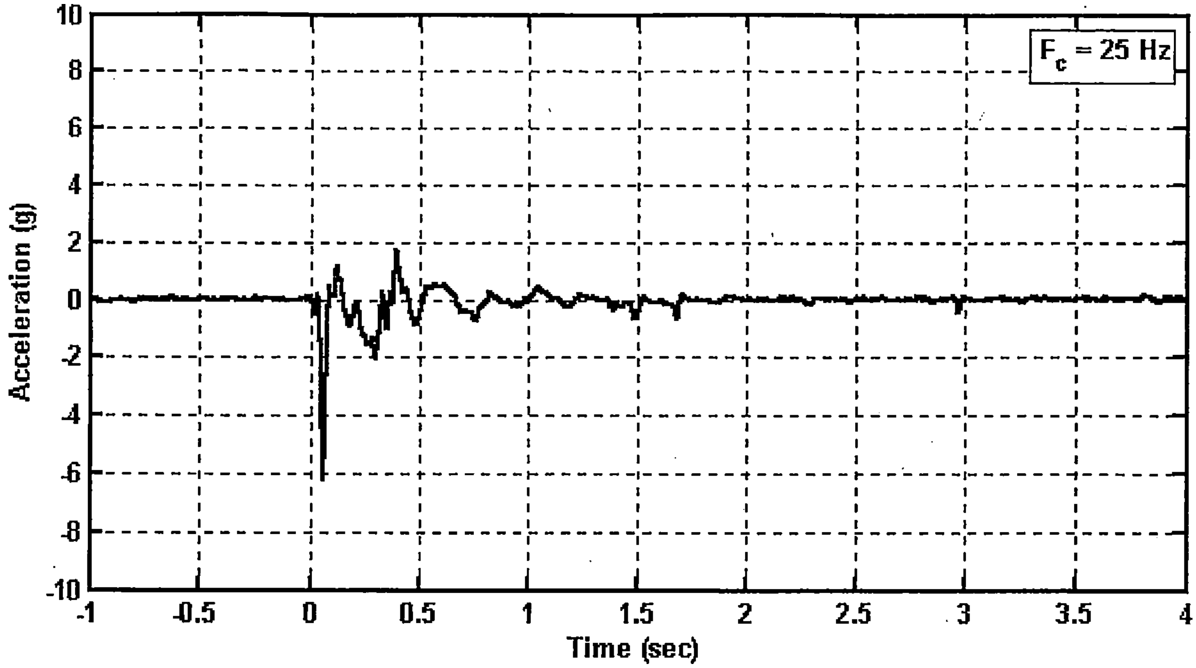

Figure D15. Locomotive event recorder, vertical acceleration
Channel Name: BL_RZ

APPENDIX F

Displacement and Coupler Force Data

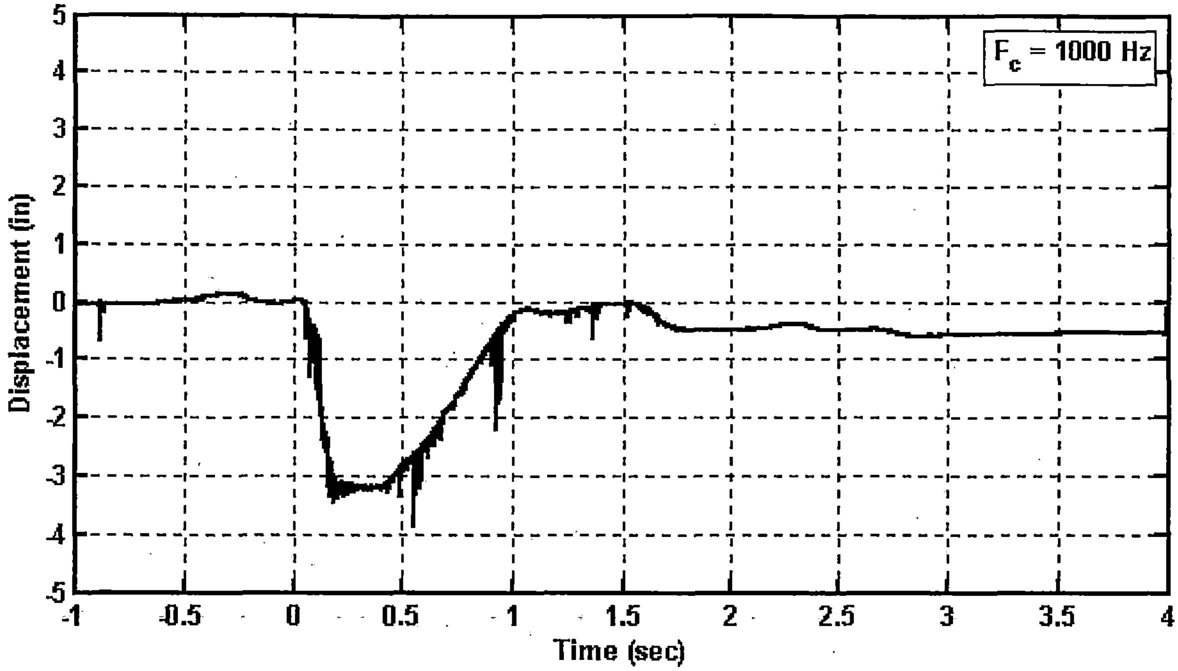

Figure E1. Bullet hopper 1, longitudinal coupler displacement
Channel Name: BH1_CAX

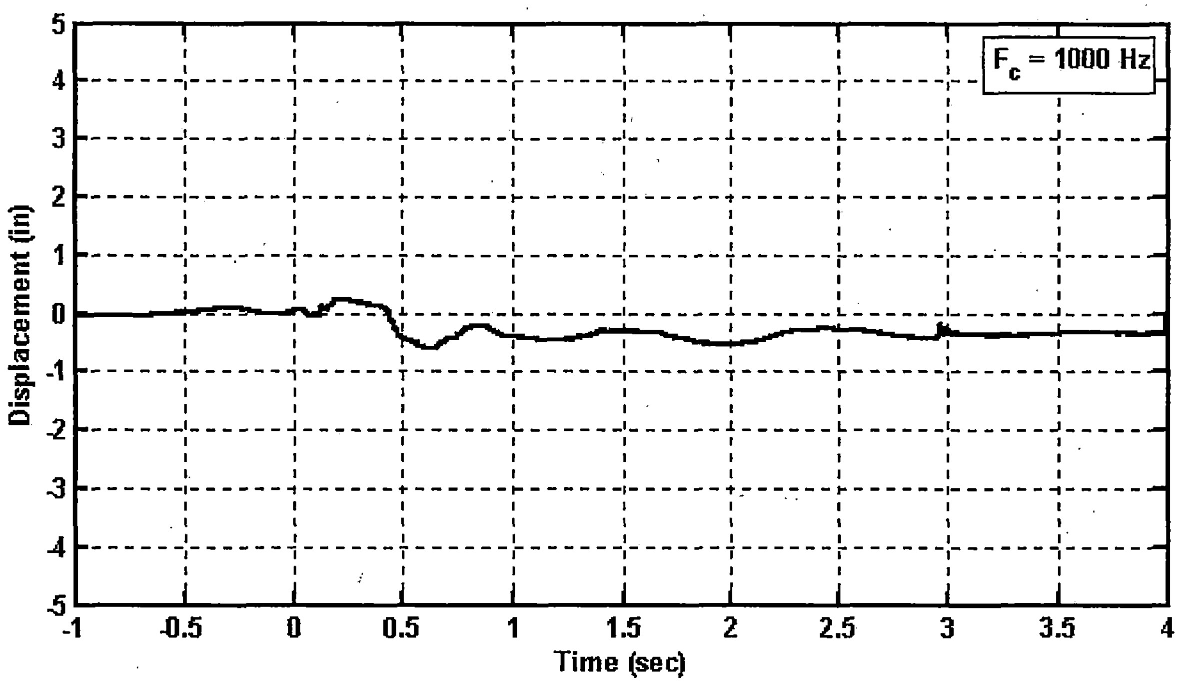

Figure E2. Bullet hopper 1, lateral coupler displacement
Channel Name: BH1_CAY

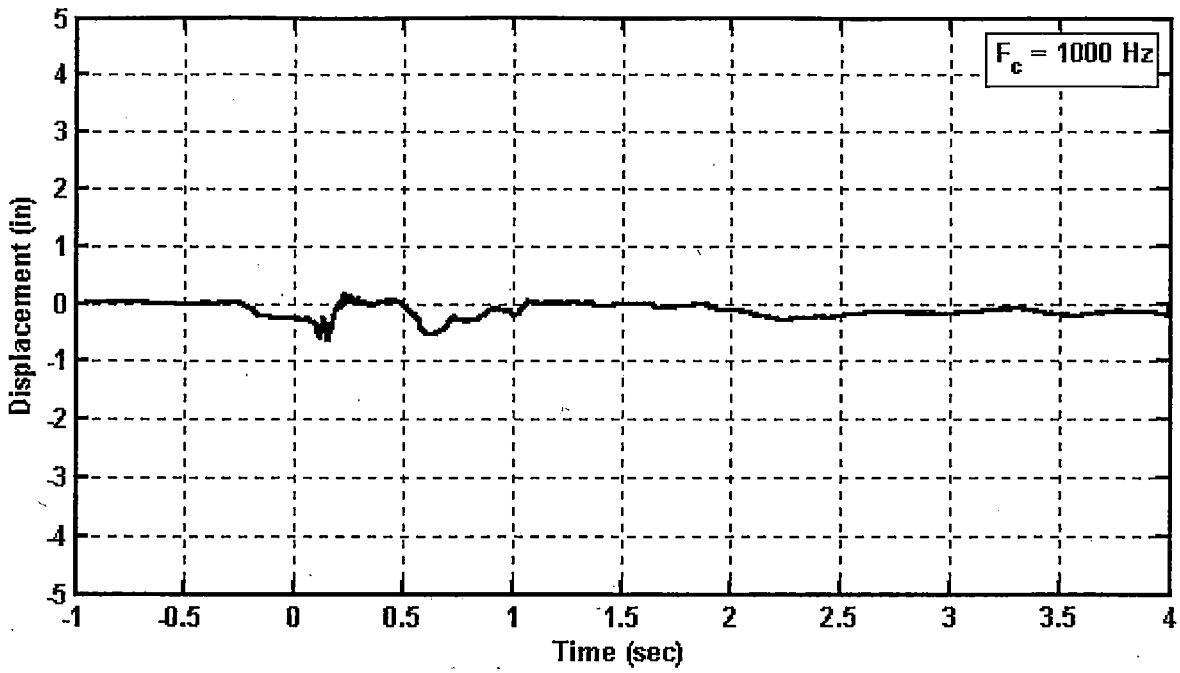

Figure E3. Bullet hopper 1, verical coupler displacement
Channel Name: BH1_CAZ

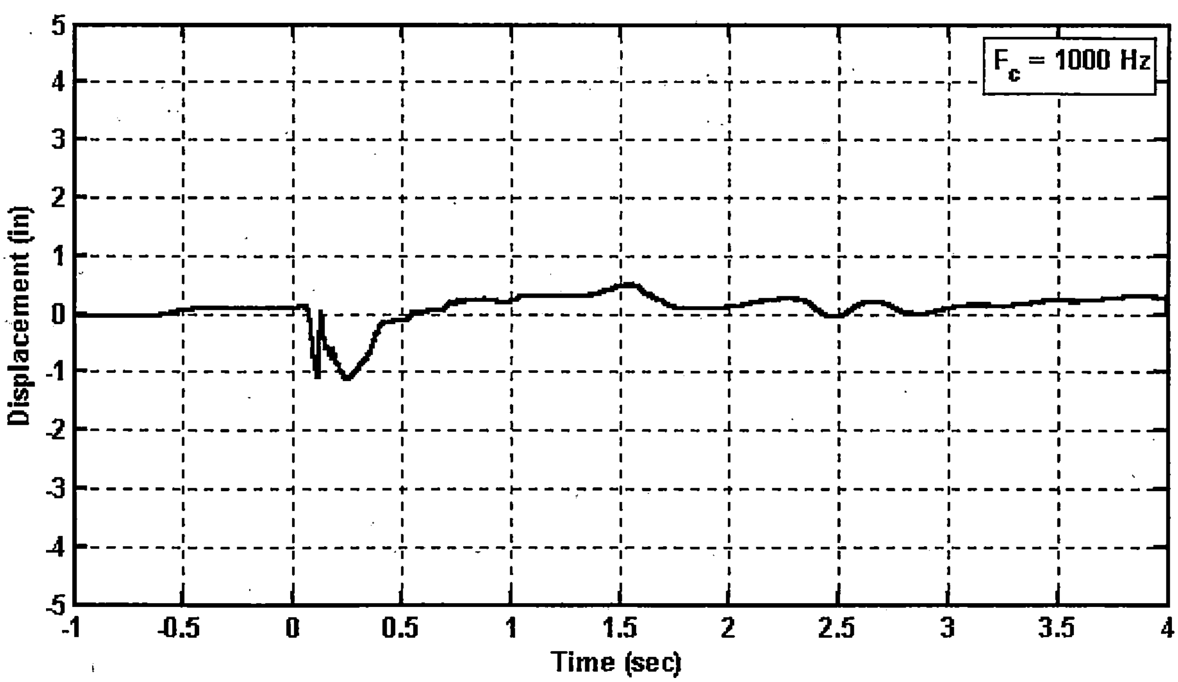

Figure E4. Locomotive, longitudinal coupler displacement
Channel Name: BL_CBX

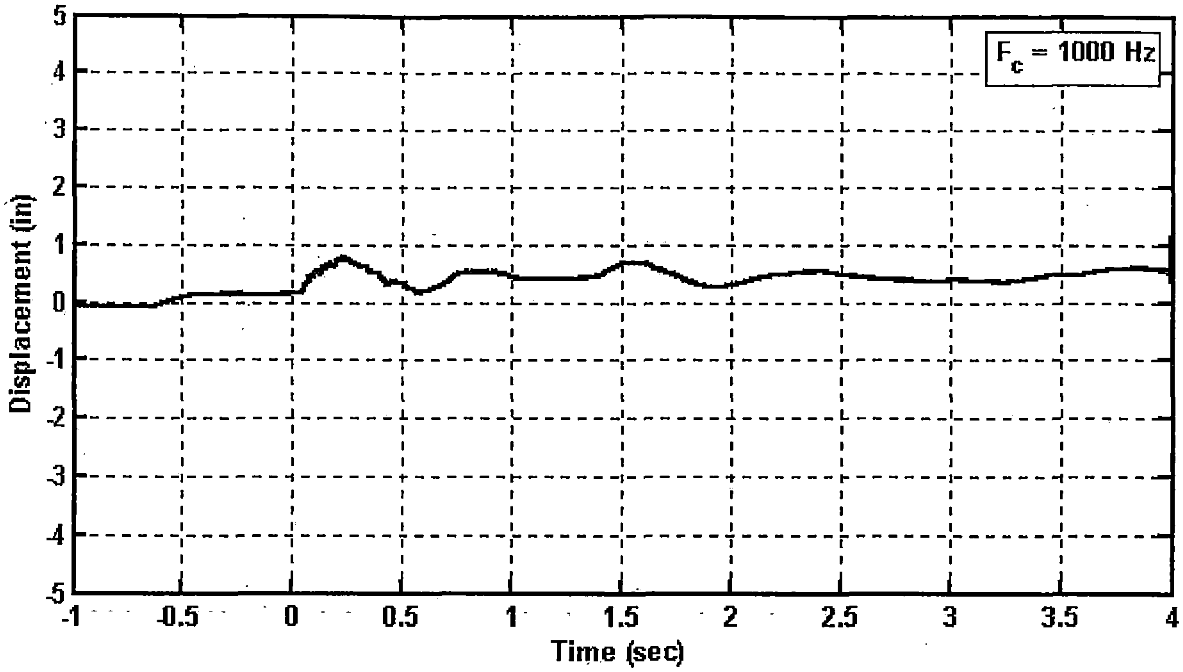

Figure E5. Locomotive, lateral coupler displacement
Channel Name: BL_CBY

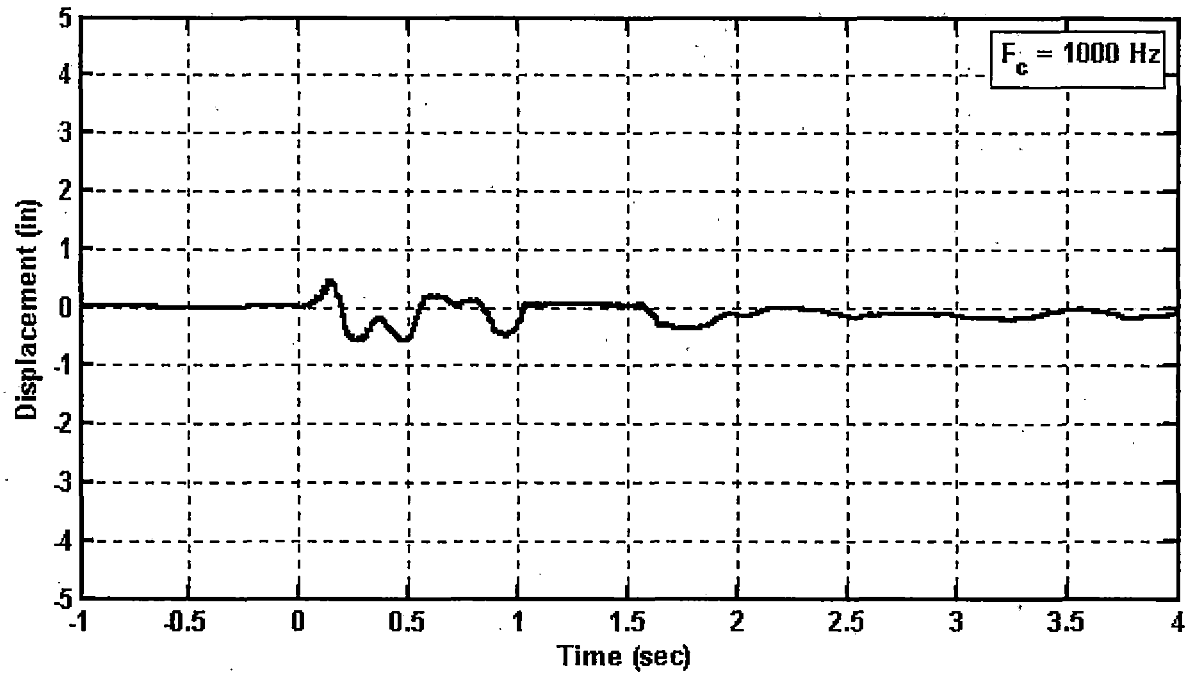

Figure E6. Locomotive, verical coupler displacement
Channel Name: BL_CBZ

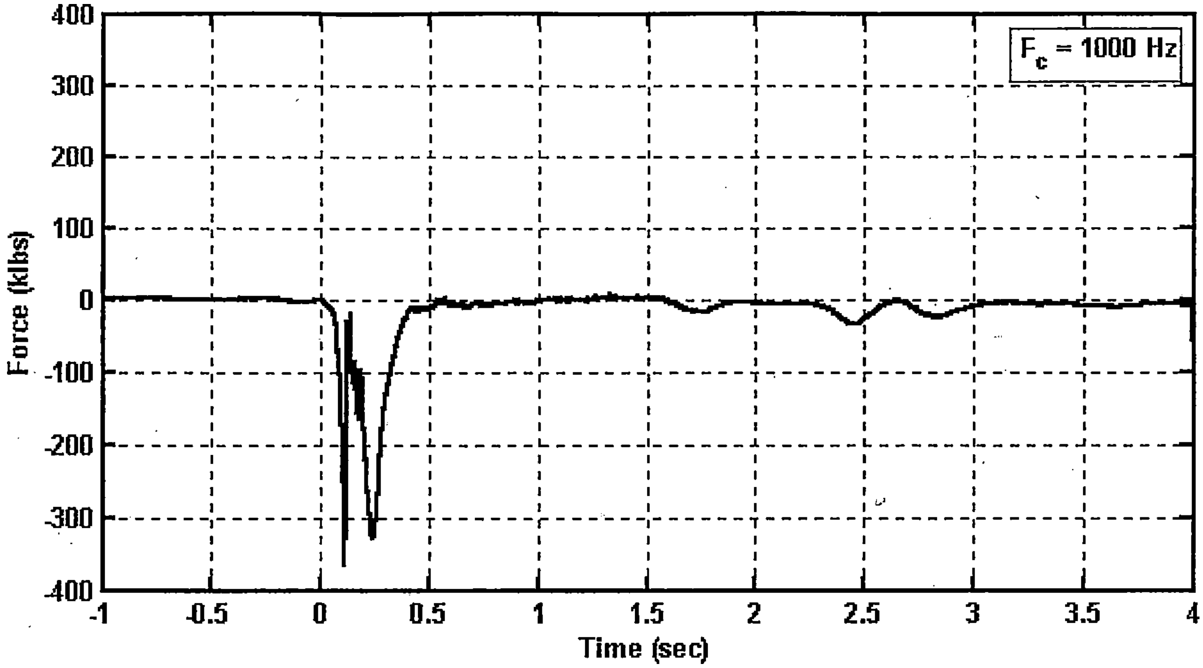

Figure E7. Bullet hopper 1, leading coupler force
Channel Name: BH1_CLoad

APPENDIX G

Anthropomorphic Test Device (ATD) Data

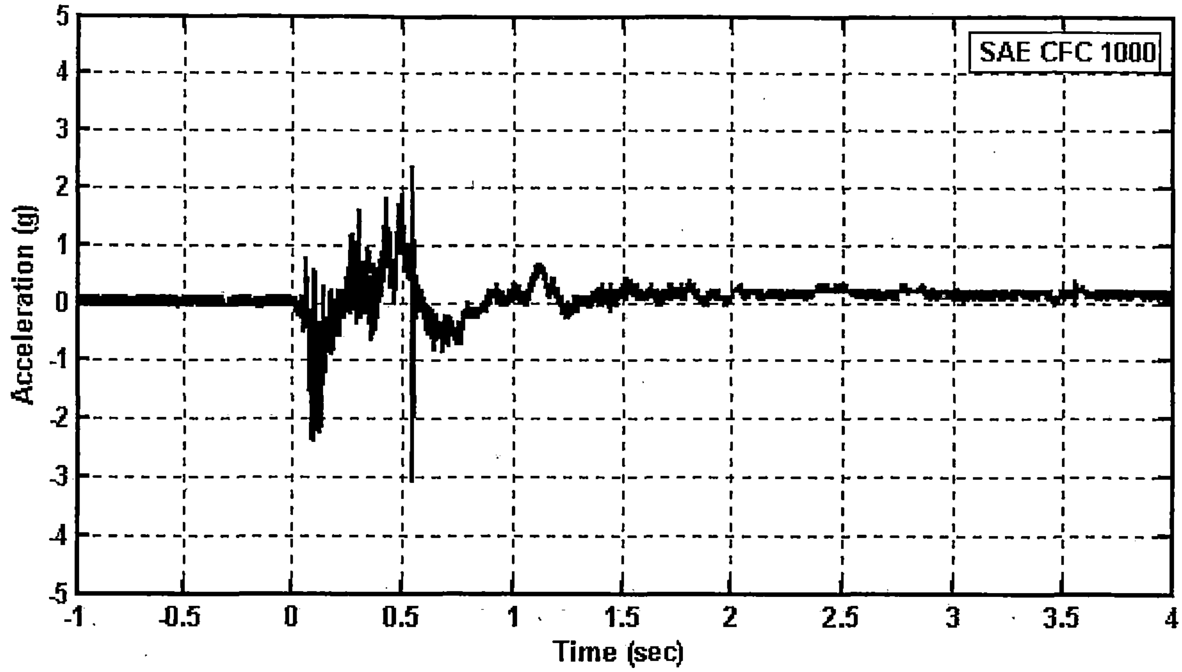

Figure G1. Anthropomorphic test device, chest acceleration, x direction
Channel Name: ATDC_X

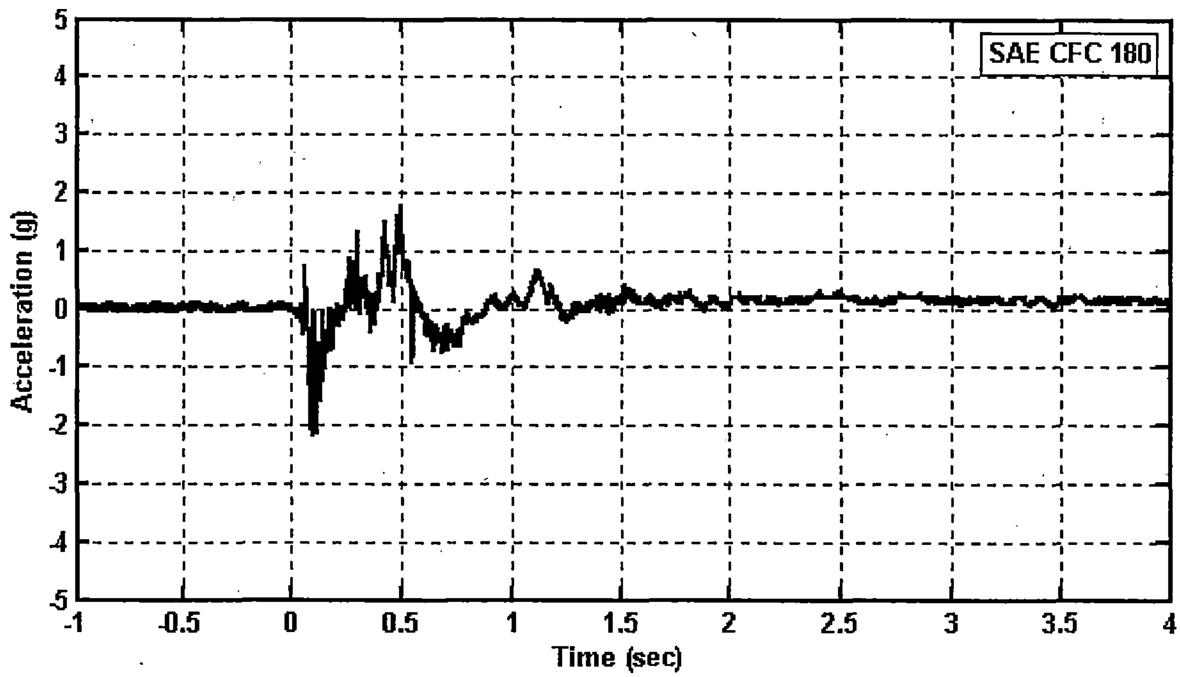

Figure G2. Anthropomorphic test device, chest acceleration, x direction
Channel Name: ATDC_X

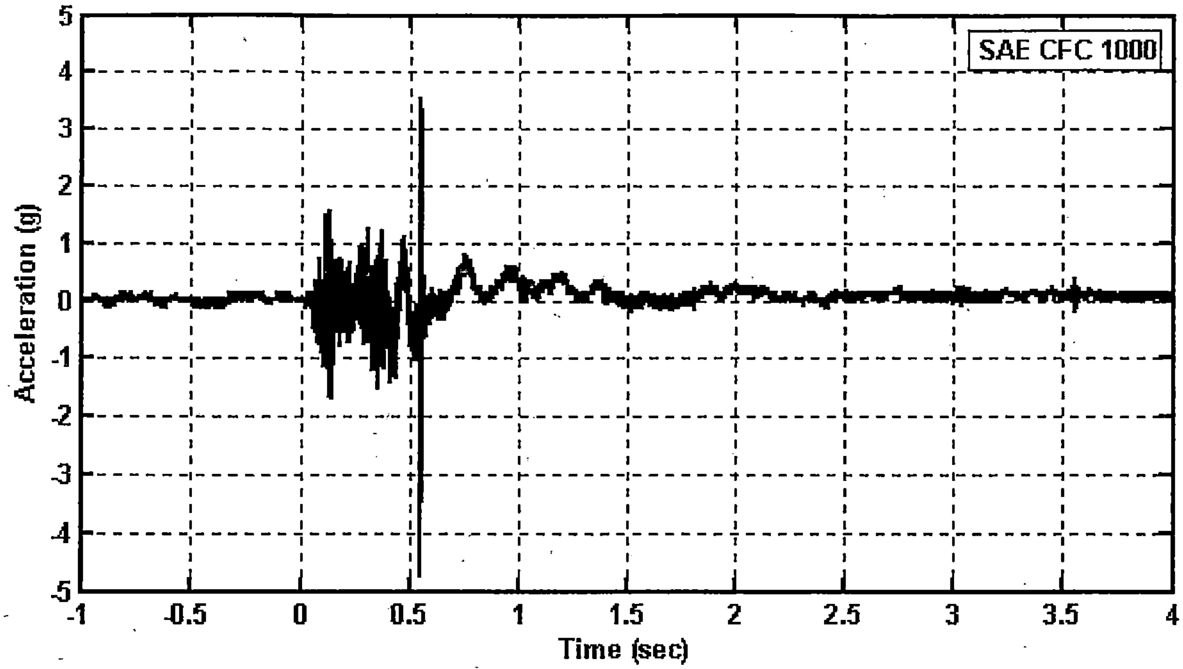

Figure G3. Anthropomorphic test device, chest acceleration, y direction
Channel Name: ATDC_Y

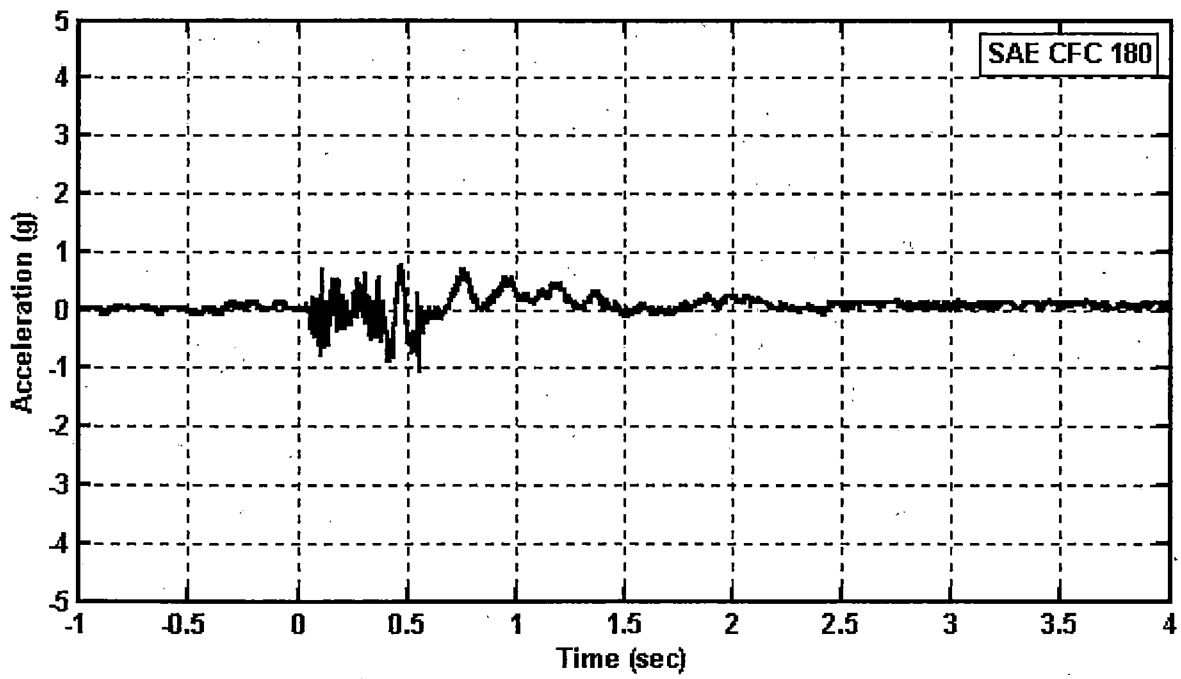

Figure G4. Anthropomorphic test device, chest acceleration, y direction
Channel Name: ATDC_Y

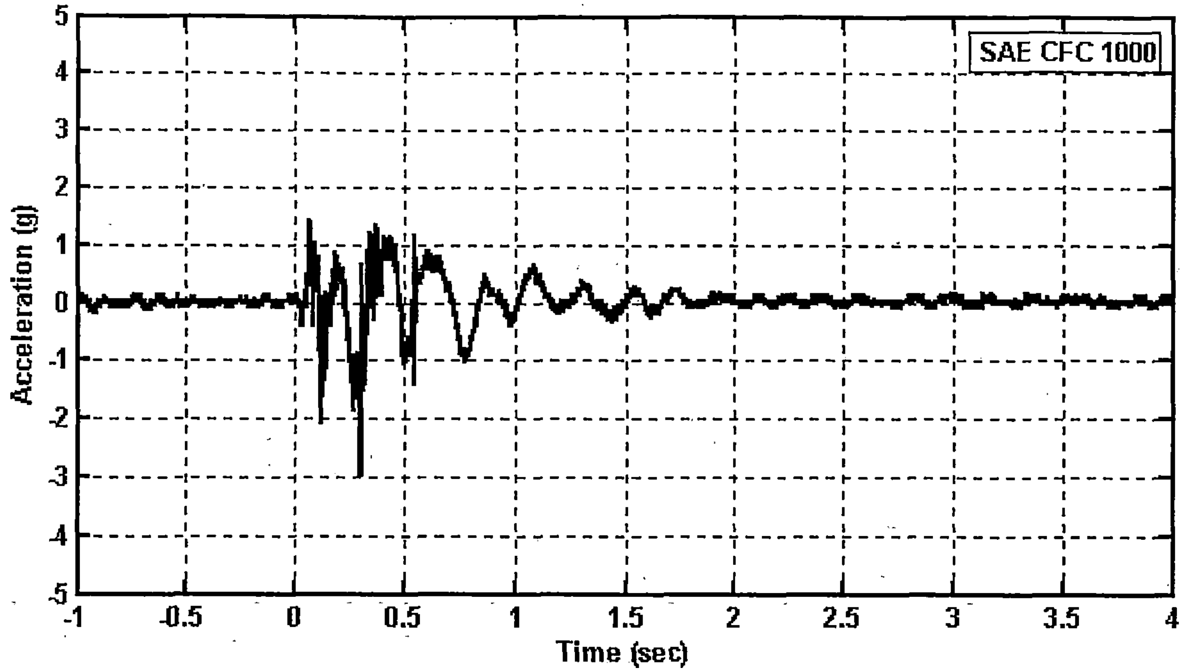

Figure G5. Anthropomorphic test device, chest acceleration, z direction
Channel Name: ATDC_Z

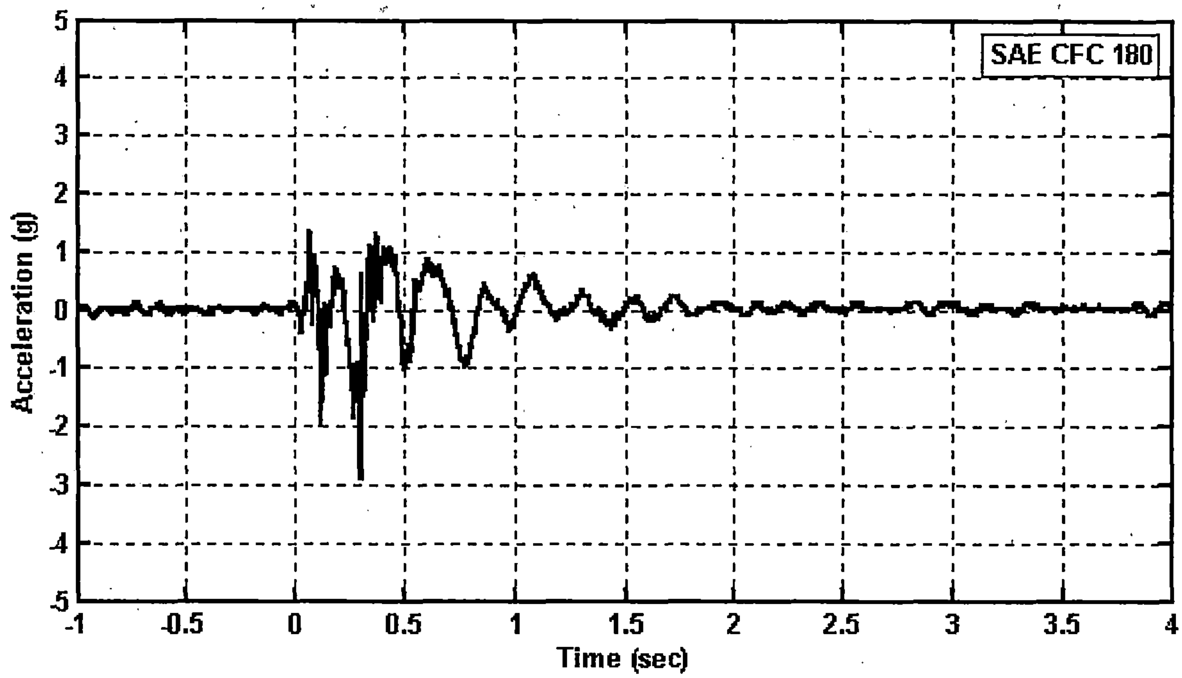

Figure G6. Anthropomorphic test device, chest acceleration, z direction
Channel Name: ATDC_Z

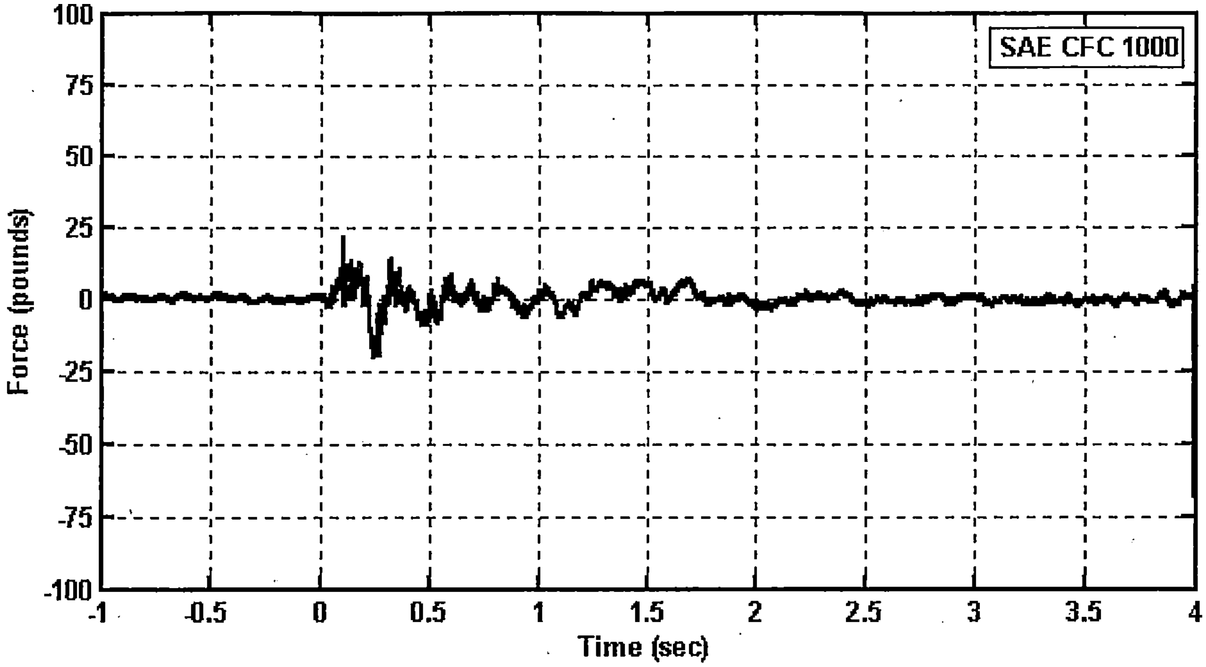

Figure G7. Anthropomorphic test device, left femur load
Channel Name: ATDF_L

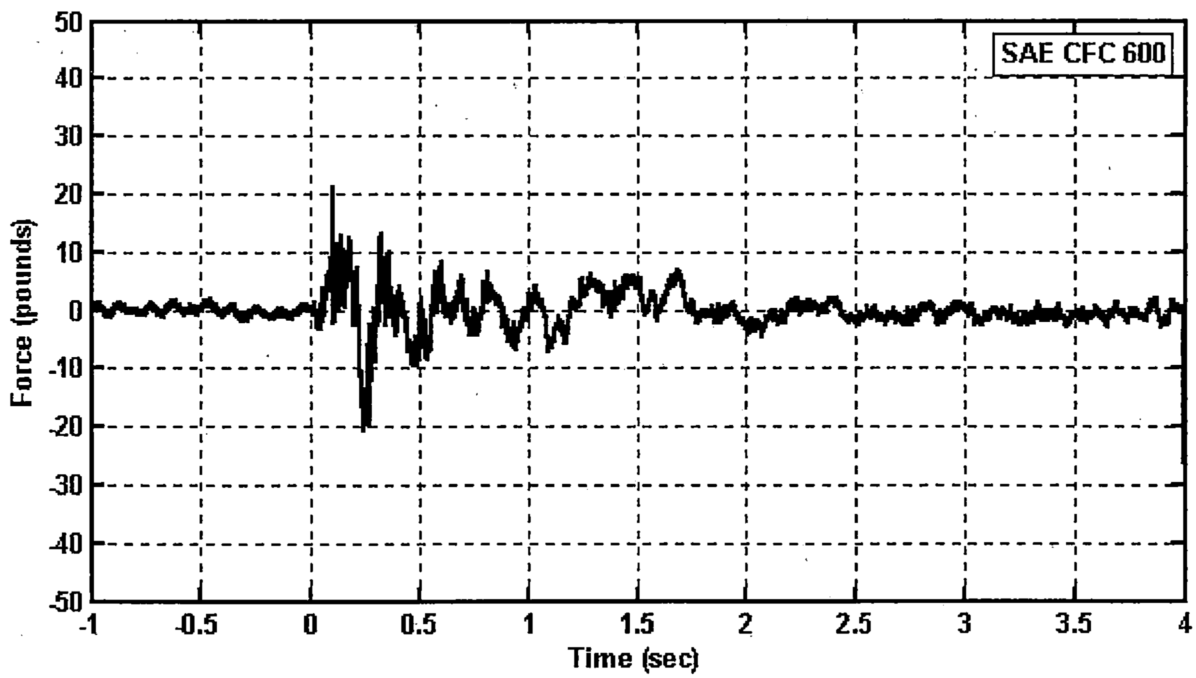

Figure G8. Anthropomorphic test device, left femur load
Channel Name: ATDF_L

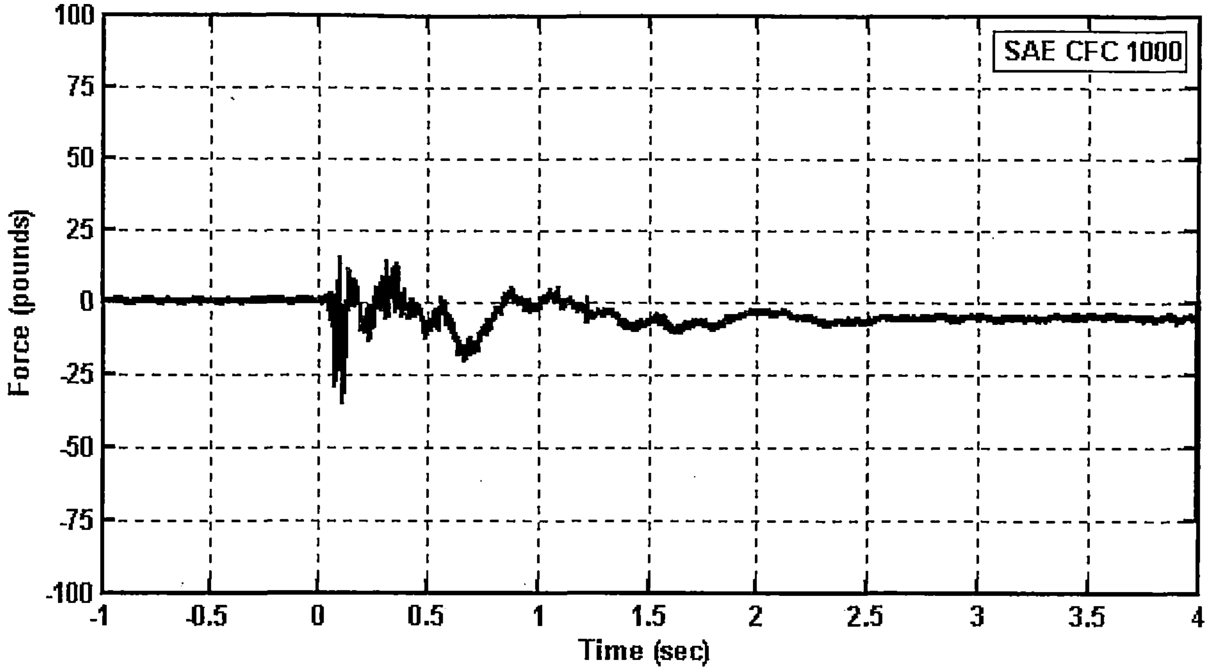

Figure G9. Anthropomorphic test device, right femur load
Channel Name: ATDF_R

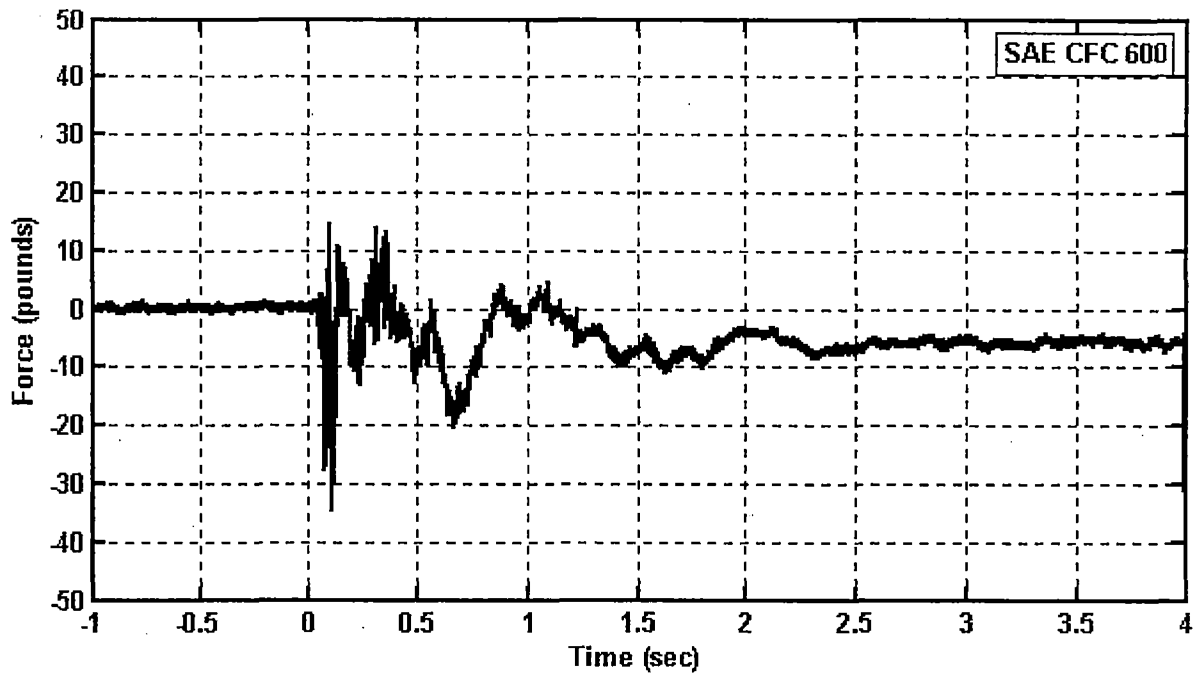

Figure G10. Anthropomorphic test device, right femur load
Channel Name: ATDF_R

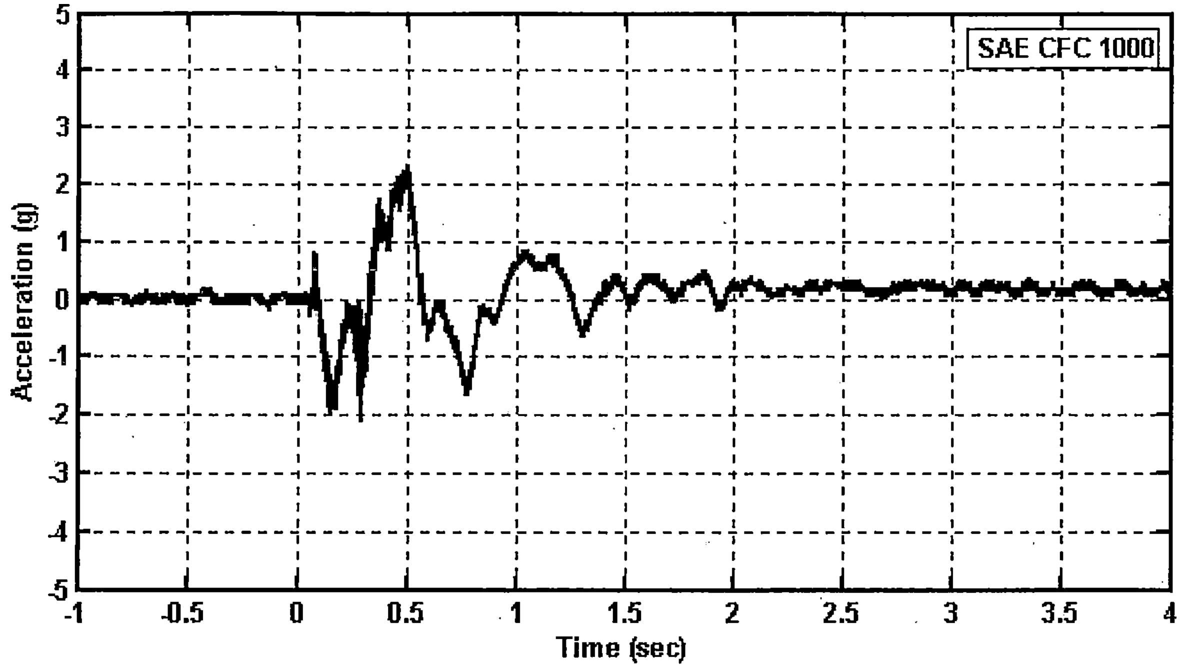

Figure G11. Anthropomorphic test device, head acceleration, x direction
Channel Name: ATDH_X

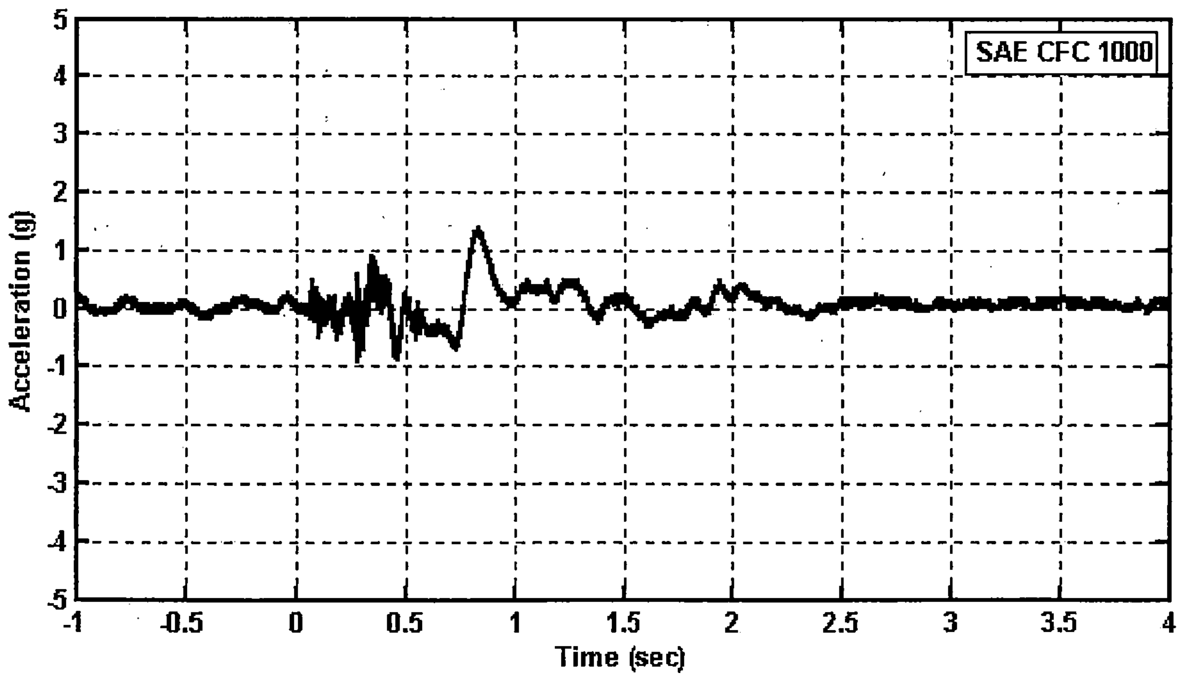

Figure G12. Anthropomorphic test device, head acceleration, y direction
Channel Name: ATDH_Y

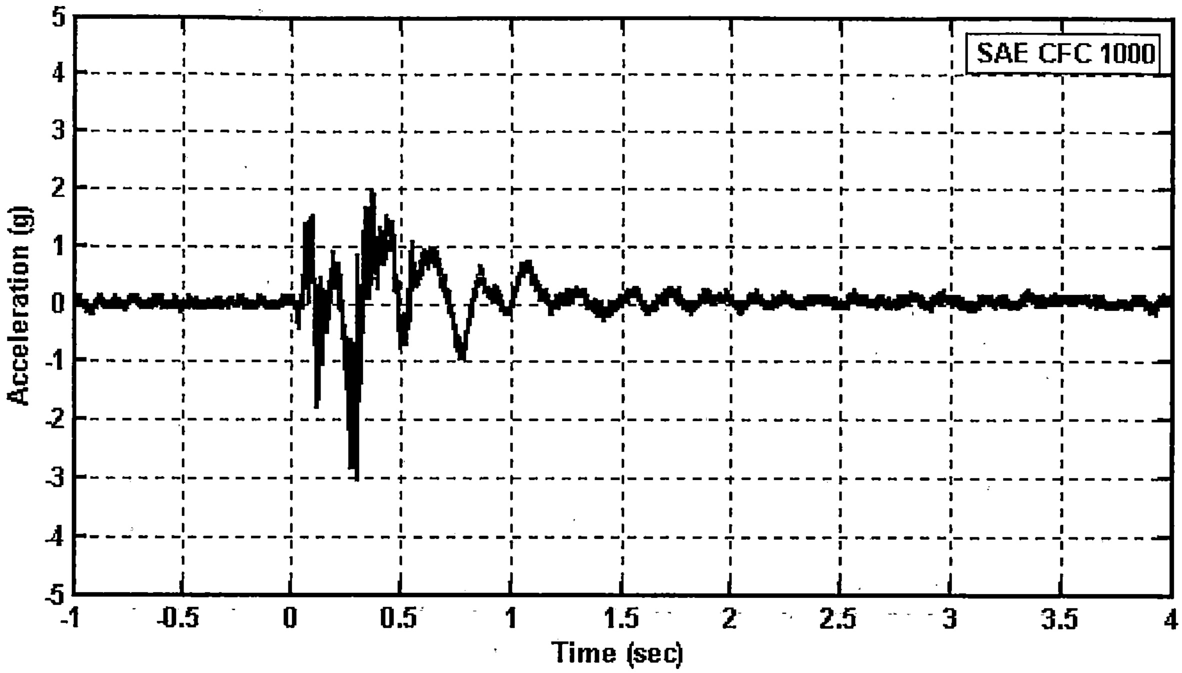

Figure G13. Anthropomorphic test device, head acceleration, z direction
Channel Name: ATDH_Z

APPENDIX H

GMH Data Report

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Instrumentation and Data Acquisition Report

for

Locomotive Crashworthiness Test #3 carried out 18 December 2002

Report Date: 7 January 2003

The instrumentation and data acquisition was carried out in compliance with the Test Implementation Plan (TIP) prepared by the Transportation Technology Center, Inc. (TTCI). Details of the test instrumentation and data acquisition follow.

Test Vehicle Naming Conventions

Moving Consist: (listed from impact point rearward)	Bullet Locomotive	(BL)
	Bullet Hopper One	(BH1)
	Bullet Hopper Two	(BH2)
Target Vehicle:	Rear Steel Coil	(SC1)
	Front Steel Coil	(SC2)

Data Acquisition Specifications

All data channels except Speed

Sample Rate: 12,800 Hz
Pre-Sample Filter Low-pass Corner Frequency, Fc: 1735 Hz
Pre-Trigger: 12,800 Samples (1.0000 seconds)
Post-Trigger: 51,200 Samples (4.0000 seconds)

Instrumentation Coordinate Systems

Accelerometers

The vehicle coordinate system for all instrumented moving vehicles is a "right handed" system oriented as follows:

- X-axis Longitudinal with the positive direction out the A-end.
- Y-axis Lateral with the positive direction towards the right side when facing in the positive X direction.
- Z-axis Vertical with the positive direction downward.

The three instrumented vehicles in the moving consist were considered to be oriented with their "A" ends in the direction of travel. This means the positive X-axis of all three vehicles was pointed in the direction of travel – towards the impact.

The coordinate systems for the two steel coils loads on the target vehicle are "right handed" systems oriented as follows:

- X-axis Longitudinal with the positive direction towards the approaching test locomotive.
- Y-axis Lateral with the positive direction towards the right side when facing in the positive X direction.
- Z-axis Vertical with the positive direction downward.

Coupler Load

The instrumented coupler on the "A" end of the first hopper car of the moving consist was configured such that tension produced a positive reading.

Coupler Motion String-Pots

The nominal zero position for all coupler motion string-pots was taken to be the average position for the time interval of 1 second prior to impact through 62.5 msec prior to impact. The coupler motion string-pots were all configured to give positive readings when the string-pot extended from it's nominal zero position. The correlation of positive reading to the motion of the four instrumented couplers was as follows:

Locomotive (BL) B end coupler:

The X-axis string-pot showed positive displacement when the coupler extended longitudinally out of the coupler pocket.
The Y-axis string-pot showed positive displacement when the coupler moved laterally towards the right side of the vehicle (forward facing).
The Z-axis string-pot showed positive displacement when the coupler moved downward (drooped) in the coupler pocket.

Bullet Hopper One (BH1) A end coupler:

The X-axis string-pot showed positive displacement when the coupler extended longitudinally out of the coupler pocket.
The Y-axis string-pot showed positive displacement when the coupler moved laterally towards the left side of the vehicle (forward facing).
The Z-axis string-pot showed positive displacement when the coupler moved downward (drooped) in the coupler pocket.

ATD Instrumentation

The ATD coordinate system, as specified by SAE J211, is a "right handed" system oriented as follows:

Accelerometers

X-axis	Longitudinal with the positive direction out the front or forward facing surface of the ATD component.
Y-axis	Lateral with the positive direction towards the right side when facing in the positive X direction.
Z-axis	Vertical with the positive direction downward.

Neck Forces

X-axis	Longitudinal with the head pulling the neck rearward representing a positive force.
Y-axis	Lateral with the head pulling the neck leftward representing a positive force.
Z-axis	Vertical with the head pulling the neck upward representing a positive force.

Neck Moments

X-axis	Positive reading from left ear to left shoulder motion.
Y-axis	Positive reading from chin to sternum motion.
Z-axis	Positive reading from head rotating to look over the left shoulder.

Comments from Review of Acquired Data

Strain Gages Channels

Some of the strain gage channels, such as CPWTR and CPWTL, could have used additional channel range. At the same time, many of the strain channels showed little dynamic strain. In crash testing where the crush dynamics are often heavily influenced by chaos, predicting which channels will see significant signal dynamics and then balancing the channel range vs. the channel resolution for the channels that do not see significant signal dynamics is a difficult task.

Bullet Locomotive and Hopper Car, Accelerometer Channels

The data from the floor triaxial accelerometer array, F1, looks good. Floor accelerometer array F2 saw saturation of the X-axis. The data for the Data Recorder accelerometer array, R, looks good for about the first 150 msec post-impact. The data from the CG accelerometer arrays for both Bullet Hopper cars looked good.

Steel Coil, Accelerometer Channels

The data from the accelerometer array in Steel Coil 1 (the rear coil) looks good through approximately 0.4 seconds after which the electrical cables failed. The data for Steel Coil 2 (the front coil) looks good for approximately 0.3 seconds after which the electrical cables failed. The data acquisition period for the Steel Coil 2 instrumentation was prematurely terminated by a failure of the DataBRICK power cable. Post-test inspection of the two steel coils suggested that the instrumentation cable failures experienced in both steel coils was due to the dynamics of the breaking coil tie-down chains.

Bullet Locomotive and Hopper Car, String-Pot Channels

The locomotive B end coupler, Y-axis string-pot mechanical cable failed at approximately 1.2 seconds post impact. This failure was most likely caused by impact debris. The data from all other string-pot channels looks good.

Bullet Locomotive, Speed Sensor

The data from the on-board Doppler speed sensor is valid for the entire run of the moving consist except for a few seconds post impact. The post-impact sensor output anomalies are due to the mechanical shock vibrations associated with the impact. The speed sensor calibration value was taken from the LOCO2 test, due to the fact that the speed sensor mount had not been disturbed since the LOCO2 test and the Speed Trap results for this test were unreliable (see explanation, below).

Bullet Hopper 1, Coupler Load

The data from the coupler load bridge looks good for the entire data acquisition period.

ATD Channels

All of the ATD channels show good data for the first 115 to 130 msec post-impact. Thereafter the data from all the channels appears to be compromised. Cable failure on the ATD accelerometer and loadcell channels may not manifest itself as a distinct data channel saturation (as is shown for the strain gage and vehicle accelerometers) due to the full-bridge, ratiometeric, nature of the ATD sensors vs. the quarter bridge configuration of the strain gage channels and the non-ratiometeric nature of the vehicle accelerometers. The ambiguous nature of the signal effects from severed ATD instrumentation channels precludes a definitive conclusion, however, I feel that the data beyond 130 msec post-impact cannot be considered reliable. A post-test inspection of the ATD showed that all of the ATD instrumentation cables had been severed during the impact.

Speed Trap Results

The speed traps both gave a nominal impact speed value of 22.5 mph. The recorded speed trap results were not consistent with the impact speed as registered by the on-board Doppler RADAR speed sensor (uncertainty of approximately ±0.5 mph) or the off-board, hand held TTCI Doppler RADAR Speed Gun (uncertainty of approximately ±0.1 mph). Therefore the speed trap results have been disregarded. While the cause of the speed trap failure is unknown, a reasonable conclusion is that the airflow generated by the passing of the moving consist caused a piece of track-side debris to pass through the speed traps prior to impact.

Data Reduction Information

Offset Values - All channels except Bullet Locomotive Speed

The average value for each data channel from T = -1.0000 to T = -0.0625 seconds (the first 12,000 data points) may be averaged and the average value subtracted from the entire data channel data set to establish the pre-impact zero value for the data channel.

Strain gage Data Channels

The strain gage data may be converted from Volts/Vexcitation to microstrain with positive values indicating tension using the following equation:

Let : $V =$ Data Channel Value $\left(\text{Volts}/\text{Vexcitation}\right)$

$F =$ Gage Factor (unitless)

$E =$ Strain (μStrains)

Then :

$$E = \frac{-4e6 * V}{F * (1 - 2 * V)}$$

Vehicle Channels

All post-acquisition low-pass filtering of vehicle accelerometer data should be accomplished using the phaseless digital low-pass filter algorithm specified in SAE J211 Rev. MAR95 Appendix C with corner frequencies of 100 and 25 Hz.

Anthropomorphic Test Dummy (ATD) Channels

The post-acquisition low-pass filtering of selected ATD data should be accomplished using the phaseless digital low-pass filter algorithm specified in SAE J211 Rev. MAR95 Appendix C. Per the recommendations of SAE J211, the ATD chest and Pelvis acceleration and neck moment data should be low-pass filtered to CFC180 and CFC600 respectively.

Certification

I certify that the data acquisition hardware and instrumentation transducers used in this test had been recently calibrated and tested and that appropriate calibration documentation is on file at the offices of GMH Engineering. I further certify that the instrumentation and data acquisition was carried out in compliance with usual and accepted engineering practice and in accordance with the TTCI prepared TIP.

Respectfully Submitted,

John J. Gordon, P.E.
GMH Engineering