U.S. Department
of Transportation

**Federal Railroad
Administration**

Passenger Train-to-Freight Train Impact Test: Test Procedures, Instrumentation and Data

Office of Research and
Development
Washington, D.C. 20590

DOT/FRA/ORD-

March 2003
Final Report

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REPORT DOCUMENTATION PAGE			Form approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0702-0288), Washington, D.C. 20503			
1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE March 2003		3. REPORT TYPE AND DATES COVERED January 31, 2002
4. TITLE AND SUBTITLE Passenger Train-to-Freight Train Impact Test: Test Procedures, Instrumentation and Data			5. FUNDING NUMBERS DTFR53-93-C-00001 Task Order 125
6. AUTHOR(S) Barrie Brickle			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Transportation Technology Center, Inc. P.O. Box 11130 Pueblo, CO 81001			8. PERFORMING ORGANIZATION REPORT NUMBERS
9. SPONSORING/MONITORING AGENGY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Research and Development 1120 Vermont Avenue, NW Washington, DC 20590			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/ABAILABILITY STATEMENT This document is available through National Technical Information Service, Springfield, VA 22161			12b. DISTRIBUTION CODE
13. ABSTRACT A full-scale passenger train-to-freight train impact test was performed on January 31, 2002 at the Transportation Technology Center, Pueblo, Colorado. The actual speed of impact, as measured by the laser speed trap, was 29.9 mph resulting in a large amount of damage to the leading cab-car, which climbed up onto the nose of the locomotive at an angle of about 20 degrees and then fell off to one side. The end-frame of the cab-car became separated from the center sill, with about 1/2 the length of the cab-car being crushed. There was very little damage to the trailing coach cars although all of them were derailed during the impact. The nose of the locomotive received very little damage but the roof and windshield of the locomotive received some superficial damage. The locomotive and hopper cars were also derailed during the impact.			
14. SUBJECT TERMS Impact test, energy absorption, crash energy management, train collisions, railway accidents, crashworthiness testing of railway vehicles, commuter rail passenger car, computational and kinematic models, crash dynamics			15. NUMBER OF PAGES 15 plus appendices 16. PRICE CODE
17. SECURITY CLASSIFICATION	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

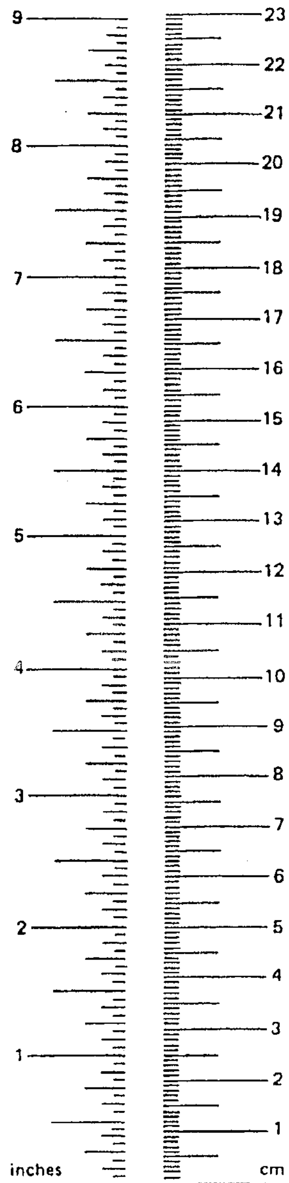
Standard Form 298 (Rec. 2-89)
Prescribed by ANSI/NISO Std. 239.18
298-102

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

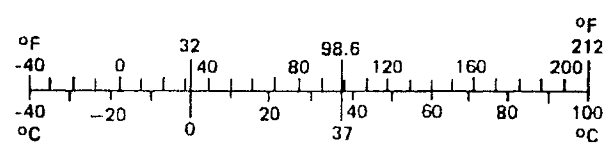
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	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
[illegible]	[illegible]	[illegible]	[illegible]	kg
			tonnes	t
	(2000 lb)			
		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



Acknowledgements

This work was performed as part of the Equipment Safety Research Program sponsored by the Office of Research and Development of the Federal Railroad Administration. Tom Tsai, Program Manager, and Claire Orth, Division Chief, Equipment and Operating Practices Division, Office of Research and Development, Federal Railroad Administration, supported this effort. Gunars Spons, Federal Railroad Administration Engineering Manager at the Transportation Technology Center, directed and coordinated the activities of all the parties involved in the test. Barrie Brickle, Scientist, Transportation Technology Center, Inc. implemented the equipment related portions of the test. David Tyrell, Program Manager, Volpe National Transportation Systems Center, coordinated technical requirements with the support of the American Public Transportation Association (APTA).

Simula Inc., the government's occupant protection test contractor, executed the interior experiments.

Southeastern Pennsylvania Transit Authority (SEPTA) donated the cab-car used in the test, Long Island Railroad (LIRR) donated the M1 coach cars and AMTRAK donated the F40 locomotives.

Arthur D. Little designed the 1990's end-frame attached to the front end of the cab-car.

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Executive Summary

A full-scale passenger train-to-freight train impact test was performed on January 31, 2002, at the Federal Railroad Administration's (FRA) Transportation Technology Center, Pueblo, Colorado, by Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR).

The purpose of the test was to measure the colliding equipment interaction and the amount of crush between the cars. Also to measure strains, accelerations, and displacements during the impact so that computational and kinematic models of the impact can be validated.

The main results of the test are:

- The speed of impact, as measured by the laser speed trap, was 29.9 mph (i.e., within 0.3% of the desired speed of 30 mph)
- There was a large amount of damage to the leading cab-car, which climbed up onto the nose of the locomotive at an angle of about 20 degrees and then fell off to one side. The impact end-frame of the cab-car was completely separated from the center sill, with about 1/2 the length of the cab car being crushed.
- There was very little damage to the trailing coach cars, although all of them were derailed. There was about a 2-foot offset between the leading cab-car and the 2nd coach car and between the 2nd coach car and the 3rd coach car.
- The nose of the locomotive received very little damage, but the roof and windshield of the locomotive received some superficial damage. The locomotive and the hopper cars also derailed during the impact.
- The maximum longitudinal acceleration recorded on the center-sill of the lead cab-car was -258 g. When filtered using a low-pass filter with a corner frequency of 100 Hz, Fc = 100 Hz, the peak acceleration was reduced to -43g.
- Those of the 2nd coach car were -75 g and -32 g.;
- Those of the 3rd coach car were 59 g and 16 g.;
- Those of the 4th coach car were 32 g and 13 g.;
- Those of the floor of the operator's cab in the stationary locomotive were -110 g and -45 g.
- The maximum value on the center-sill stationary locomotive was over 400 g. (Filtered data was corrupted due to saturation effects)

The test was performed by colliding a passenger train made up of a Budd Company Pioneer-type cab-car, two M1 passenger cars, an instrumentation car (T-car), and a trailing locomotive into a stationary freight train made up of a locomotive and two hopper cars.

The impact cab-car was fitted with a modified front end that conforms to 1990 standards. The impact locomotive had a modified hood and collision post fitted to comply with AAR Crashworthiness Standard S-580.

The seats were removed from the cab-car and the leading M1 to allow installation of two rows of seats in the cab-car and four rows of seats in the leading M1car. Anthropomorphic Test Devices (ATD's) were installed in the cab car and leading M1 car, as well as in the cab of the target locomotive.

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1.0 INTRODUCTION AND OBJECTIVES

Transportation Technology Center, Inc. (TTCI) performed a full-scale train-to-train impact test January 31, 2002, when a Budd Company Pioneer-type cab-car led train impacted a stationary Amtrak F40 locomotive led freight train at 29.9 mph. The moving consist included the cab-car, two LIRR M1 passenger cars, an instrumentation car (T-car), and a trailing Amtrak F40 locomotive. The stationary consist included a locomotive and two hopper cars, one loaded and one empty.

The purpose of the test was to measure the colliding equipment interaction and the amount of crush among the cars. Also to measure strains, accelerations, and displacements during the impact so that computational and kinematic models of the colliding equipment can be validated.

2.0 DESCRIPTION OF TEST VEHICLES

The test was conducted using a Budd Company Pioneer-type cab-car provided by the Southeastern Pennsylvania Transportation Authority (SEPTA), two M1 passenger cars provided by the Long Island Railroad (LIRR), a T-car provided by the Federal Railroad Administration (FRA), two F-40 locomotives provided by Amtrak, and two hopper cars provided by the FRA.

The impact cab-car was fitted with an end-frame designed to conform to 1990 standards. Arthur D. Little, Inc. designed this front end. The original seats were removed, along with other under-floor and ancillary equipment. Approximately 10,000 pounds of concrete was added, mostly under the floor in the center of the car, to make up for the weight of the missing equipment.

The seats were removed from one of the M1 cars so that the internal seat experiments could be installed, and some of the under-floor equipment was removed from both cars so that accelerometers could be mounted on the center sill. Both car bodies had some superficial damage, which was repaired and patched up with thin stainless steel sheets.

The impact locomotive was fitted with a modified hood and collision posts so that it complied with AAR Locomotive Crashworthiness Standard S-580.

The couplers were left installed at the impact ends of both the cab-car and the locomotive. Flat plates were welded to the front of each coupler in order to mount Tape Switches™ to trigger the instrumentation at impact. An instrumented coupler was fitted between the cab-car and the leading M1 car.

Simula Technologies Inc. fitted two rows of three-place M-style seats in the rear of the cab-car, two rows of two-place Amtrak Inter-city seats in the front of the leading M1 car, and two rows of three-place M-style seats in the rear of the leading M1 car. They also fitted a one-person seat in the cab of the impact locomotive. (The description of these seat experiments and the resulting data are the subject of another report.)

A bike-rack, with a bike, was installed on a vertical face in the T-car.

The moving consist was made up of the cab-car, two M1 cars, the T-car and a trailing locomotive. It was not possible to seal all the brake pipes on the M1 cars, so none of the brakes on this consist was set to come on after impact.

The hand brakes were set during the impact on the stationary consist, which was made up of a F-40 locomotive and two hopper cars.

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 train-to-train test, Appendix A of this report.

The Impact Test was performed by pushing the test consist with a locomotive, releasing it at a pre-determined point, then letting it run along the track into the stationary consist. The release distance and the speed of the locomotive at release were calculated from a series of speed calibration tests carried out on the Precision Test Track (PTT) and over the actual test site (Figure 1). Simulation calculations were also performed using TOES™ (TTCI's train action model) based on the actual track profile. The target speed for the test was 30 mph.

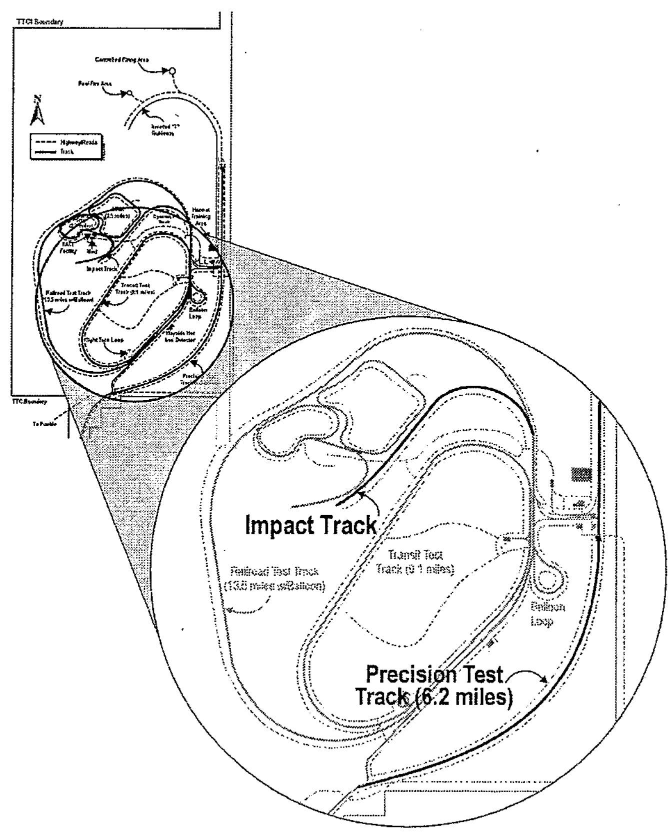

Figure 1. Precision Test Track and Impact Test Track

4.0 RESULTS

4.1 Items Measured Before The Test

4.1.1 Lengths

Moving Consist

Length of cab-car (SEPTA245), buffer beam to buffer beam = 83.46 ft
Length of leading M1 car (LIRR9614), buffer beam to buffer beam = 83.45 ft
Length of trailing M1 car (LIRR9441), buffer beam to buffer beam = 83.37 ft
Length of T-7 car, buffer beam to buffer beam = 83.64 ft
Length of trailing locomotive (202) = 54.23 ft

Stationary Consist

Length of stationary locomotive (234) = 53.57 ft
Length of leading hopper car (UP32022) = 49.25 ft
Length of trailing hopper car (UP32057) = 49.28 ft

4.1.2 Weights

Moving Consist

Weight of cab-car (SEPTA245) = 75,014 lb
Weight of leading M1 car (LIRR9614) = 73,427 lb
Weight of trailing M1 car (LIRR9441) = 72,836 lb
Weight of T-7 car = 148,944 lb
Weight of trailing locomotive (202) = 267,054 lb

Total weight = 637,275 lb

Stationary Consist

Weight of stationary locomotive (234) = 244,584 lb
Weight of leading hopper car (UP32022) = 312,598 lb
Weight of trailing hopper car (UP32057) = 78,459 lb

Total weight = 635,641 lb

(Note: The accuracy of the weigh-bridge is within 50 lb)

4.1.3 Weather Conditions

The weather conditions just before the test:

- Temperature = 32°F
- Wind speed = 7 mph from the SW

4.1.4 Photographs Taken Before Test

Photographs showing the vehicles, just before the test, are shown in Figures 2, 3, and 4.

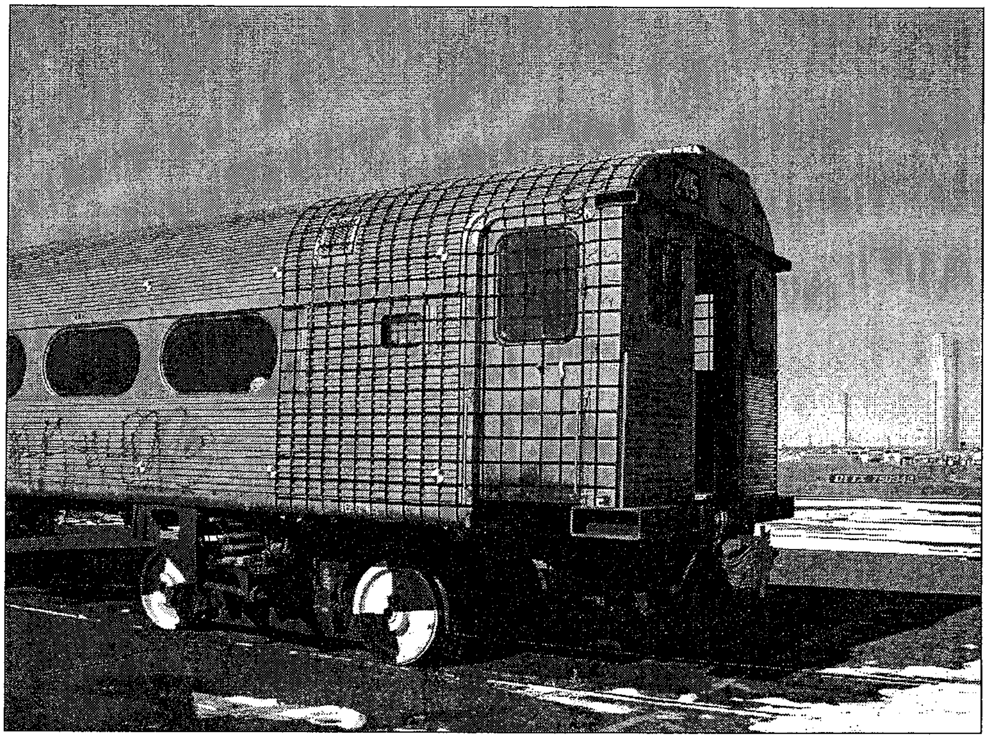

Figure 2. Cab-Car before Impact

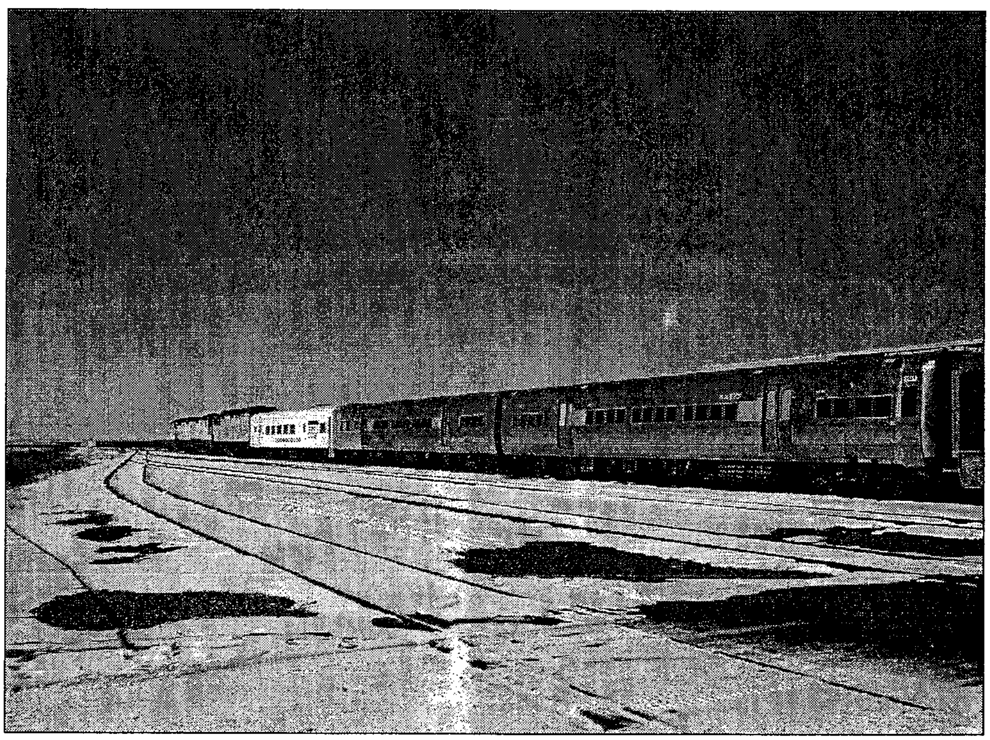

Figure 3. Moving Consist behind Cab-Car before Impact

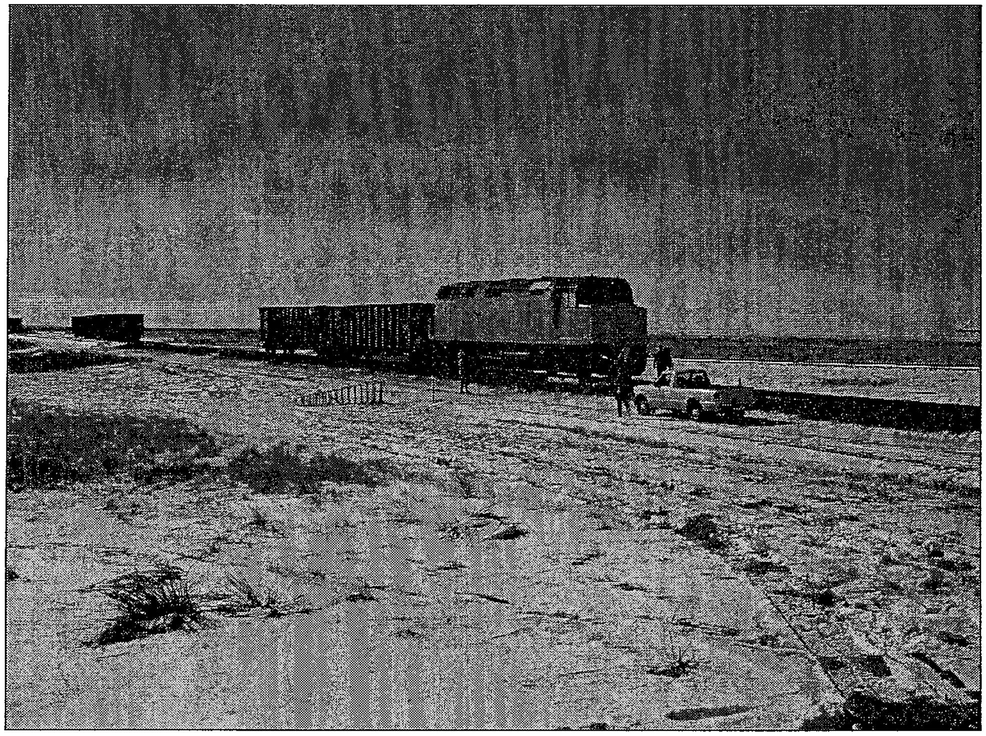

Figure 4. Stationary Consist before Impact

4.2 ITEMS MEASURED DURING THE TEST

Speed, strain, displacement, and force were measured during the test. The test implementation plan (Appendix A) gives the number, type, and location of the transducers used for this purpose. Ruggedized, 8-channel data collection systems, known commercially as Data BRICKs, were used to collect data for this impact test. Except as noted in Section 4.2.4, all of the Data BRICKs were set to filter analog data at 1017Hz and digitize and sample at 7945 samples-per-second.

The following anomalies occurred with the data acquisition system:

- Three channels for the impact cab-car (B1) were not acquired due to trigger failure on Data BRICK SN90002 (C1X, AR-tapeswitch, AL-tapeswitch)
- Seven channels on the 4th coach car (B4) were not acquired due to battery failure (C2X, C2Y, C2Z, C3X, C3Y, C3Z, BBZ)
- Eight channels for the impact cab-car were affected by periodic noise pulses that were superimposed on the valid signals. The fault was later traced to a faulty power supply module in Data BRICK SN90068 (CSR3U, CSL3U, CSR3L, CSL3L, SSR1, SSR2, SSL1, SSL2)

4.2.1 Speed

The moving consist was accelerated from rest by a locomotive and released at a point 1,500 feet from the front of the stationary locomotive. The speed of the consist just before impact, as measured by the laser based speed trap, was:

Laser 1	43.85 ft/s
Laser 2	43.85 ft/s
Average	43.85 ft/s = 29.9 mph

The amount of energy (E) dissipated during the impact can be calculated from the speed of the moving consist just before impact, $V_0 = 43.85$ ft/s, and the total weight of the moving consist, $M_0 = 637{,}275$ lb.

$$
\begin{aligned}
E &= ½.\, M_0.\, V_0^2 \\
&= ½ \text{ x } 637{,}275 \text{ x } 43.85^2 / 32.2 \\
&= 19.03 \text{ x } 10^6 \text{ ft.lb} \\
&= 25.8 \text{ MJ}
\end{aligned}
$$

4.2.2 Accelerations

Acceleration was measured on each vehicle used in the test. The Test Implementation Plan (Appendix A) shows the locations of acceleration measurements for each vehicle. Raw data was filtered at 1017Hz and digitized and sampled at 7945 samples-per-second. Data was later digitally filtered at 100Hz and 25Hz using the filter algorithm specified in Appendix C of SAE J-211 (Butterworth 4-pole phaseless digital filter).

Table 1 shows an overview of the longitudinal acceleration data for the test. The channel with the largest amplitude peak is shown for each car and filter frequency.

Table 1. Statistics for Longitudinal Accelerometer Data from 0 to 1s

Car	Frequency	Channel	Minimum (g)	Maximum (g)
Leading Cab-Car	1000Hz	B1_C3X	-258	123
	100Hz	B1_L4X	-43	20
	25Hz	B1_C7X	-14	6
Second Passenger Car	1000Hz	B2_C1X	-75	60
	100Hz	B2_C4X	-32	13
	25Hz	B2_C4X	-26	10
Third Passenger Car	1000Hz	B3_C5X	-45	59
	100Hz	B3_C5X	-14	16
	25Hz	B3_C5X	-10	9
Fourth Passenger Car	1000Hz	B4_C1X	-24	32
	100Hz	B4_C1X	-13	13
	25Hz	B4_C1X	-7	1
Trailing Locomotive	1000Hz	BL_C3X	-25	29
	100Hz	BL_C2X	<1	4
	25Hz	BL_C2X	<1	4
Standing Locomotive	1000Hz	SL_C1X*	<-400	>400
	100Hz	SL_C3X	-115	131
	25Hz	SL_C3X	-3	9
Standing Hopper 1	1000Hz	SH1_C1	-33	55
	100Hz	SH1_C1	-2	17
	25Hz	SH1_C1	-2	9
Standing Hopper 2	1000Hz	SH2_C1	-18	28
	100Hz	SH2_C2	-6	1
	25Hz	SH2_C2	-4	<1

* SL_C1X was saturated. Filtered data is corrupted due to saturation effects so the next highest locations are shown for 100Hz and 25Hz.

The results shown in table demonstrate that the highest magnitude accelerations were on the standing locomotive, except at the 25Hz frequency where the second passenger car showed the highest value.

It is apparent that the magnitudes of the acceleration are very dependent on the frequency of interest. It is therefore recommended that time histories be used to compare with other test or model data. Time histories for each acceleration channel are shown in Appendix B for 1000Hz data, Appendix C for 100Hz data, and Appendix D for 25Hz data.

4.2.3 Displacements

The vertical displacement across the secondary suspension of the cab-car and the two M1 cars were measured using string potentiometers between the car body and the truck. Statistics for these channels are shown in Table 2. The average of the data for the two seconds before the impact was subtracted from the data to show the nominal displacement.

Table 2. Statistics for Suspension Displacement Data from 0 to 1s

Car	Location	Channel	Minimum (in)	Maximum (in)
Leading Cab-Car	A Truck Left	B1_AL	-2.72	4.93
	A Truck Right	B1_AR	-2.25	5.13
	B Truck Left	B1_BL	-2.49	2.36
	B Truck Right	B1_BR	-2.61	3.07
Second Passenger Car	A Truck Left	B2_AL	-1.82	2.14
	A Truck Right	B2_AR	-2.01	0.85
	B Truck Left	B2_BL	-0.25	4.88
	B Truck Right	B2_BR	-2.17	5.01
Third Passenger Car	A Truck Left	B3_AL	-1.40	0.08
	A Truck Right	B3_AR	-1.24	0.06
	B Truck Left	B3_BL	-0.05	2.08
	B Truck Right	B3_BR	-0.50	2.63

The largest suspension displacements occurred on the leading cab car. The minimum displacements occurred just after impact, while the maximums occurred when the bogies were lifted from the track as the cab-car climbed onto the locomotive.

The displacements (in each direction) between the cab-car trailing end coupler and the car body, the M1 car bodies and their couplers, and the T-car leading end coupler and car body were also measured using string potentiometers. Statistics for these channels are shown in Table 3.

Table 3. Statistics for Coupler Displacement Data from 0 to 1s

Car	Location	Channel	Minimum (in)	Maximum (in)
Leading Cab Car	B Coupler Vert	B1_CBX	-1.76	12.48
	B Coupler Lat	B1_CBY	-0.34	10.81
	B Coupler Long	B1_CBZ	-0.49	9.39
Second Passenger Car	A Coupler Vert	B2_CAX	-1.36	7.11
	A Coupler Lat	B2_CAY	-0.16	9.70
	A Coupler Long	B2_CAZ	-1.42	3.50
	B Coupler Vert	B2_CBX	-2.33	5.70
	B Coupler Lat	B2_CBY	-1.09	11.52
	B Coupler Long	B2_CBZ	-1.85	4.29
Third Passenger Car	A Coupler Vert	B3_CAX	-2.00	2.10
	A Coupler Lat	B3_CAY	-0.34	5.39
	A Coupler Long	B3_CAZ	-0.11	6.38
	B Coupler Vert	B3_CBX	-6.11	0.20
	B Coupler Lat	B3_CBY	-0.65	0.61
	B Coupler Long	B3_CBZ	-1.14	1.55
Fourth Passenger Car	A Coupler Vert	B2_CAX	-0.59	0.39
	A Coupler Lat	B2_CAY	-1.75	2.80
	A Coupler Long	B2_CAZ	-0.35	3.16

Coupler displacements were very large due to the action of the cars after they derailed.

For the cab-car string potentiometers, the Data Brick was set to a filter frequency of 500Hz and a sample rate of 3,972Hz. For the 3rd coach car the filter frequency was 502Hz and the sample rate was 3,981 Hz. For all other displacement measurements the Data Bricks were set to filter frequencies of 1017Hz and sample rates of 7,945 Hz. For all measurements the pre-trigger time was set to 2 s and the post-trigger time to 6 s.

The Test Implementation Plan in Appendix A describes where the displacement transducers were mounted. Appendix E contains time plots of all displacement channels.

4.2.5 Longitudinal Force In Coupler

The coupler at the trailing end of the impact cab-car was strain gauged and calibrated so that the longitudinal force could be measured. The coupler force measurement saturated at a force of 919 kips about 60ms after impact. The coupler force time history is located in Appendix E.

4.2.6 Strains

Strain was measured on the leading cab-car and on the standing locomotive.

Five strain channels on the leading cab car saturated during the test. Three of these, B1_CSR3L, B1_CSL1U, and B1_CSR3U, appeared to saturate due to noise on the signal. The other two gages were B1_CSR1U, which saturated at 4825 micro-strain 0.490 seconds after impact and B1_CSR1L, which saturated at 4706 micro-strain 0.466 seconds after impact.

One strain channel on the standing locomotive, SL_MSL2U, saturated due to noise. The next highest strain reading on the locomotive was 1697 micro-strain on channel SL_MSL1U.

The Test Implementation Plan in Appendix A shows the positions of all the individual strain gauges. Time plots of the strains are shown in Appendix F.

4.2.4 Longitudinal Velocity

The x-axis acceleration time histories for all the center sill accelerometers on all the moving cars have been integrated to give velocity and then plotted against time. The Test Implementation Plan in Appendix A shows the positions of the accelerometers. Time plots of the longitudinal velocity are shown in Appendix G.

4.2.7 High Speed And Video Photography

The Impact Test was visually recorded with 10 high-speed film cameras and 14 video cameras. Camera coverage was selected to provide views of both the left and right sides of the vehicle, overhead views, and an overall view of the impact.

The film and video camera positions are shown in Figure 5.

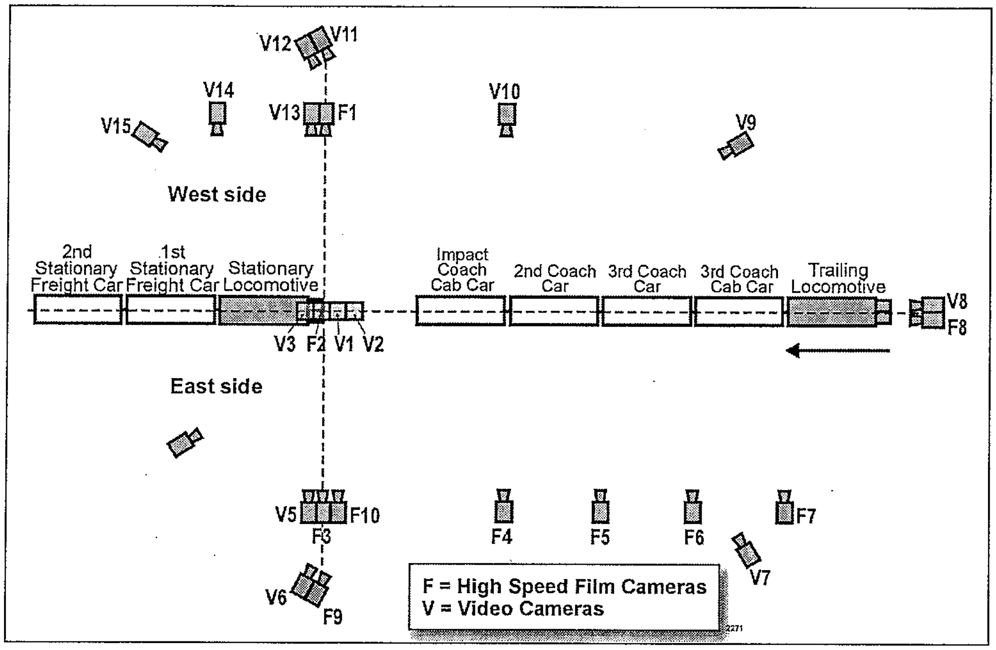

Figure 5. Camera Positions

Set-up sheets for the film camera are presented in Appendix H.

Two high-speed film cameras, F1 and F10, did not run due to a power failure.

One video camera, V9, did not run for an unknown reason.

4.3 ITEMS MEASURED AFTER THE TEST

Figure 6 shows the cars at the moment of impact. Figures 7, 8, and 9 show the cab-car and other passenger cars after impact. The second and third passenger cars after impact are shown in Figure 10. The locomotive after impact is shown in Figure 11. The relative positions of all the vehicles after impact are shown in diagrammatic form in Figure 12.

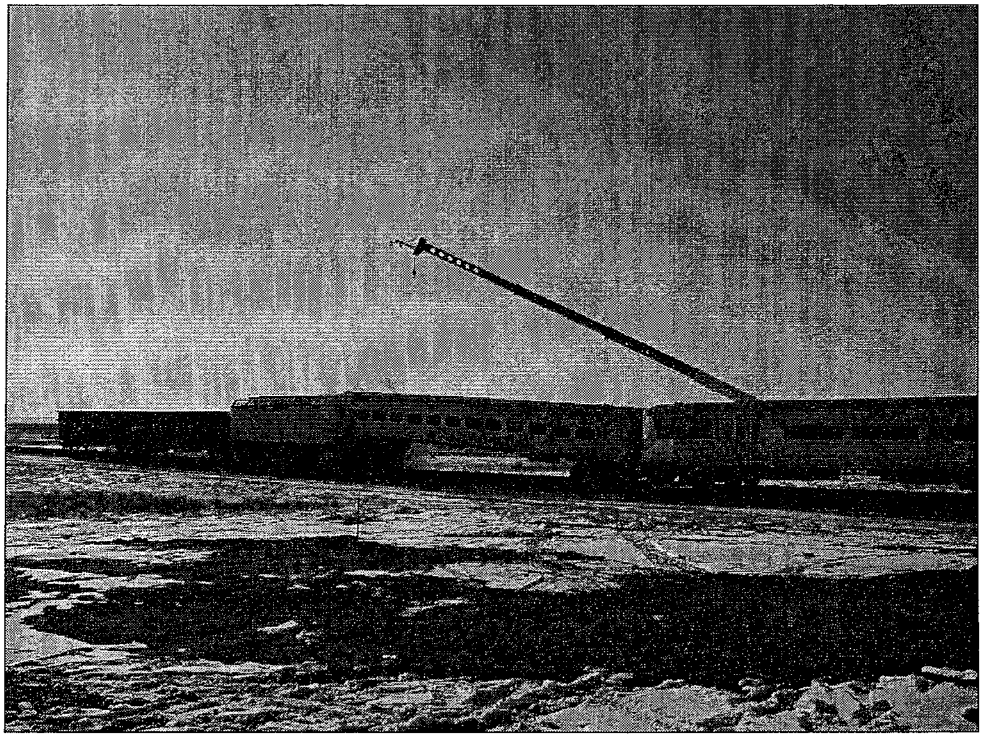

Figure 6. Cars at Moment of Impact

Figure 7. Cab-Car after Impact

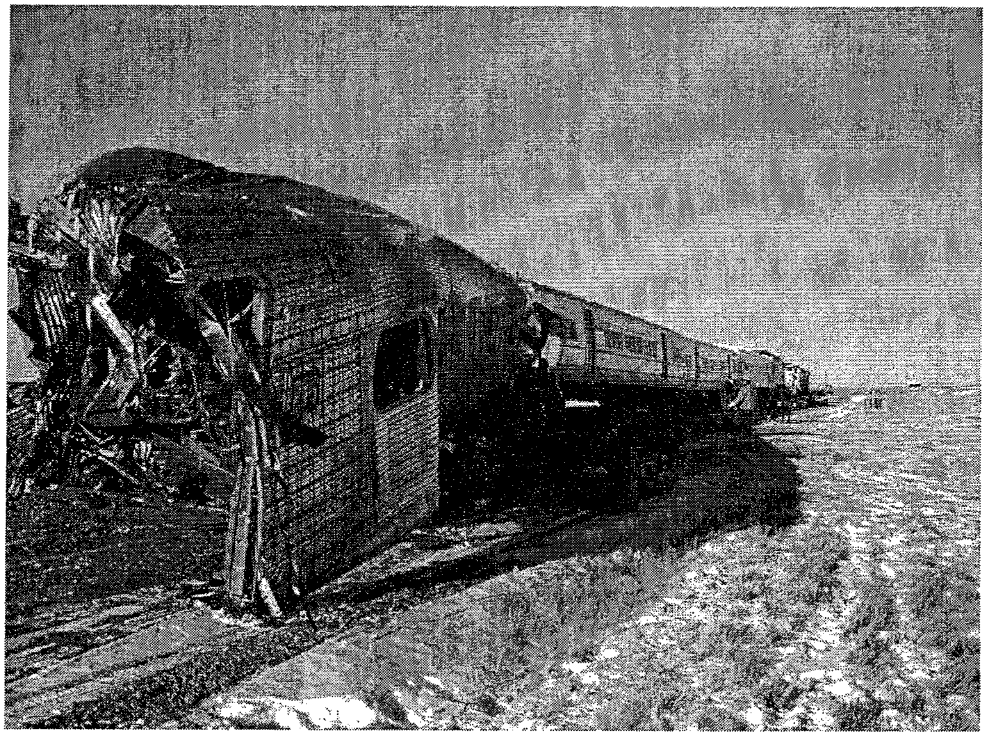

Figure 8. Moving Consist after Impact

Figure 9. Cab-Car after Impact


Figure 10. Second and Third Passenger Cars after Impact

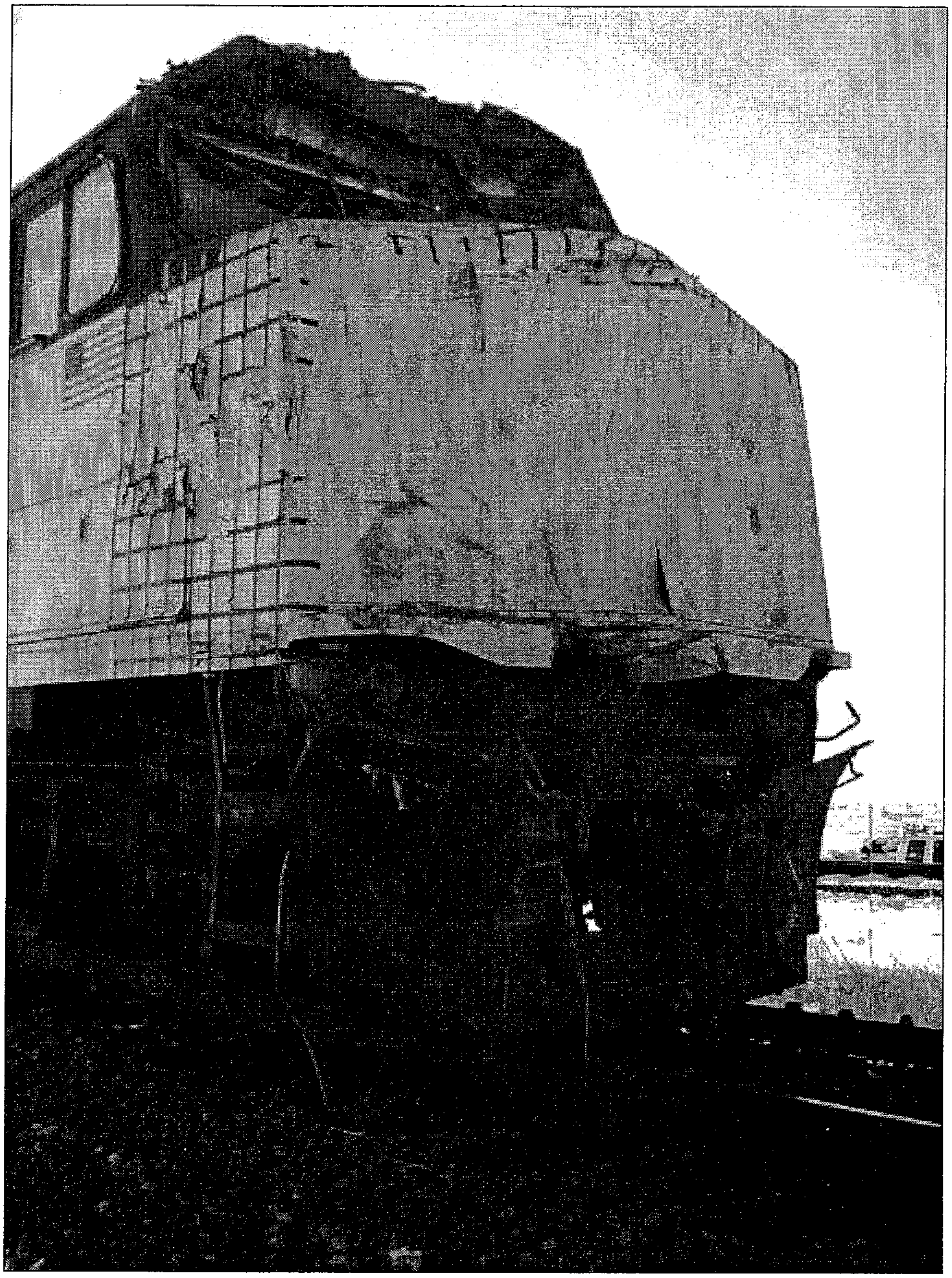

Figure 11. Locomotive after Impact

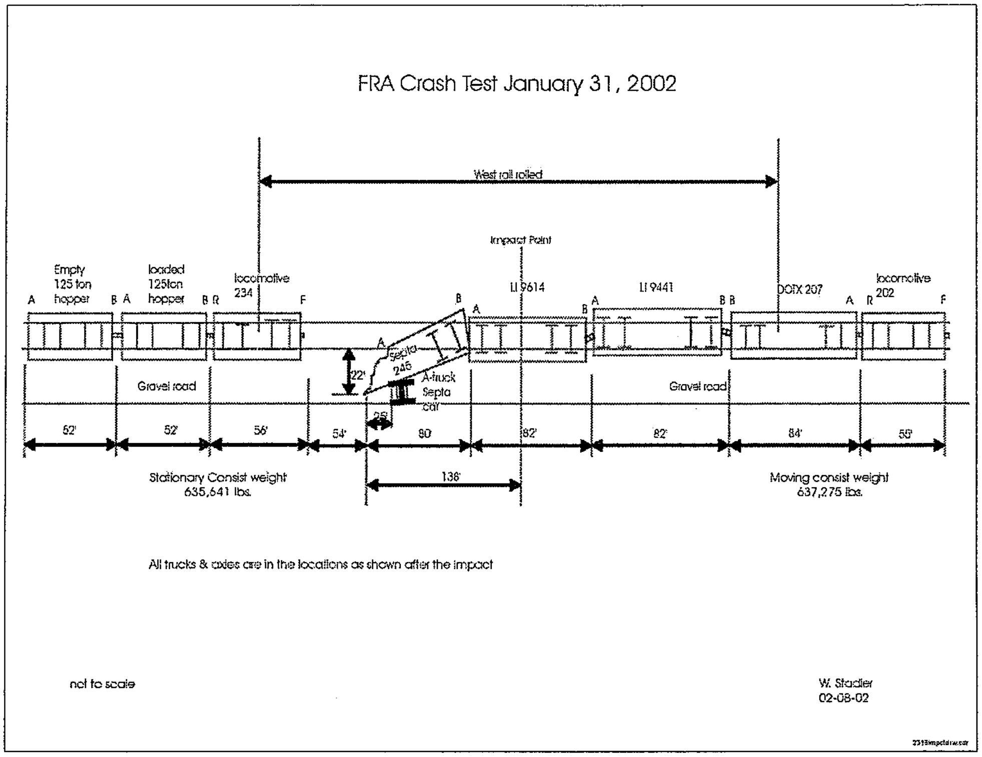

Figure 12. Positions of Cars after Impact

5.0 DISCUSSION/CONCLUSIONS

The objective of the test, to measure the interaction of the cars and the amount of crush between the cars, was met. The actual speed of impact, as measured by the laser speed trap, was 29.9 mph resulting in a large amount of damage to the leading cab-car, which climbed up onto the nose of the locomotive at an angle of about 20 degrees and then fell off to one side. The end-frame of the cab-car became separated from the center sill, with about 1/2 the length of the cab-car being crushed. There was very little damage to the trailing coach cars although all of them were derailed during the impact. The nose of the locomotive received very little damage but the roof and windshield of the locomotive received some superficial damage. The locomotive and hopper cars were also derailed during the impact.

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Appendix A

Test Implementation Plan

Test Implementation Plan for Cab-Car To Locomotive Impact Test

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January 18, 2002
Version 3.0

1.0 Purpose

To run a cab car, four coupled passenger cars and a trailing locomotive into a stationary locomotive led freight train with two loaded hopper cars on level tangent track at an impact speed of approximately 30 mph. Computer simulations show that the "stationary" locomotive will move back 100 feet on impact, and that the leading passenger car will crush by approximately 14 feet. The cab-car, passenger cars and locomotives will be instrumented to measure material strains, structural accelerations, suspension displacements, coupler forces and coupler displacements throughout the vehicles in sufficient quantity to allow correlation with analytical predictions.

2.0 Requirements

To impact a cab-car, four coupled passenger cars and a locomotive into a stationary locomotive led freight train at an impact speed of 30 mph (+ or – 5 mph).

3.0 Test Cars

The test will be conducted using a cab-car provided by SEPTA, four passenger cars provided by Long Island Railroad and locomotives provided by AMTRAK.

The cab-car will be modified to bring it up to 1990 standards by fitting a re-designed front end. A load test will be performed on the cab-car to show that it conforms to 1990's standards.

The stationary locomotive will be modified to bring the structure up to AAR Locomotive Crashworthiness Standard S-580. This will involve modifying the collision posts, short hood and anti-climber.

The cab-car and passenger cars will be modified internally so that a number of seat configurations can be tested. The stationary locomotive will have one interior test. All the interior experiments will be provided by SIMULA.

Ballast will be added to the test cab-car and passenger cars to replace the seats and other equipment removed from them before the test. The freight cars will be loaded with ballast.

4.0 Test Method

The test will be performed at the TTC by impacting the coupled passenger test cars into the stationary locomotive led freight train at a speed of 30 mph. The impact test will be carried out by pushing the test cars and trailing locomotive with another locomotive and then releasing them and allowing them to roll along the track and into the stationary locomotive and loaded freight cars. The release distance, and the speed of the locomotive at the release point, will be determined from a series of calibration runs carried out before the locomotive led freight train is put in place.

An on-board radar speed measuring system will be used for speed calibration of the test cars. 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 to measure the speed of the test cars just before impact.

On-board instrumentation will record accelerations, displacements and strains at various points on the test cars, locomotives and freight cars during and after the impact. High speed film cameras and video cameras will be used to record both the impact between the lead cab-car and the locomotive and between the passenger cars themselves.

5.0 Measured Items

The length and weight of each vehicle will be measured before the 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 gages 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 the test:

1. The speed of the cab-car just before impact using a laser based speed trap.
2. Longitudinal strains at draft sills and center sills of the impacting cab-car (see Figure 1)(12 strain gages)
3. Longitudinal strains at the side sills and cant rails of the impacting cab-car (see Figure 2)(12 strain gages)
4. Accelerations of draft sills, center sill and left and right side sills of the impacting cab-car (see Figure 3)(23 accelerometers)
5. Accelerations of each truck of the impacting cab-car in the longitudinal, vertical and lateral directions (6 accelerometers)
6. Accelerations of draft sills, center sill and left and right side sills of the second coach car (see Figure 4)(17 accelerometers)
7. Accelerations of each truck of the second coach car in the lateral direction (2 accelerometers)

8. Accelerations of draft sills and center sill of the third coach car (see Figure 5)(11 accelerometers)
9. Accelerations of each truck of the third coach car in the lateral direction (2 accelerometers)
10. Accelerations of center sill of the fourth coach car (see Figure 6)(9 accelerometers)
11. Accelerations of each truck of the fourth coach car in the lateral direction (2 accelerometers)
12. Accelerations of center sill of the fifth coach car (see Figure 7)(9 accelerometers)
13. Accelerations of each truck of the fifth coach car in the lateral direction (2 accelerometers)
14. Accelerations of the main sill of the trailing locomotive (see Figure 8)(9 accelerometers)
15. Accelerations of each truck of the trailing locomotive in the lateral direction (2 accelerometers)
16. Accelerations of the main sill of the stationary locomotive (see Figure 9)(9 accelerometers)
17. Accelerations of each truck of the stationary locomotive (6 accelerometers)
18. Acceleration of the Operator's Cab of the stationary locomotive (see Figure 10)(3 accelerometers)
19. Longitudinal strains on the main sill of the stationary locomotive (see Figure 11)(12 strain gages)
20. Longitudinal accelerations of center sill of the first and second stationary freight cars (see Figure 12)(4 accelerometers)
21. Displacement across each secondary suspension of the impacting cab-car (4 string potentiometers)
22. Displacement across each secondary suspension of the first coach car (4 string potentiometers).
23. Displacement across each secondary suspension of the second coach car (4 string potentiometers)
24. Lateral and vertical displacements of couplers relative to car body between impacting cab-car and first coach car (3string potentiometers on each coupler, i.e. total of 6 string potentiometers).
25. Lateral and vertical displacements of couplers relative to car body between first coach car and second coach car (3string potentiometers on each coupler, i.e. total of 6 string potentiometers)
26. Lateral and vertical displacements of couplers relative to car body between second coach car and third coach car (3string potentiometers on each coupler, i.e. total of 6 string potentiometers)
27. Longitudinal strain on coupler between impacting cab-car and first coach car (1 strain gage bridge)
28. Tape switches on each corner post of impact end of leading cab-car (2 tape switches).

This amounts to a total of 185 channels.

High-speed film cameras and video cameras will be used to record the impact. 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 length of each vehicle will be measured after the test.

6.0 Instrumentation

6.1 Strain measurements

6.1.1 Strain measurements, Impact Cab-Car

Figure 1 shows the general arrangement of strain gages on the Center Sill.

Table 1 lists the locations and strain gage types for all the strain gages on the center sill.

Location	Strain Gage	Channel
CS-R-1-U	Standard	1
CS-L-1-U	Standard	2
CS-R-1-L	Standard	3
CS-L-1-L	Standard	4
CS-R-2-U	Standard	5
CS-L-2-U	Standard	6
CS-R-2-L	Standard	7
CS-L-2-L	Standard	8
CS-R-3-U	Standard	9
CS-L-3-U	Standard	10
CS-R-3-L	Standard	11
CS-L-3-L	Standard	12

Table 1 Impact Cab-Car, Strain gage location and type, Center Sill

Figure 2 shows the general arrangement of strain gages on the Side Sill and Cant Rail.

Table 2 lists the locations and strain gage types for all the strain gages on the side sills and cant rails.

1.1 Location	Strain Gage	Channel
SS-R-1	Standard	1
SS-L-1	Standard	2
SS-R-2	Standard	3
SS-L-2	Standard	4
SS-R-3	Standard	5
SS-R-3	Standard	6
CR-R-1	Standard	7
CR-L-1	Standard	8
CR-R-2	Standard	9
CR-L-2	Standard	10
CR-R-3	Standard	11
CR-L-3	Standard	12

Table 2 Impact Cab-Car, Strain gage location and type, Side Sill and Cant Rail

6.1.2 Strain Measurements, Stationary Locomotive

Figure 11 shows the general arrangement of strain gages on the Main Sill of the Locomotive.

Table 3 lists the locations and strain gage types for all the strain gages on the main sill of the locomotive.

Location	Strain Gage	Channel
MS-R-1-U	Standard	1
MS-L-1-U	Standard	2
MS-R-1-L	Standard	3
MS-L-1-L	Standard	4
MS-R-2-U	Standard	5
MS-L-2-U	Standard	6
MS-R-2-L	Standard	7
MS-L-2-L	Standard	8
MS-R-3-U	Standard	9
MS-L-3-U	Standard	10
MS-R-3-L	Standard	11
MS-L-3-L	Standard	12

Table 3. Stationary Locomotive, Strain gage location and type, MainSill

6.1.3 Coupler Force

The coupler will be strain gauged with a single gage bridge measuring the longitudinal force.

6.2 Acceleration measurements

The car-bodies gross and flexible motions will be measured using accelerometers. The gross motions of the car-bodies are the longitudinal, lateral, and vertical translational displacements, as well as the pitch, yaw and roll angular displacements. The flexible modes include vertical and lateral bending as well as torsional displacement about axis of the body. Measurements of these motions are required to fully characterize the secondary collision environment.

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.

6.2.1 Accelerometer measurements, Impact Cab-Car

Figure 3 shows the general arrangement of accelerometers on the Impact Cab-Car.

Table 4 lists the accelerometer locations, accelerometer types, and data channels for the Impact Cab-Car.

Location	Accelerometer	Measurement		Channel	
C-1	Single axis	Longitudinal	X	1	1,000G
C-2	Three axis	Longitudinal	X	2	1,000G
		Lateral	Y	3	100G
		Vertical	Z	4	400G
C-3	Two axis	Longitudinal	X	5	400G
		Vertical	Z	6	400G
C-4	Three axis	Longitudinal	X	7	400G
		Lateral	Y	8	100G
		Vertical	Z	9	200G
C-5	Two axis	Longitudinal	X	10	400G
		Vertical	Z	11	200G
C-6	Three axis	Longitudinal	X	12	400G
		Lateral	Y	13	100G
		Vertical	Z	14	200G
C-7	Single axis	Longitudinal	X	15	400G
R-2	Single axis	Vertical	Z	16	400G
R-4	Two axis	Longitudinal	X	17	400G
		Vertical	Z	18	200G
R-6	Single axis	Vertical	Z	19	200G
L-2	Single axis	Vertical	Z	20	400G
L-4	Two axis	Longitudinal	X	21	400G
		Vertical	Z	22	200G
L-6	Single axis	Vertical	Z	23	200G
B-1 (Bogie)	Three axis	Longitudinal	X	24	400G
		Lateral	Y	25	100G
		Vertical	Z	26	400G
B-2 (Bogie)	Three axis	Longitudinal	X	27	400G
		Lateral	Y	28	100G
		Vertical	Z	29	200G

Table 4 Impact Cab-Car, Accelerometers

6.2.2 Accelerometer measurements, Second Coach Car

Figure 4 shows the general arrangement of accelerometers on the Second Coach Car.

Table 5 lists the accelerometer locations, accelerometer types, and data channels for the Second Coach Car.

Location	Accelerometer	Measurement		Channel	
C-1	Single axis	Longitudinal	X	1	200G
C-2	Three axis	Longitudinal	X	2	200G
		Lateral	Y	3	100G
		Vertical	Z	4	200G
C-3	Single axis	Longitudinal	X	5	200G
C-4	Three axis	Longitudinal	X	6	200G
		Lateral	Y	7	100G
		Vertical	Z	8	200G
C-5	Single axis	Longitudinal	X	9	200G
C-6	Three axis	Longitudinal	X	10	200G
		Lateral	Y	11	100G
		Vertical	Z	12	100G
C-7	Single axis	Longitudinal	X	13	200G
R-4	Two axis	Longitudinal	X	14	200G
		Vertical	Z	15	100G
L-4	Two axis	Longitudinal	X	16	200G
		Vertical	Z	17	100G
B-1 (Bogie)	Single axis	Vertical	Z	18	100G
B-2 (Bogie)	Single axis	Vertical	Z	19	100G

Table 5 Second Coach Car, Accelerometers

6.2.3 Accelerometer measurements, Third Coach Car

Figure 5 shows the general arrangement of accelerometers on the Third Coach Car.

Table 6 lists the accelerometer locations, accelerometer types, and data channels for the Third Coach Car.

Location	Accelerometer	Measurement		Channel	
C-1	Single axis	Longitudinal	X	1	100G
C-2	Three axis	Longitudinal	X	2	100G
		Lateral	Y	3	25G
		Vertical	Z	4	50G
C-3	Three axis	Longitudinal	X	5	100G
		Lateral	Y	6	25G
		Lateral	Z	7	50G
C-4	Three axis	Longitudinal	X	8	100G
		Lateral	Y	9	25G
		Vertical	Z	10	50G
C-5	Single axis	Longitudinal	X	11	100G
B-1 (Bogie)	Single axis	Vertical	Z	12	50G
B-2 (Bogie)	Single axis	Vertical	Z	13	50G

Table 6 Third Coach Car, Accelerometers

6.2.4 Accelerometer measurements, Fourth Coach Car

Figure 6 shows the general arrangement of accelerometers on the Fourth Coach Car.

Table 7 lists the accelerometer locations, accelerometer types, and data channels for the Fourth Coach Car.

Location	Accelerometer	Measurement		Channel	
C-1	Three axis	Longitudinal	X	1	100G
		Lateral	Y	2	25G
		Vertical	Z	3	50G
C-2	Three axis	Longitudinal	X	4	100G
		Lateral	Y	5	25G
		Vertical	Z	6	50G
C-3	Three axis	Longitudinal	X	7	100G
		Lateral	Y	8	25G
		Vertical	Z	9	50G
B-1 (Bogie)	Single axis	Vertical	Z	10	50G
B-2 (Bogie)	Single axis	Vertical	Z	11	50G

Table 7 Fourth Coach Car, Accelerometers

6.2.5 Accelerometer measurements, Fifth Coach Car

Figure 7 shows the general arrangement of accelerometers on the Fifth Coach Car.

Table 8 lists the accelerometer locations, accelerometer types, and data channels for the Fifth Coach Car.

Location	Accelerometer	Measurement		Channel	
C-1	Three axis	Longitudinal	X	1	100G
		Lateral	Y	2	25G
		Vertical	Z	3	50G
C-2	Three axis	Longitudinal	X	4	100G
		Lateral	Y	5	25G
		Vertical	Z	6	50G
C-3	Three axis	Longitudinal	X	7	100G
		Lateral	Y	8	25G
		Vertical	Z	9	50G
B-1 (Bogie)	Single axis	Vertical	Z	10	50G
B-2 (Bogie)	Single axis	Vertical	Z	11	50G

Table 8 Fifth Coach Car, Accelerometers

6.2.6 Accelerometer measurements, Trailing Locomotive

Figure 8 shows the general arrangement of accelerometers on the Trailing Locomotive.

Table 9 lists the accelerometer locations, accelerometer types, and data channels for the Trailing Locomotive.

Location	Accelerometer	Measurement		Channel	
C-1	Three axis	Longitudinal	X	1	100G
		Lateral	Y	2	25G
		Vertical	Z	3	50G
C-2	Three axis	Longitudinal	X	4	100G
		Lateral	Y	5	25G
		Vertical	Z	6	50G
C-3	Three axis	Longitudinal	X	7	100G
		Lateral	Y	8	25G
		Vertical	Z	9	50G
B-1 (Bogie)	Single axis	Vertical	Z	10	50G
B-2 (Bogie)	Single axis	Vertical	Z	11	50G

Table 9 Trailing Locomotive, Accelerometers

6.2.7 Accelerometer measurements, Stationary Locomotive

Figure 9 shows the general arrangement of accelerometers on the Trailing Locomotive.

Table 10 lists the accelerometer locations, accelerometer types, and data channels for the Trailing Locomotive.

Location	Accelerometer	Measurement		Channel	
C-1	Three axis	Longitudinal	X	1	400G
		Lateral	Y	2	200G
		Vertical	Z	3	400G
C-2	Three axis	Longitudinal	X	4	400G
		Lateral	Y	5	200G
		Vertical	Z	6	400G
C-3	Three axis	Longitudinal	X	7	400G
		Lateral	Y	8	200G
		Vertical	Z	9	400G
B-1 (Bogie)	Three axis	Longitudinal	X	10	400G
		Lateral	Y	11	200G
		Vertical	Z	12	200G
B-2 (Bogie)	Three axis	Longitudinal	X	13	400G
		Lateral	Y	14	200G
		Vertical	Z	15	200G
Operator's Cab	Three axis	Longitudinal	X	16	400G
		Lateral	Y	17	200G
		Vertical	Z	18	400G

Table 10 Stationary Locomotive, Accelerometers

6.2.8 Accelerometer measurements, First Stationary Freight Car

Figure 10 shows the general arrangement of accelerometers on the First Stationary Freight Car.

Table 11 lists the accelerometer locations, accelerometer types, and data channels for the First Stationary Freight Car.

Location	Accelerometer	Measurement		Channel	
C-1	Single axis	Longitudinal	X	1	100G
C-2	Single axis	Longitudinal	X	2	100G

Table 11 First Stationary Freight Car , Accelerometers

6.2.9 Accelerometer measurements, Second Stationary Freight Car

Figure 10 shows the general arrangement of accelerometers on the Second Stationary Freight Car.

Table 12 lists the accelerometer locations, accelerometer types, and data channels for the Second Stationary Freight Car.

Location	Accelerometer	Measurement		Channel	
C-1	Single axis	Longitudinal	X	1	100G
C-2	Single axis	Longitudinal	X	2	100G

Table 12 Second Stationary Freight Car , Accelerometers

6.3 String Potentiometers

Four string potentiometers will be fixed across each secondary suspension on the impacting cab-car, second coach car and third coach car between body bolster and bogie bolster to measure the relative vertical displacement (Total of 12 string potentiometers).

Six string potentiometers will be fixed between the couplers and car bodies of the impacting cab-car and second coach car, between the second coach car and third coach car and between the third coach car and fourth coach car, to measure lateral and vertical displacements (Total of 18 potentiometers).

6.4 High-speed and real-time photography

Ten high-speed film cameras and fourteen video cameras will document the impact test. The cameras will be located either side of the impact point between the cab-car and the locomotive and either side of the intersection between the impact cab-car and first coach car, the first coach car and second coach car and second coach car and third coach car. Other cameras will be located looking along the passenger train and looking down on the impact point from overhead. 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.

Four-in. diameter 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 the 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 running at a nominal speed of 500 frames per second will run for about eight seconds before the100-ft film is entirely exposed.

6.5 Data Acquisition

Twenty-five, 8-channel battery-powered on-board data acquisition systems will provide excitation to the strain gages and accelerometers, analog anti-aliasing filtering of the signals, analog-to-digital conversion, and recording. 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 four systems 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.

6.6 Tape Switches

Tape Switches will be installed on the coupler of the impacting cab-car and the coupler of the locomotive. Closure of these switches at impact will indicate contact between the cab-car and locomotive. The switch closures will trigger each Data Brick. The tape switches are manufactured by the Tapeswitch Corporation, model 1201-131-A.

Tape switches will also be mounted on the corner posts of the impacting cab-car to indicate the time of contact with the locomotive.

6.7 Speed Trap

A dual channel speed trap will accurately measure the impact speed of the cab-car when it is within 0.5 meter of the locomotive. 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 impact cab-car. Final rod location will be determined prior to installation.

7.0 Test Procedure

(1) The lead cab-car will be modified to bring it up to current FRA standards by strengthening the corner posts and collision posts.

(2) The stationary locomotive will be modified to bring the structure up to AAR Locomotive Crashworthiness Standard S-580. This will involve modifying the collision posts, short hood and anti-climber.

(3) The cab-car and passenger cars will be modified internally with the appropriate seating arrangements required for the test.

(4) Strain gages will be attached on the center sills, side sills and cant rails of the cab-car bodies.

(5) Strain gages will be attached to the stationary locomotive.

(6) The coupler will be strain gauged with a single gage bridge measuring the longitudinal force.

(6) Speed calibration runs will be carried out using the test cars. The test cars will pushed by a locomotive and then released at points of varying distance from the impact point. The speed of the test cars will be measured as they pass the impact point, using a laser speed trap. These runs will be carried out at different ambient temperatures and wind speeds. Having passed the impact point, the test cars will be stopped by a locomotive catching them up, catching the coupler, and then slowing down and bringing the cars back to the start point. A calibration chart of speed versus distance for different ambient temperatures and wind speeds will be produced from these tests

(7) The test equipment, including the accelerometers and data acquisition system will be mounted on the test vehicles. The strain gages will be connected to the data acquisition system and tested.

(8) The cameras will be set up.
(9) The length and weight of each vehicle will be measured just prior to the test.
(10) All instruments will be calibrated and a zero reading carried out.
(11) A trial low speed soft impact (less than 1 mph) of the test cars will be carried out into the locomotive to confirm all the instruments work properly.
(12) The instruments will be re-calibrated, the Tape Switches replaced and the test cars pulled back.
(13) The test cars will pushed by a locomotive and released at the appropriate distance from the stationary locomotive, triggering the cameras just before impact.
(14) The instrumentation will be triggered on impact.
(15) Visual inspection of the car bodies will be carried out after impact. Still photographs will be taken of all the vehicles.
(16) The data will be downloaded onto lap-top computers from the on-board data acquisition system.

A checklist will be utilized for the actual test, based on the above list, which 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 vehicle's impact with the barrier and subtract the offset from the entire data set for each channel. It is expected that between 0.05 and 0.50 s 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 Output

Every channel as recorded (raw data) will be plotted against time
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 longitudinal velocity will be integrated to give the crush displacement against time. The longitudinal accelerations at the center of gravity of the car body will be averaged and multiplied by the mass of the car body to give the force against time during the impact.
The strain gage time histories will be presented
All data recorded by the Data Bricks, and the derived values mentioned above, will be presented to the FRA in digital form on a Zip disc as well as on paper.
The film from each side 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.

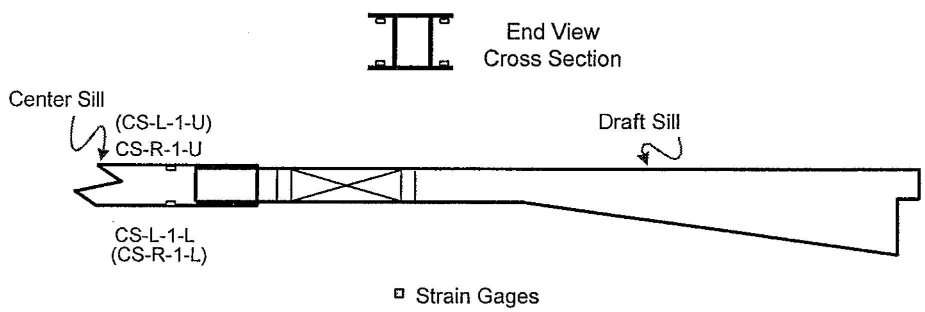
All the data output described in this section will be presented in a report and submitted to the FRA. The report will also contain general information about the crash test and describe how it was conducted.

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.

1st Cab Car
Strain Gages

Strain Gage Locations
Cab Car, Both Ends and Middle, Center Sill



Draft Sill and Center Sill
(right side shown)

<u>Strain Gages</u>
cab car - 24
<u>Loco - 12</u>
Total 36

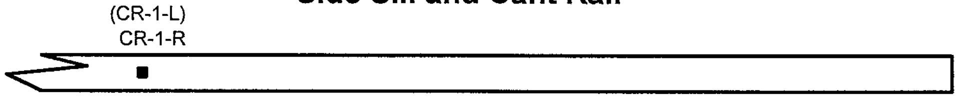
Note: (4 Data Channels per center sill location)
12 Total Channels

Figure 1

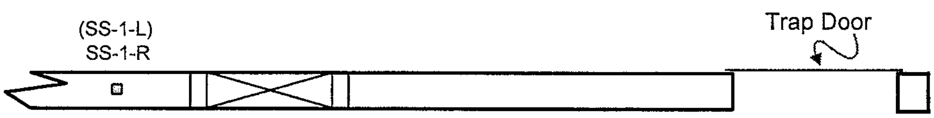
1938gages.ppt

1st Cab Car
Strain Gages

Strain Gage Locations
Cab Car, Both Ends and Middle,
Side Sill and Cant Rail



Cant Rail
Note: (2 Data Channels per Cant Rail Location)
6 Total Channels

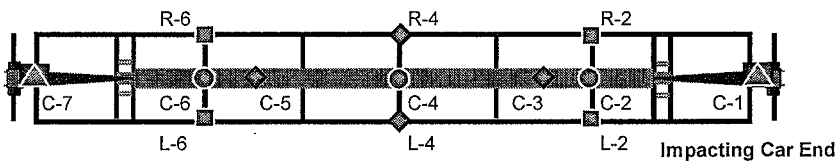


Side Sill
(right side shown)

Strain Gages
Note: (2 Data Channels per Side Sill Location)
6 Total Channels
1938gages.ppt

Figure 2

1st Cab Car
Accelerometers



◆ Two-axis (Longitudinal and Vertical) Accelerometer Locations (8 ch.)

● Three-axis Accelerometer Locations (9 ch.)

■ Single-axis (vertical) Accelerometer Locations (4 ch.)

▲ Single-axis (longitudinal) Accelerometer Locations (2 ch.)

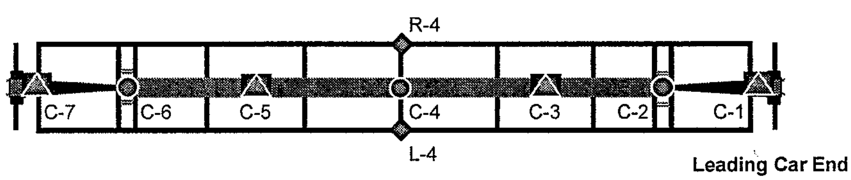
Underframe
Plan View

Note: (23 Car body / 6 truck)
29 total Data Channels

Figure 3

1938gages.ppt

2nd Coach Car
Accelerometers



◆ Two-axis (Longitudinal and Vertical) Accelerometer Locations (4 ch.)

● Three-axis Accelerometer Locations (9 ch.)

▲ Single-axis (longitudinal) Accelerometer Locations (4 ch.)

Underframe
Plan View

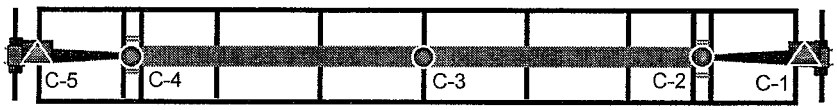
Note: (17 Car body / 2 truck)
19 total Data Channels

Figure 4

1938gages.ppt

3rd Coach Car

Accelerometers



Leading Car End

● Three-axis Accelerometer Locations (9 ch.)

▲ Single-axis (longitudinal) Accelerometer Locations (2 ch.)

Underframe
Plan View

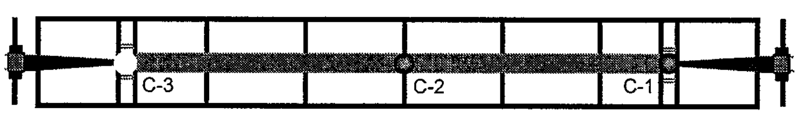
Note: (11 Car body / 2 truck)
13 total Data Channels

Figure 5

1938gages.ppt

4th Coach Car

Accelerometers



Leading Car End

● Three-axis Accelerometer Locations (9 ch.)

Underframe
Plan View

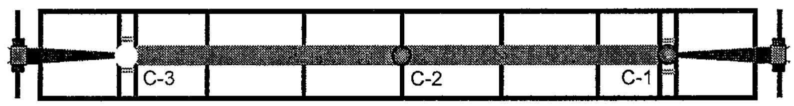
Note: (9 Car body / 2 truck)
11 total Data Channels

Figure 6

1938gages.ppt

5th Coach Cars

Accelerometer



Leading Car End

● Three-axis Accelerometer Locations (9 ch.)

Underframe
Plan View

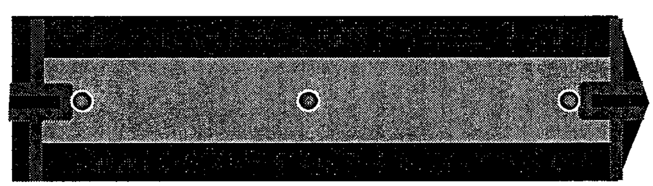
Note: (9 Car body / 2 truck)
11 total Data Channels

Figure 7

1938gages.ppt

Pushing Locomotive Frame

Accelerometers



Leading End

● Three-axis Accelerometer Locations (9 ch.)

Underframe
Plan View

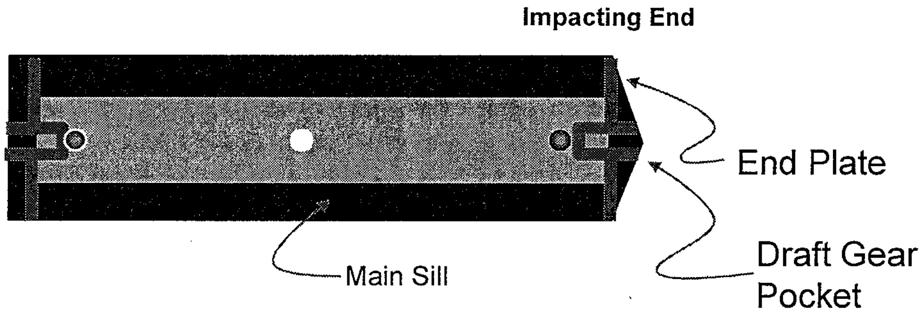
Note: (9 Car body / 2 truck)
11 total Data Channels

Figure 8

1938gages.ppt

Standing Locomotive Frame

Accelerometers



● Three-axis Accelerometer Locations (9 ch.)

Note: 9 Loco/6 Truck
15 Total Data Channels

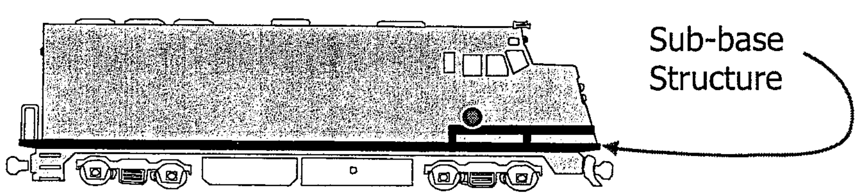
Underframe
Plan View

Figure 9

1938gages.ppt

Standing Locomotive Operator's Cab

Accelerometer



● Three-axis Accelerometer Locations (3 ch.)

Locomotive
Elevation View

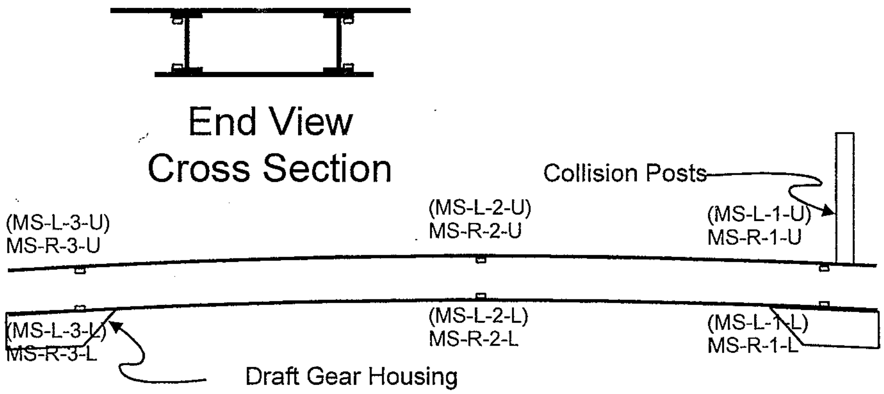
Note: 3 Total Data
Channels

1938gages.ppt

Figure 10

Standing Locomotive
Strain Gages

Strain Gage Location
Locomotive Main Sill



Elevation View
(right side shown)

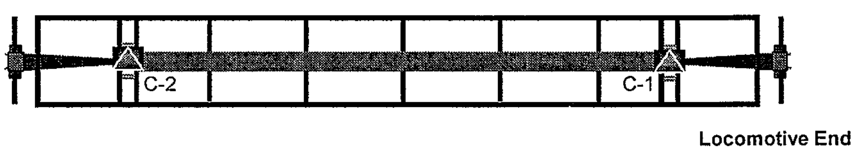
Note: 12 Total Data Channels

1938gages.ppt

Figure 11

1st, 2nd, and 3rd Standing Car

Accelerometers



Single-axis (longitudinal) Accelerometer Locations (2 ch.)

Underframe
Plan View

Note: (2 per Car body)
2 total Data Channels

1938gages.ppt

Figure 12

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APPENDIX B

Acceleration Data, Fc = 1000 Hz

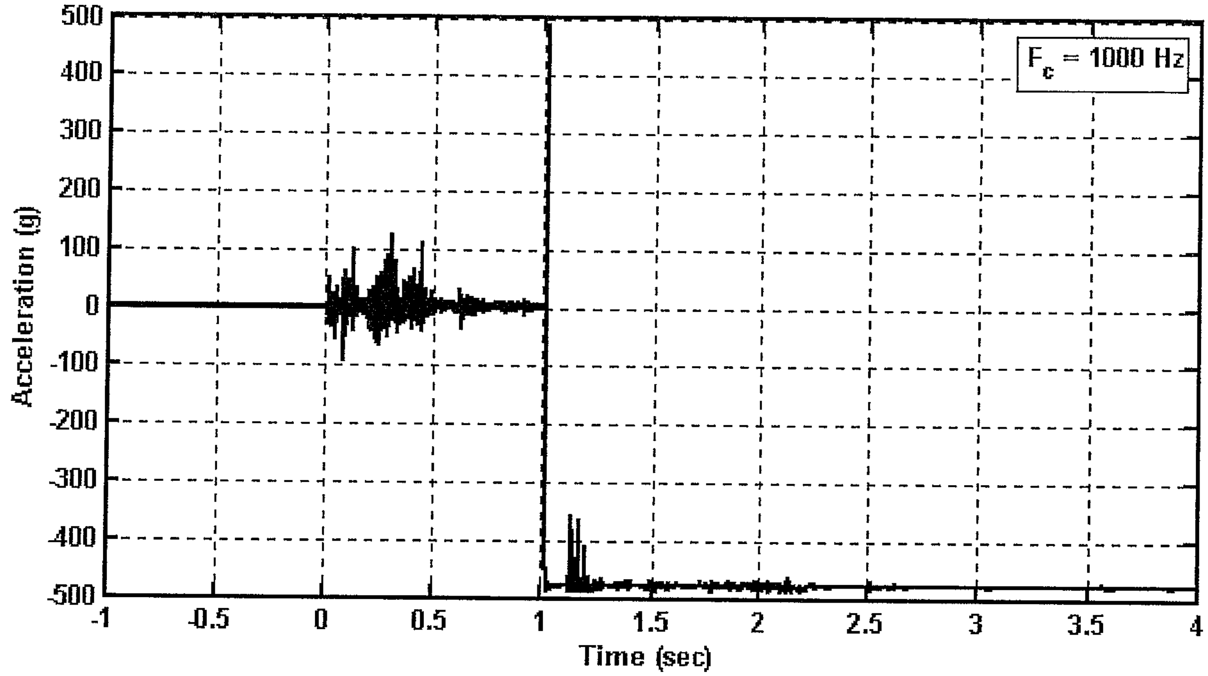


Figure B1. Bullet car 1, A truck, longitudinal acceleration
Channel Name: B1_BAX

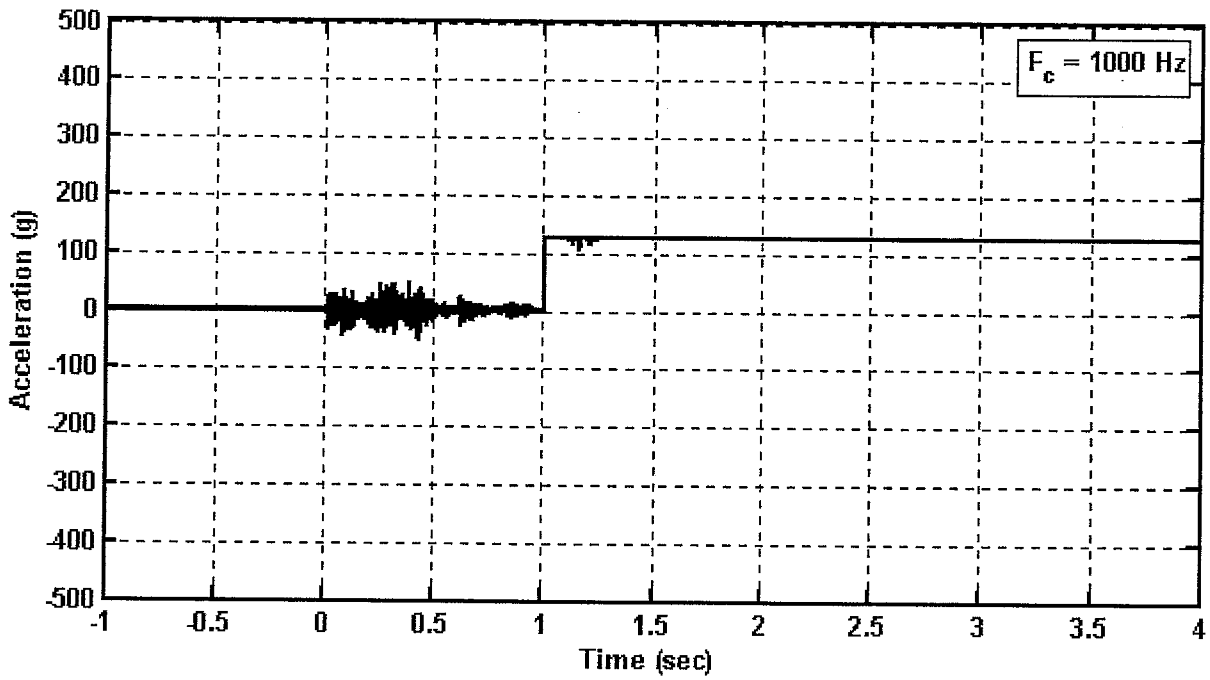


Figure B2. Bullet car 1, A truck, lateral acceleration
Channel Name: B1_BAY

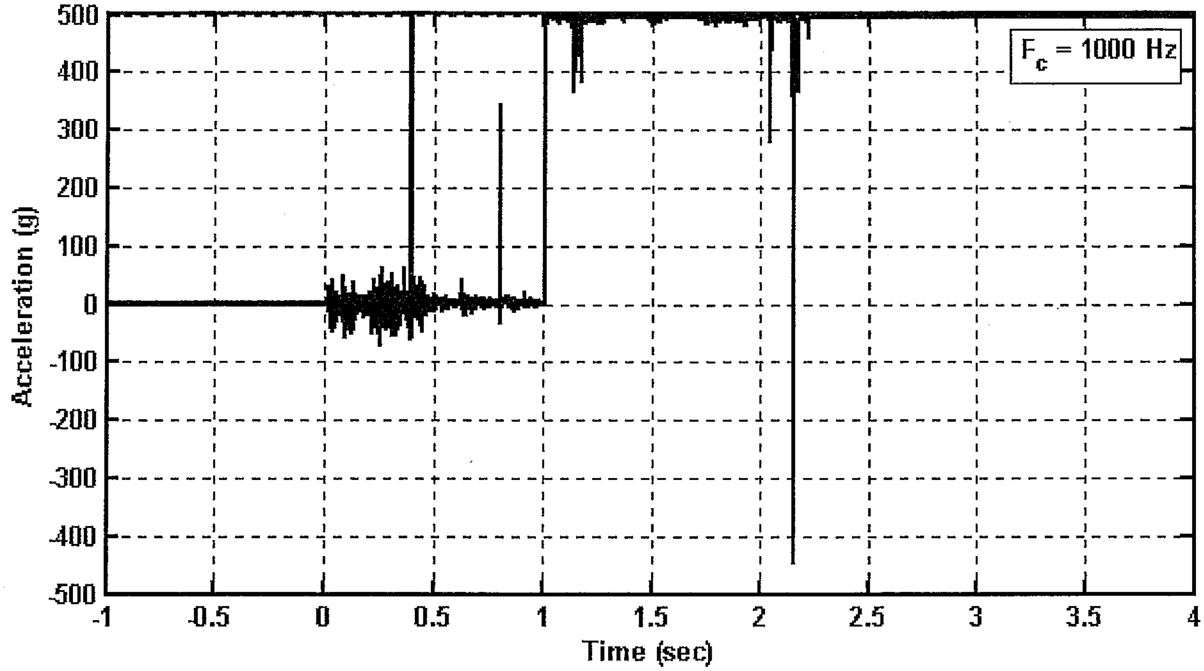


Figure B3. Bullet car 1, A truck, vertical acceleration
Channel Name: B1_BAZ

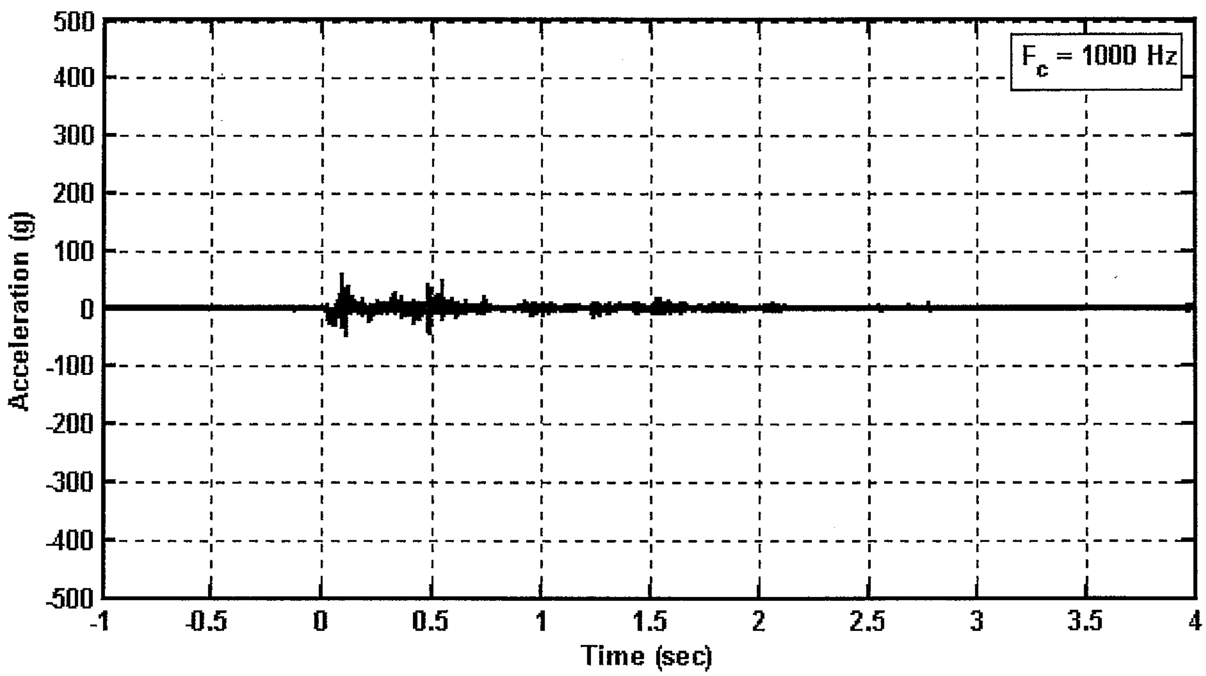


Figure B4. Bullet car 1, B truck, longitudinal acceleration
Channel Name: B1_BBX

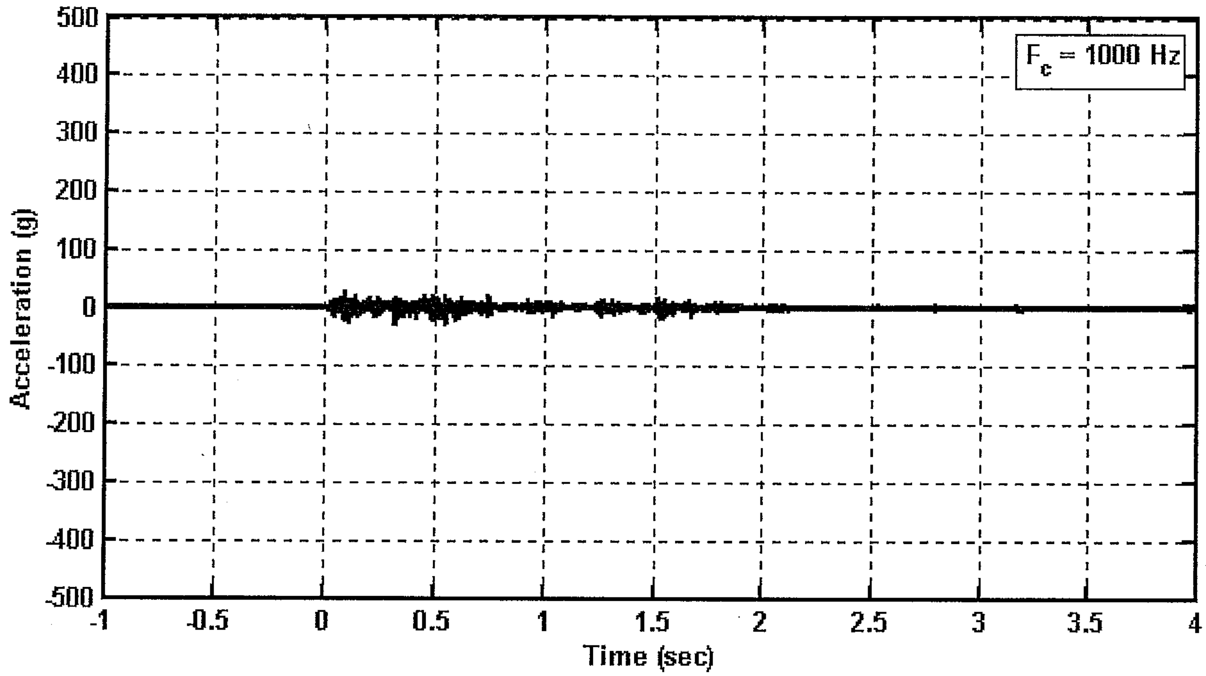


Figure B5. Bullet car 1, B truck, lateral acceleration
Channel Name: B1_BBY

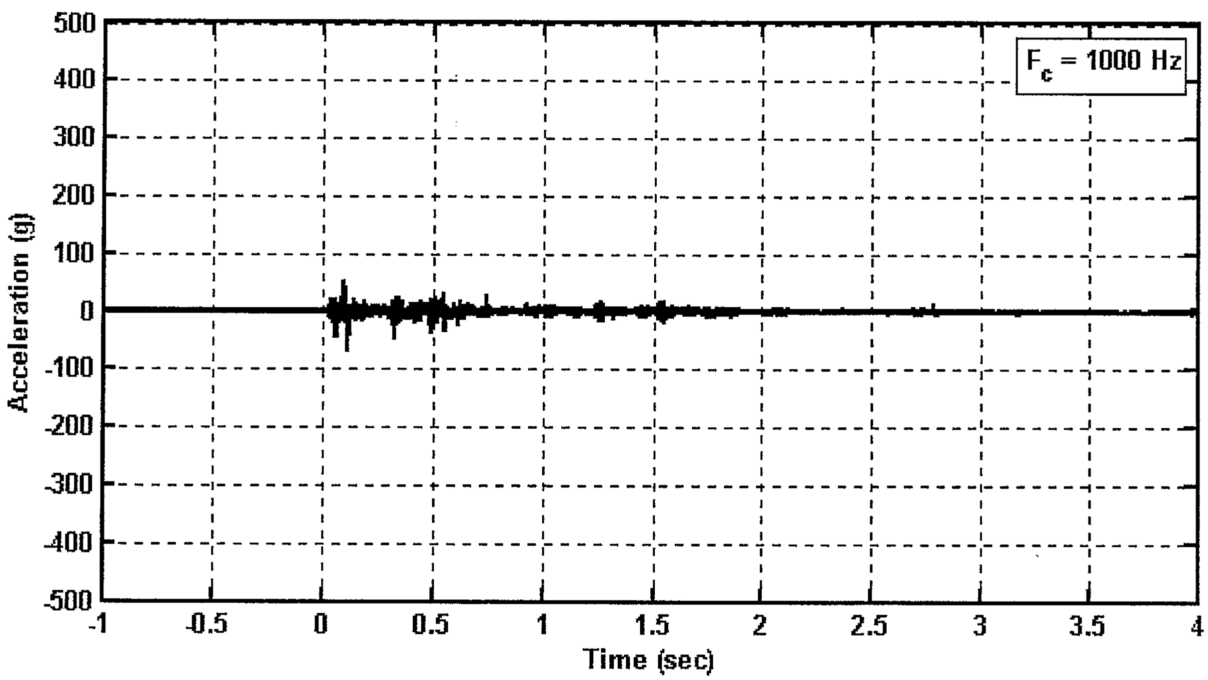


Figure B6. Bullet car 1, B truck, vertical acceleration
Channel Name: B1_BBZ

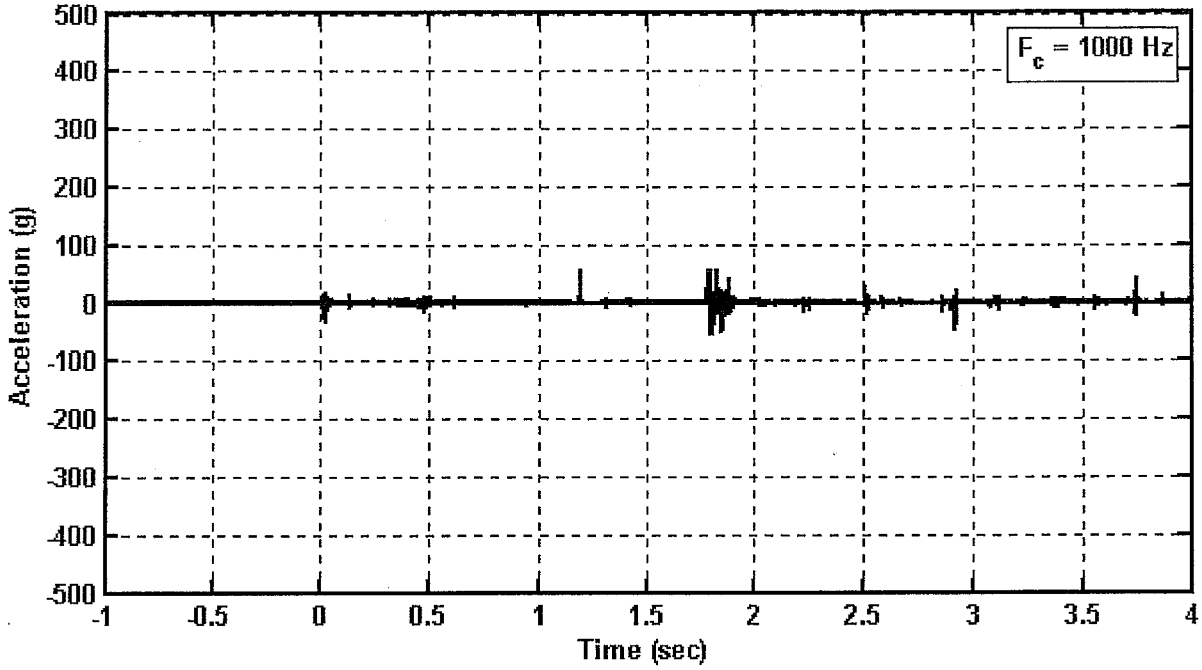


Figure B7. Bullet car 1, position 2, center sill, longitudinal acceleration
Channel Name: B1_C2X

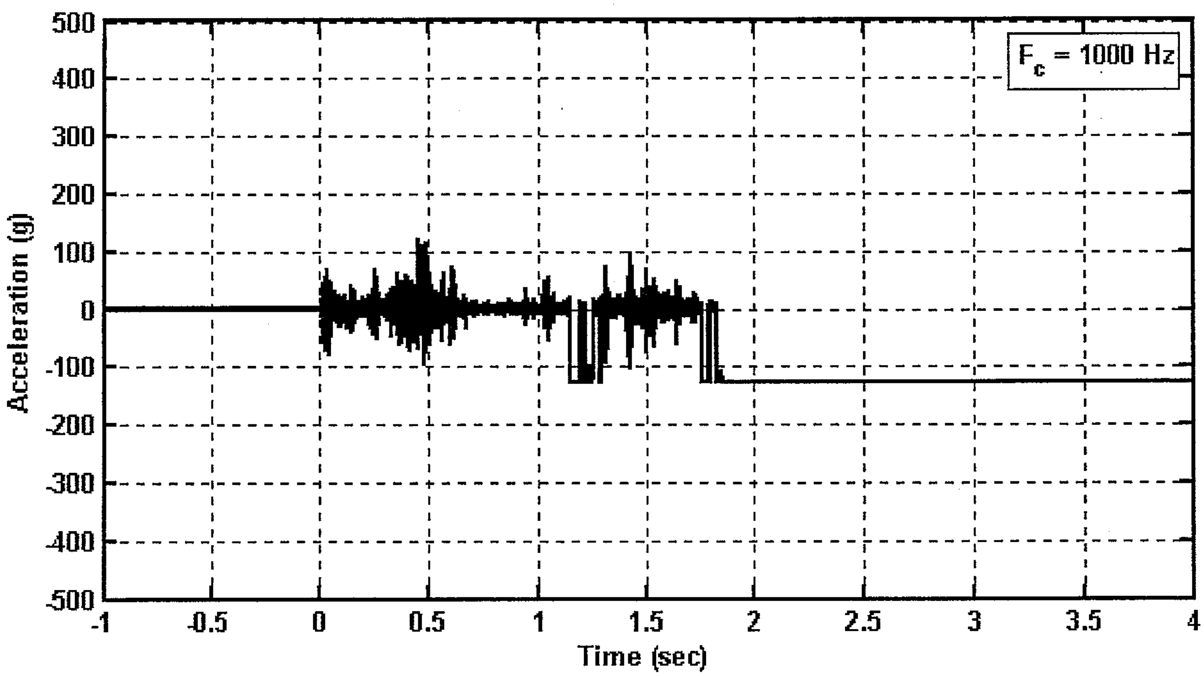


Figure B8. Bullet car 1, position 2, center sill, lateral acceleration
Channel Name: B1_C2Y

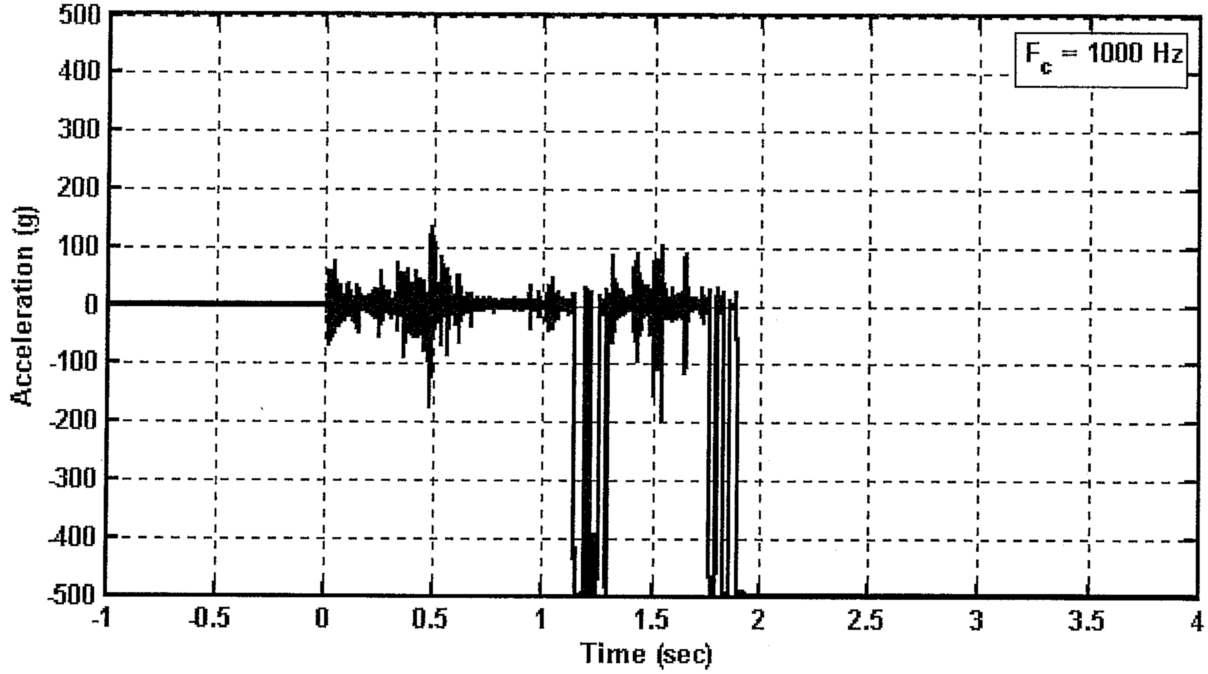


Figure B9. Bullet car 1, position 2, center sill, vertical acceleration
Channel Name: B1_C2Z

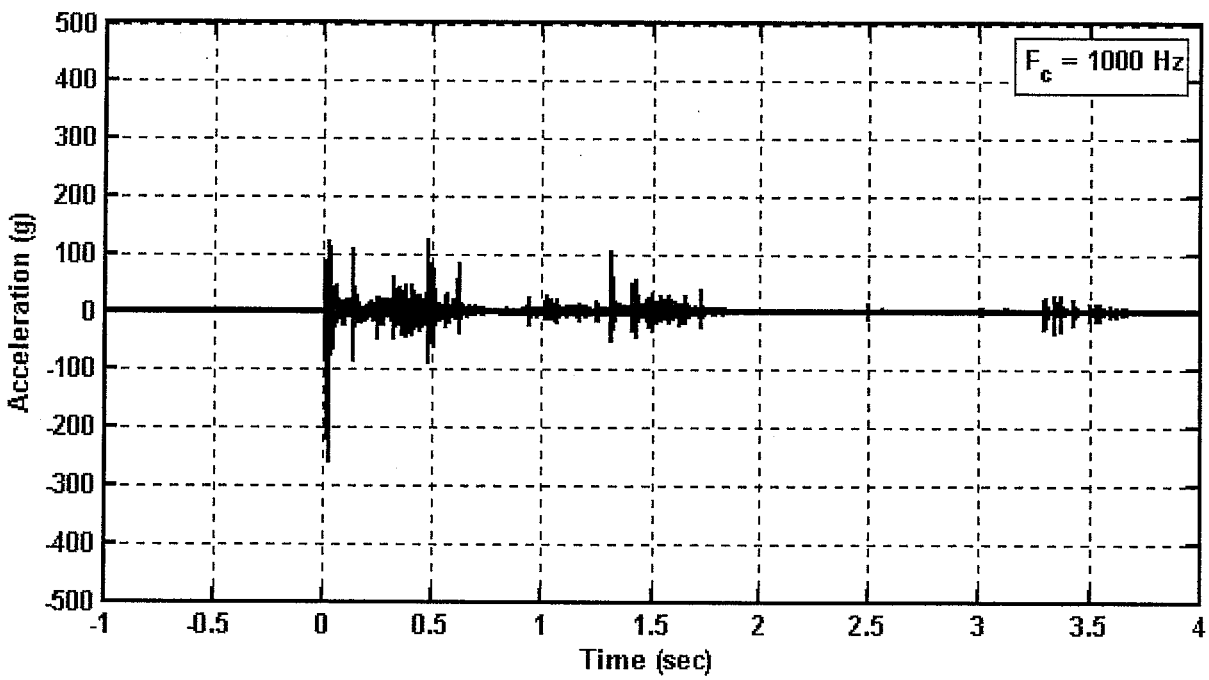


Figure B10. Bullet car 1, position 3, center sill, longitudinal acceleration
Channel Name: B1_C3X

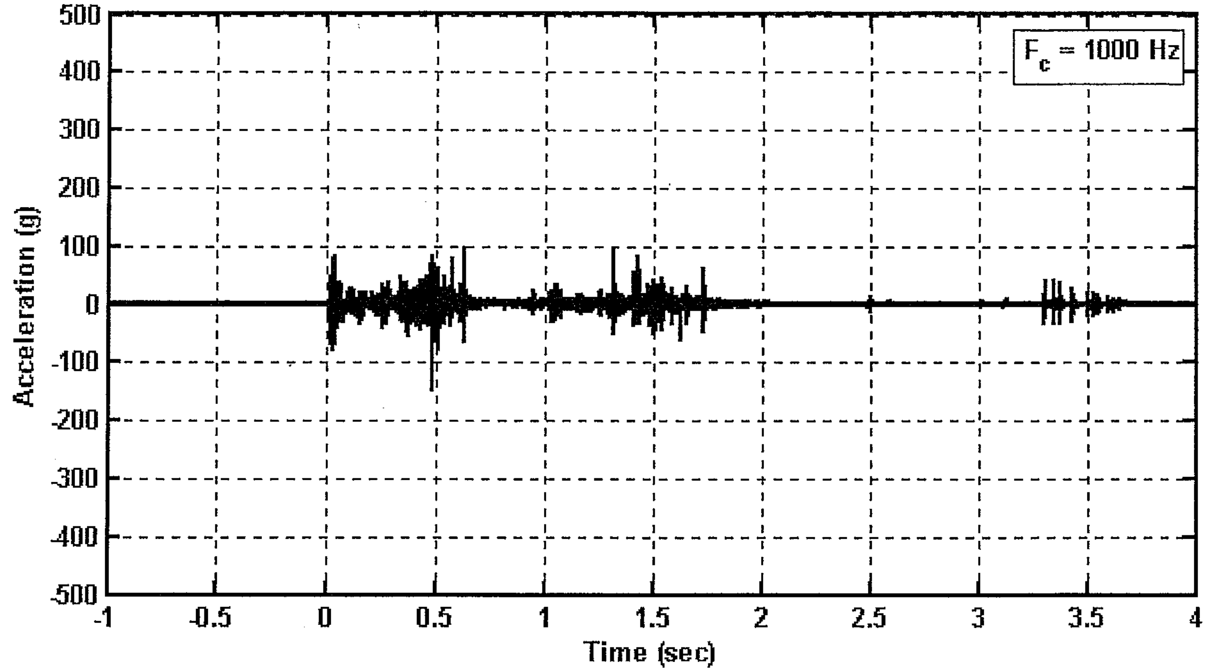


Figure B11. Bullet car 1, position 3, center sill, vertical acceleration
Channel Name: B1_C3Z

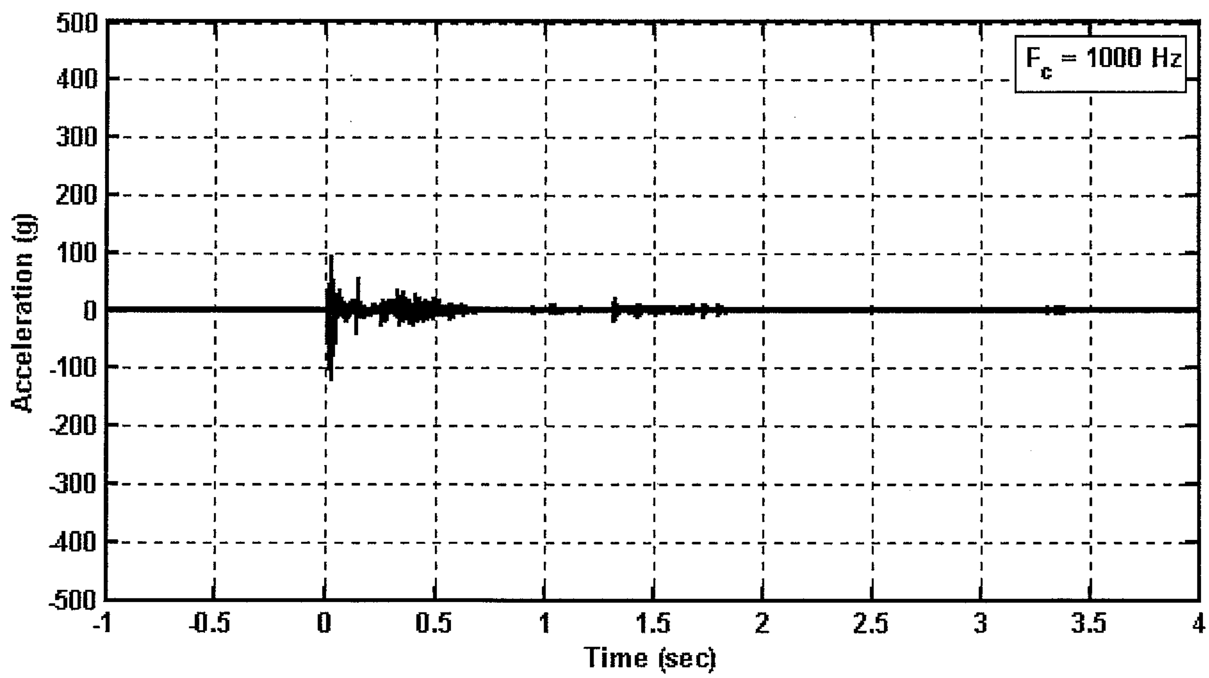


Figure B12. Bullet car 1, position 4, center sill, longitudinal acceleration
Channel Name: B1_C4X

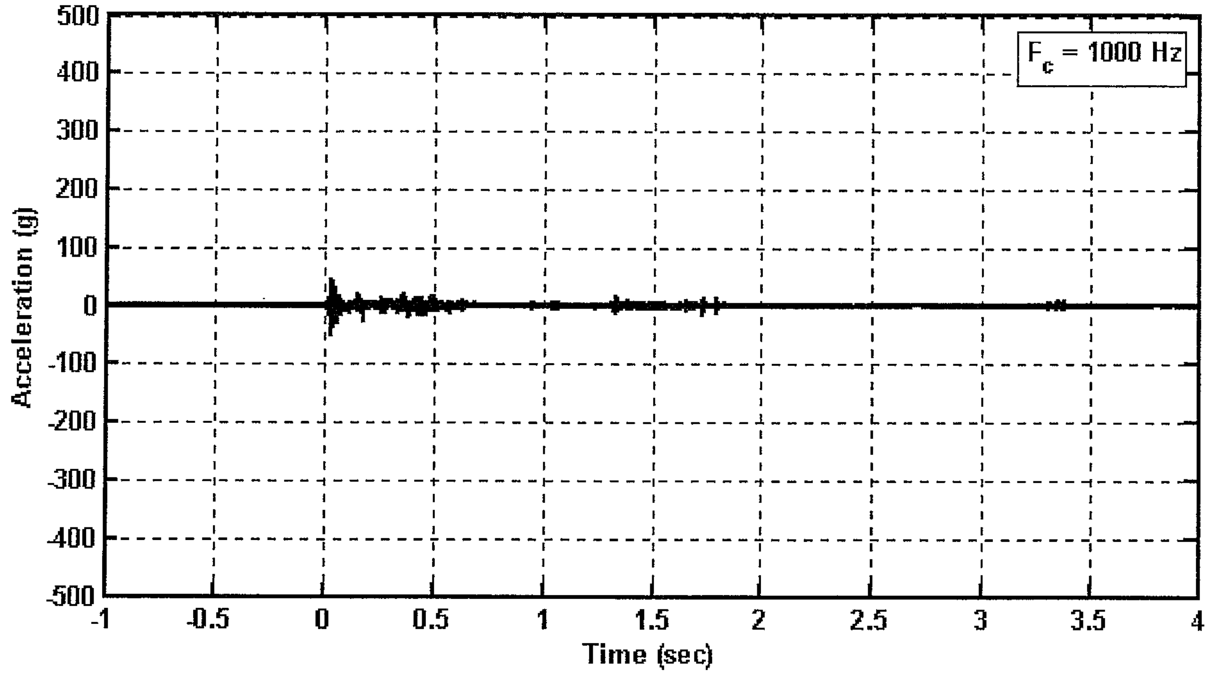


Figure B13. Bullet car 1, position 4, center sill, lateral acceleration
Channel Name: B1_C4Y

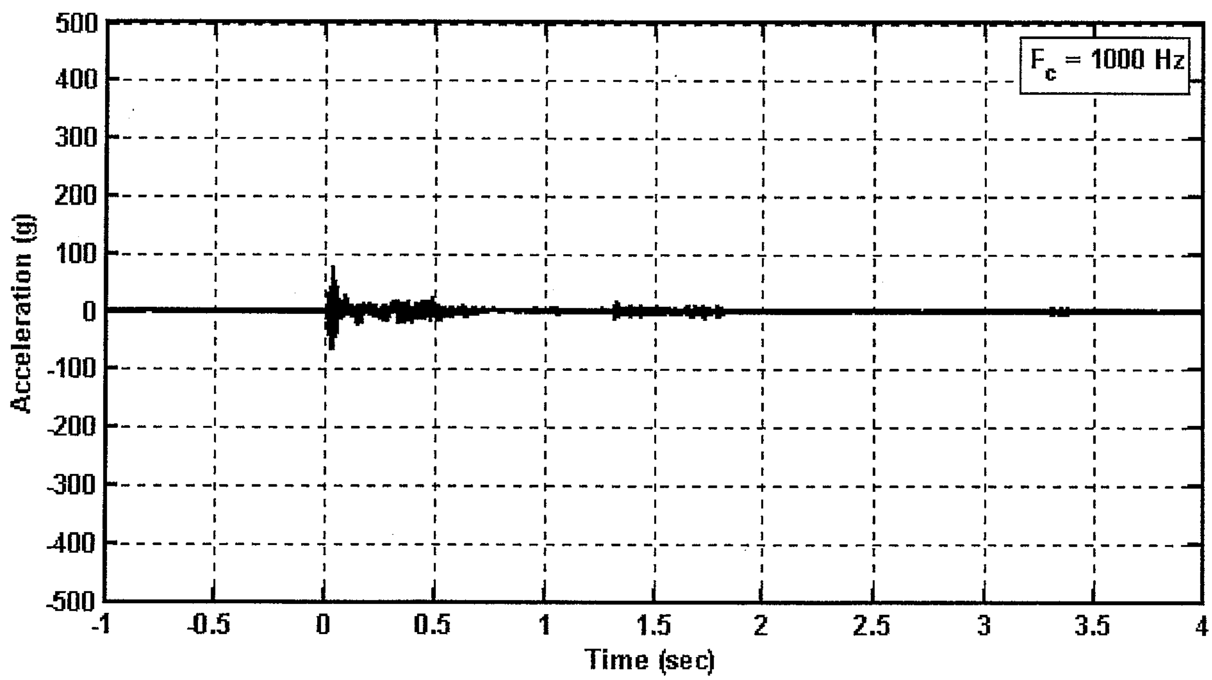


Figure B14. Bullet car 1, position 4, center sill, vertical acceleration
Channel Name: B1_C4Z

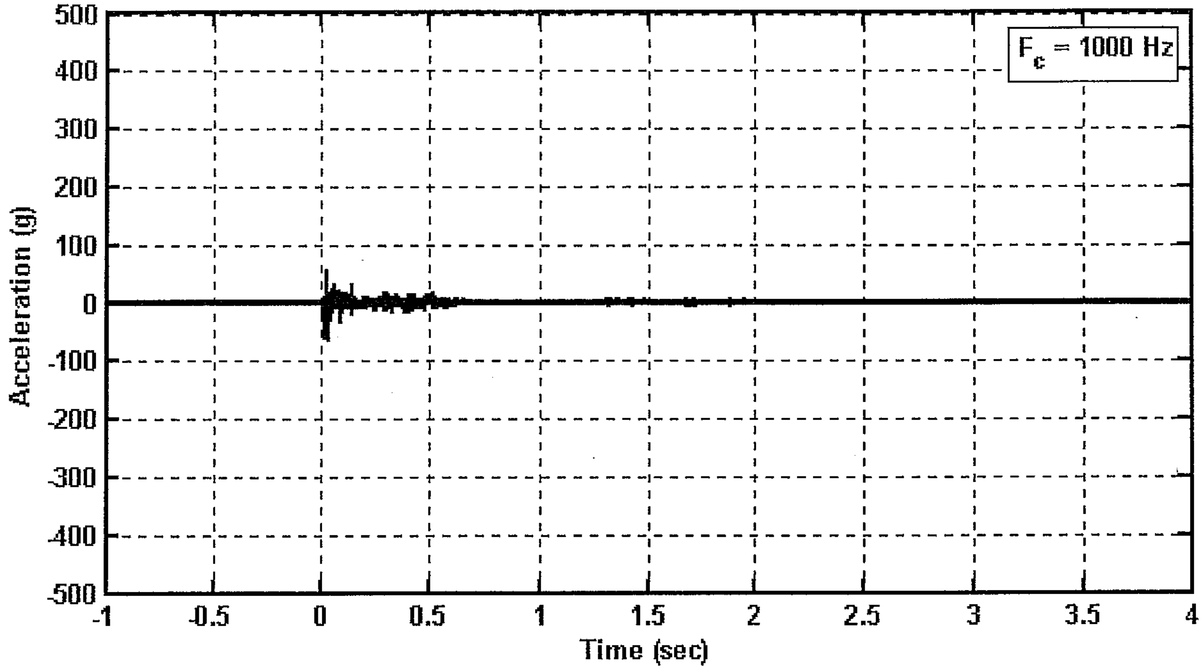


Figure B15. Bullet car 1, position 5, center sill, longitudinal acceleration
Channel Name: B1_C5X

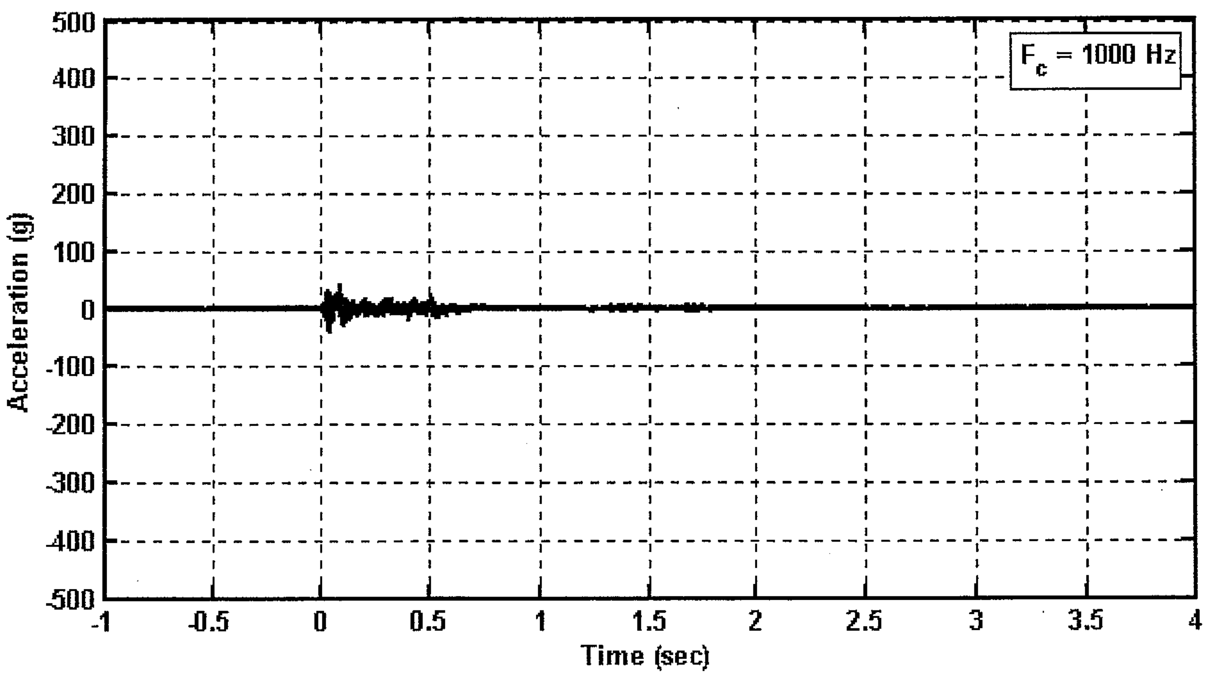


Figure B16. Bullet car 1, position 5, center sill, vertical acceleration
Channel Name: B1_C5Z

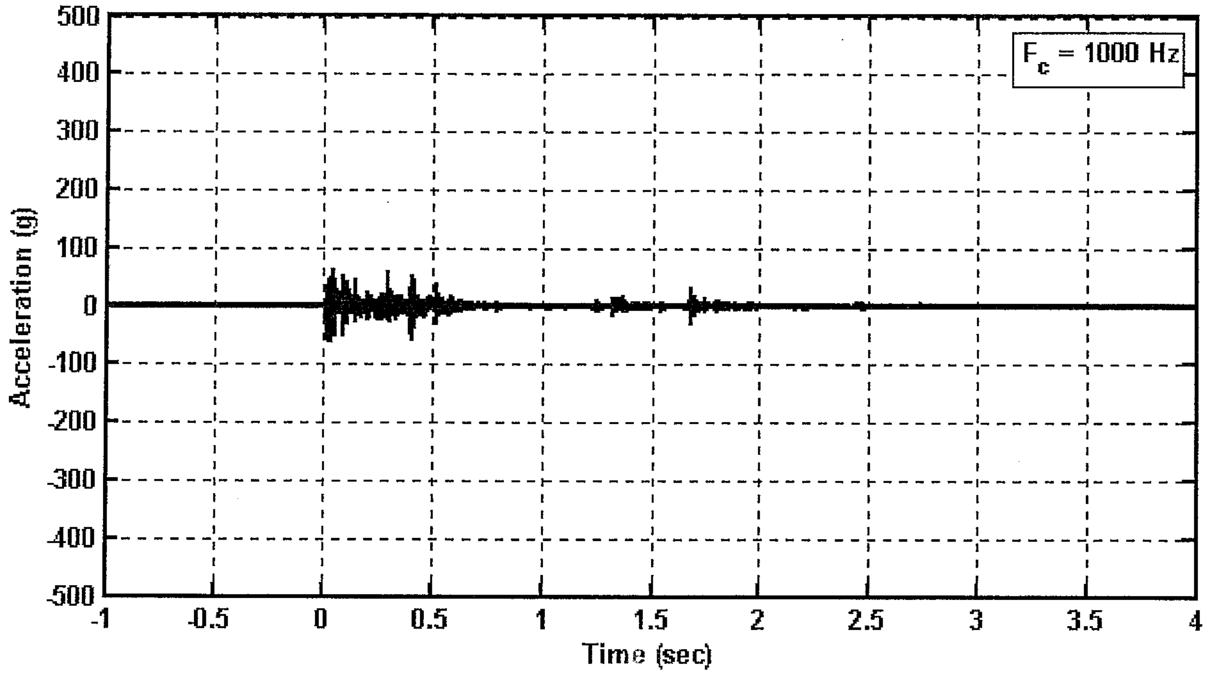


Figure B17. Bullet car 1, position 6 center sill, longitudinal acceleration
Channel Name: B1_C6X

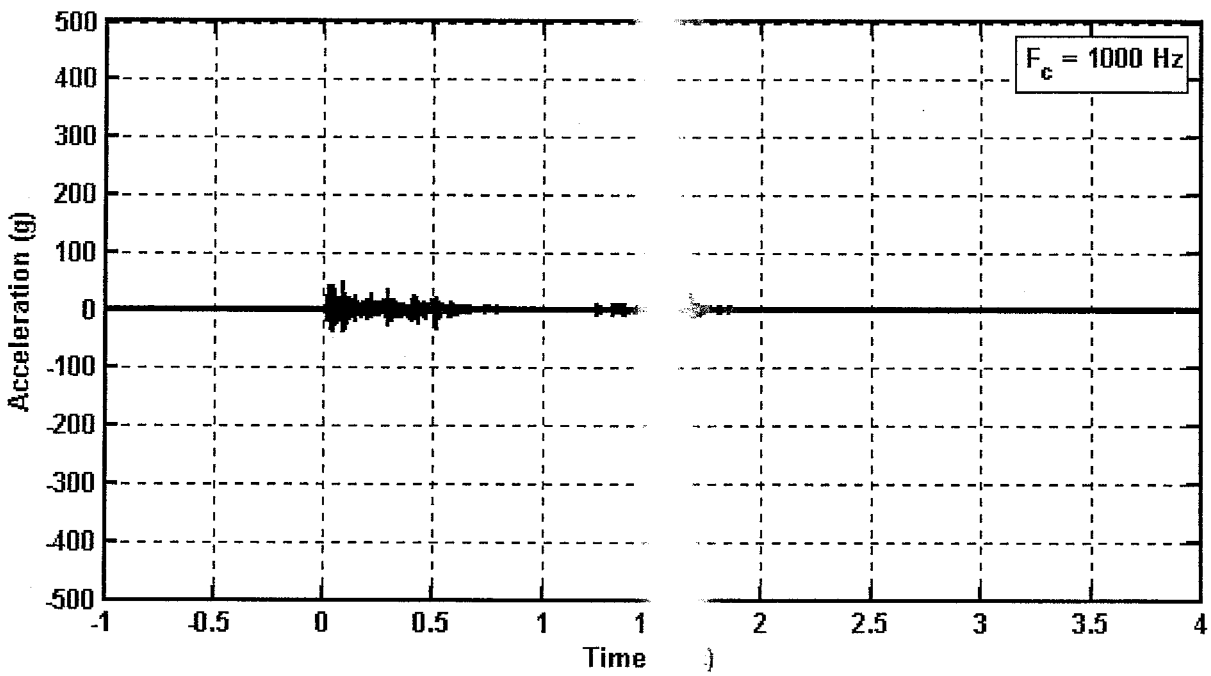


Figure B18. Bullet car 1, position nter sill, lateral acceleration
Channel Na B1_C6Y

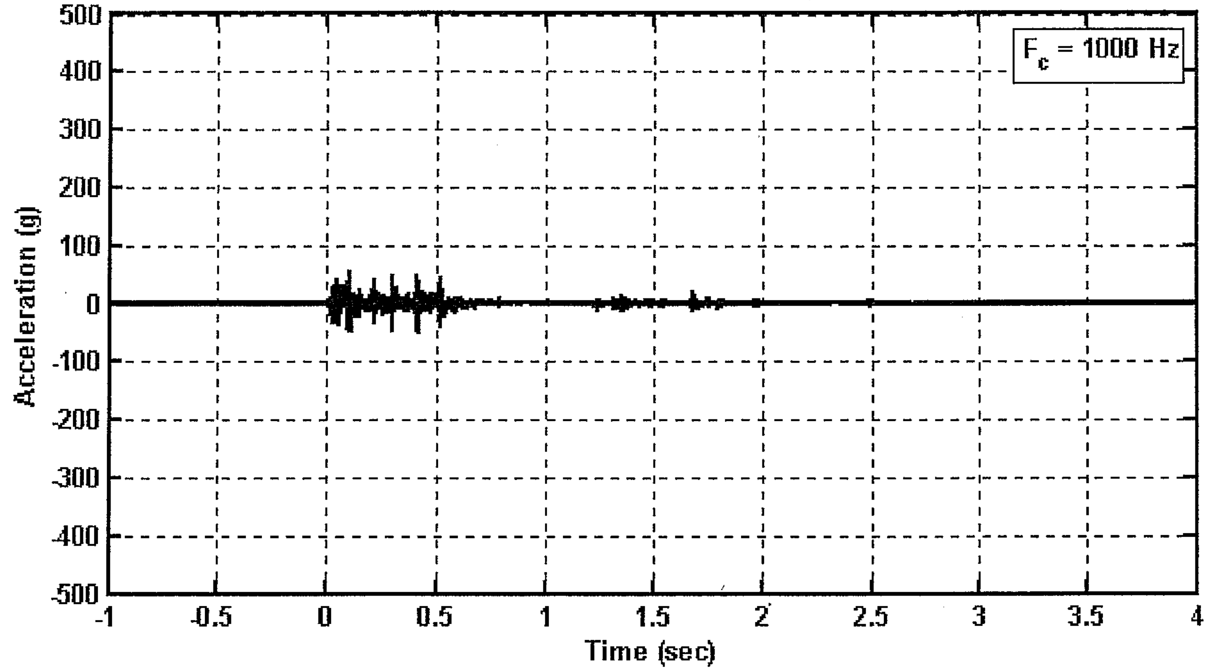


Figure B19. Bullet car 1, position 6, center sill, vertical acceleration
Channel Name: B1_C6Z

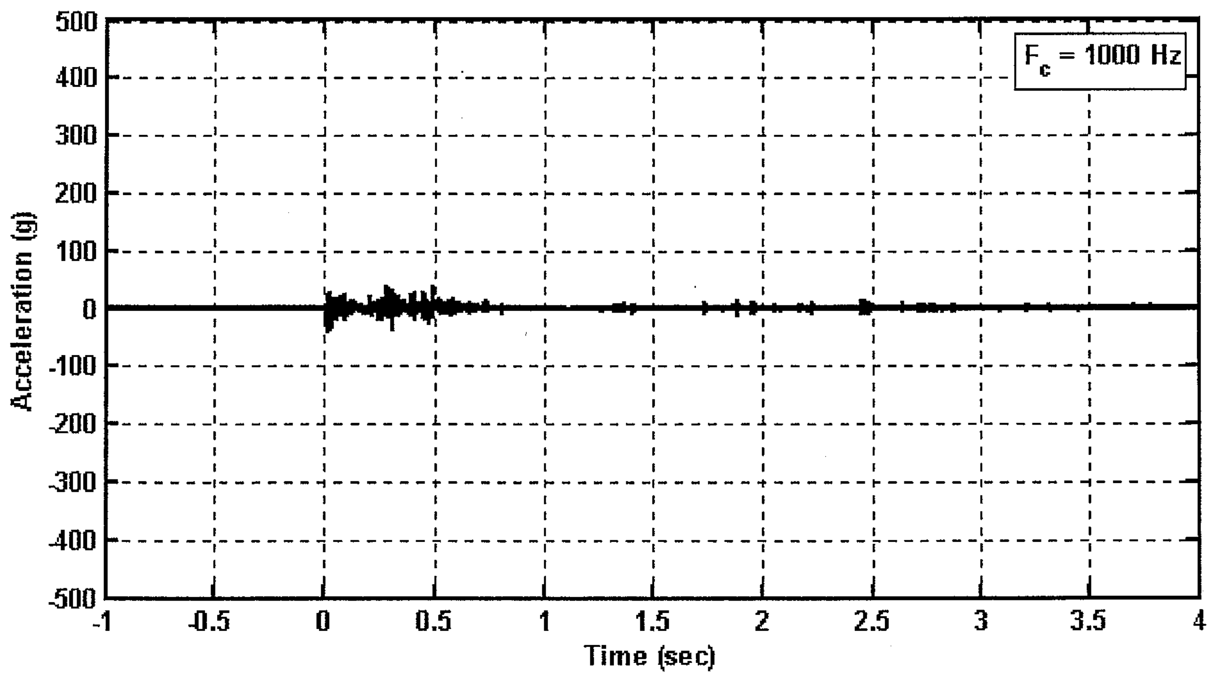


Figure B20. Bullet car 1, position 7, center sill, longitudinal acceleration
Channel Name: B1_C7X

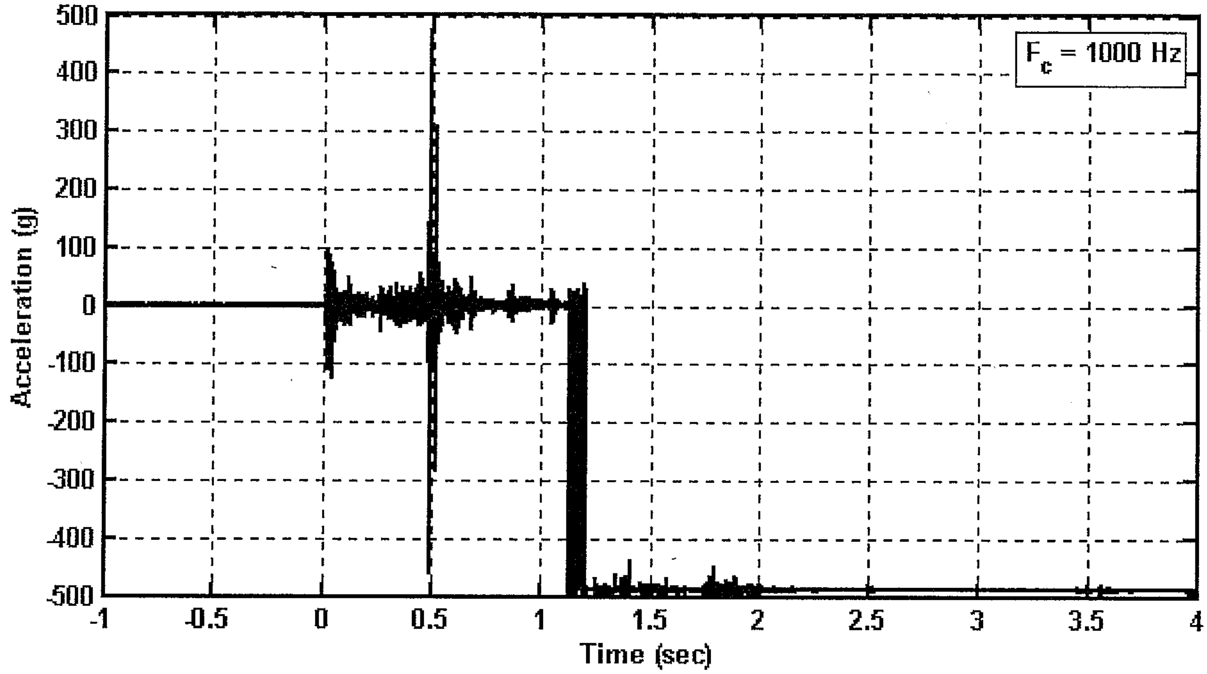


Figure B21. Bullet car 1, position 2, left side, vertical acceleration
Channel Name: B1_L2Z

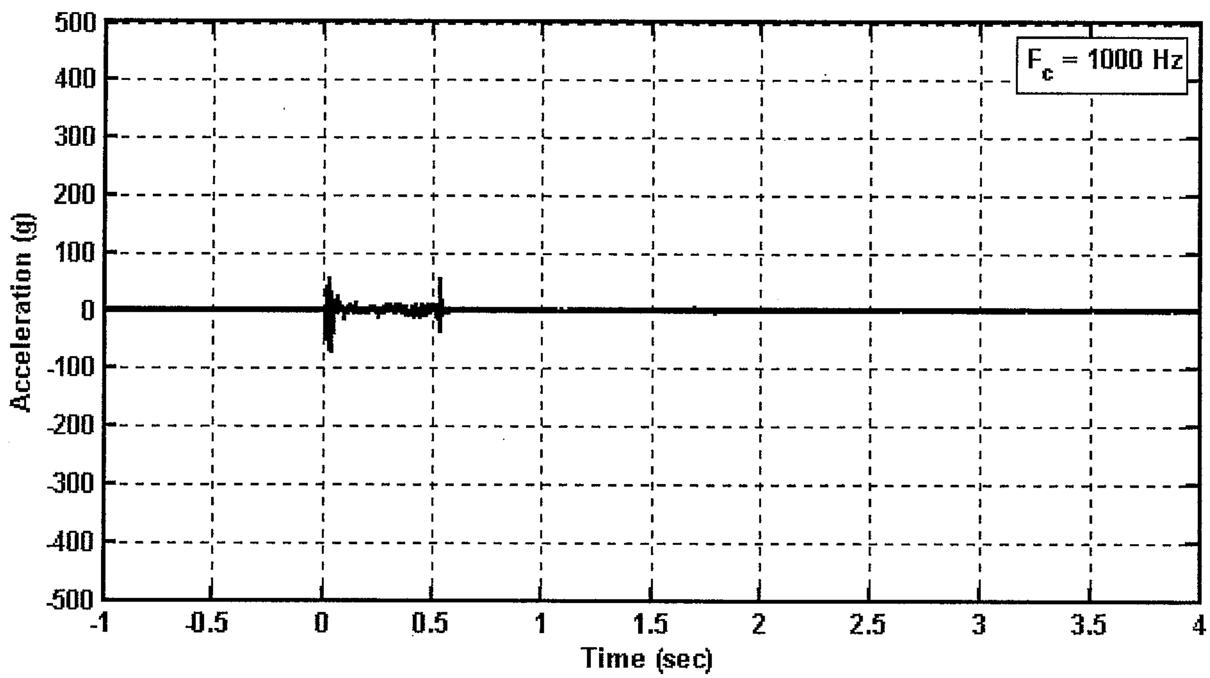


Figure B22. Bullet car 1, position 4, left side, longitudinal acceleration
Channel Name: B1_L4X

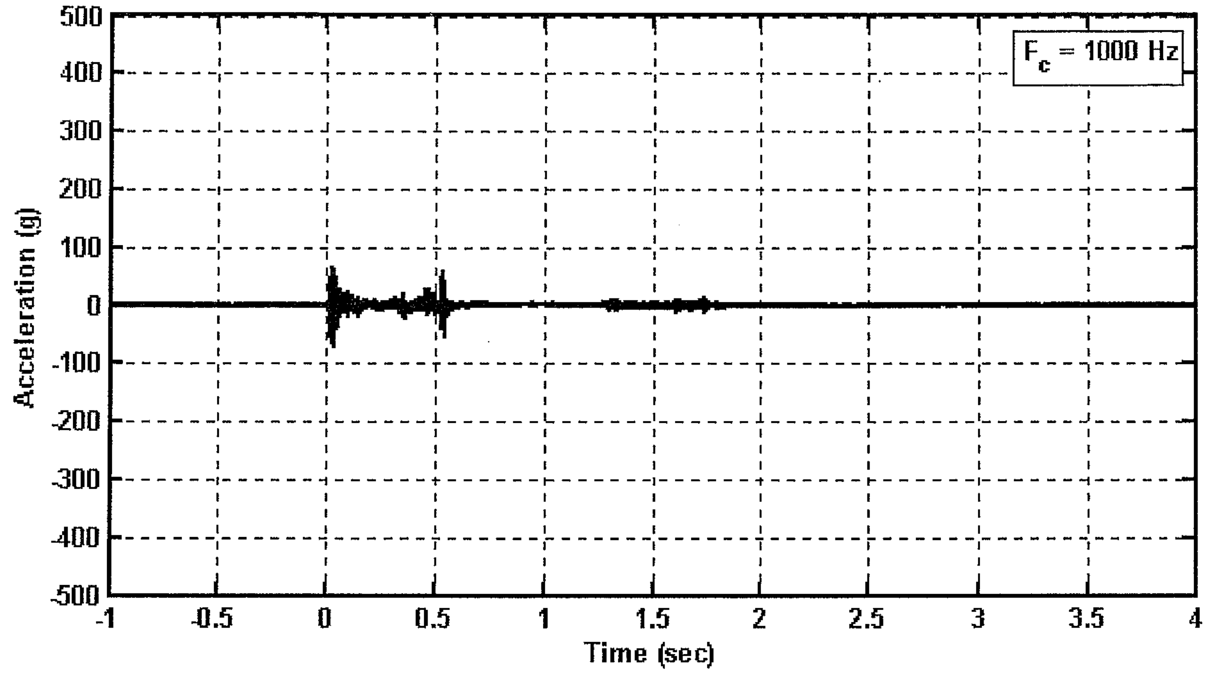


Figure B23. Bullet car 1, position 4, left side, vertical acceleration
Channel Name: B1_L4Z

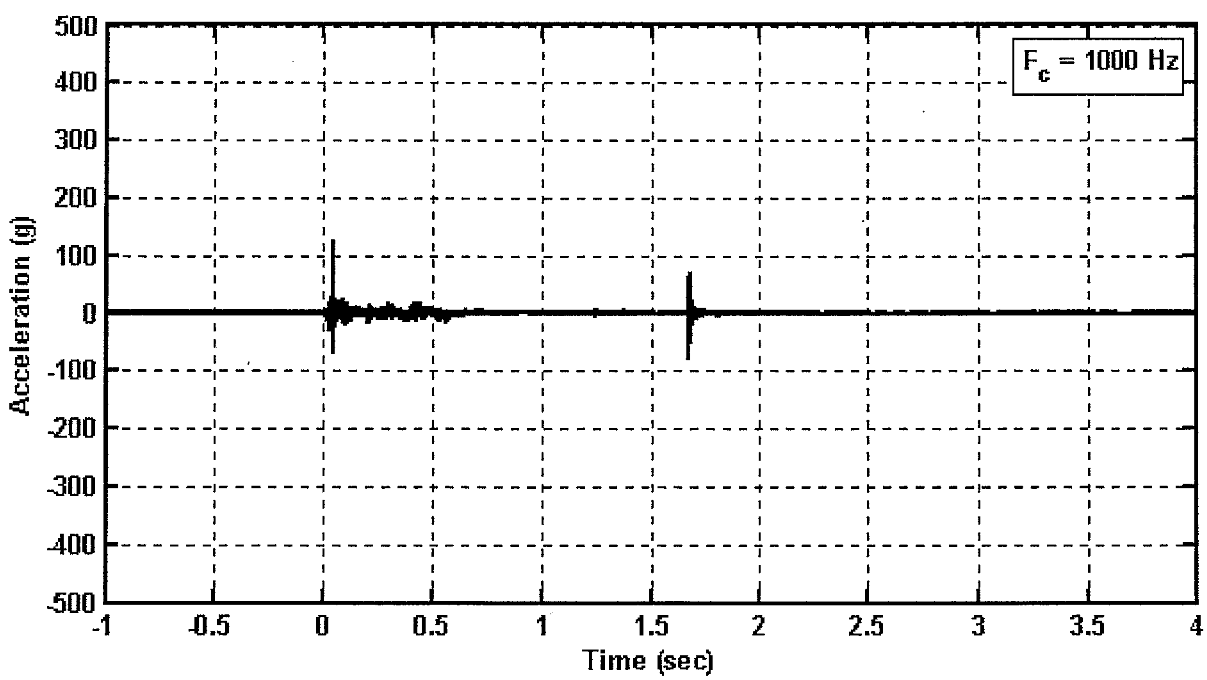


Figure B24. Bullet car 1, position 6, left side, vertical acceleration
Channel Name: B1_L6Z

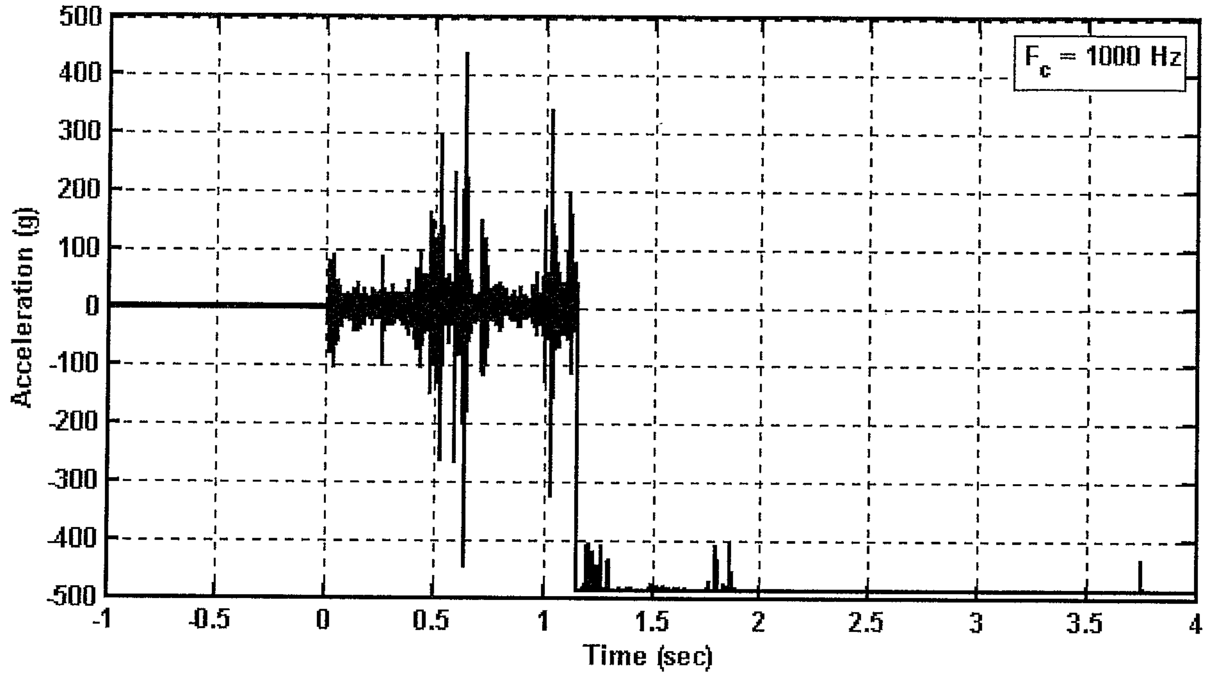


Figure B25. Bullet car 1, position 2, right side, vertical acceleration
Channel Name: B1_R2Z

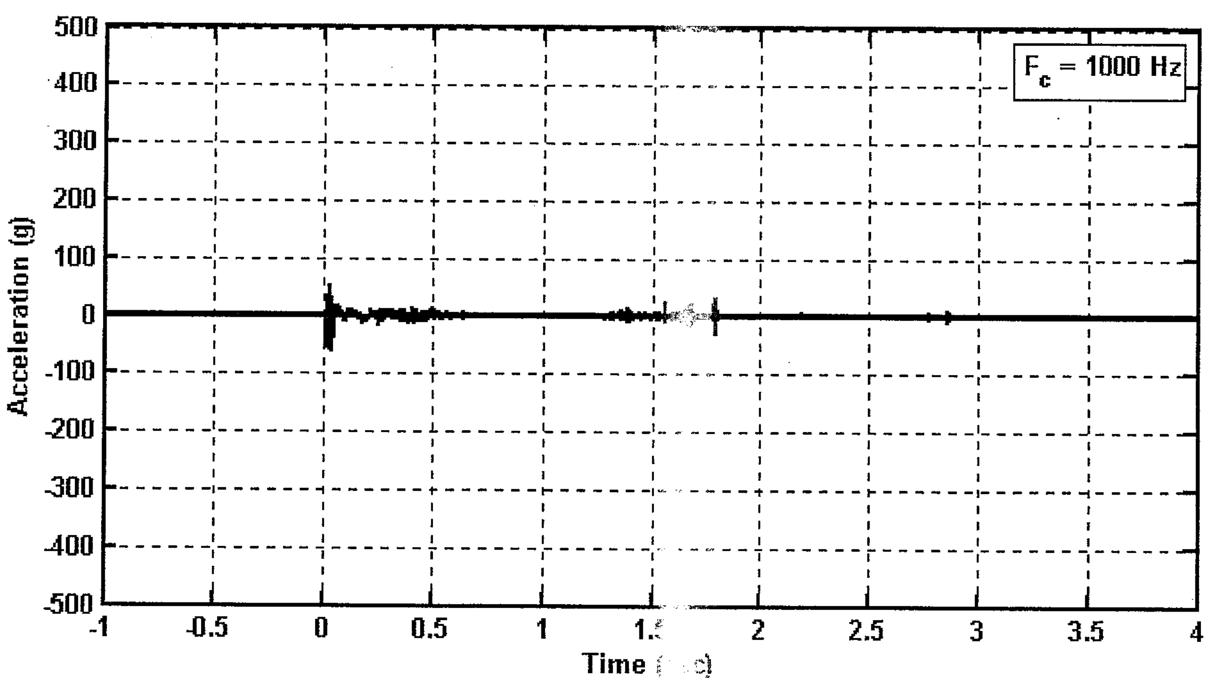


Figure B26. Bullet car 1, position 4, [illegible] side, longitudinal acceleration
Channel Nar[illegible] B1_R4X

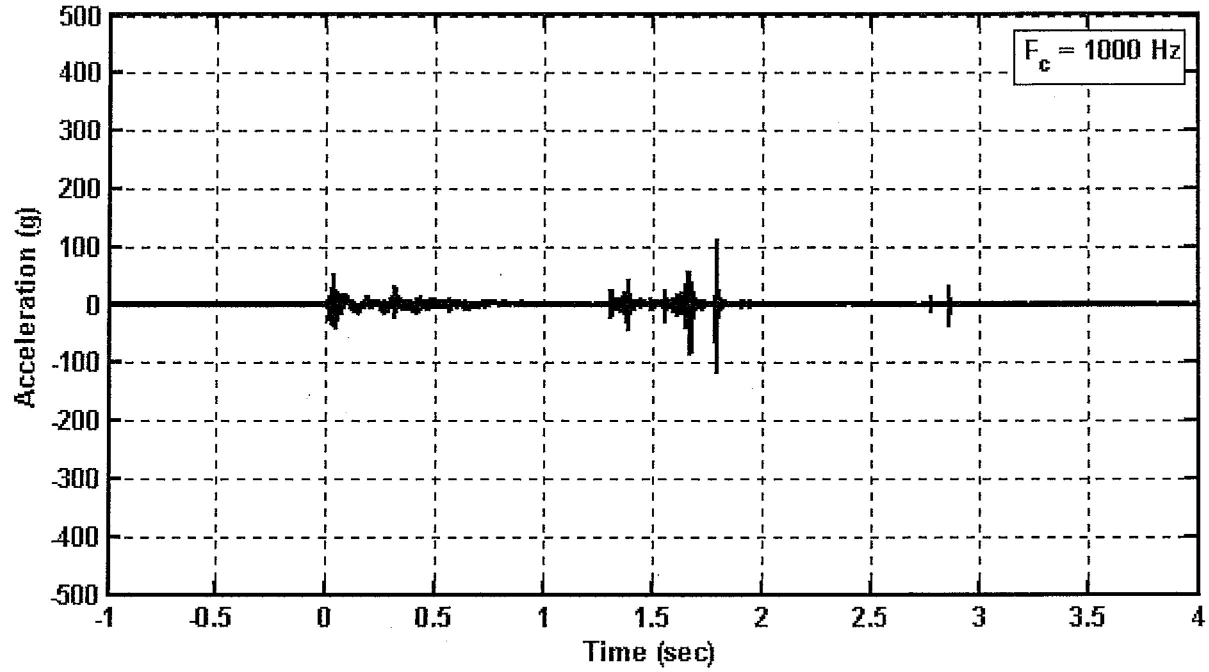


Figure B27. Bullet car 1, position 4, right side, vertical acceleration
Channel Name: B1_R4Z

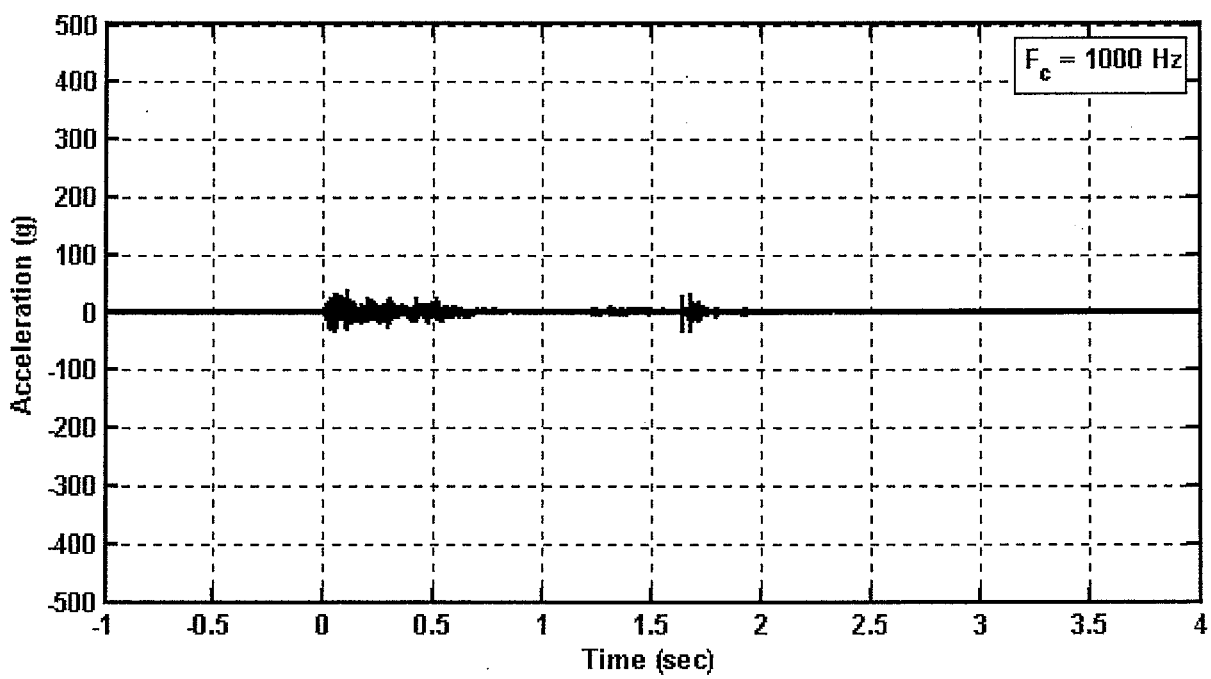


Figure B28. Bullet car 1, position 6, right side, vertical acceleration
Channel Name: B1_R6Z

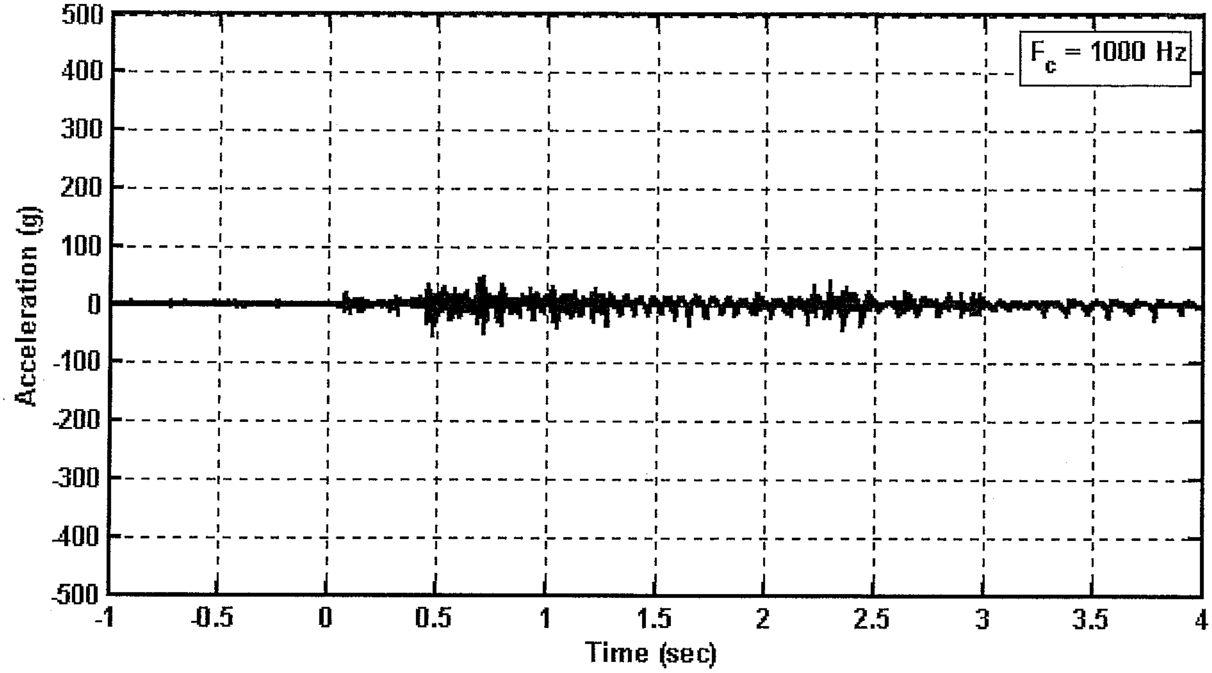


Figure B29. Bullet car 2, A truck, vertical acceleration
Channel Name: B2_BAZ

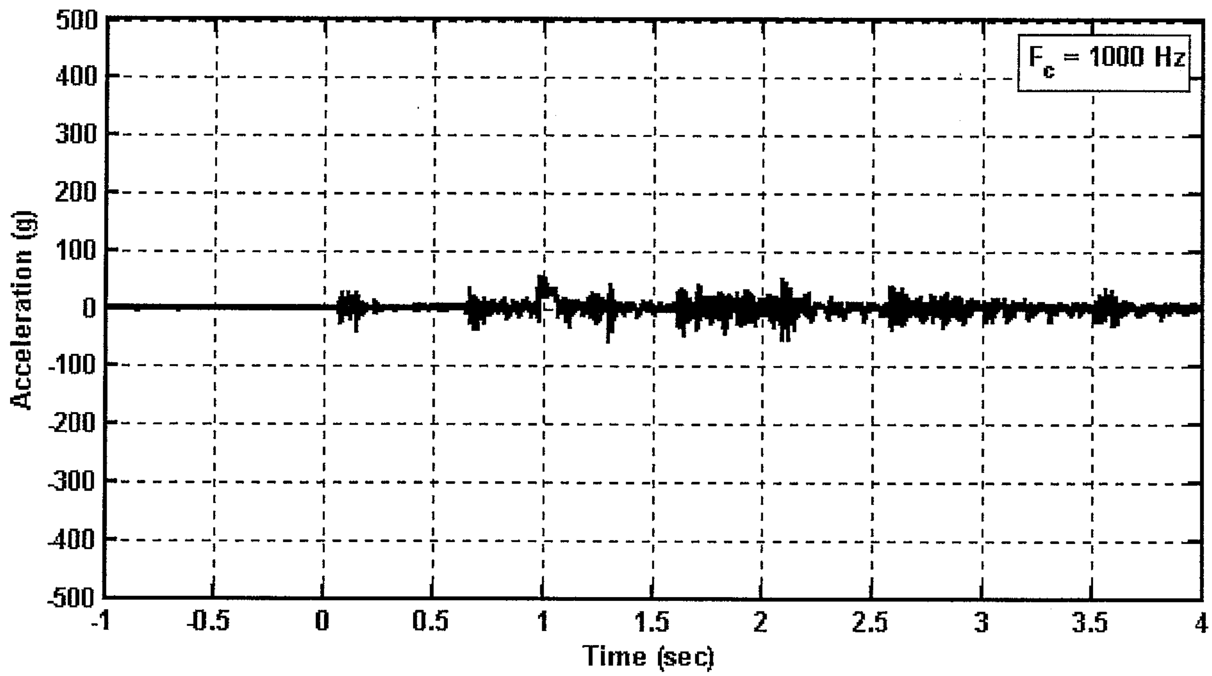


Figure B30. Bullet car 2, B truck, vertical acceleration
Channel Name: B2_BBZ

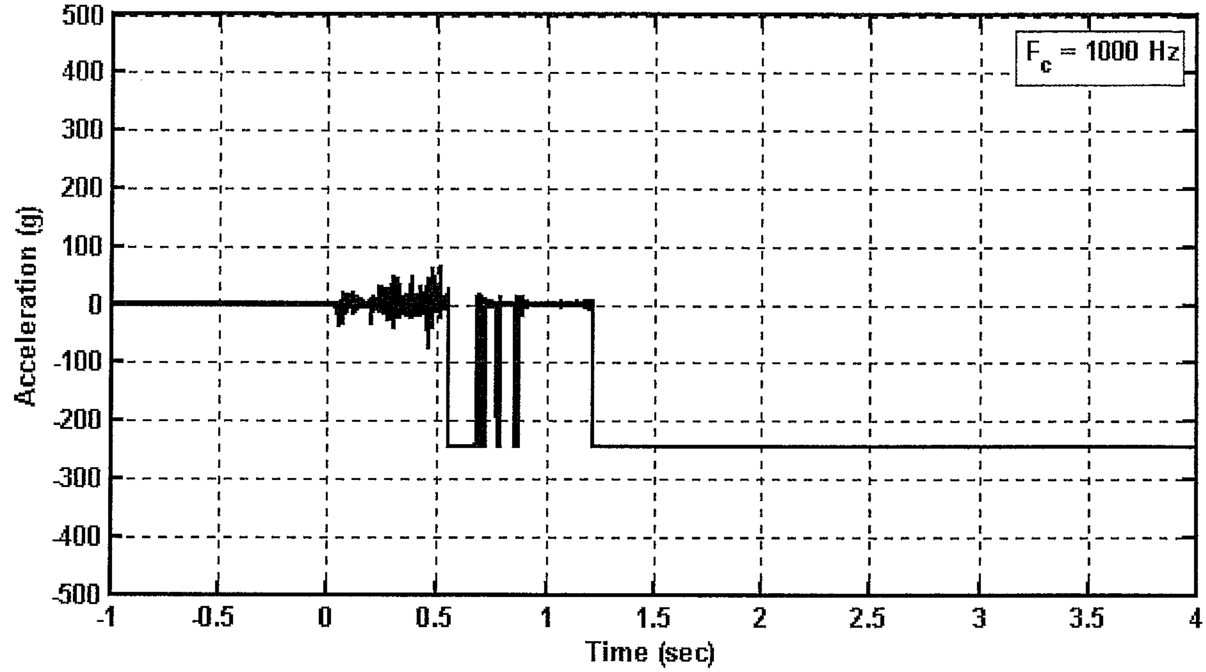


Figure B31. Bullet car 2, position 1, center sill, longitudinal acceleration
Channel Name: B2_C1X

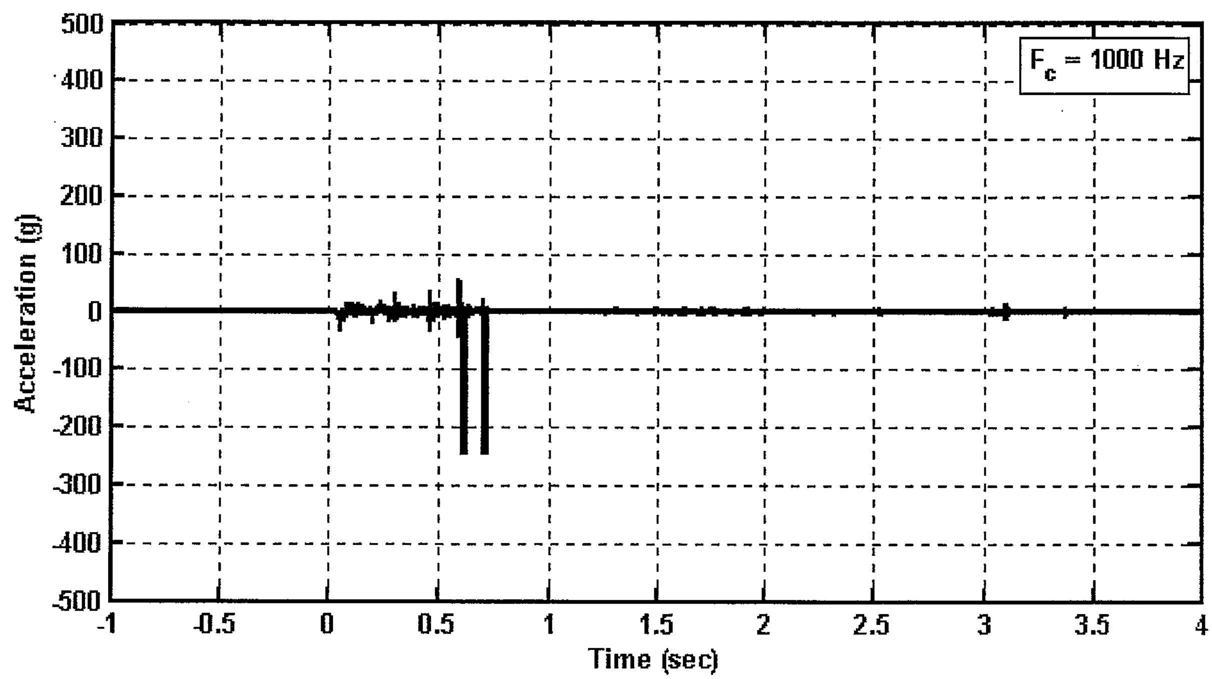


Figure B32. Bullet car 2, position 2, center sill, longitudinal acceleration
Channel Name: B2_C2X

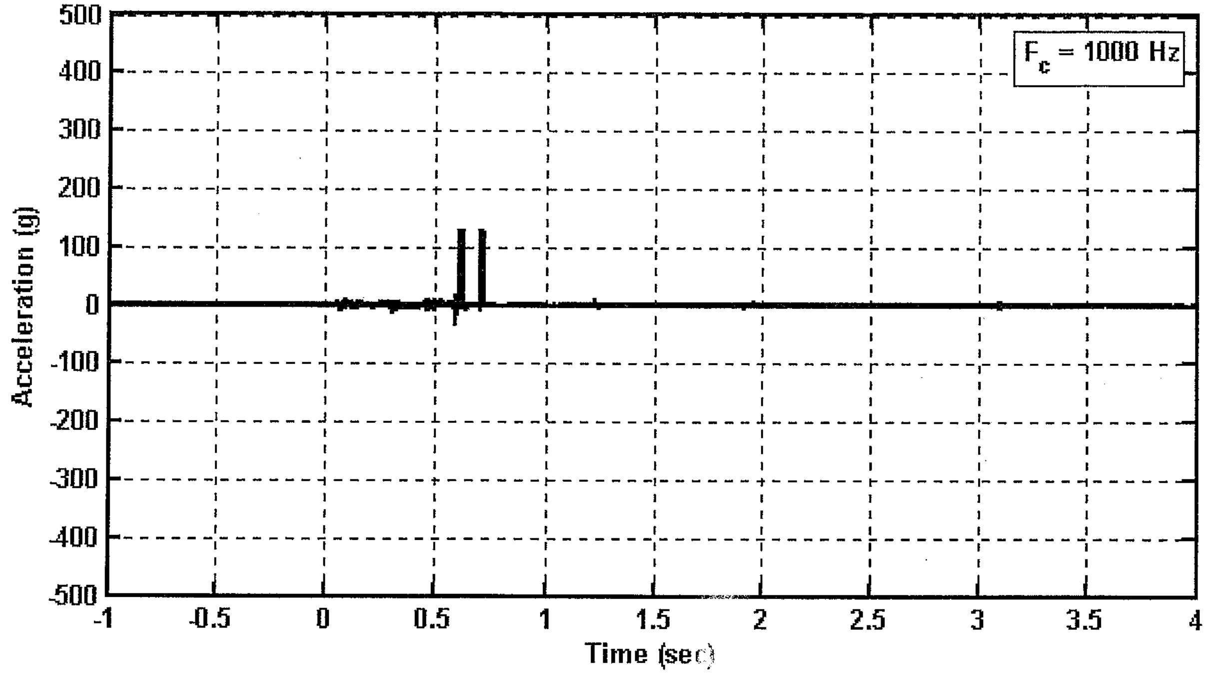


Figure B33. Bullet car 2, position 2, center sill, lateral acceleration
Channel Name: B2_C2Y

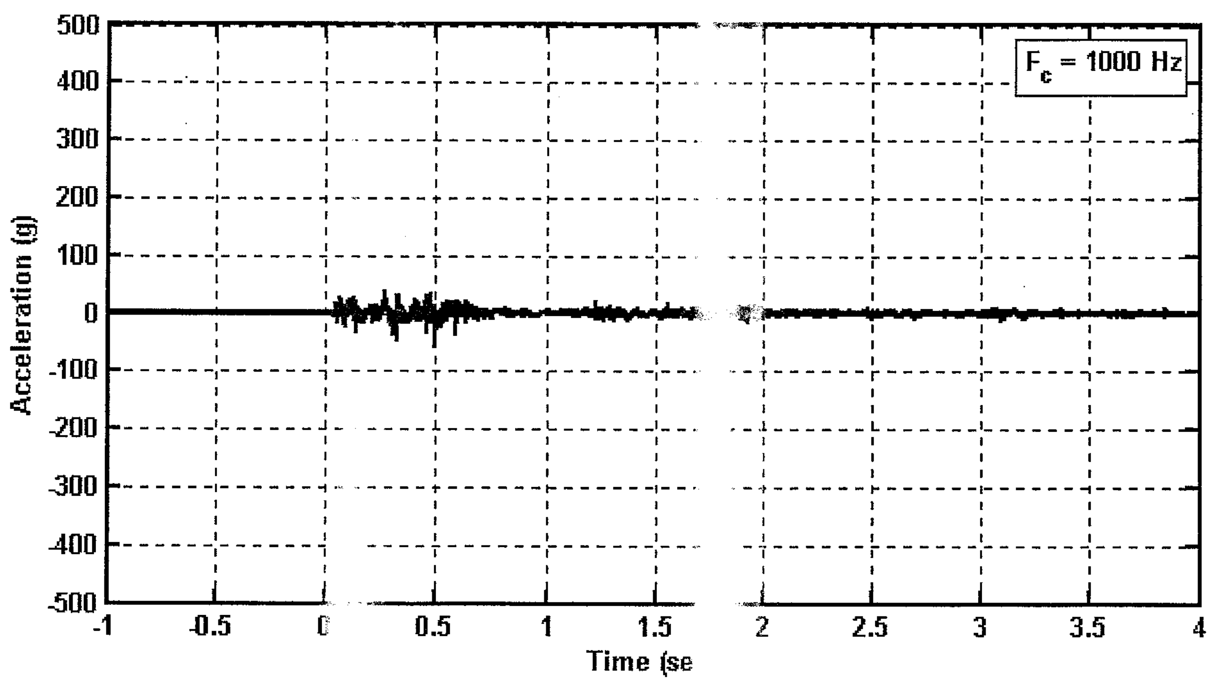


Figure B Bullet car 2, position 2, c er sill, vertical acceleration
Channel Name _C2Z

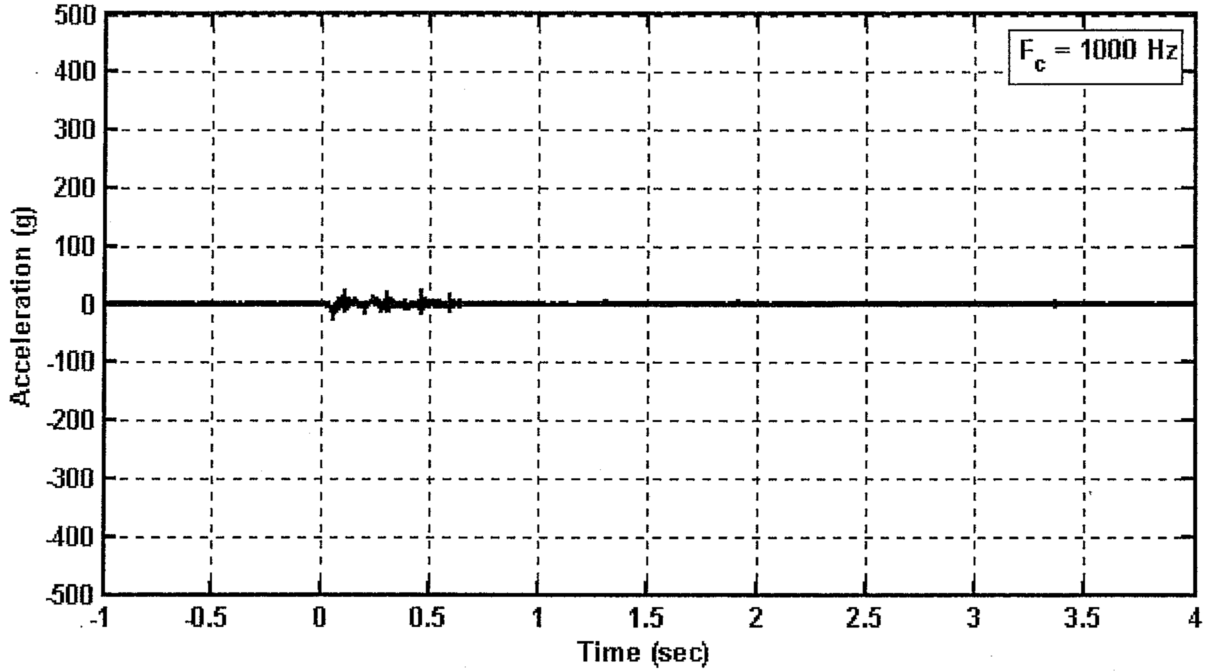


Figure B35. Bullet car 2, position 3, center sill, longitudinal acceleration
Channel Name: B2_C3X

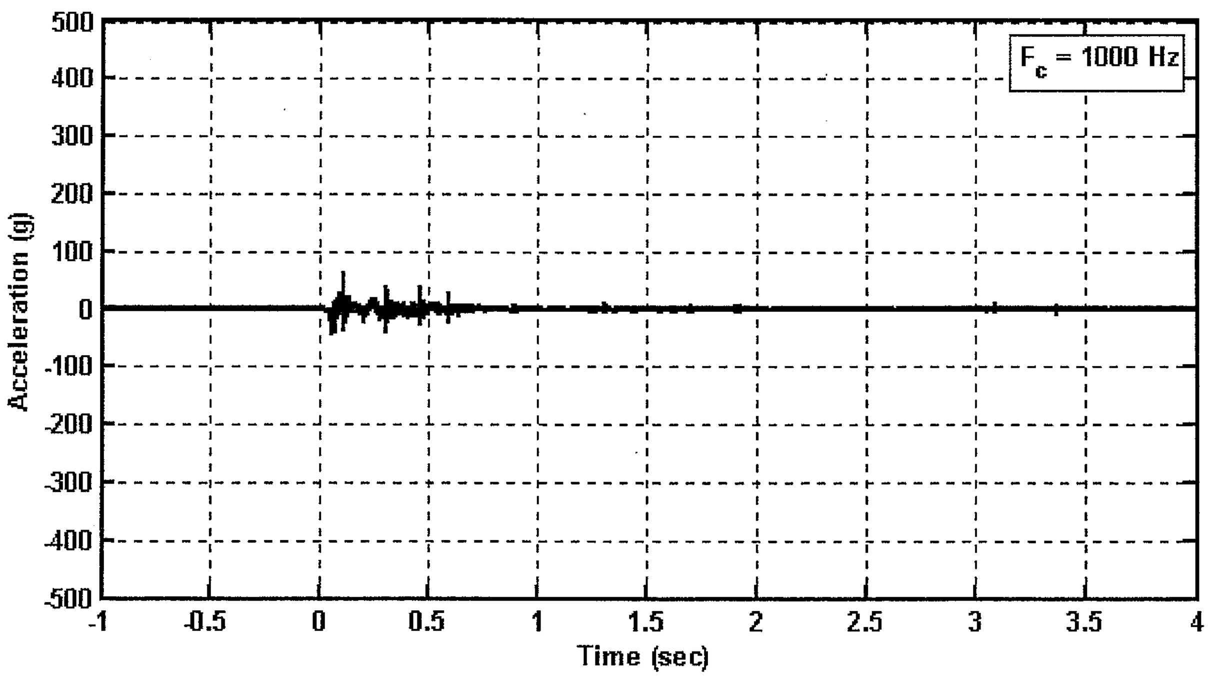


Figure B36. Bullet car 2, position 4, center sill, longitudinal acceleration
Channel Name: B2_C4X

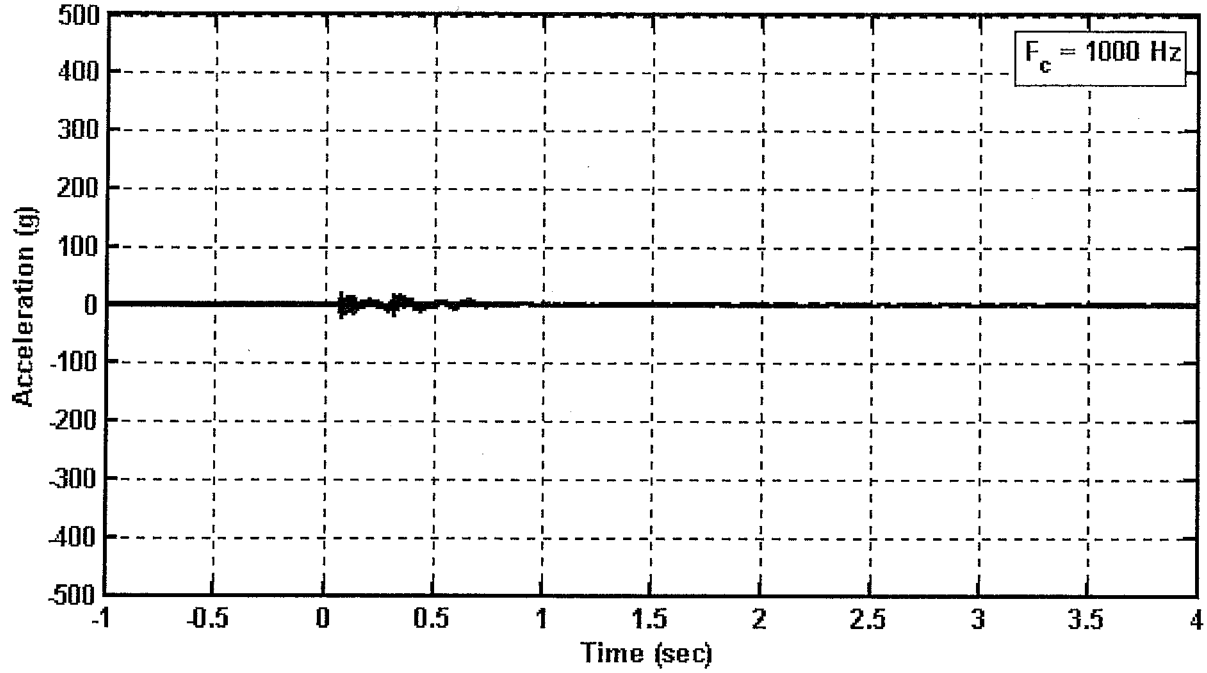


Figure B37. Bullet car 2, position 4, center sill, lateral acceleration
Channel Name: B2_C4Y

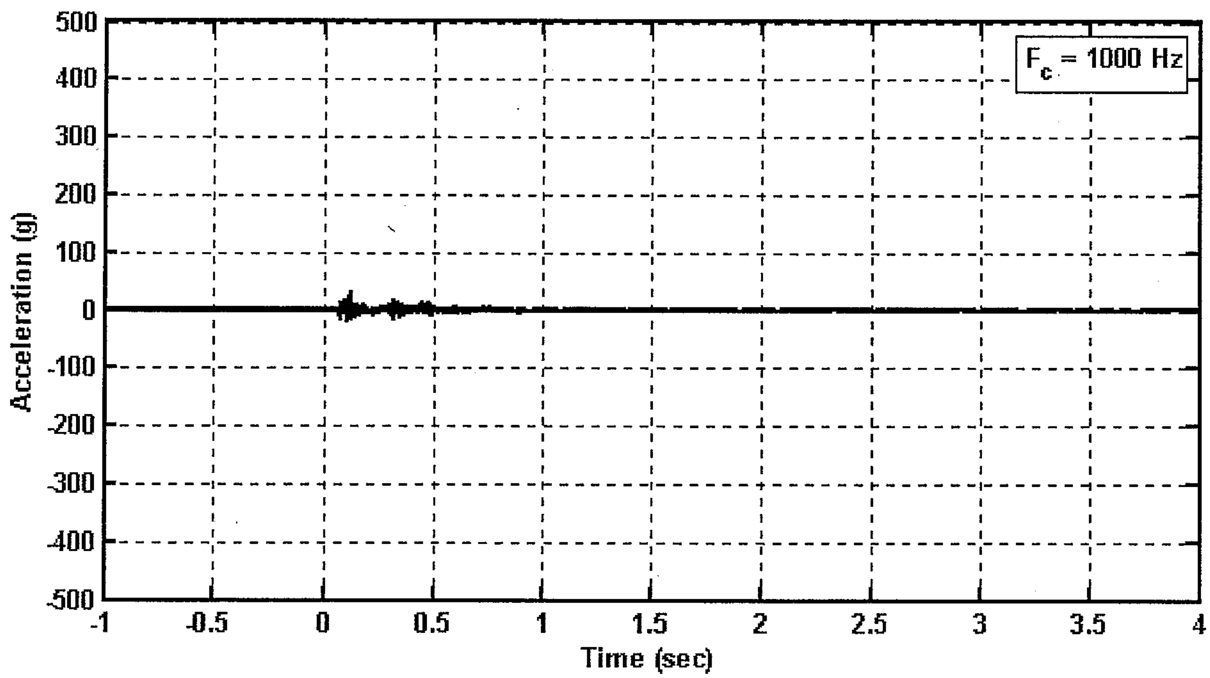


Figure B38. Bullet car 2, position 4, center sill, vertical acceleration
Channel Name: B2_C4Z

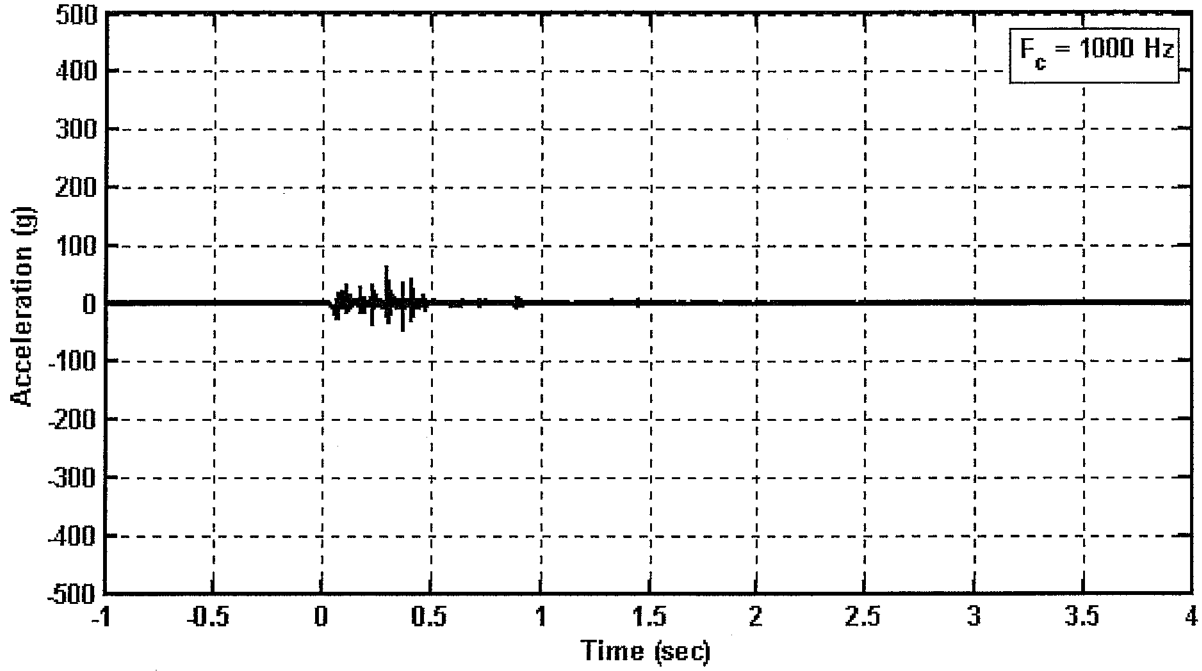


Figure B39. Bullet car 2, position 5, center sill, longitudinal acceleration
Channel Name: B2_C5X

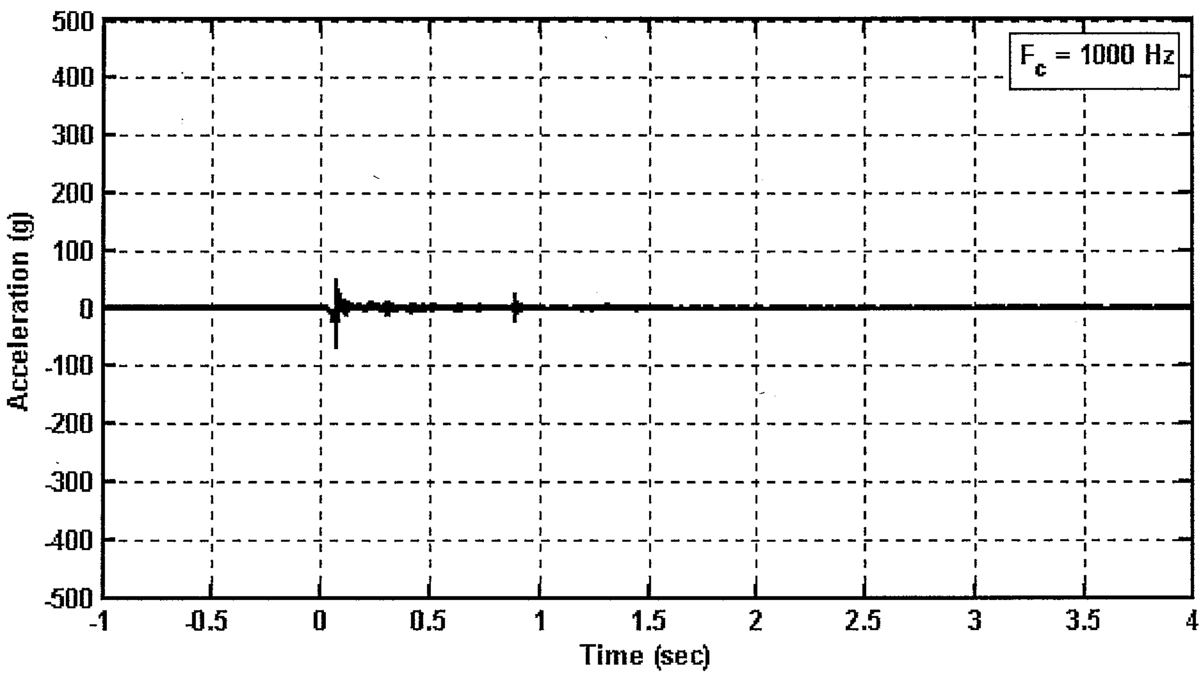


Figure B40. Bullet car 2, position 6, center sill, longitudinal acceleration
Channel Name: B2_C6X

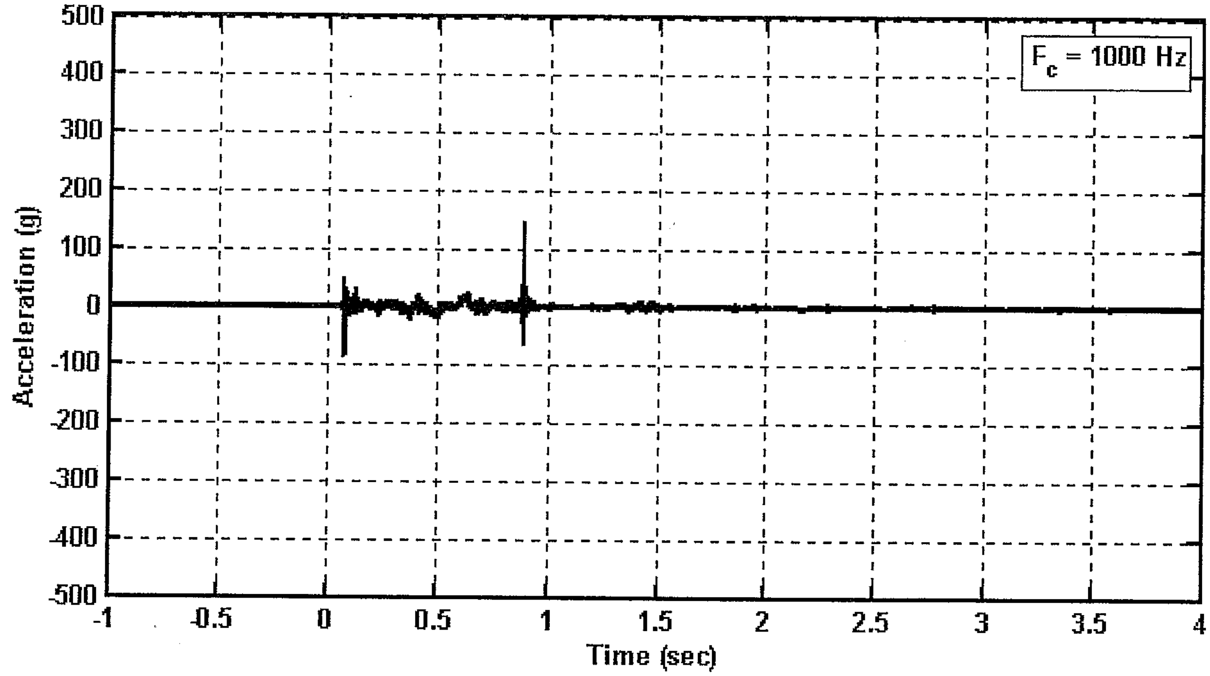


Figure B41. Bullet car 2, position 6, center sill, lateral acceleration
Channel Name: B2_C6Y

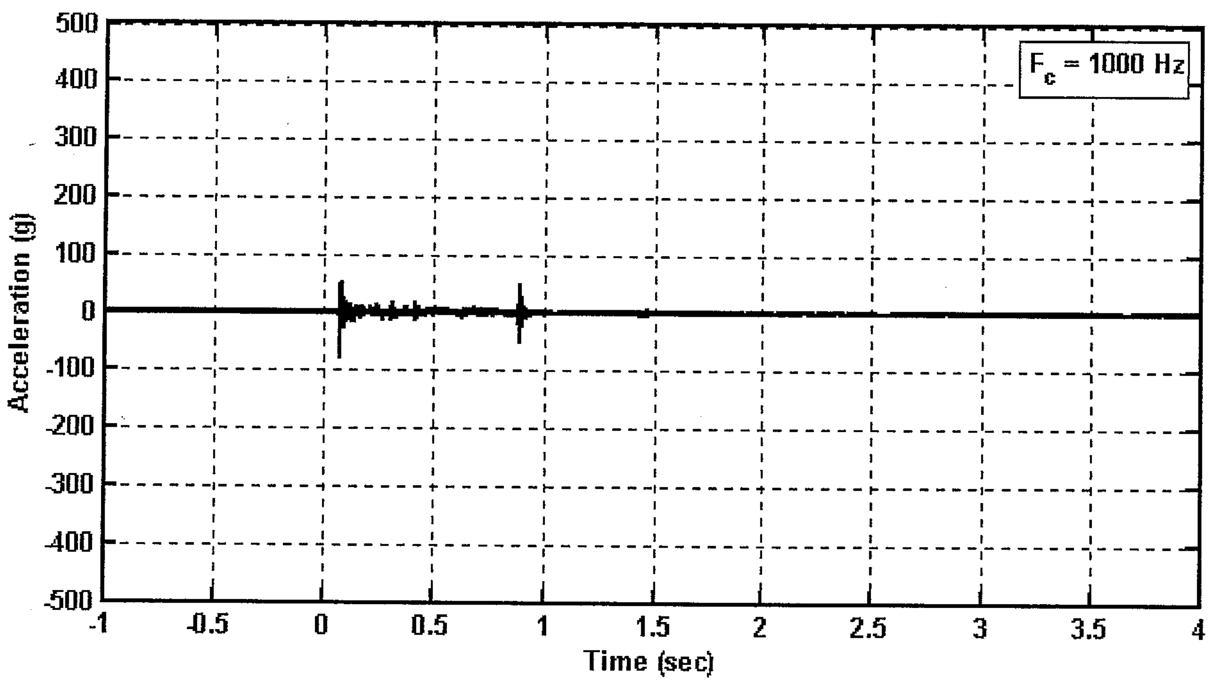


Figure B42. Bullet car 2, position 6, center sill, vertical acceleration
Channel Name: B2_C6Z

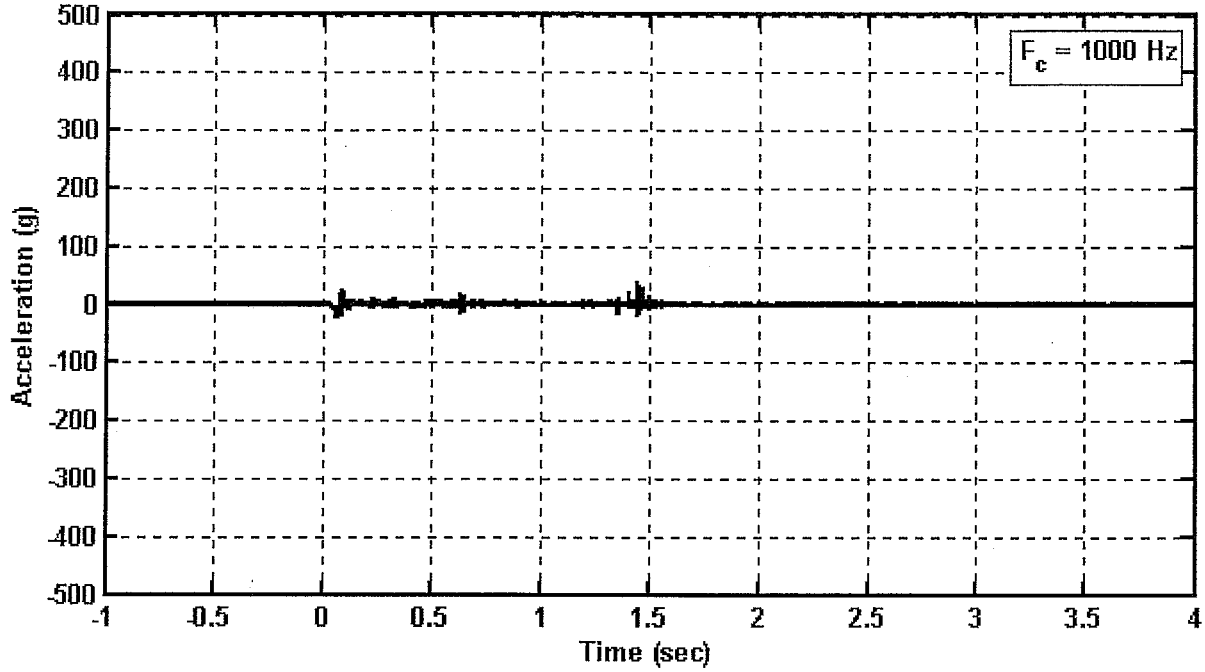


Figure B43. Bullet car 2, position 7, center sill, longitudinal acceleration
Channel Name: B2_C7X

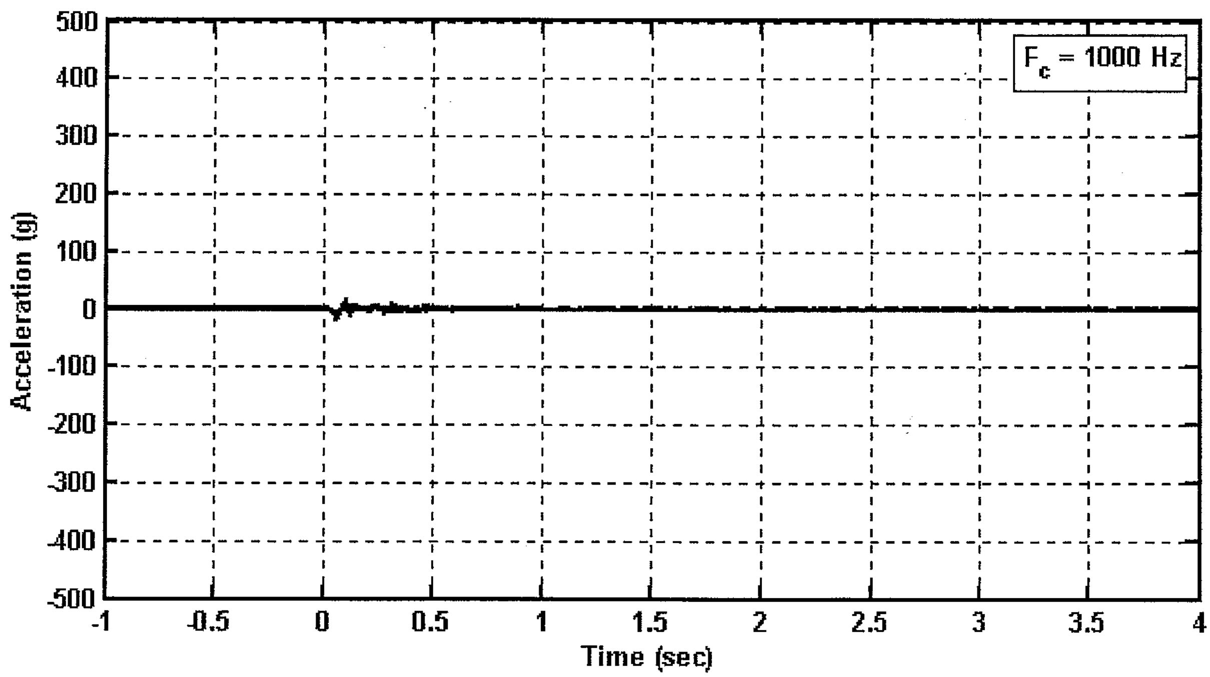


Figure B44. Bullet car 2, position 4, left side, longitudinal acceleration
Channel Name: B2_L4X

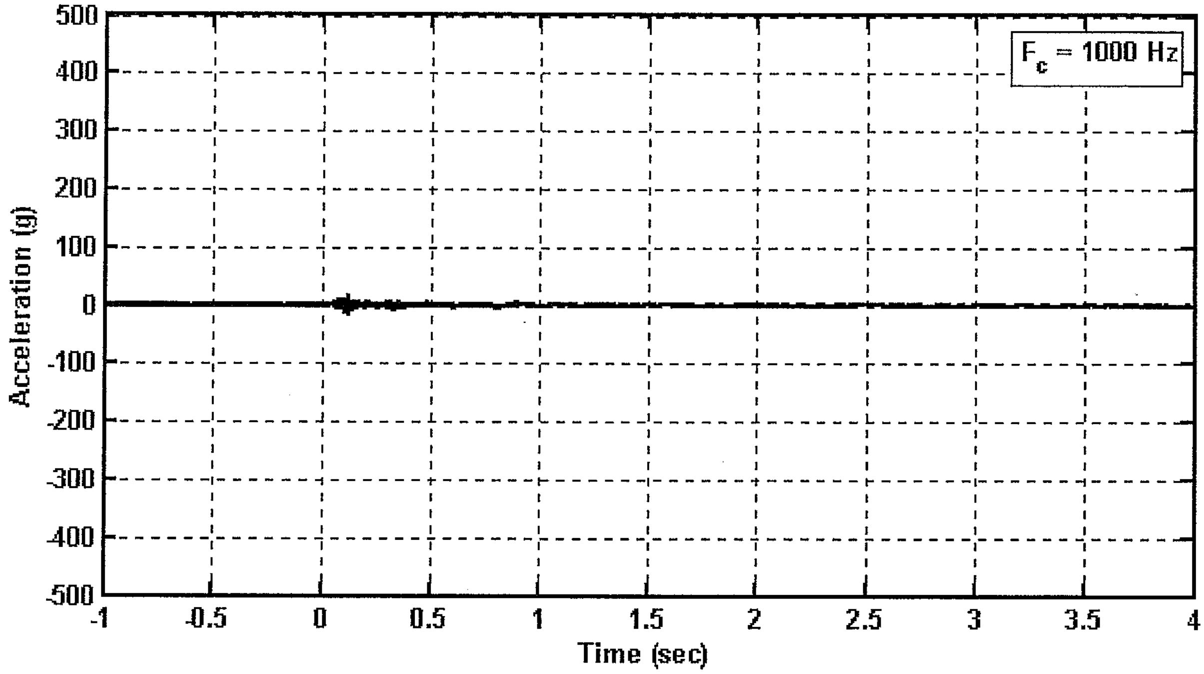


Figure B45. Bullet car 2, position 4, left side, vertical acceleration
Channel Name: B2_L4Z

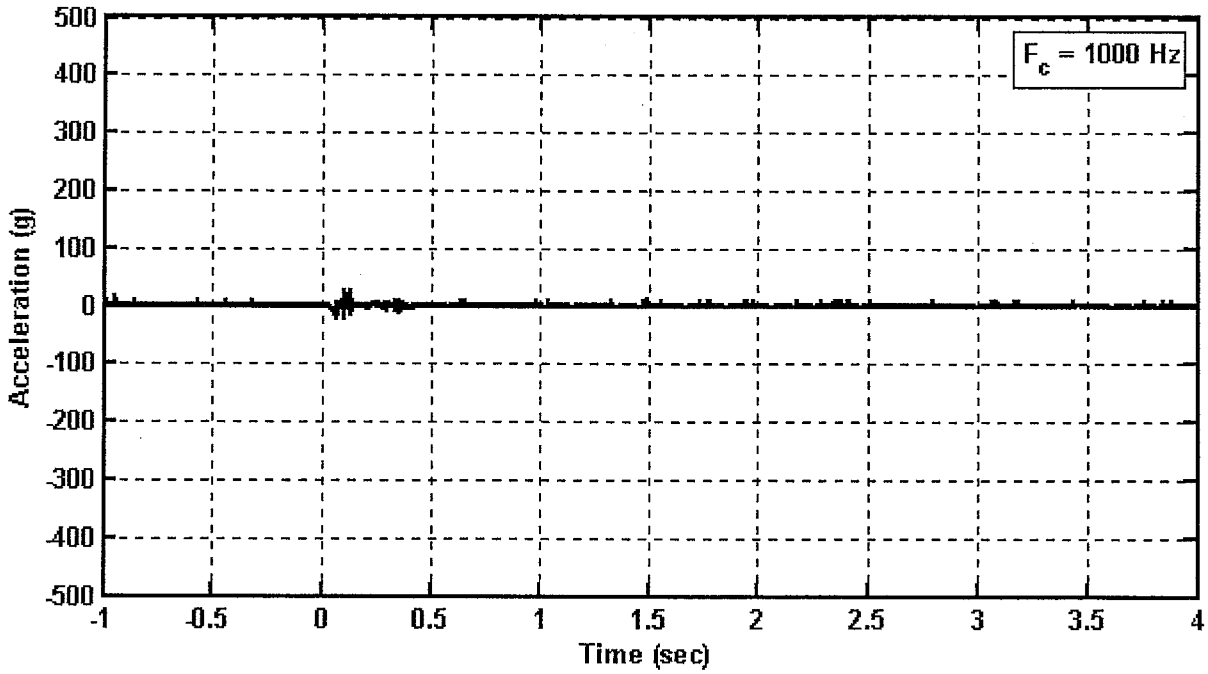


Figure B46. Bullet car 2, position 4, right side, longitudinal acceleration
Channel Name: B2_R4X

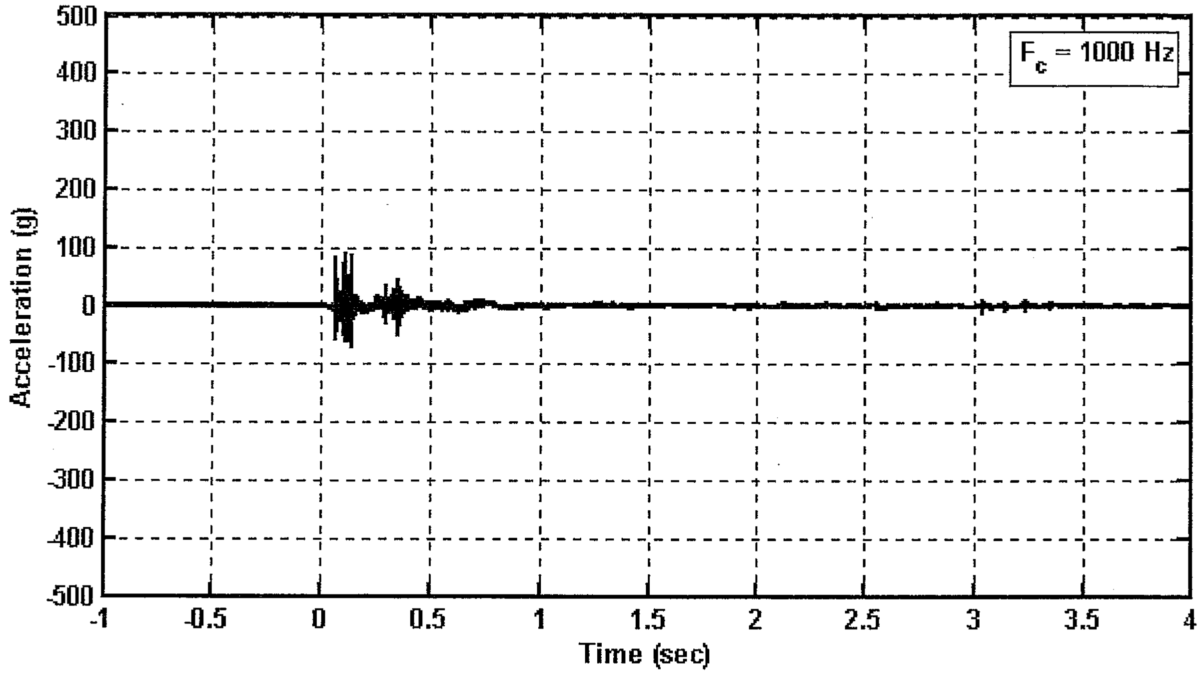


Figure B47. Bullet car 2, position 4, right side, vertical acceleration
Channel Name: B2_R4Z

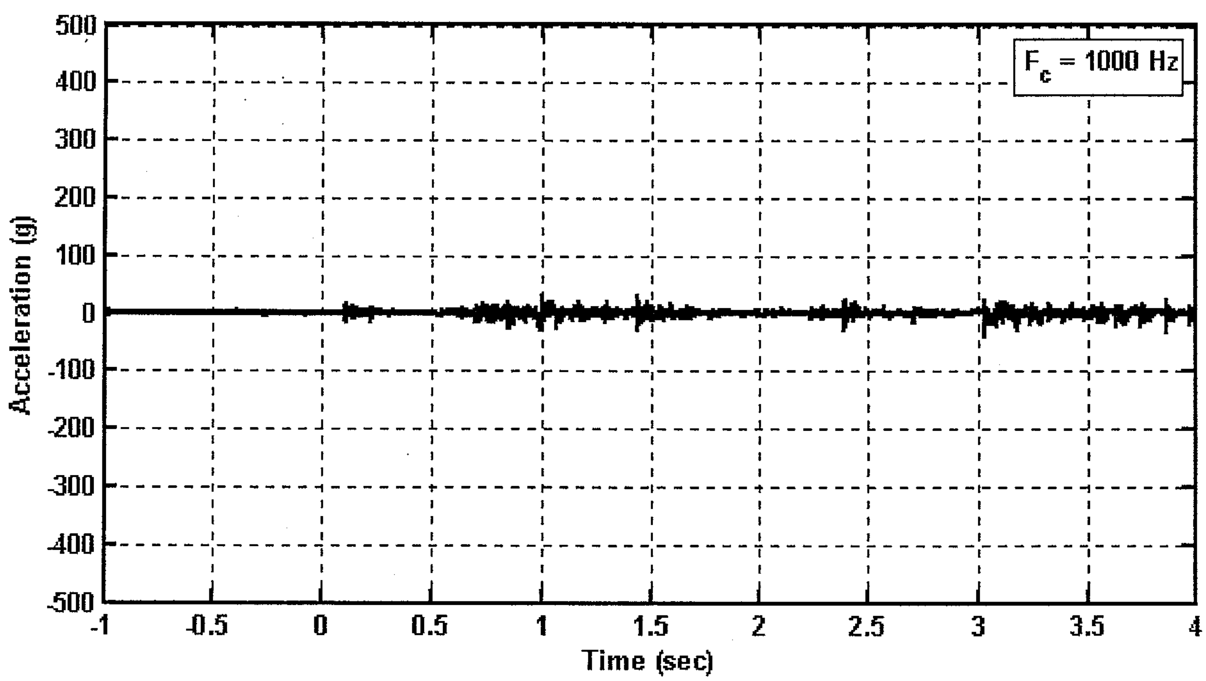


Figure B48. Bullet car 3, A truck, vertical acceleration
Channel Name: B3_BAZ

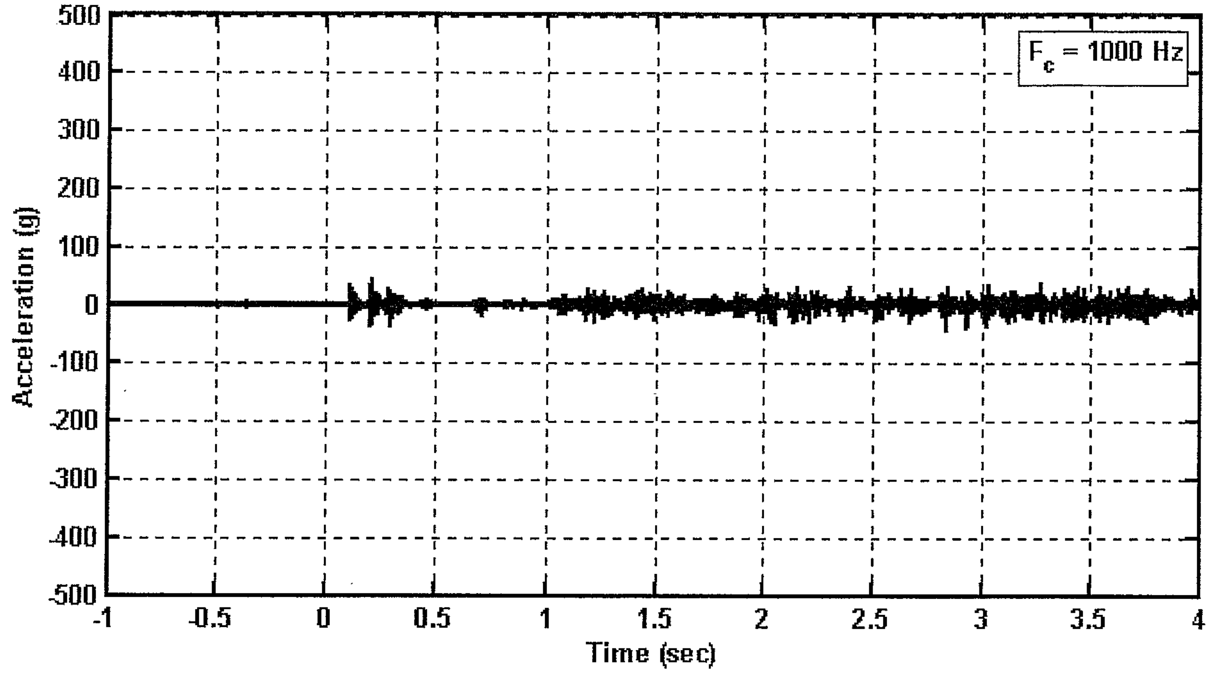


Figure B49. Bullet car 3, B truck, vertical acceleration
Channel Name: B3_BBZ

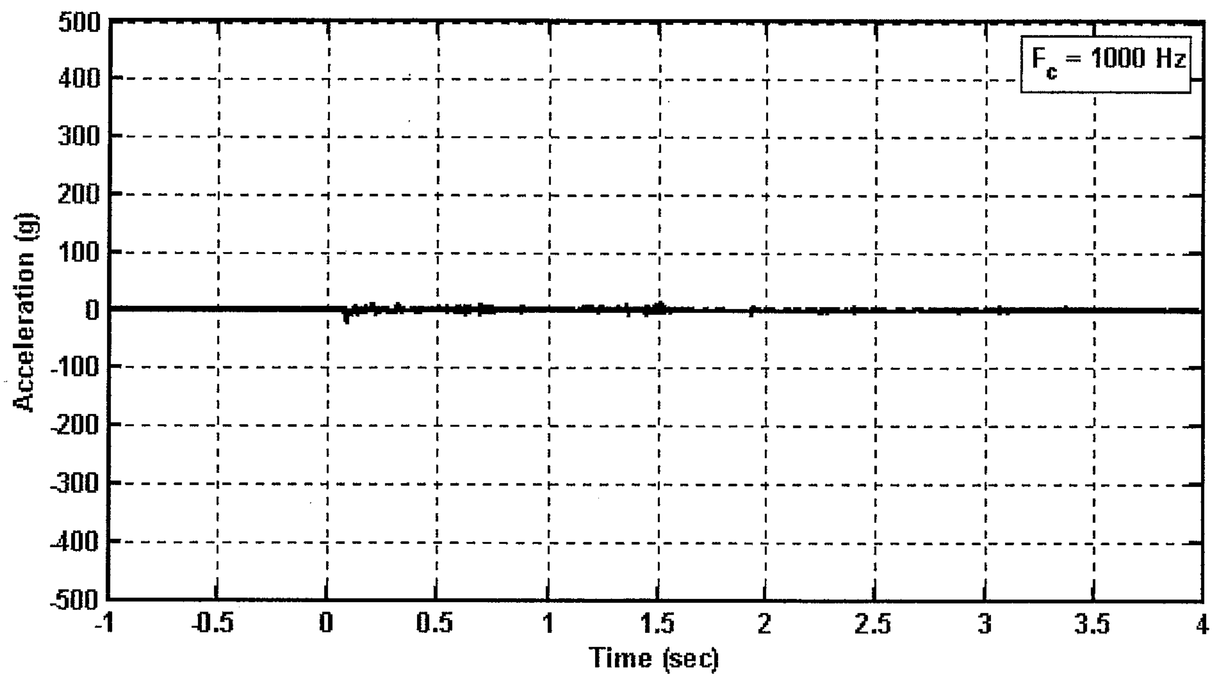


Figure B50. Bullet car 3, position 1, center sill, longitudinal acceleration
Channel Name: B3_C1X

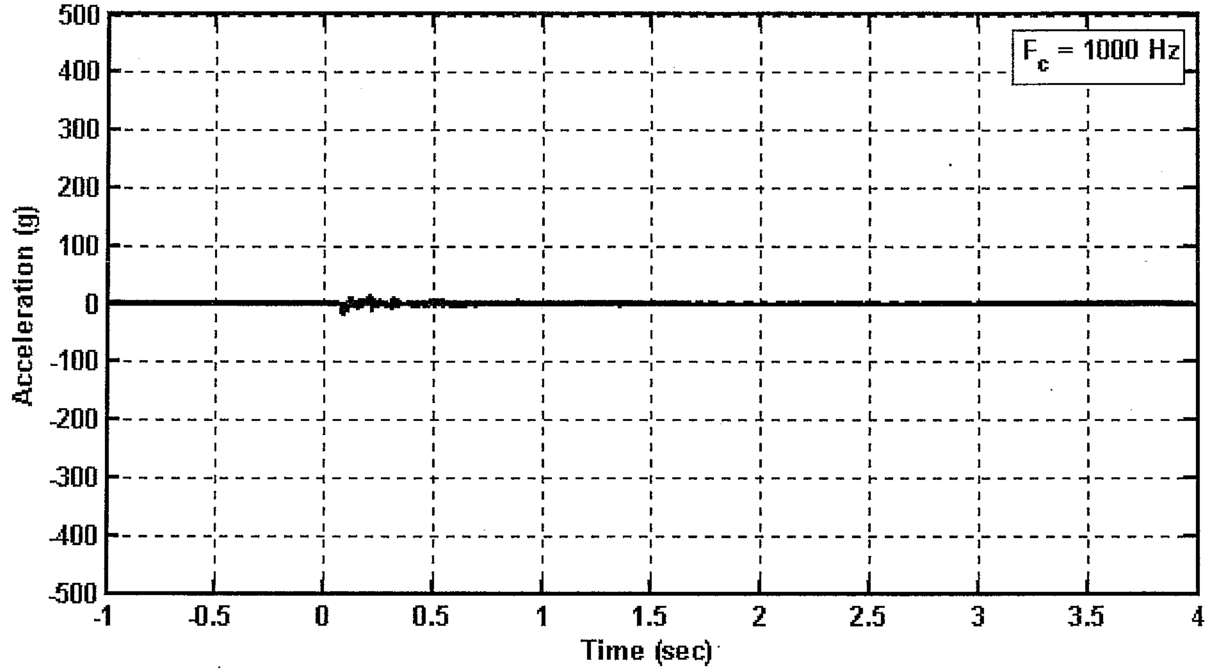


Figure B51. Bullet car 3, position 2, center sill, longitudinal acceleration
Channel Name: B3_C2X

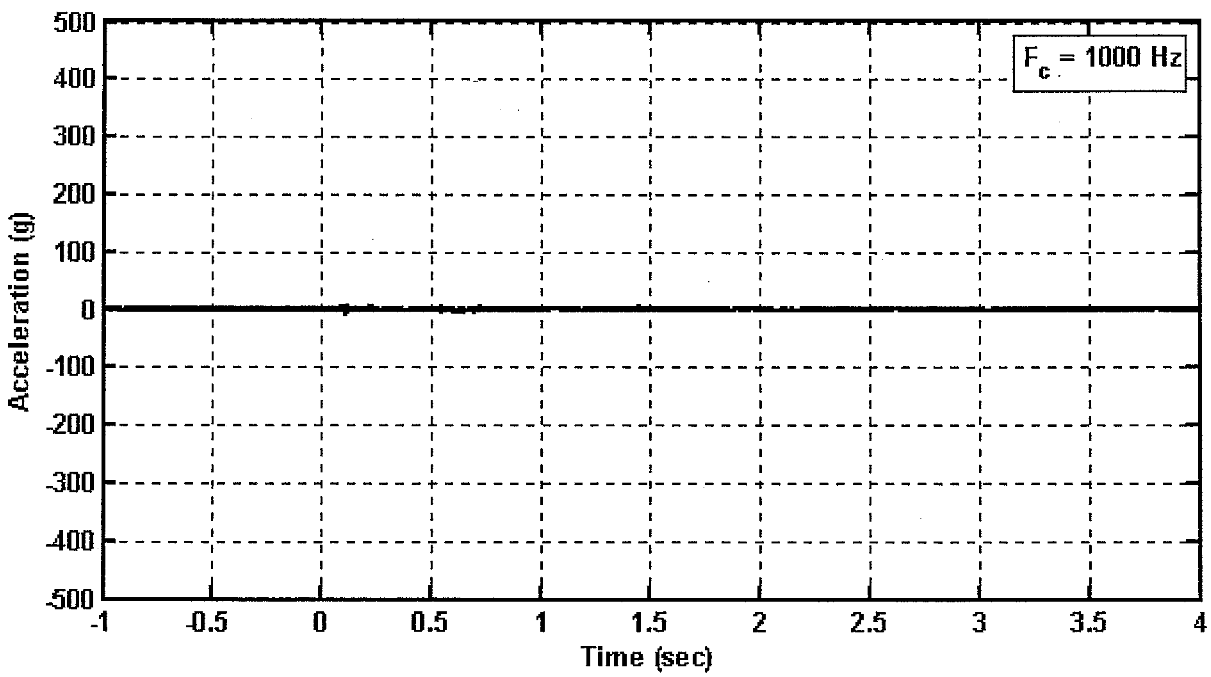


Figure B52. Bullet car 3, position 2, center sill, lateral acceleration
Channel Name: B3_C2Y

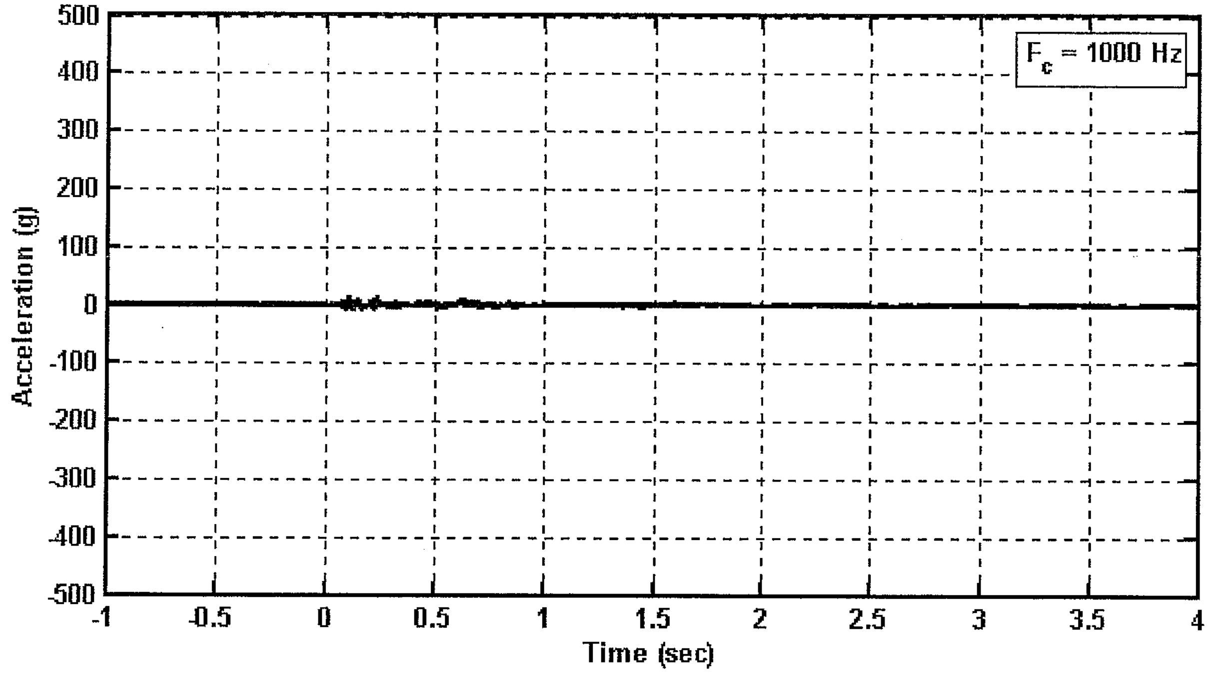


Figure B53. Bullet car 3, position 2, center sill, vertical acceleration
Channel Name: B3_C2Z

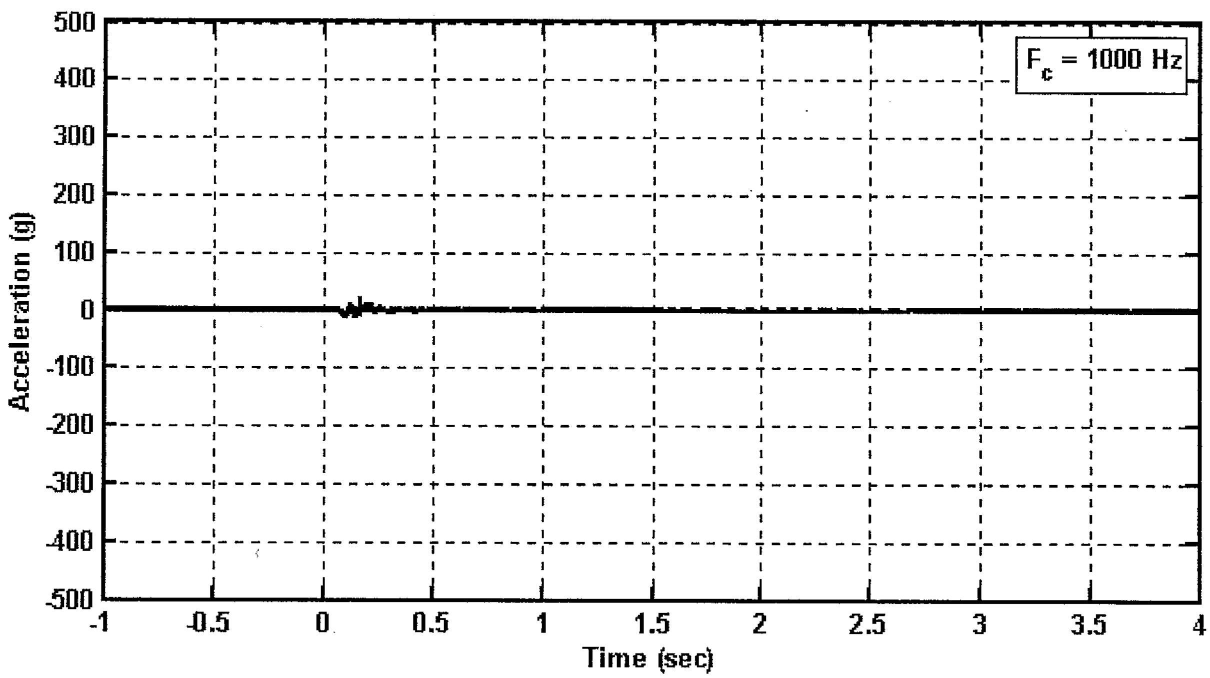


Figure B54. Bullet car 3, position 3, center sill, longitudinal acceleration
Channel Name: B3_C3X

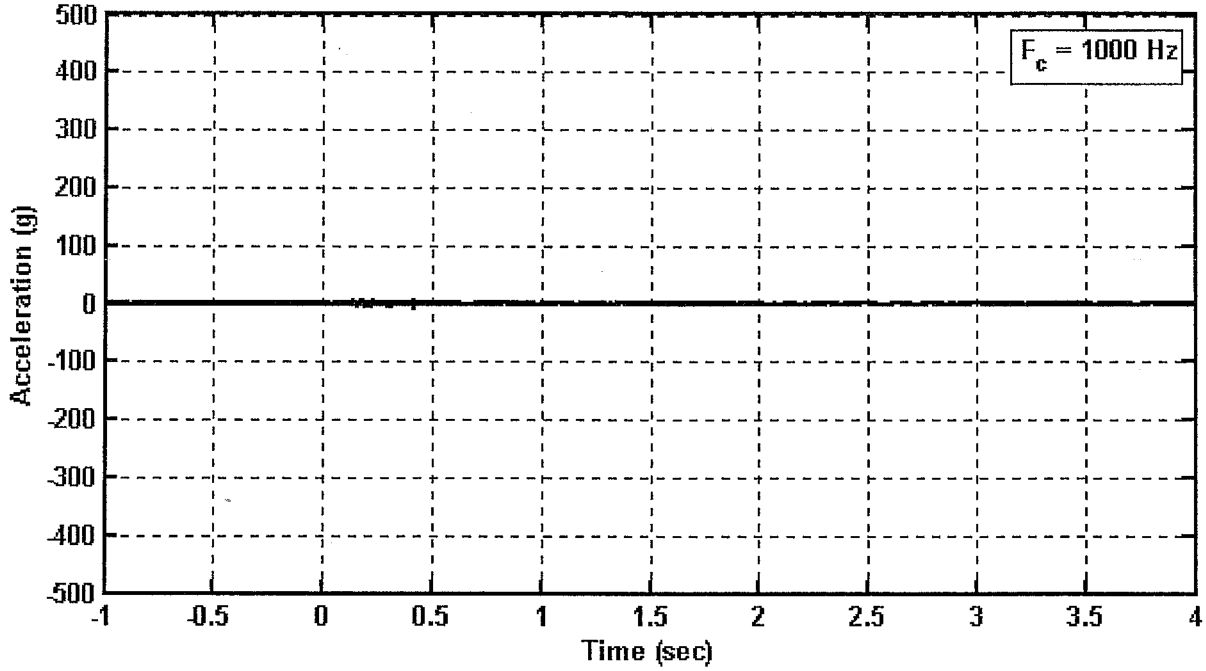


Figure B55. Bullet car 3, position 3, center sill, lateral acceleration
Channel Name: B3_C3Y

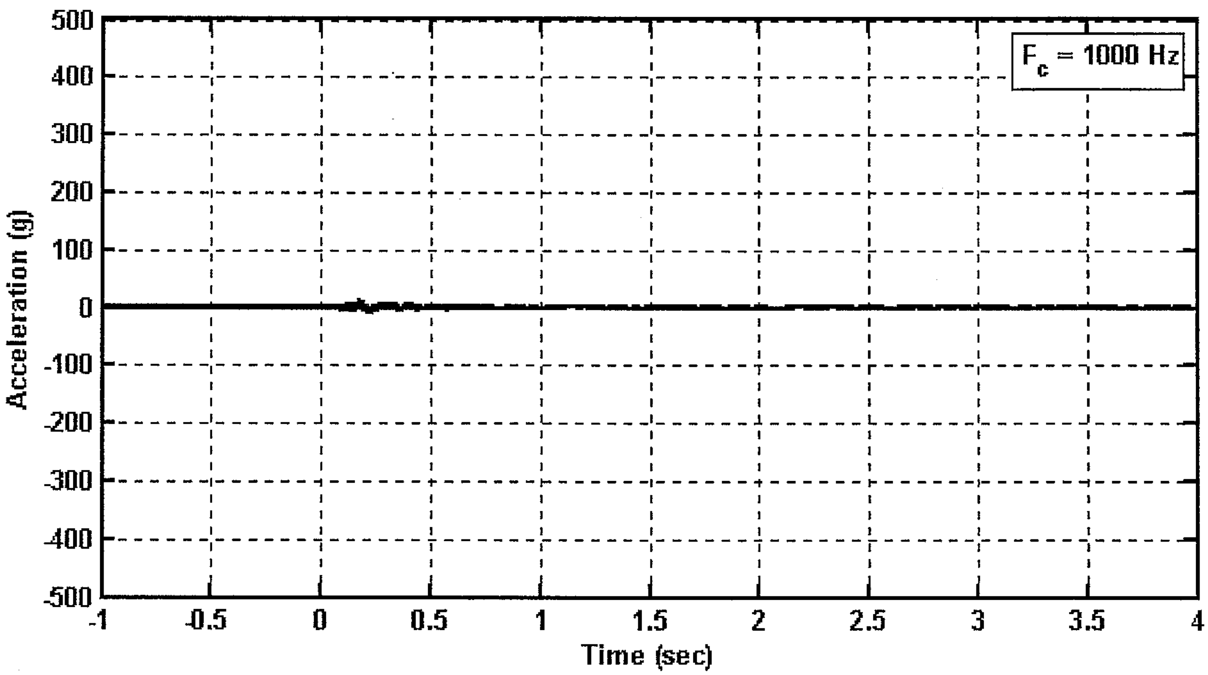


Figure B56. Bullet car 3, position 3, center sill, vertical acceleration
Channel Name: B3_C3Z

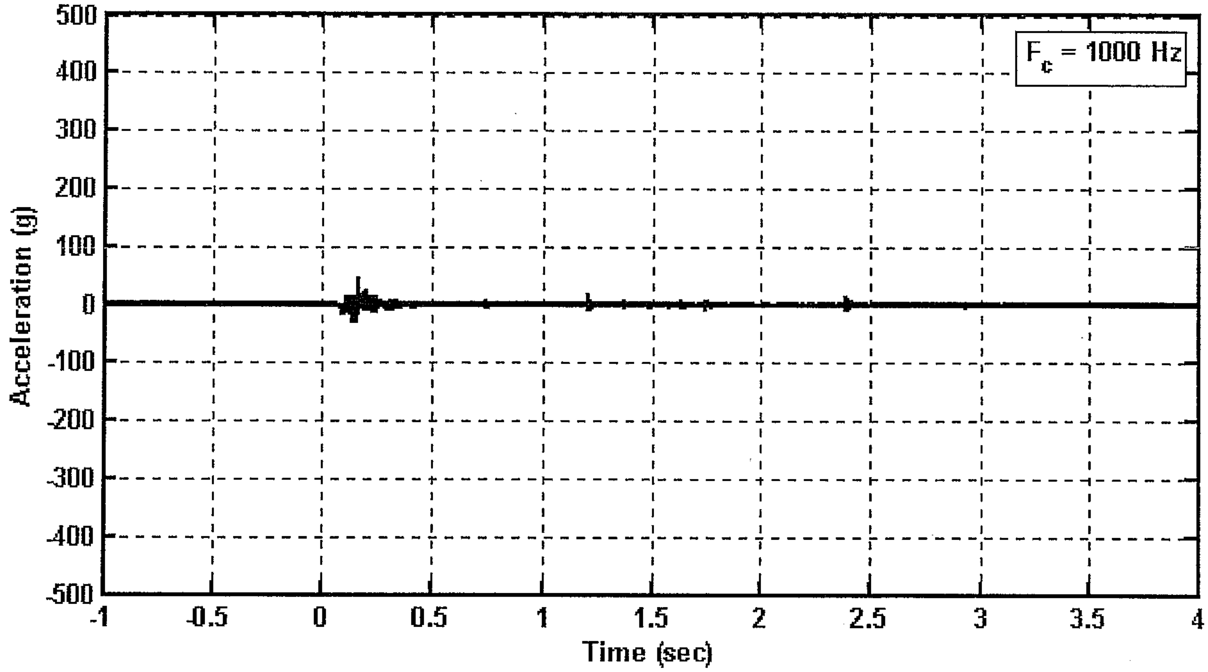


Figure B57. Bullet car 3, position 4, center sill, longitudinal acceleration
Channel Name: B3_C4X

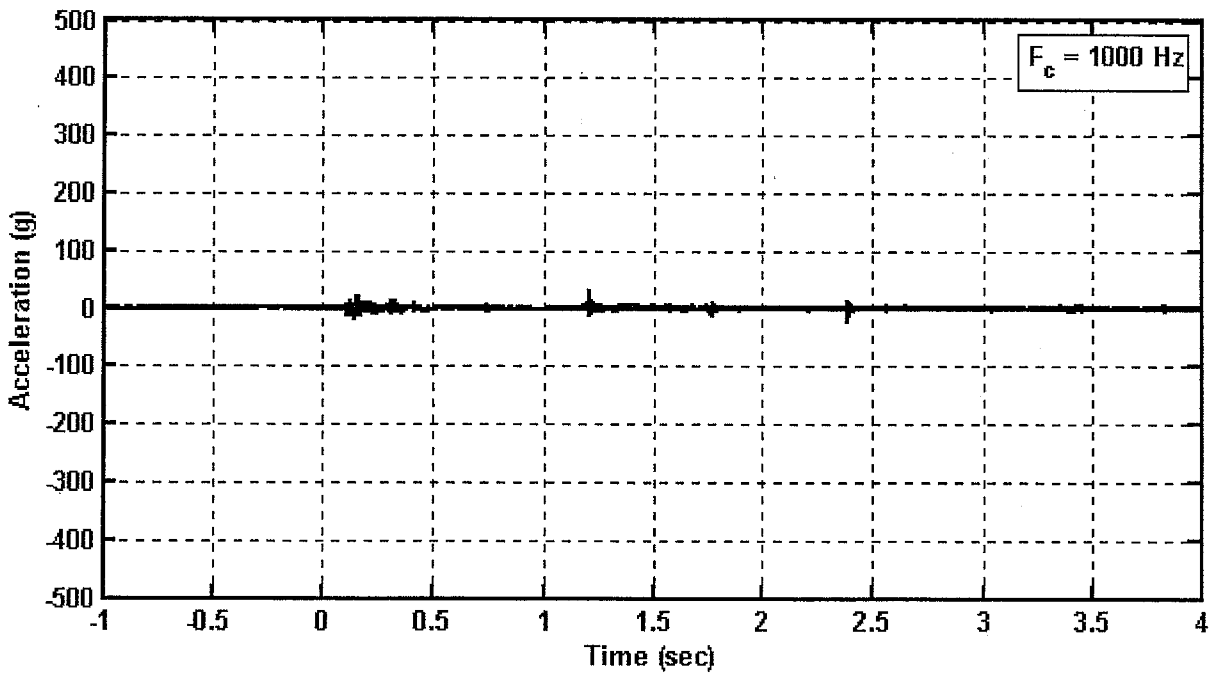


Figure B58. Bullet car 3, position 4, center sill, lateral acceleration
Channel Name: B3_C4Y

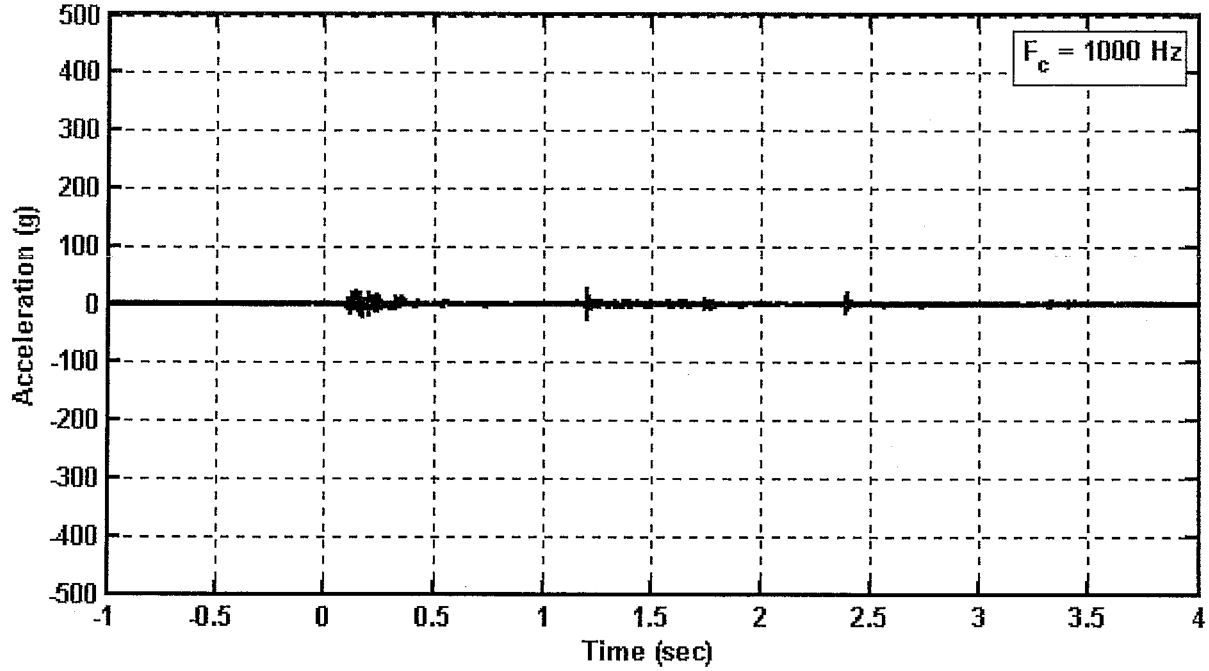


Figure B59. Bullet car 3, position 4, center sill, vertical acceleration
Channel Name: B3_C4Z

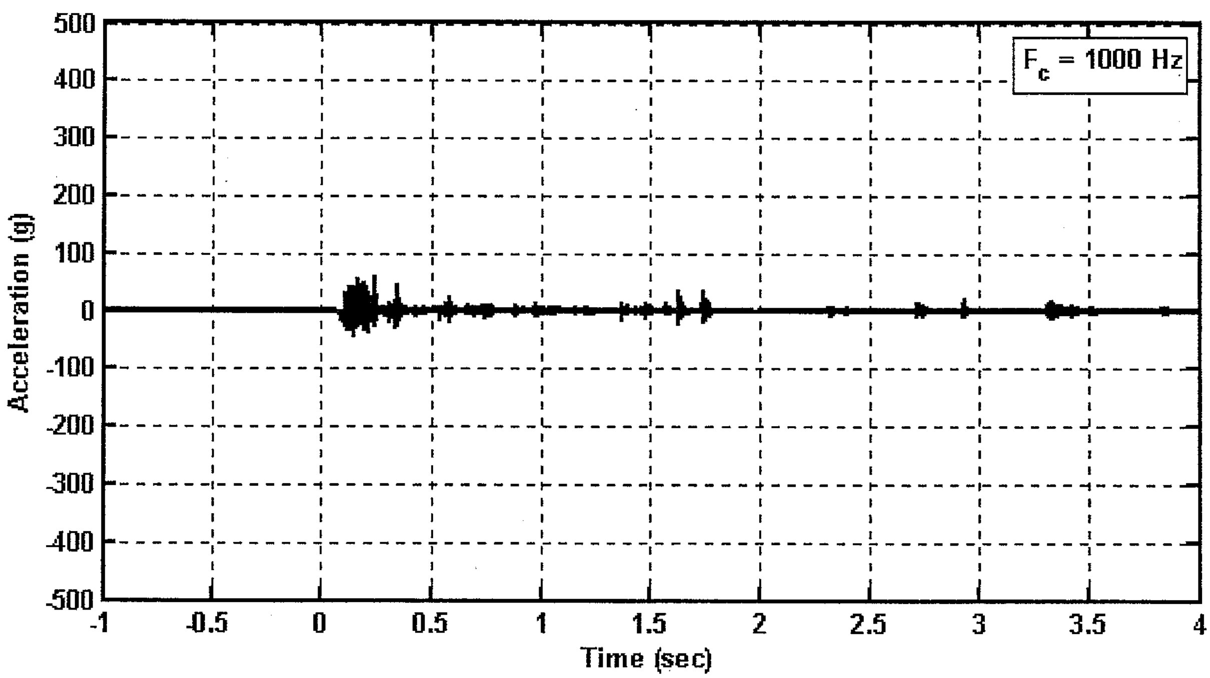


Figure B60. Bullet car 3, position 5, center sill, longitudinal acceleration
Channel Name: B3_C5X

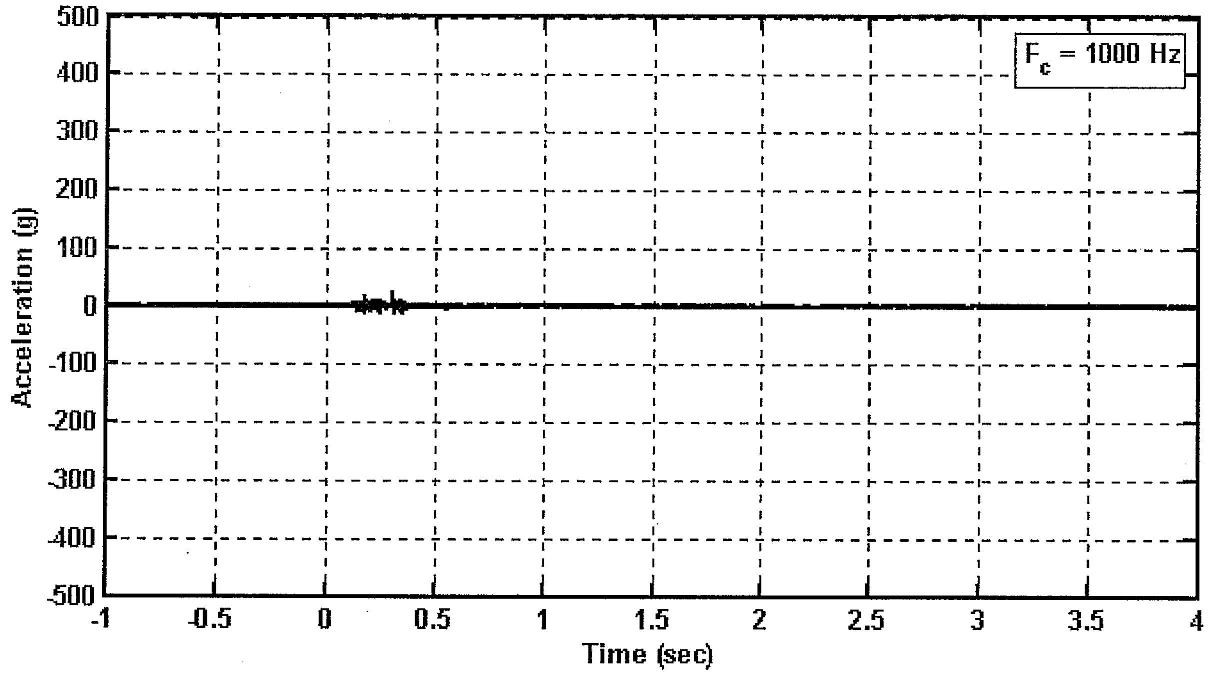


Figure B61. Bullet car 4, A truck, vertical acceleration
Channel Name: B4_BAZ

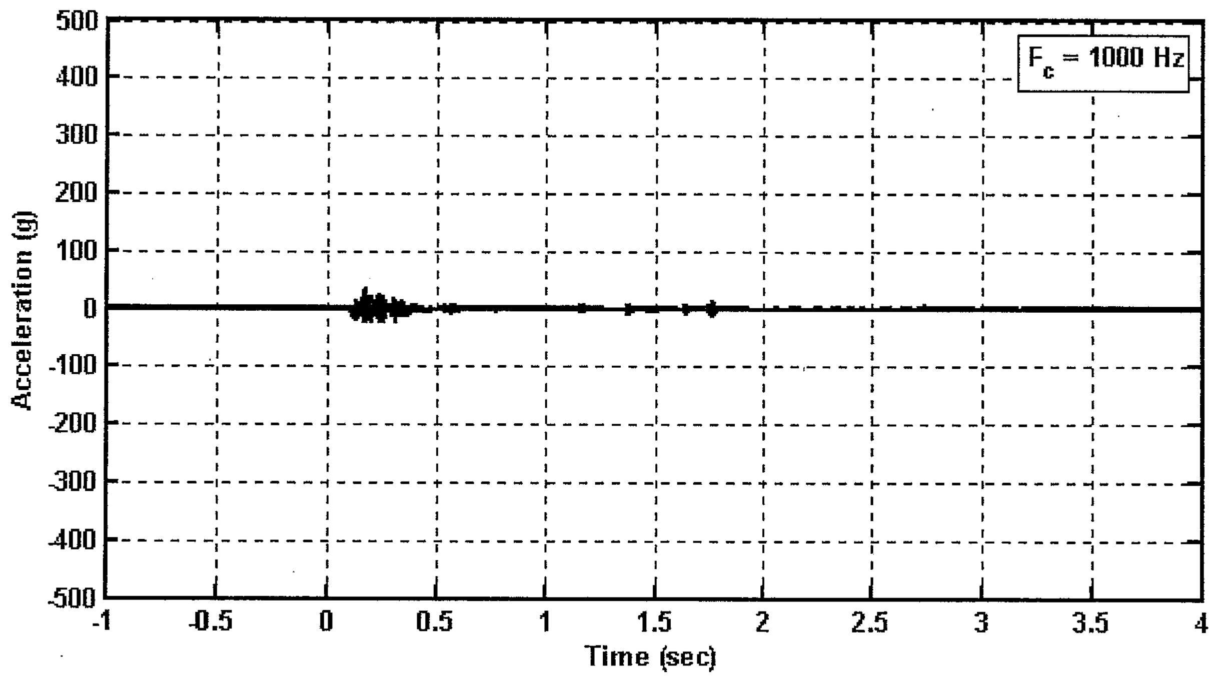


Figure B62. Bullet car 4, position 1, center sill, longitudinal acceleration
Channel Name: B4_C1X

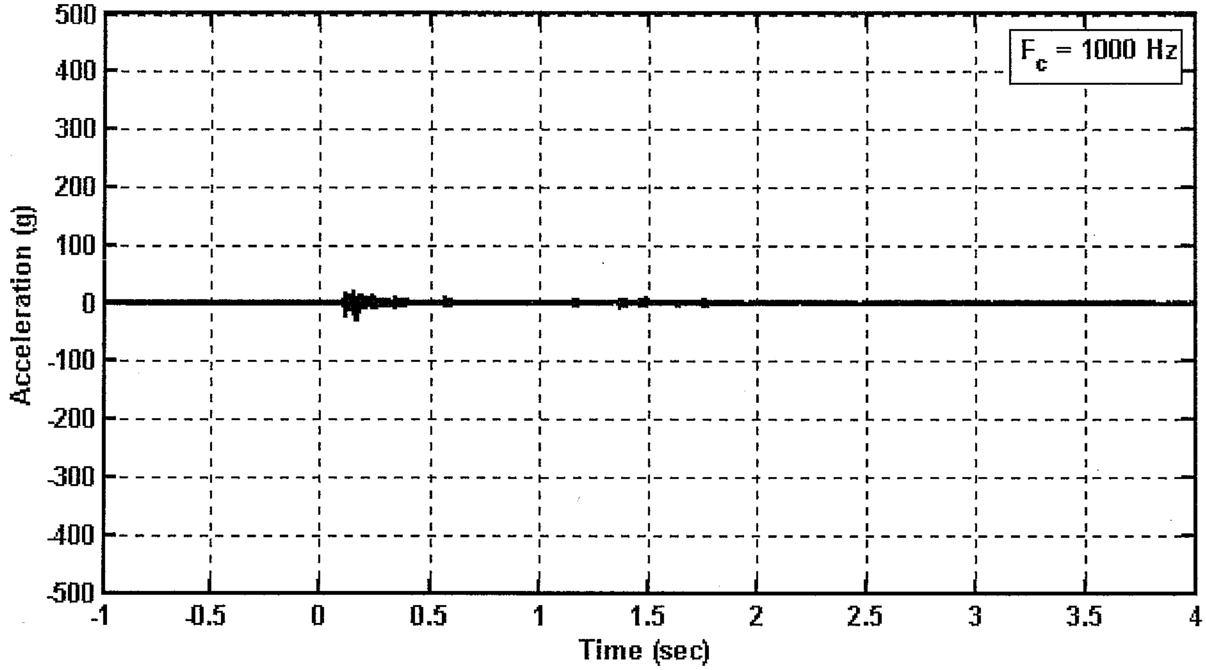


Figure B63. Bullet car 4, position 1, center sill, lateral acceleration
Channel Name: B4_C1Y

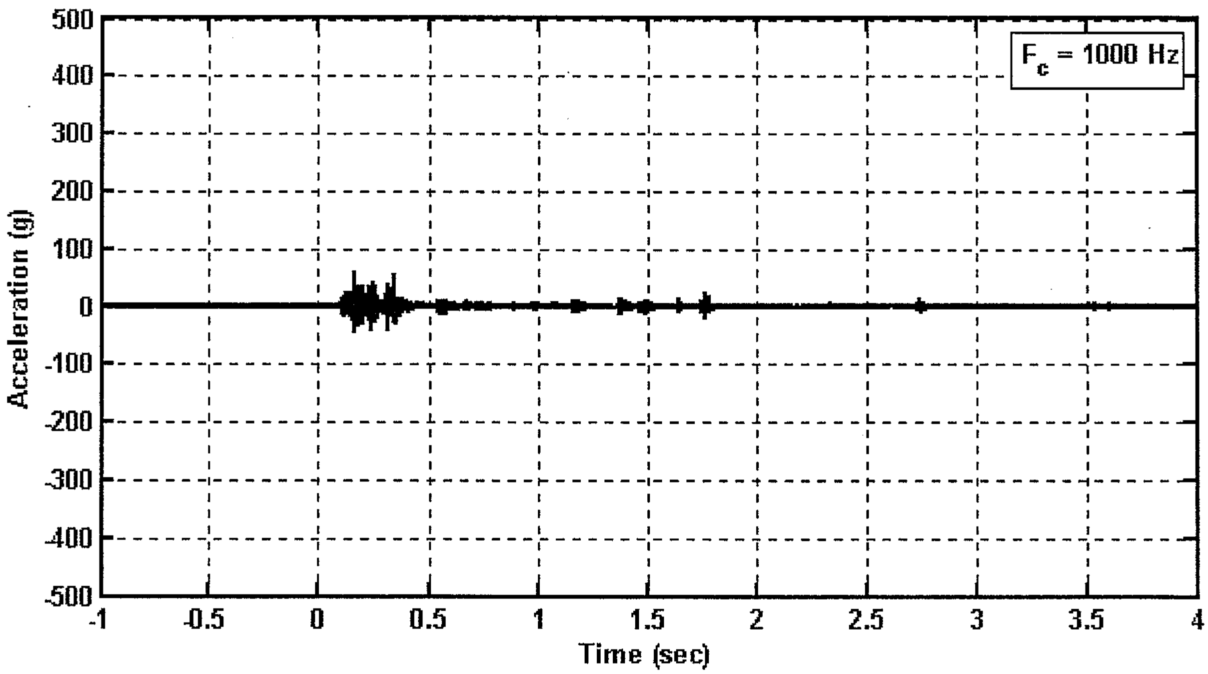


Figure B64. Bullet car 4, position 1, center sill, vertical acceleration
Channel Name: B4_C1Z

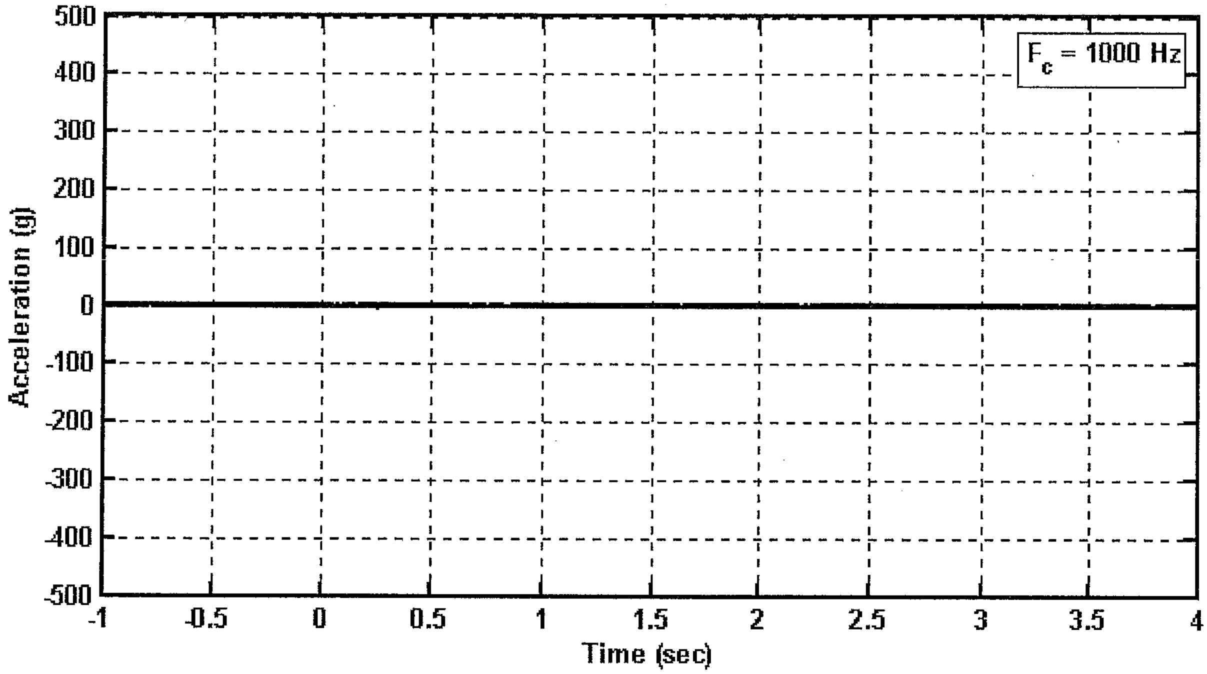


Figure B65. Bullet locomotive, A truck, vertical acceleration
Channel Name: BL_BAZ

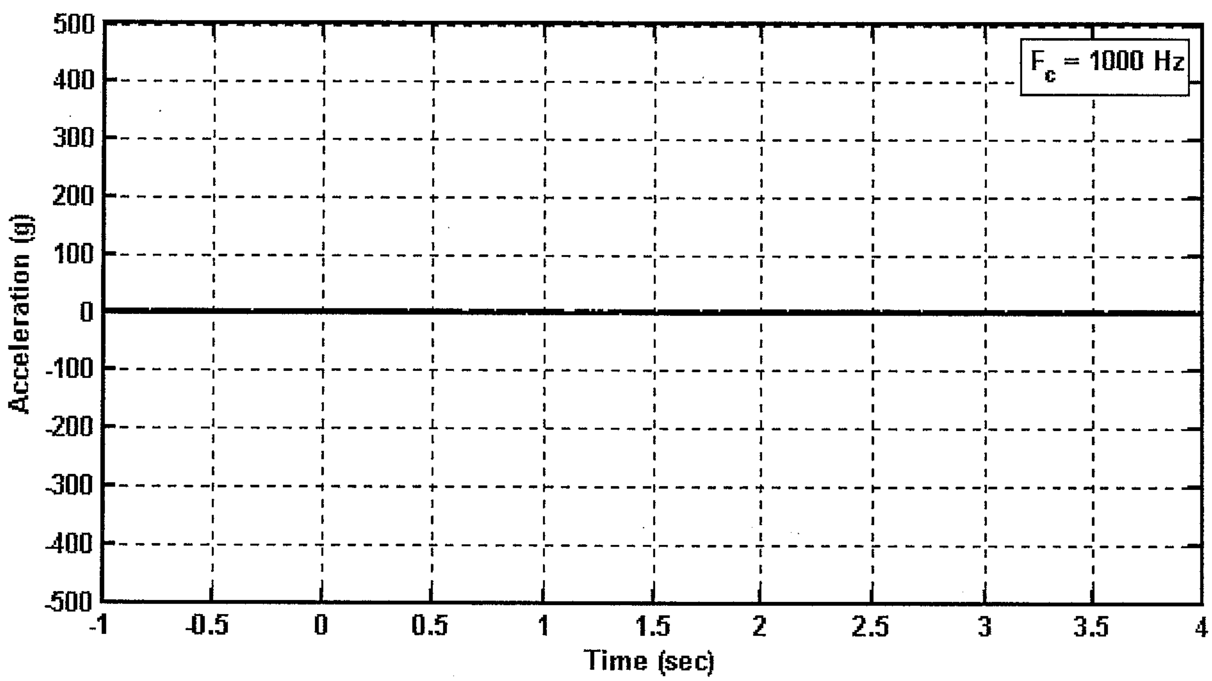


Figure B66. Bullet locomotive, B truck, vertical acceleration
Channel Name: BL_BBZ

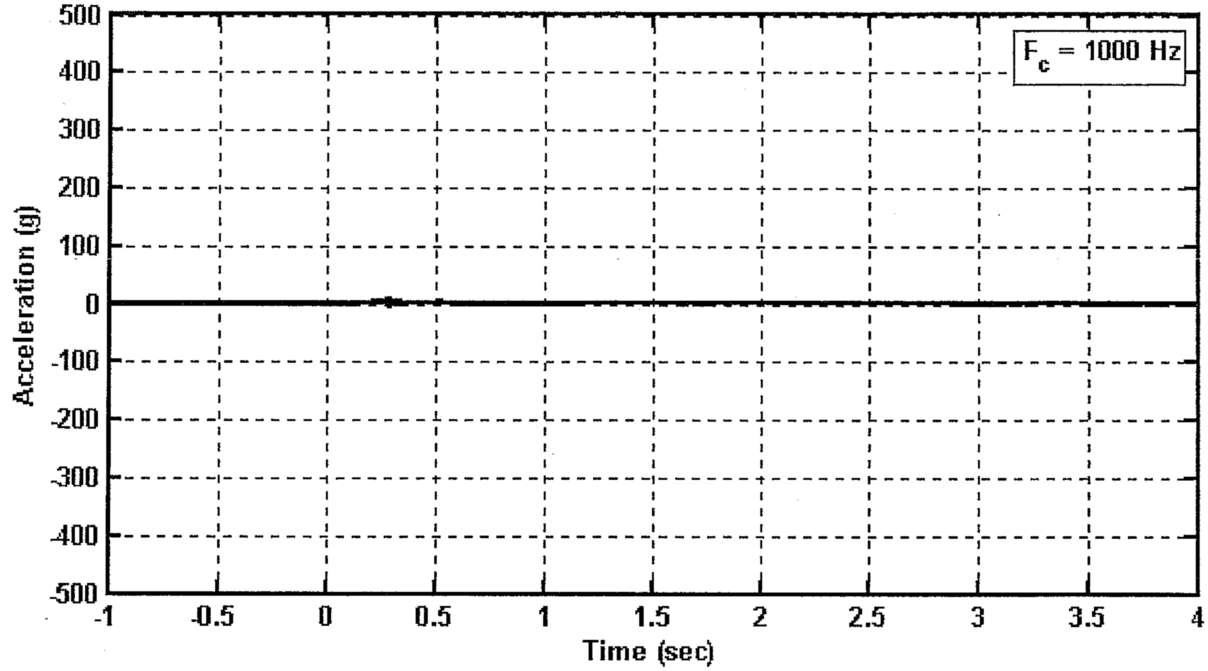


Figure B67. Bullet locomotive, position 1, center sill, longitudinal acceleration
Channel Name: BL_C1X

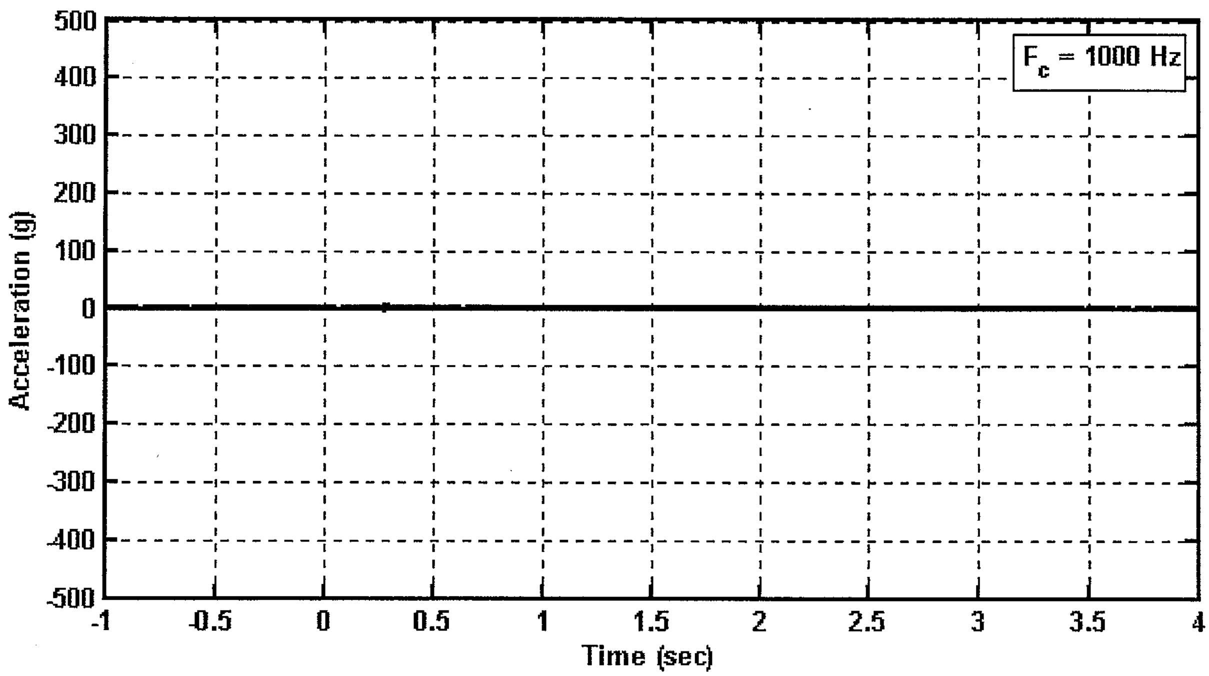


Figure B68. Bullet locomotive, position 1, center sill, lateral acceleration
Channel Name: BL_C1Y

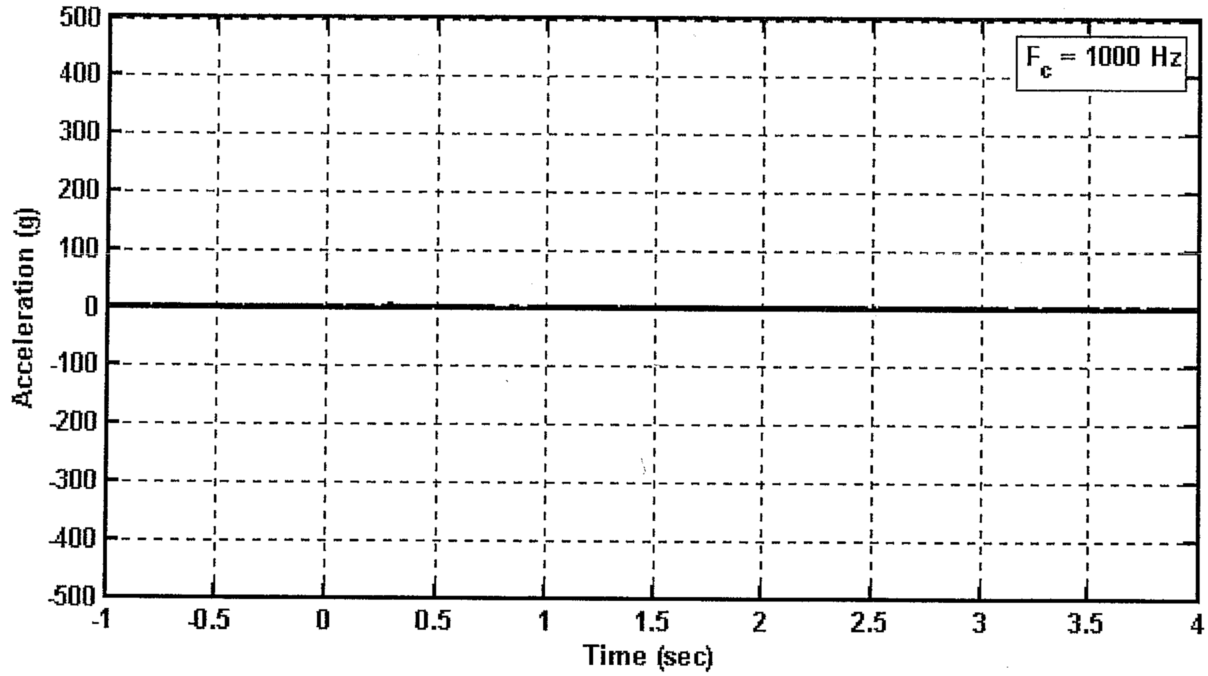


Figure B69. Bullet locomotive, position 1, center sill, vertical acceleration
Channel Name: BL_C1Z

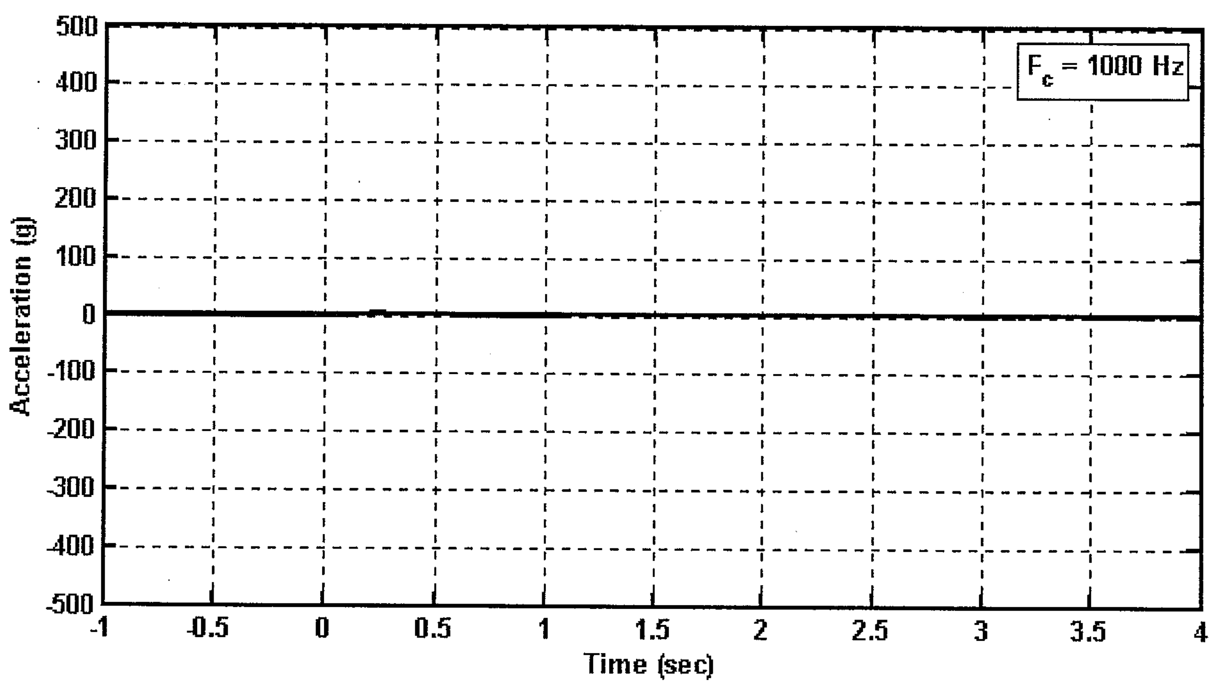


Figure B70. Bullet locomotive, position 2, center sill, longitudinal acceleration
Channel Name: BL_C2X

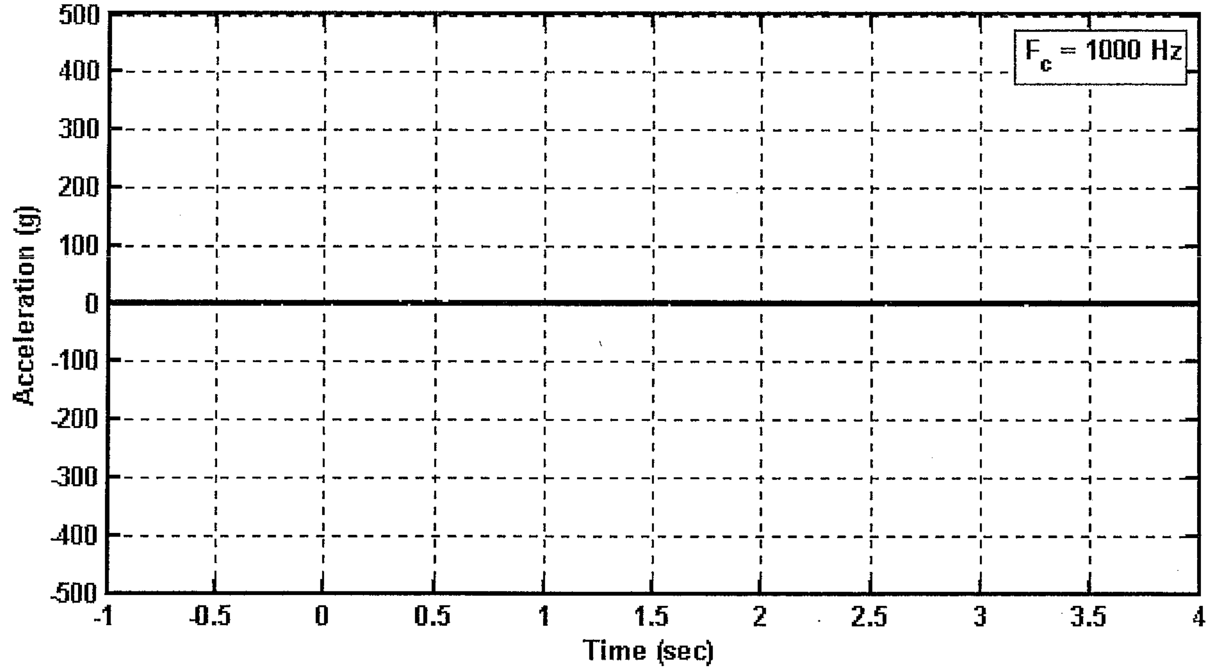


Figure B71. Bullet locomotive, position 2, center sill, lateral acceleration
Channel Name: BL_C2Y

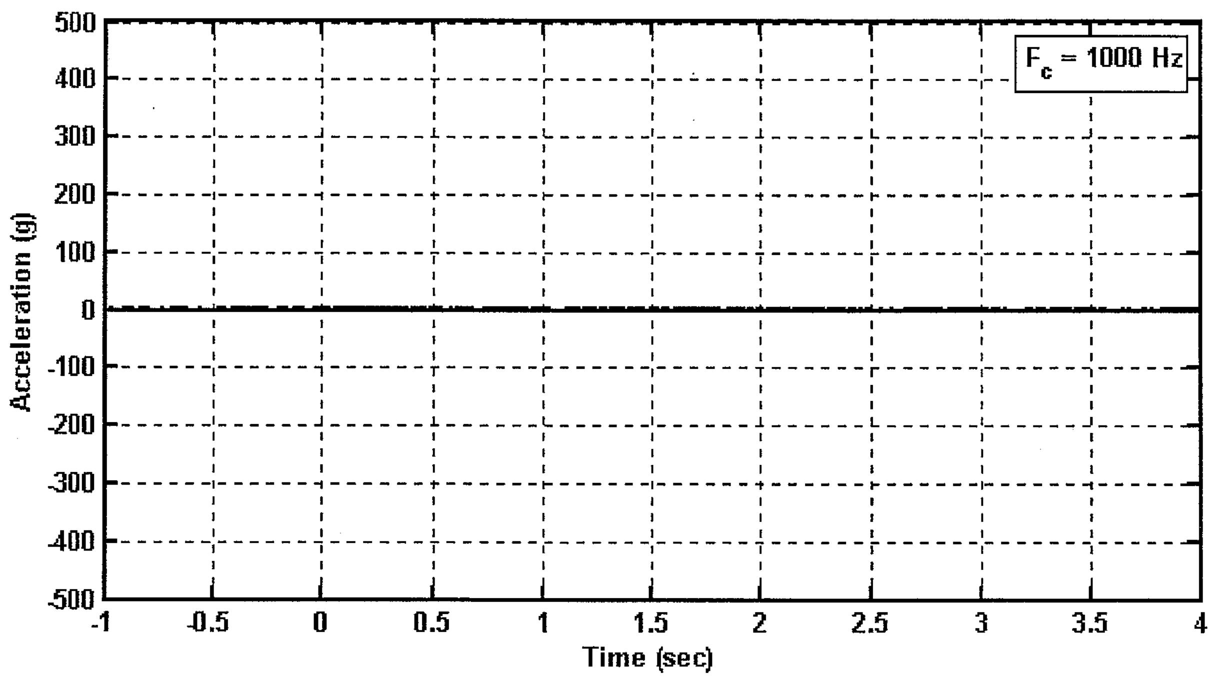


Figure B72. Bullet locomotive, position 2, center sill, vertical acceleration
Channel Name: BL_C2Z

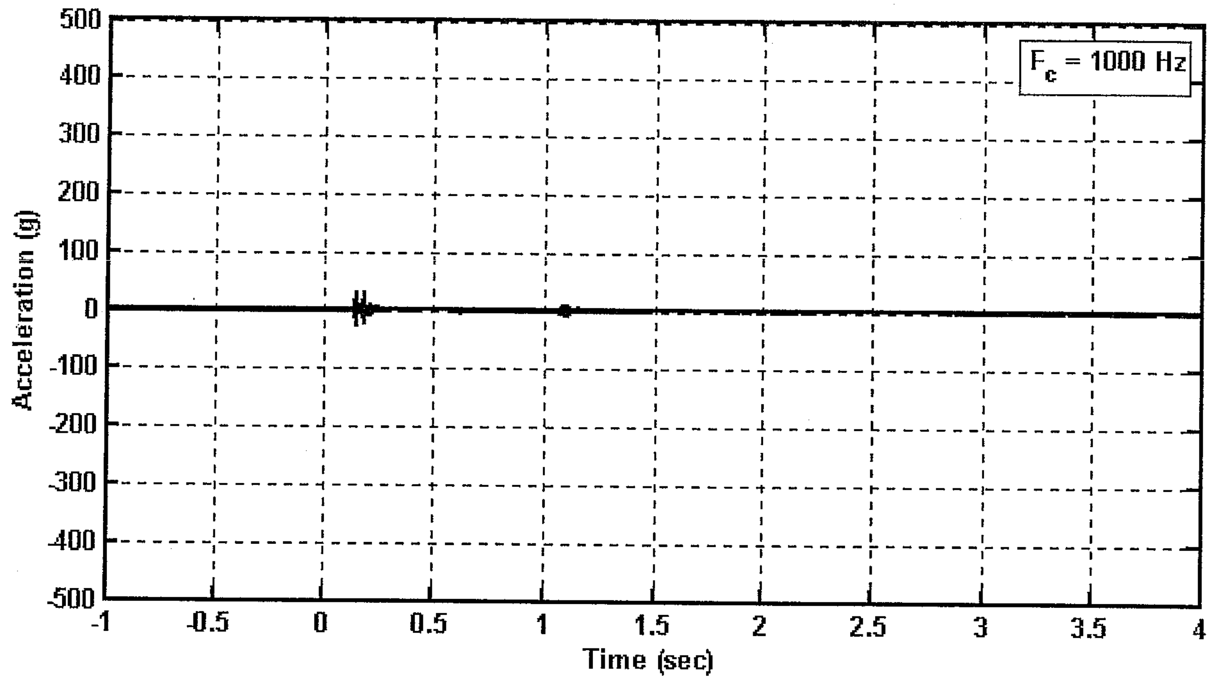


Figure B73. Bullet locomotive, position 3, center sill, longitudinal acceleration
Channel Name: BL_C3X

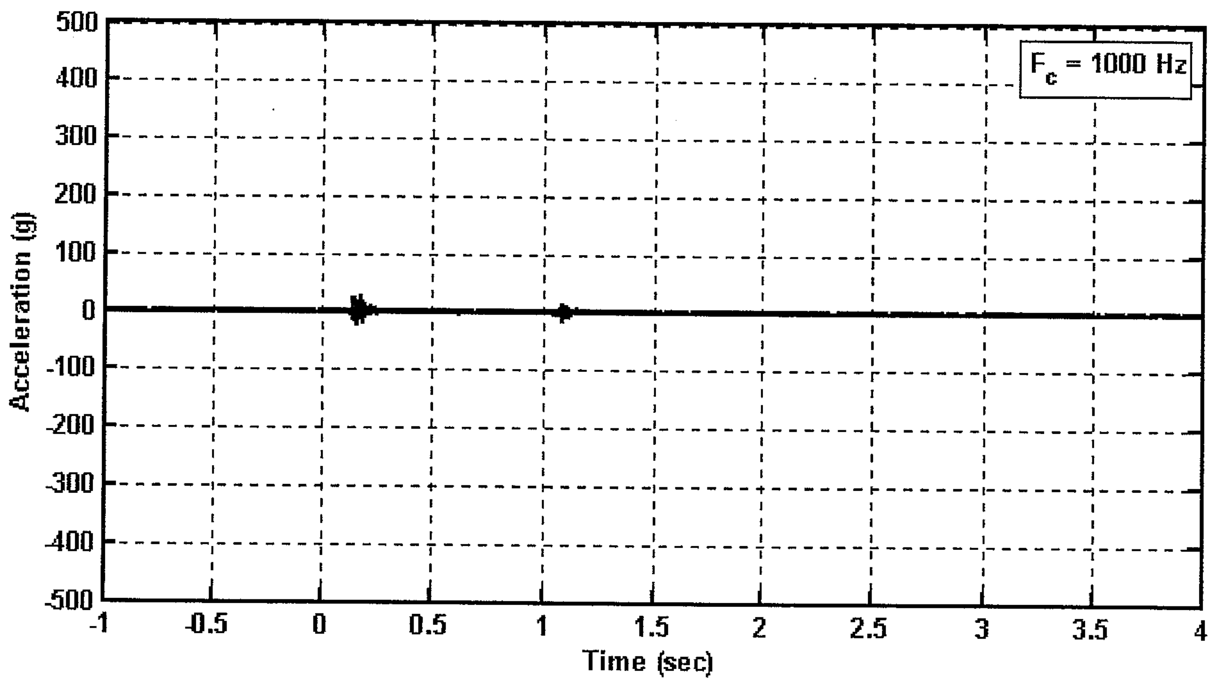


Figure B74. Bullet locomotive, position 3, center sill, lateral acceleration
Channel Name: BL_C3Y

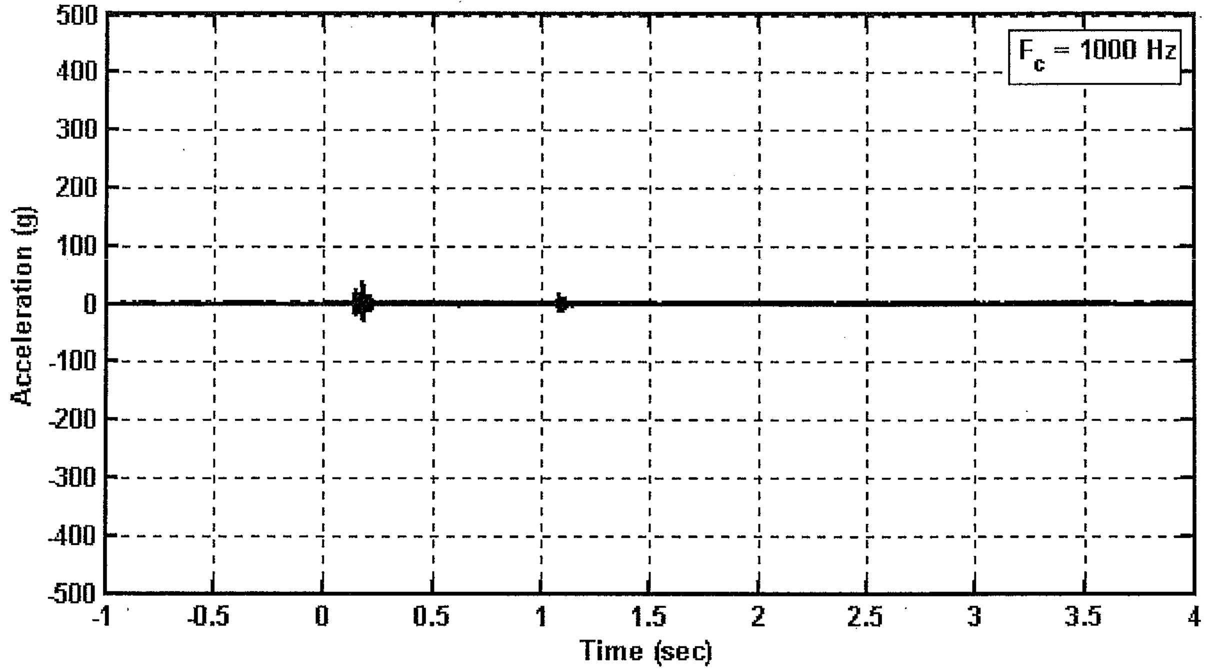


Figure B75. Bullet locomotive, position 3, center sill, vertical acceleration
Channel Name: BL_C3Z

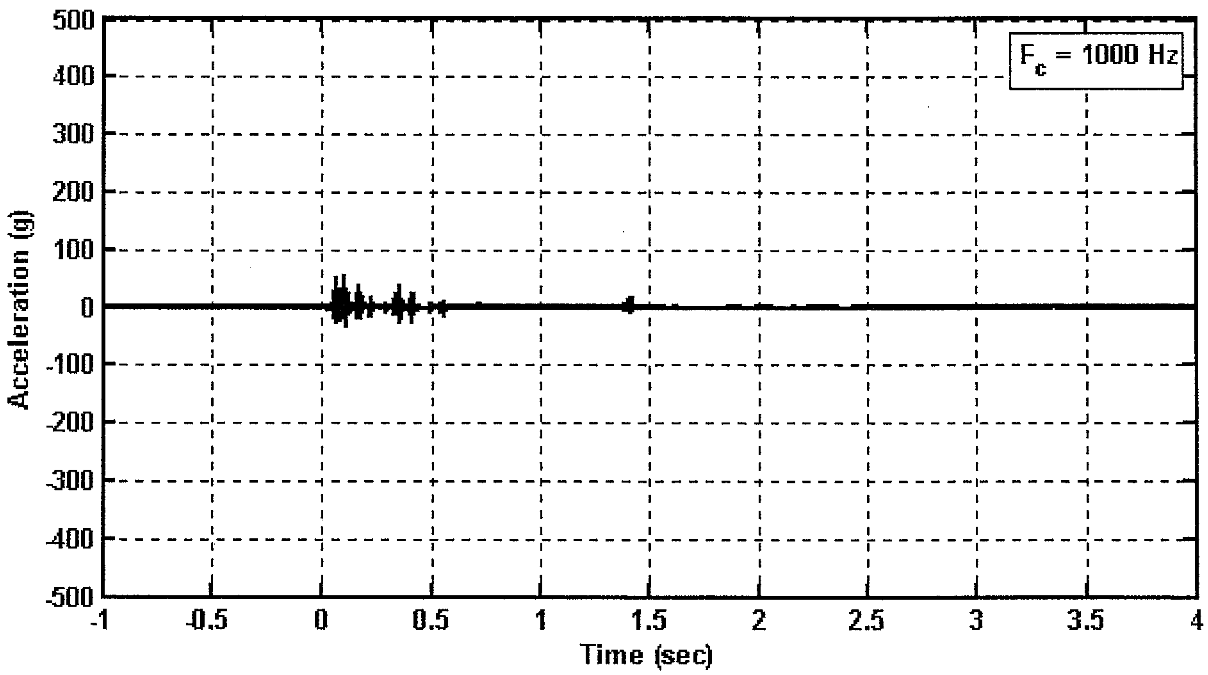


Figure B76. Target car 1, position 1, center sill, longitudinal acceleration
Channel Name: SH1_C1X

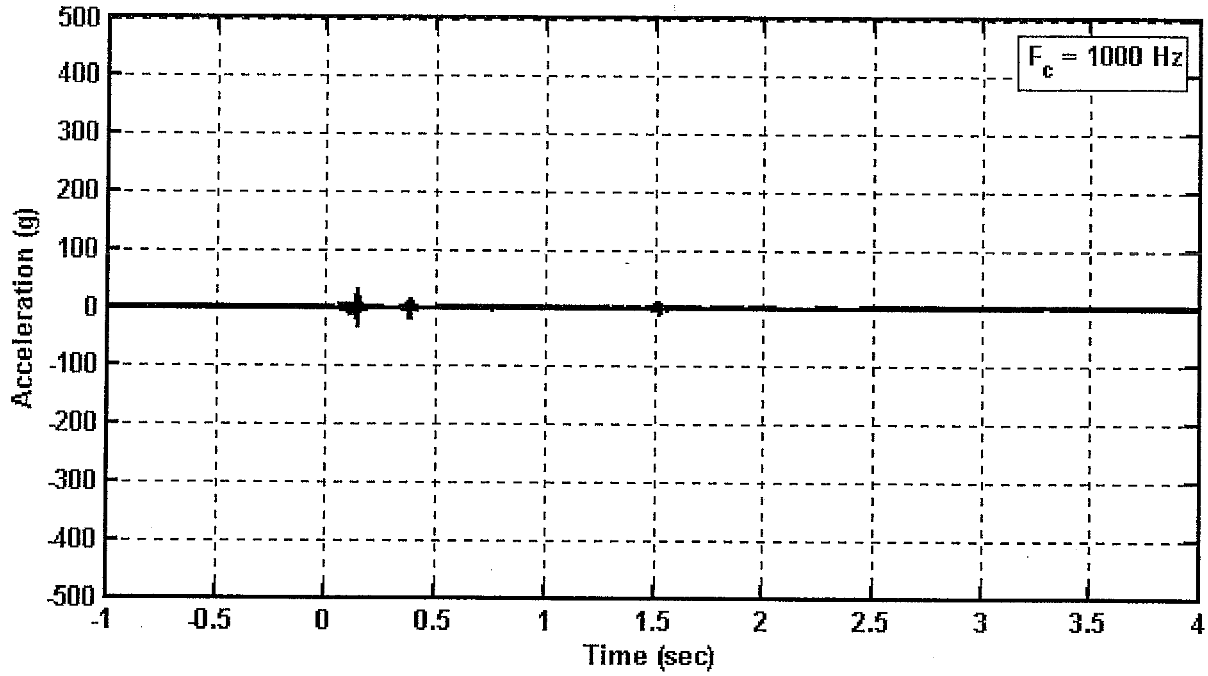


Figure B77. Target car 1, position 2, center sill, longitudinal acceleration
Channel Name: SH1_C2X

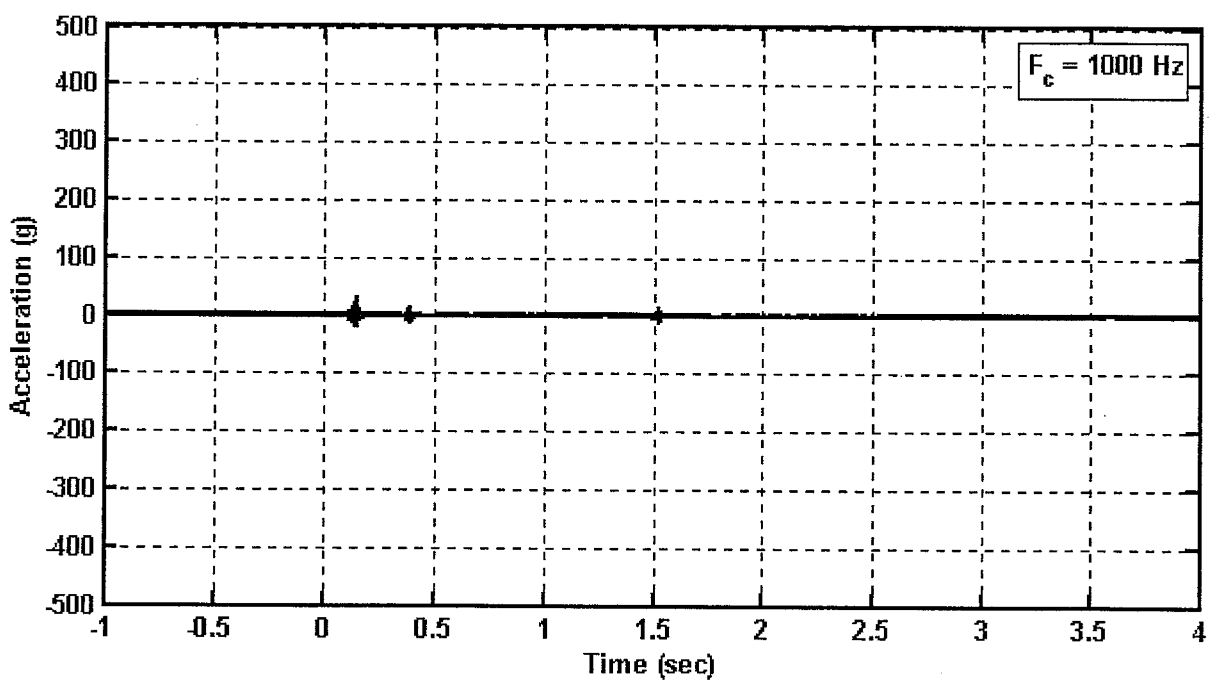


Figure B78. Target car 2, position 1, center sill, longitudinal acceleration
Channel Name: SH2_C1X

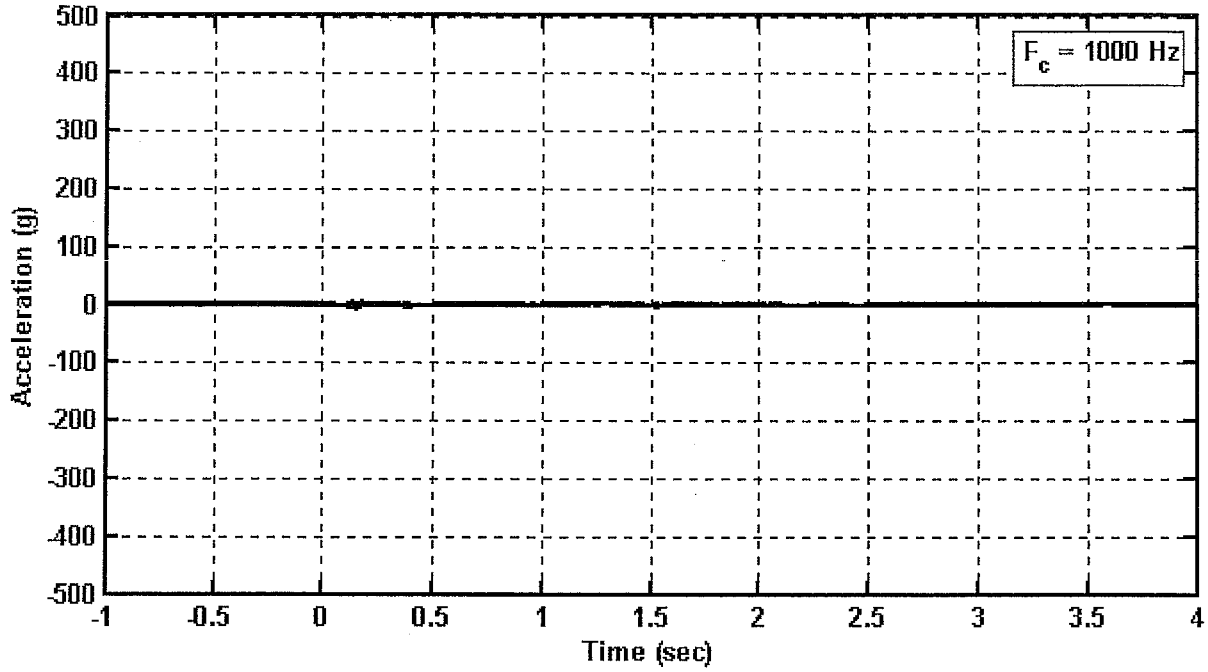


Figure B79. Target car 2, position 2, center sill, longitudinal acceleration
Channel Name: SH2_C2X

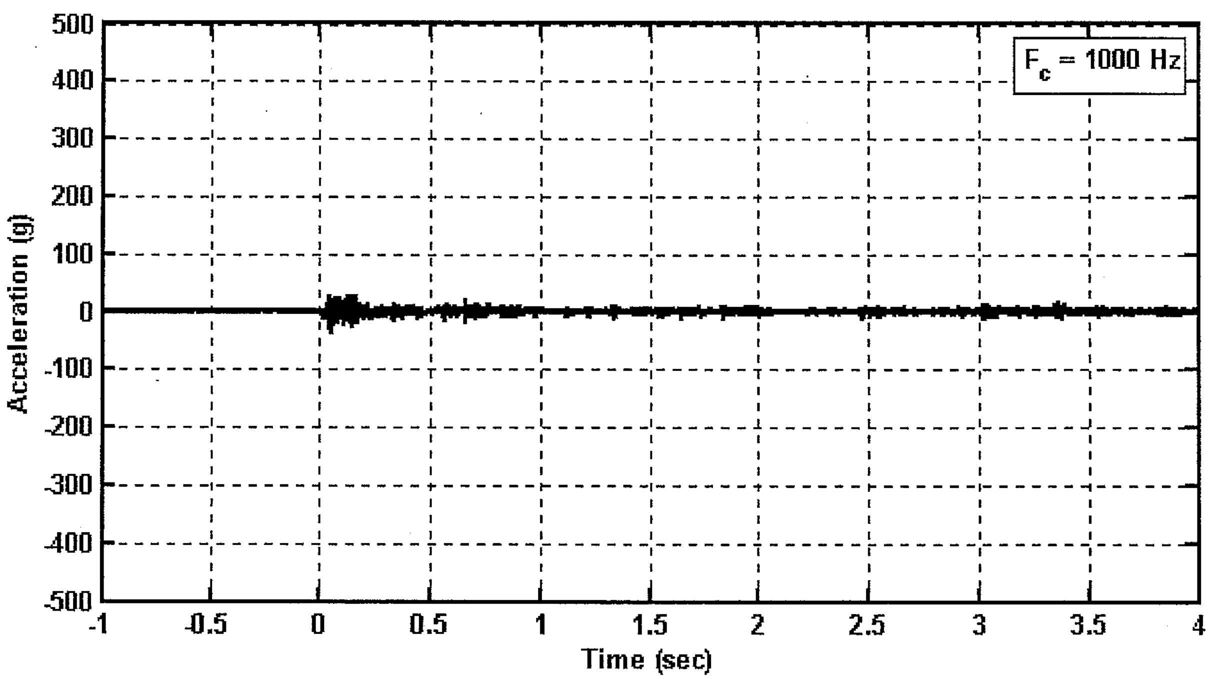


Figure B80. Target locomotive, A truck, longitudinal acceleration
Channel Name: SL_BAX

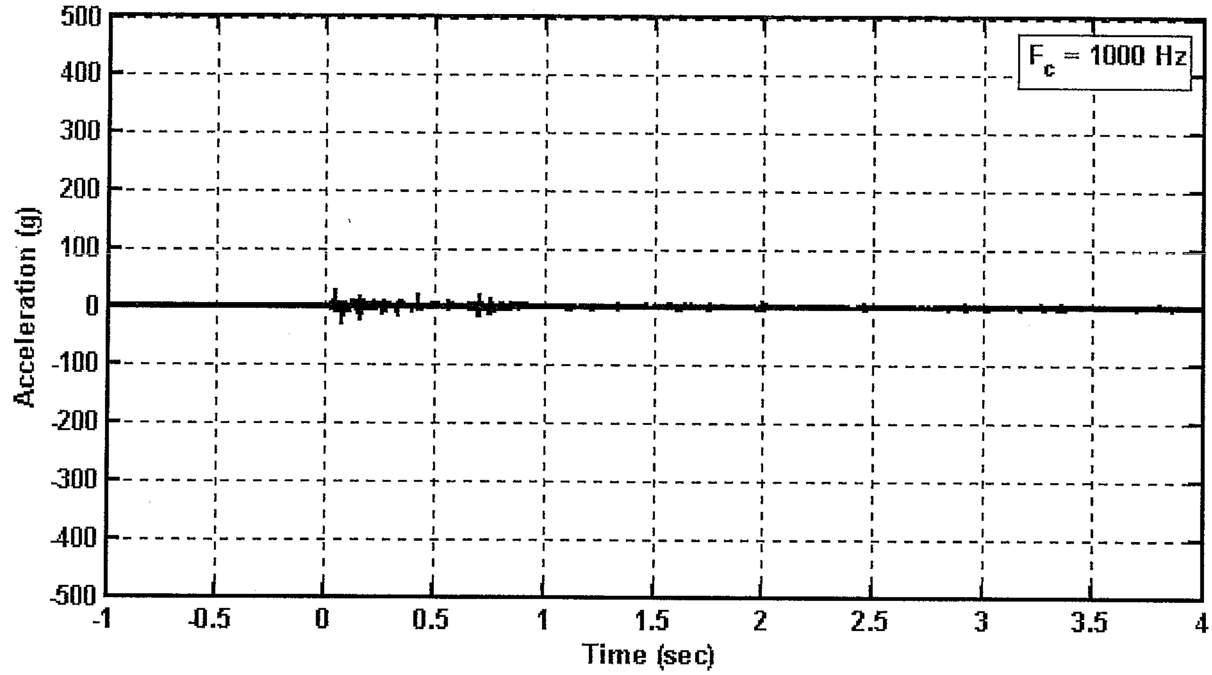


Figure B81. Target locomotive, A truck, lateral acceleration
Channel Name: SL_BAY

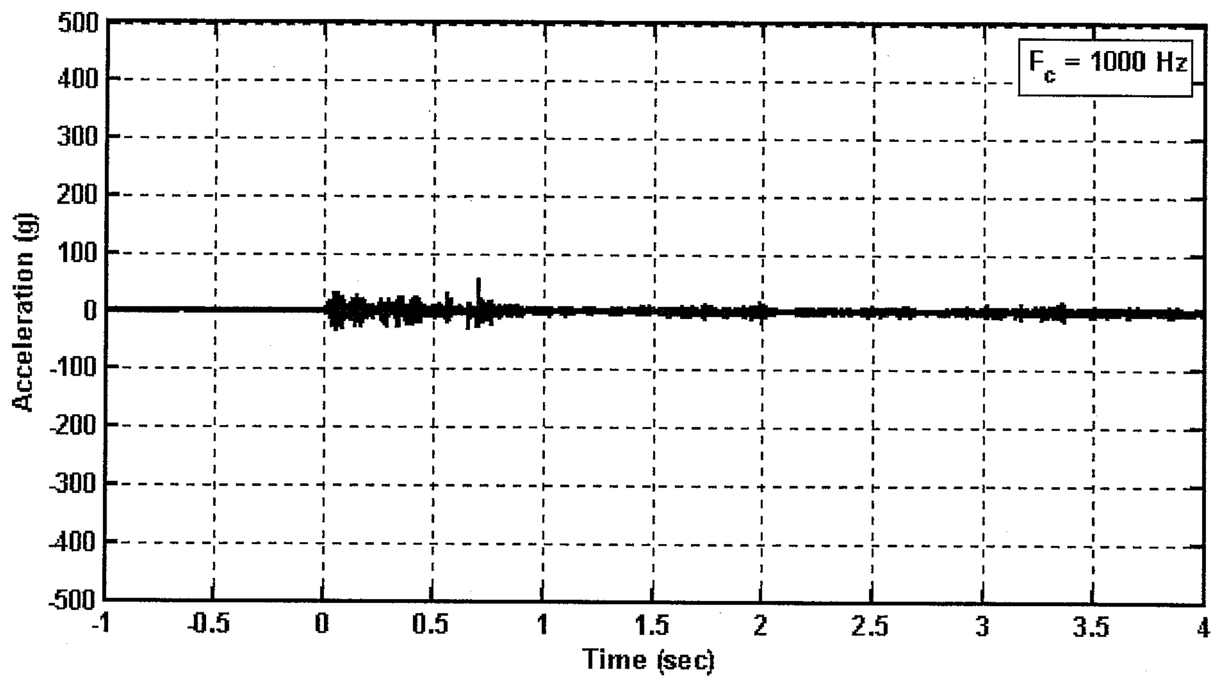


Figure B82. Target locomotive, A truck, vertical acceleration
Channel Name: SL_BAZ

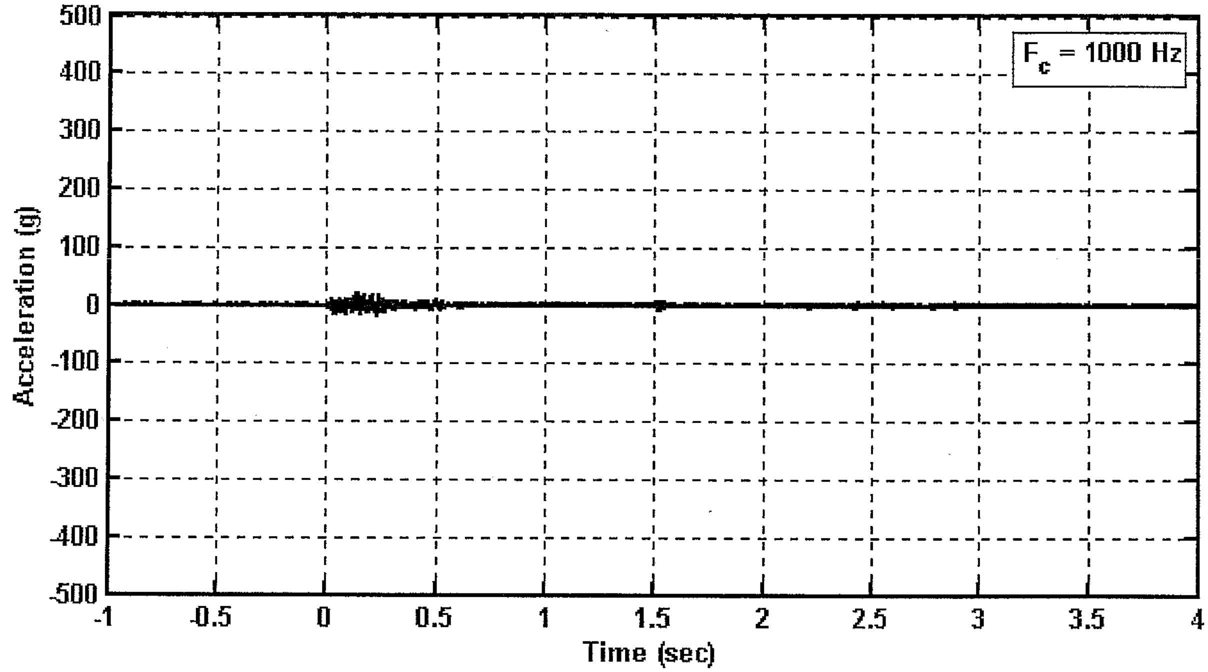


Figure B83. Target locomotive, B truck, longitudinal acceleration
Channel Name: SL_BBX

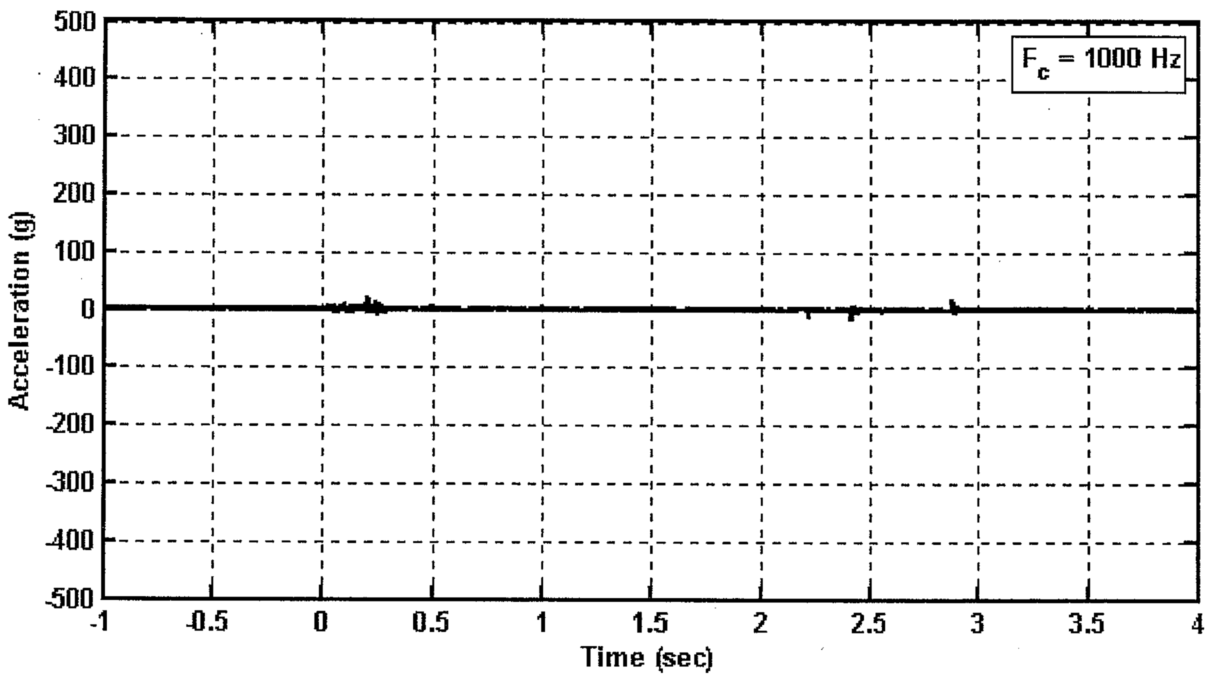


Figure B84. Target locomotive, B truck, lateral acceleration
Channel Name: SL_BBY

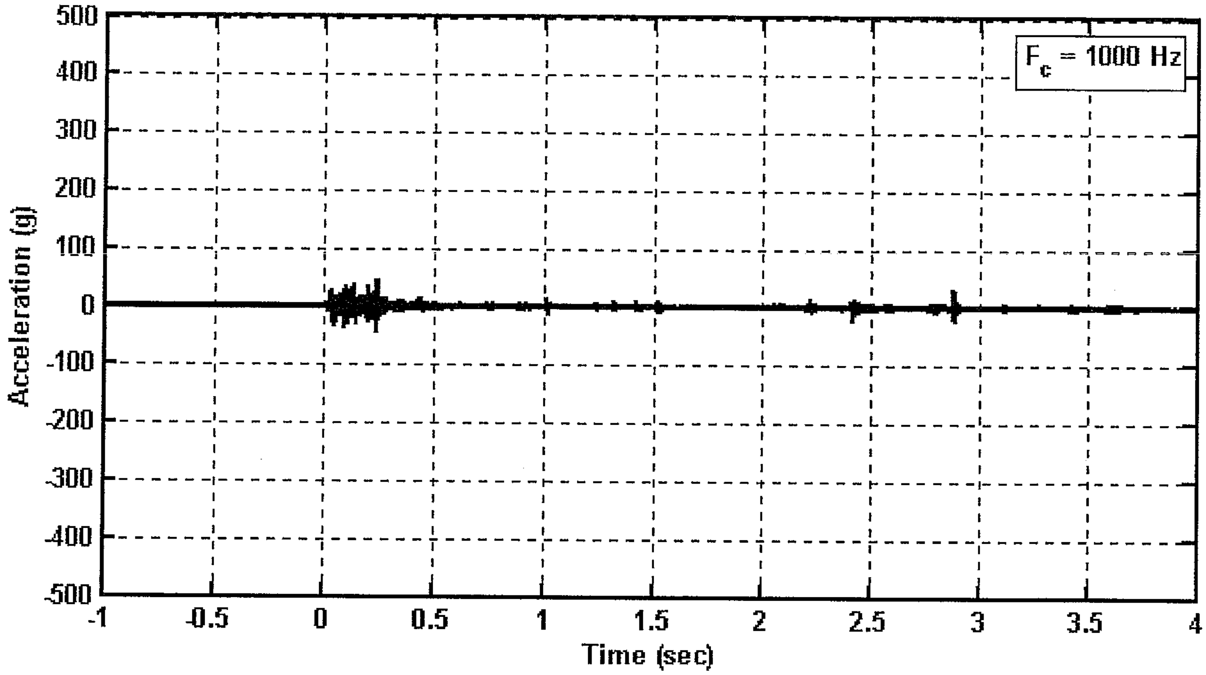


Figure B85. Target locomotive, B truck, vertical acceleration
Channel Name: SL_BBZ

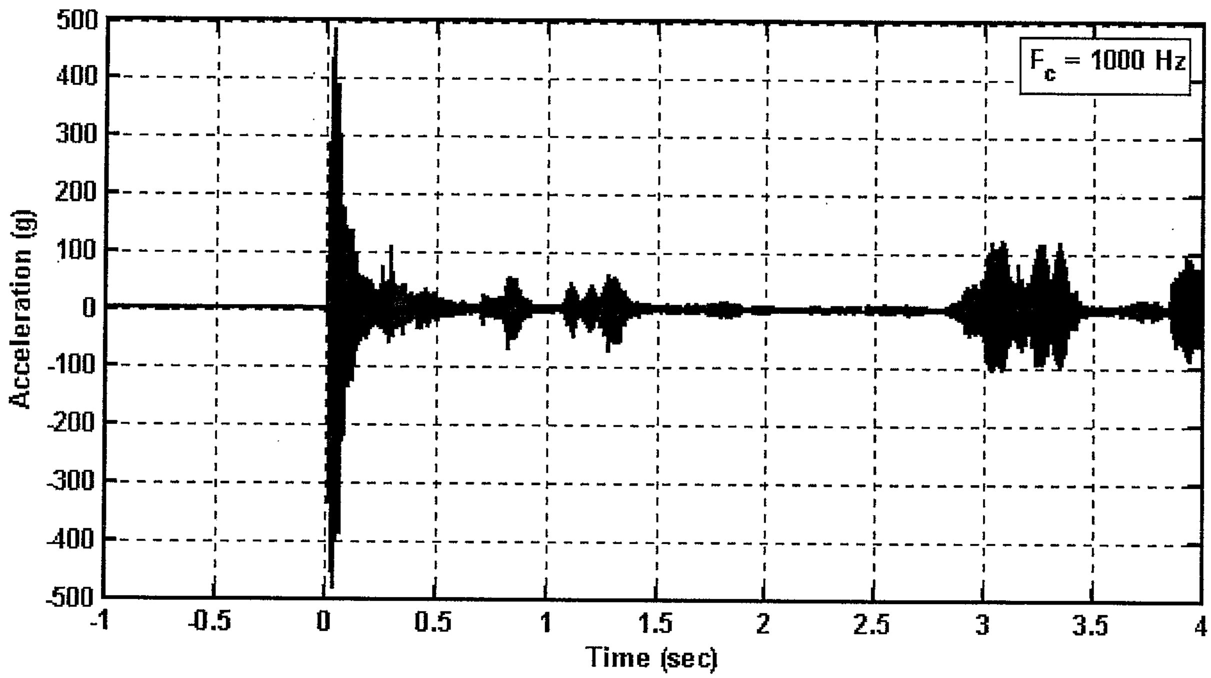


Figure B86. Target locomotive, position 1, center sill, longitudinal acceleration
Channel Name: SL_C1X

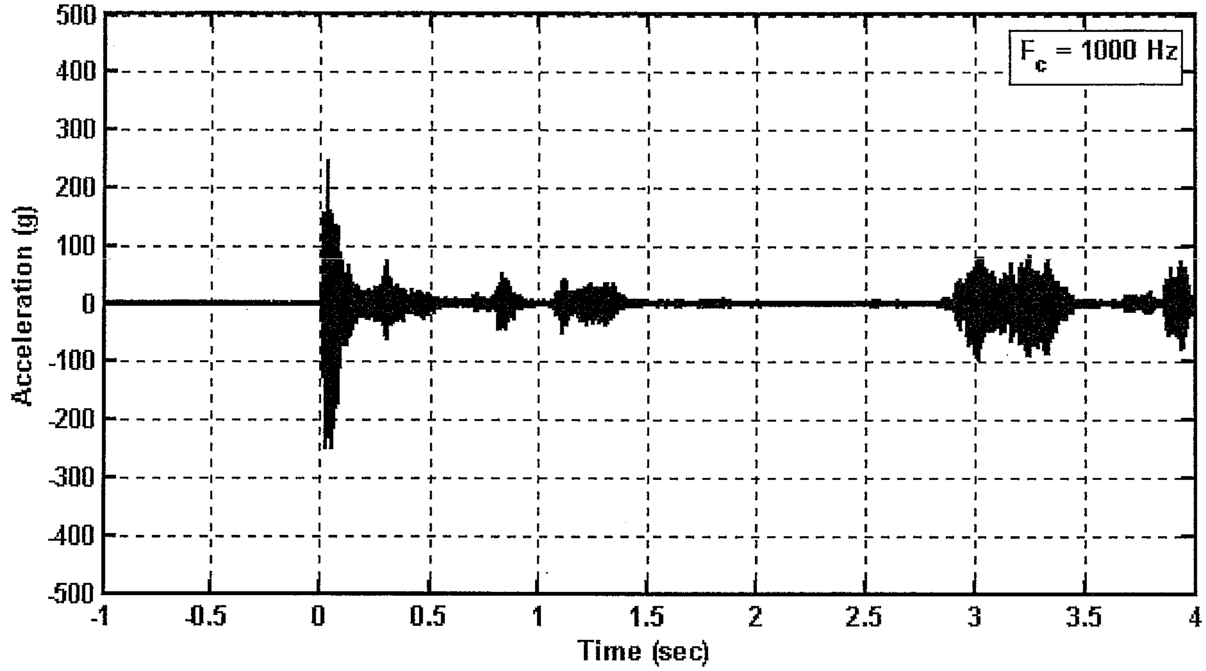


Figure B87. Target locomotive, position 1, center sill, lateral acceleration
Channel Name: SL_C1Y

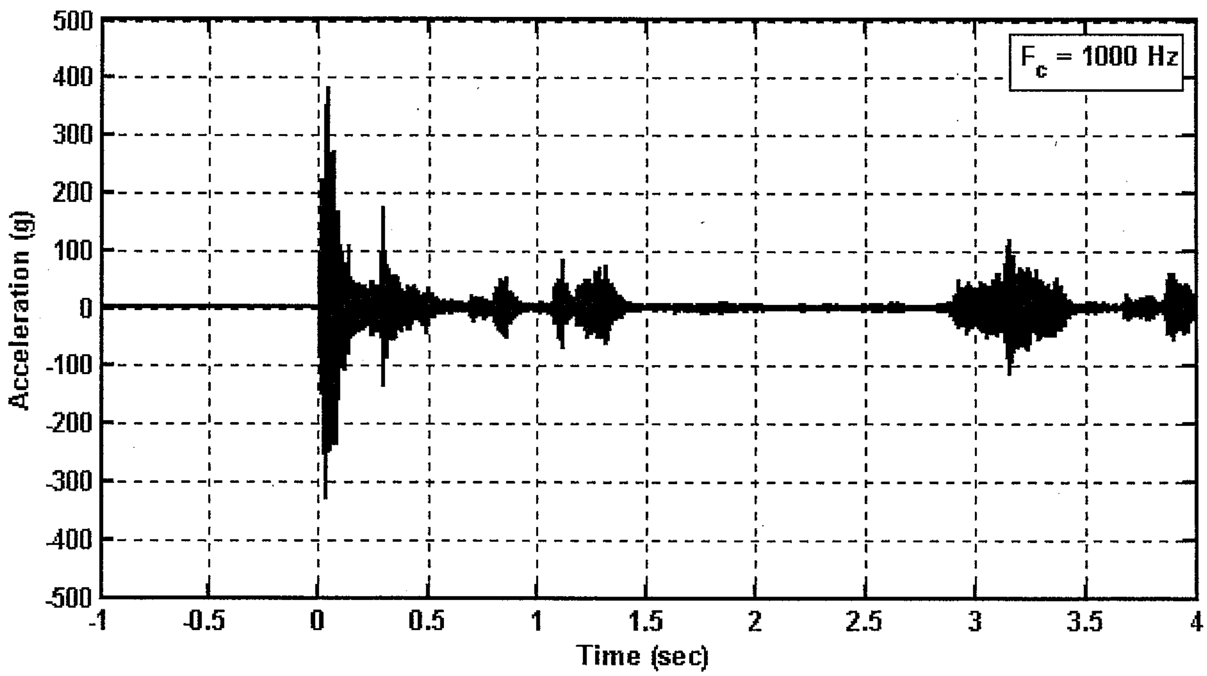


Figure B88. Target locomotive, position 1, center sill, vertical acceleration
Channel Name: SL_C1Z

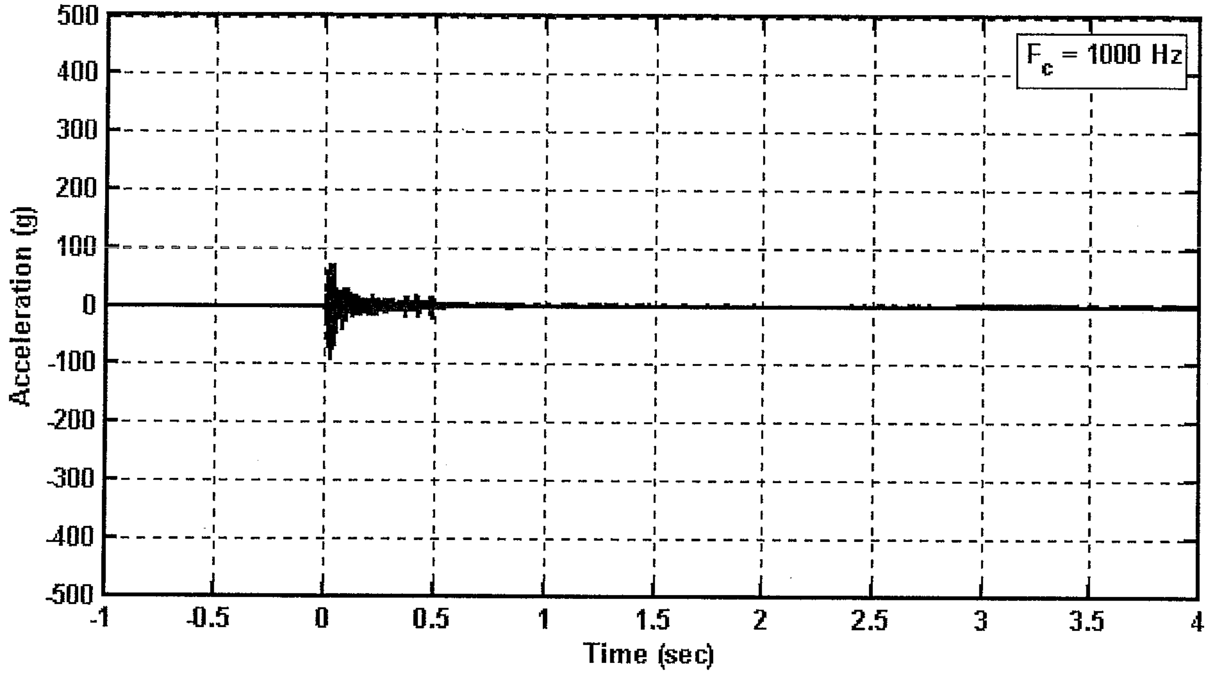


Figure B89. Target locomotive, position 2, center sill, longitudinal acceleration
Channel Name: SL_C2X

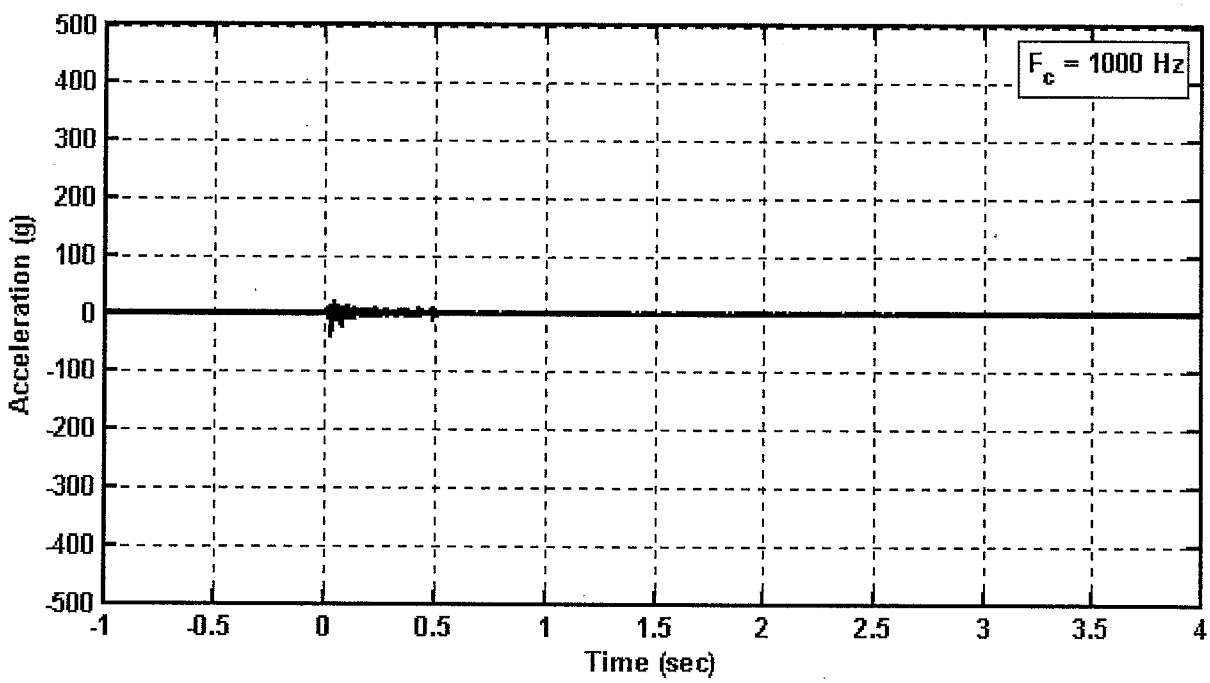


Figure B90. Target locomotive, position 2, center sill, lateral acceleration
Channel Name: SL_C2Y

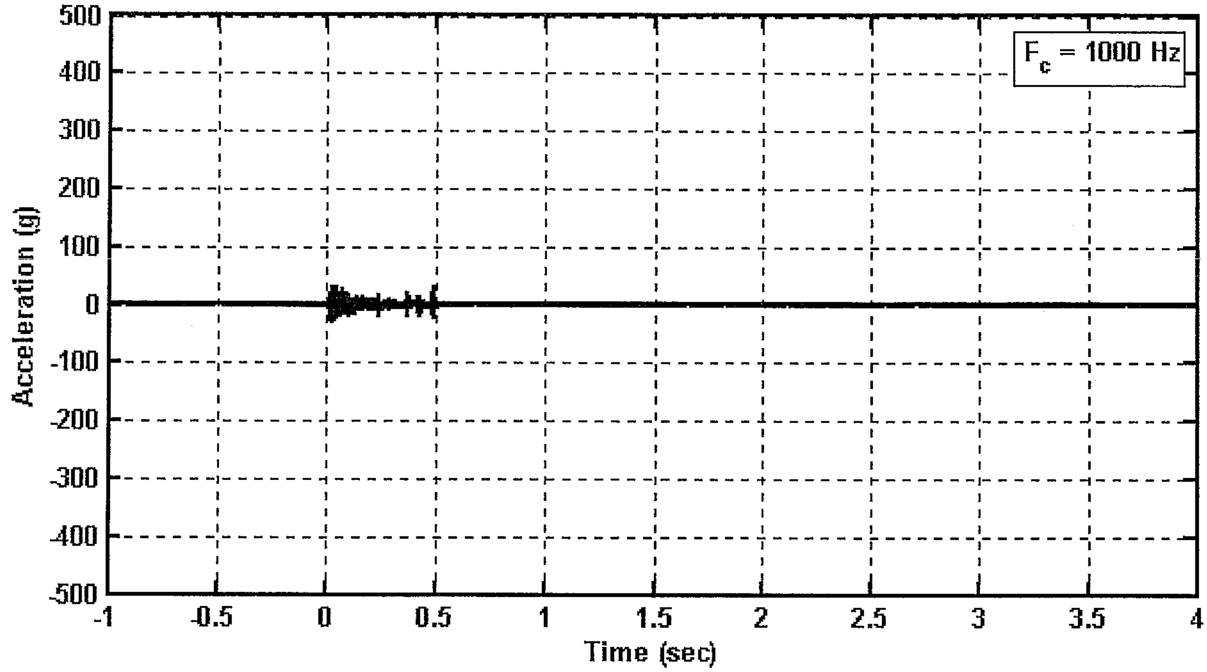


Figure B91. Target locomotive, position 2, center sill, vertical acceleration
Channel Name: SL_C2Z

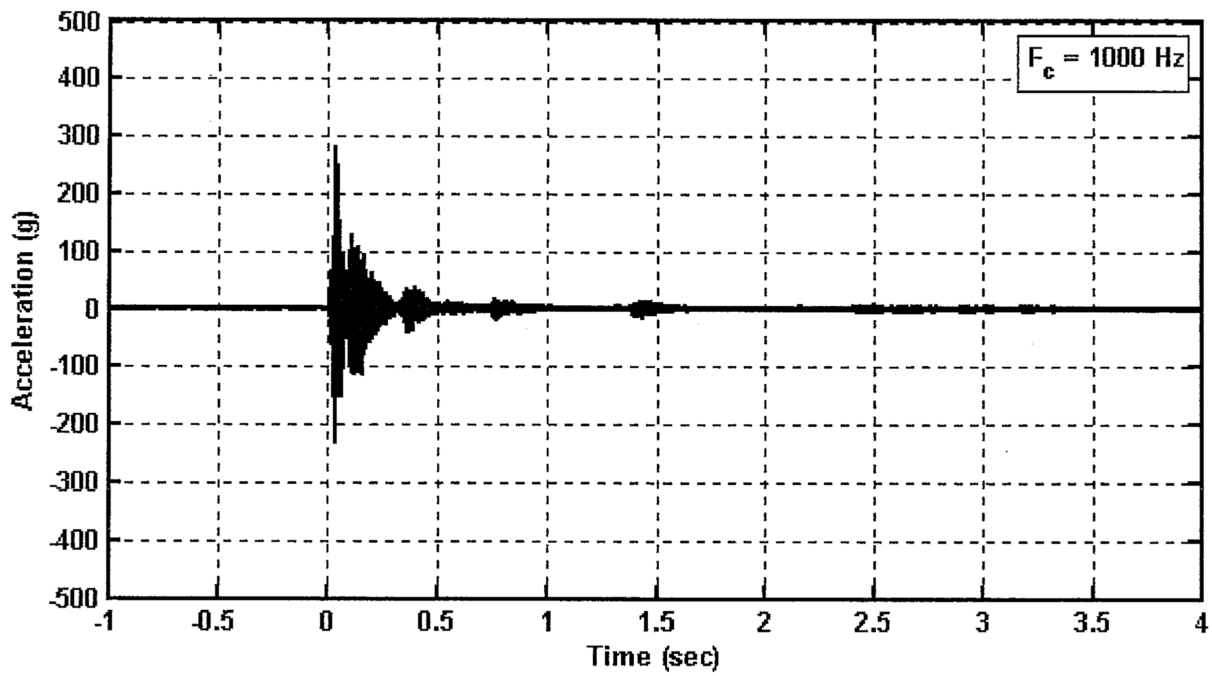


Figure B92. Target locomotive, position 3, center sill, longitudinal acceleration
Channel Name: SL_C3X

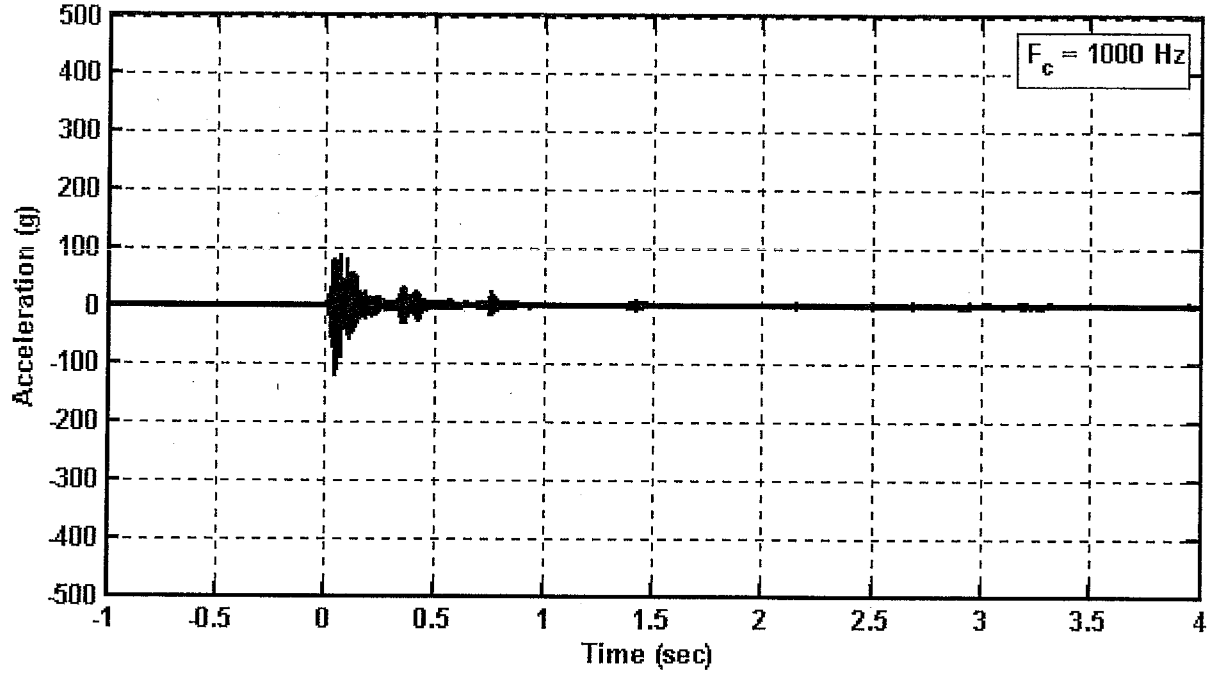


Figure B93. Target locomotive, position 3, center sill, lateral acceleration
Channel Name: SL_C3Y

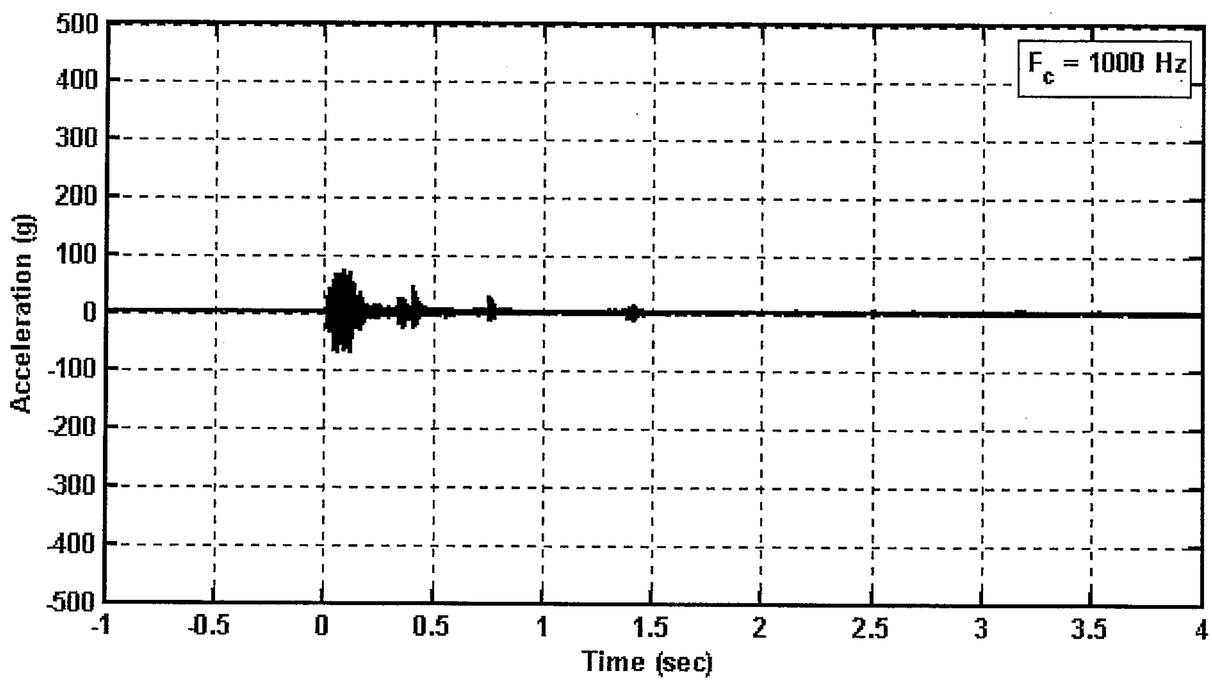


Figure B94. Target locomotive, position 3, center sill, vertical acceleration
Channel Name: SL_C3Z

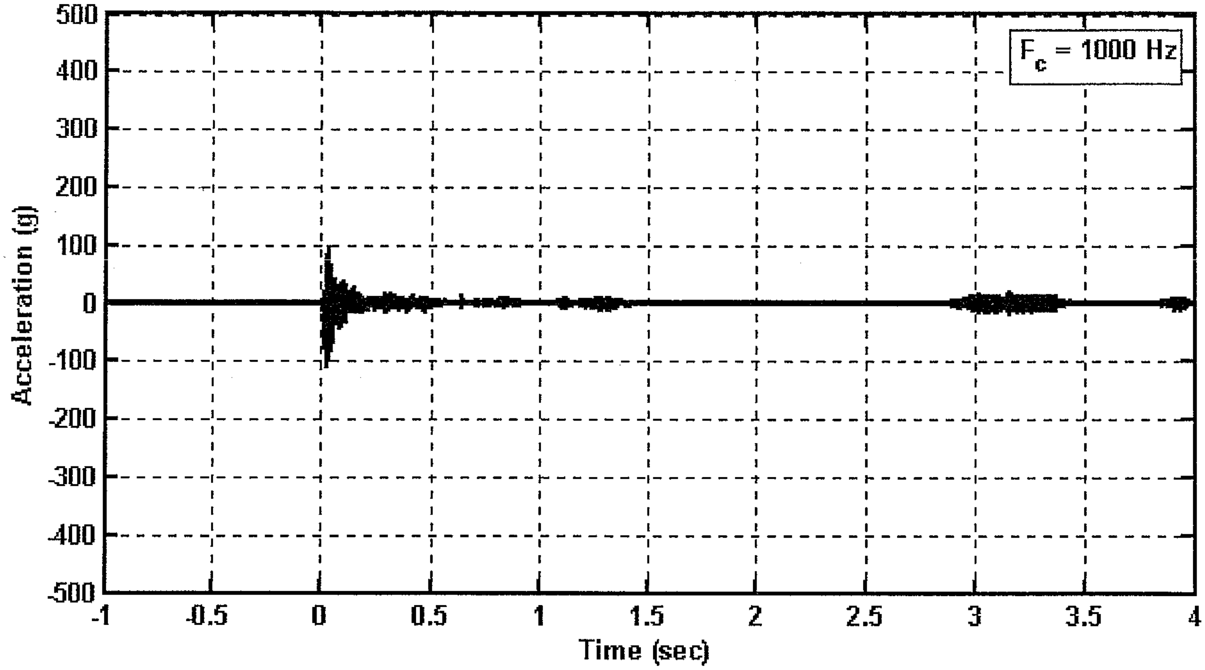


Figure B95. Target locomotive, position 3, cab floor, longitudinal acceleration
Channel Name: SL_F1X

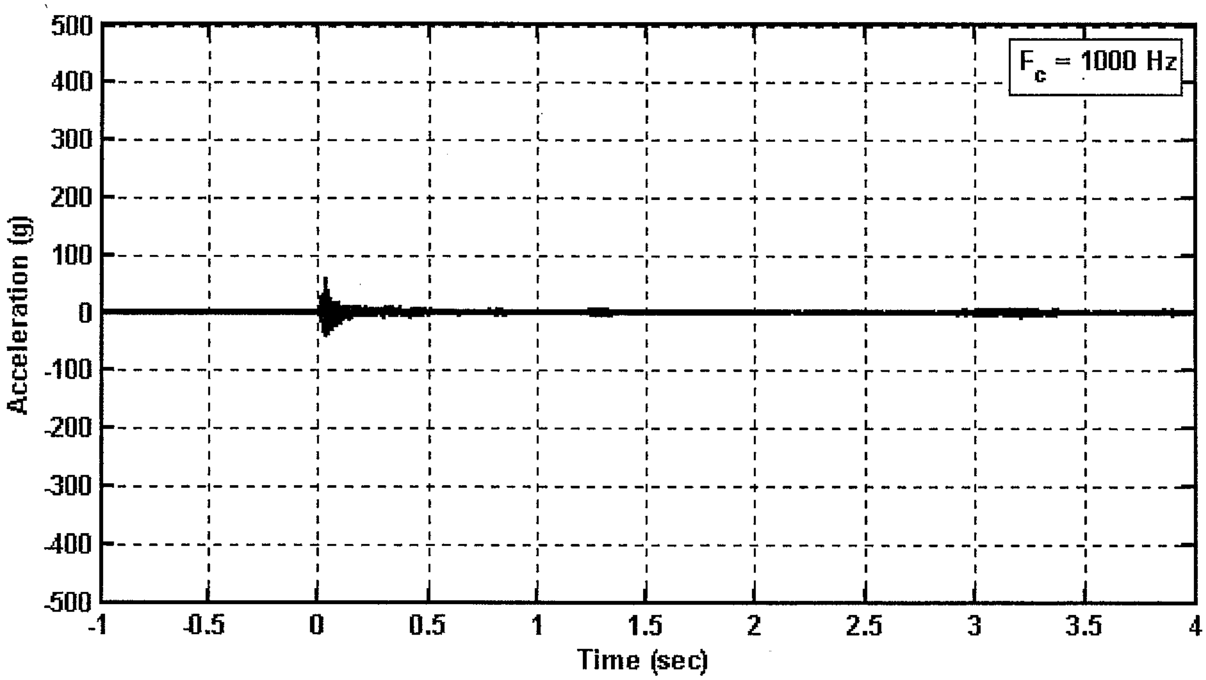


Figure B96. Target locomotive, position 3, cab floor, lateral acceleration
Channel Name: SL_F1Y

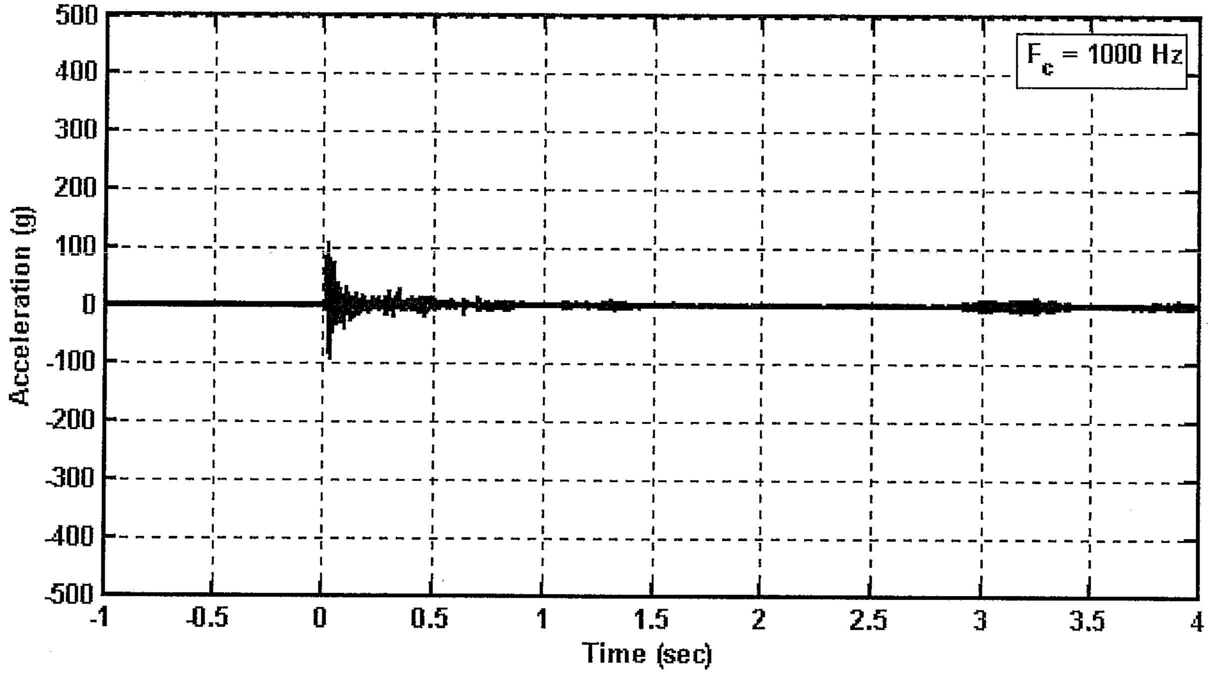


Figure B97. Target locomotive, position 3, cab floor, vertical acceleration
Channel Name: SL_F1Z

APPENDIX C

Acceleration Data, Fc = 100 Hz

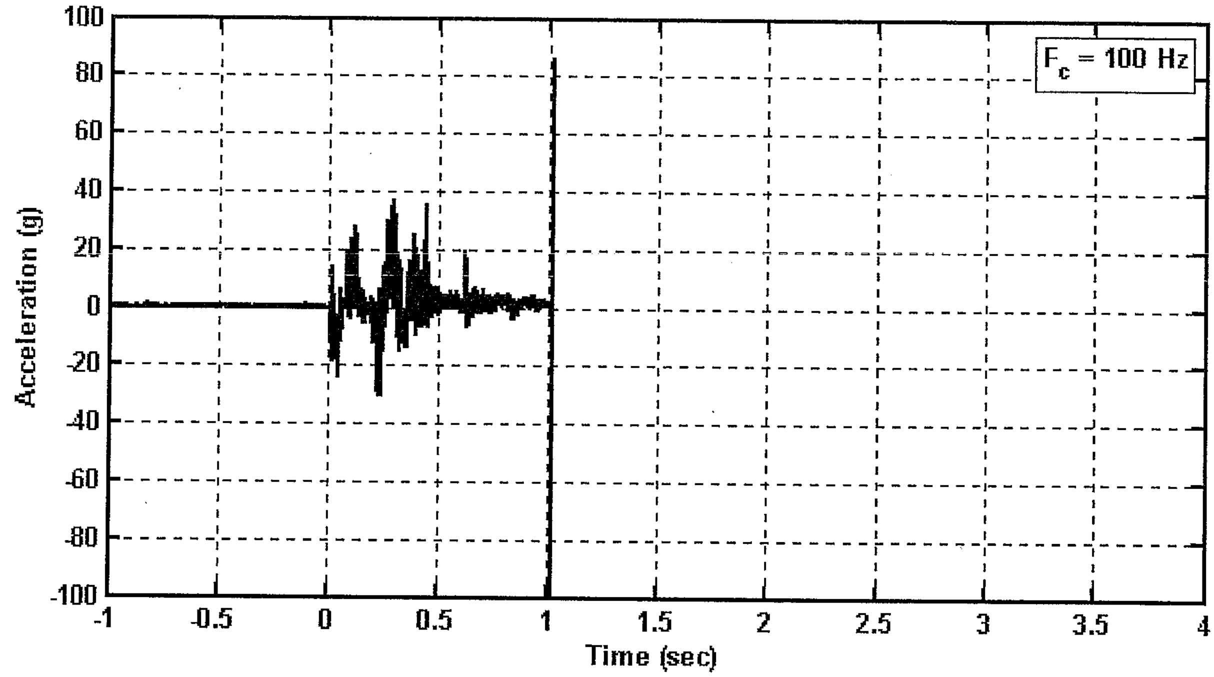


Figure C1. Bullet car 1, A truck, longitudinal acceleration
Channel Name: B1_BAX

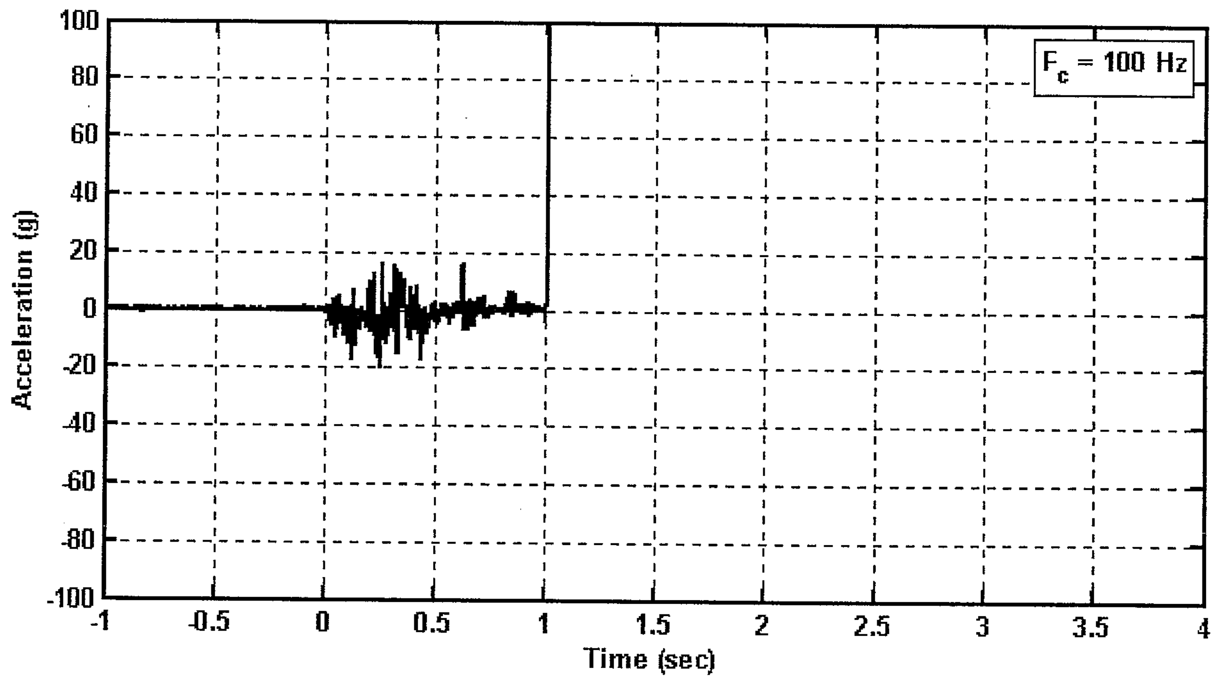


Figure C2. Bullet car 1, A truck, lateral acceleration
Channel Name: B1_BAY

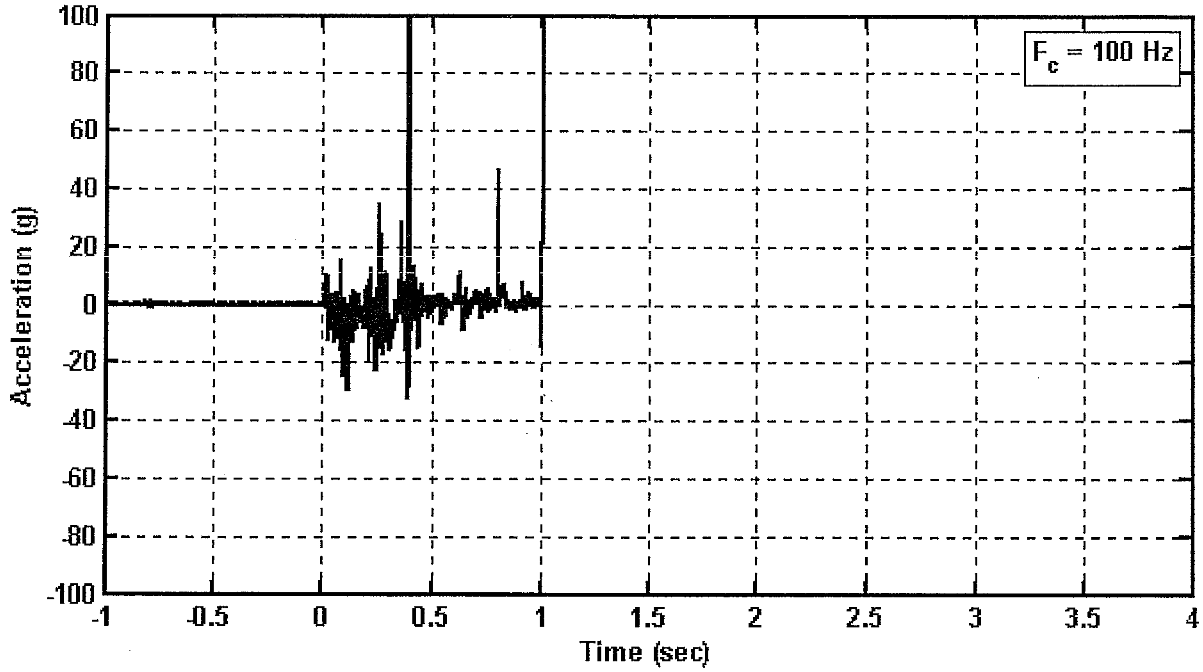


Figure C3. Bullet car 1, A truck, vertical acceleration
Channel Name: B1_BAZ

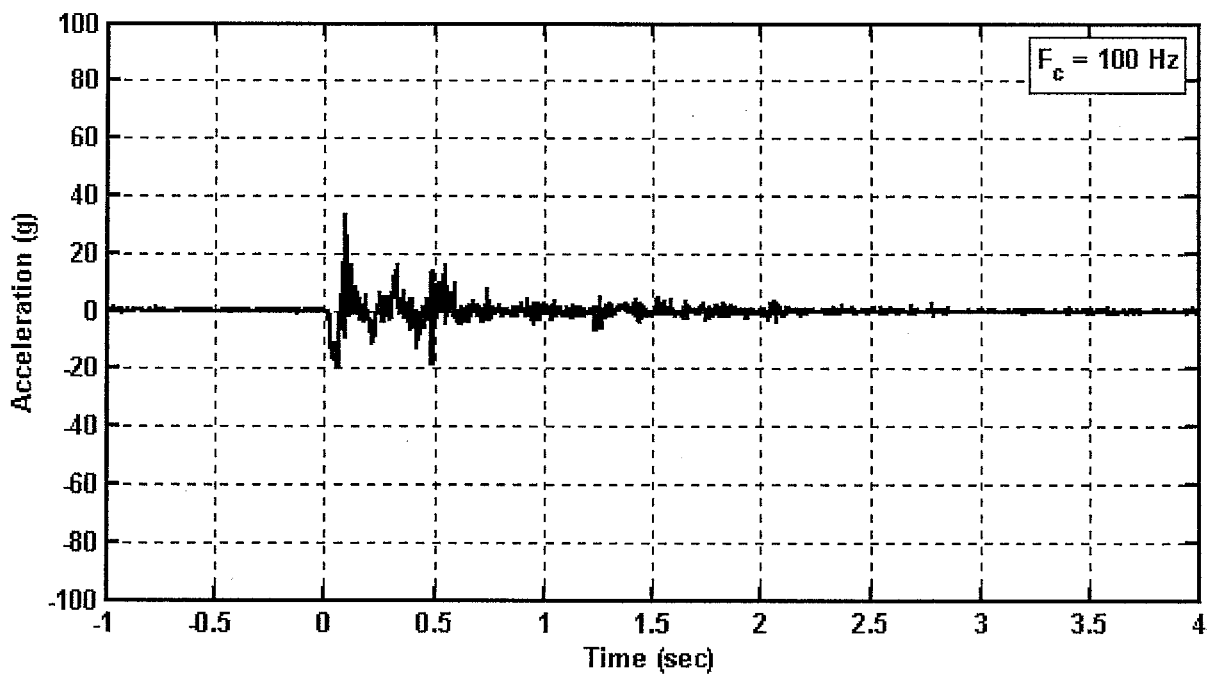


Figure C4. Bullet car 1, B truck, longitudinal acceleration
Channel Name: B1_BBX

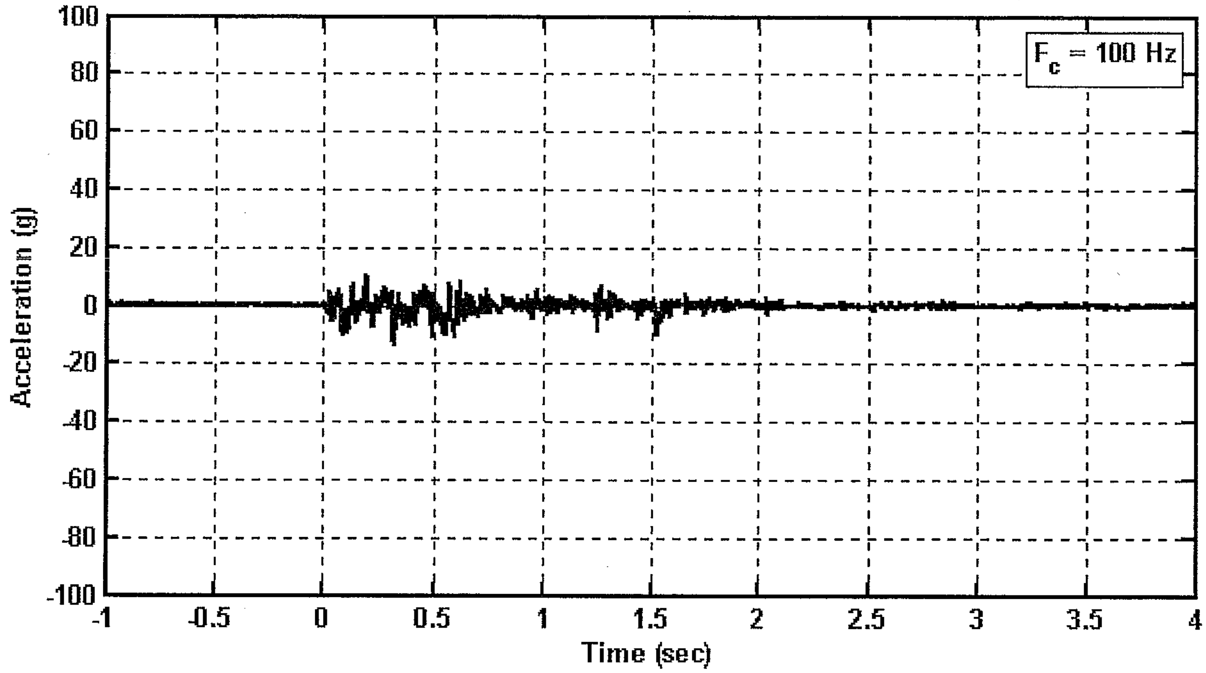


Figure C5. Bullet car 1, B truck, lateral acceleration
Channel Name: B1_BBY

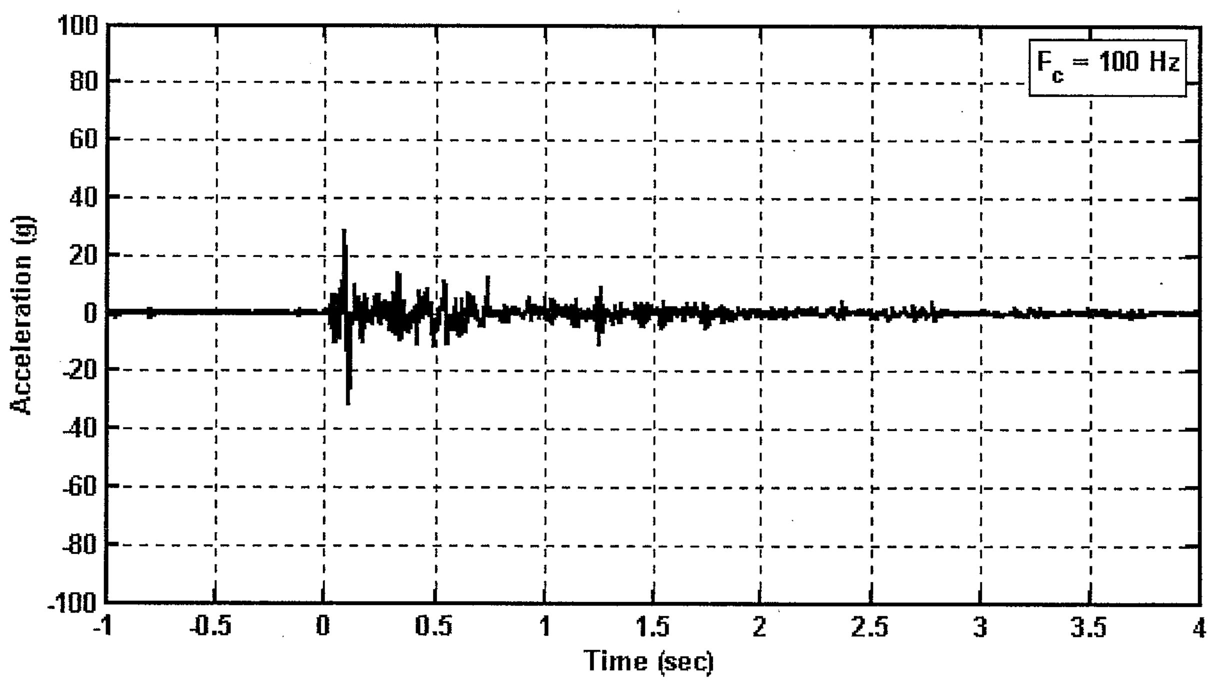


Figure C6. Bullet car 1, B truck, vertical acceleration
Channel Name: B1_BBZ

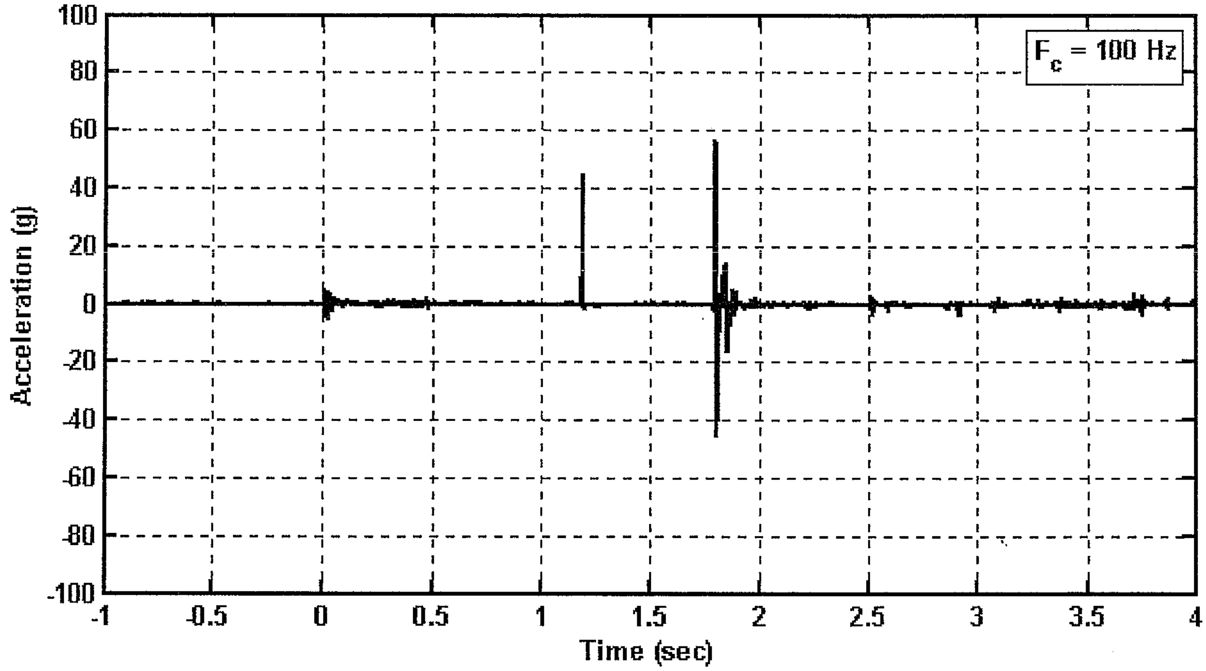


Figure C7. Bullet car 1, position 2, center sill, longitudinal acceleration
Channel Name: B1_C2X

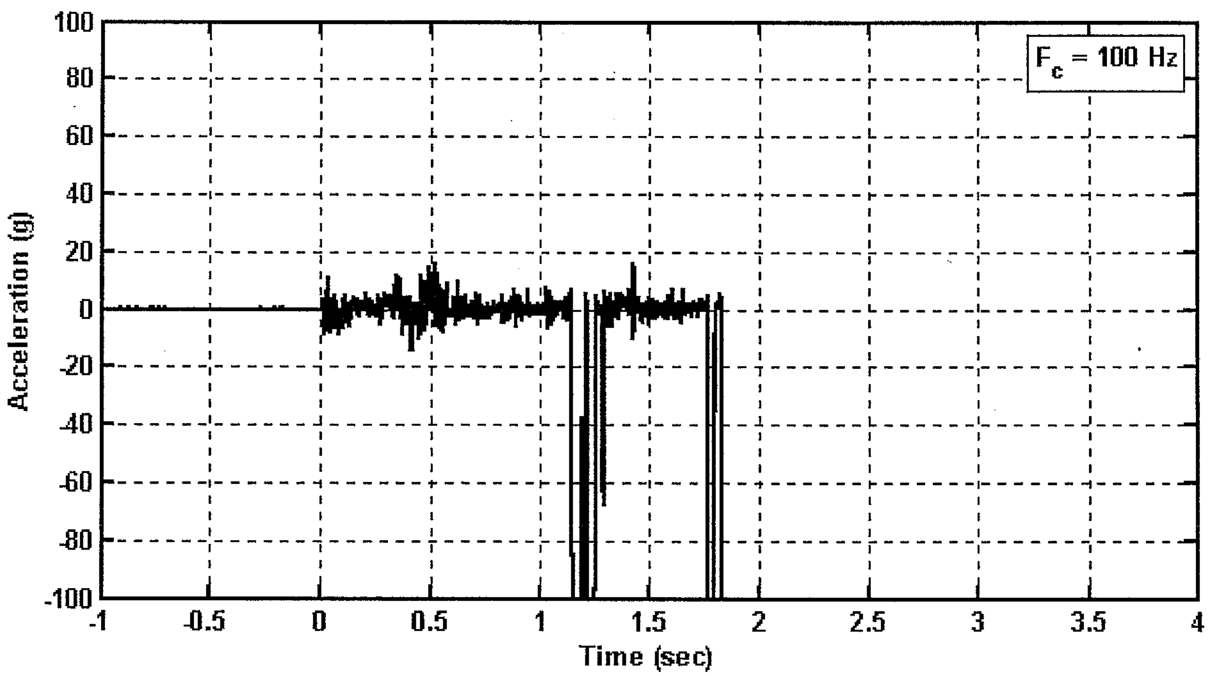


Figure C8. Bullet car 1, position 2, center sill, lateral acceleration
Channel Name: B1_C2Y

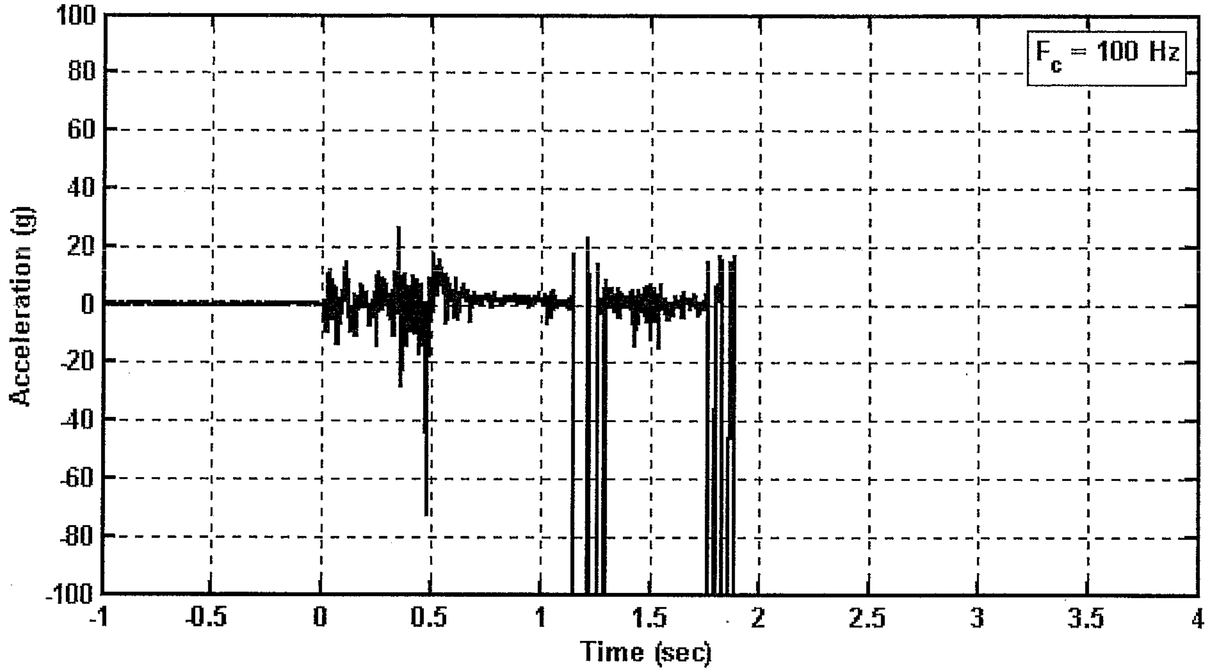


Figure C9. Bullet car 1, position 2, center sill, vertical acceleration
Channel Name: B1_C2Z

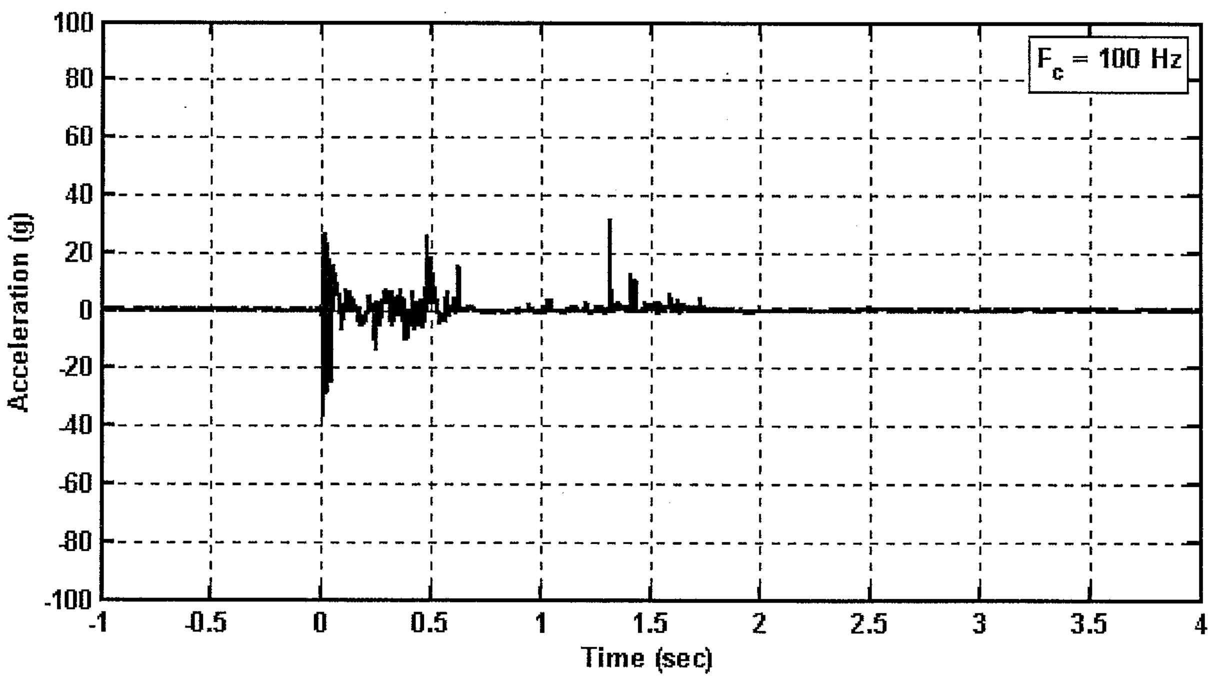


Figure C10. Bullet car 1, position 3, center sill, longitudinal acceleration
Channel Name: B1_C3X

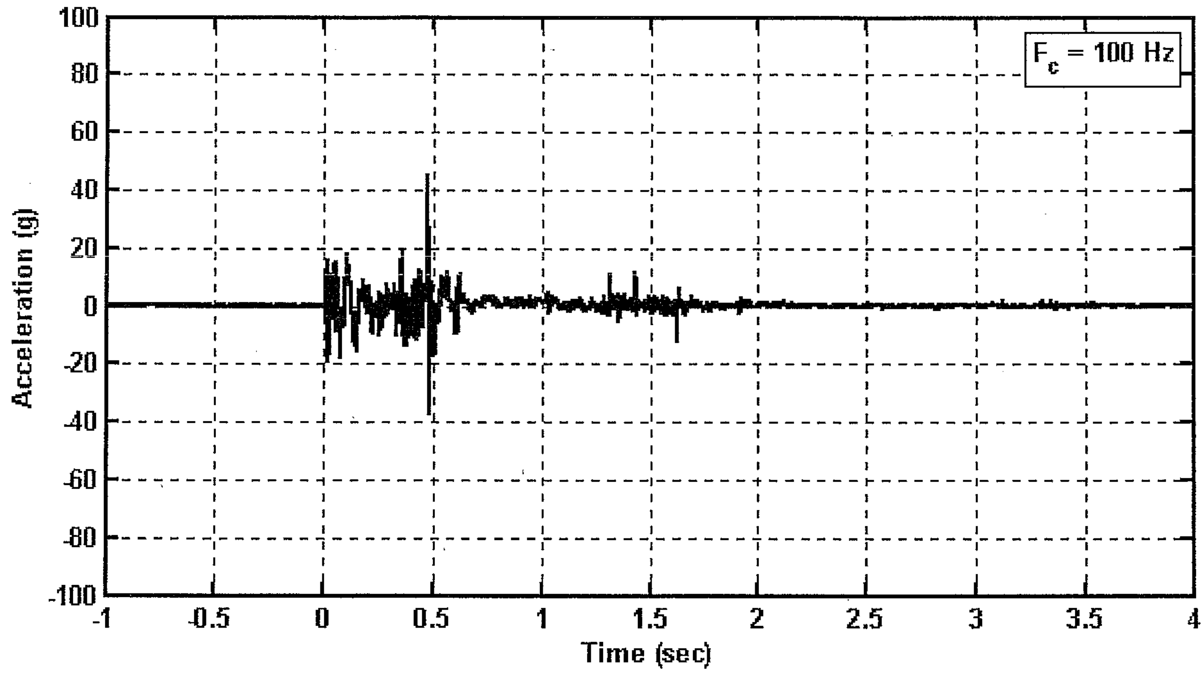


Figure C11. Bullet car 1, position 3, center sill, vertical acceleration
Channel Name: B1_C3Z

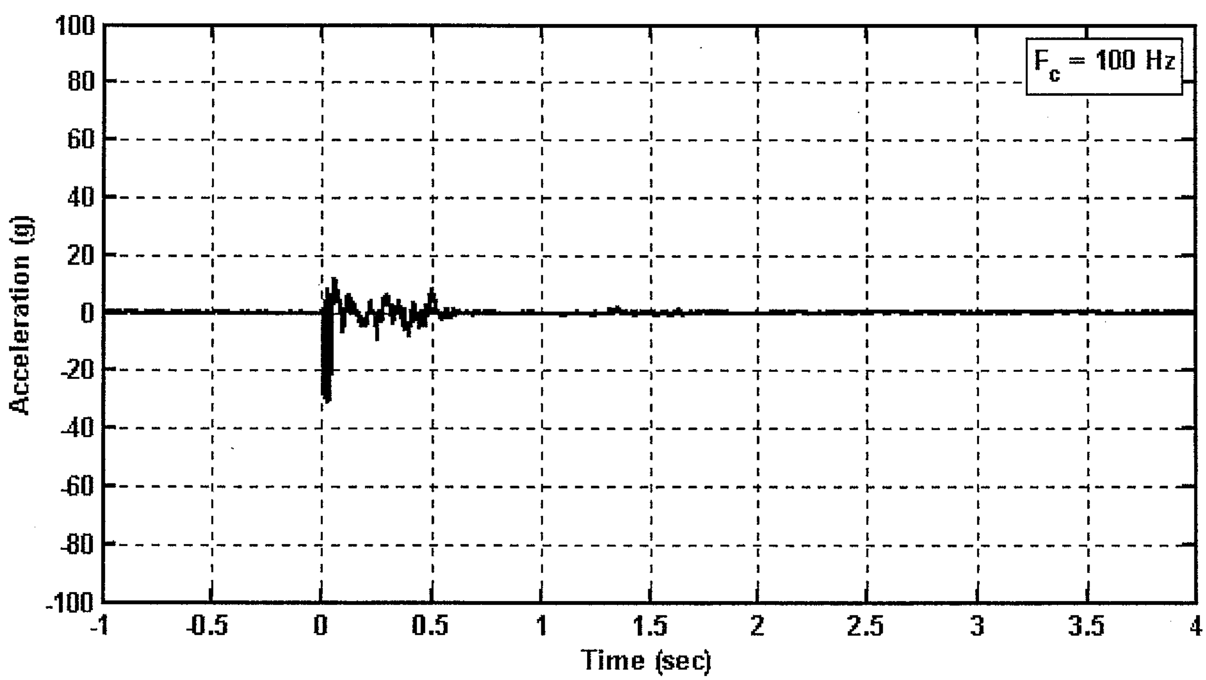


Figure C12. Bullet car 1, position 4, center sill, longitudinal acceleration
Channel Name: B1_C4X

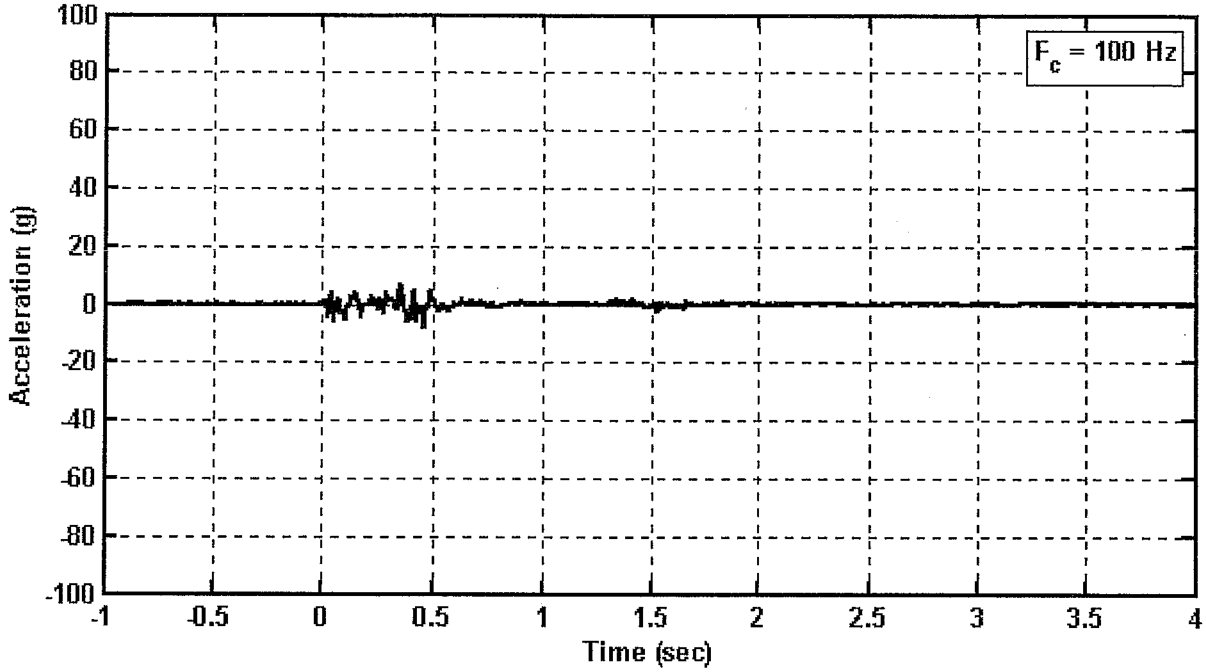


Figure C13. Bullet car 1, position 4, center sill, lateral acceleration
Channel Name: B1_C4Y

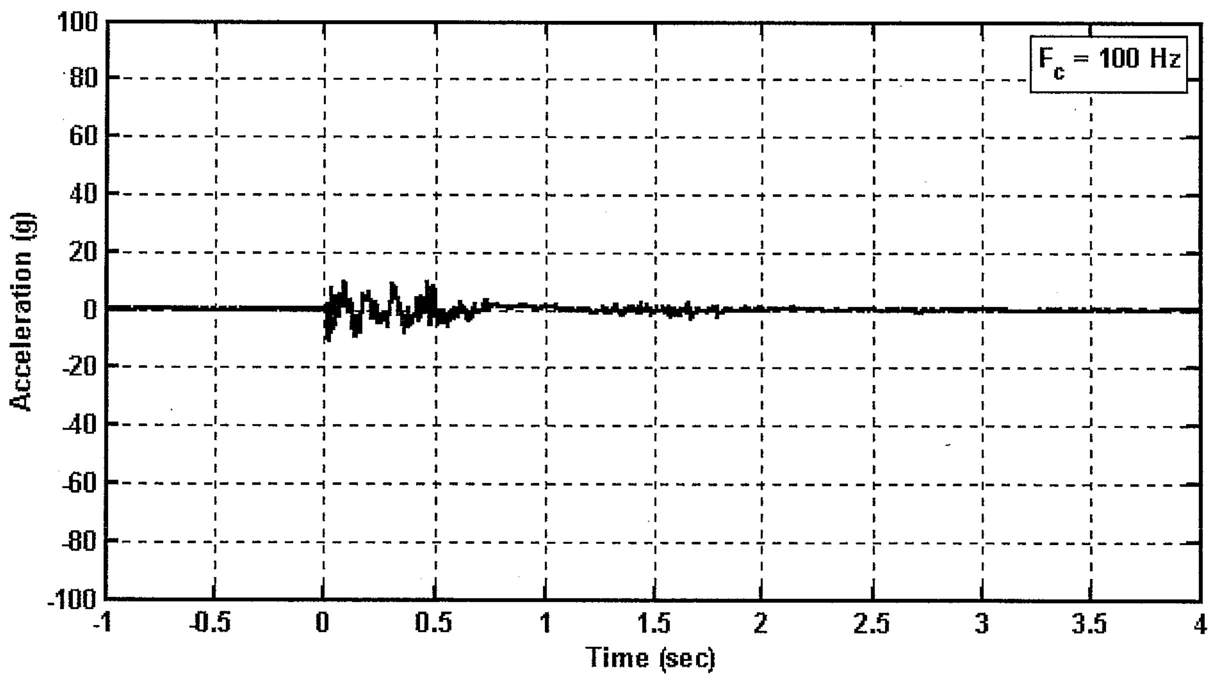


Figure C14. Bullet car 1, position 4, center sill, vertical acceleration
Channel Name: B1_C4Z

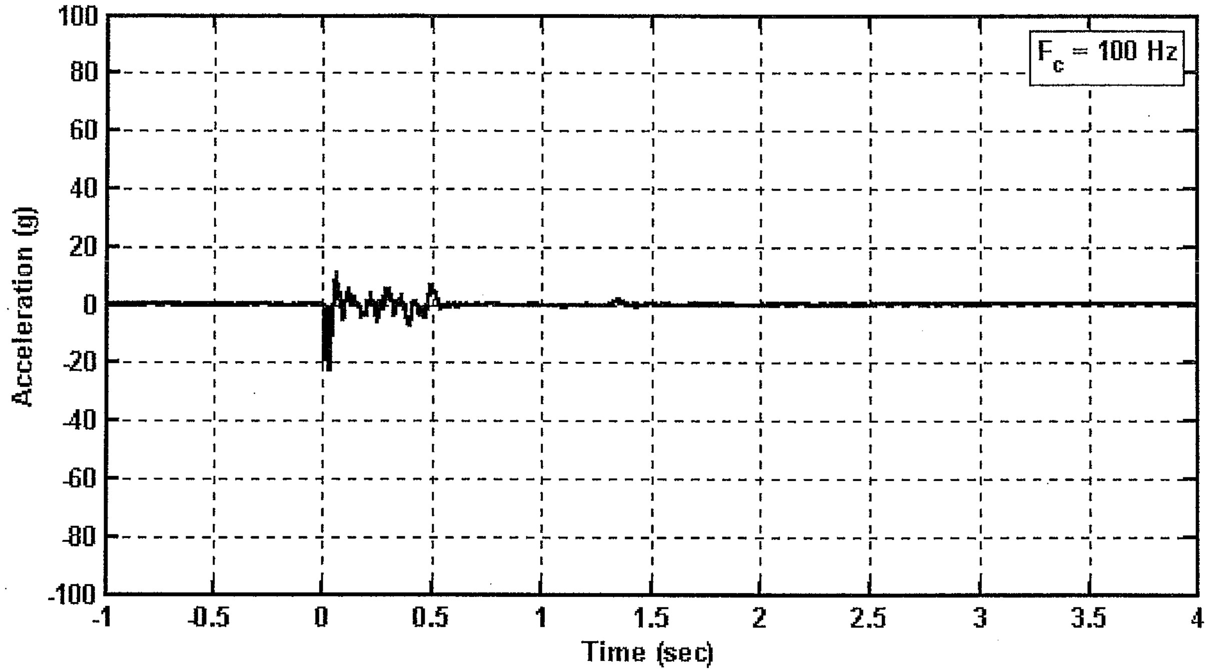


Figure C15. Bullet car 1, position 5, center sill, longitudinal acceleration
Channel Name: B1_C5X

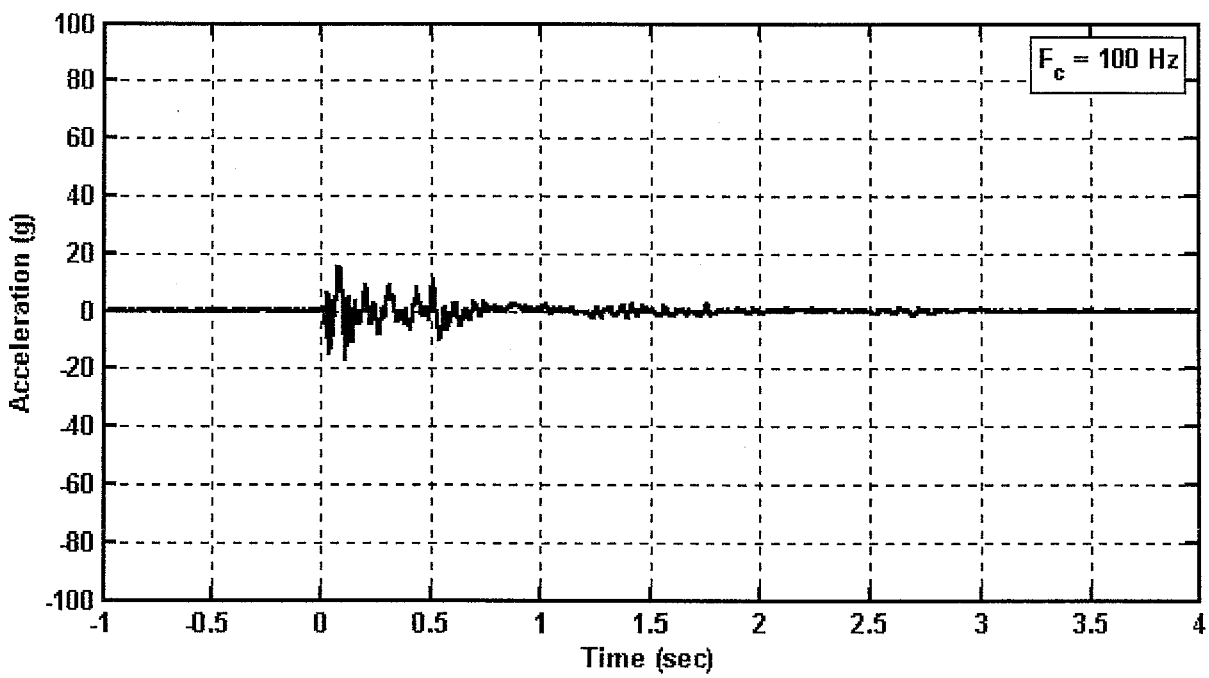


Figure C16. Bullet car 1, position 5, center sill, vertical acceleration
Channel Name: B1_C5Z

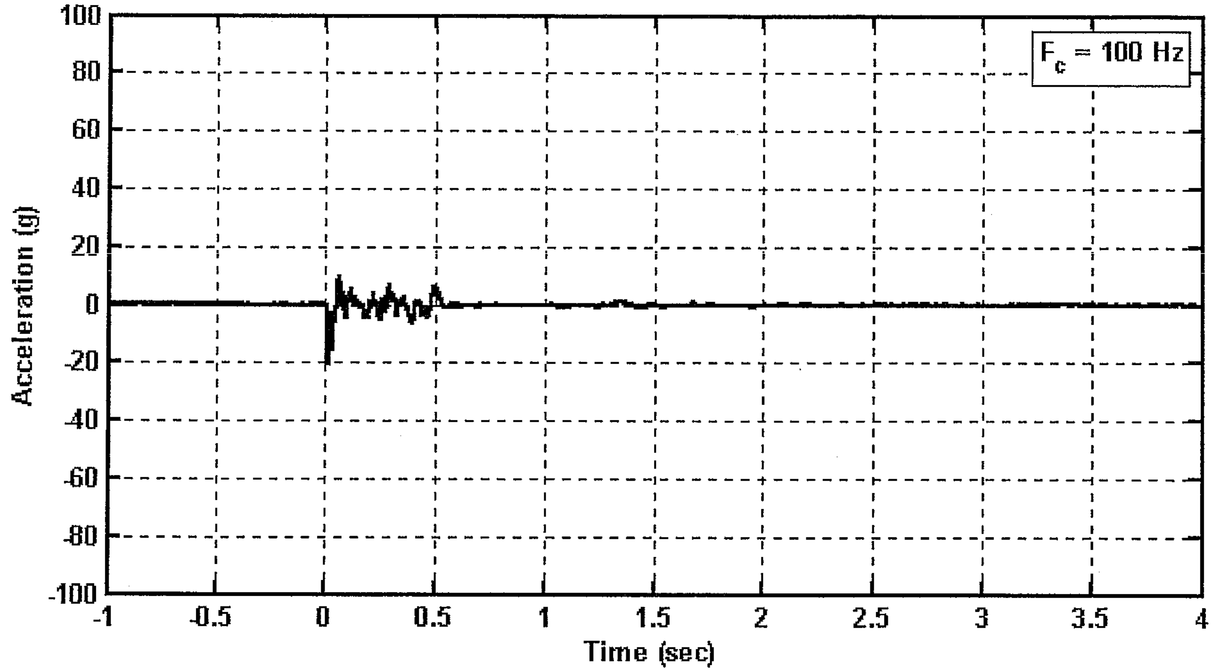


Figure C17. Bullet car 1, position 6, center sill, longitudinal acceleration
Channel Name: B1_C6X

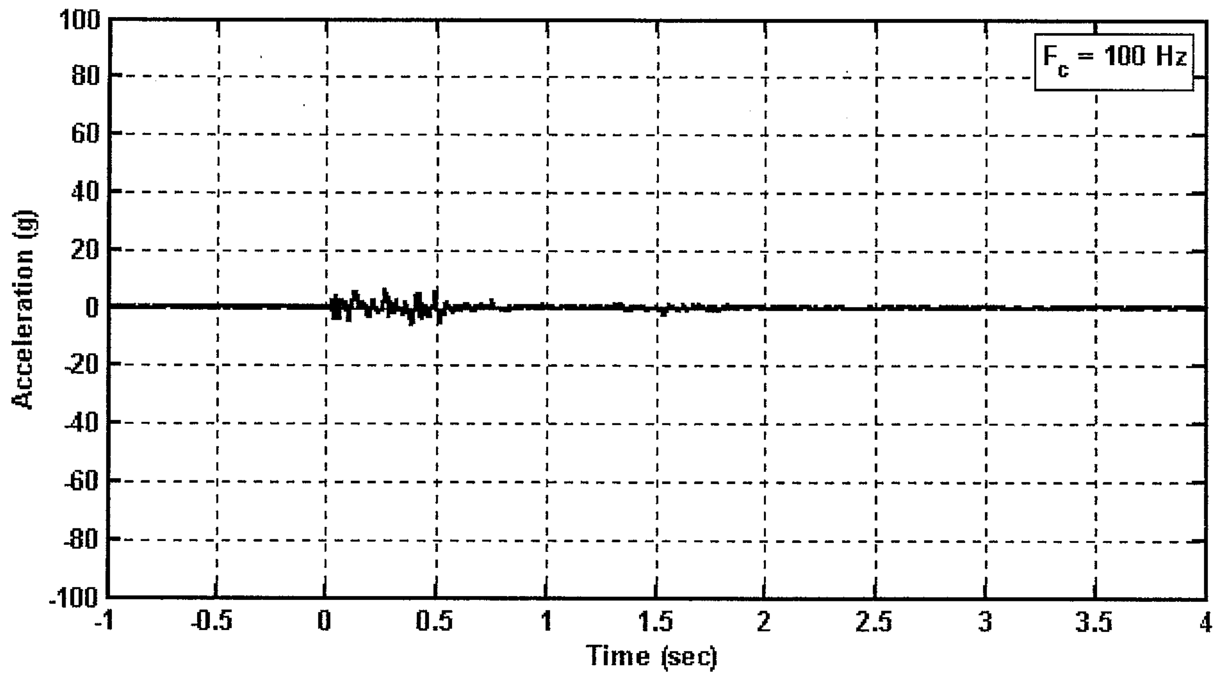


Figure C18. Bullet car 1, position 6, center sill, lateral acceleration
Channel Name: B1_C6Y

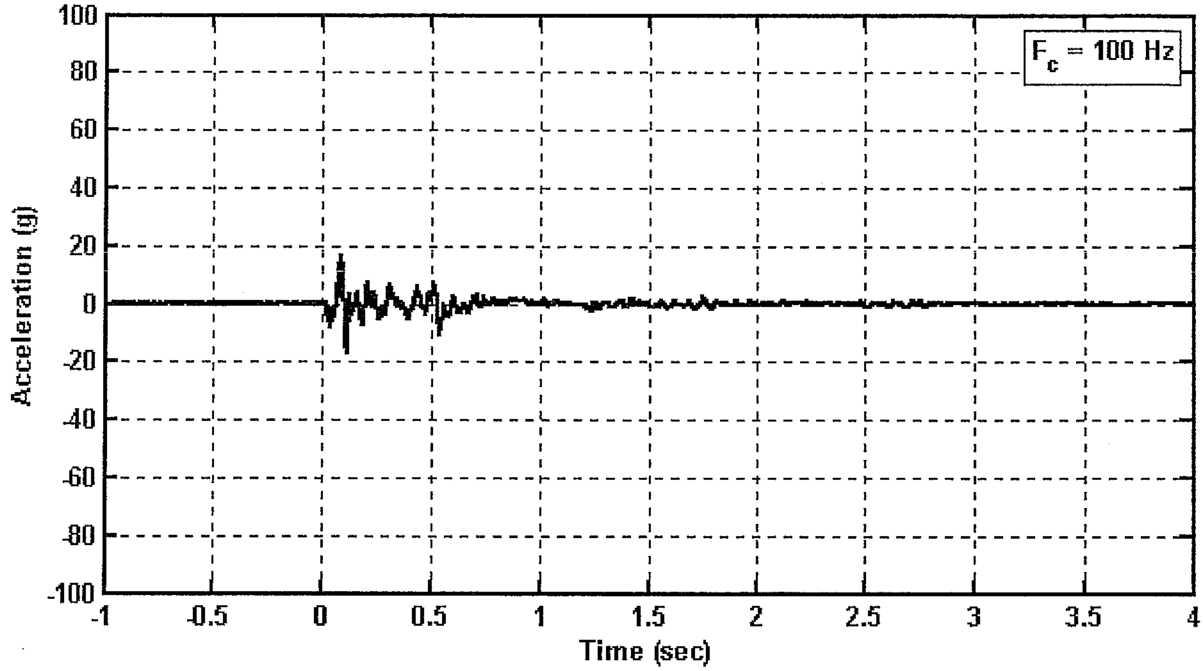


Figure C19. Bullet car 1, position 6, center sill, vertical acceleration
Channel Name: B1_C6Z

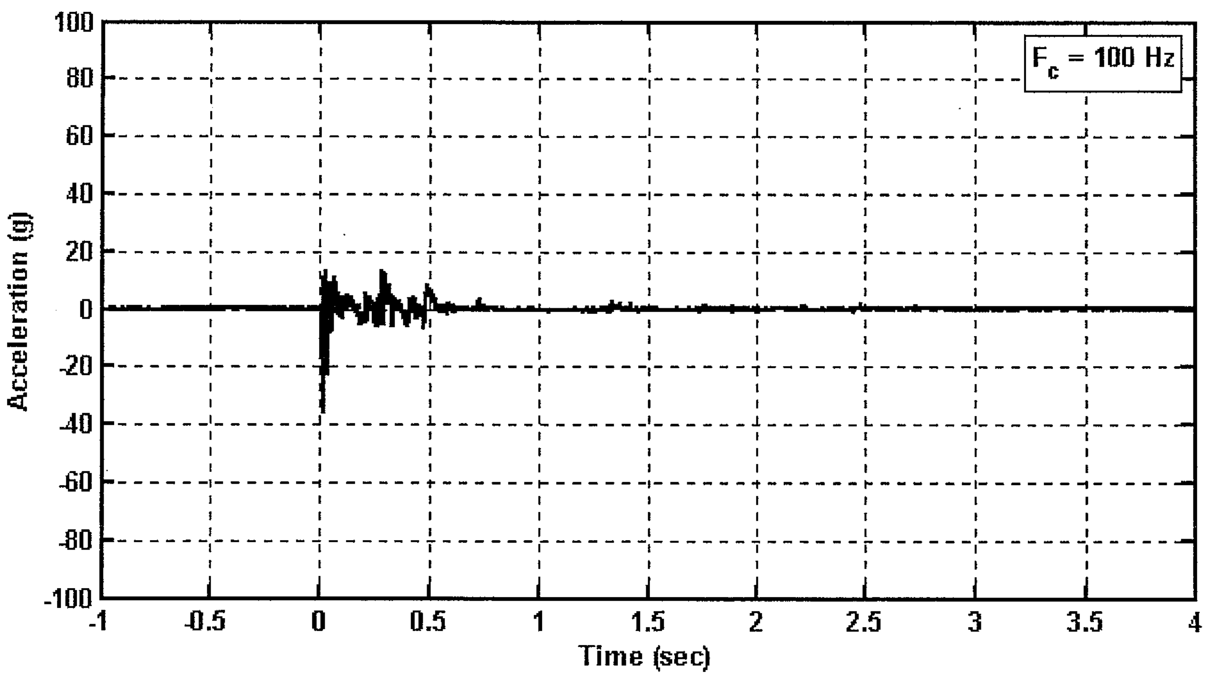


Figure C20. Bullet car 1, position 7, center sill, longitudinal acceleration
Channel Name: B1_C7X

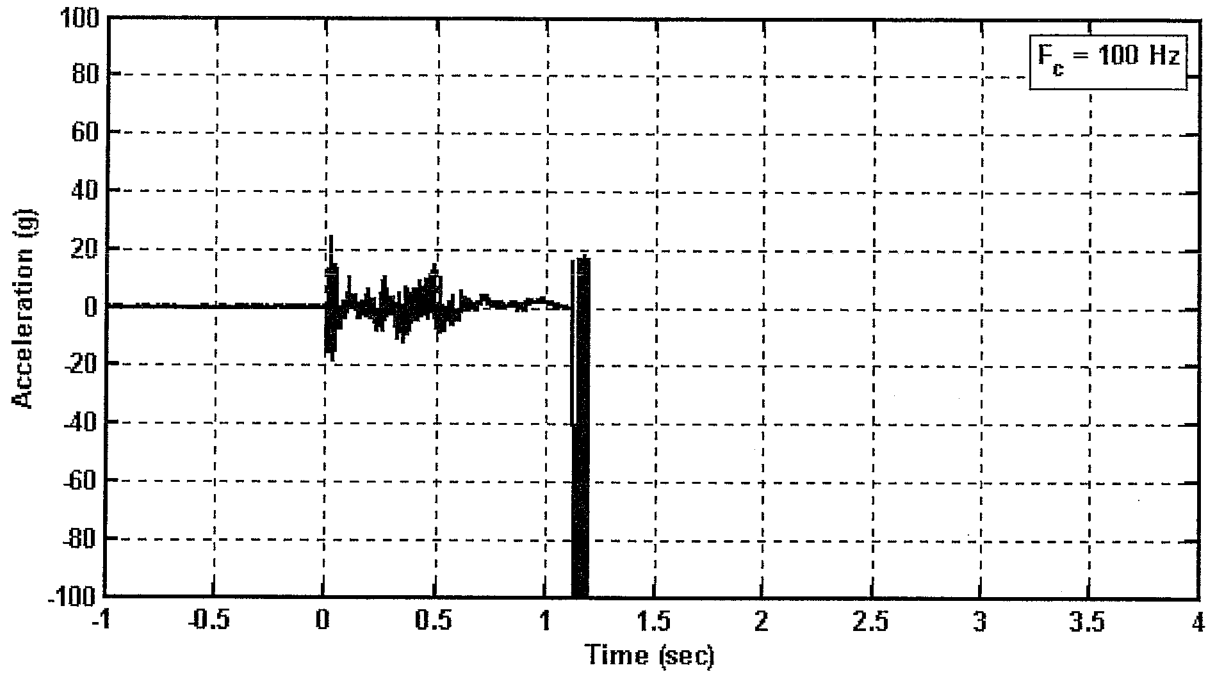


Figure C21. Bullet car 1, position 2, left side, vertical acceleration
Channel Name: B1_L2Z

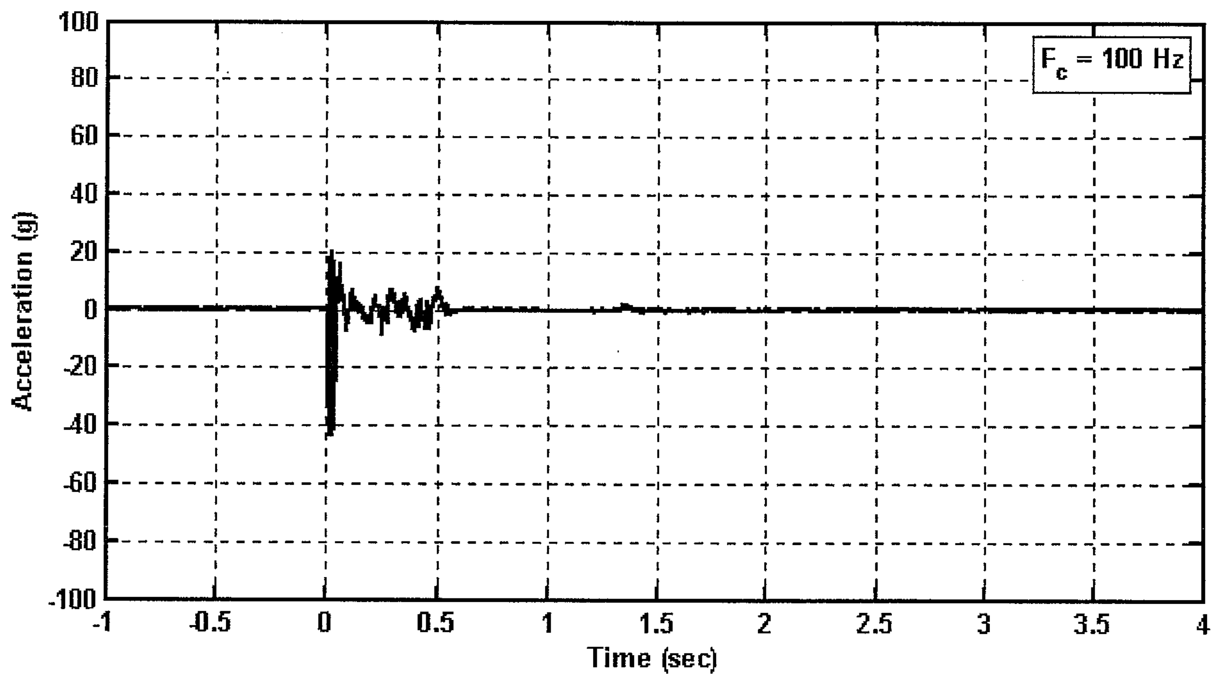


Figure C22. Bullet car 1, position 4, left side, longitudinal acceleration
Channel Name: B1_L4X

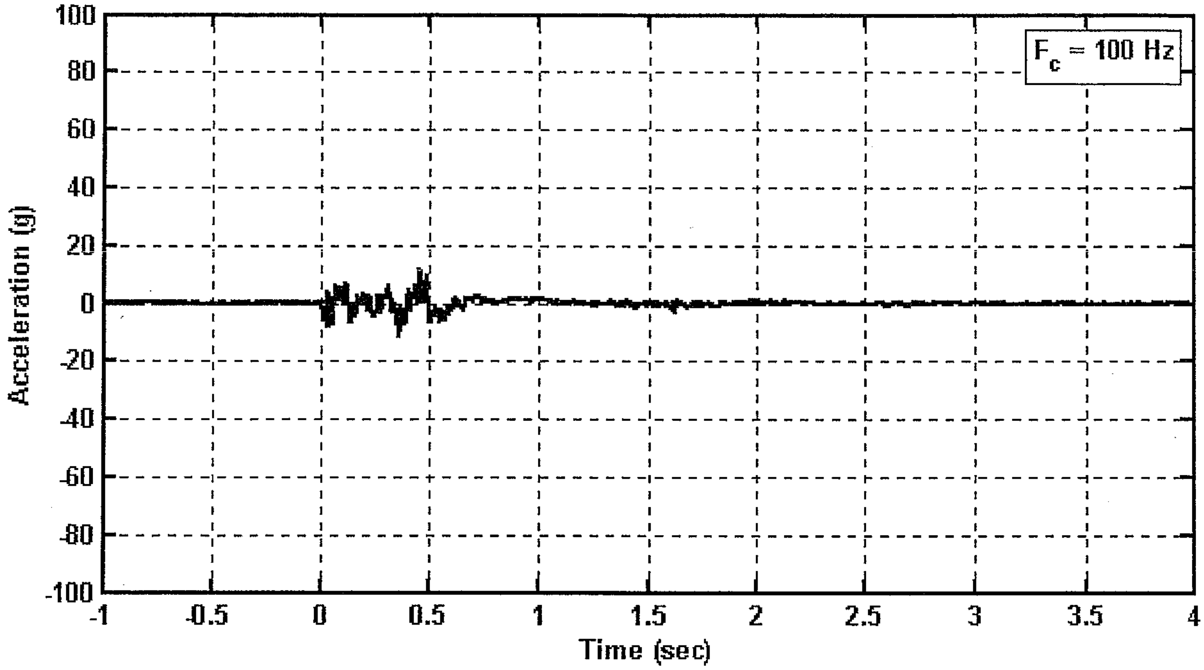


Figure C23. Bullet car 1, position 4, left side, vertical acceleration
Channel Name: B1_L4Z

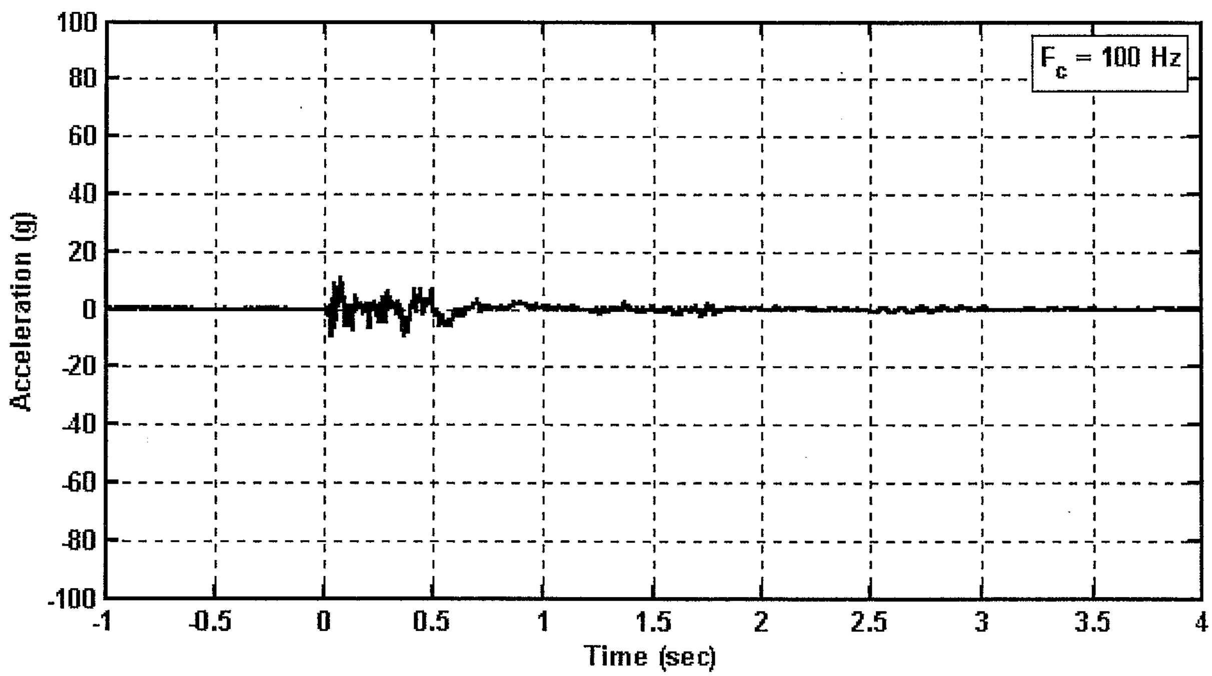


Figure C24. Bullet car 1, position 6, left side, vertical acceleration
Channel Name: B1_L6Z

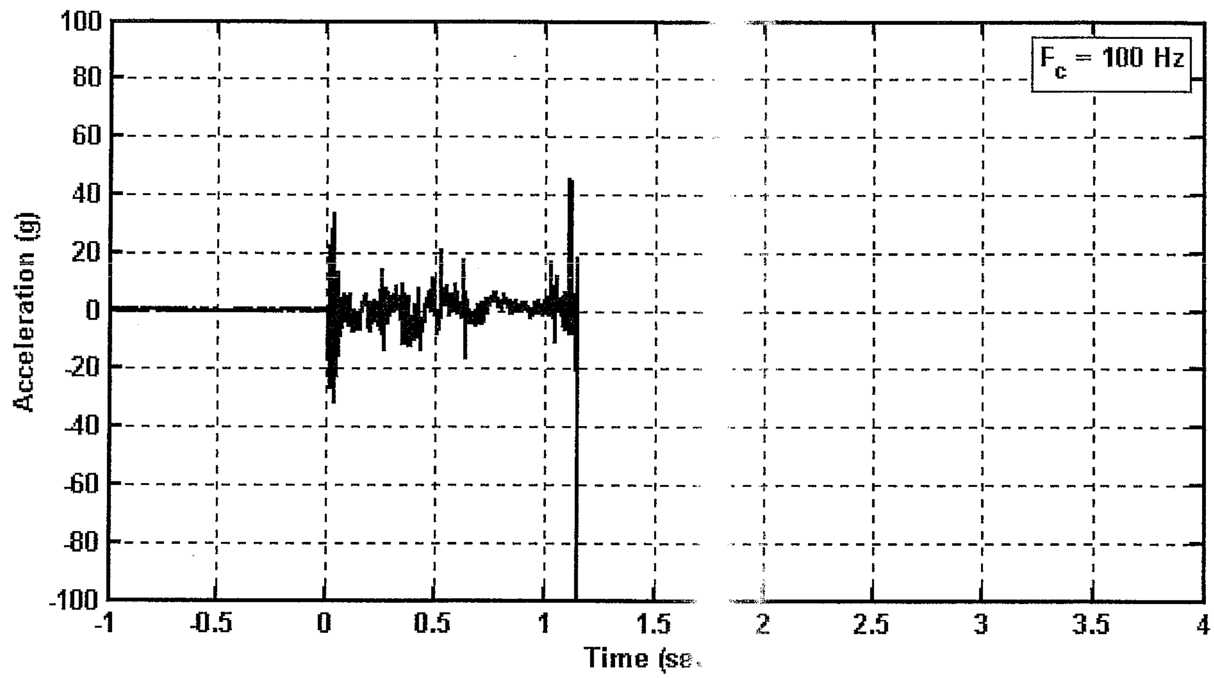


Figure C25. Bullet car 1, position 2, r ht side, vertical acceleration
Channel Name: 31_R2Z

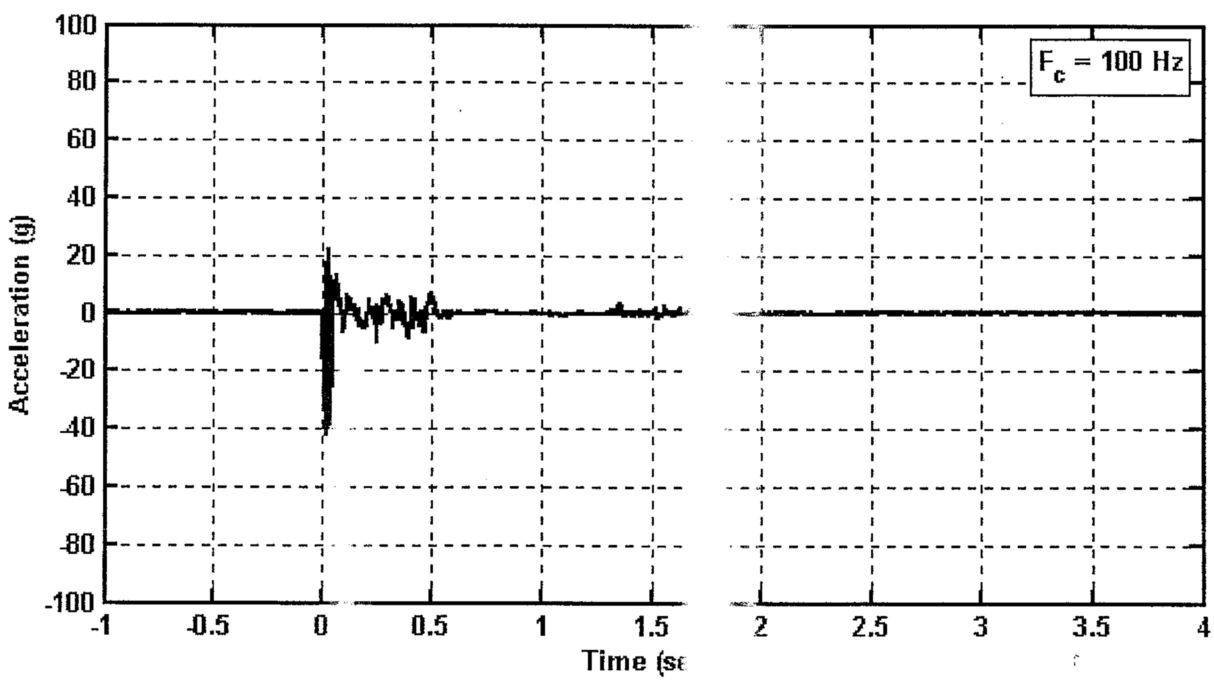


Figure C26. Bullet car 1, position 4, rig ide, longitudinal acceleration
Channel Name 1_R4X

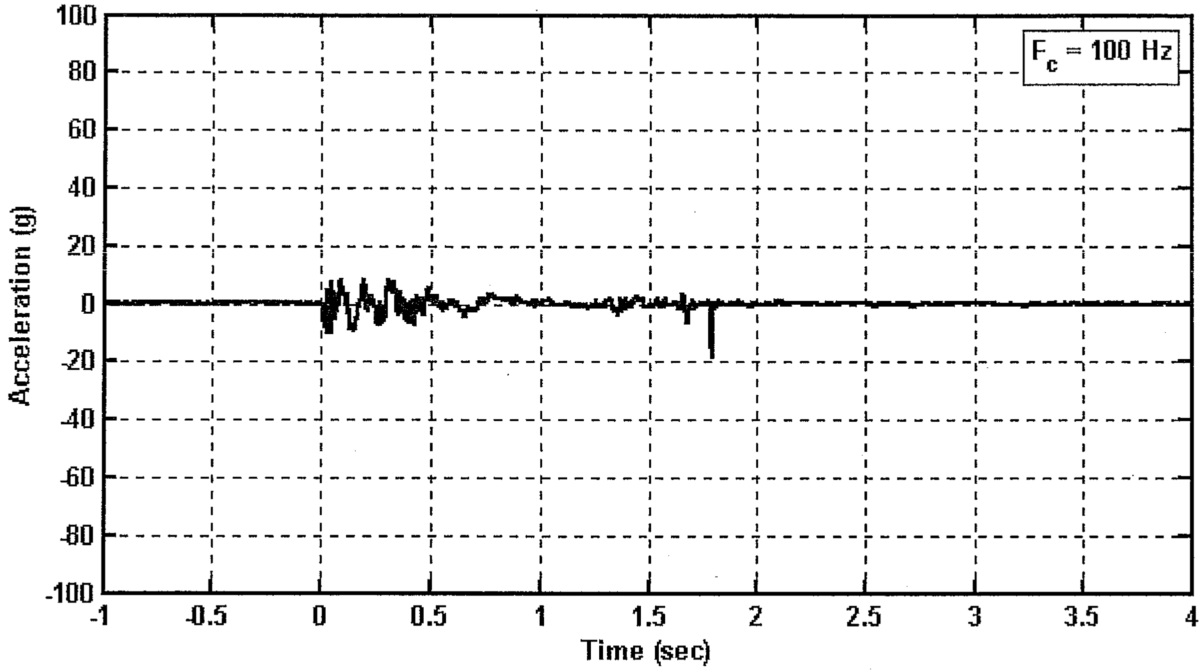


Figure C27. Bullet car 1, position 4, right side, vertical acceleration
Channel Name: B1_R4Z

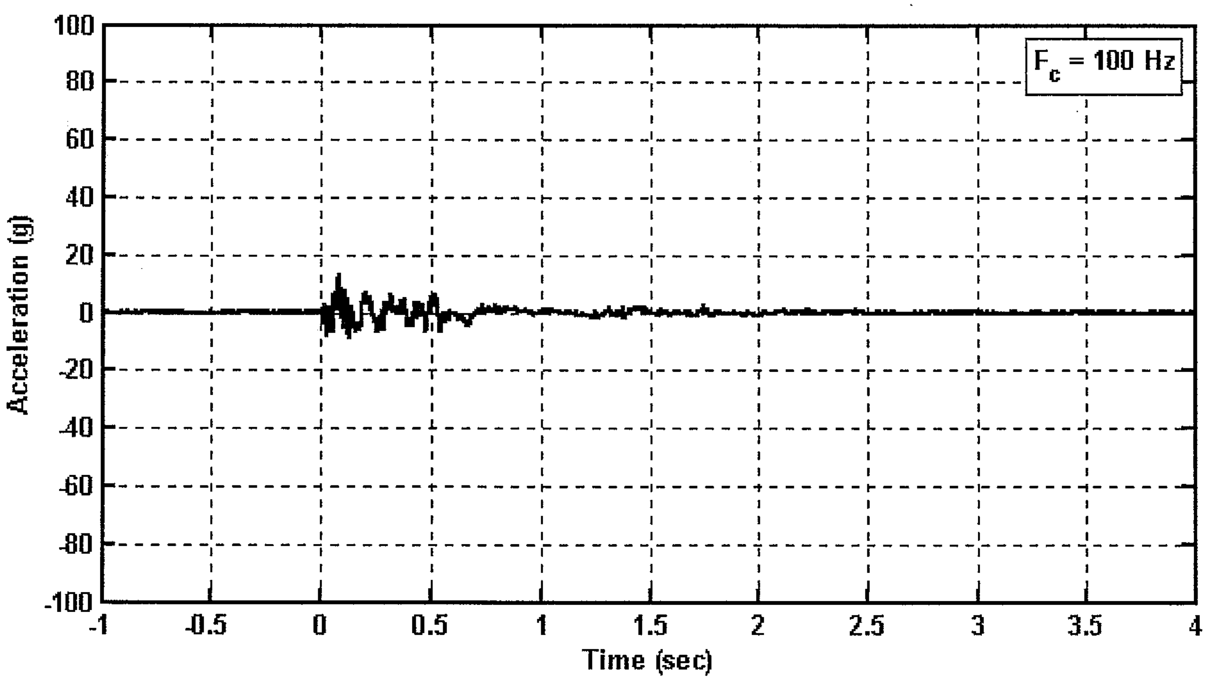


Figure C28. Bullet car 1, position 6, right side, vertical acceleration
Channel Name: B1_R6Z

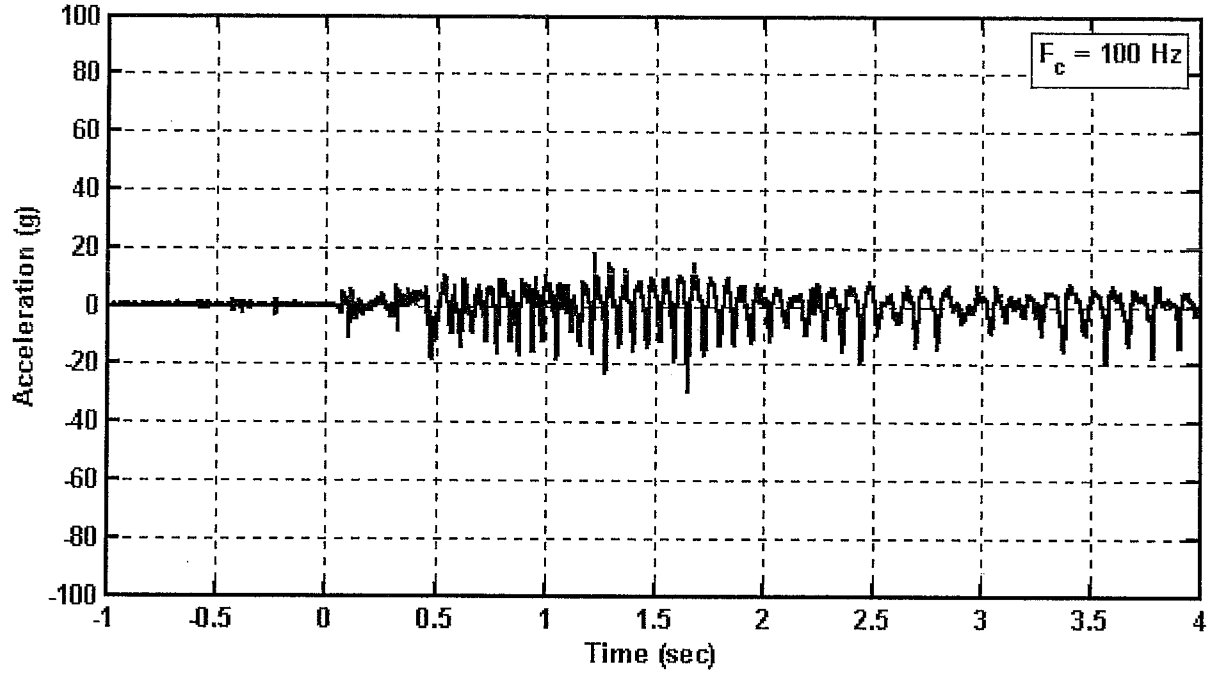


Figure C29. Bullet car 2, A truck, vertical acceleration
Channel Name: B2_BAZ

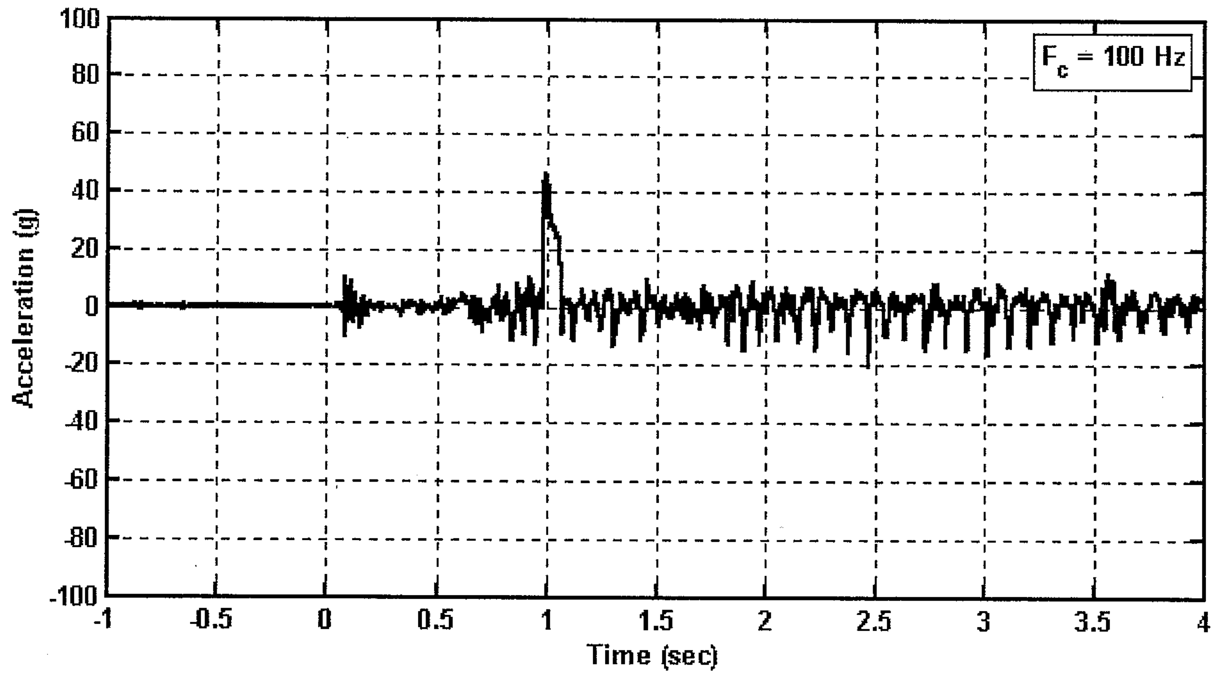


Figure C30. Bullet car 2, B truck, vertical acceleration
Channel Name: B2_BBZ

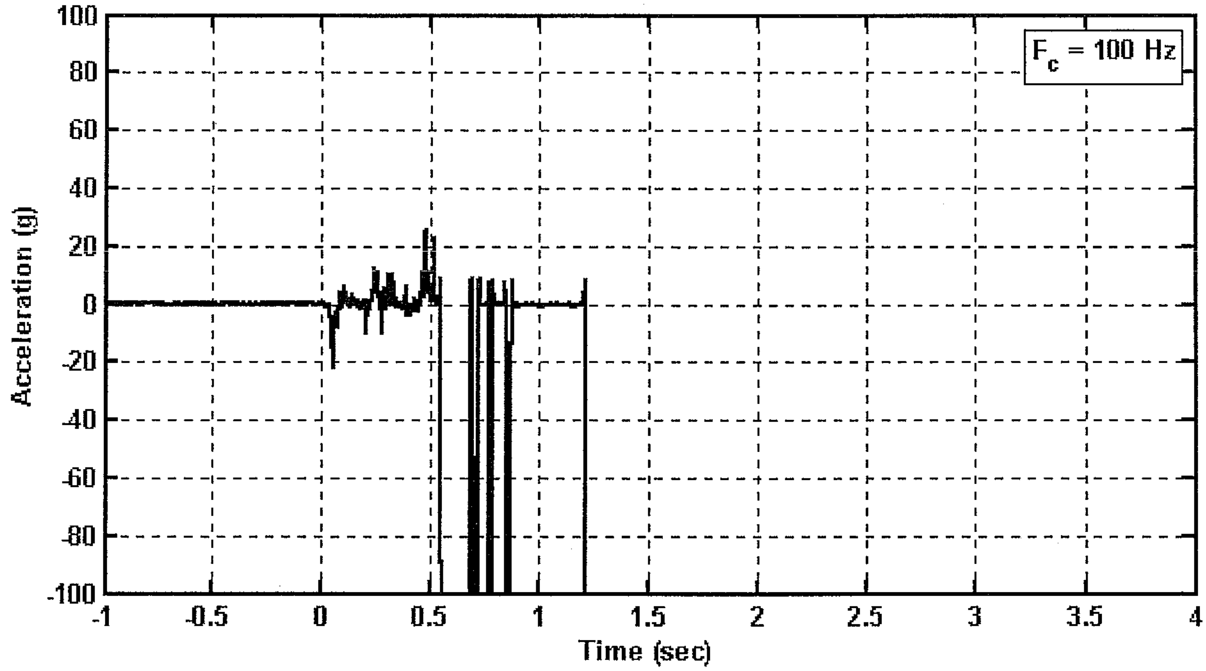


Figure C31. Bullet car 2, position 1, center sill, longitudinal acceleration
Channel Name: B2_C1X

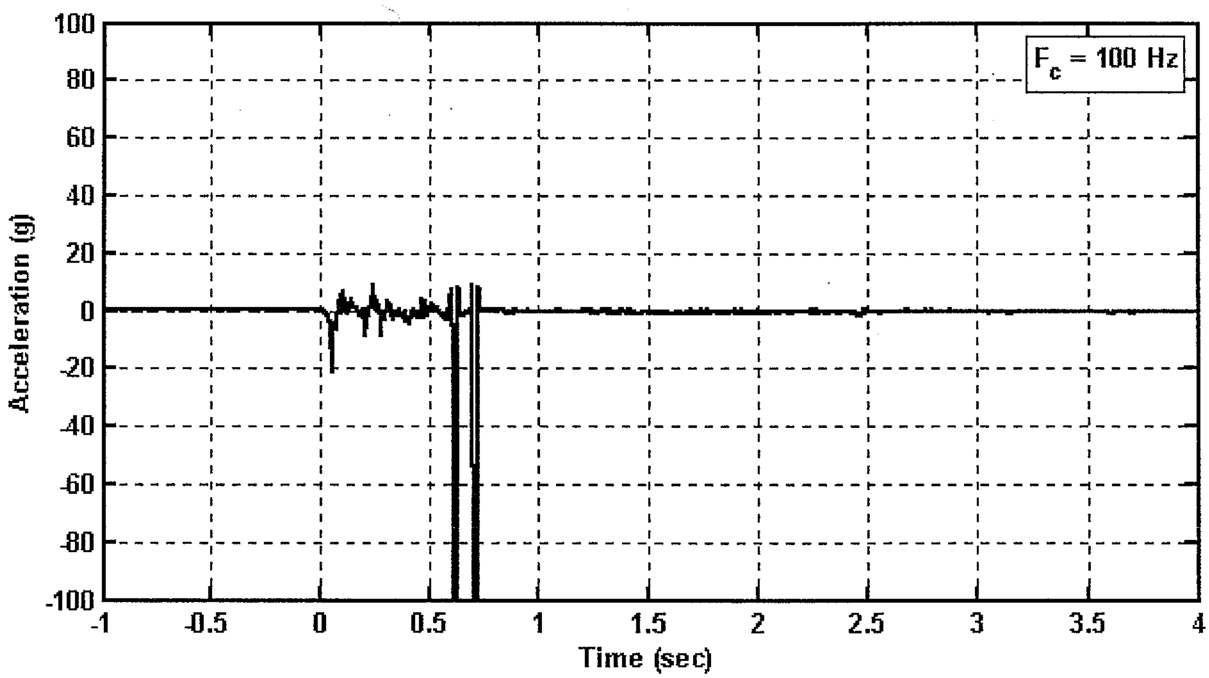


Figure C32. Bullet car 2, position 2, center sill, longitudinal acceleration
Channel Name: B2_C2X

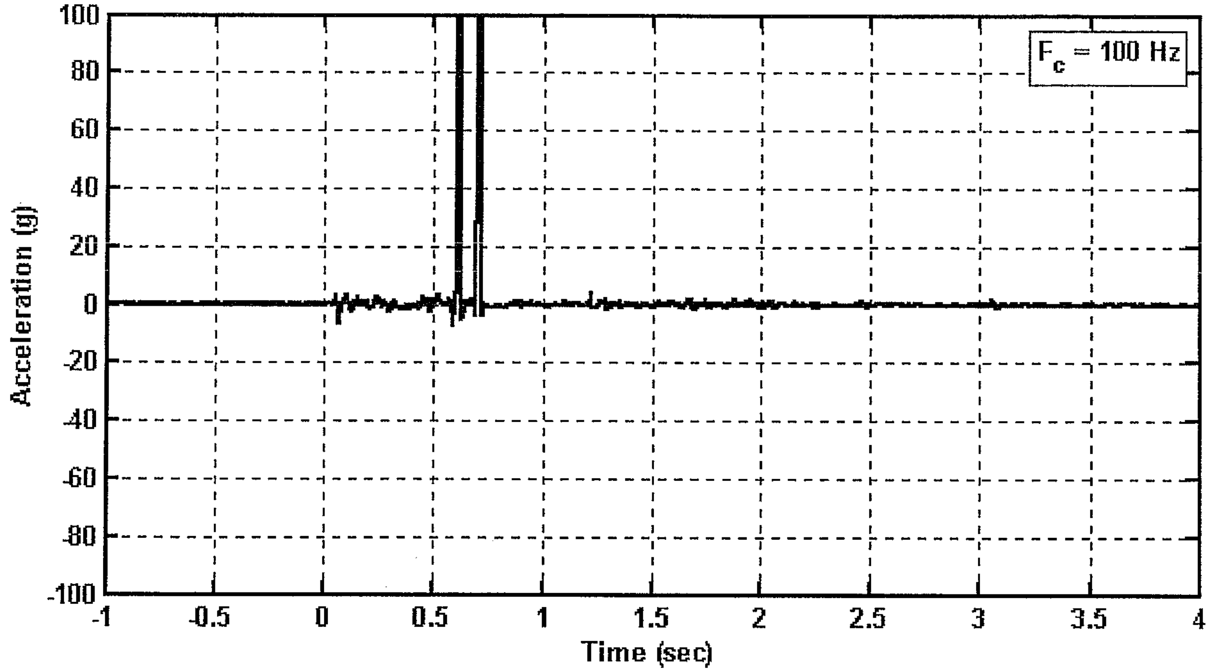


Figure C33. Bullet car 2, position 2, center sill, lateral acceleration
Channel Name: B2_C2Y

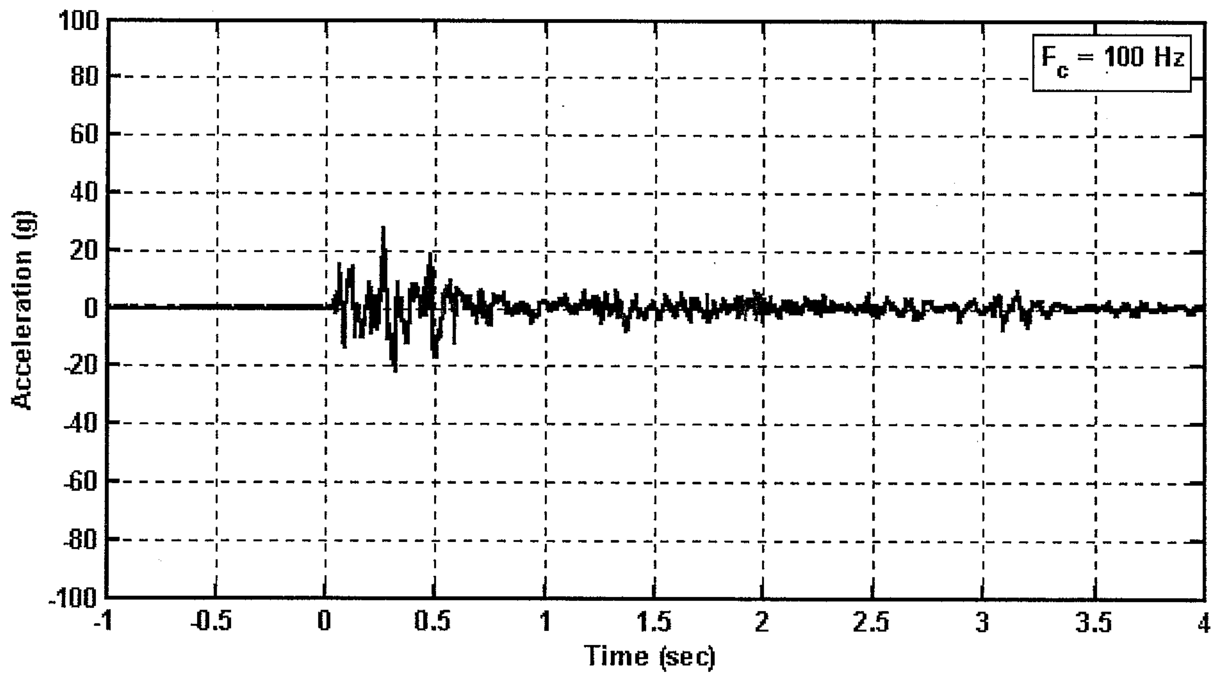


Figure C34. Bullet car 2, position 2, center sill, vertical acceleration
Channel Name: B2_C2Z

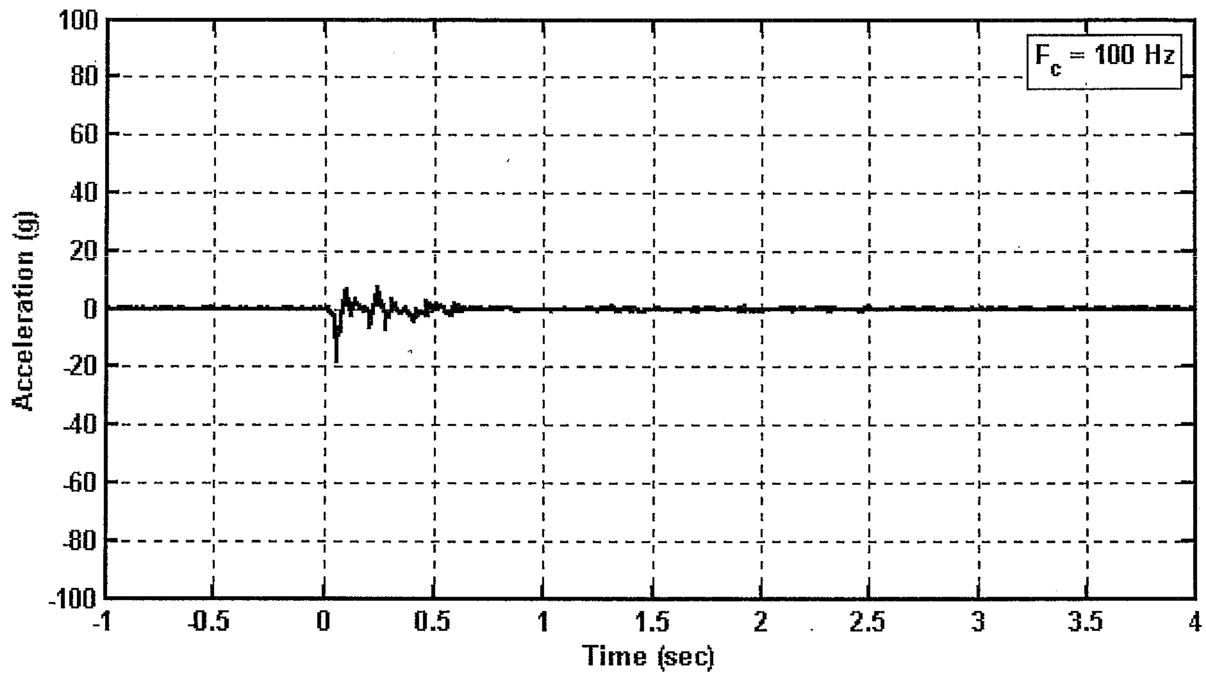


Figure C35. Bullet car 2, position 3, center sill, longitudinal acceleration
Channel Name: B2_C3X

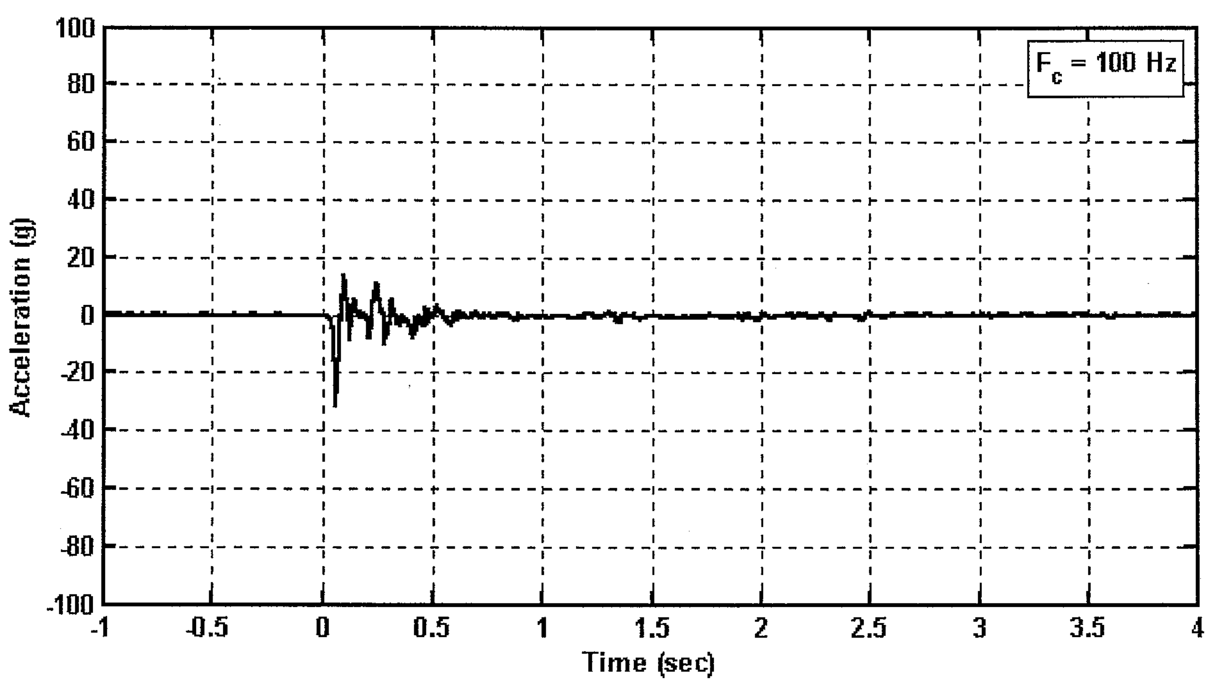


Figure C36. Bullet car 2, position 4, center sill, longitudinal acceleration
Channel Name: B2_C4X

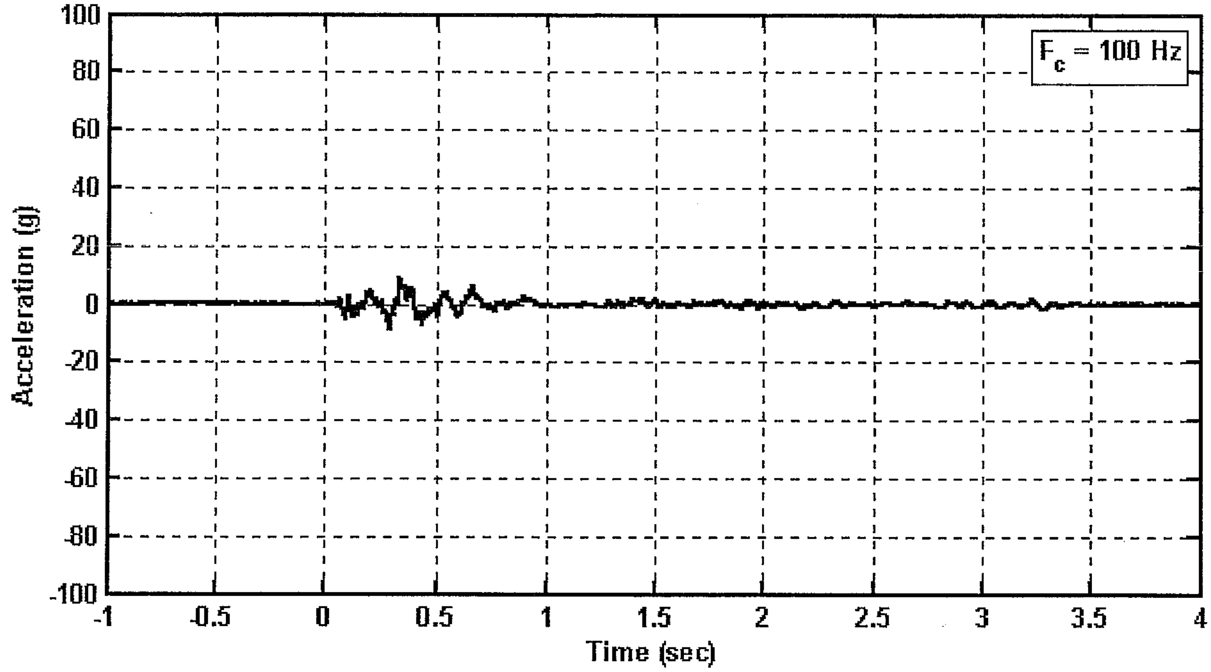


Figure C37. Bullet car 2, position 4, center sill, lateral acceleration
Channel Name: B2_C4Y

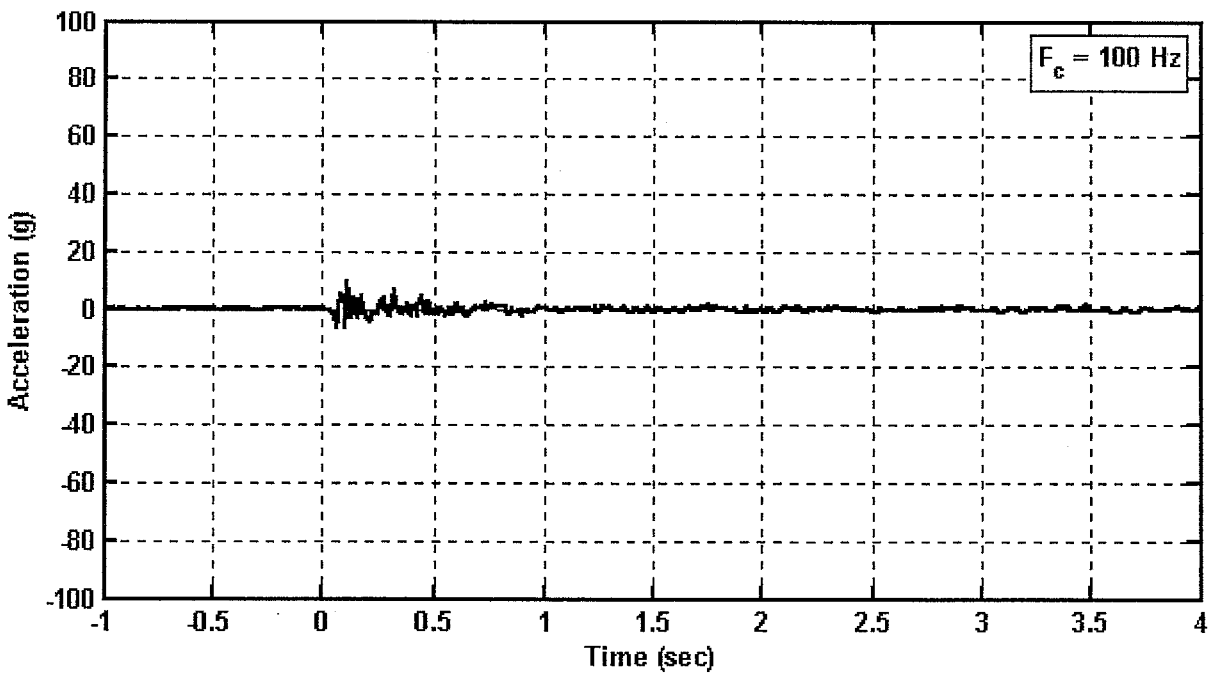


Figure C38. Bullet car 2, position 4, center sill, vertical acceleration
Channel Name: B2_C4Z

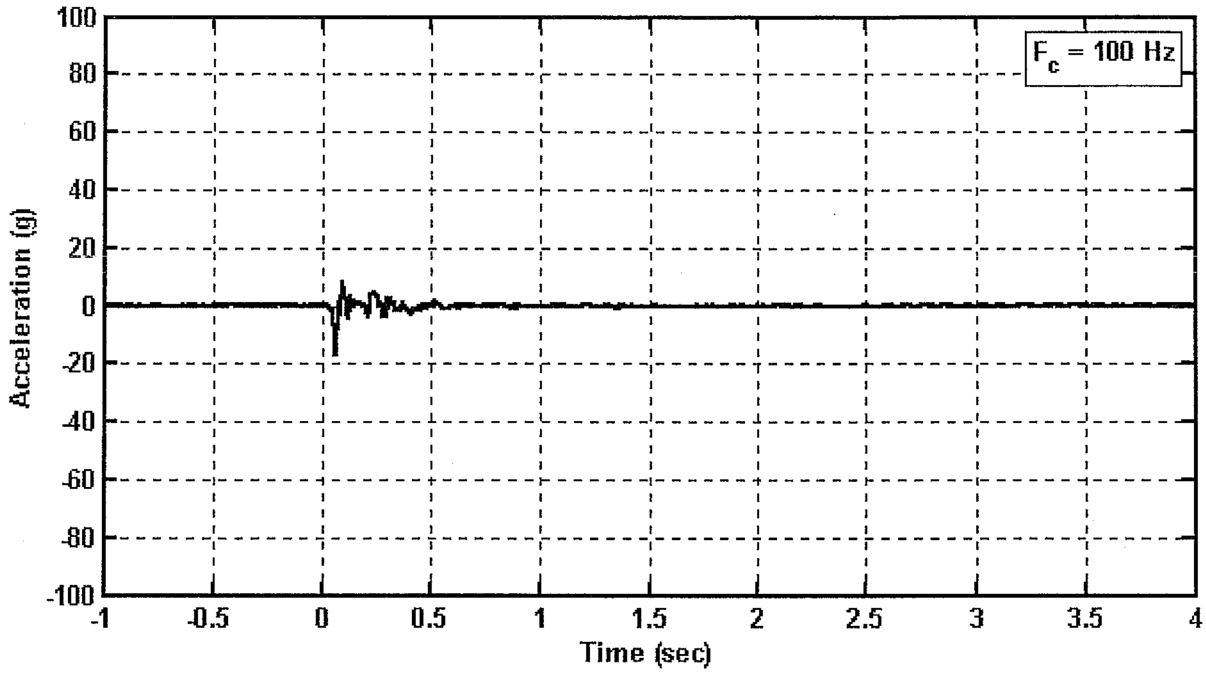


Figure C39. Bullet car 2, position 5, center sill, longitudinal acceleration
Channel Name: B2_C5X

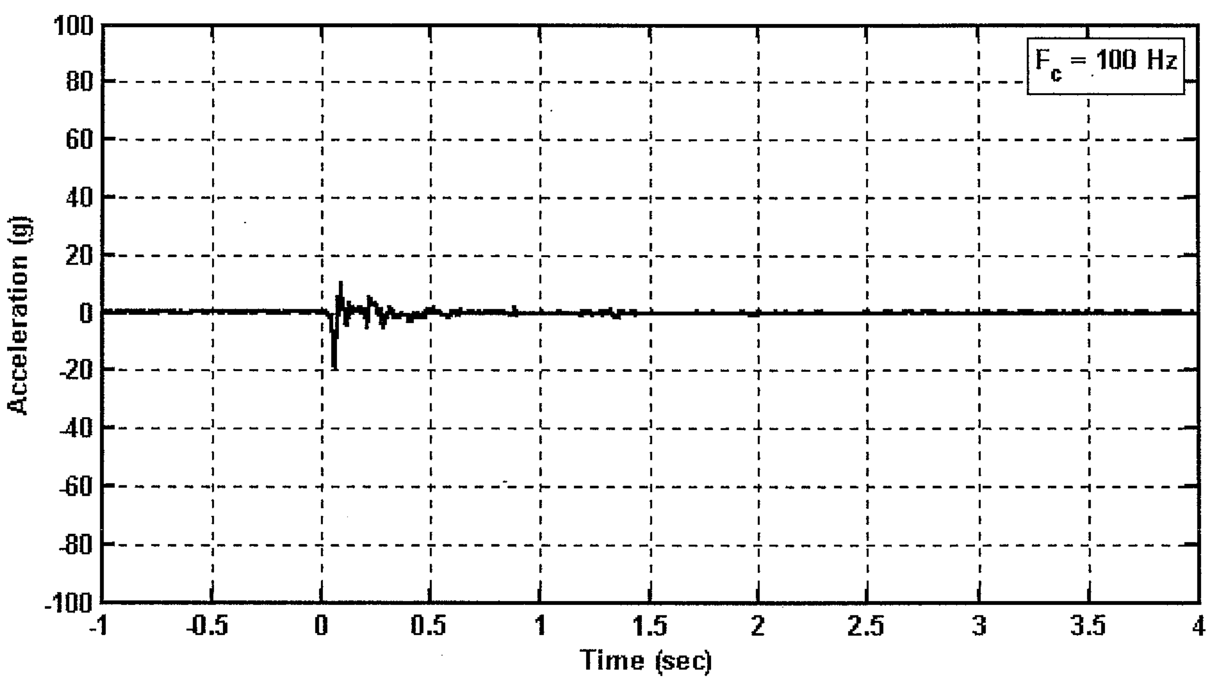


Figure C40. Bullet car 2, position 6, center sill, longitudinal acceleration
Channel Name: B2_C6X

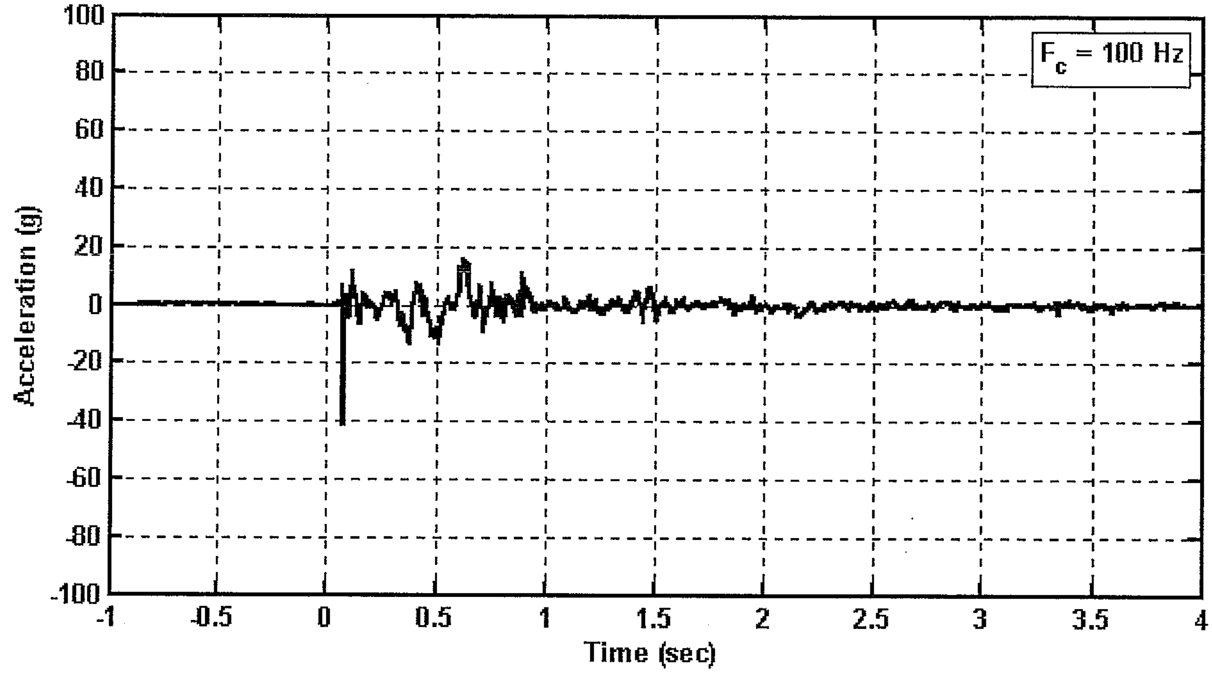


Figure C41. Bullet car 2, position 6, center sill, lateral acceleration
Channel Name: B2_C6Y

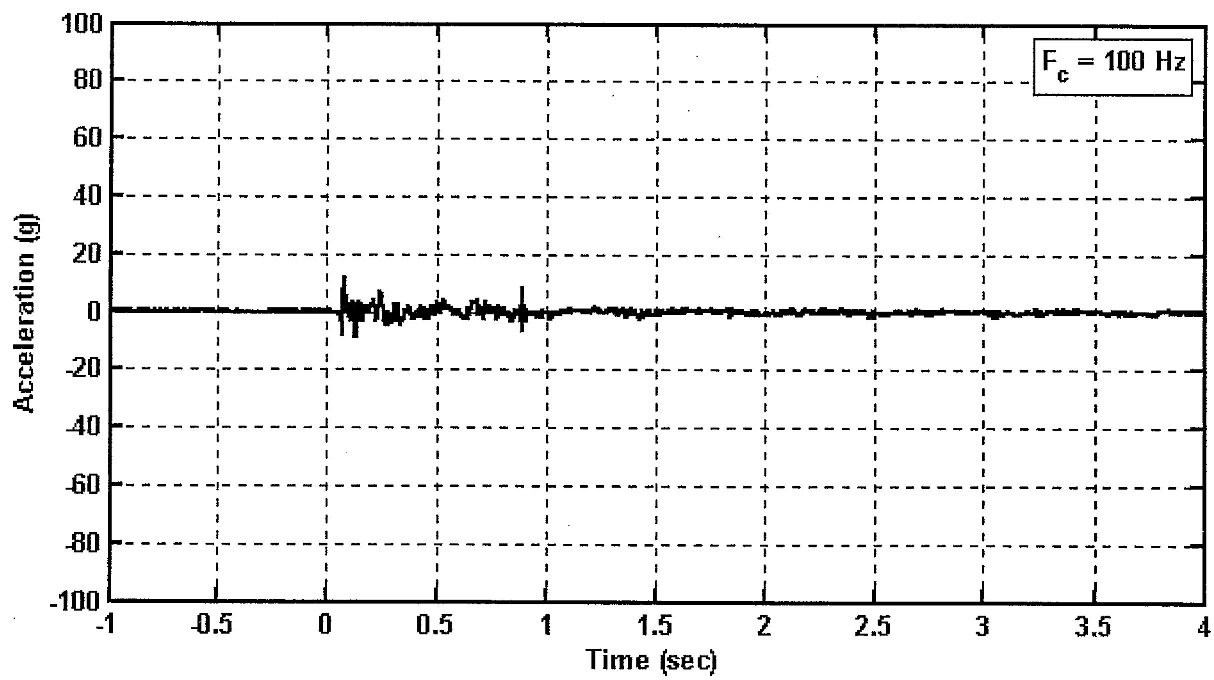


Figure C42. Bullet car 2, position 6, center sill, vertical acceleration
Channel Name: B2_C6Z

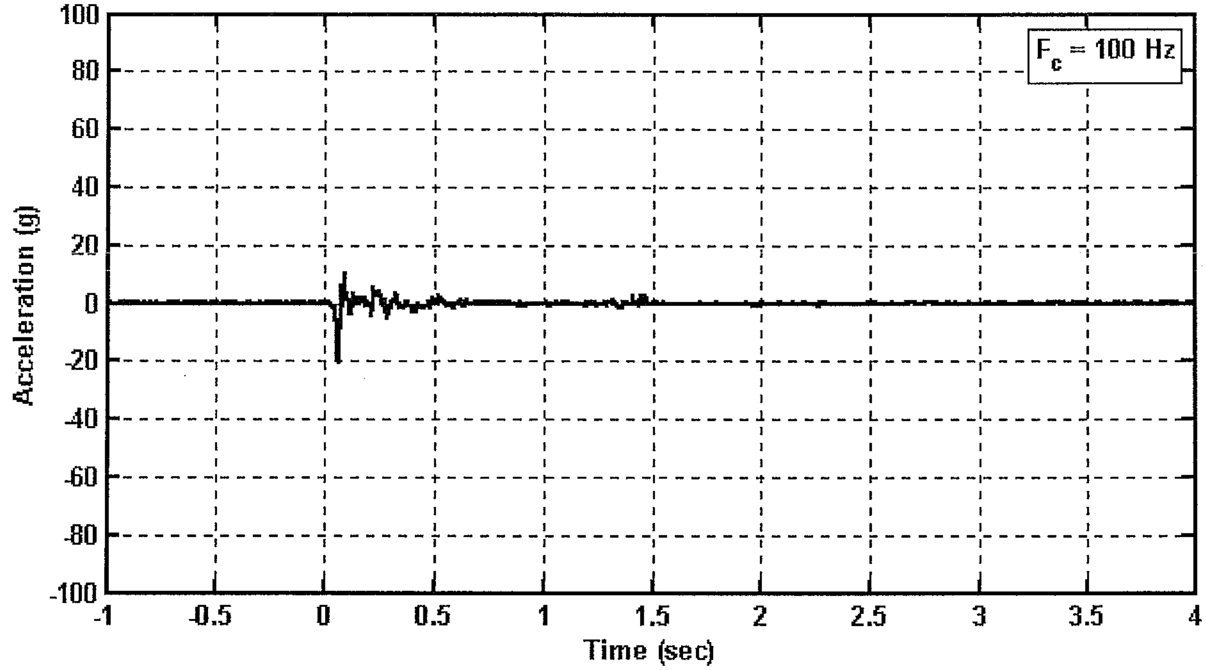


Figure C43. Bullet car 2, position 7, center sill, longitudinal acceleration
Channel Name: B2_C7X

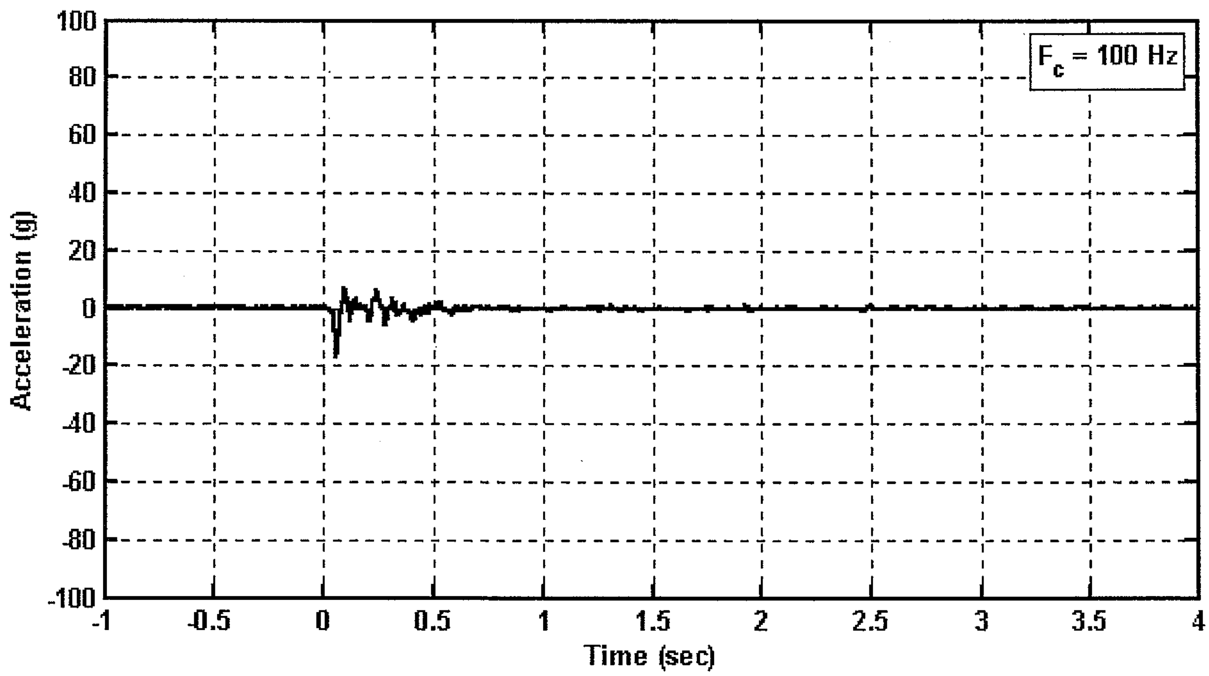


Figure C44. Bullet car 2, position 4, left side, longitudinal acceleration
Channel Name: B2_L4X

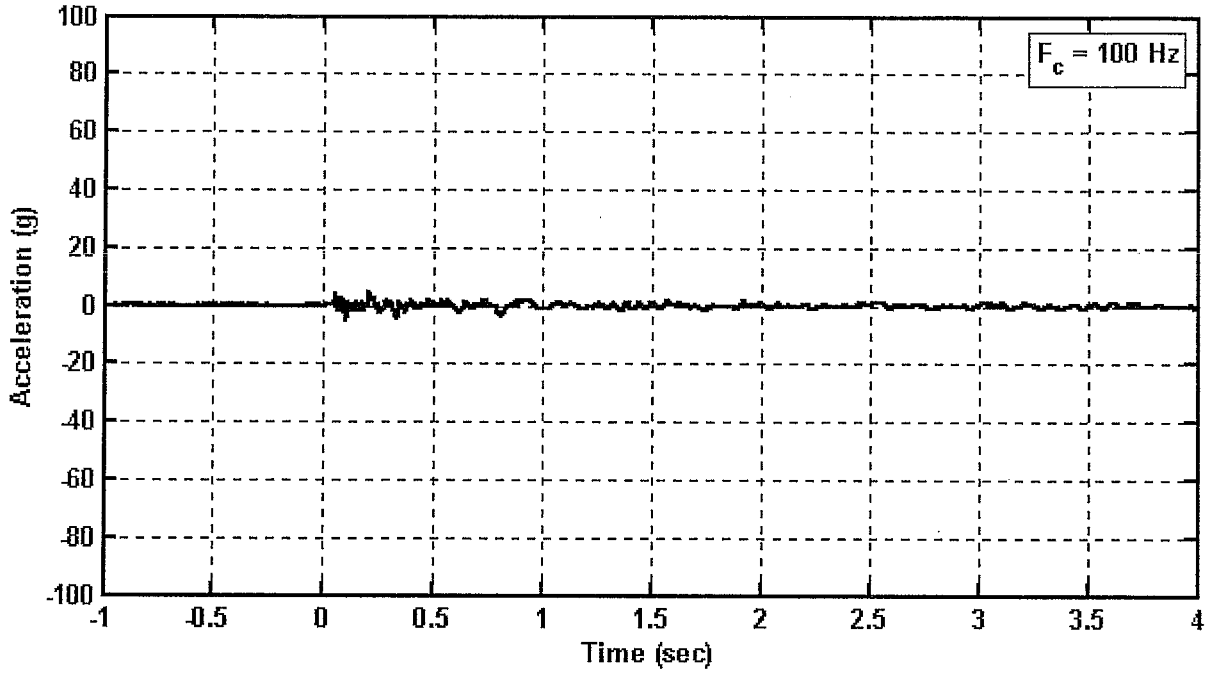


Figure C45. Bullet car 2, position 4, left side, vertical acceleration
Channel Name: B2_L4Z

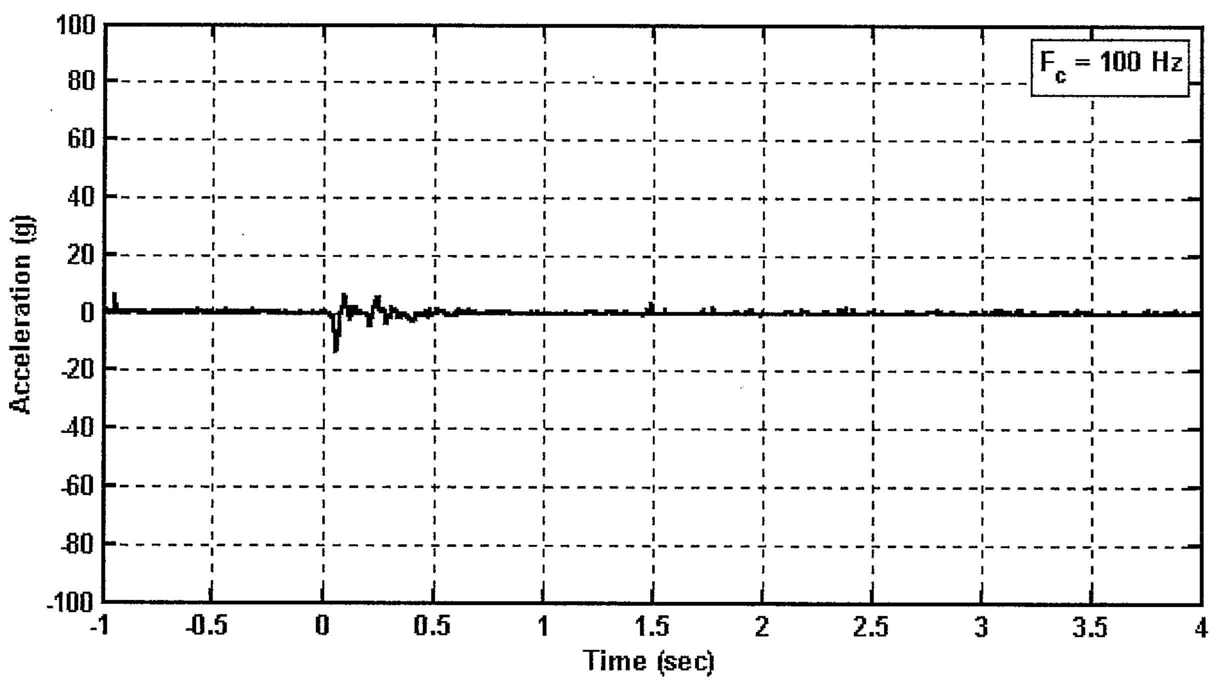


Figure C46. Bullet car 2, position 4, right side, longitudinal acceleration
Channel Name: B2_R4X

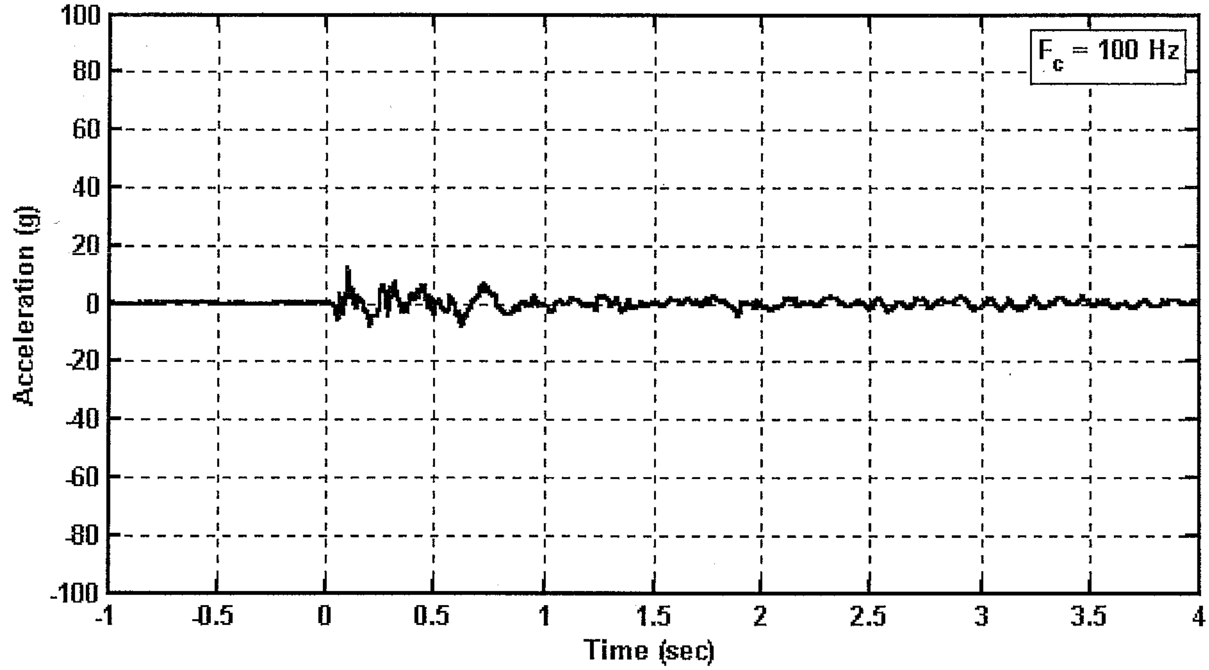


Figure C47. Bullet car 2, position 4, right side, vertical acceleration
Channel Name: B2_R4Z

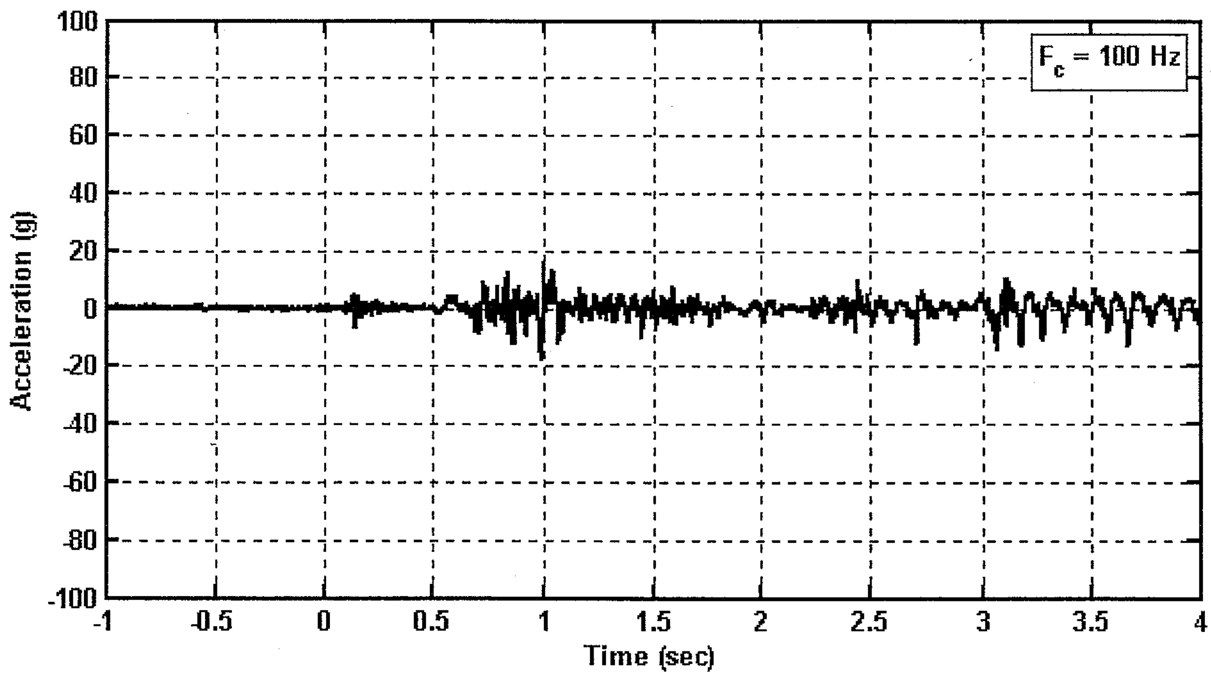


Figure C48. Bullet car 3, A truck, vertical acceleration
Channel Name: B3_BAZ

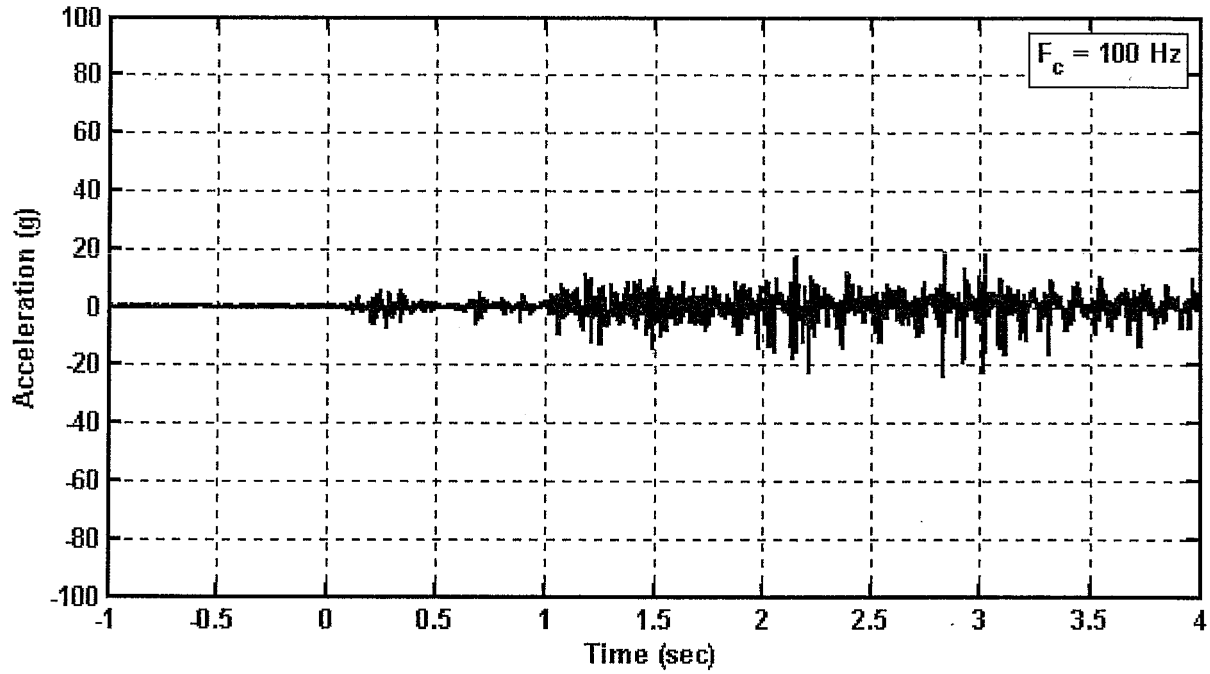


Figure C49. Bullet car 3, B truck, vertical acceleration
Channel Name: B3_BBZ

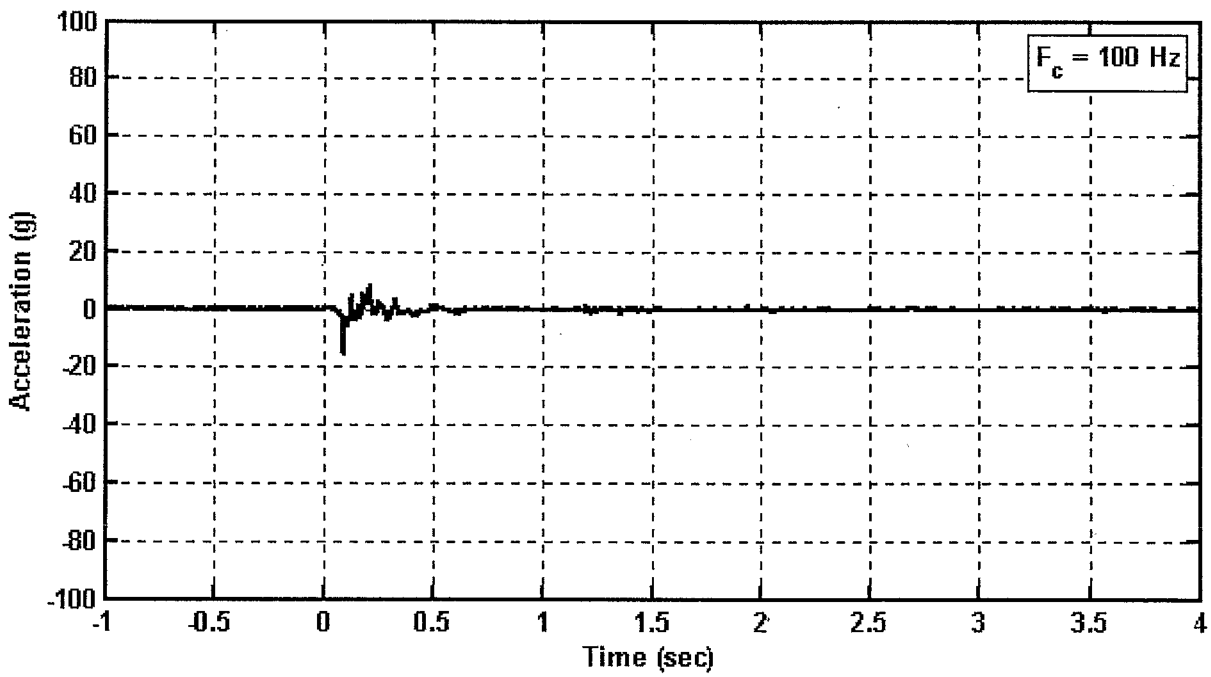


Figure C50. Bullet car 3, position 1, center sill, longitudinal acceleration
Channel Name: B3_C1X

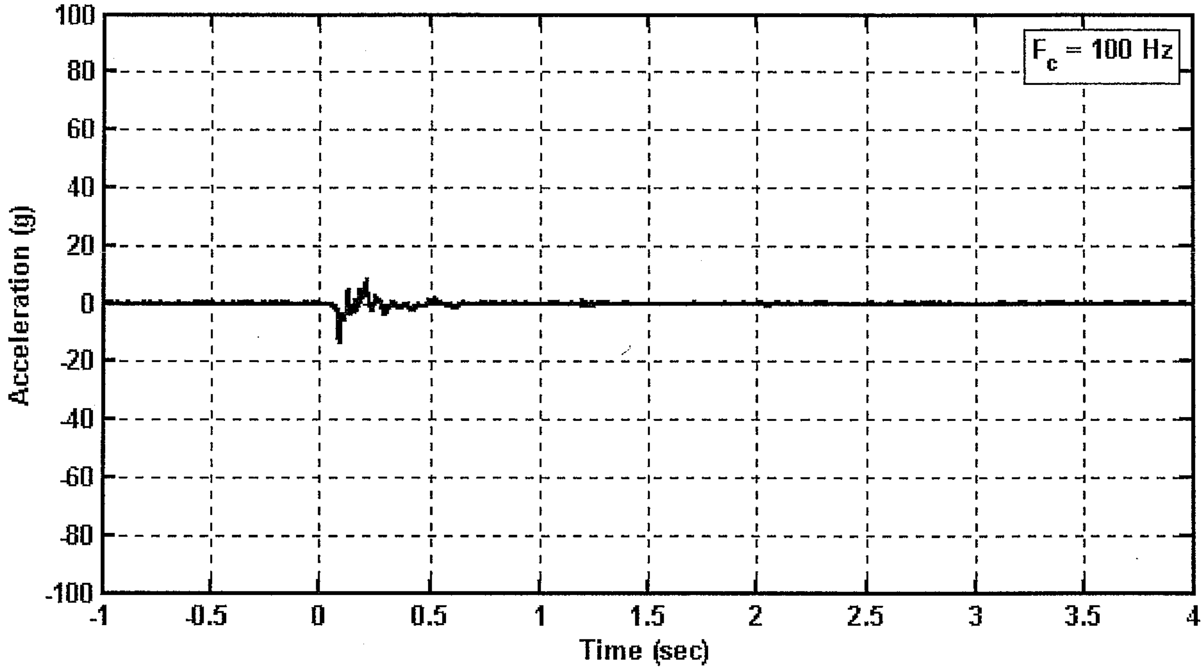


Figure C51. Bullet car 3, position 2, center sill, longitudinal acceleration
Channel Name: B3_C2X

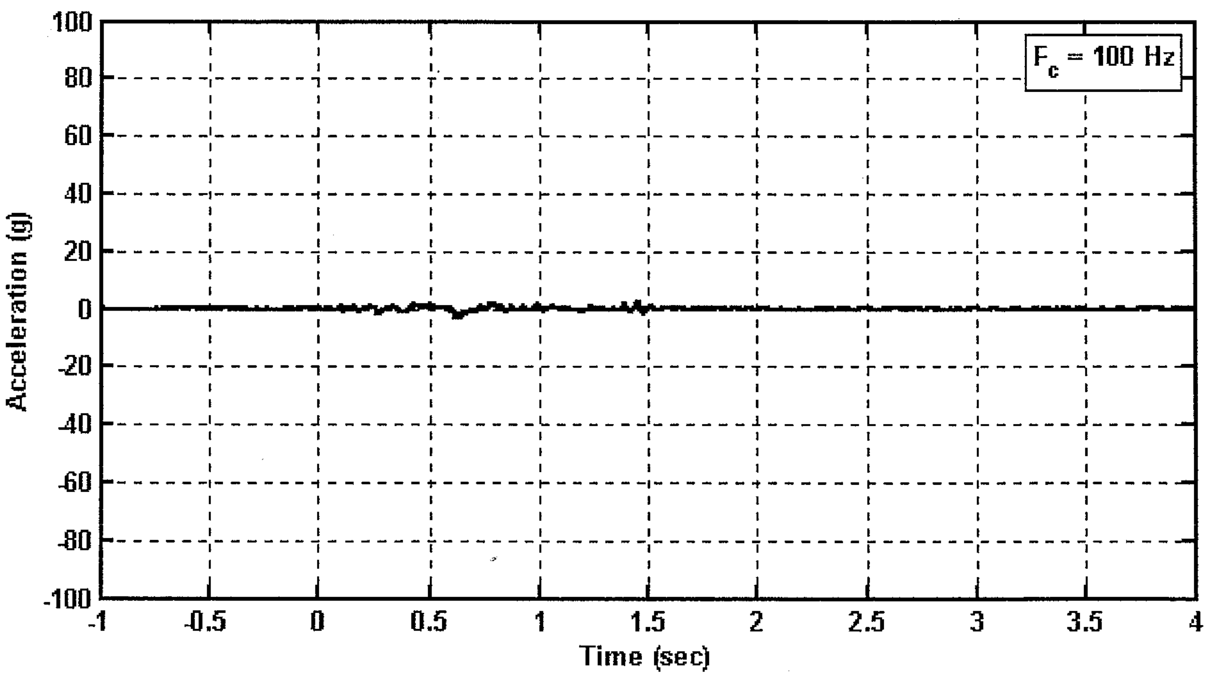


Figure C52. Bullet car 3, position 2, center sill, lateral acceleration
Channel Name: B3_C2Y

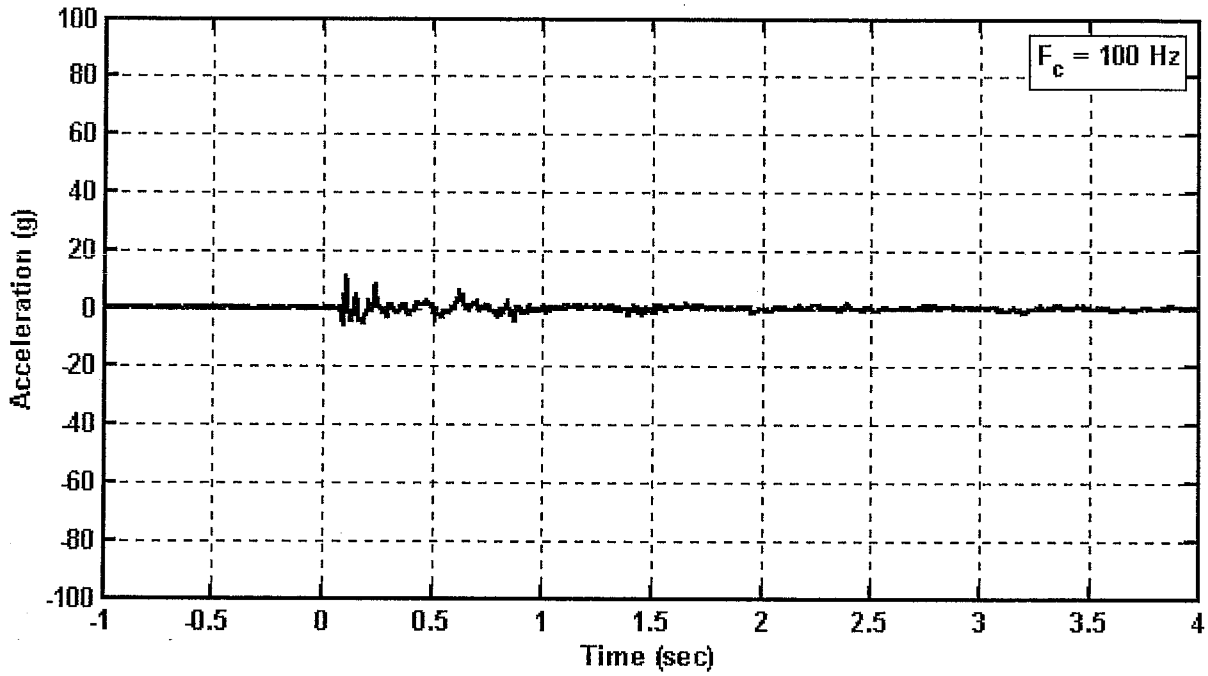


Figure C53. Bullet car 3, position 2, center sill, vertical acceleration
Channel Name: B3_C2Z

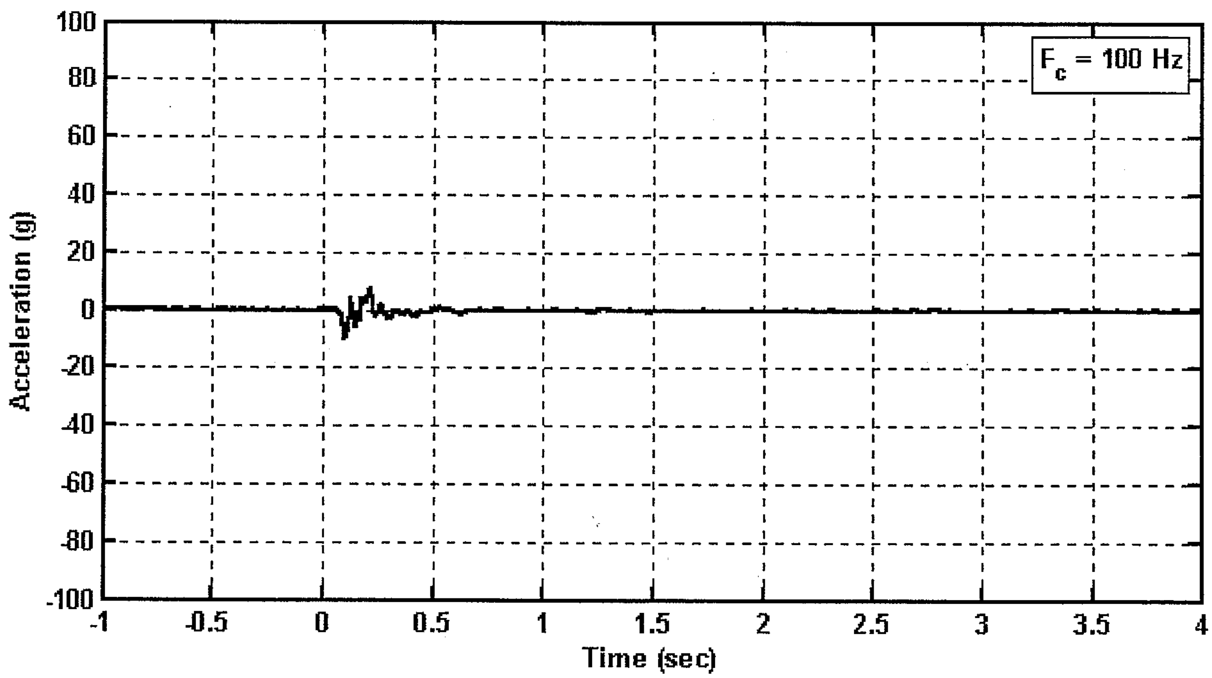


Figure C54. Bullet car 3, position 3, center sill, longitudinal acceleration
Channel Name: B3_C3X

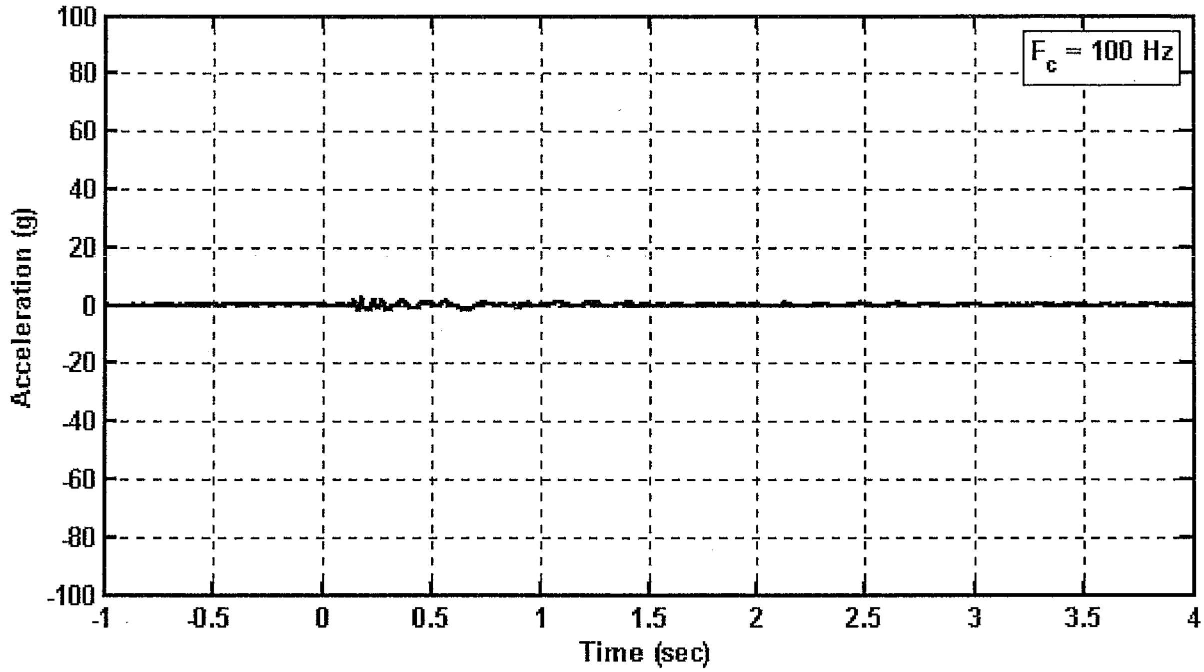


Figure C55. Bullet car 3, position 3, center sill, lateral acceleration
Channel Name: B3_C3Y

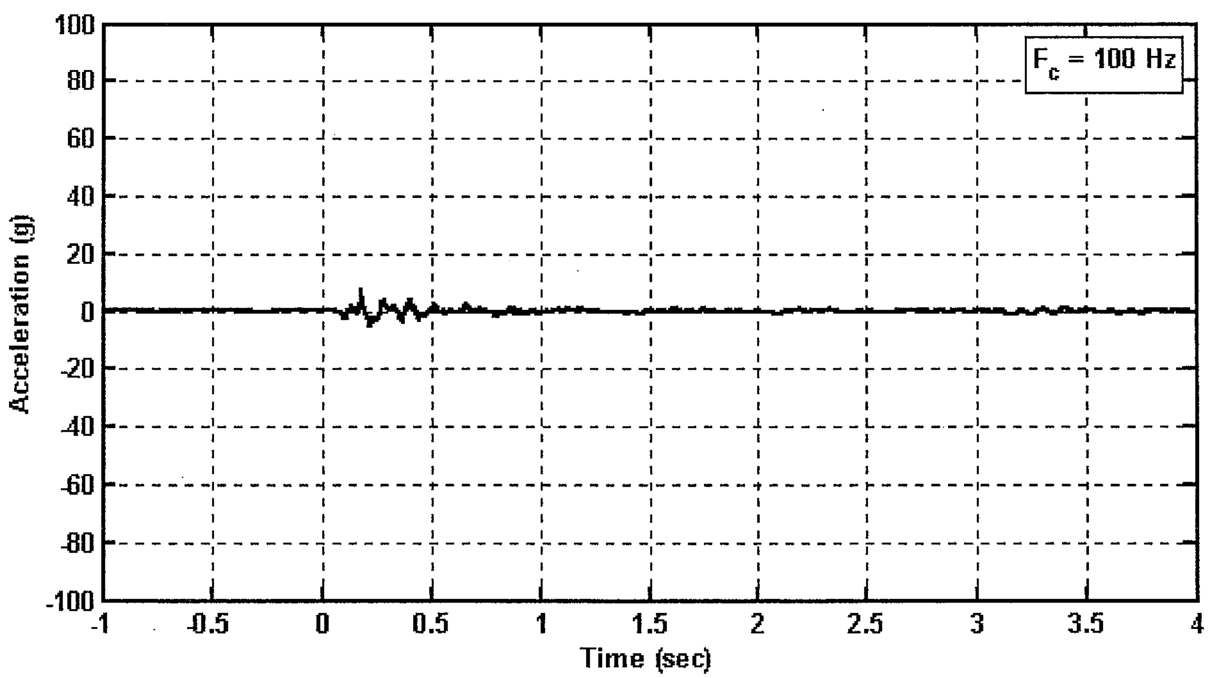


Figure C56. Bullet car 3, position 3, center sill, vertical acceleration
Channel Name: B3_C3Z

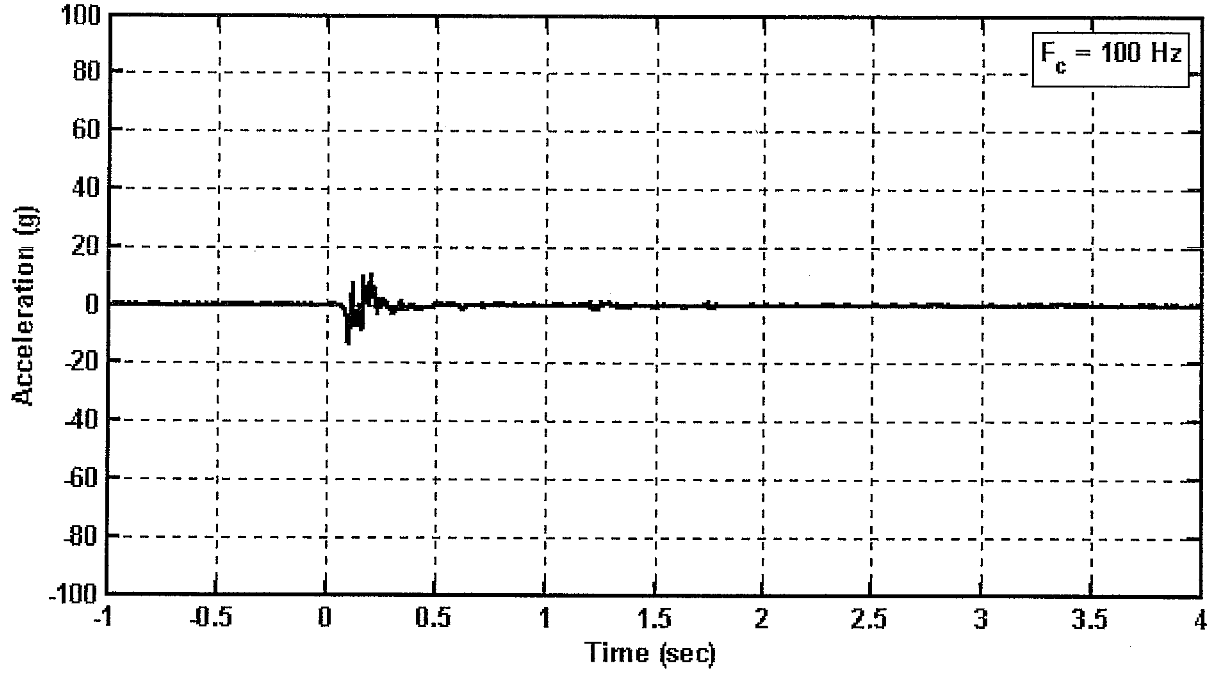


Figure C57. Bullet car 3, position 4, center sill, longitudinal acceleration
Channel Name: B3_C4X

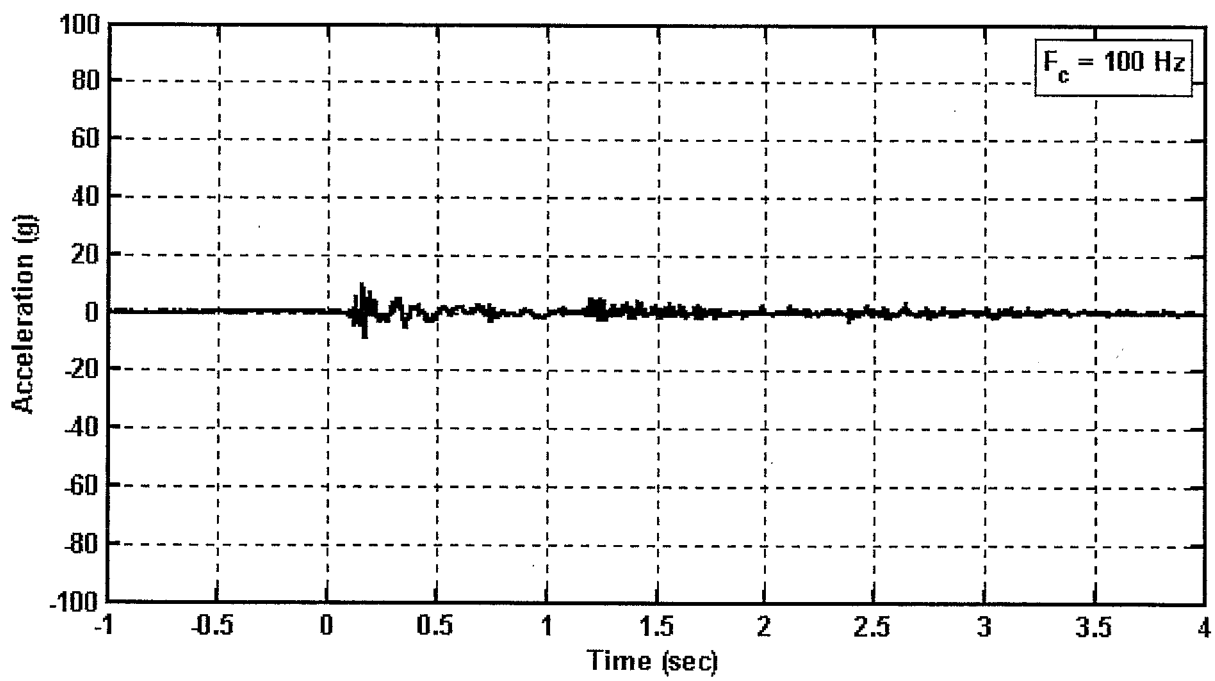


Figure C58. Bullet car 3, position 4, center sill, lateral acceleration
Channel Name: B3_C4Y

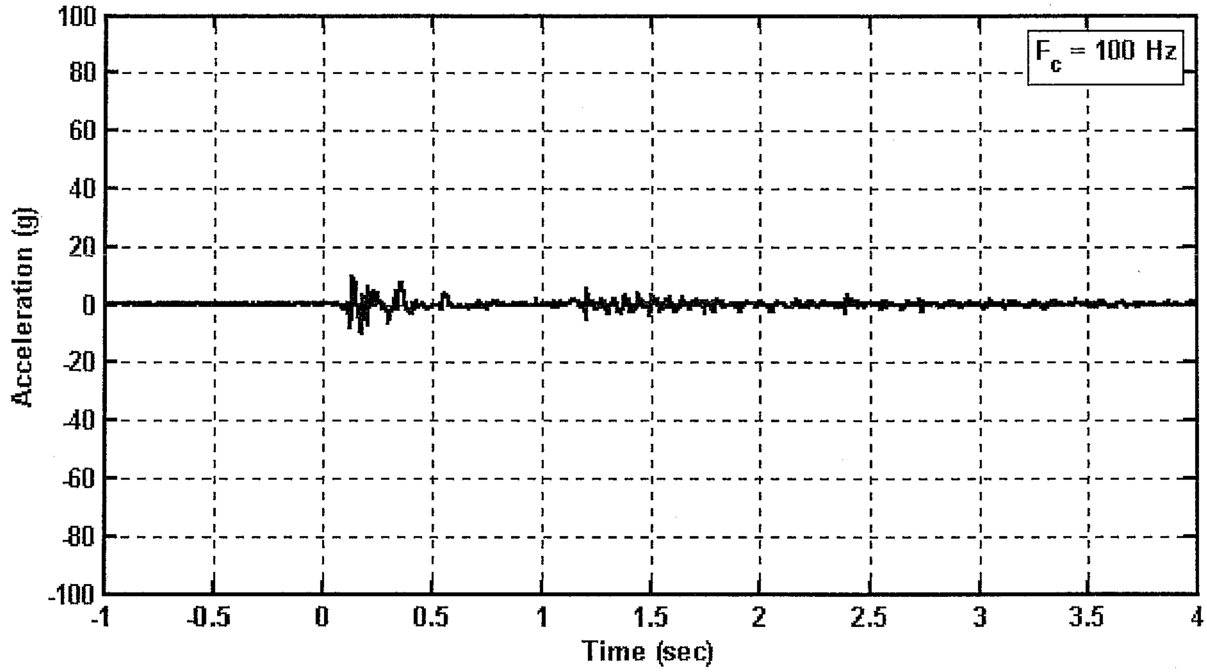


Figure C59. Bullet car 3, position 4, center sill, vertical acceleration
Channel Name: B3_C4Z

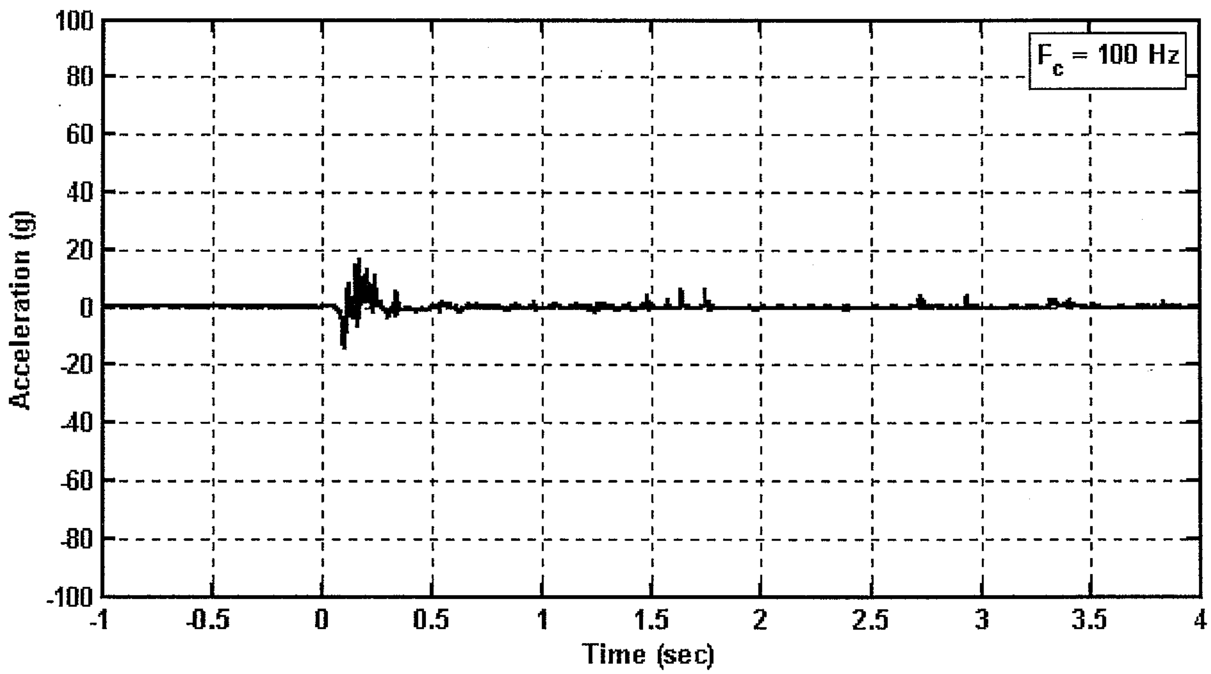


Figure C60. Bullet car 3, position 5, center sill, longitudinal acceleration
Channel Name: B3_C5X

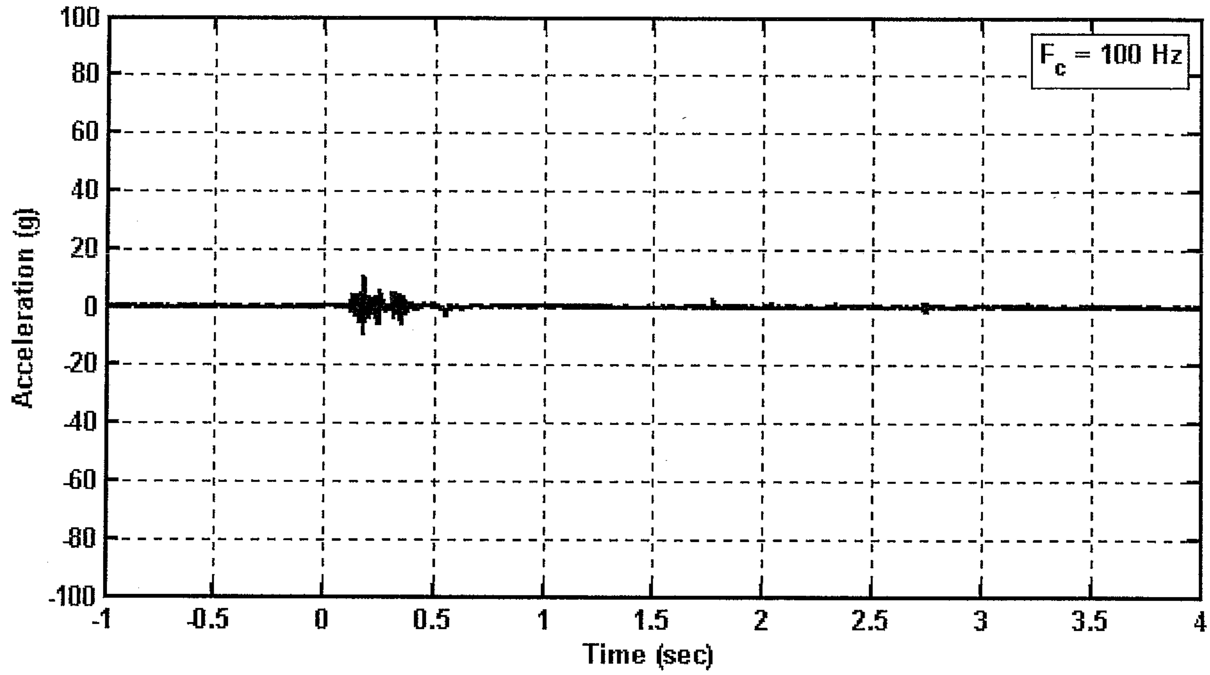


Figure C61. Bullet car 4, A truck, vertical acceleration
Channel Name: B4_BAZ

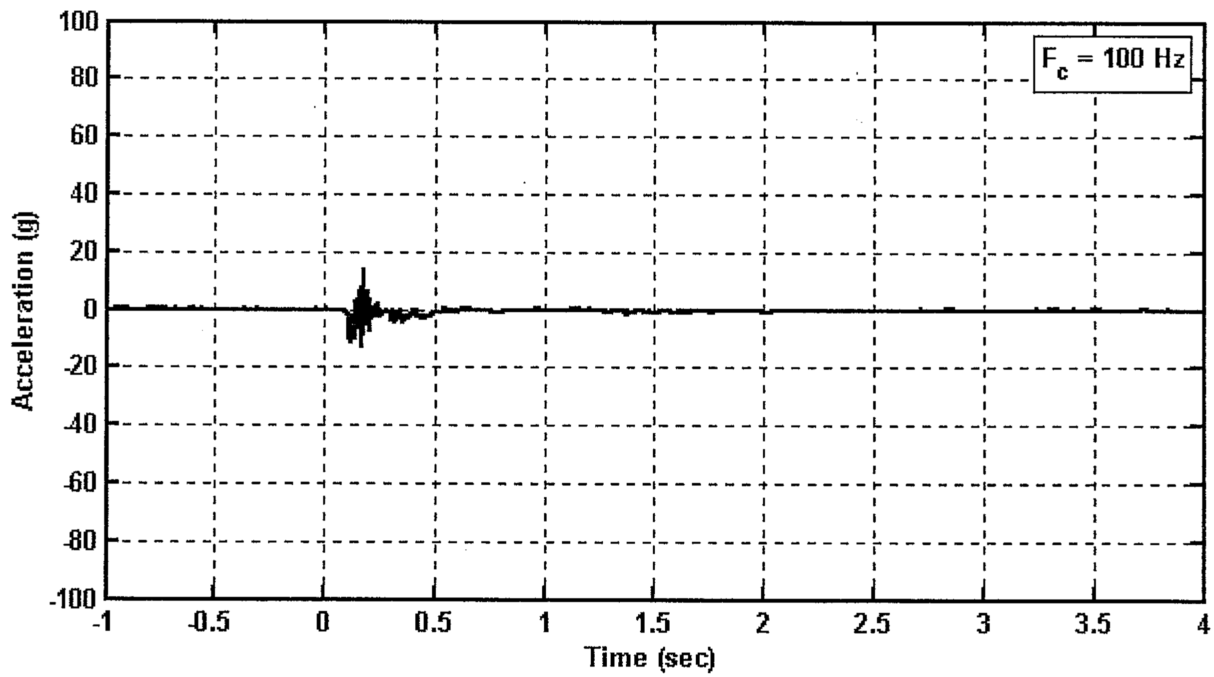


Figure C62. Bullet car 4, position 1, center sill, longitudinal acceleration
Channel Name: B4_C1X

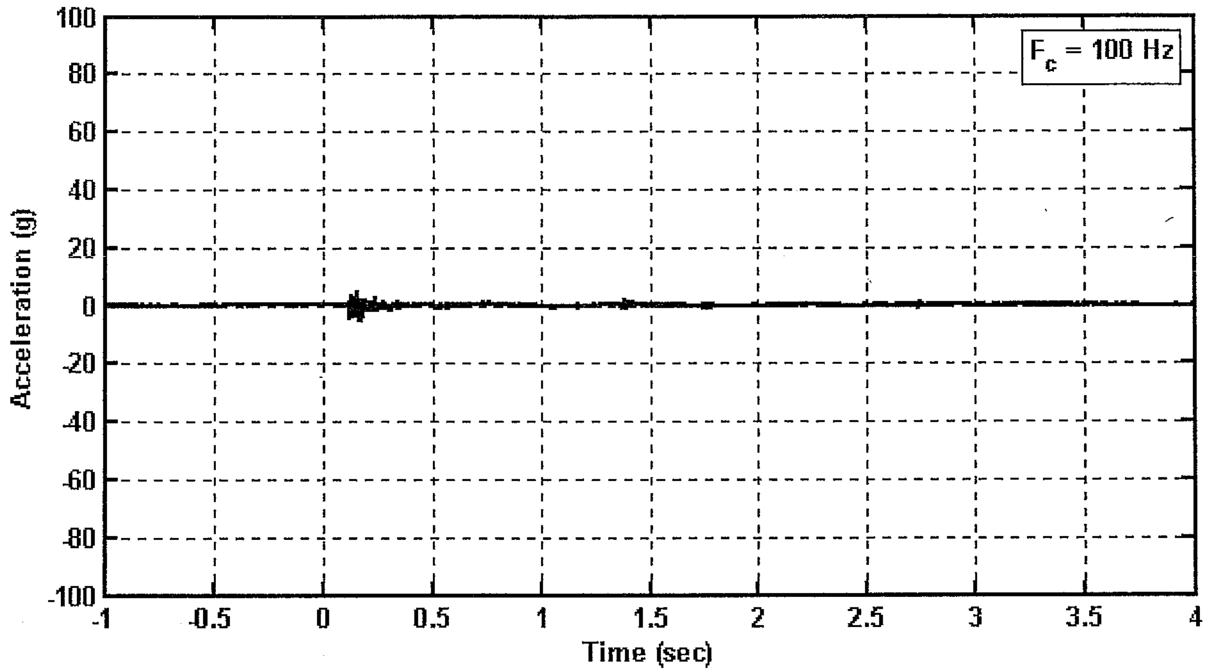


Figure C63. Bullet car 4, position 1, center sill, lateral acceleration
Channel Name: B4_C1Y

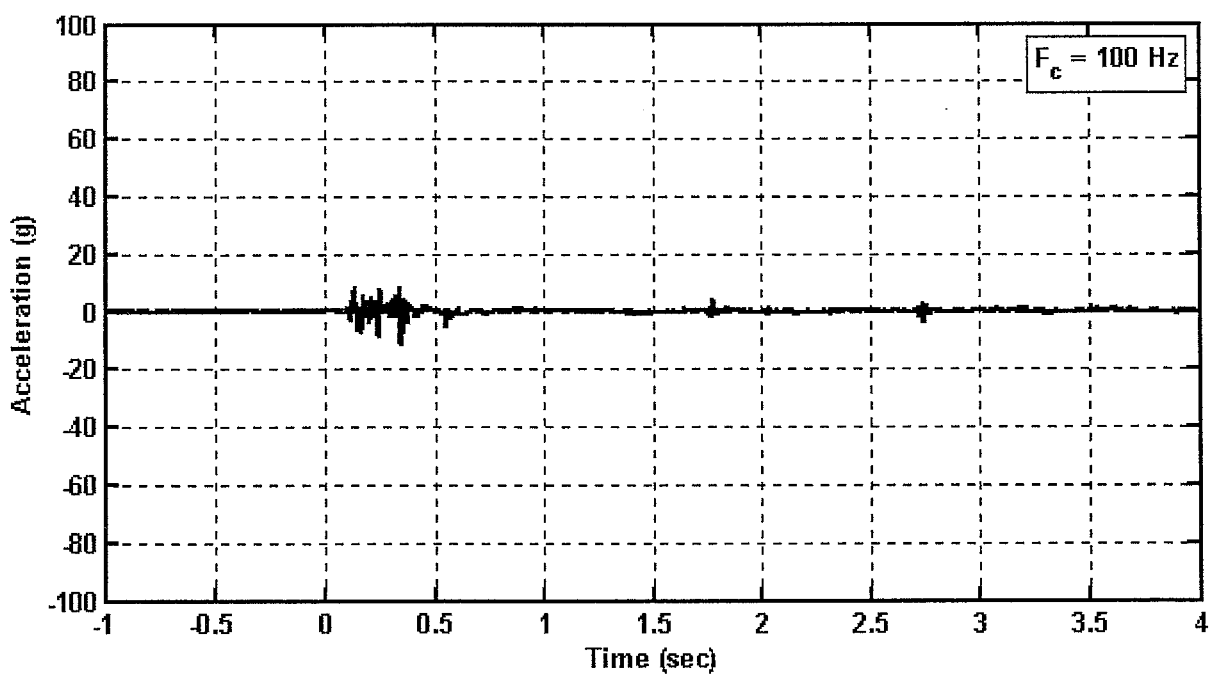


Figure C64. Bullet car 4, position 1, center sill, vertical acceleration
Channel Name: B4_C1Z

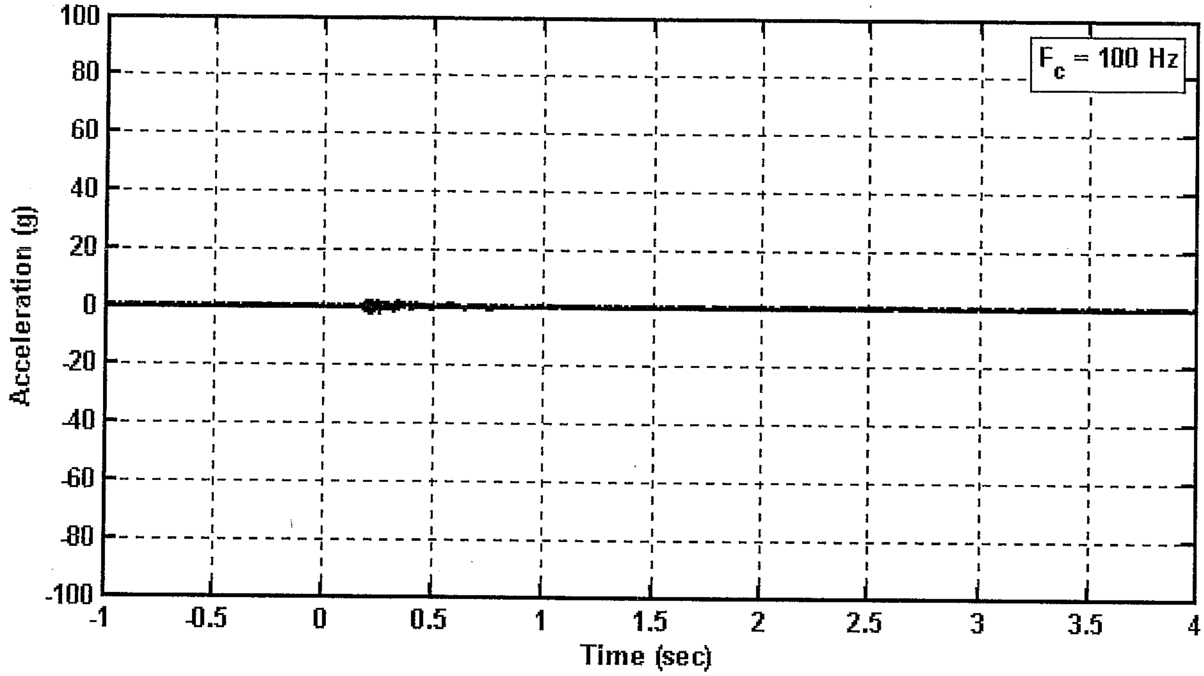


Figure C65. Bullet locomotive, A truck, vertical acceleration
Channel Name: BL_BAZ

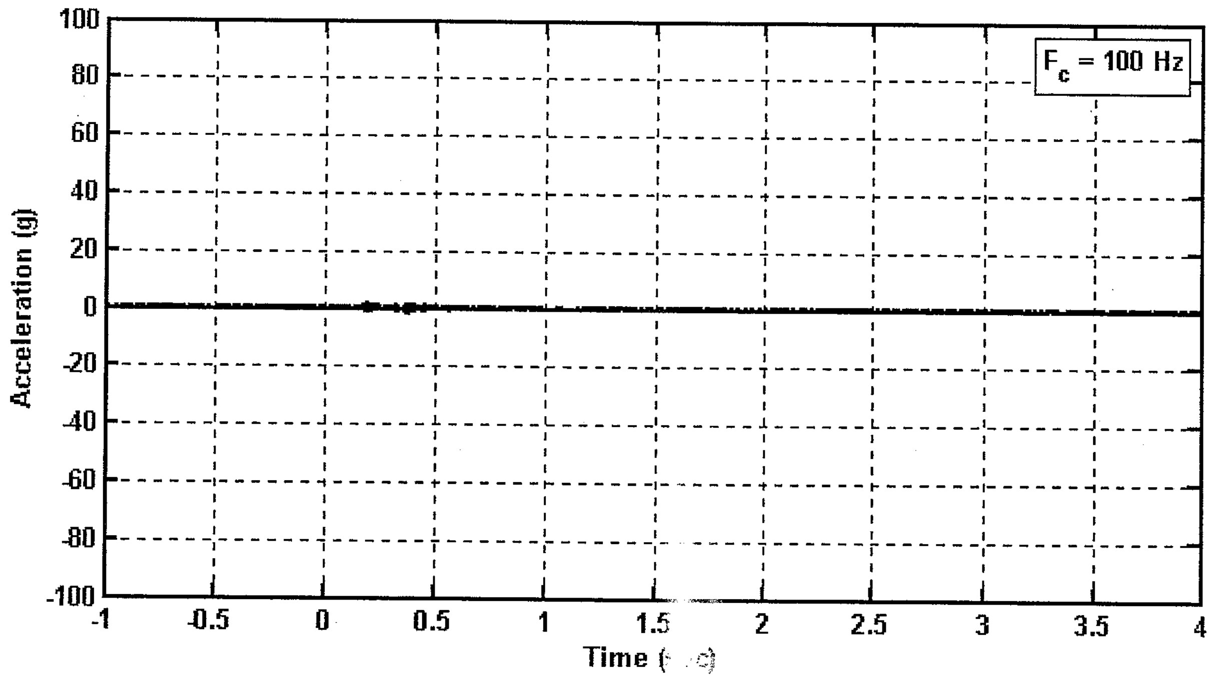


Figure C66. Bullet locomotive, [illegible]ruck, vertical acceleration
Channel Nam[illegible] BL_BBZ

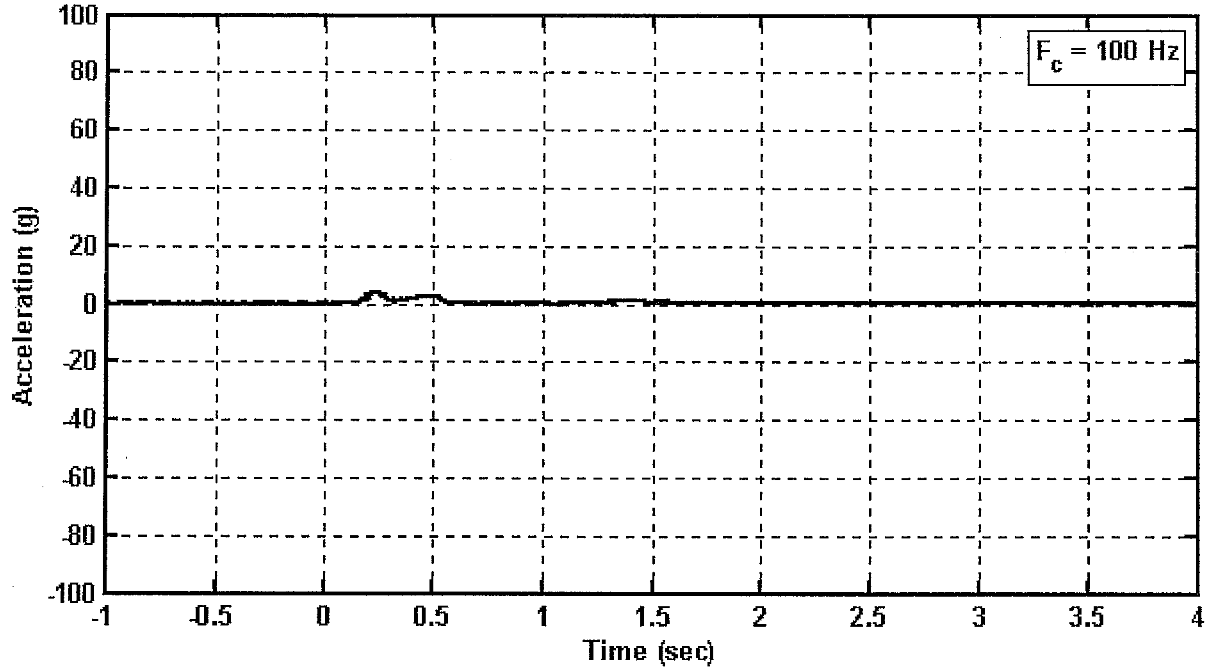


Figure C67. Bullet locomotive, position 1, center sill, longitudinal acceleration
Channel Name: BL_C1X

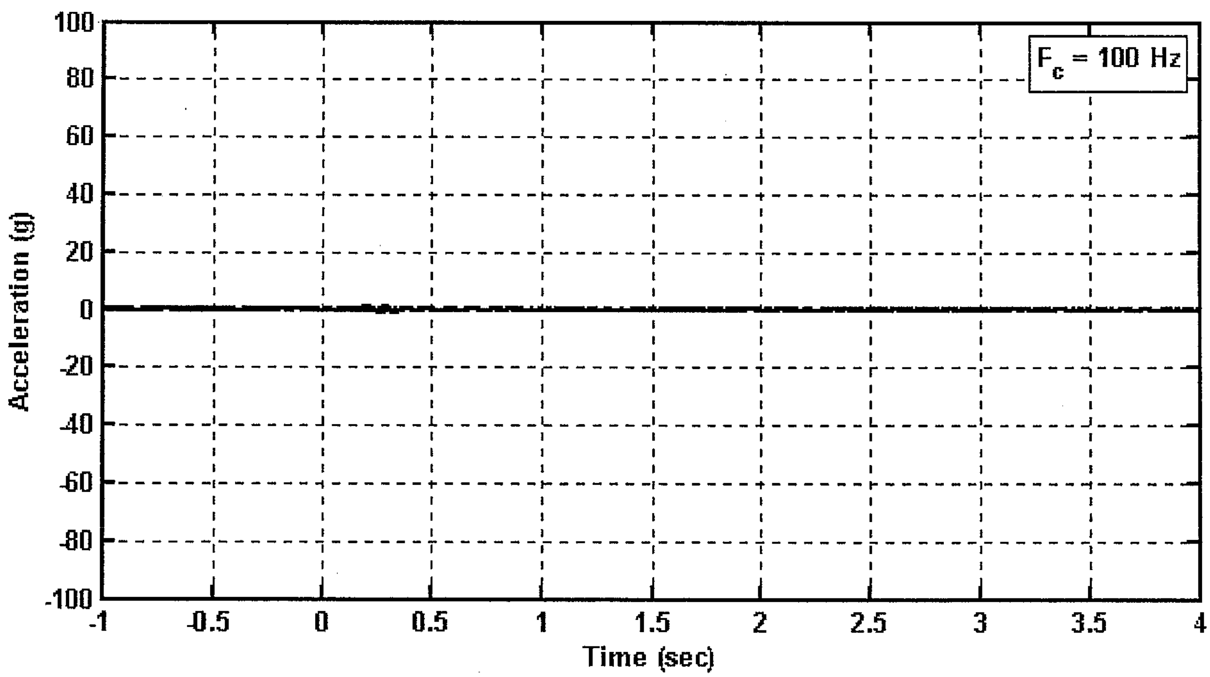


Figure C68. Bullet locomotive, position 1, center sill, lateral acceleration
Channel Name: BL_C1Y

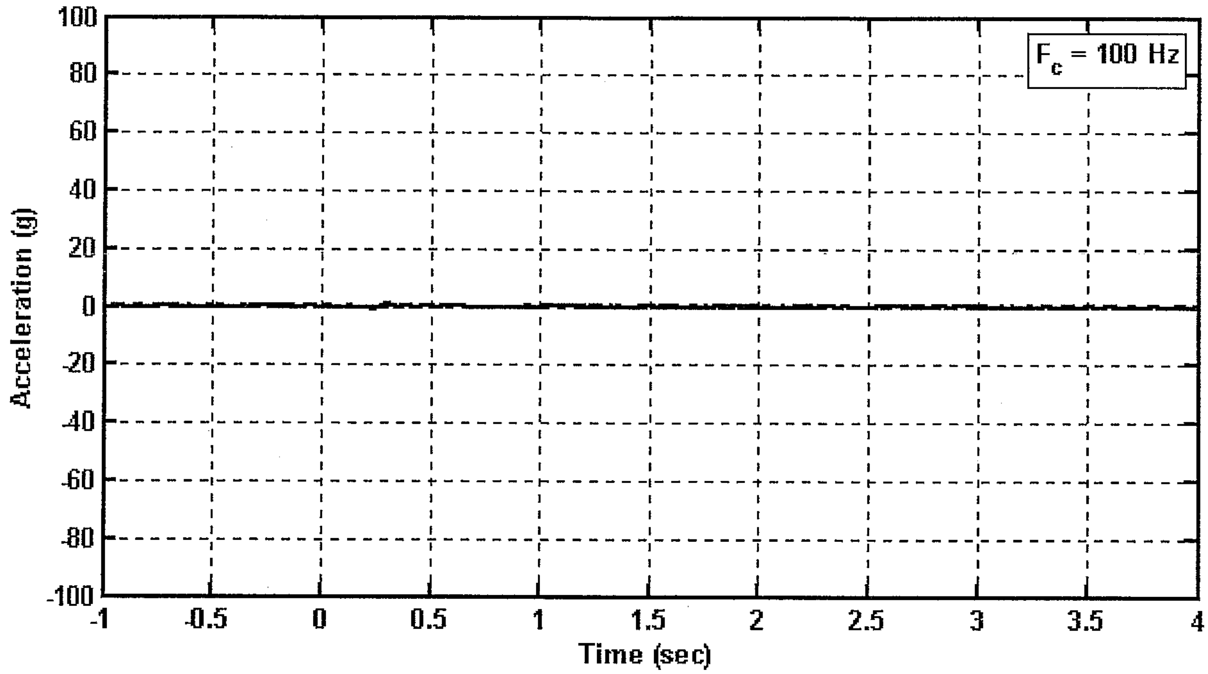


Figure C69. Bullet locomotive, position 1, center sill, vertical acceleration
Channel Name: BL_C1Z

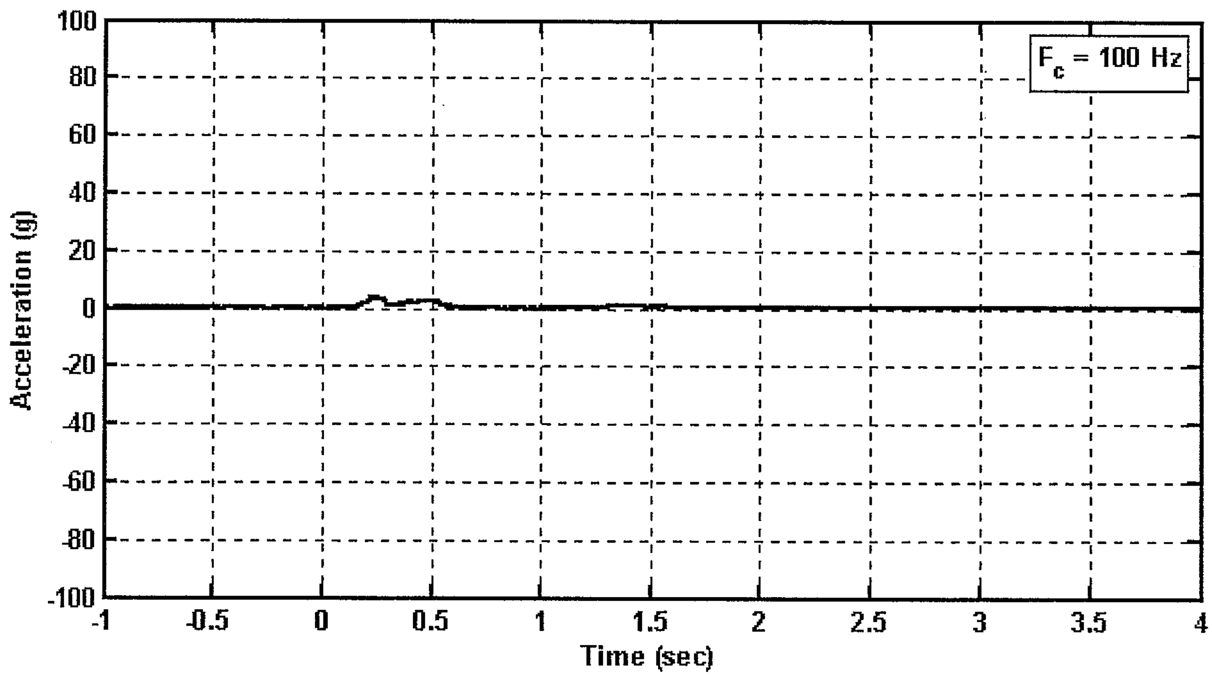


Figure C70. Bullet locomotive, position 2, center sill, longitudinal acceleration
Channel Name: BL_C2X

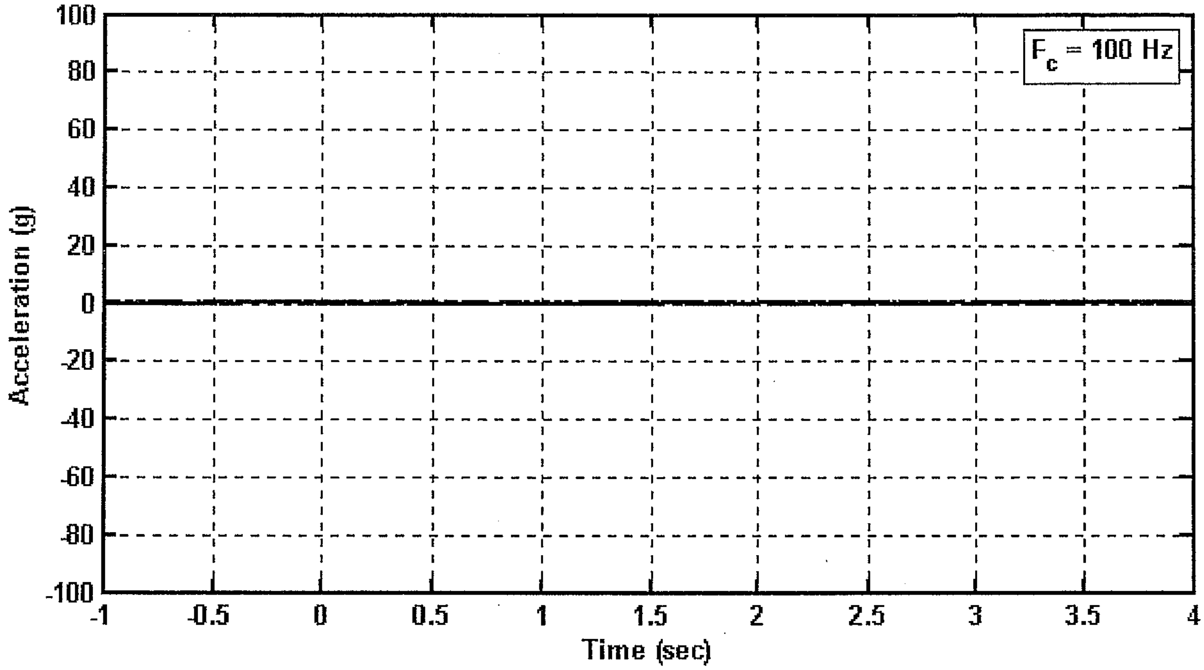


Figure C71. Bullet locomotive, position 2, center sill, lateral acceleration
Channel Name: BL_C2Y

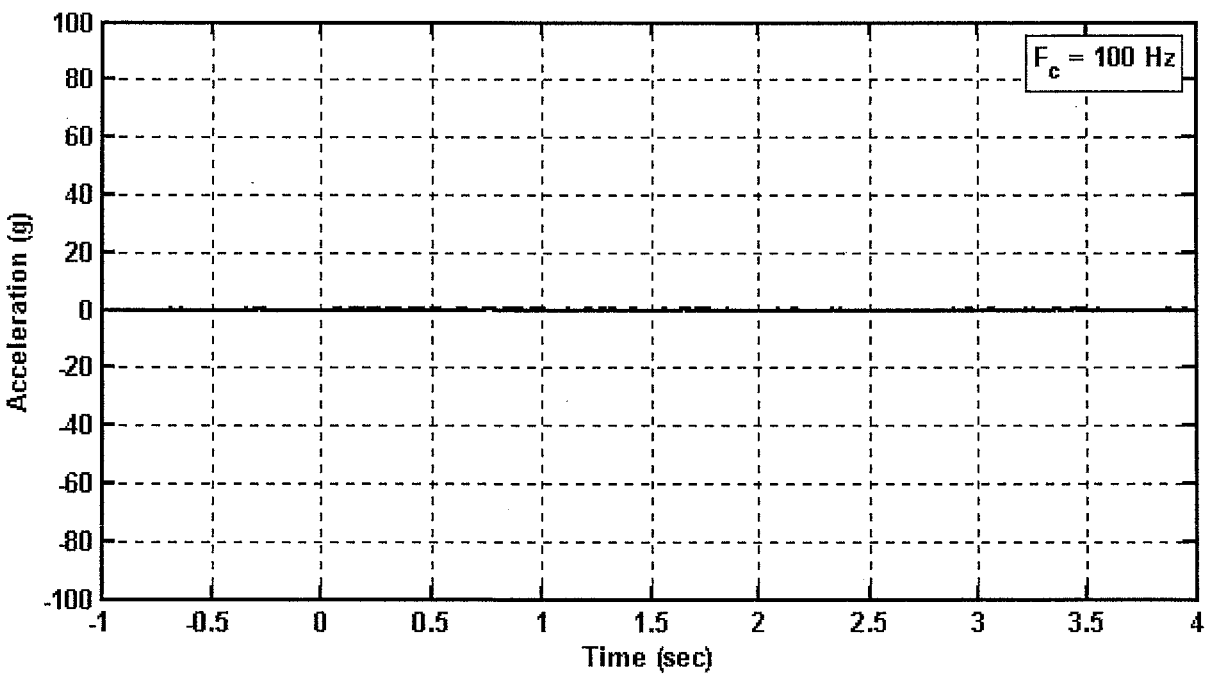


Figure C72. Bullet locomotive, position 2, center sill, vertical acceleration
Channel Name: BL_C2Z

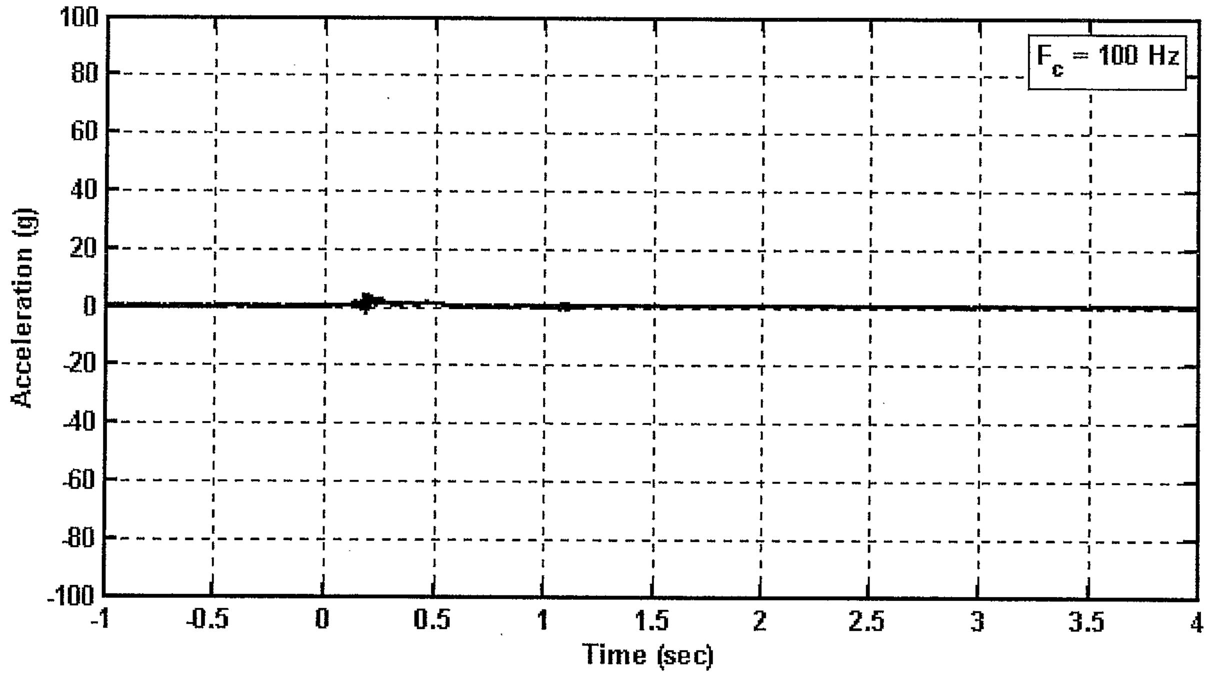


Figure C73. Bullet locomotive, position 3, center sill, longitudinal acceleration
Channel Name: BL_C3X

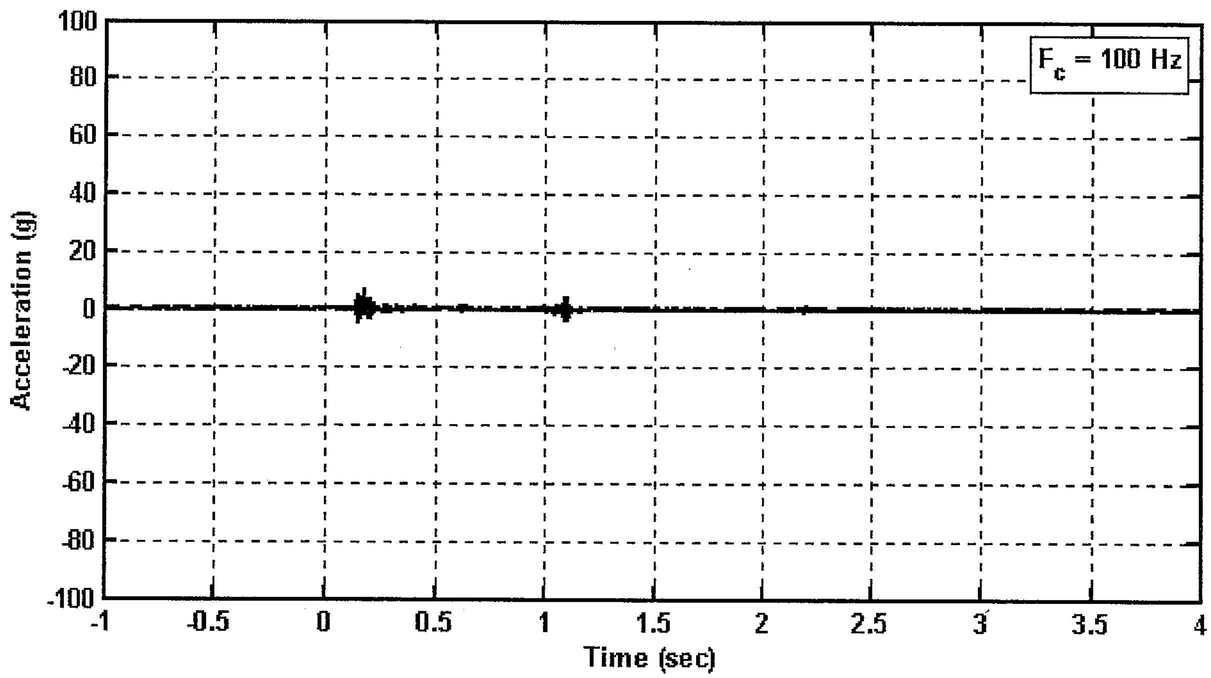


Figure C74. Bullet locomotive, position 3, center sill, lateral acceleration
Channel Name: BL_C3Y

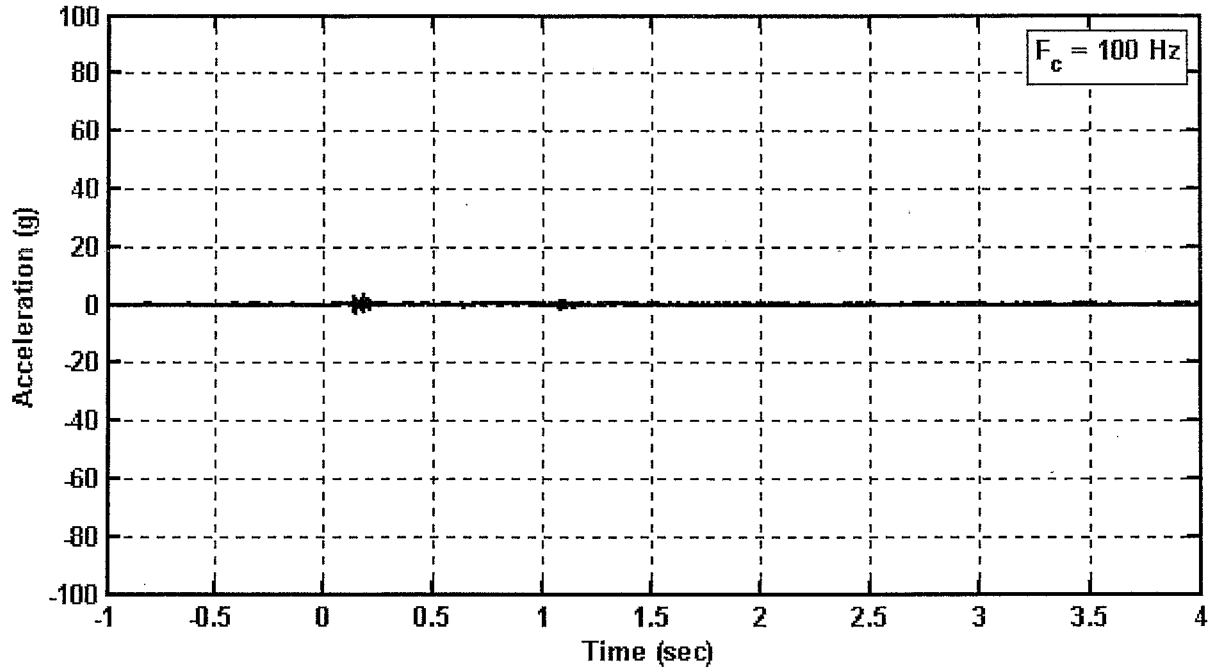


Figure C75. Bullet locomotive, position 3, center sill, vertical acceleration
Channel Name: BL_C3Z

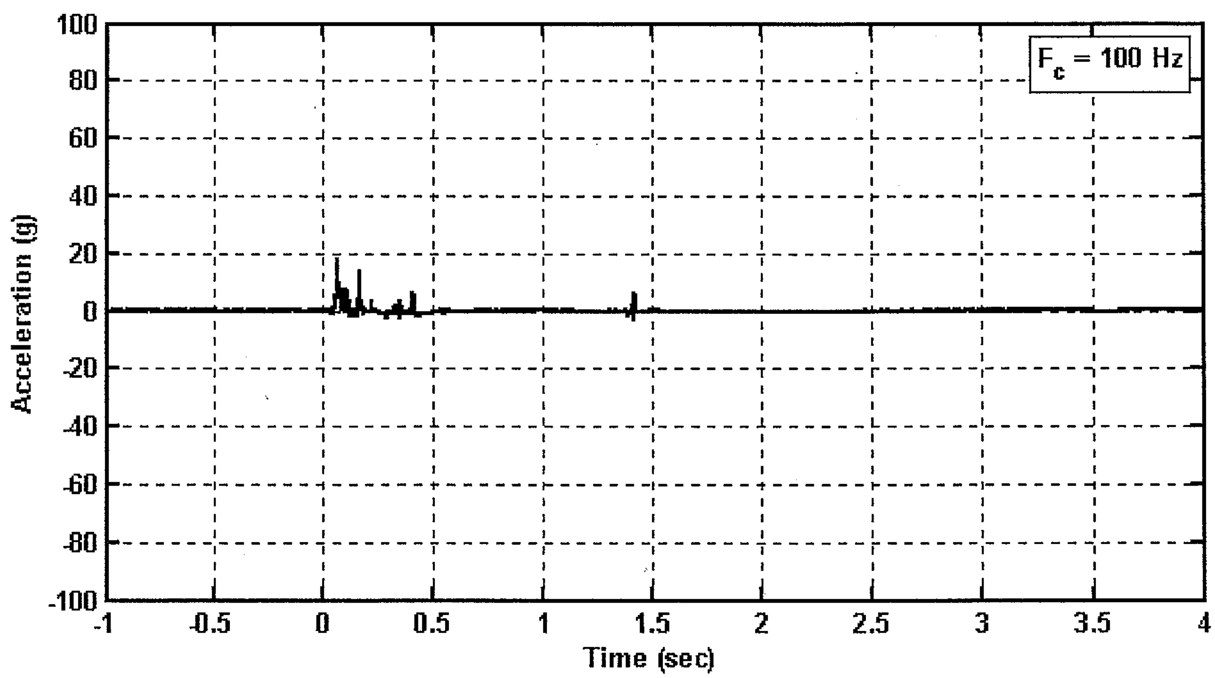


Figure C76. Target car 1, position 1, center sill, longitudinal acceleration
Channel Name: SH1_C1X

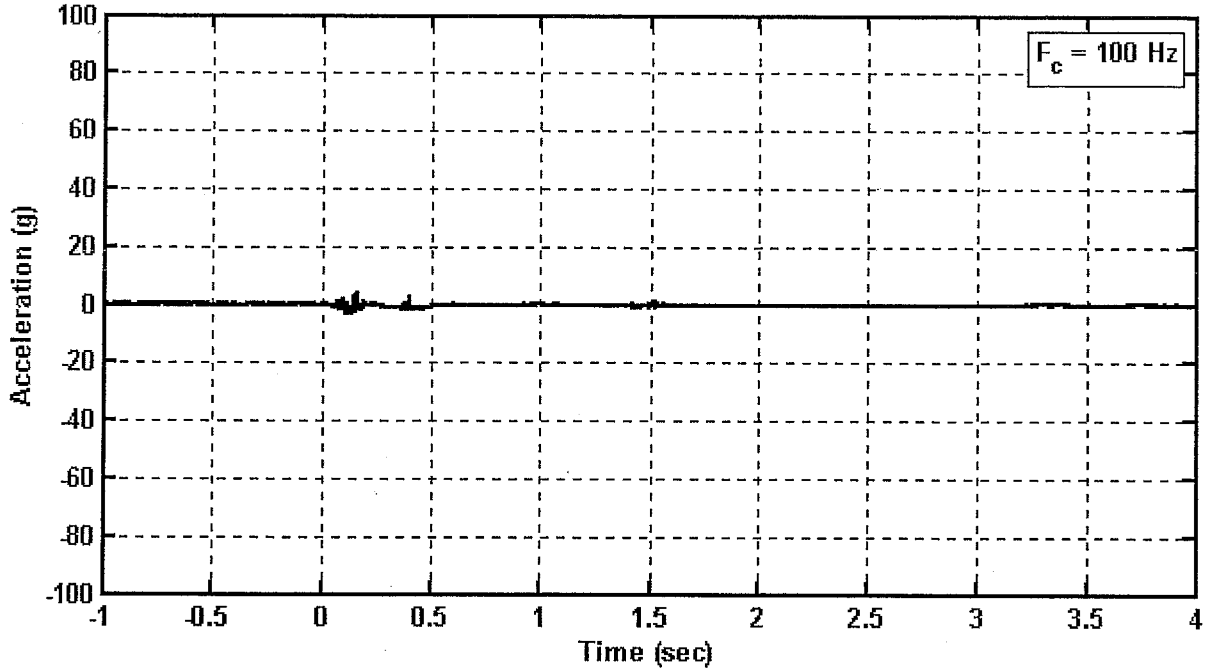


Figure C77. Target car 1, position 2, center sill, longitudinal acceleration
Channel Name: SH1_C2X

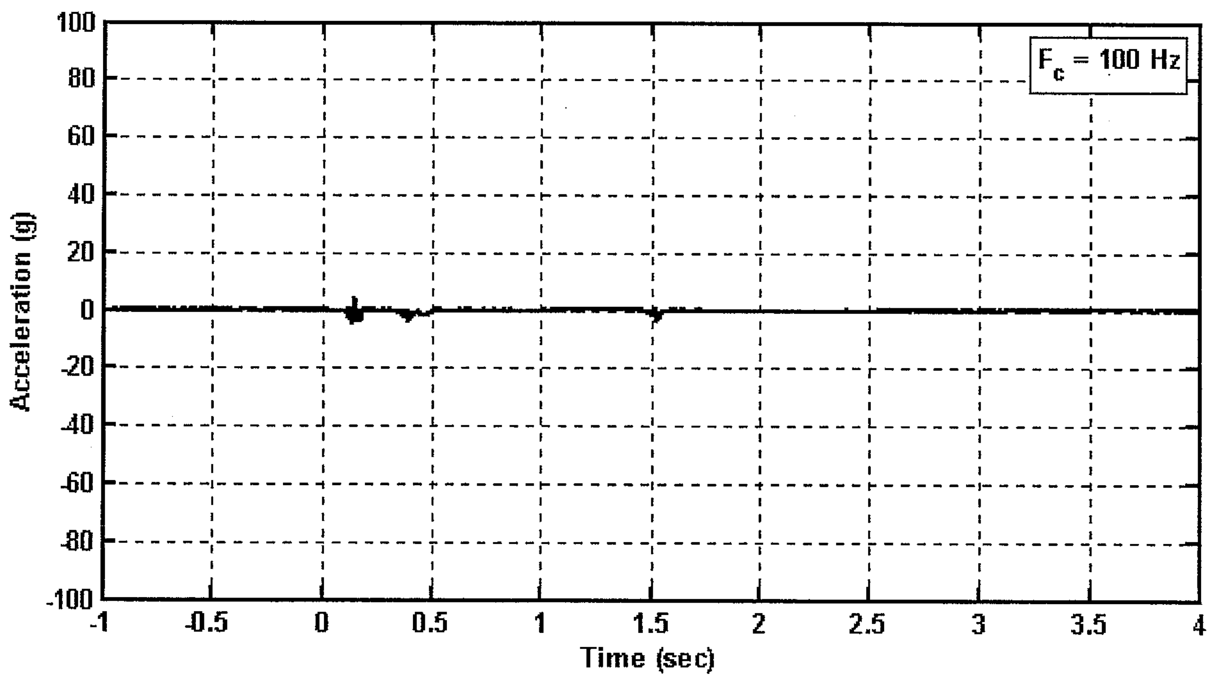


Figure C78. Target car 2, position 1, center sill, longitudinal acceleration
Channel Name: SH2_C1X

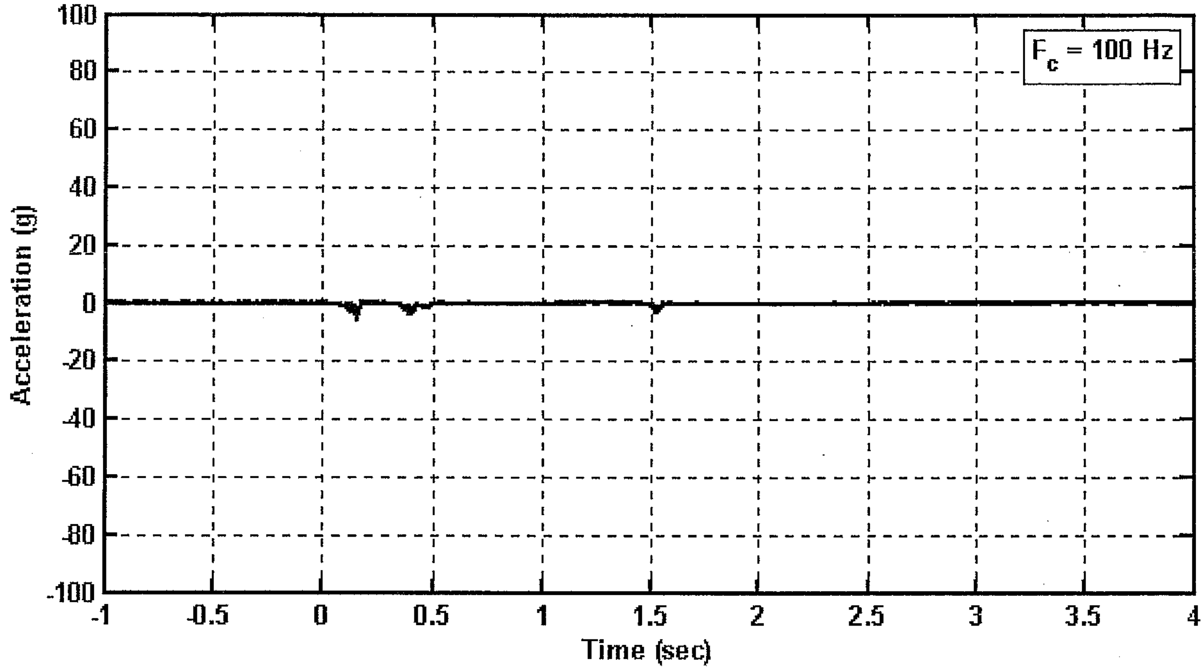


Figure C79. Target car 2, position 2, center sill, longitudinal acceleration
Channel Name: SH2_C2X

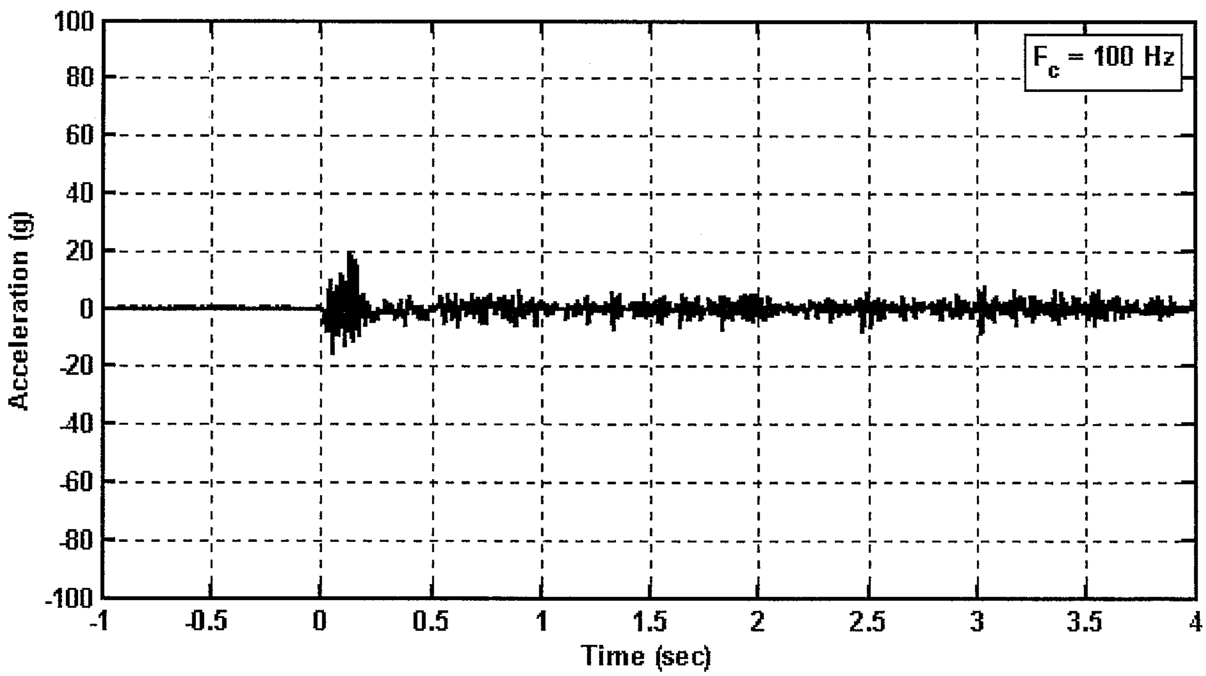


Figure C80. Target locomotive, A truck, longitudinal acceleration
Channel Name: SL_BAX

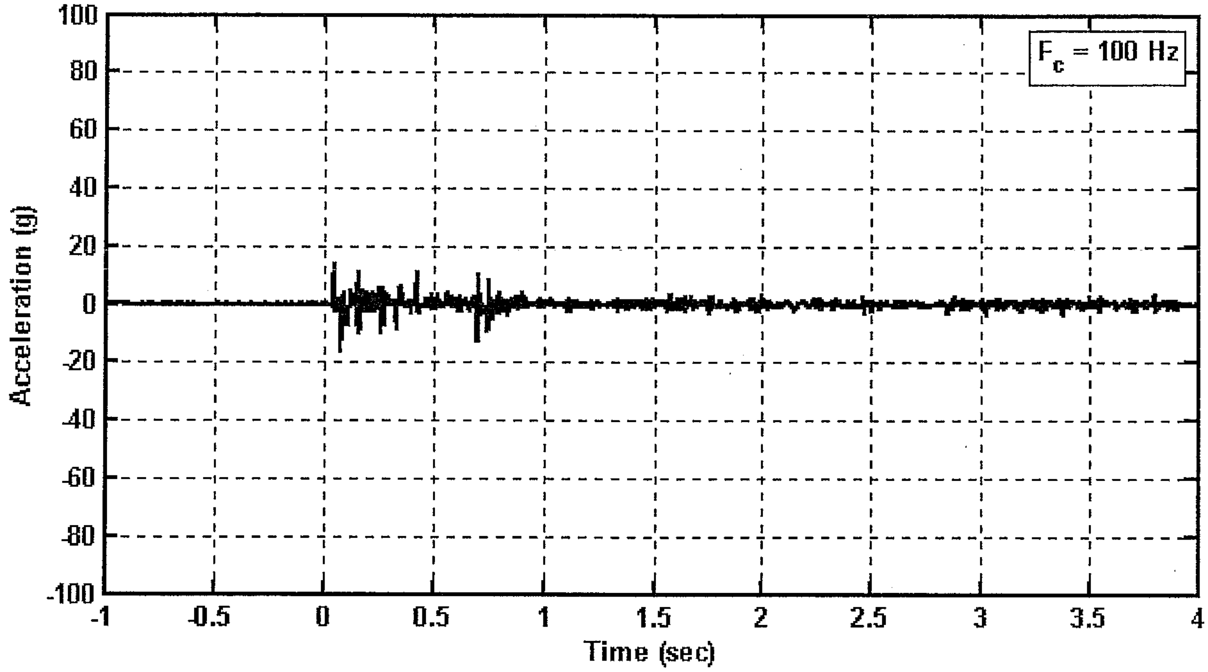


Figure C81. Target locomotive, A truck, lateral acceleration
Channel Name: SL_BAY

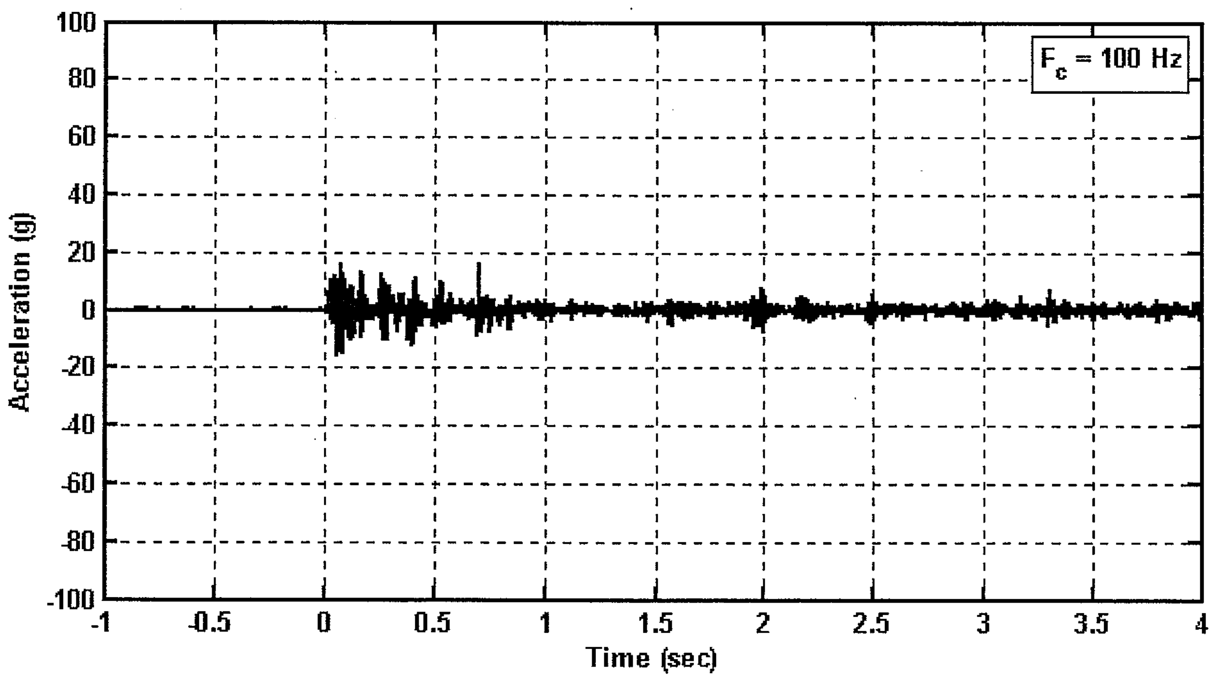


Figure C82. Target locomotive, A truck, vertical acceleration
Channel Name: SL_BAZ

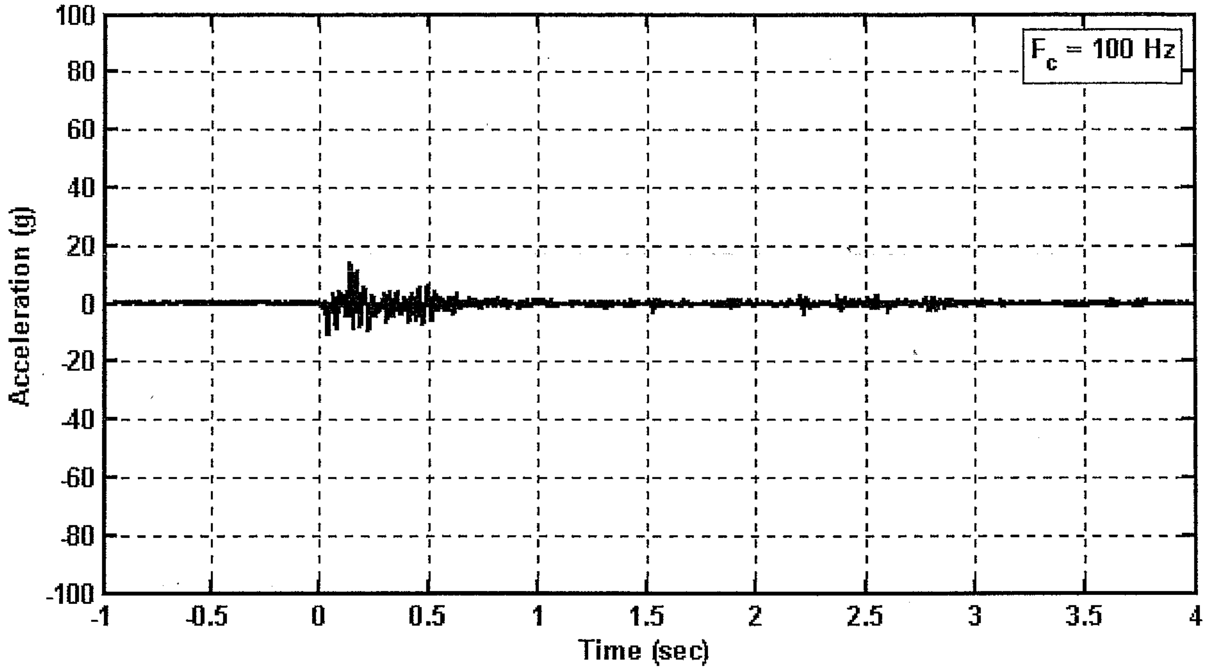


Figure C83. Target locomotive, B truck, longitudinal acceleration
Channel Name: SL_BBX

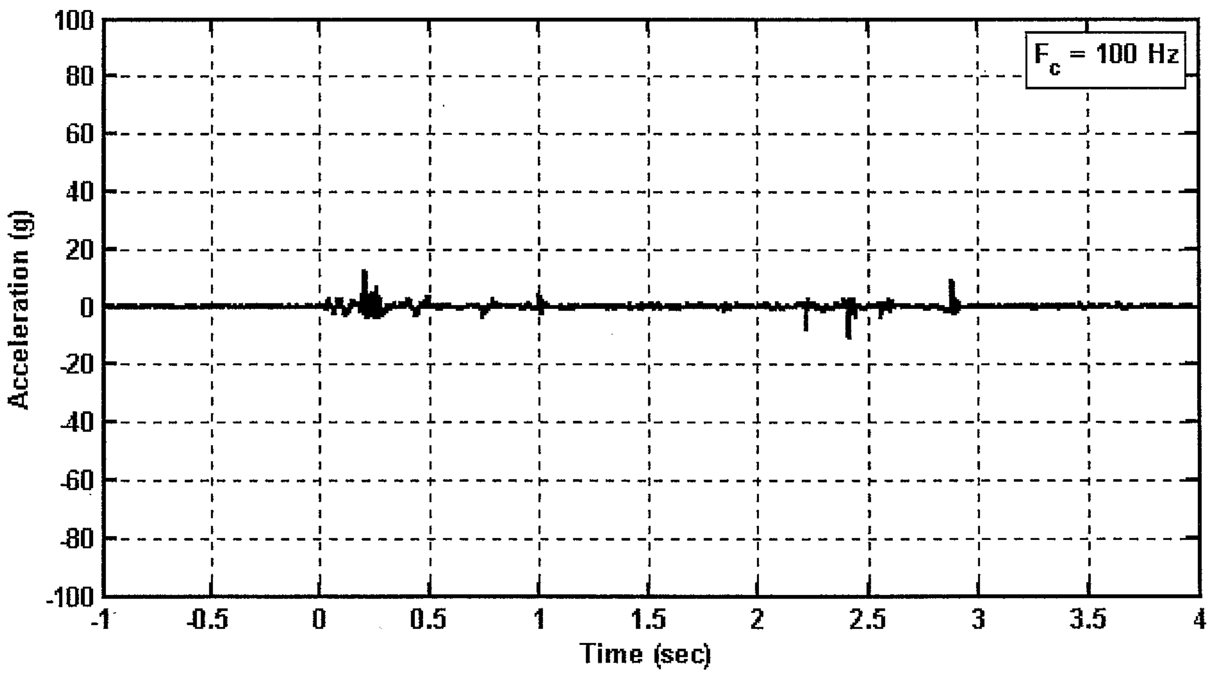


Figure C84. Target locomotive, B truck, lateral acceleration
Channel Name: SL_BBY

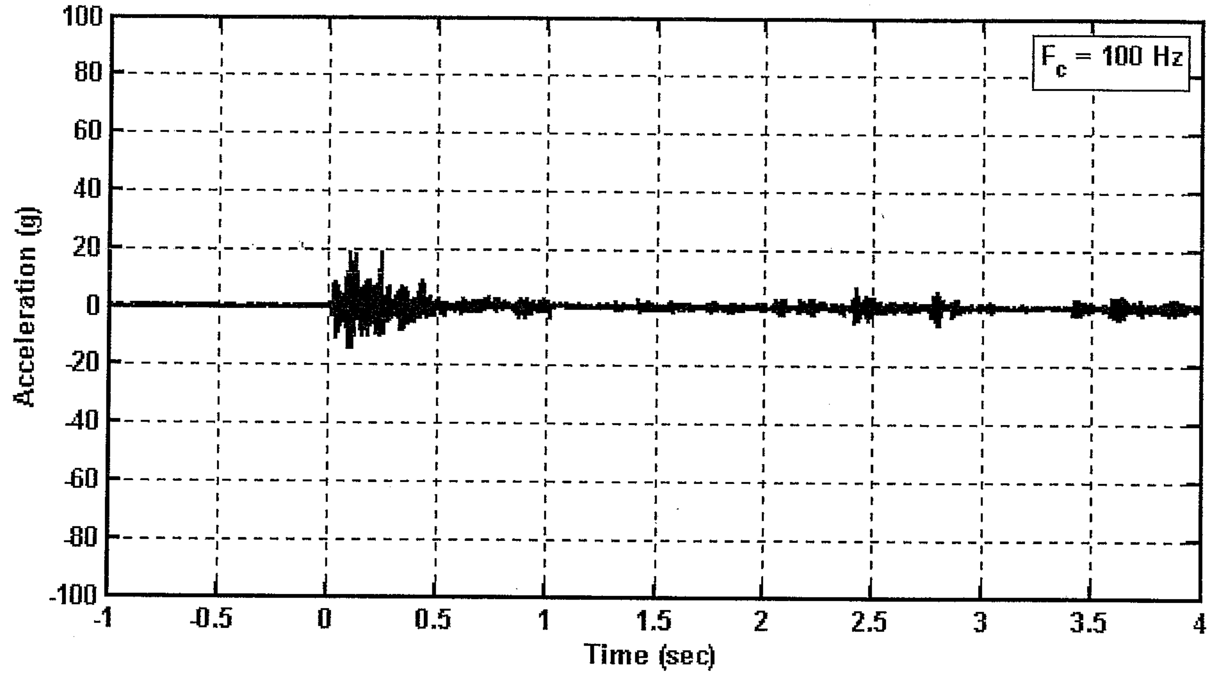


Figure C85. Target locomotive, B truck, vertical acceleration
Channel Name: SL_BBZ

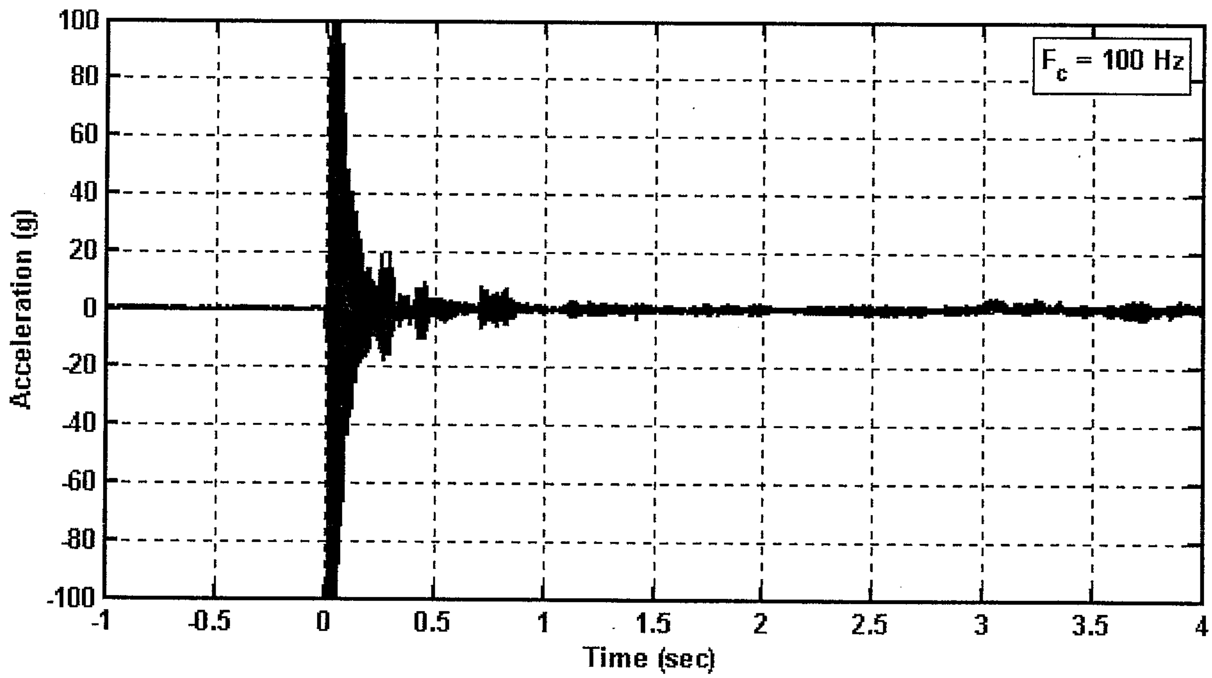


Figure C86. Target locomotive, position 1, center sill, longitudinal acceleration
Channel Name: SL_C1X

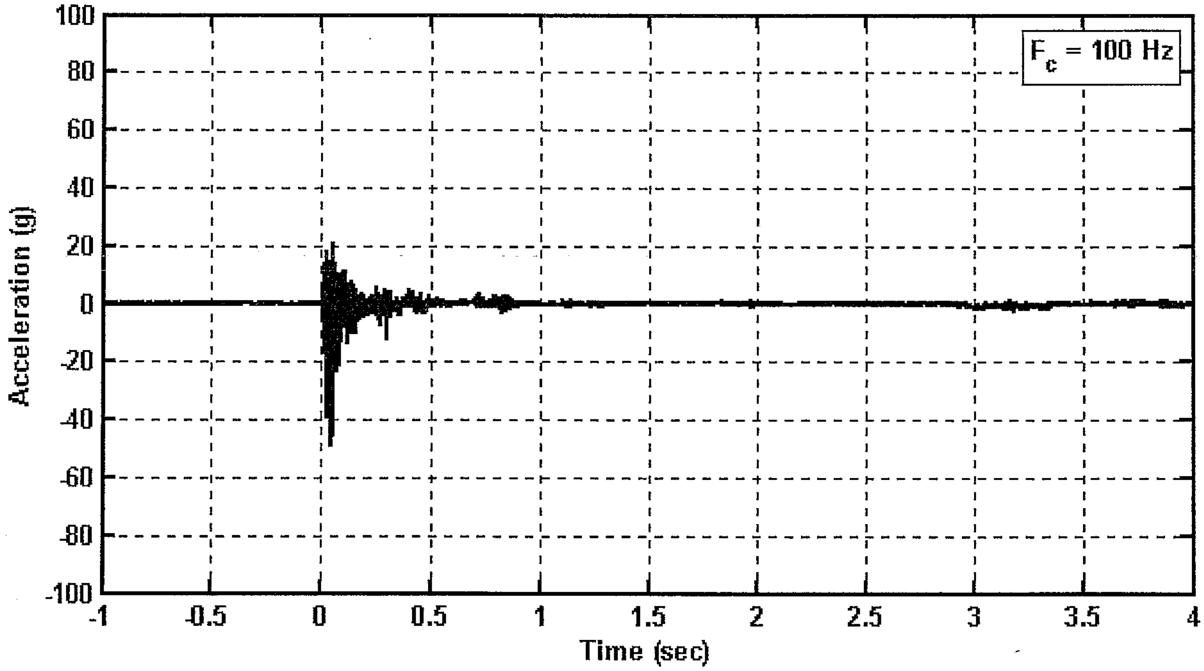


Figure C87. Target locomotive, position 1, center sill, lateral acceleration
Channel Name: SL_C1Y

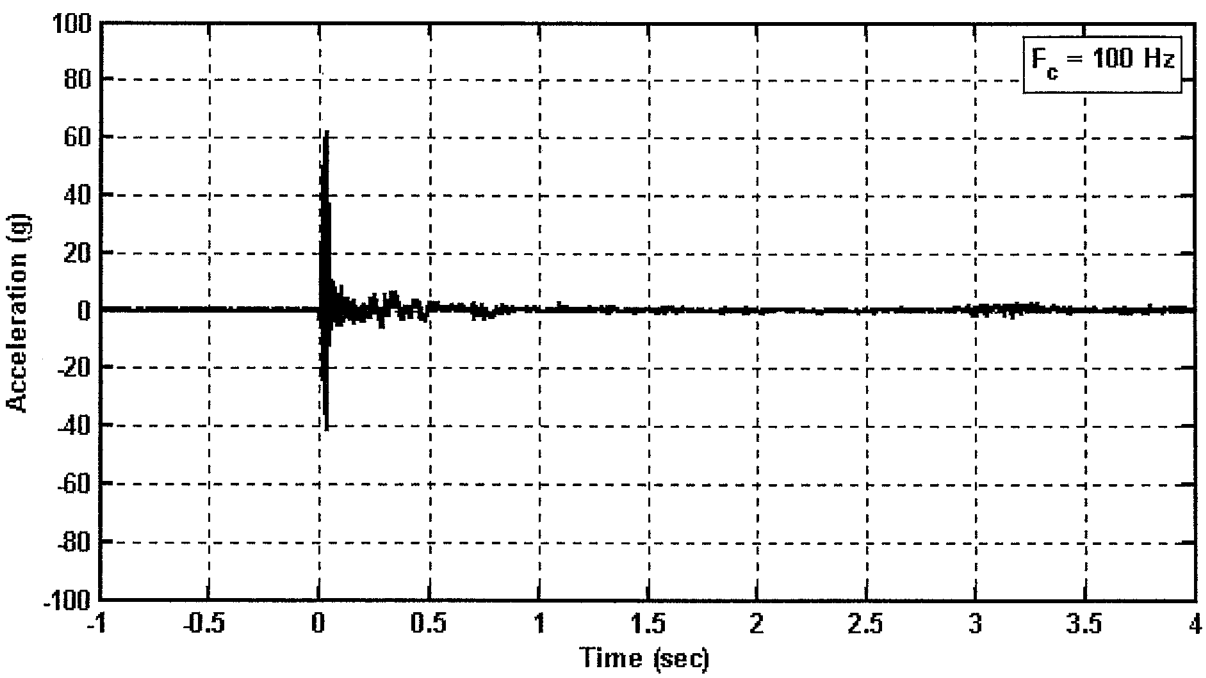


Figure C88. Target locomotive, position 1, center sill, vertical acceleration
Channel Name: SL_C1Z

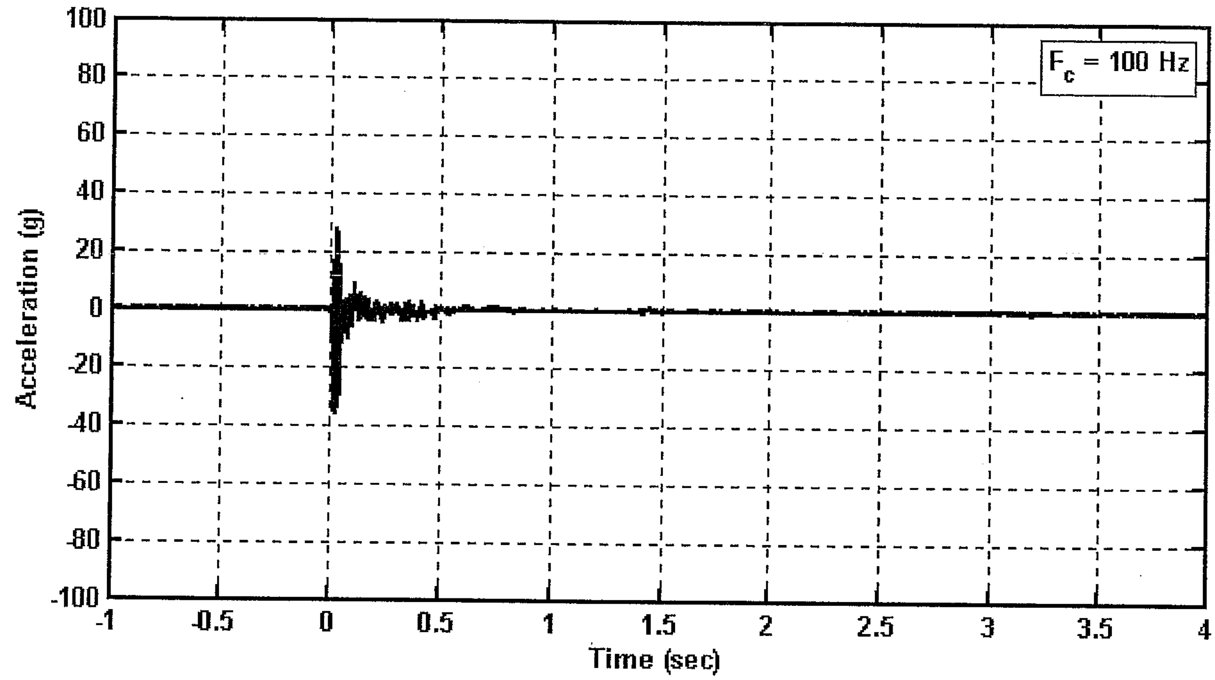


Figure C89. Target locomotive, position 2, center sill, longitudinal acceleration
Channel Name: SL_C2X

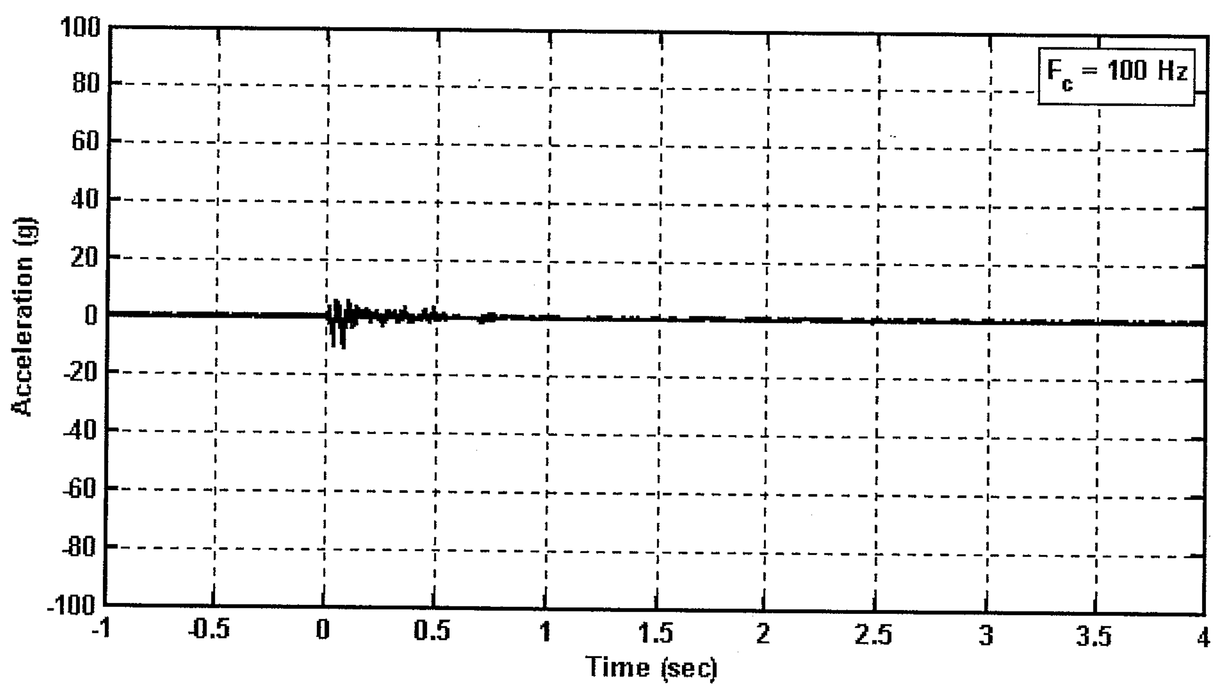


Figure C90. Target locomotive, position 2, center sill, lateral acceleration
Channel Name: SL_C2Y

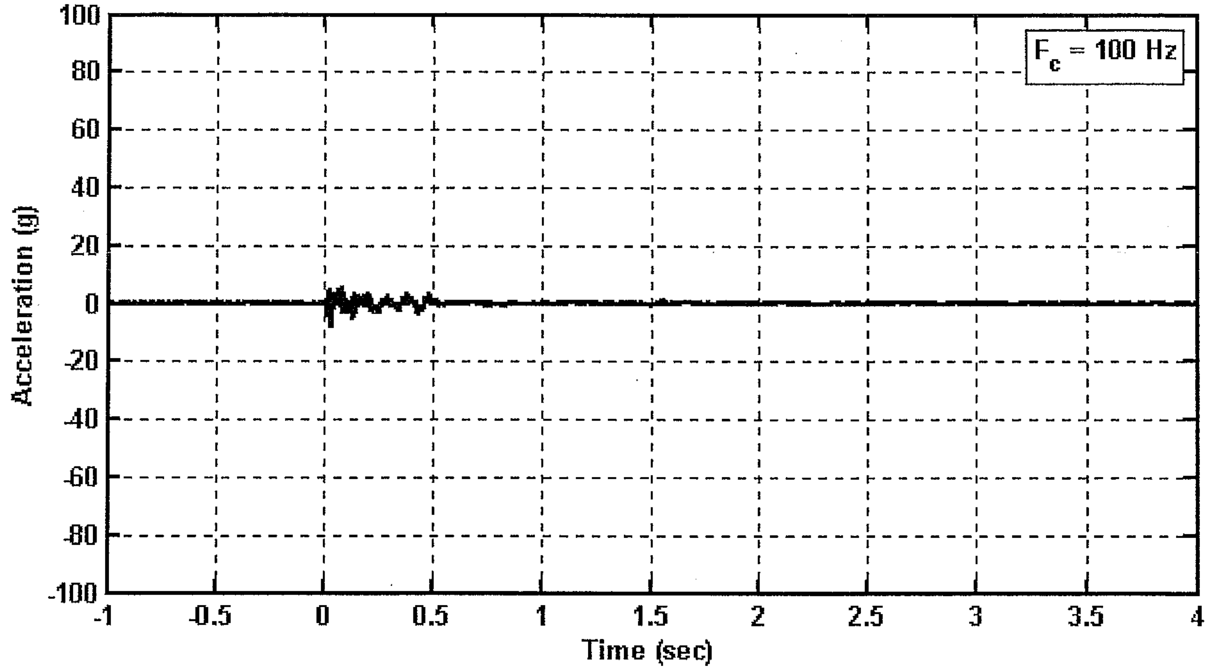


Figure C91. Target locomotive, position 2, center sill, vertical acceleration
Channel Name: SL_C2Z

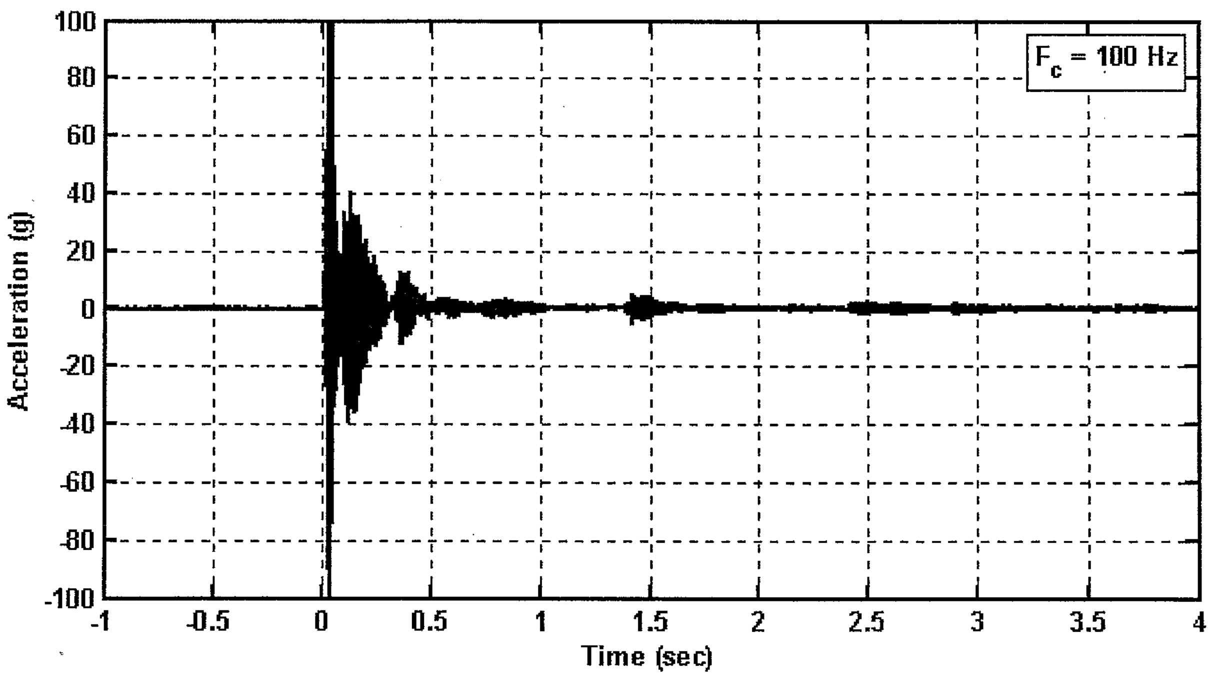


Figure C92. Target locomotive, position 3, center sill, longitudinal acceleration
Channel Name: SL_C3X

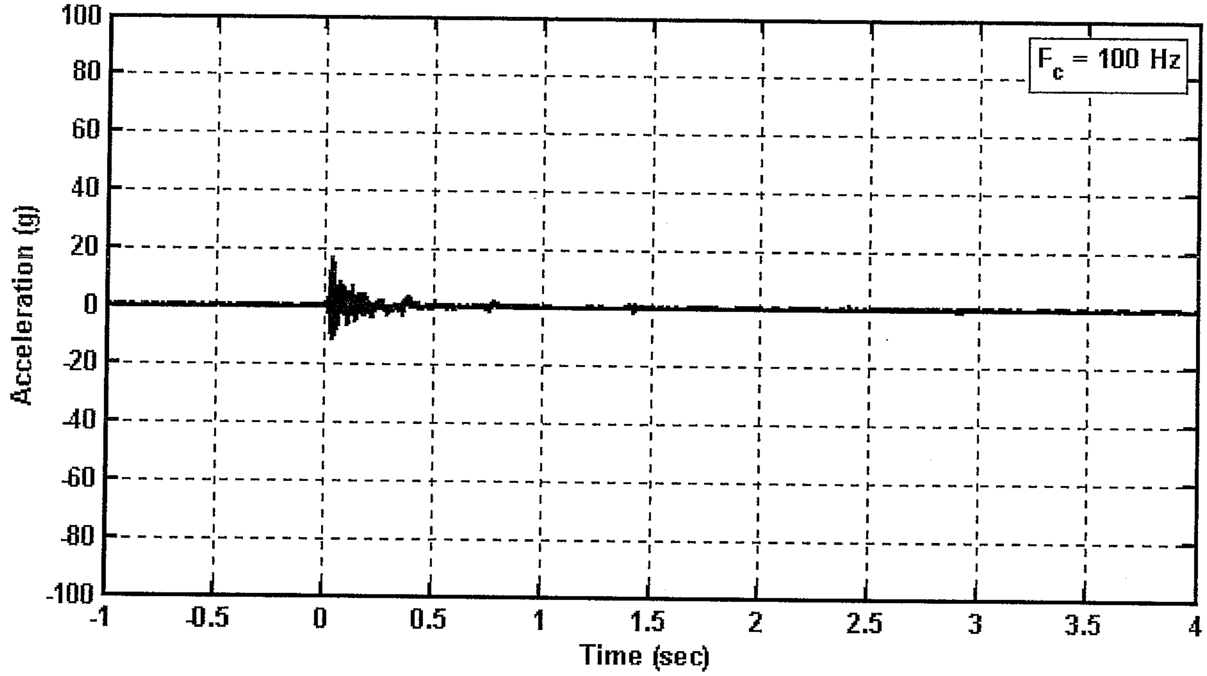


Figure C93. Target locomotive, position 3, center sill, lateral acceleration
Channel Name: SL_C3Y

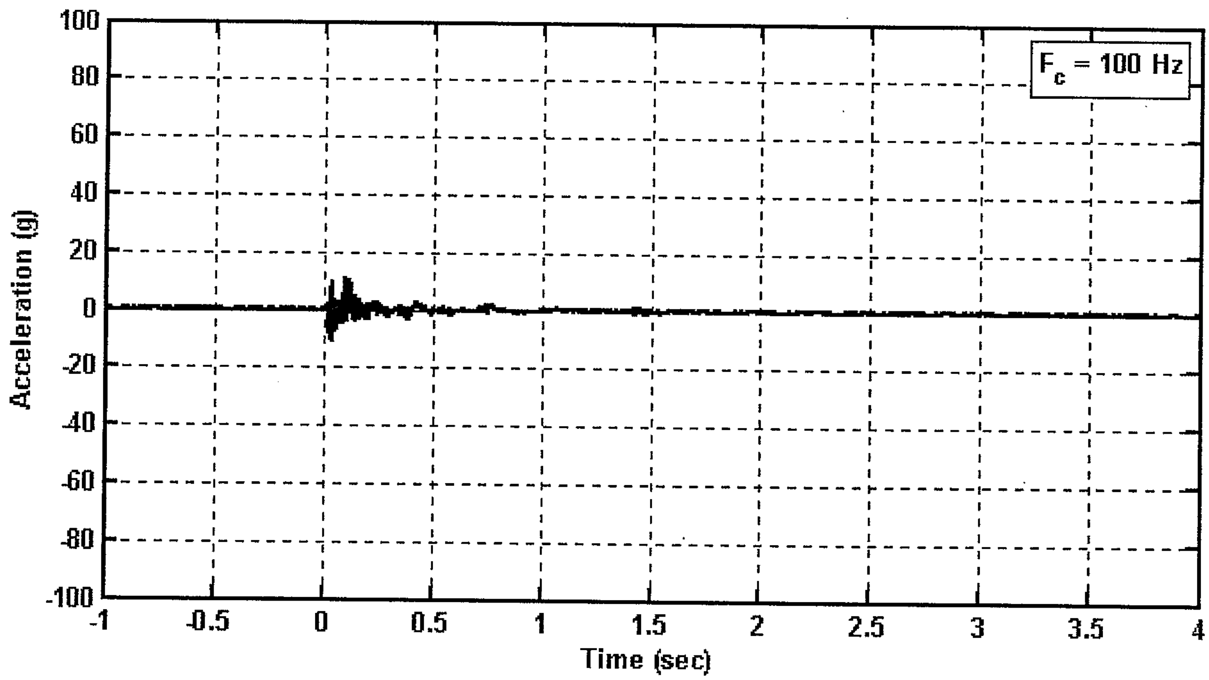


Figure C94. Target locomotive, position 3, center sill, vertical acceleration
Channel Name: SL_C3Z

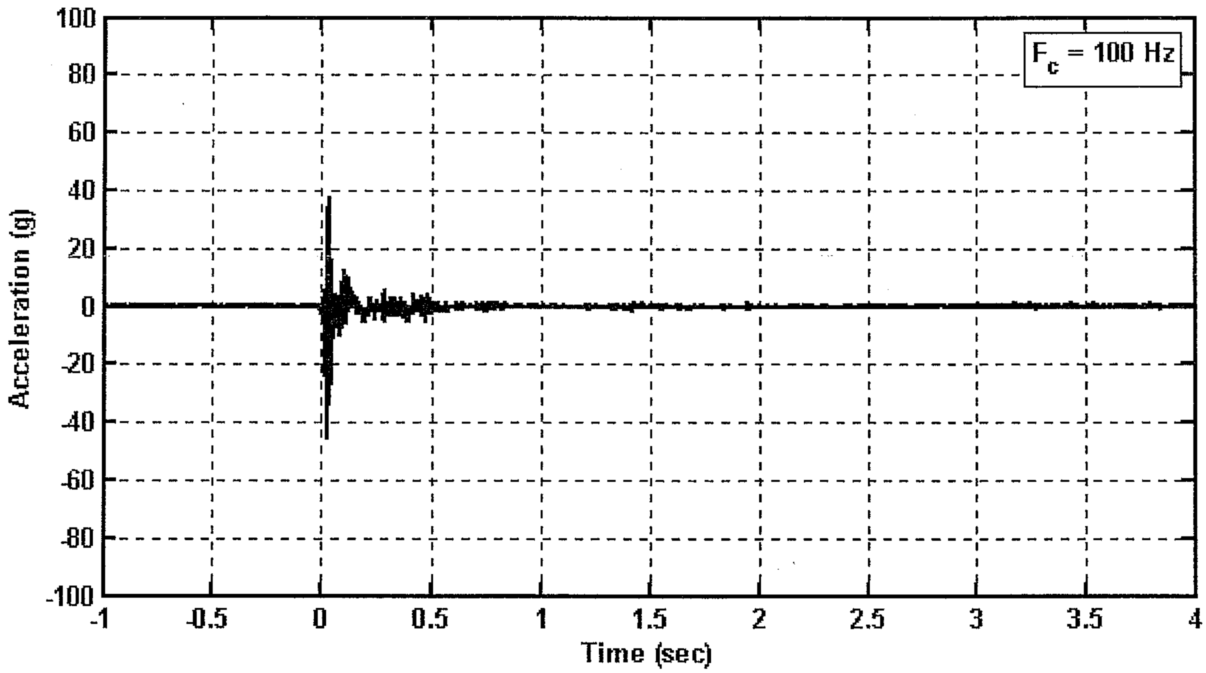


Figure C95. Target locomotive, position 3, cab floor, longitudinal acceleration
Channel Name: SL_F1X

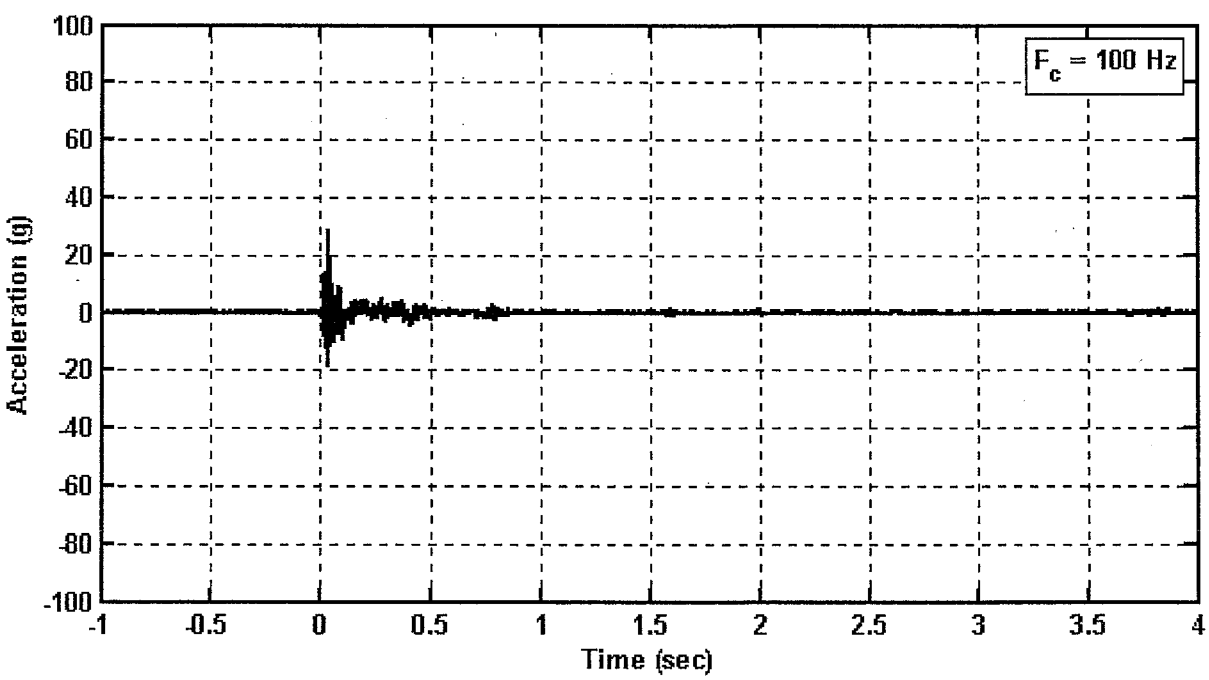


Figure C96. Target locomotive, position 3, cab floor, lateral acceleration
Channel Name: SL_F1Y

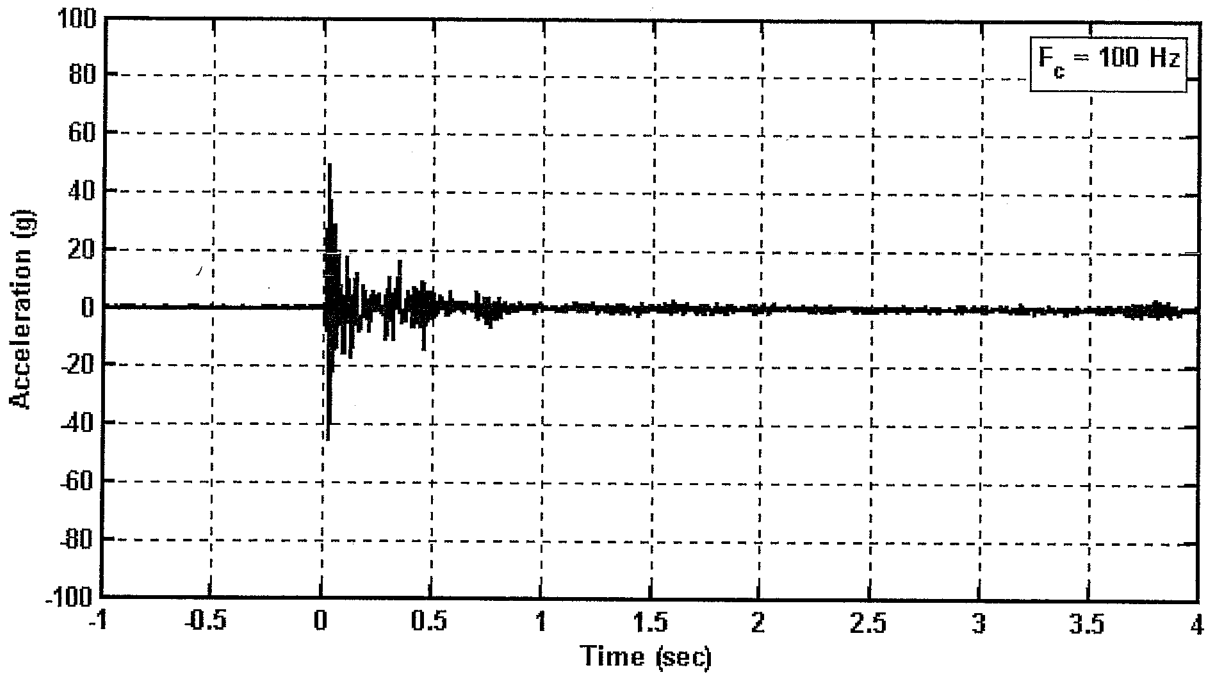


Figure C97. Target locomotive, position 3, cab floor, vertical acceleration
Channel Name: SL_F1Z

APPENDIX D

Acceleration Data, Fc = 25 Hz

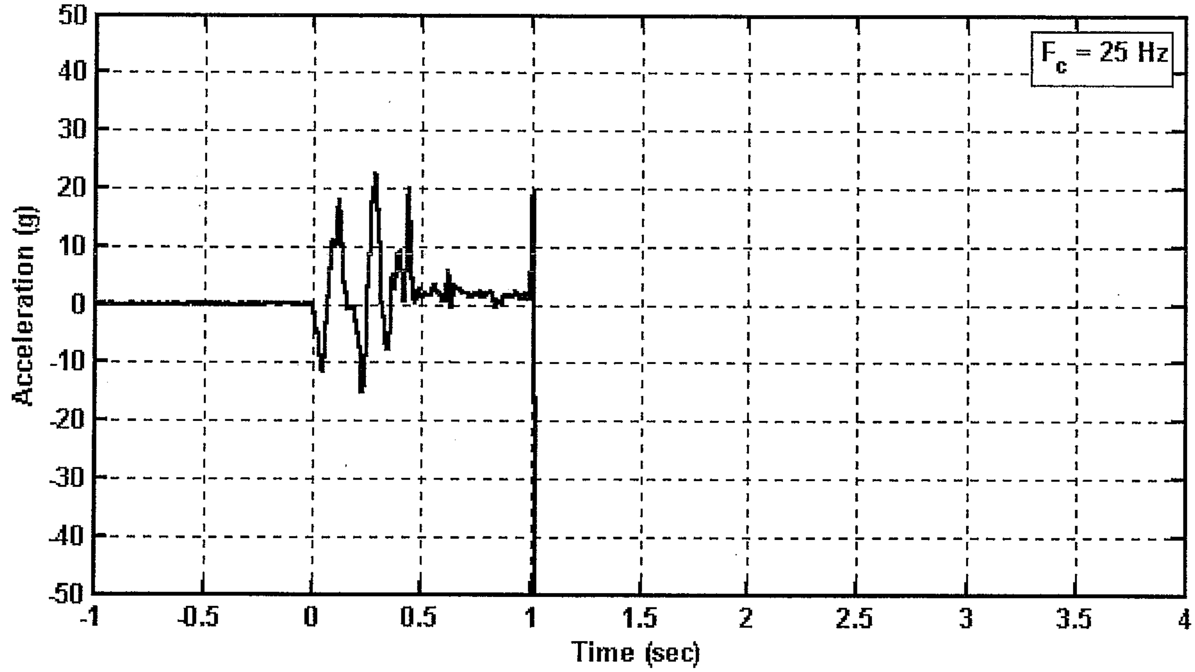


Figure D1. Bullet car 1, A truck, longitudinal acceleration
Channel Name: B1_BAX

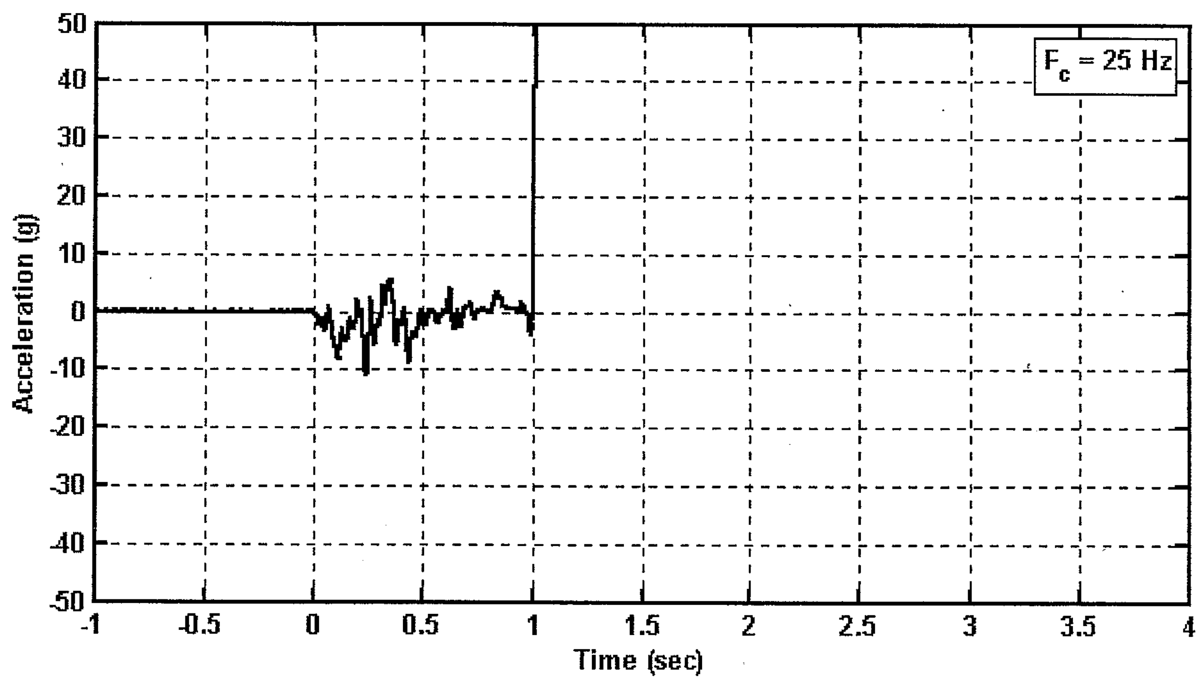


Figure D2. Bullet car 1, A truck, lateral acceleration
Channel Name: B1_BAY

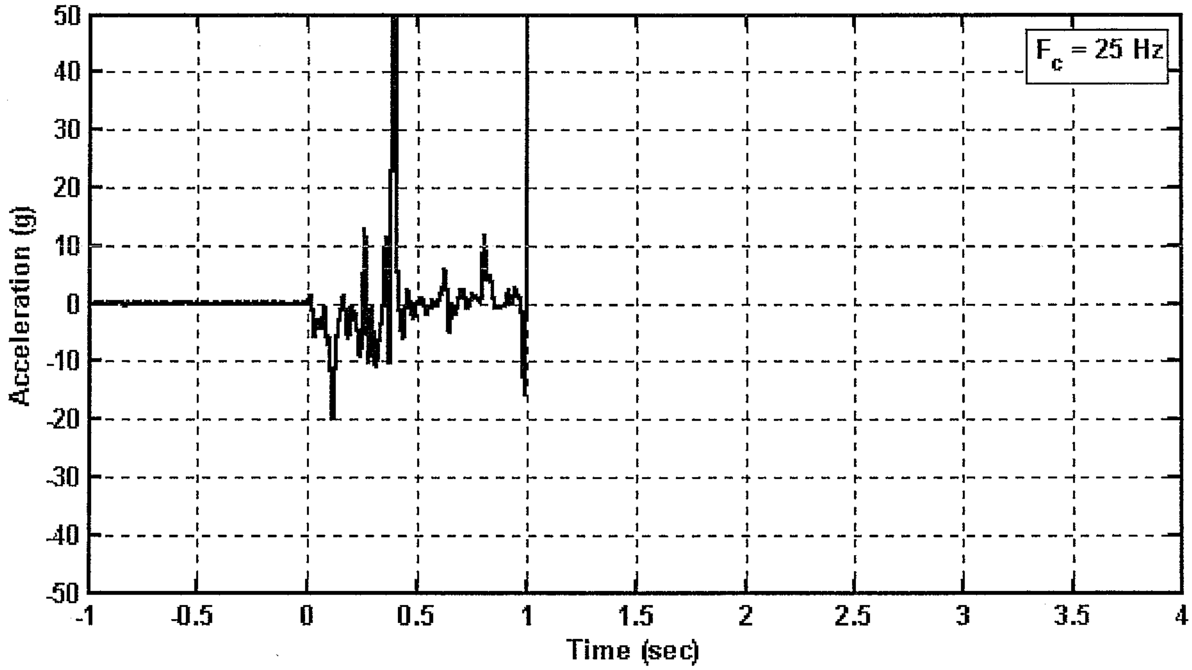


Figure D3. Bullet car 1, A truck, vertical acceleration
Channel Name: B1_BAZ

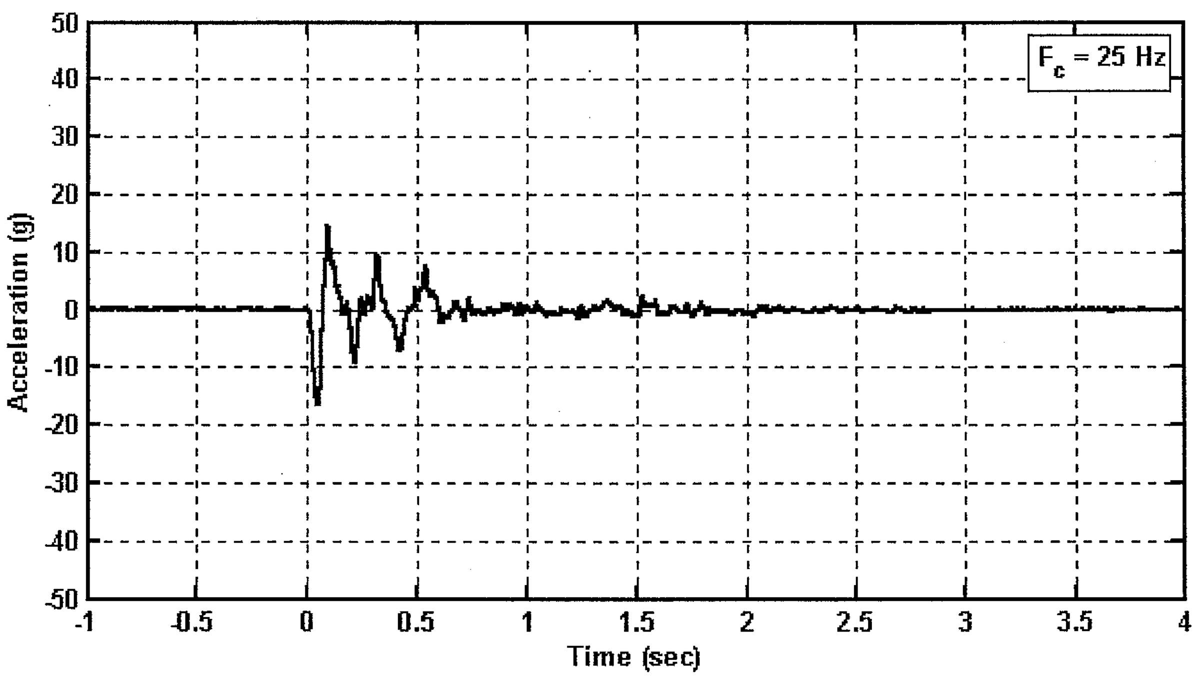


Figure D4. Bullet car 1, B truck, longitudinal acceleration
Channel Name: B1_BBX

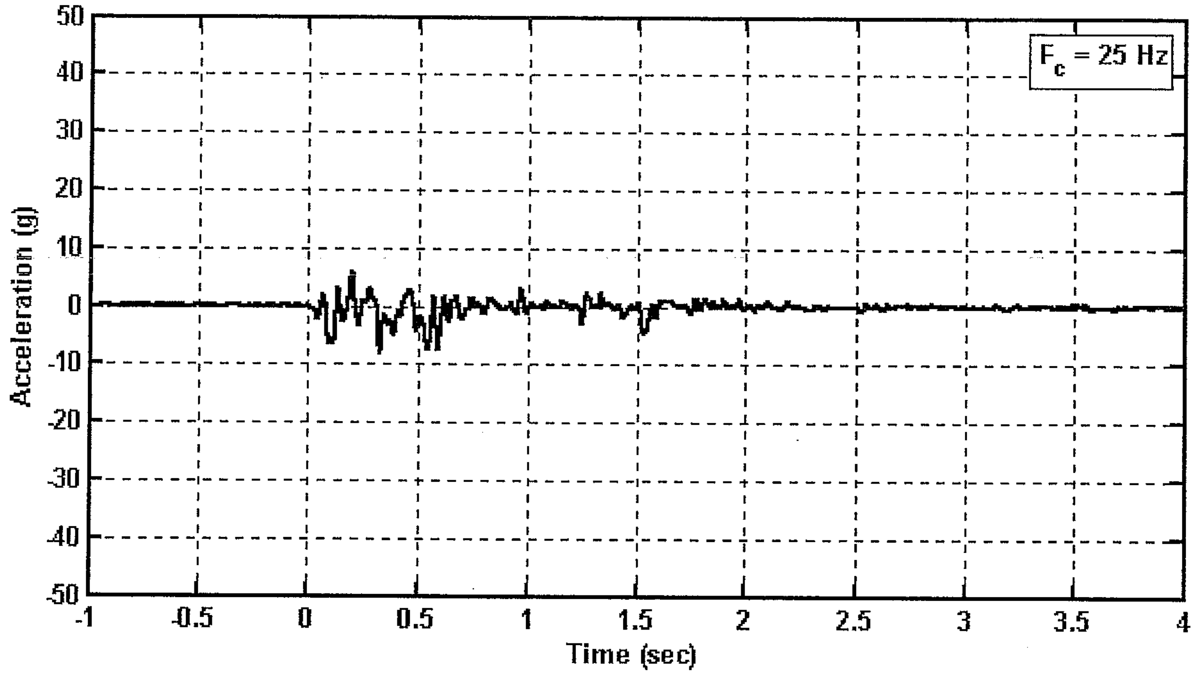


Figure D5. Bullet car 1, B truck, lateral acceleration
Channel Name: B1_BBY

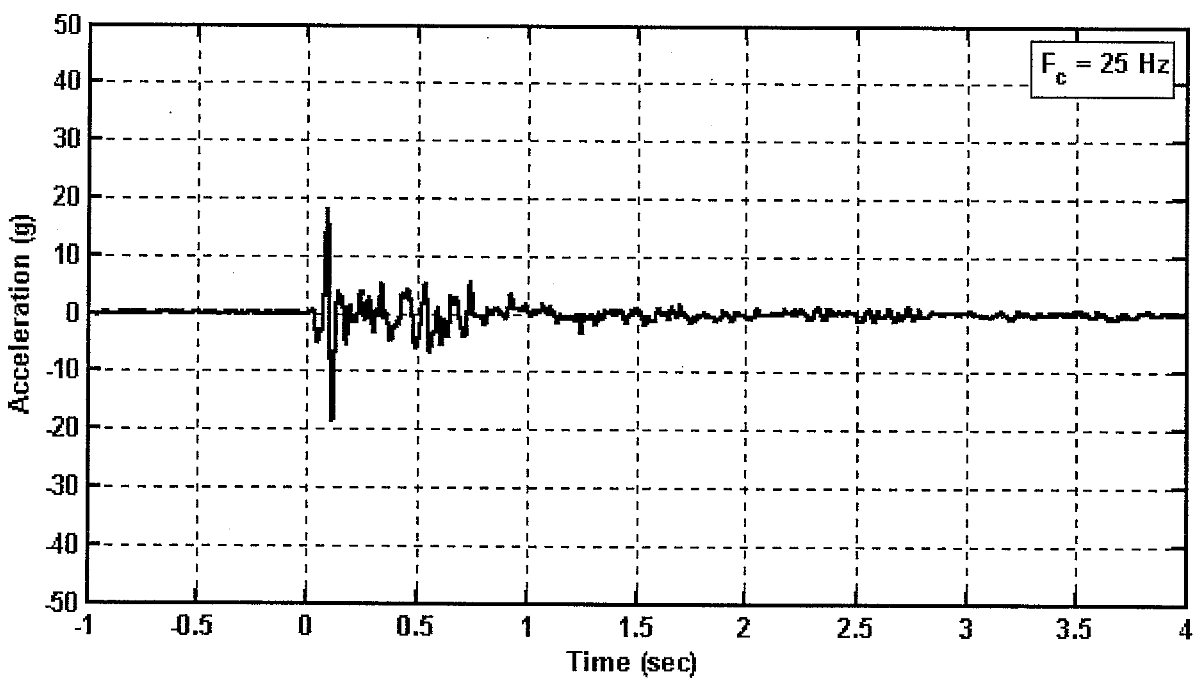


Figure D6. Bullet car 1, B truck, vertical acceleration
Channel Name: B1_BBZ

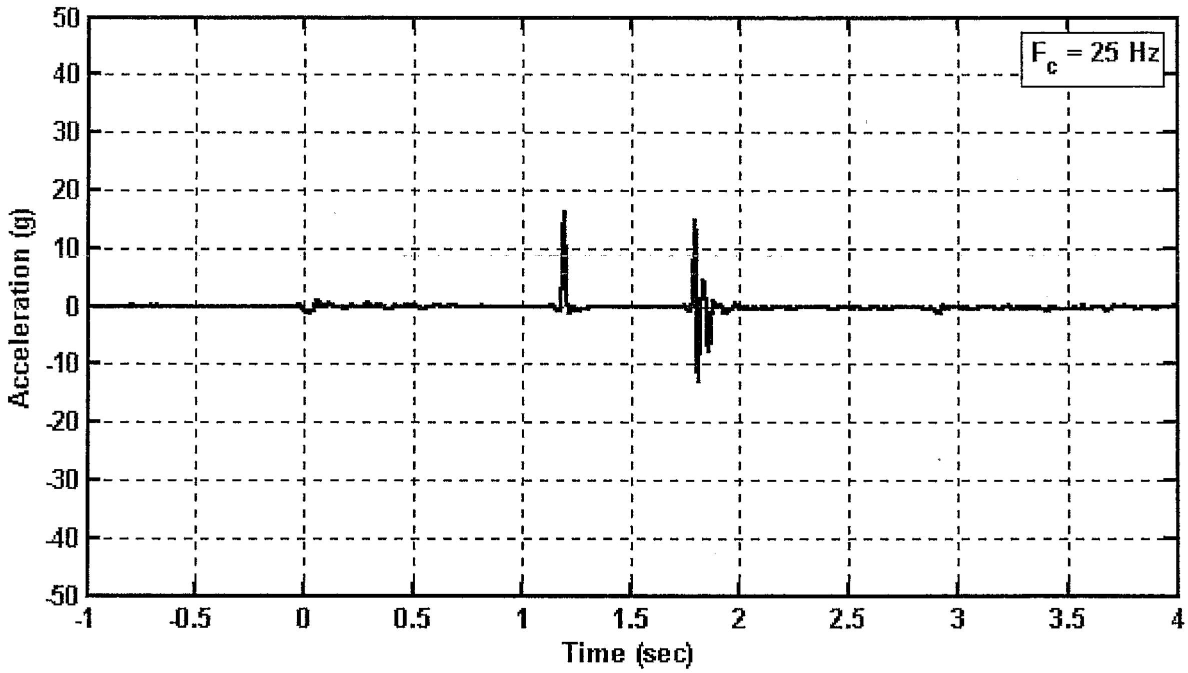


Figure D7. Bullet car 1, position 2, center sill, longitudinal acceleration
Channel Name: B1_C2X

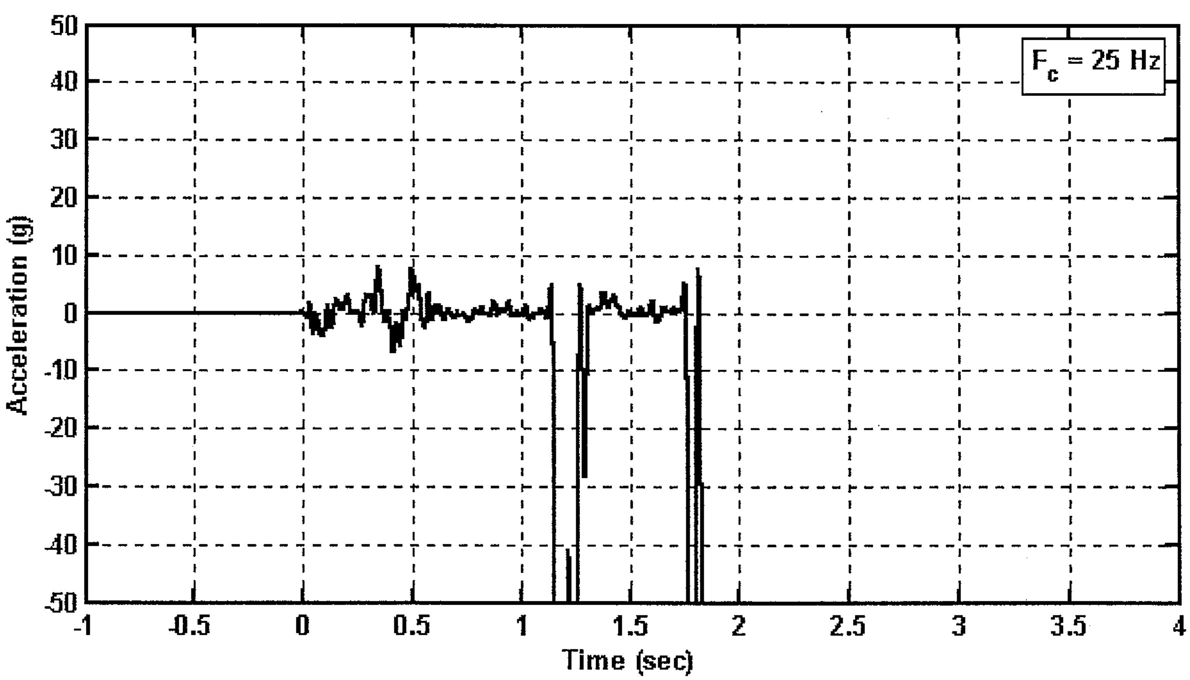


Figure D8. Bullet car 1, position 2, center sill, lateral acceleration
Channel Name: B1_C2Y

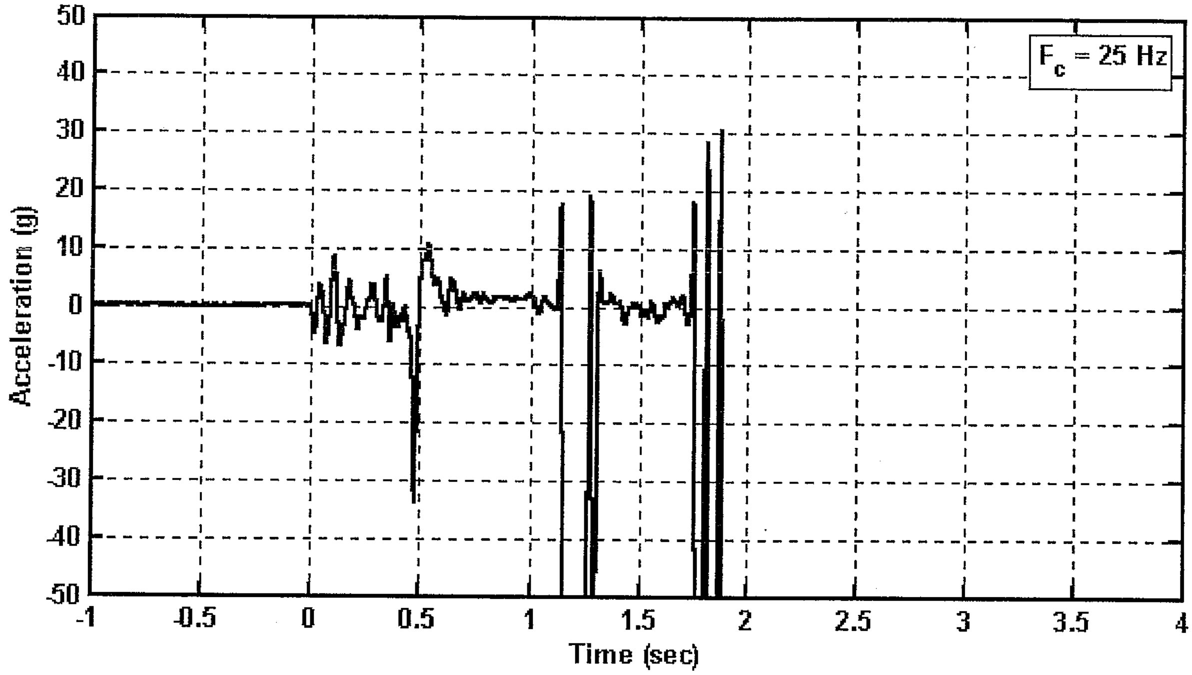


Figure D9. Bullet car 1, position 2, center sill, vertical acceleration
Channel Name: B1_C2Z

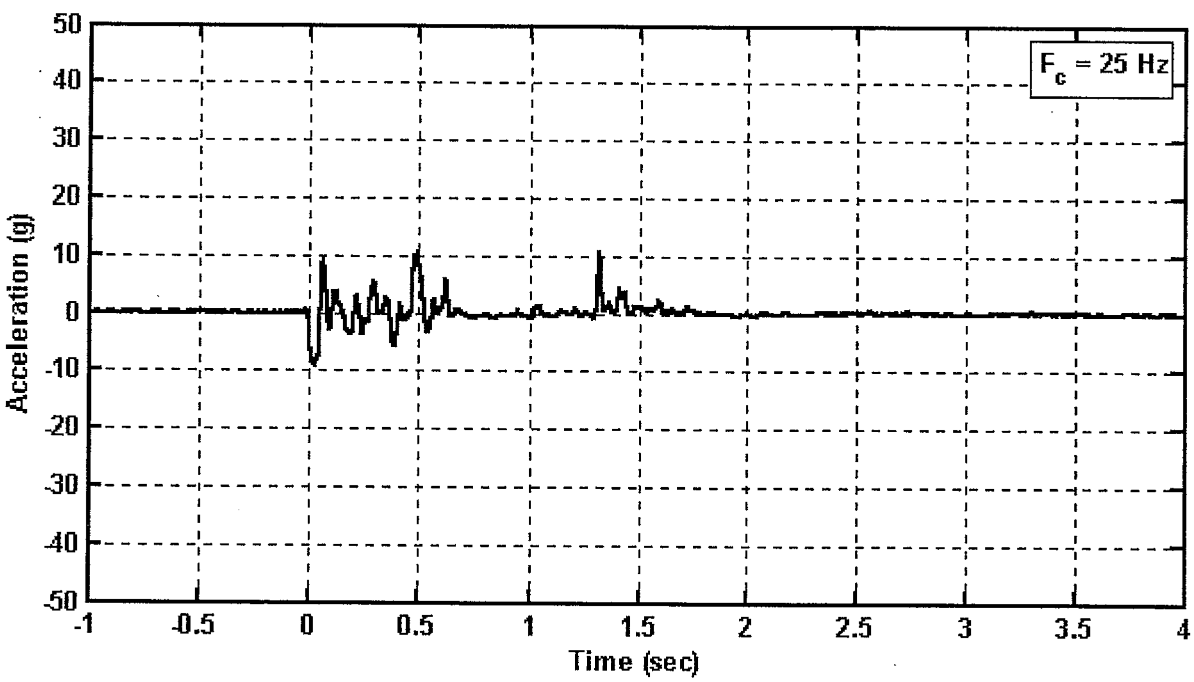


Figure D10. Bullet car 1, position 3, center sill, longitudinal acceleration
Channel Name: B1_C3X

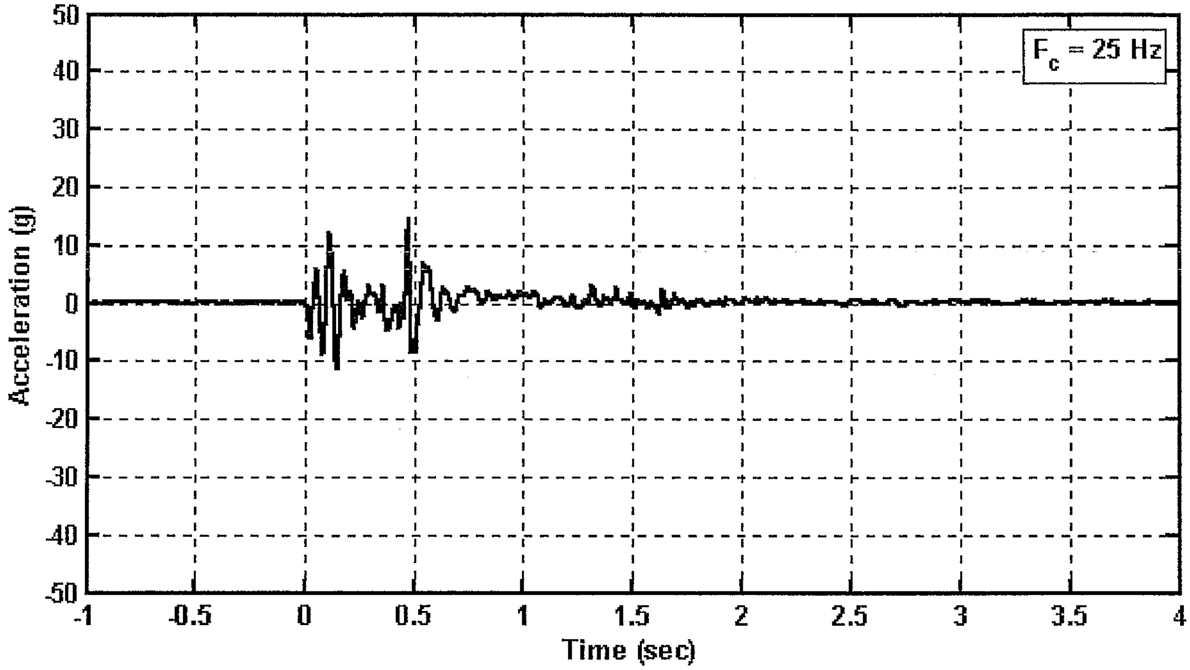


Figure D11. Bullet car 1, position 3, center sill, vertical acceleration
Channel Name: B1_C3Z

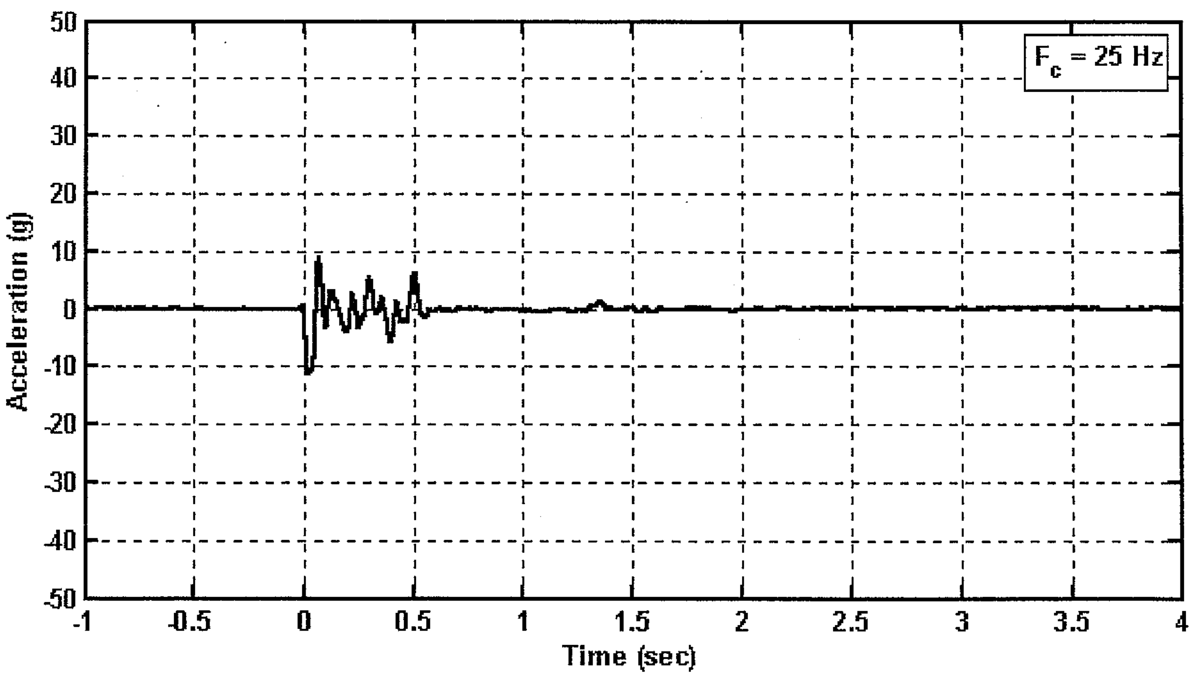


Figure D12. Bullet car 1, position 4, center sill, longitudinal acceleration
Channel Name: B1_C4X

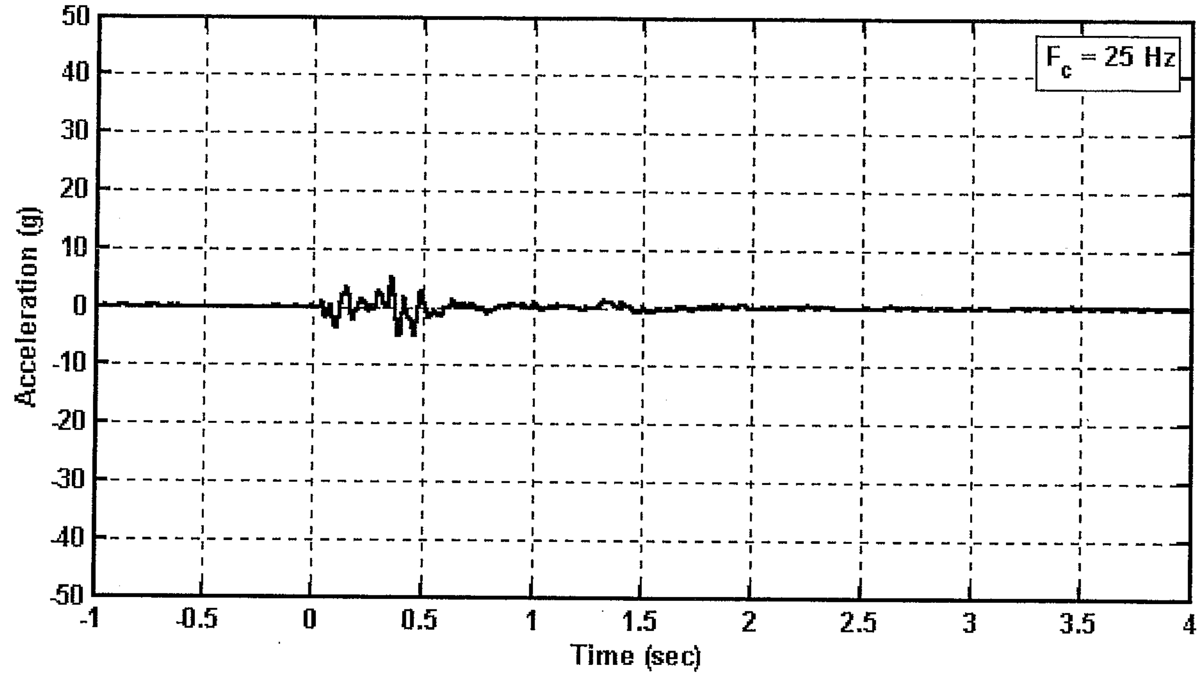


Figure D13. Bullet car 1, position 4, center sill, lateral acceleration
Channel Name: B1_C4Y

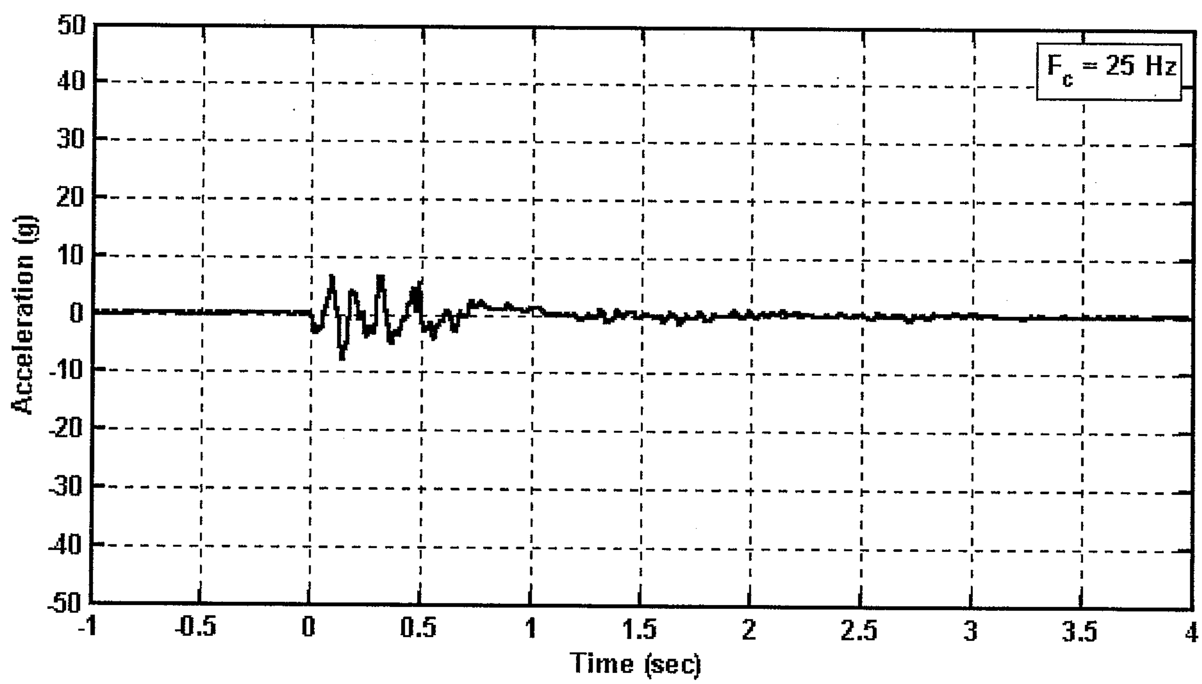


Figure D14. Bullet car 1, position 4, center sill, vertical acceleration
Channel Name: B1_C4Z

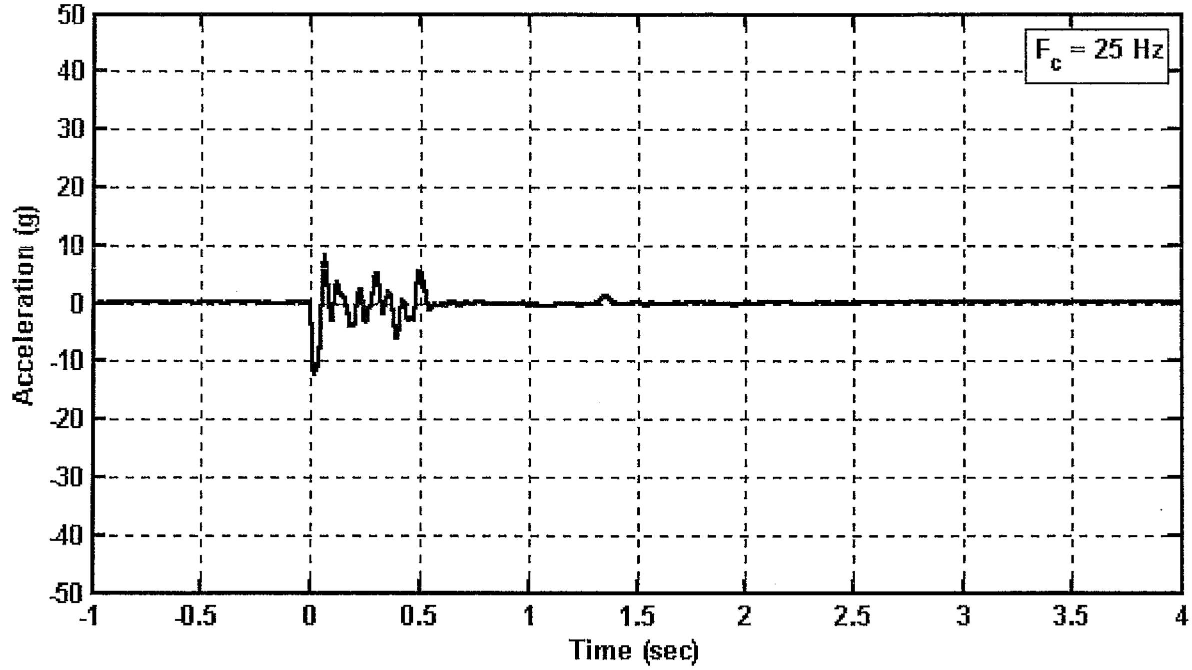


Figure D15. Bullet car 1, position 5, center sill, longitudinal acceleration
Channel Name: B1_C5X

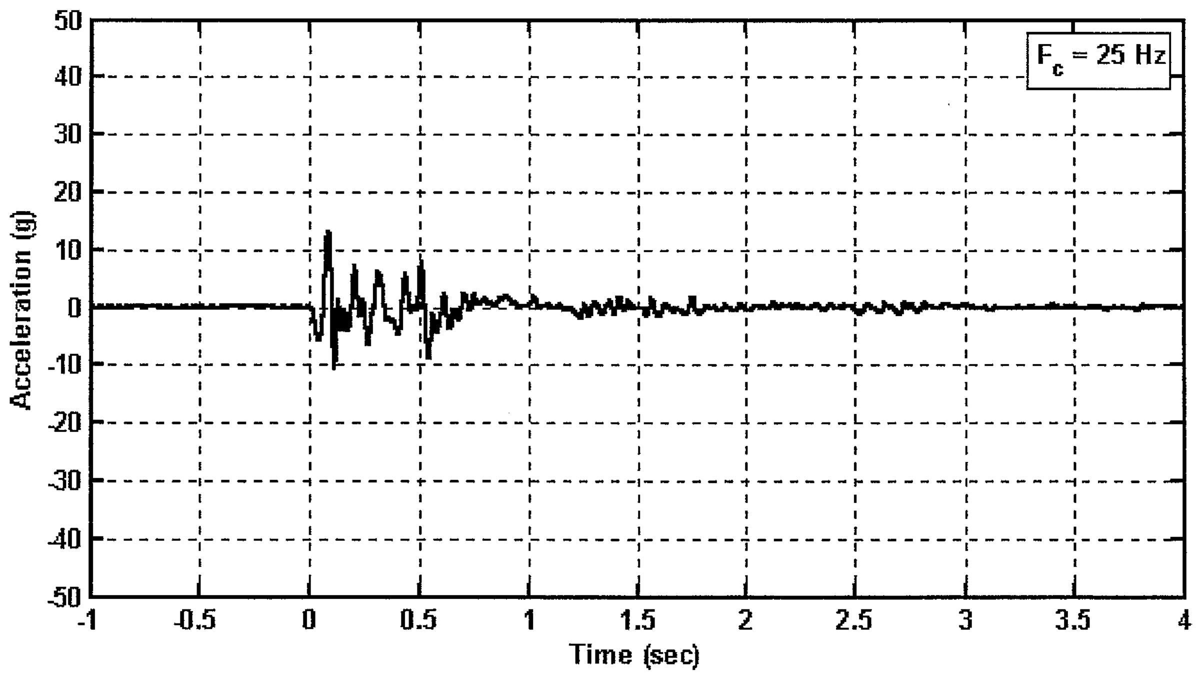


Figure D16. Bullet car 1, position 5, center sill, vertical acceleration
Channel Name: B1_C5Z

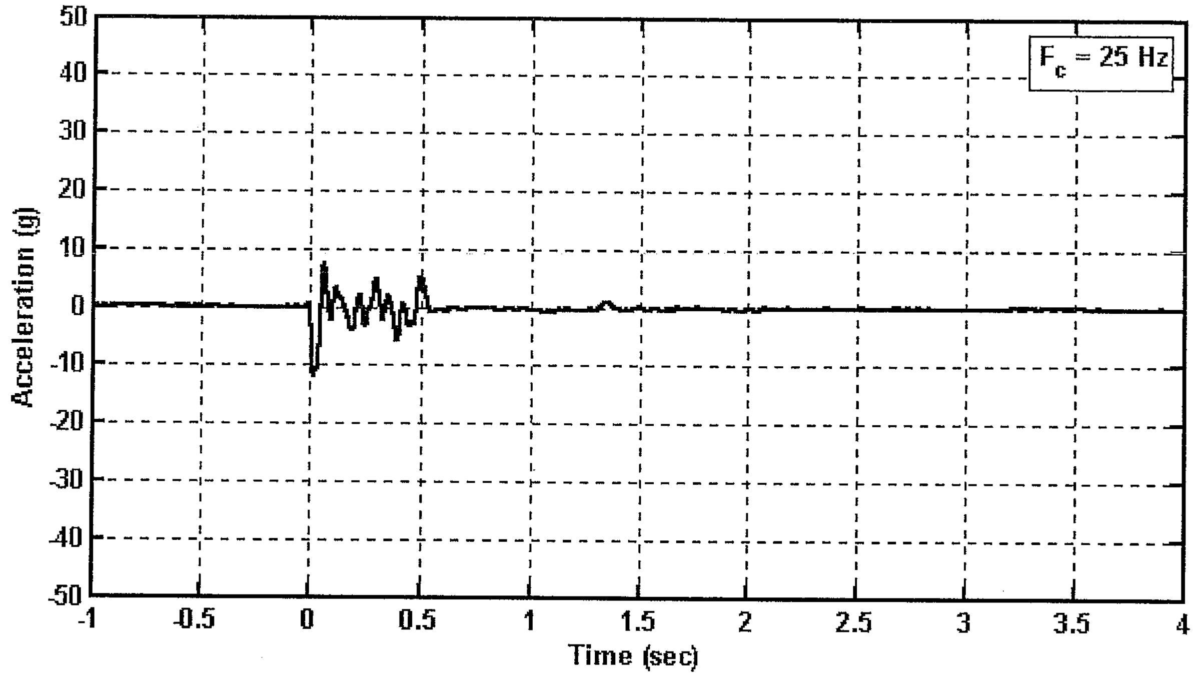


Figure D17. Bullet car 1, position 6, center sill, longitudinal acceleration
Channel Name: B1_C6X

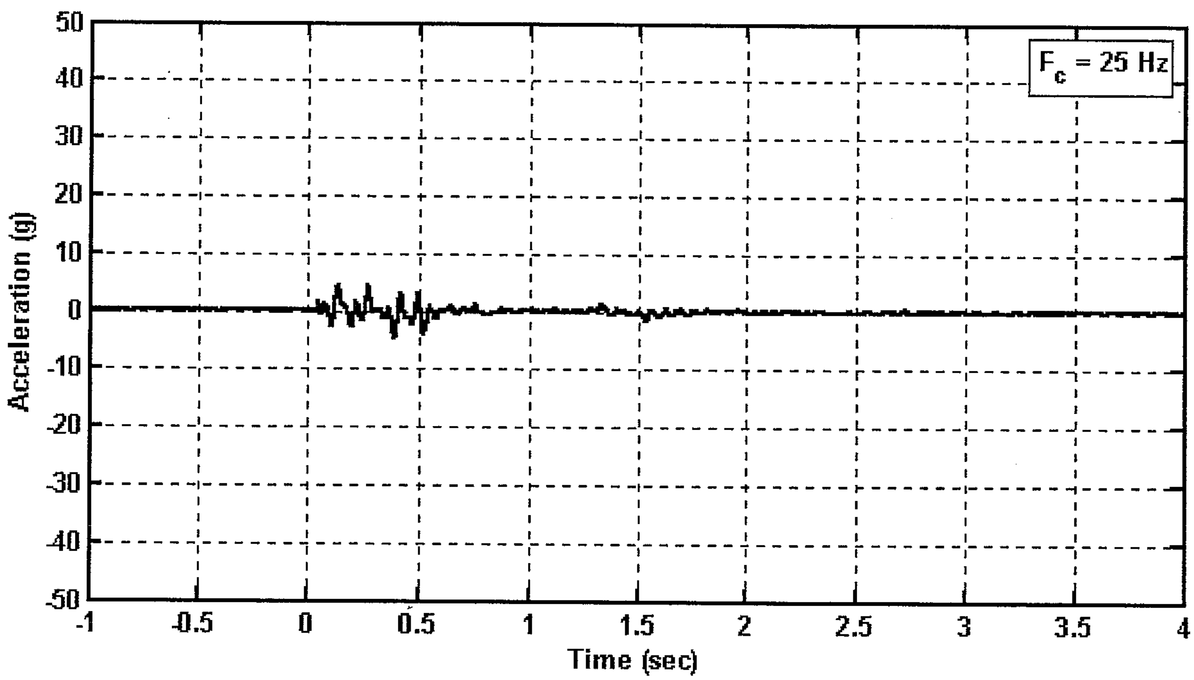


Figure D18. Bullet car 1, position 6, center sill, lateral acceleration
Channel Name: B1_C6Y

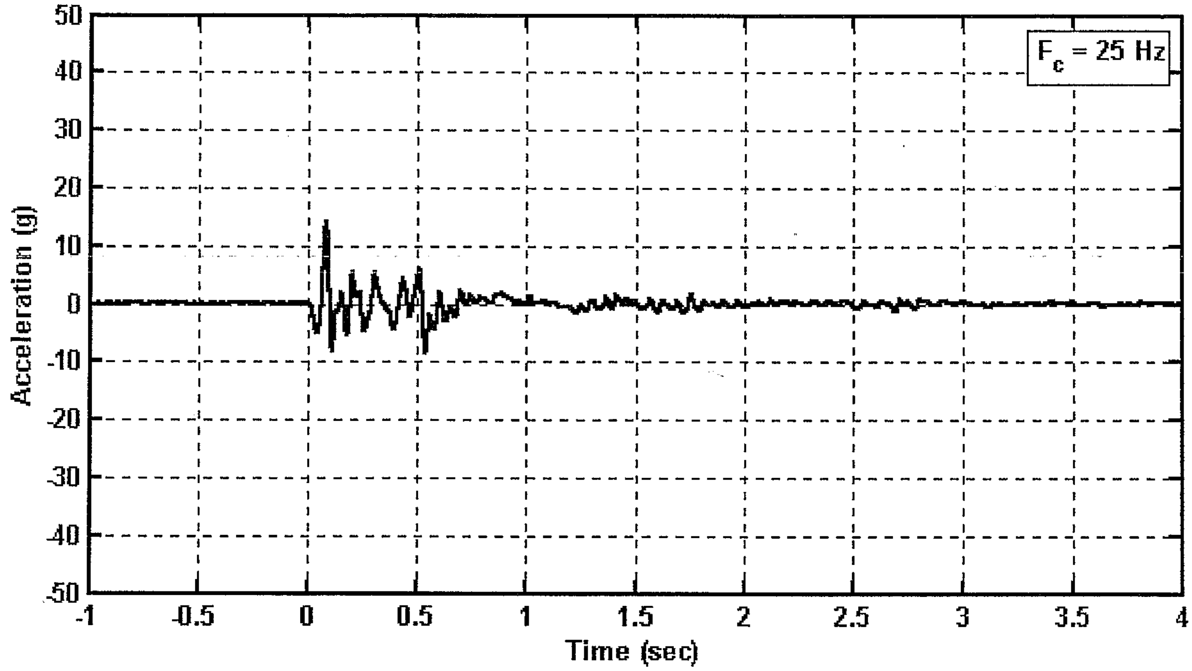


Figure D19. Bullet car 1, position 6, center sill, vertical acceleration
Channel Name: B1_C6Z

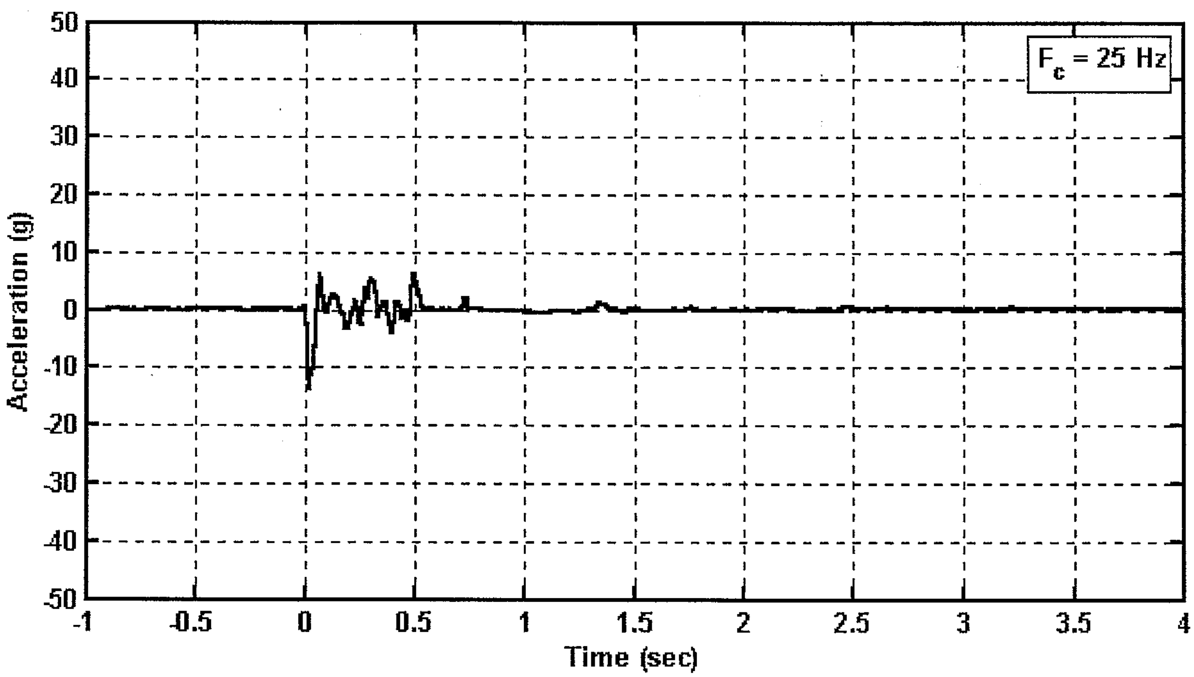


Figure D20. Bullet car 1, position 7, center sill, longitudinal acceleration
Channel Name: B1_C7X

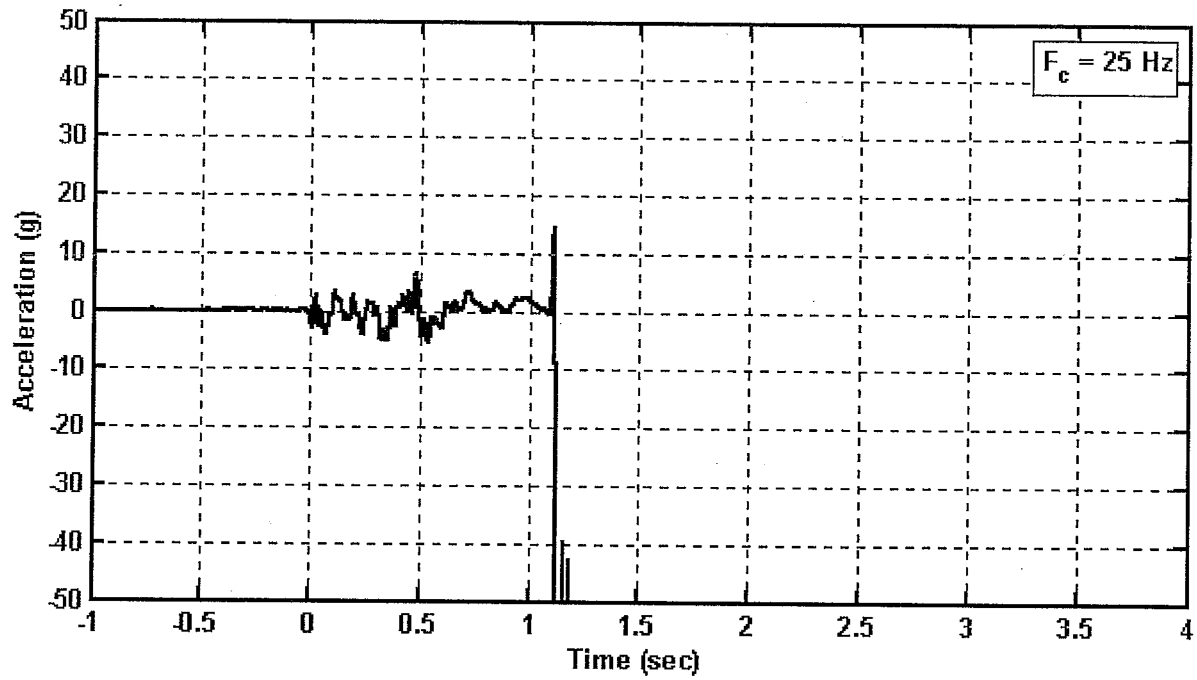


Figure D21. Bullet car 1, position 2, left side, vertical acceleration
Channel Name: B1_L2Z

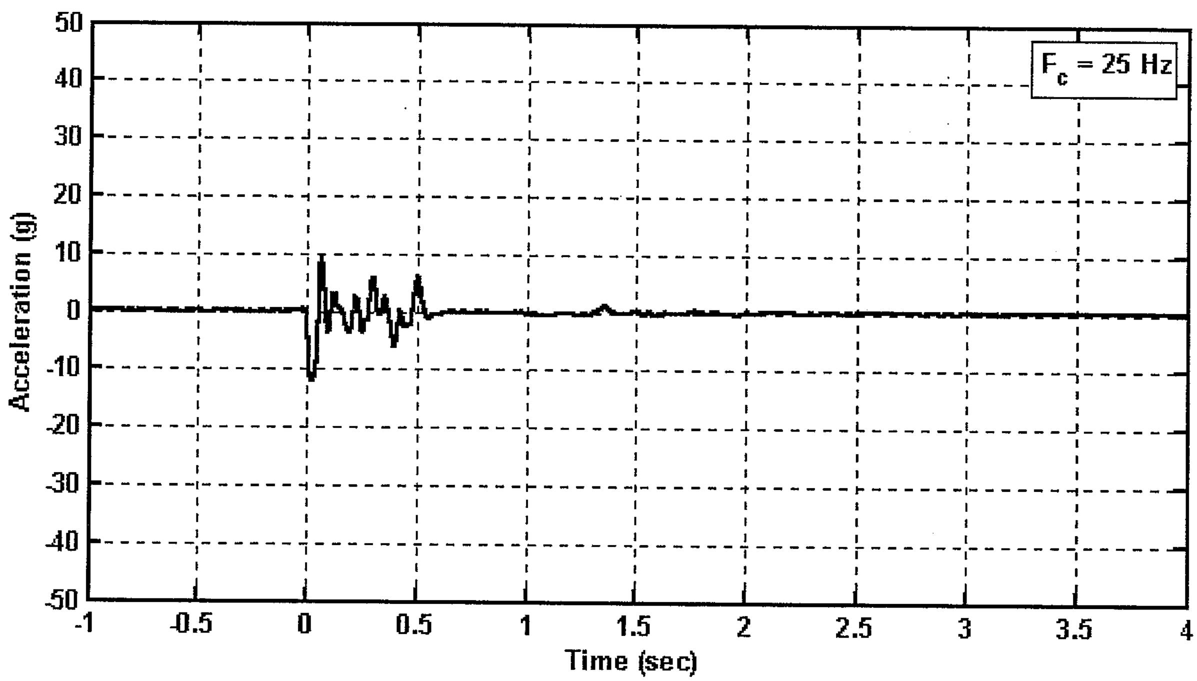


Figure D22. Bullet car 1, position 4, left side, longitudinal acceleration
Channel Name: B1_L4X

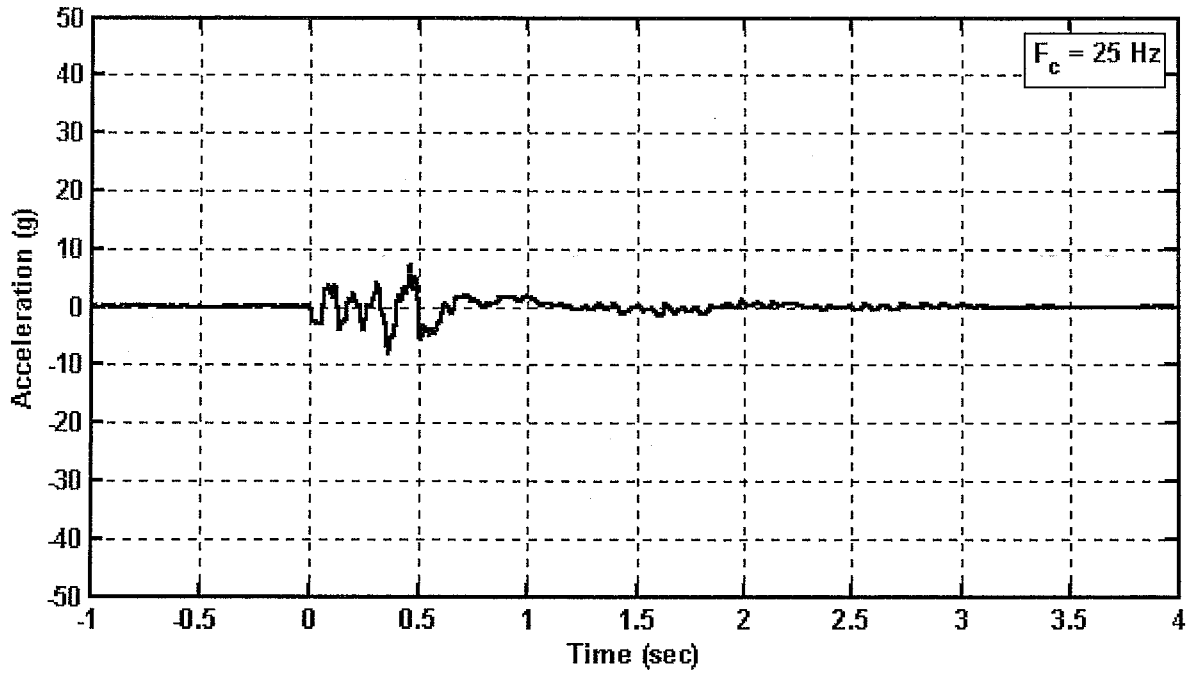


Figure D23. Bullet car 1, position 4, left side, vertical acceleration.
Channel Name: B1_L4Z

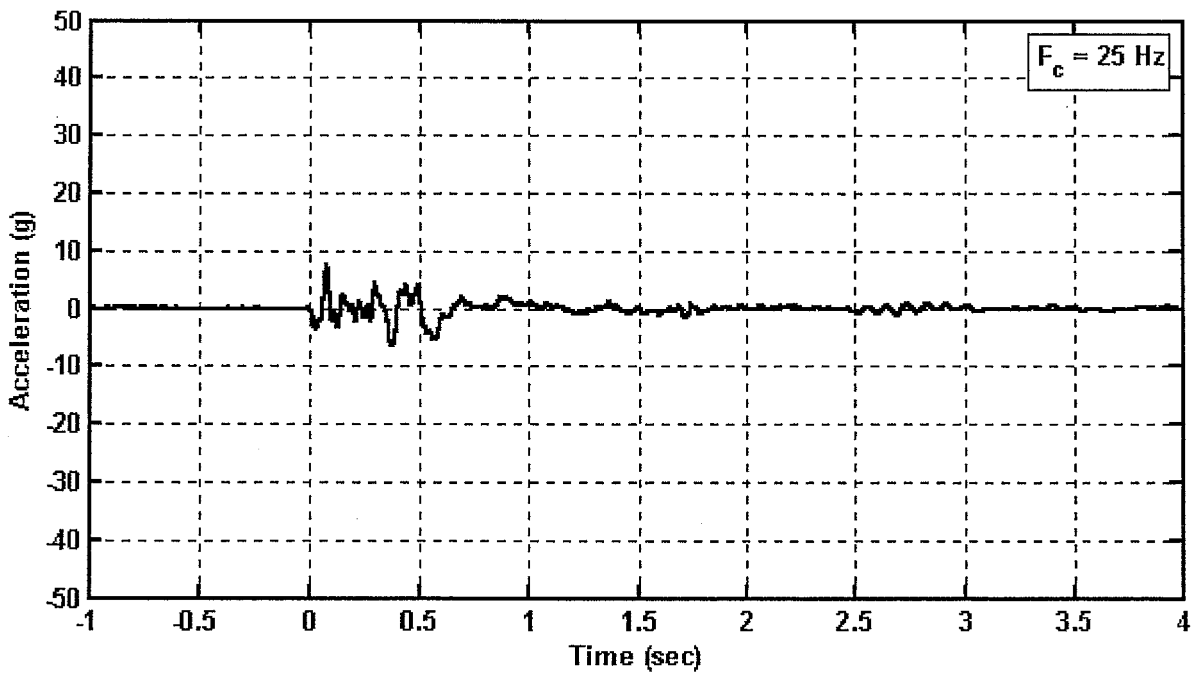


Figure D24. Bullet car 1, position 6, left side, vertical acceleration
Channel Name: B1_L6Z

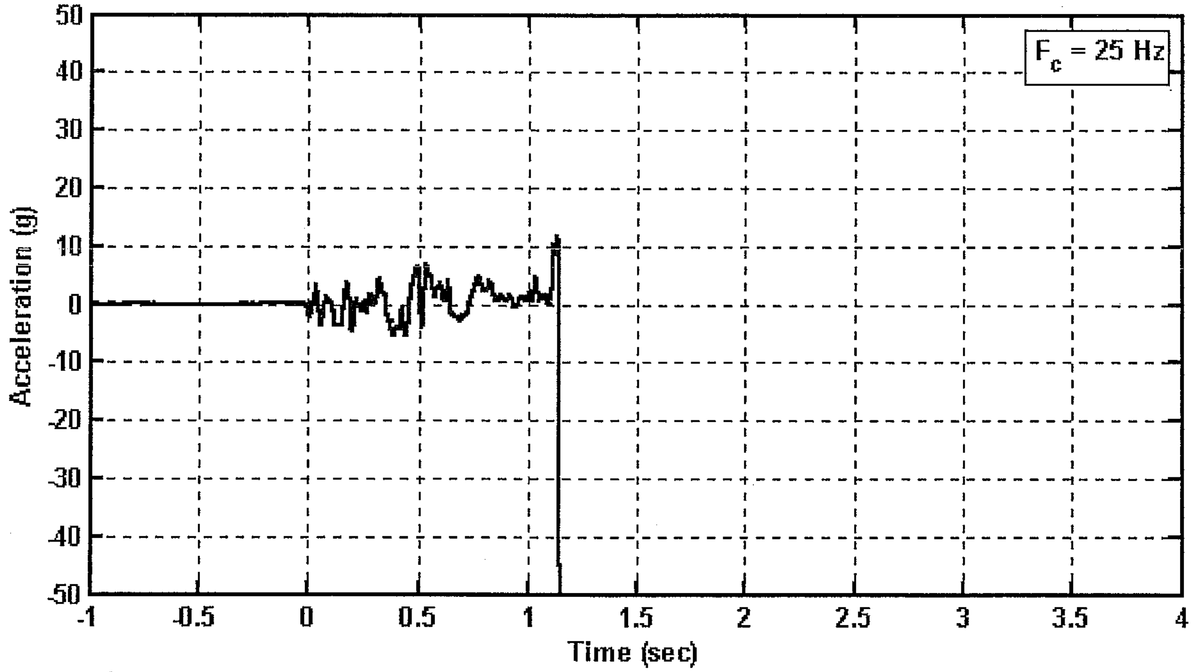


Figure D25. Bullet car 1, position 2, right side, vertical acceleration
Channel Name: B1_R2Z

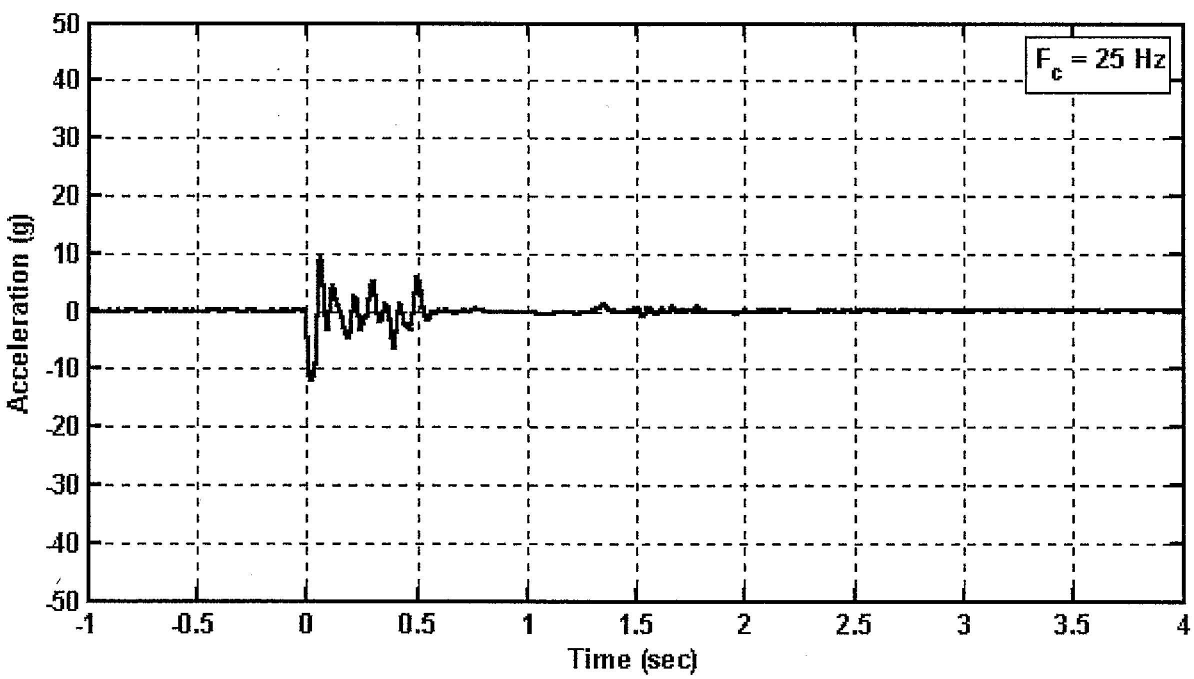


Figure D26. Bullet car 1, position 4, right side, longitudinal acceleration
Channel Name: B1_R4X

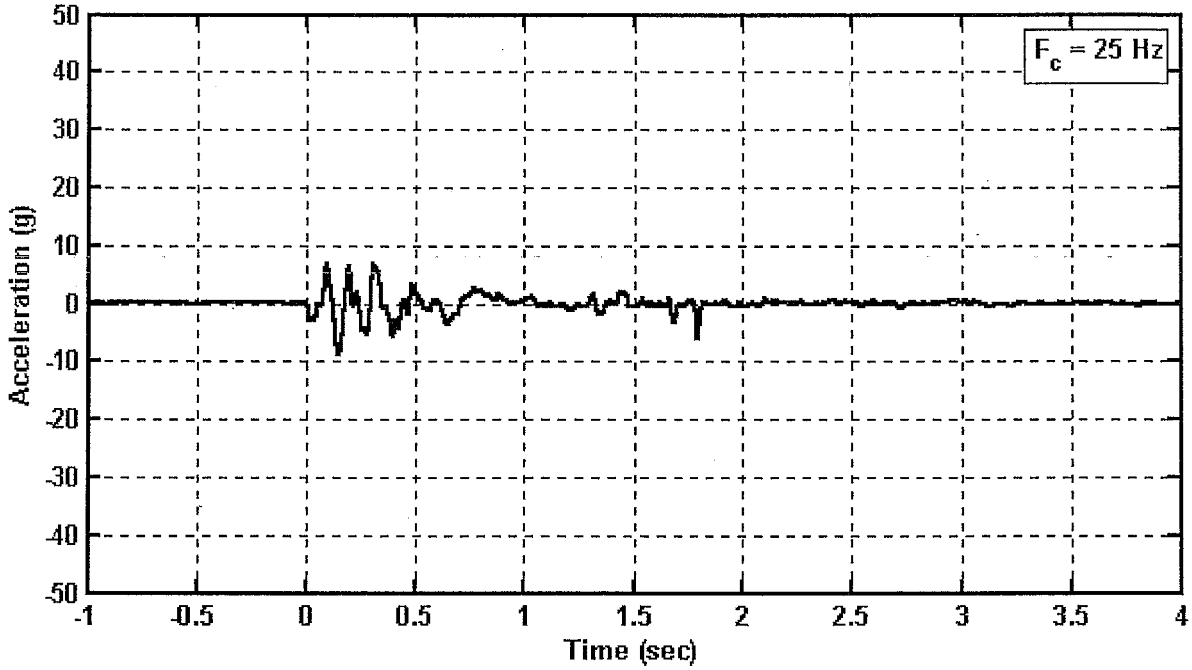


Figure D27. Bullet car 1, position 4, right side, vertical acceleration
Channel Name: B1_R4Z

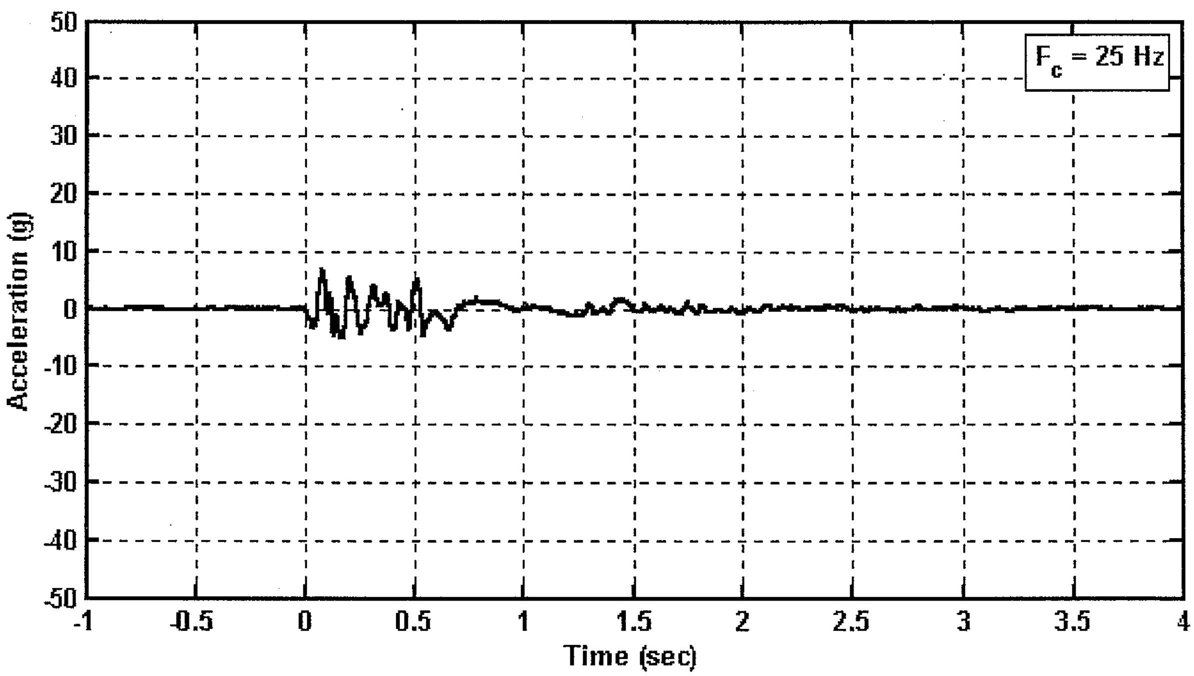


Figure D28. Bullet car 1, position 6, right side, vertical acceleration
Channel Name: B1_R6Z

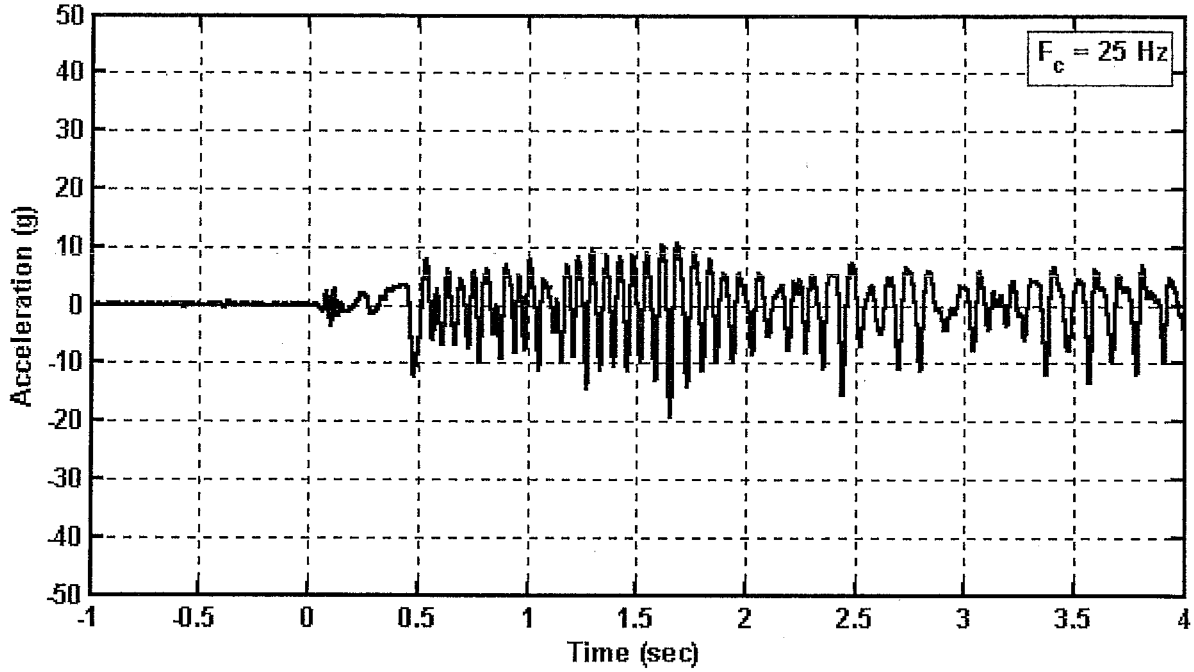


Figure D29. Bullet car 2, A truck, vertical acceleration
Channel Name: B2_BAZ

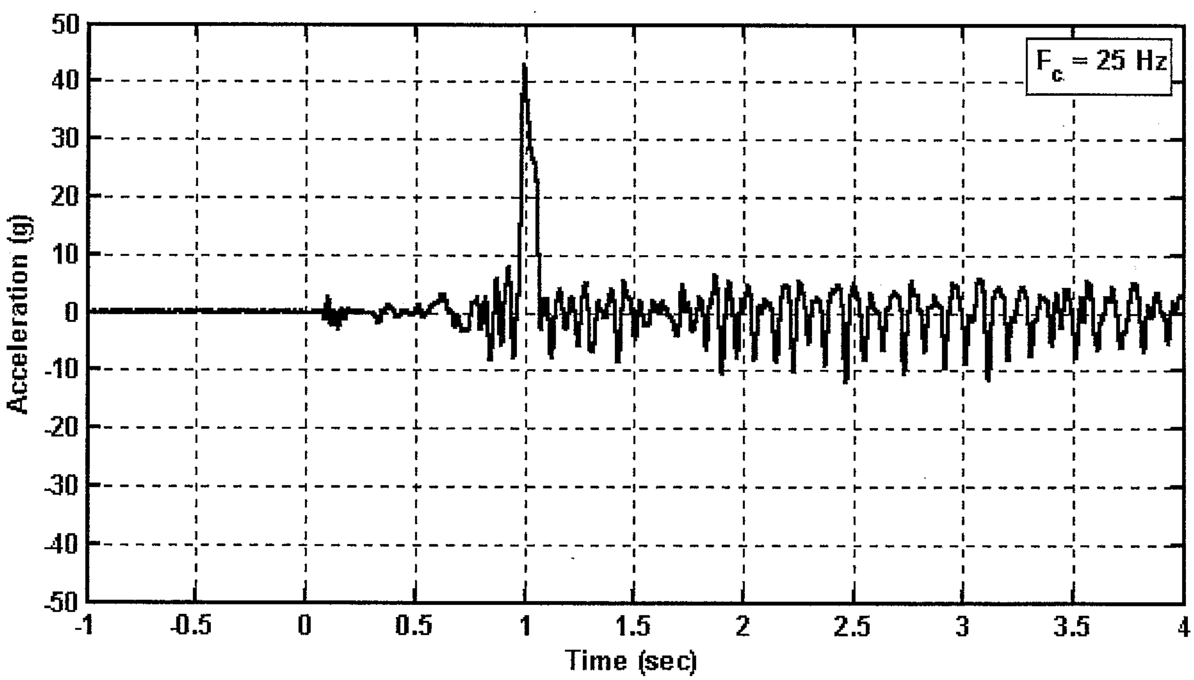


Figure D30. Bullet car 2, B truck, vertical acceleration
Channel Name: B2_BBZ

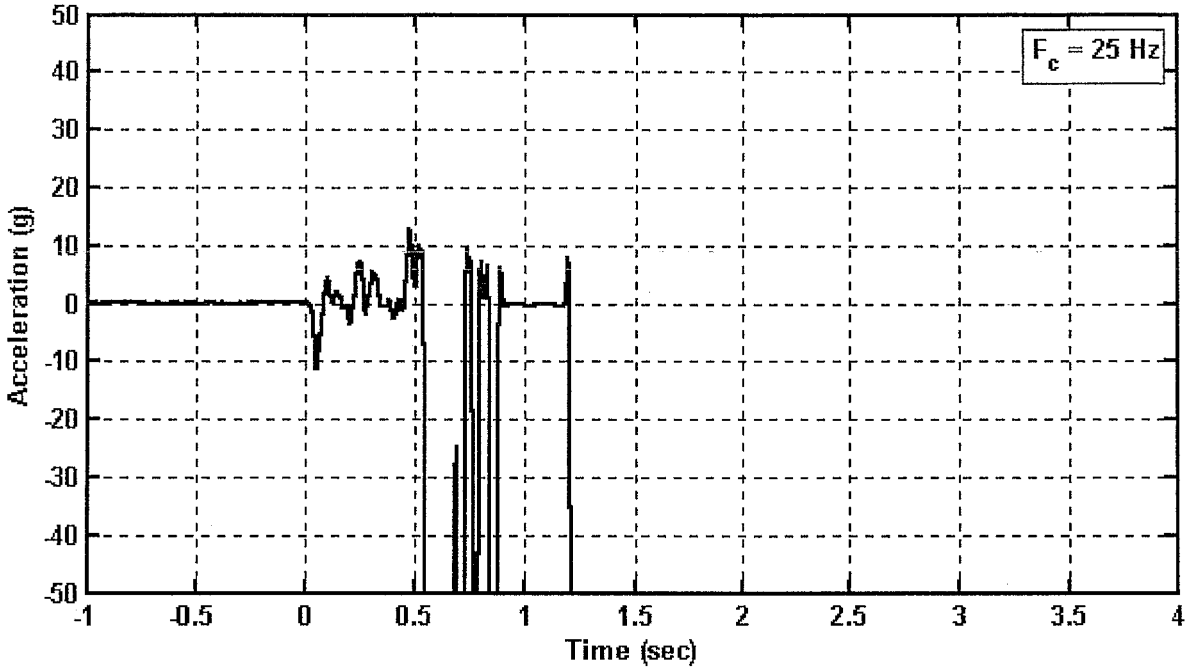


Figure D31. Bullet car 2, position 1, center sill, longitudinal acceleration
Channel Name: B2_C1X

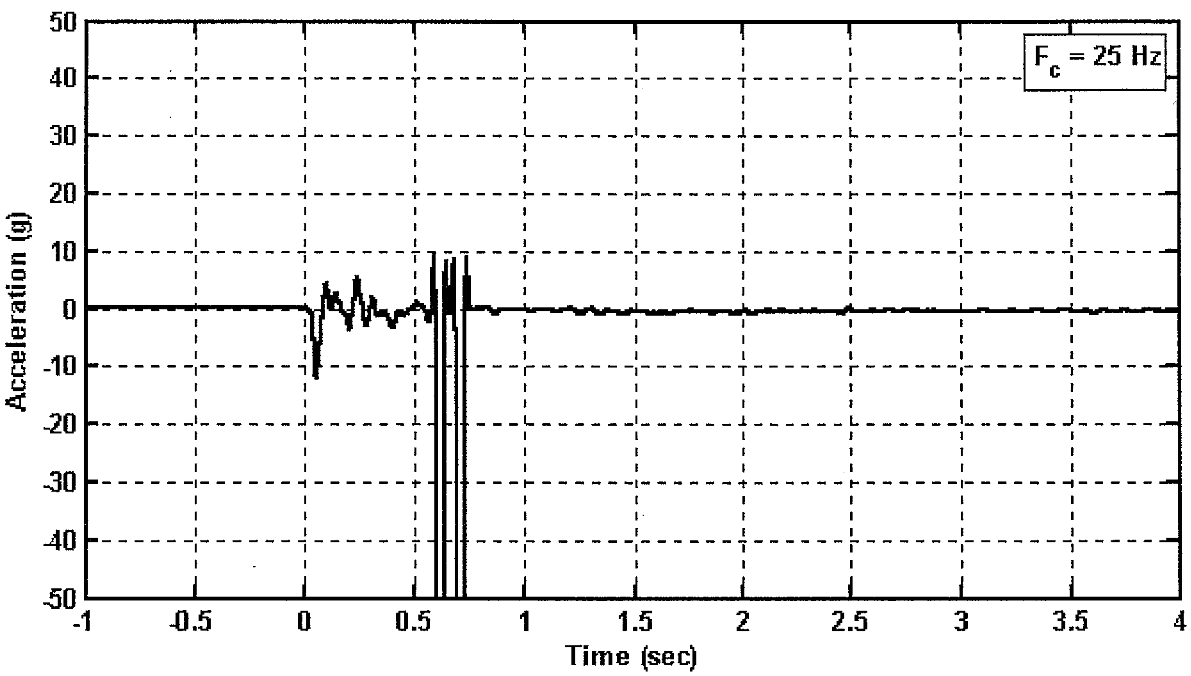


Figure D32. Bullet car 2, position 2, center sill, longitudinal acceleration
Channel Name: B2_C2X

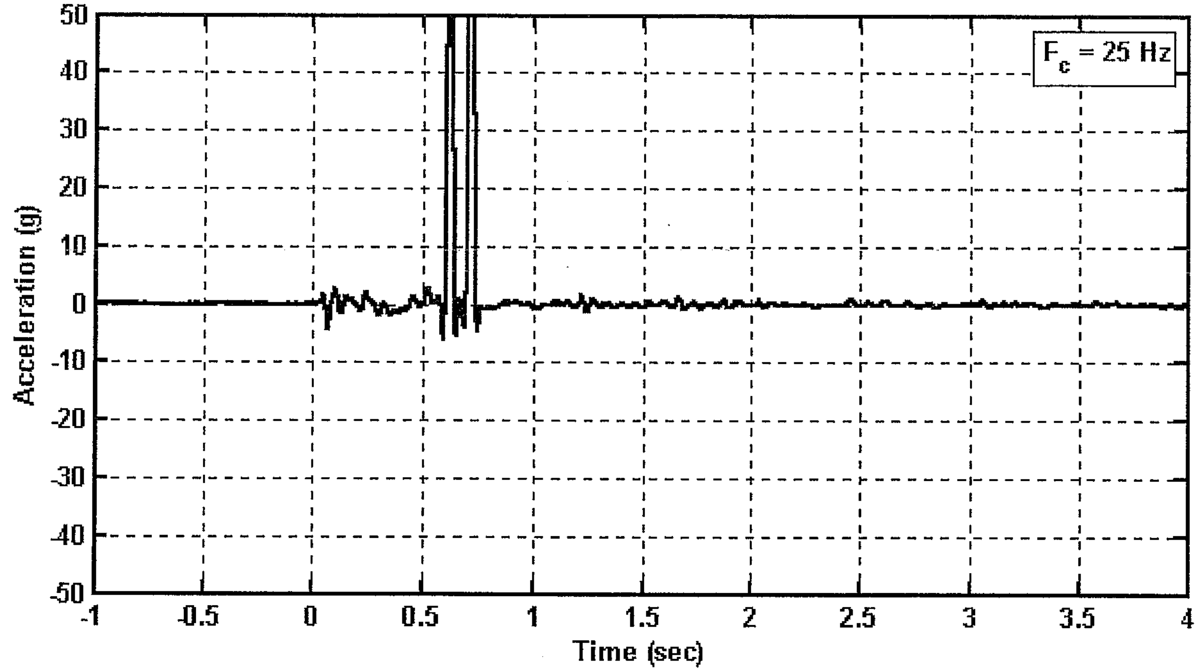


Figure D33. Bullet car 2, position 2, center sill, lateral acceleration
Channel Name: B2_C2Y

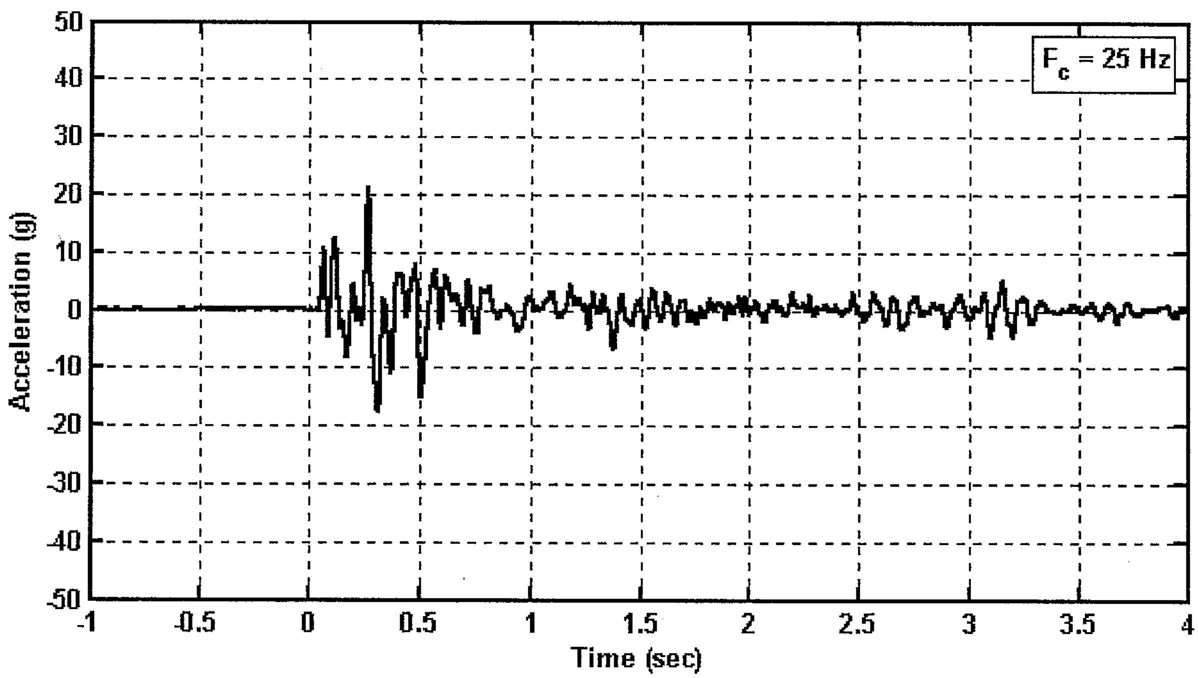


Figure D34. Bullet car 2, position 2, center sill, vertical acceleration
Channel Name: B2_C2Z

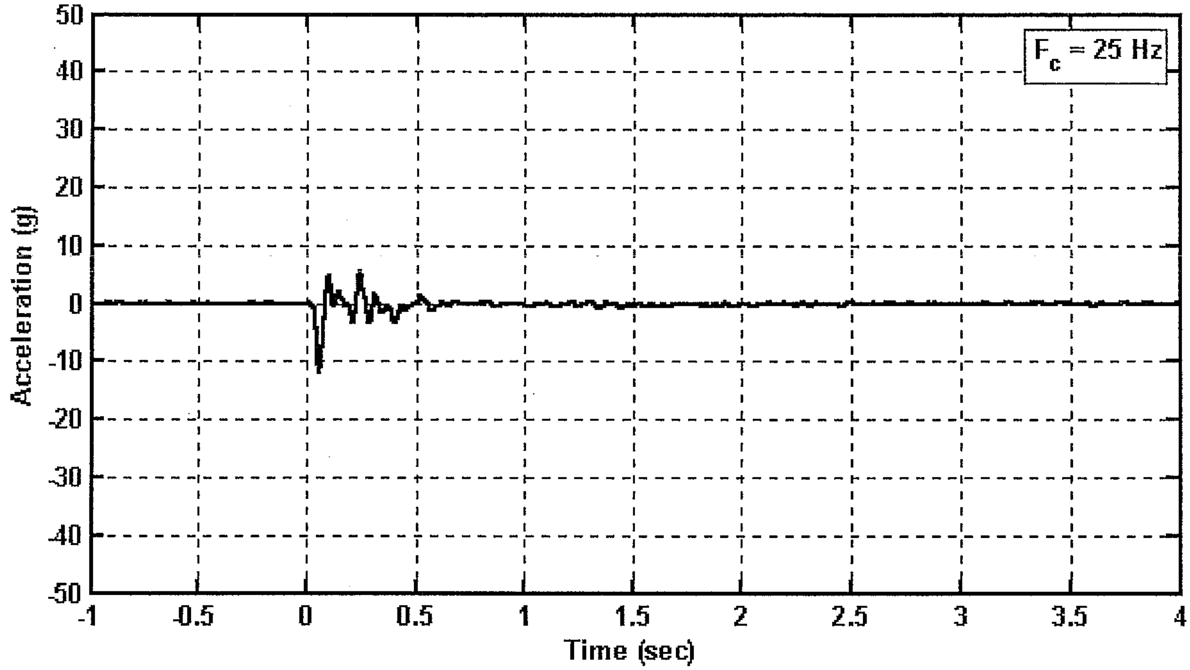


Figure D35. Bullet car 2, position 3, center sill, longitudinal acceleration
Channel Name: B2_C3X

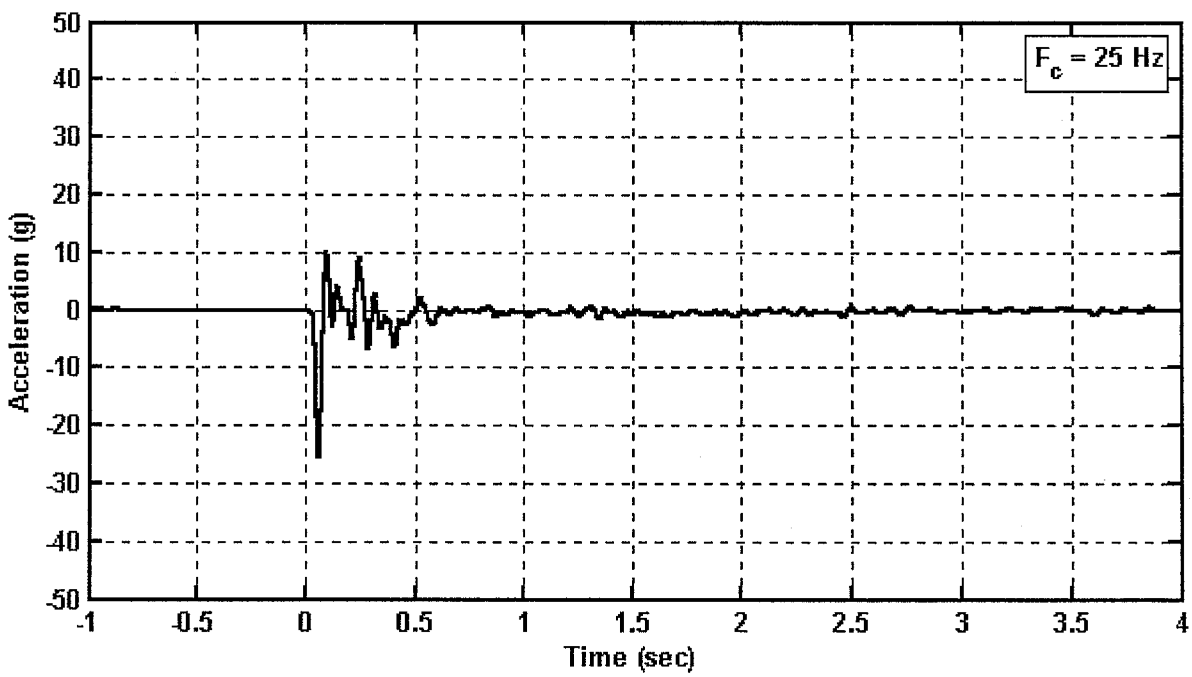


Figure D36. Bullet car 2, position 4, center sill, longitudinal acceleration
Channel Name: B2_C4X

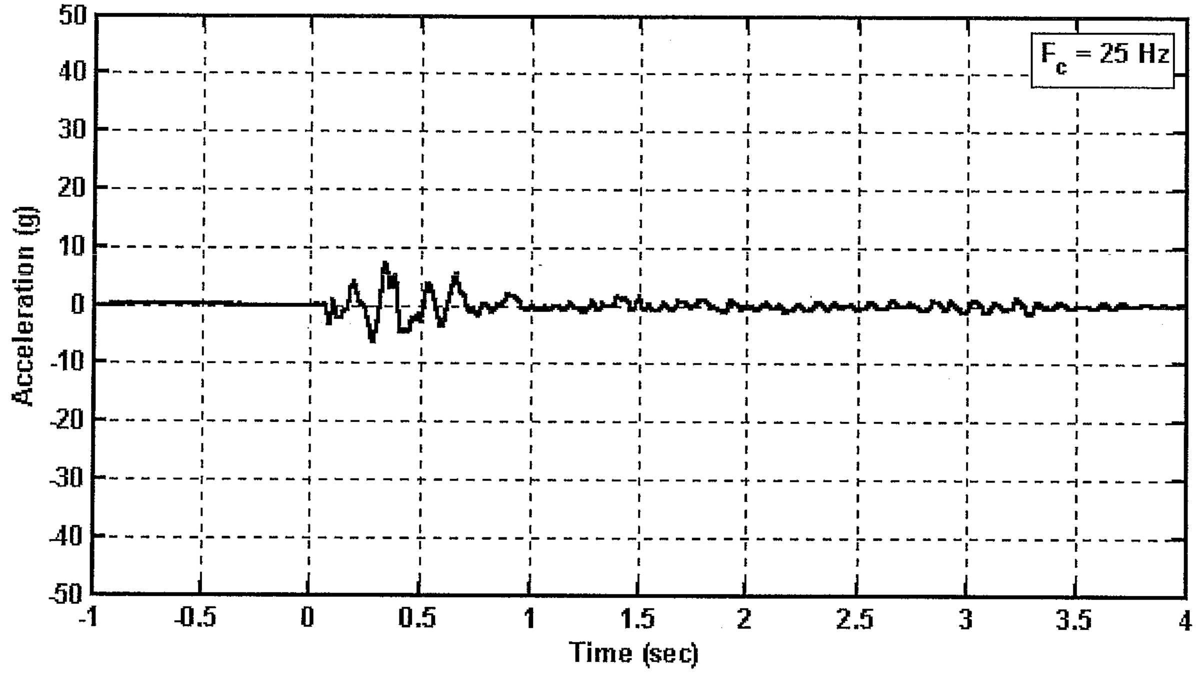


Figure D37. Bullet car 2, position 4, center sill, lateral acceleration
Channel Name: B2_C4Y

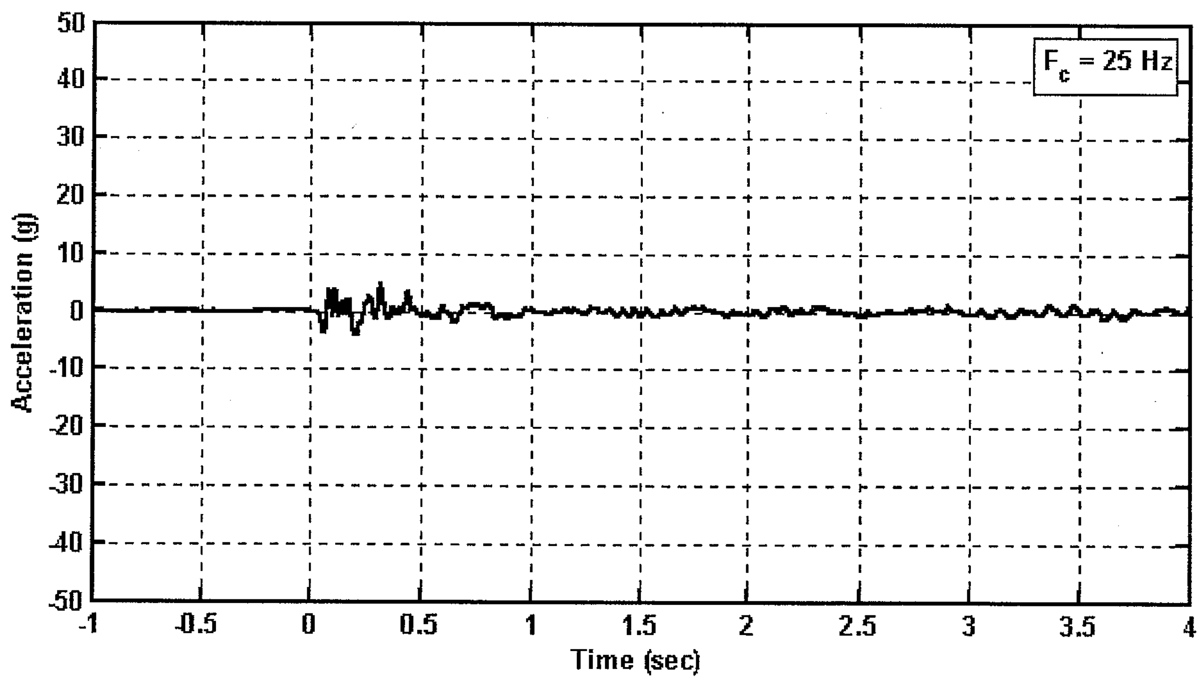


Figure D38. Bullet car 2, position 4, center sill, vertical acceleration
Channel Name: B2_C4Z

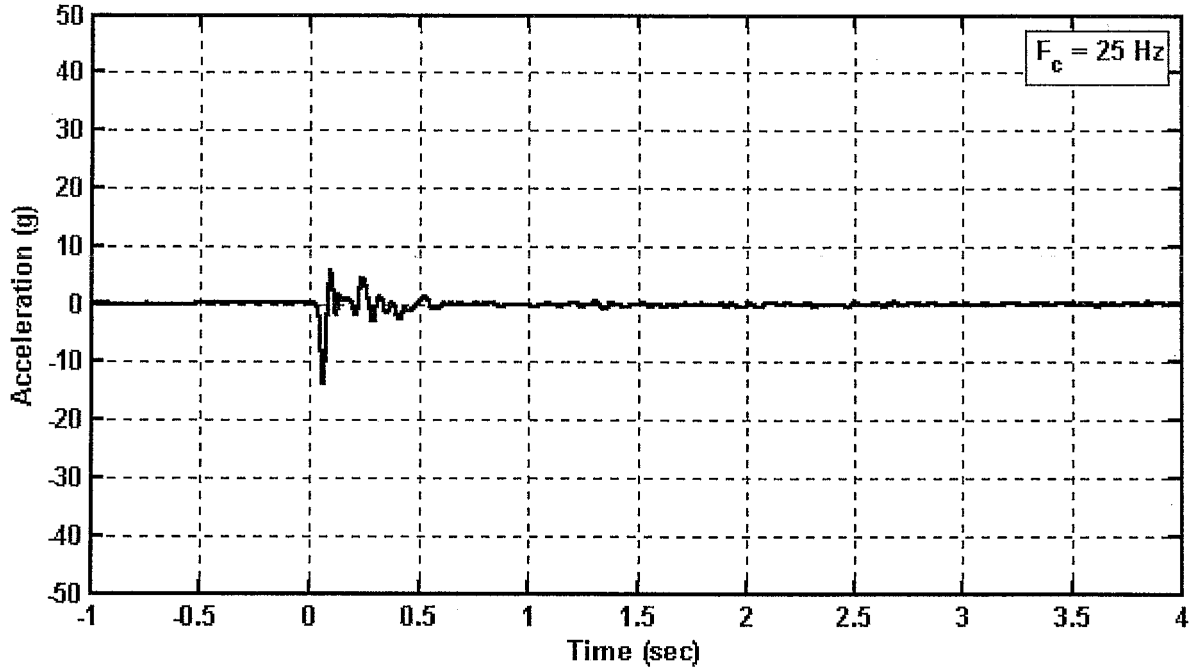


Figure D39. Bullet car 2, position 5, center sill, longitudinal acceleration
Channel Name: B2_C5X

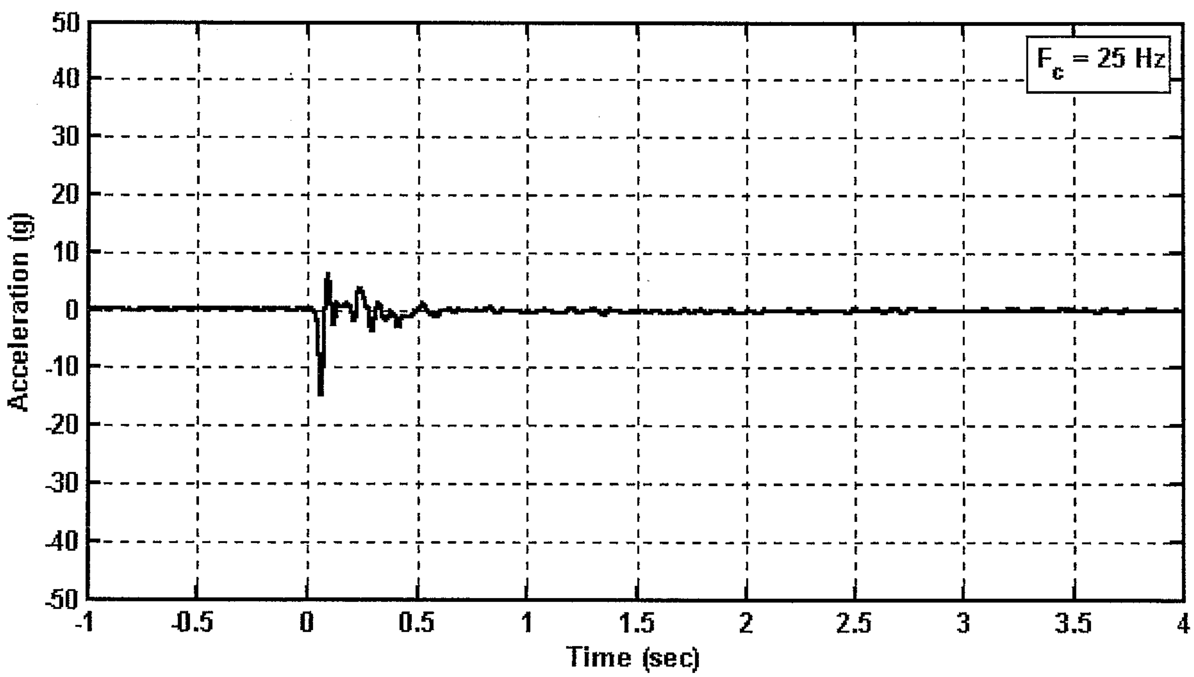


Figure D40. Bullet car 2, position 6, center sill, longitudinal acceleration
Channel Name: B2_C6X

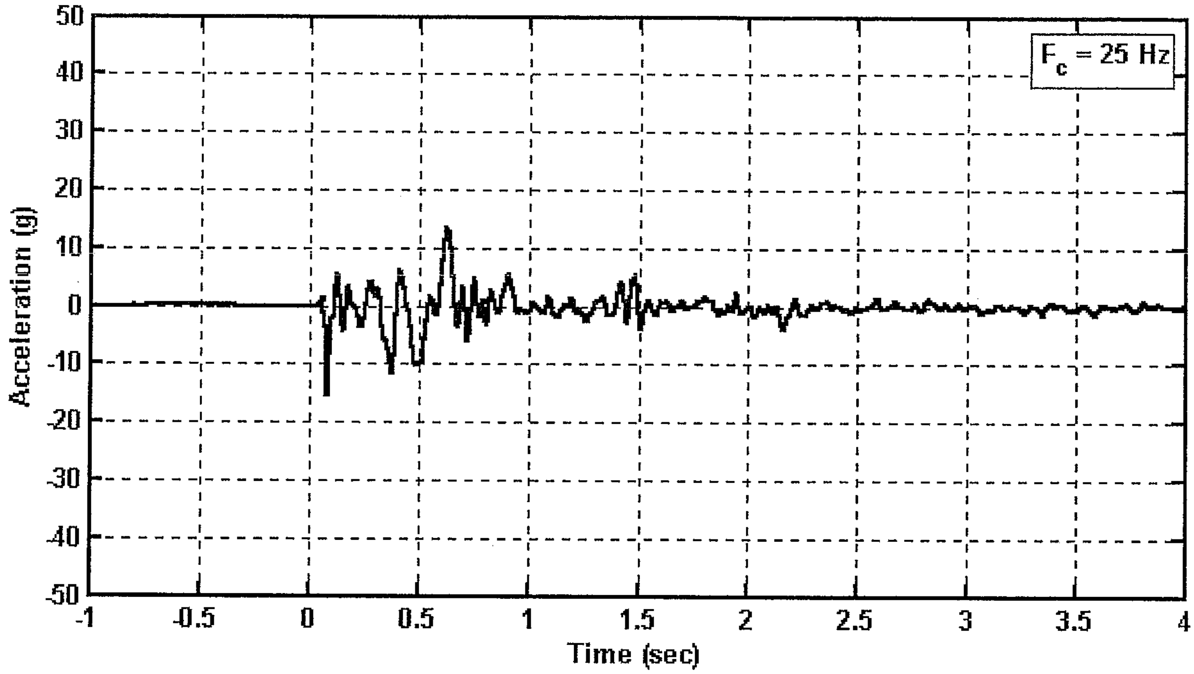


Figure D41. Bullet car 2, position 6, center sill, lateral acceleration
Channel Name: B2_C6Y

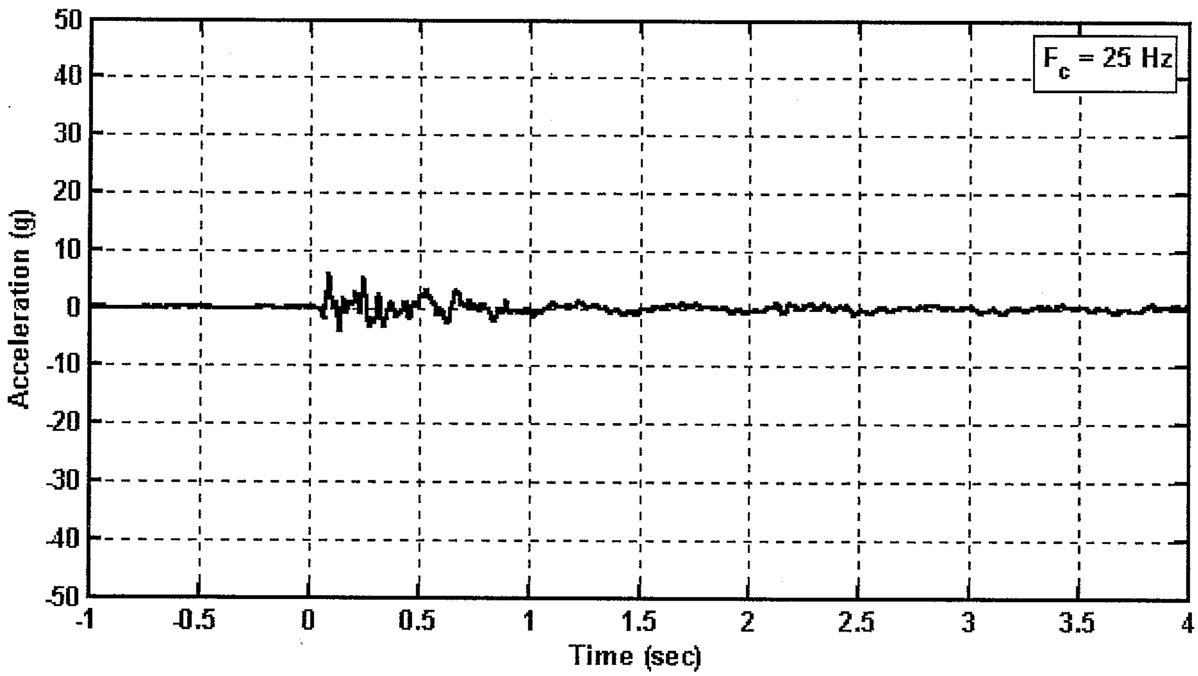


Figure D42. Bullet car 2, position 6, center sill, vertical acceleration
Channel Name: B2_C6Z

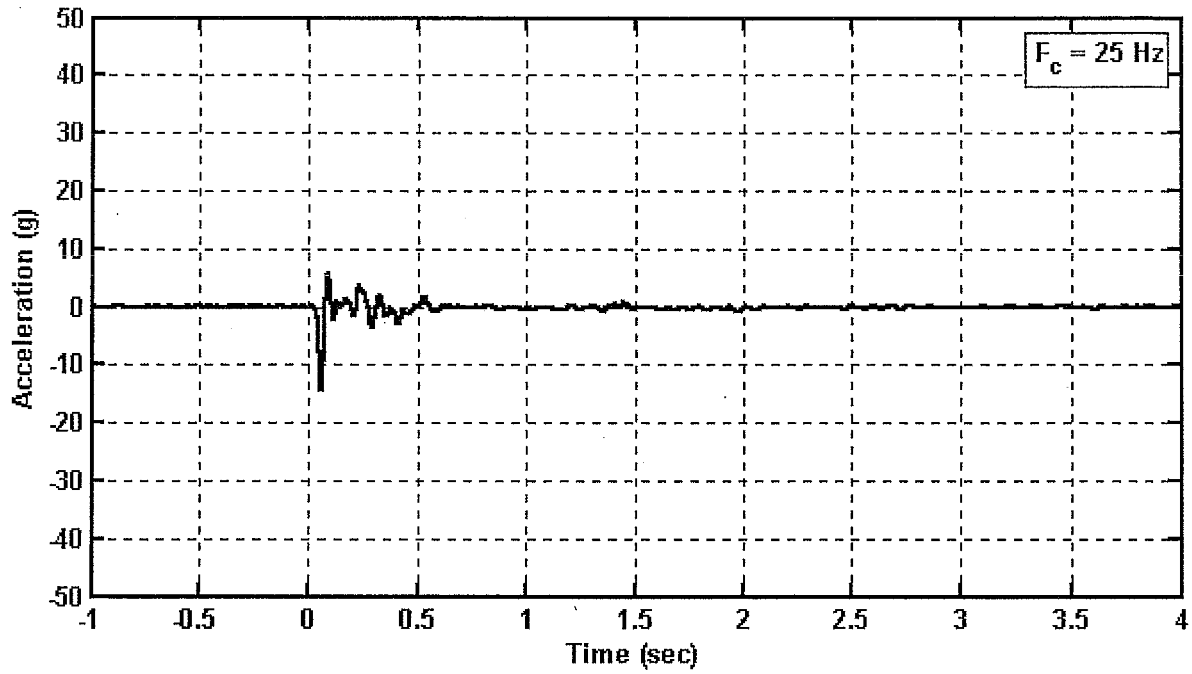


Figure D43. Bullet car 2, position 7, center sill, longitudinal acceleration
Channel Name: B2_C7X

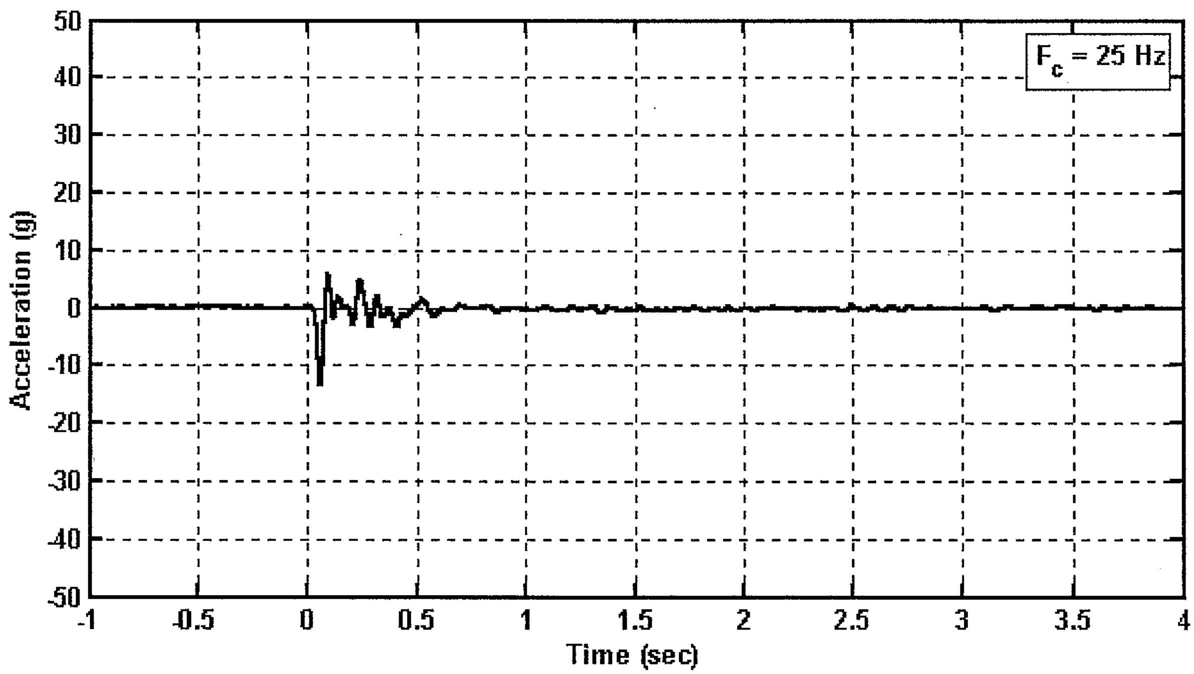


Figure D44. Bullet car 2, position 4, left side, longitudinal acceleration
Channel Name: B2_L4X

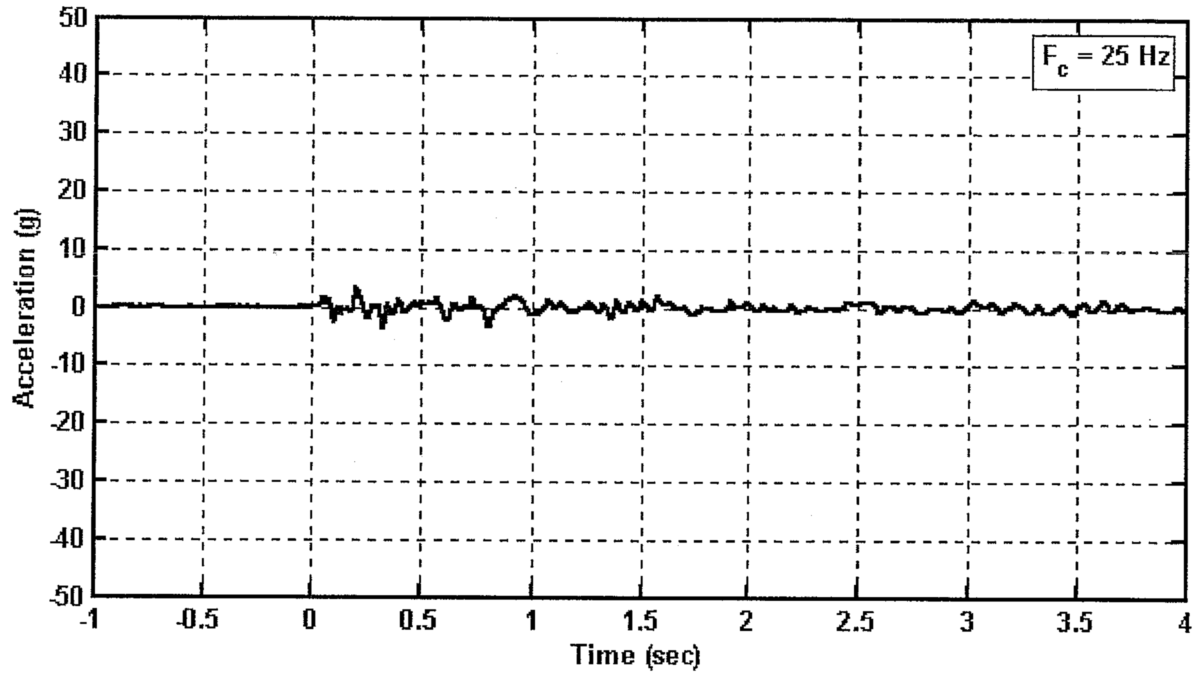


Figure D45. Bullet car 2, position 4, left side, vertical acceleration
Channel Name: B2_L4Z

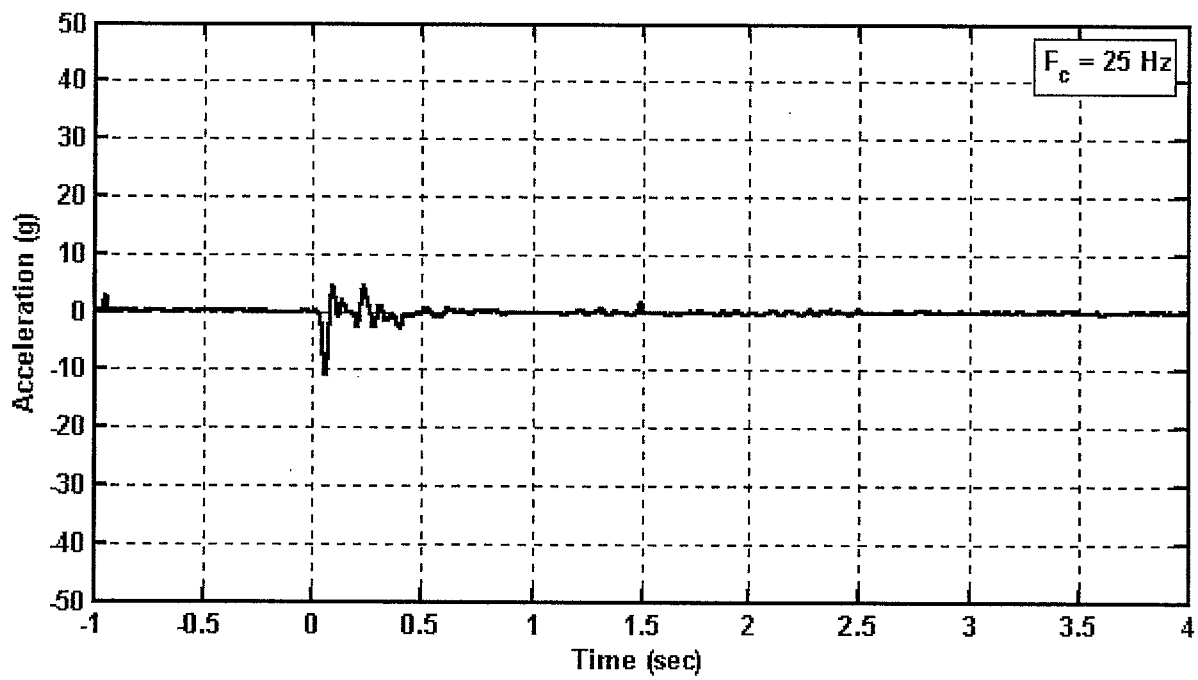


Figure D46. Bullet car 2, position 4, right side, longitudinal acceleration
Channel Name: B2_R4X

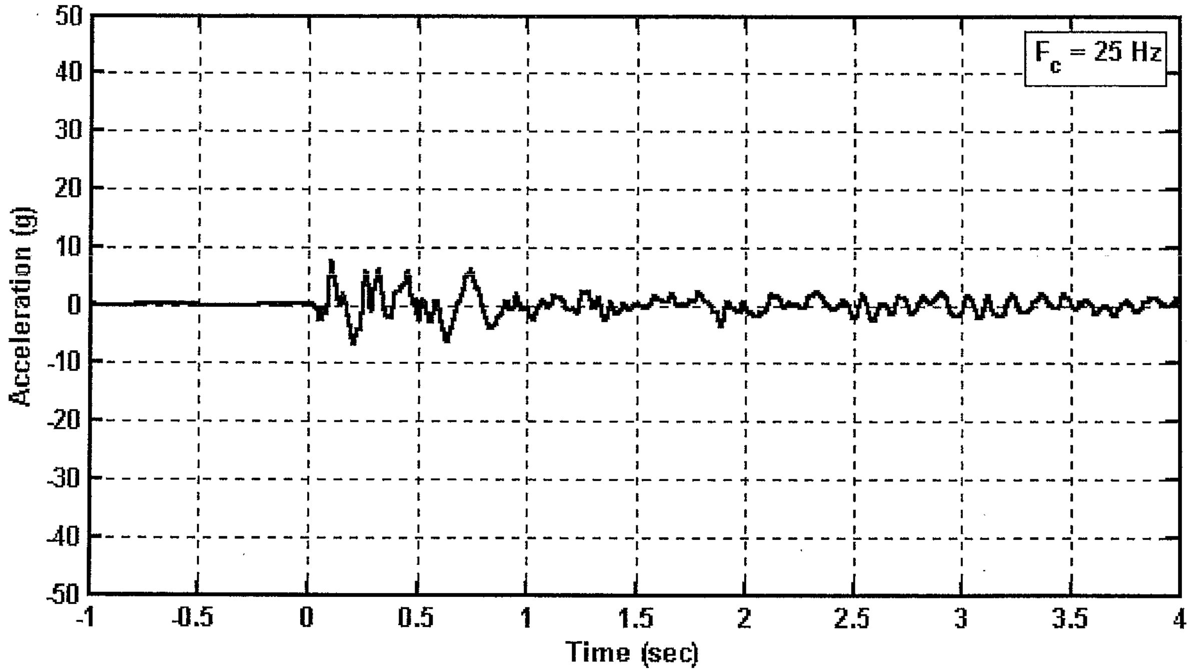


Figure D47. Bullet car 2, position 4, right side, vertical acceleration
Channel Name: B2_R4Z

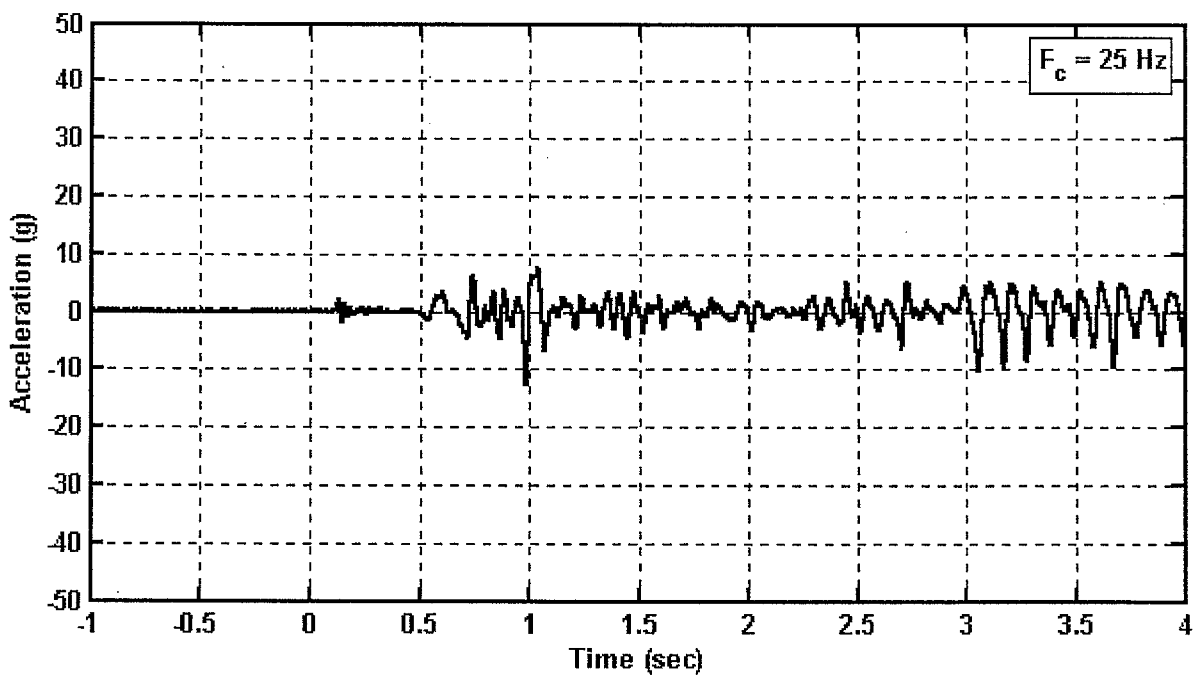


Figure D48. Bullet car 3, A truck, vertical acceleration
Channel Name: B3_BAZ

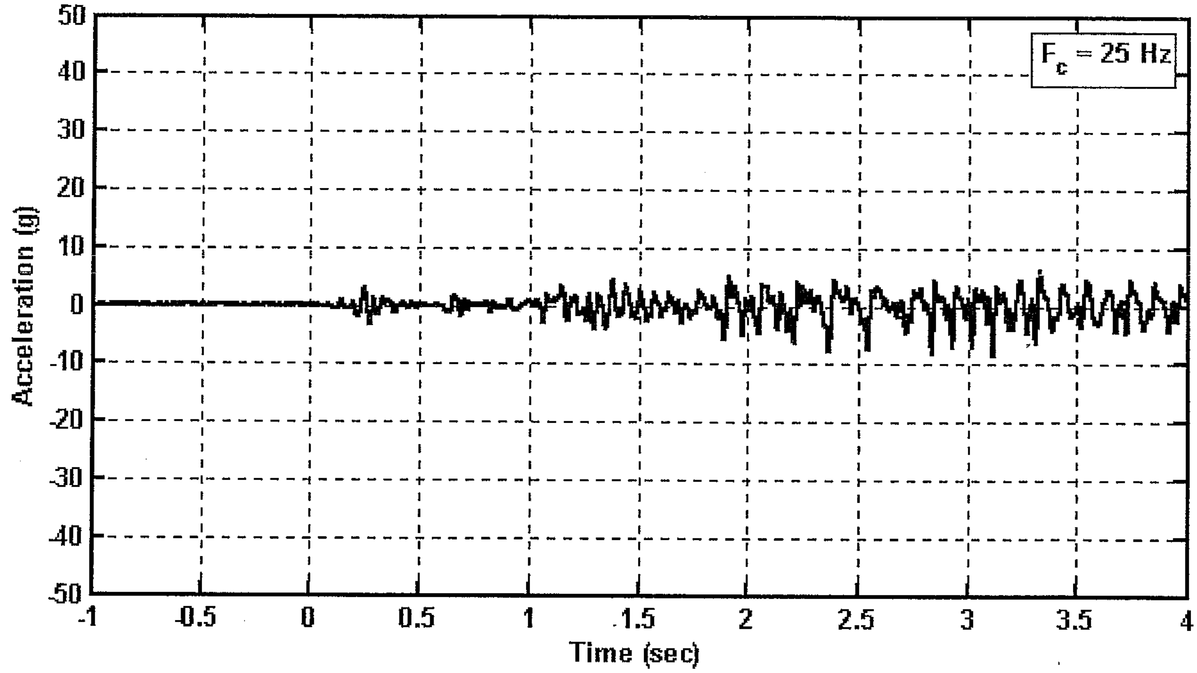


Figure D49. Bullet car 3, B truck, vertical acceleration
Channel Name: B3_BBZ

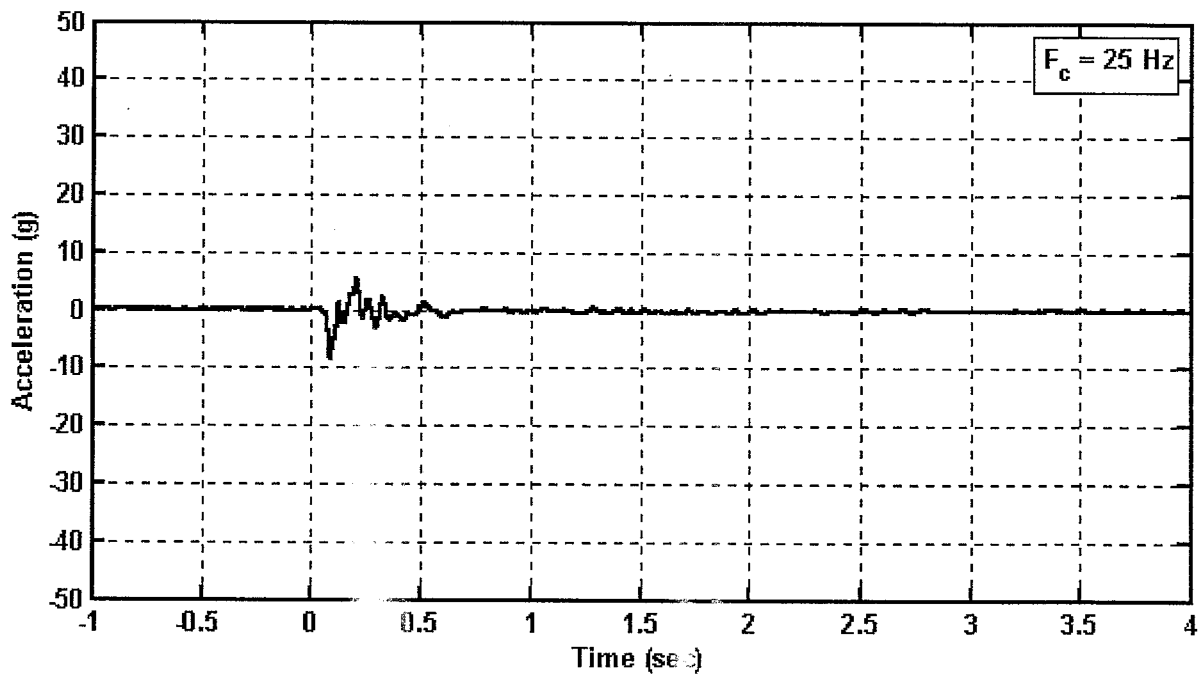


Figure D50. Bullet car 3, position 1, center sill, longitudinal acceleration
Channel Name: B3_C1X

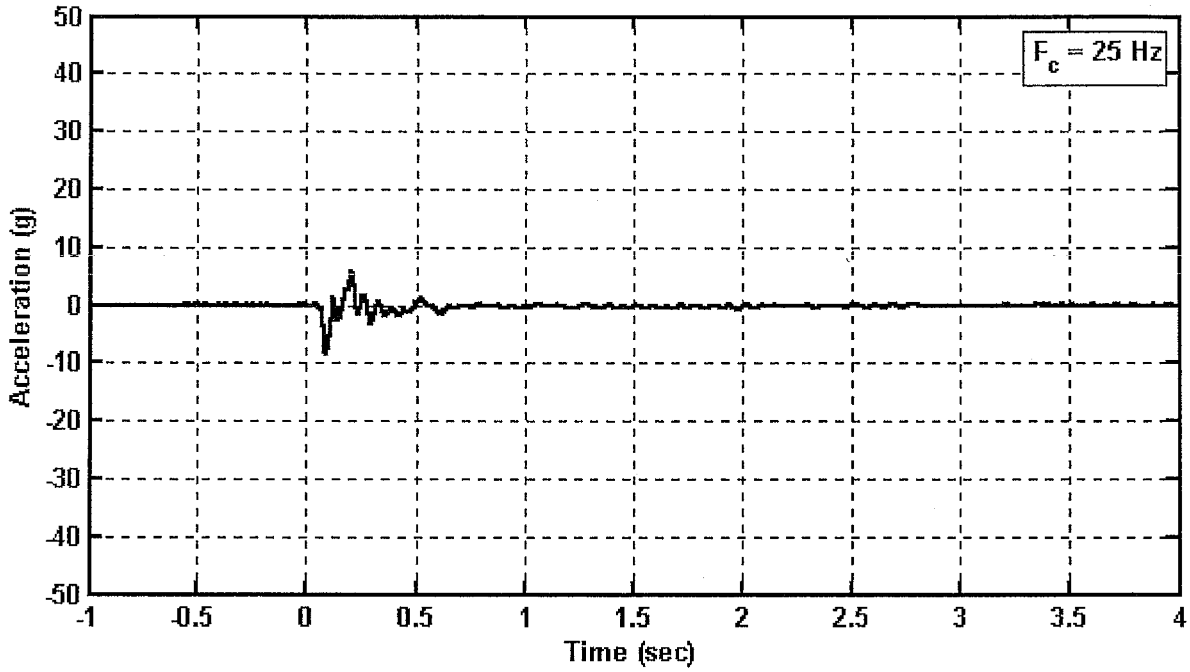


Figure D51. Bullet car 3, position 2, center sill, longitudinal acceleration
Channel Name: B3_C2X

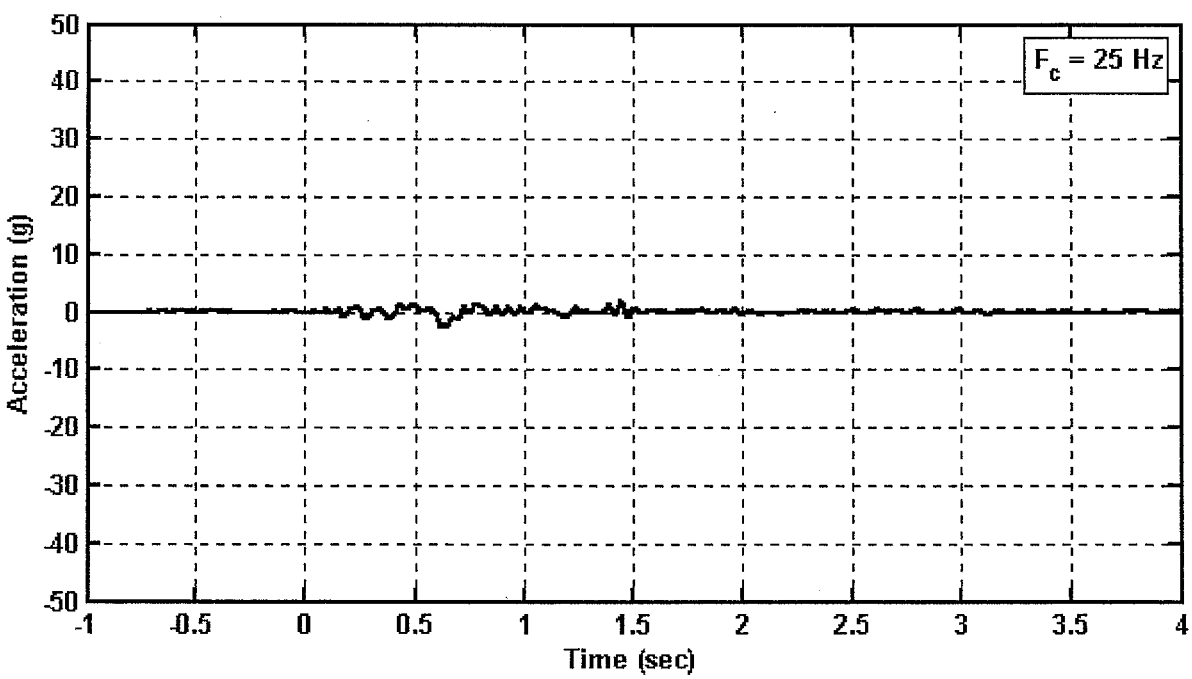


Figure D52. Bullet car 3, position 2, center sill, lateral acceleration
Channel Name: B3_C2Y

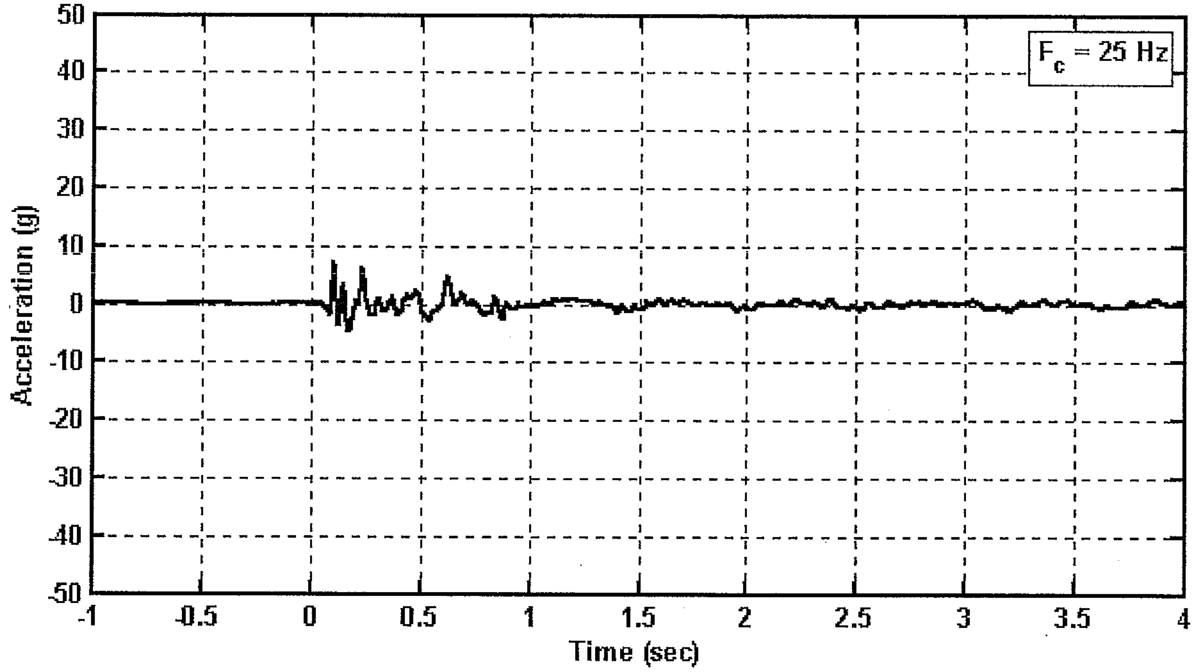


Figure D53. Bullet car 3, position 2, center sill, vertical acceleration
Channel Name: B3_C2Z

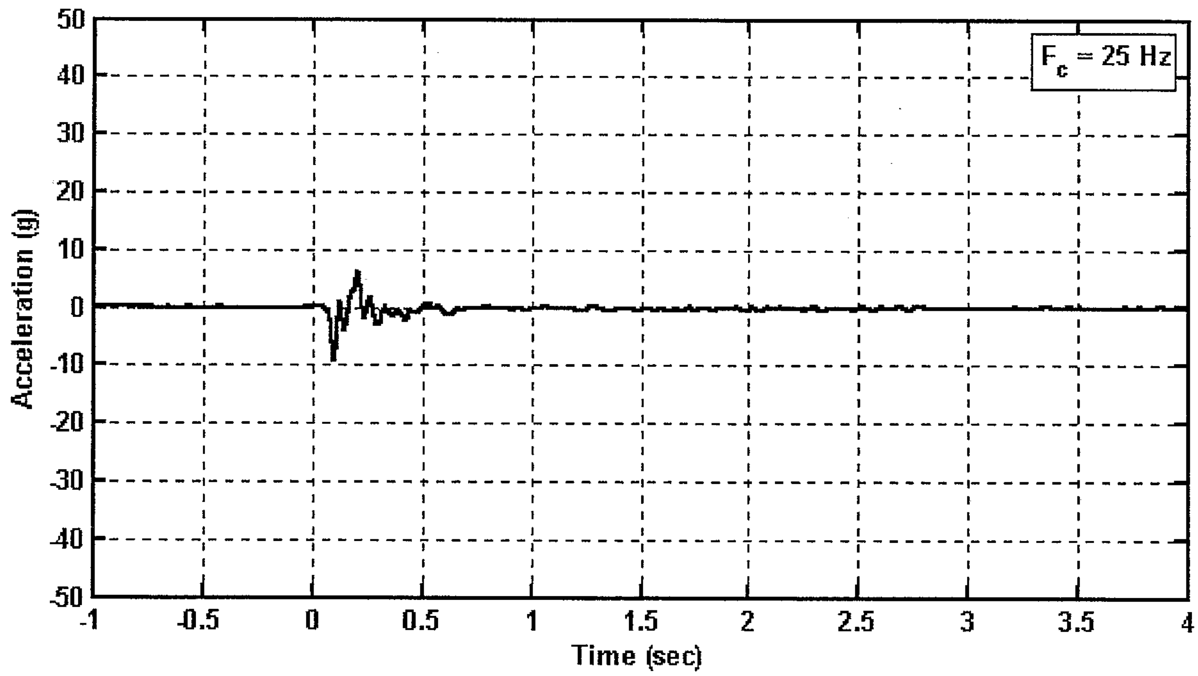


Figure D54. Bullet car 3, position 3, center sill, longitudinal acceleration
Channel Name: B3_C3X

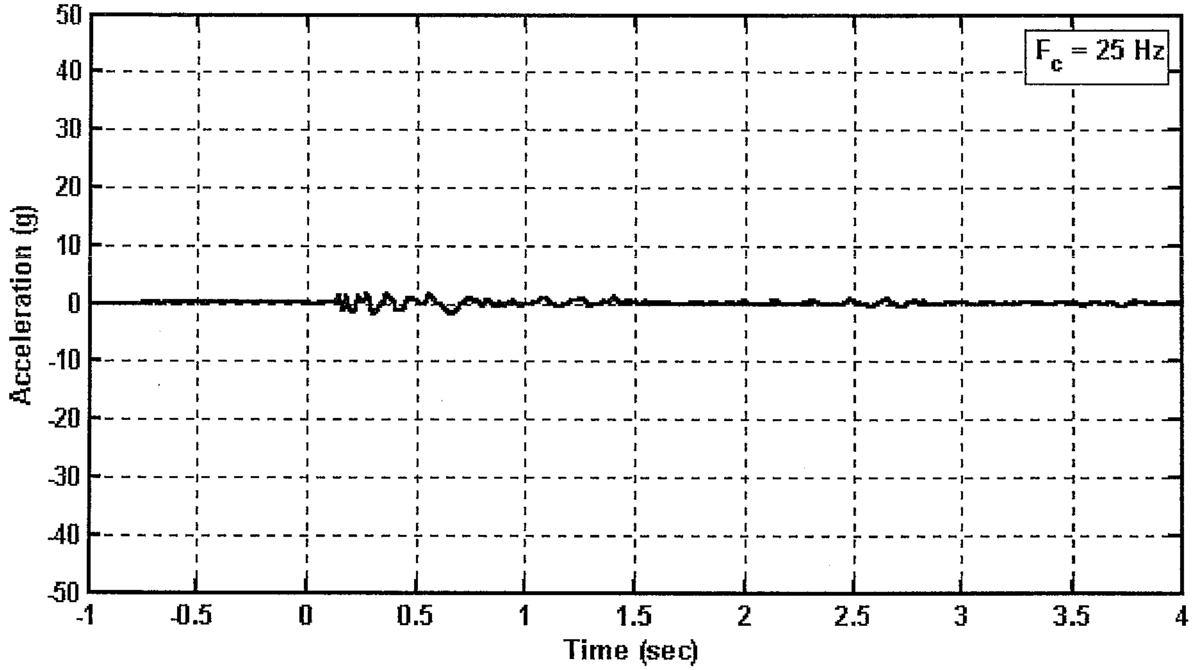


Figure D55. Bullet car 3, position 3, center sill, lateral acceleration
Channel Name: B3_C3Y

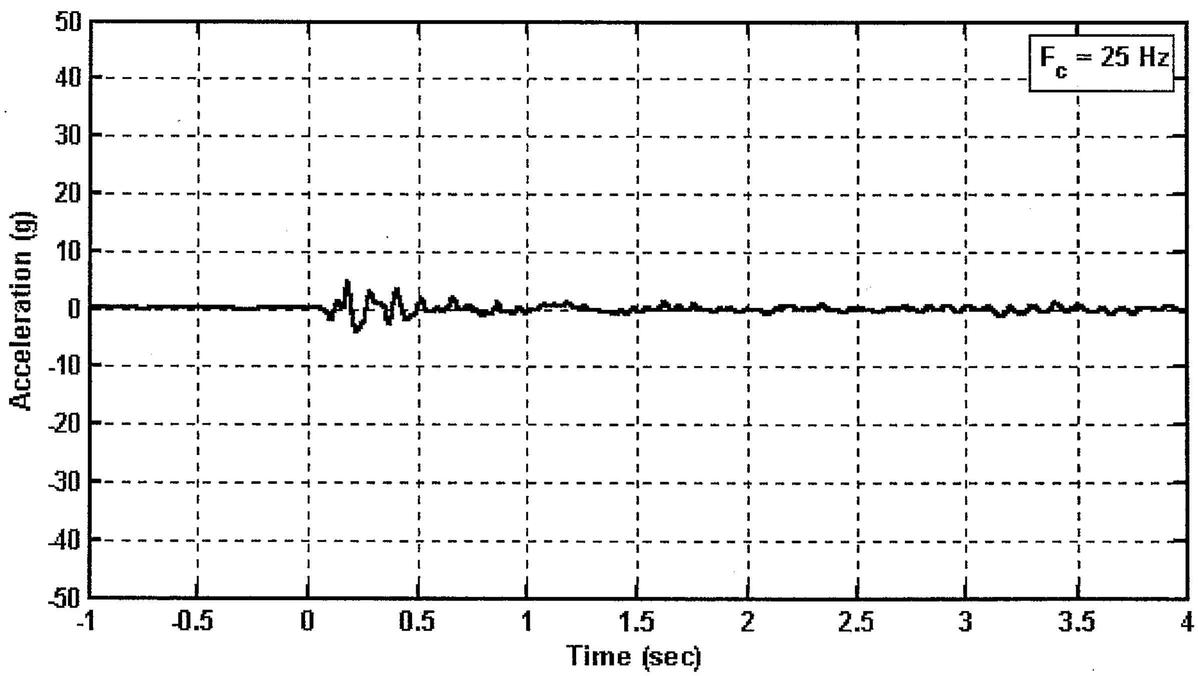


Figure D56. Bullet car 3, position 3, center sill, vertical acceleration
Channel Name: B3_C3Z

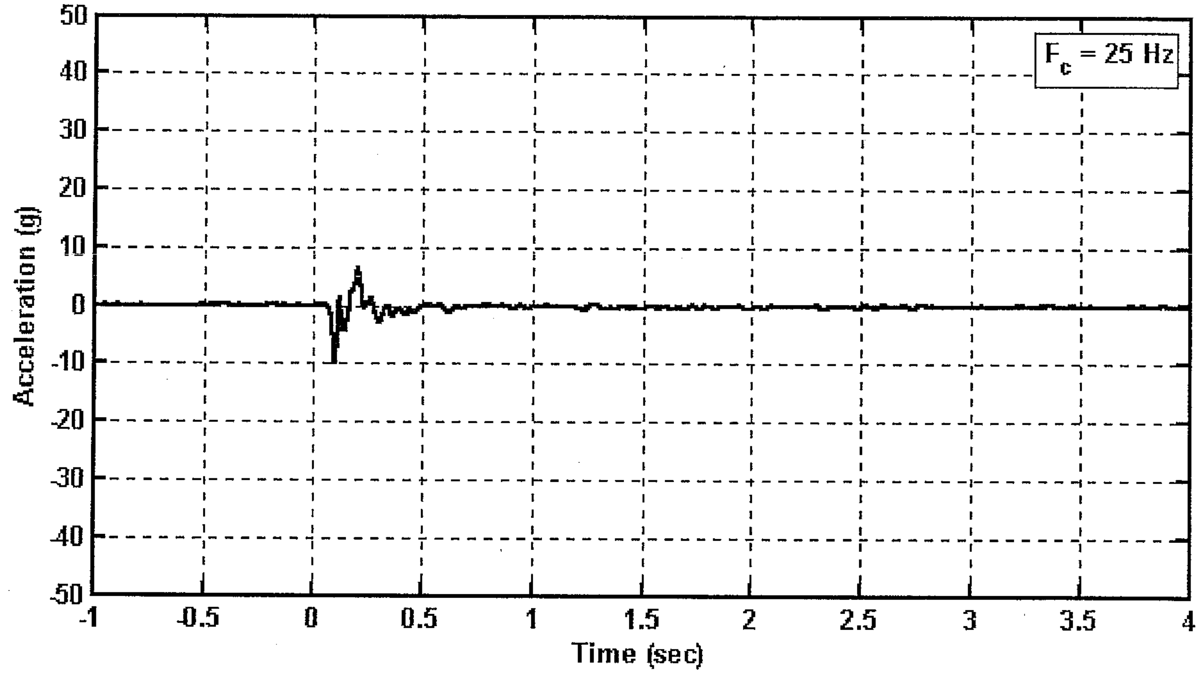


Figure D57. Bullet car 3, position 4, center sill, longitudinal acceleration
Channel Name: B3_C4X

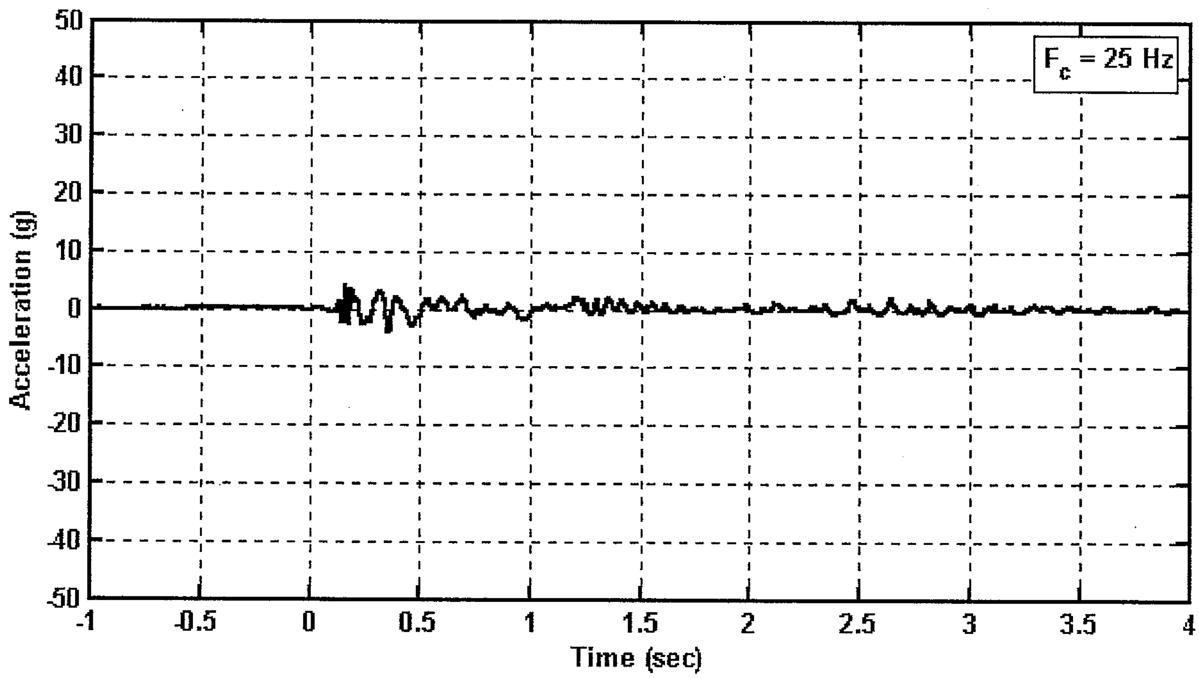


Figure D58. Bullet car 3, position 4, center sill, lateral acceleration
Channel Name: B3_C4Y

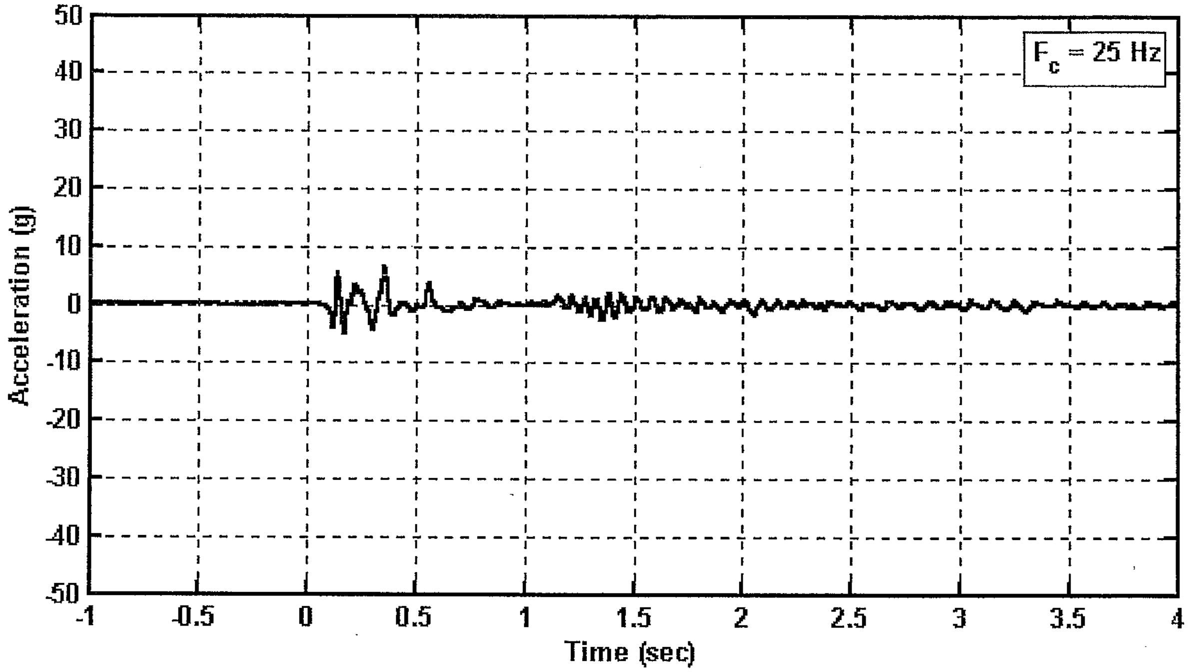


Figure D59. Bullet car 3, position 4, center sill, vertical acceleration
Channel Name: B3_C4Z

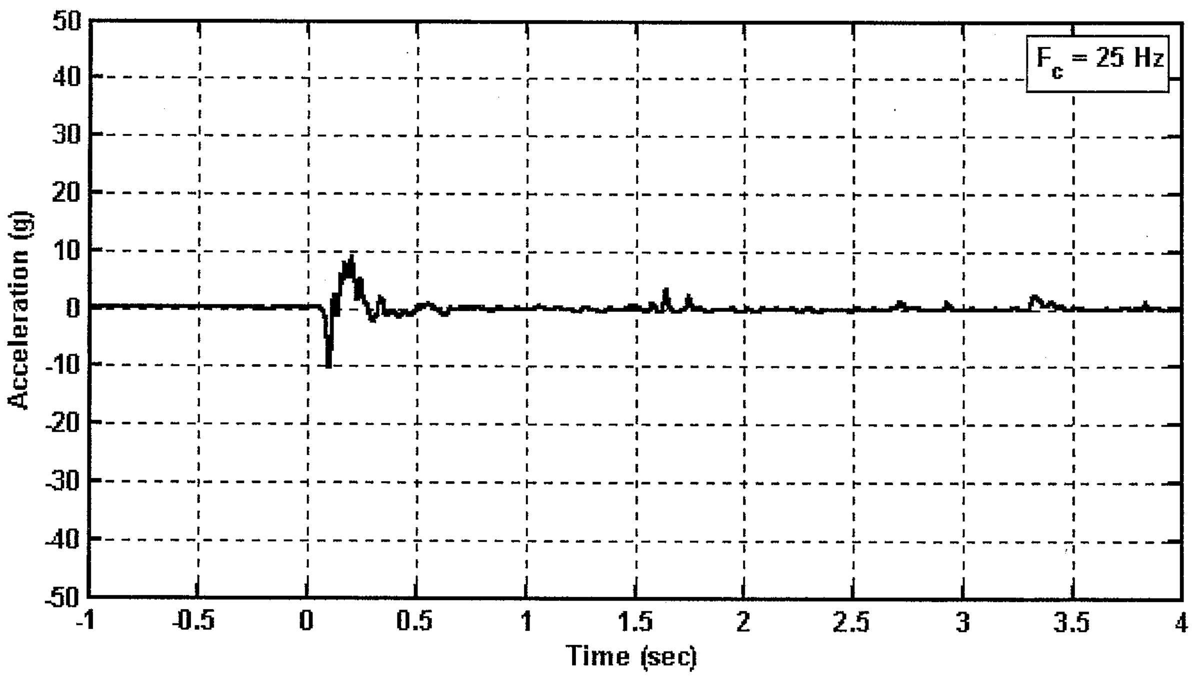


Figure D60. Bullet car 3, position 5, center sill, longitudinal acceleration
Channel Name: B3_C5X

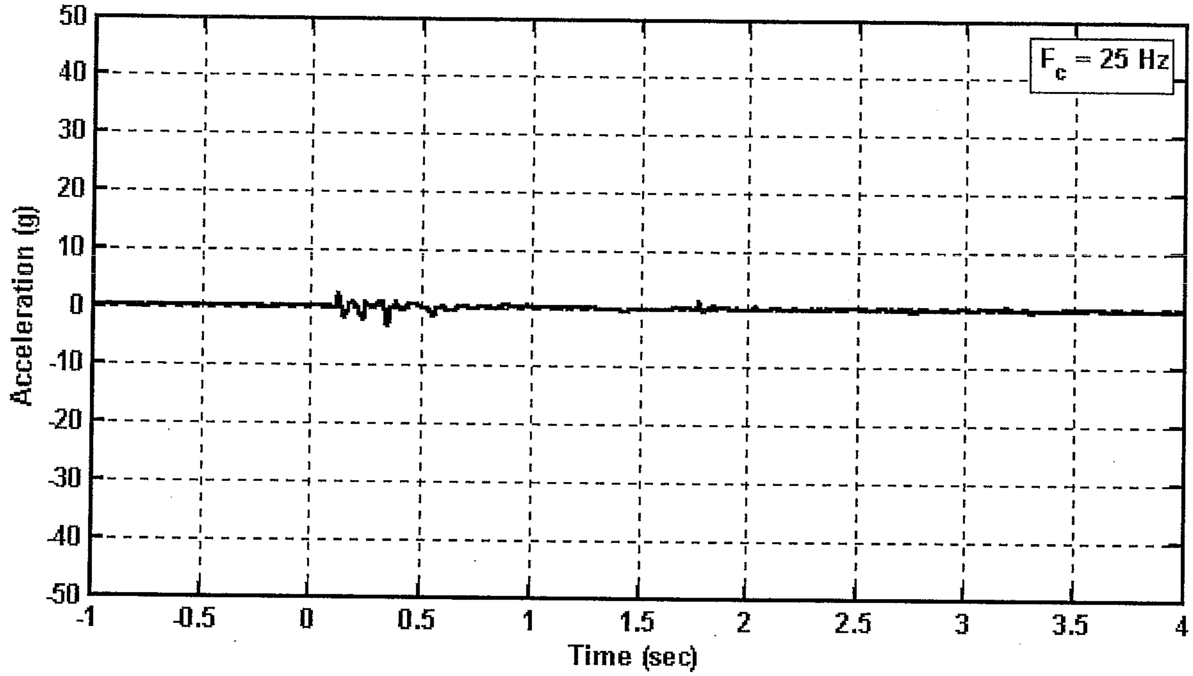


Figure D61. Bullet car 4, A truck, vertical acceleration
Channel Name: B4_BAZ

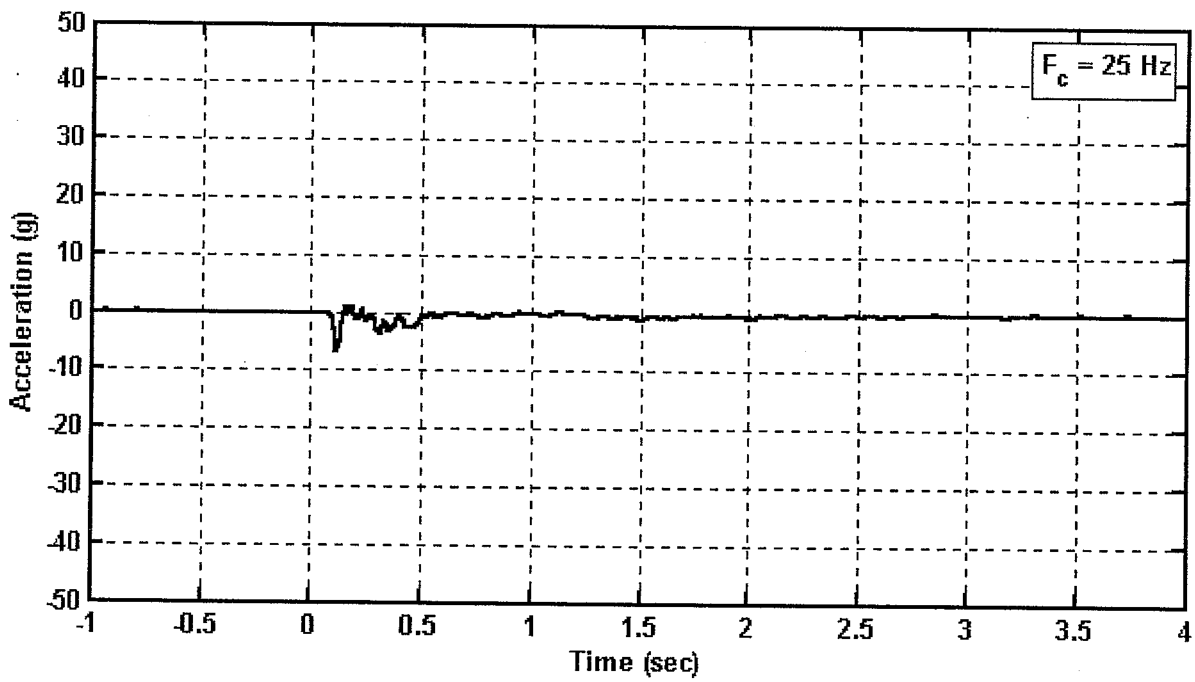


Figure D62. Bullet car 4, position 1, center sill, longitudinal acceleration
Channel Name: B4_C1X

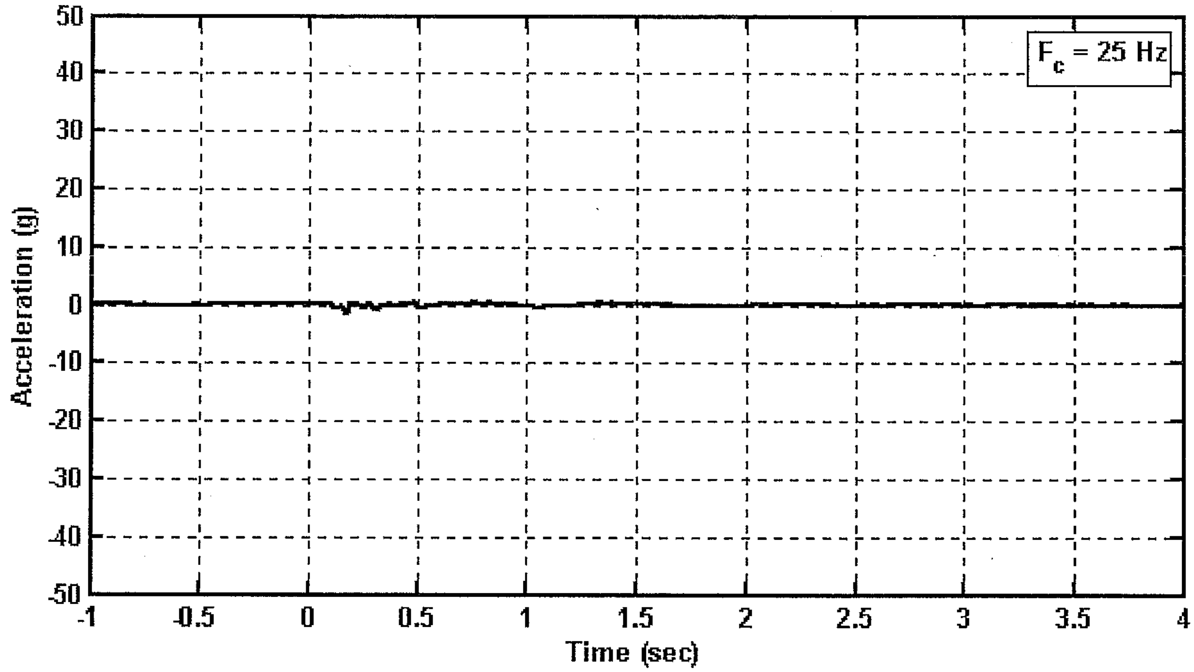


Figure D63. Bullet car 4, position 1, center sill, lateral acceleration
Channel Name: B4_C1Y

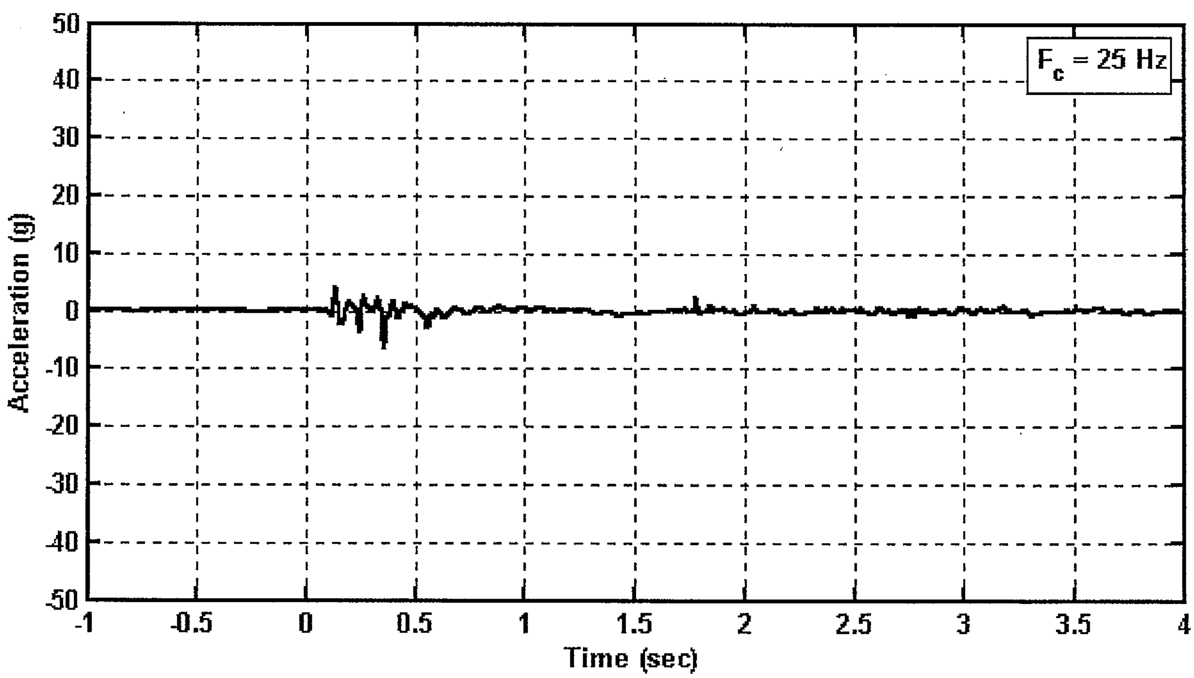


Figure D64. Bullet car 4, position 1, center sill, vertical acceleration
Channel Name: B4_C1Z

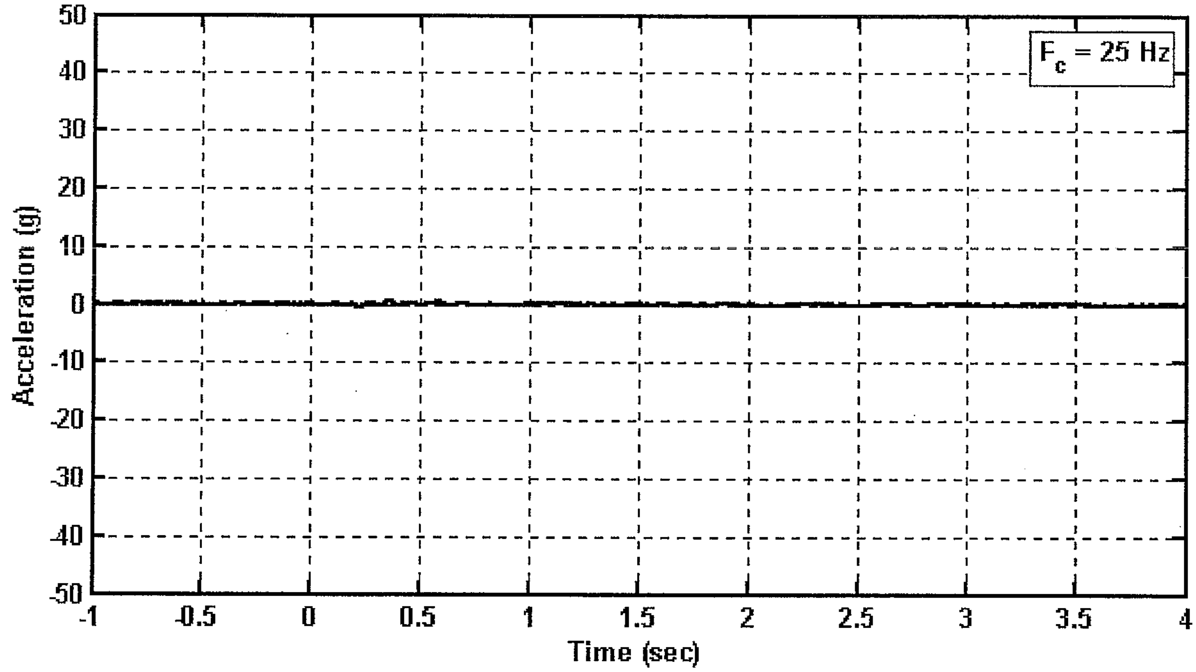


Figure D65. Bullet locomotive, A truck, vertical acceleration
Channel Name: BL_BAZ

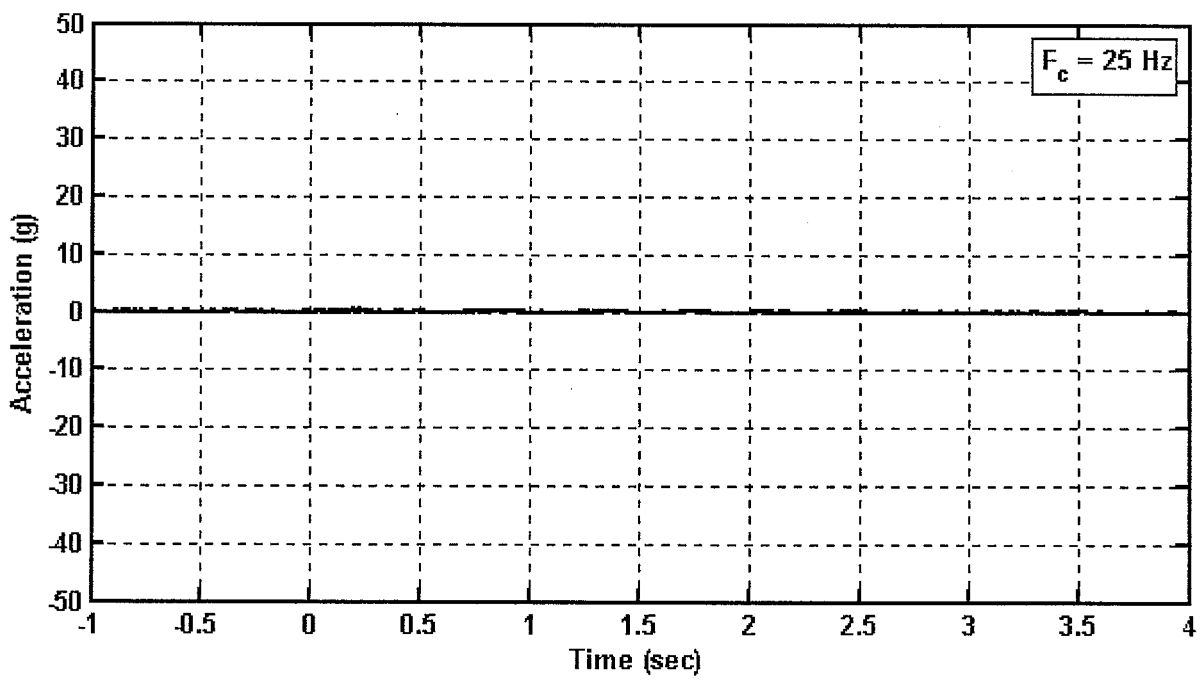


Figure D66. Bullet locomotive, B truck, vertical acceleration
Channel Name: BL_BBZ

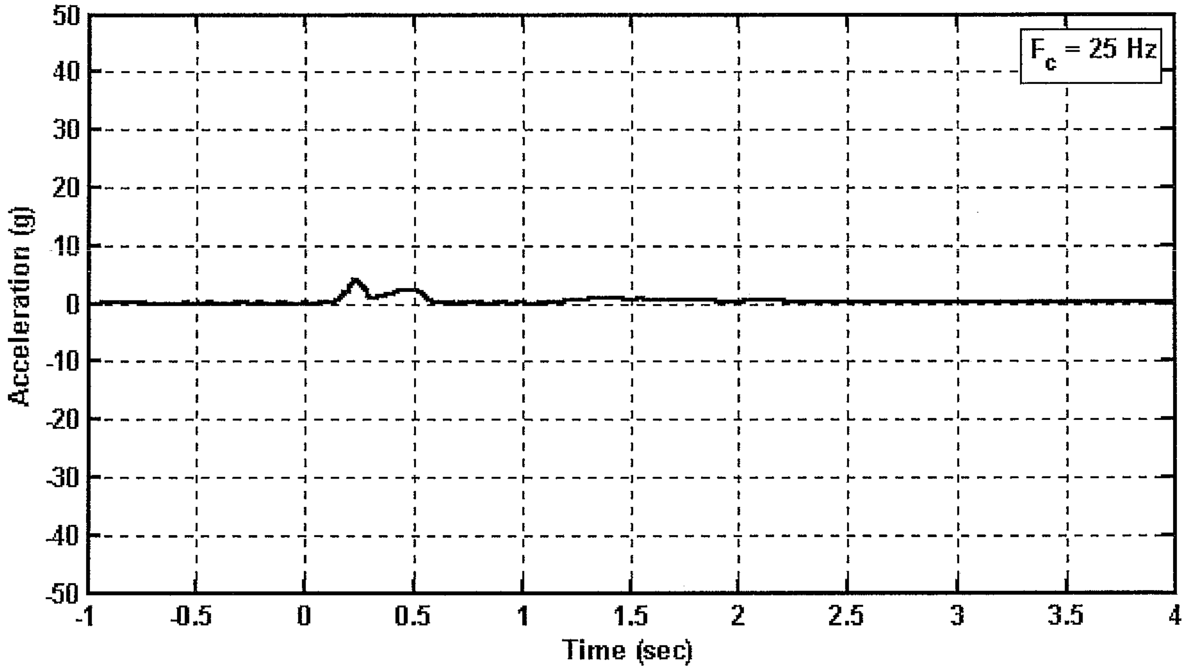


Figure D67. Bullet locomotive, position 1, center sill, longitudinal acceleration
Channel Name: BL_C1X

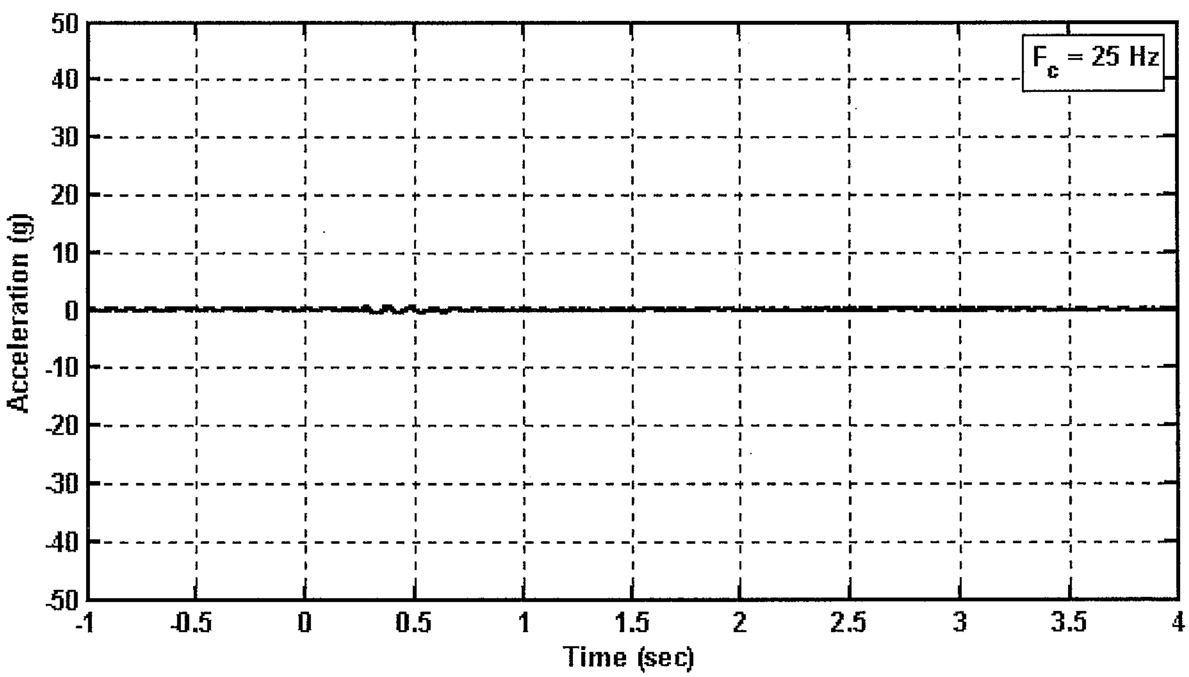


Figure D68. Bullet locomotive, position 1, center sill, lateral acceleration
Channel Name: BL_C1Y

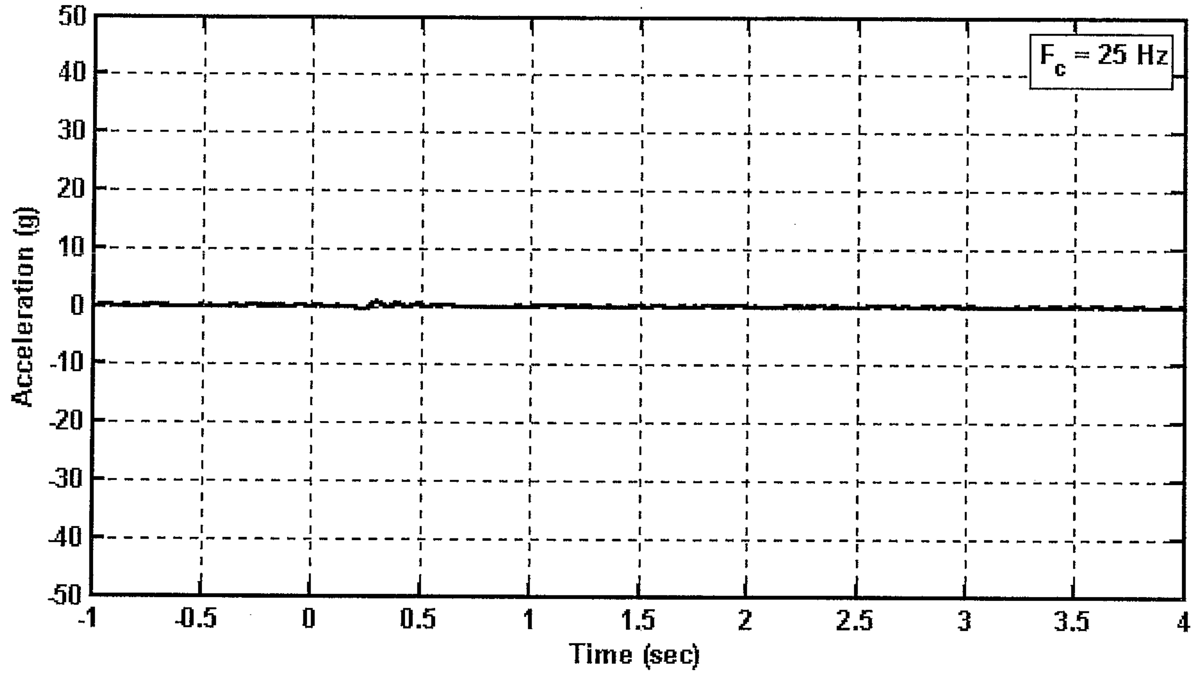


Figure D69. Bullet locomotive, position 1, center sill, vertical acceleration
Channel Name: BL_C1Z

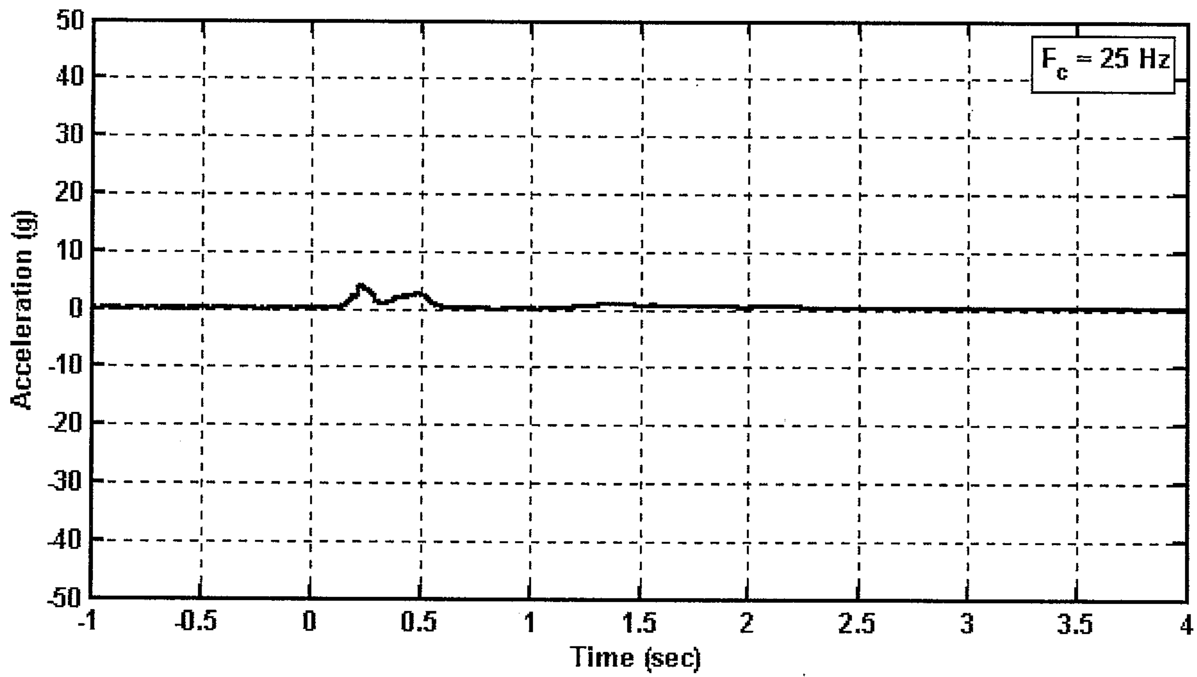


Figure D70. Bullet locomotive, position 2, center sill, longitudinal acceleration
Channel Name: BL_C2X

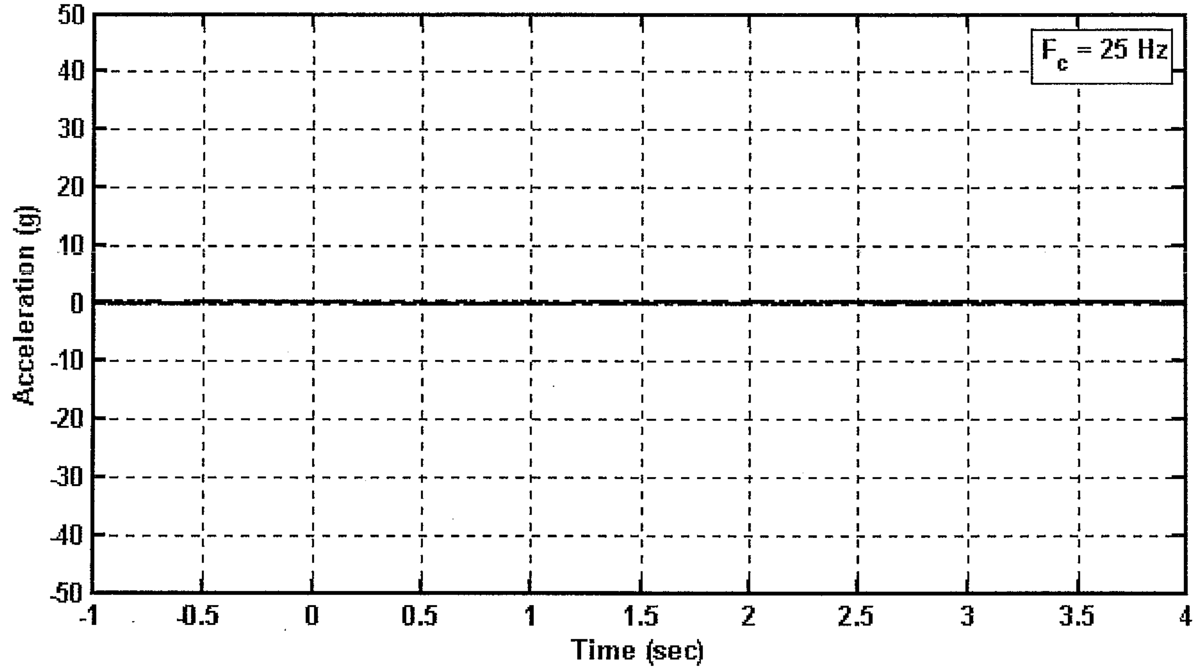


Figure D71. Bullet locomotive, position 2, center sill, lateral acceleration
Channel Name: BL_C2Y

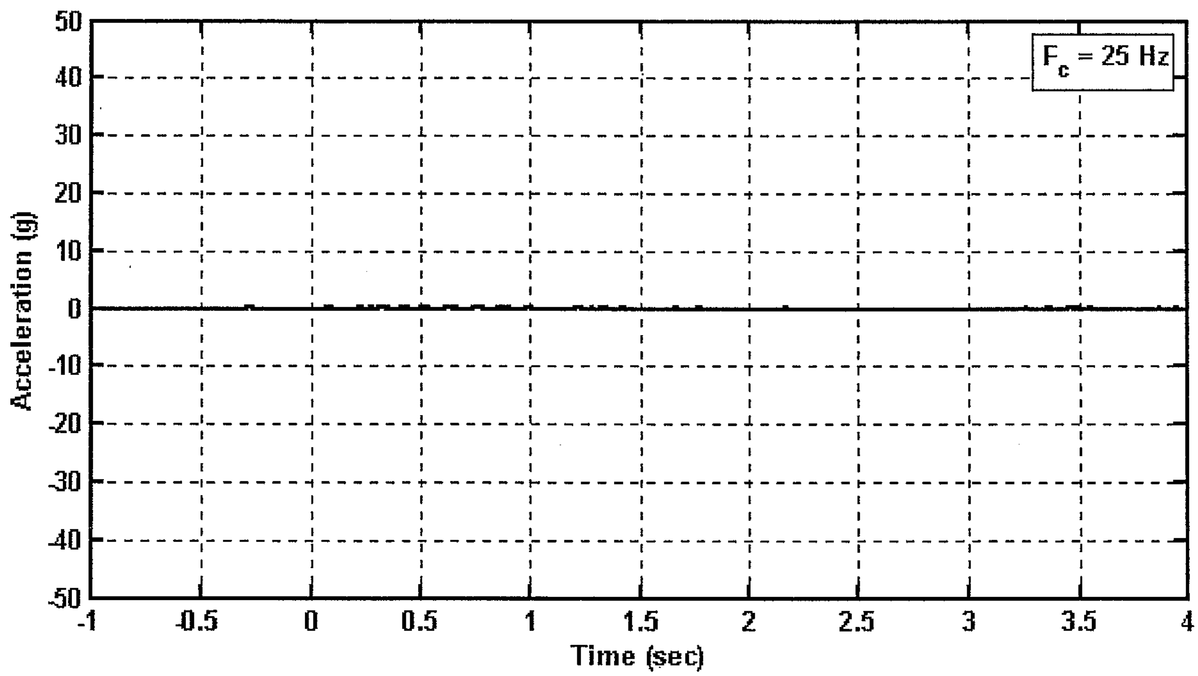


Figure D72. Bullet locomotive, position 2, center sill, vertical acceleration
Channel Name: BL_C2Z

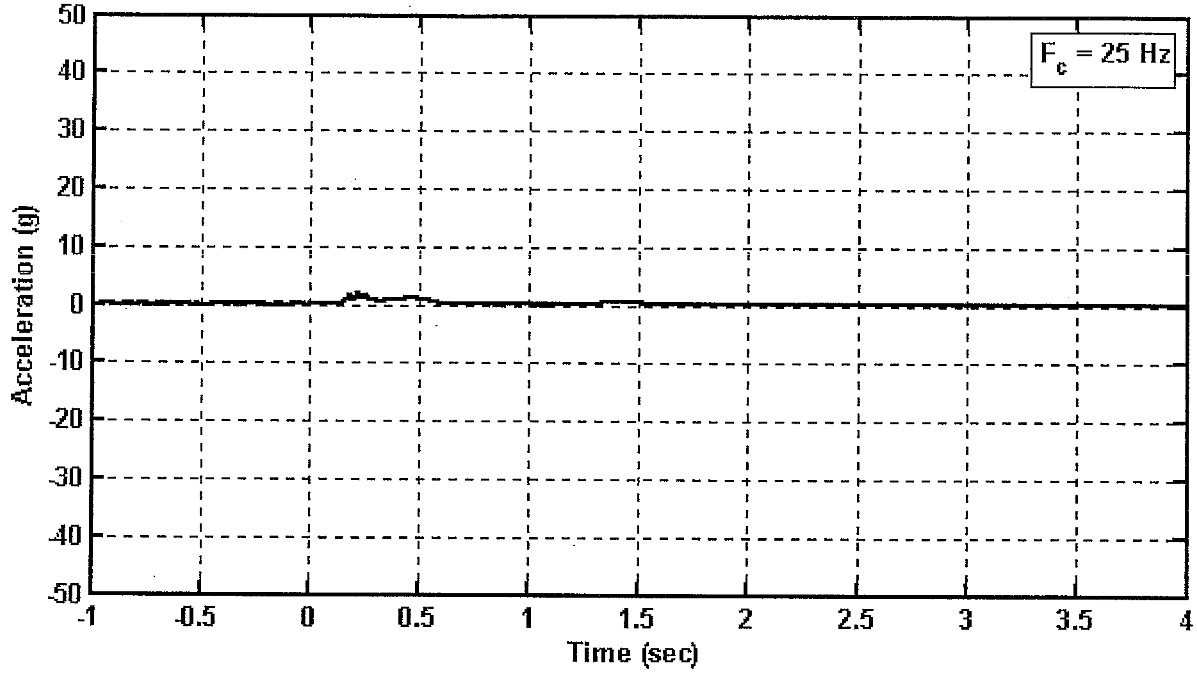


Figure D73. Bullet locomotive, position 3, center sill, longitudinal acceleration
Channel Name: BL_C3X

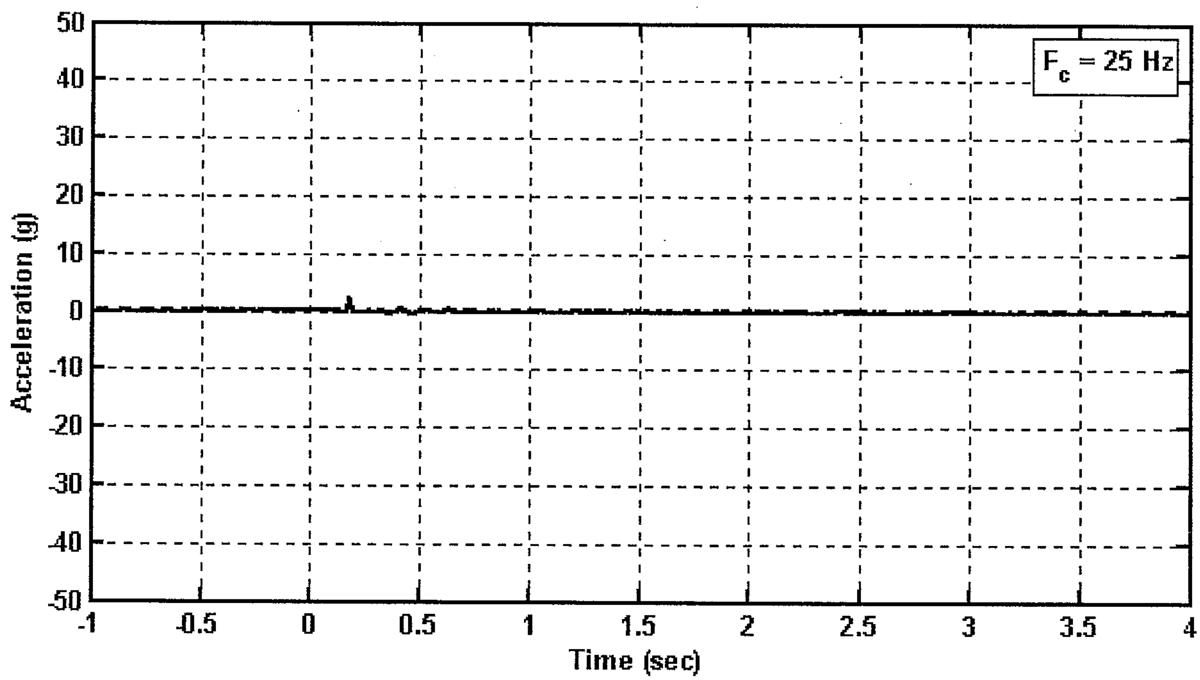


Figure D74. Bullet locomotive, position 3, center sill, lateral acceleration
Channel Name: BL_C3Y

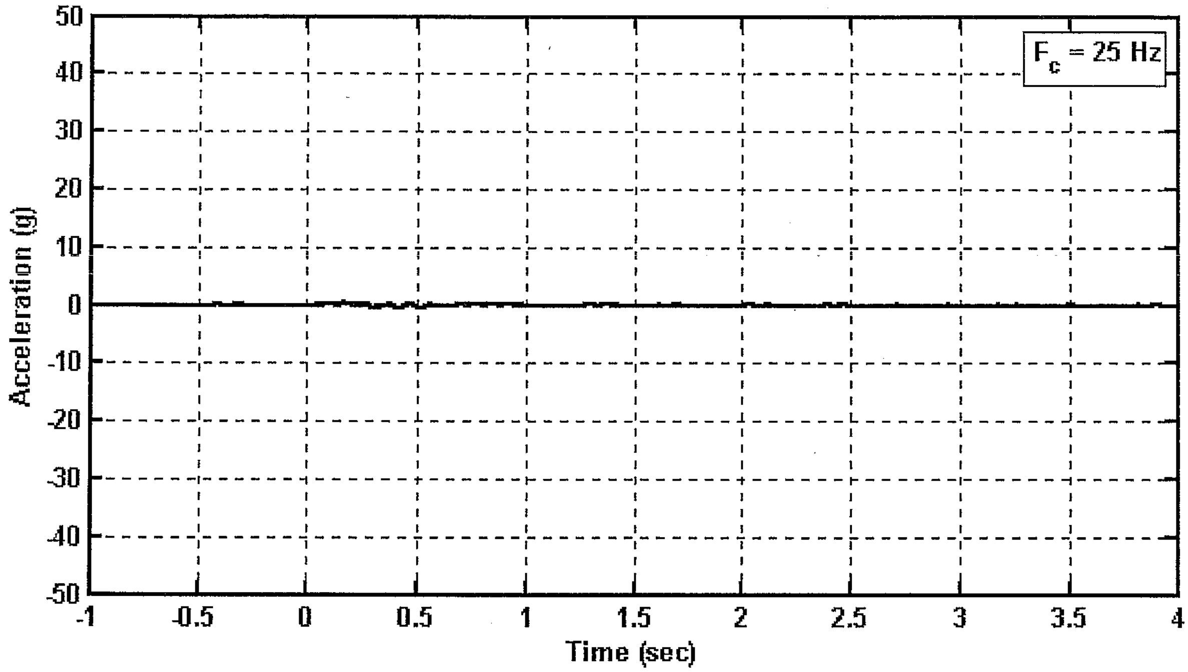


Figure D75. Bullet locomotive, position 3, center sill, vertical acceleration
Channel Name: BL_C3Z

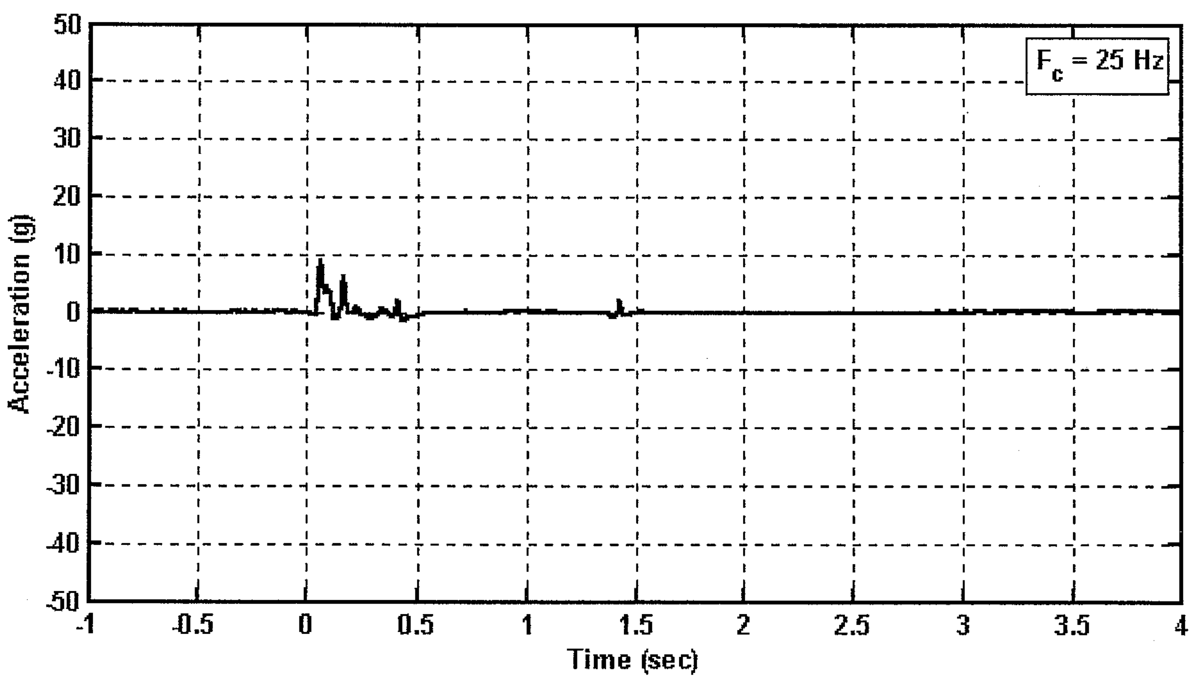


Figure D76. Target car 1, position 1, center sill, longitudinal acceleration
Channel Name: SH1_C1X

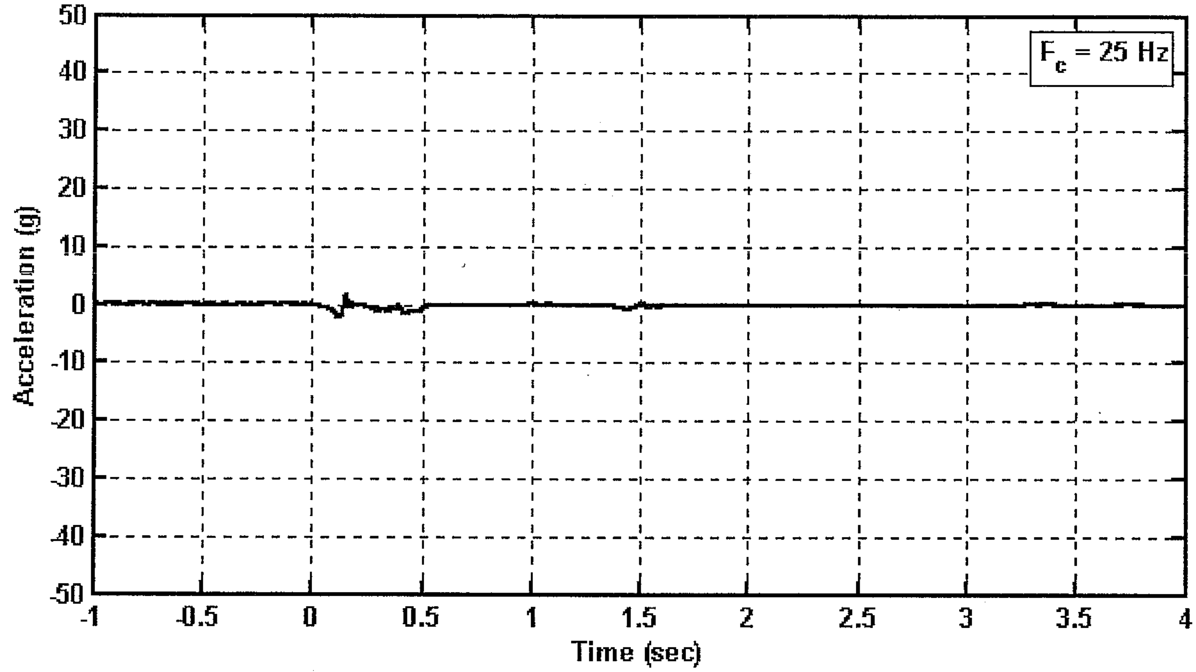


Figure D77. Target car 1, position 2, center sill, longitudinal acceleration
Channel Name: SH1_C2X

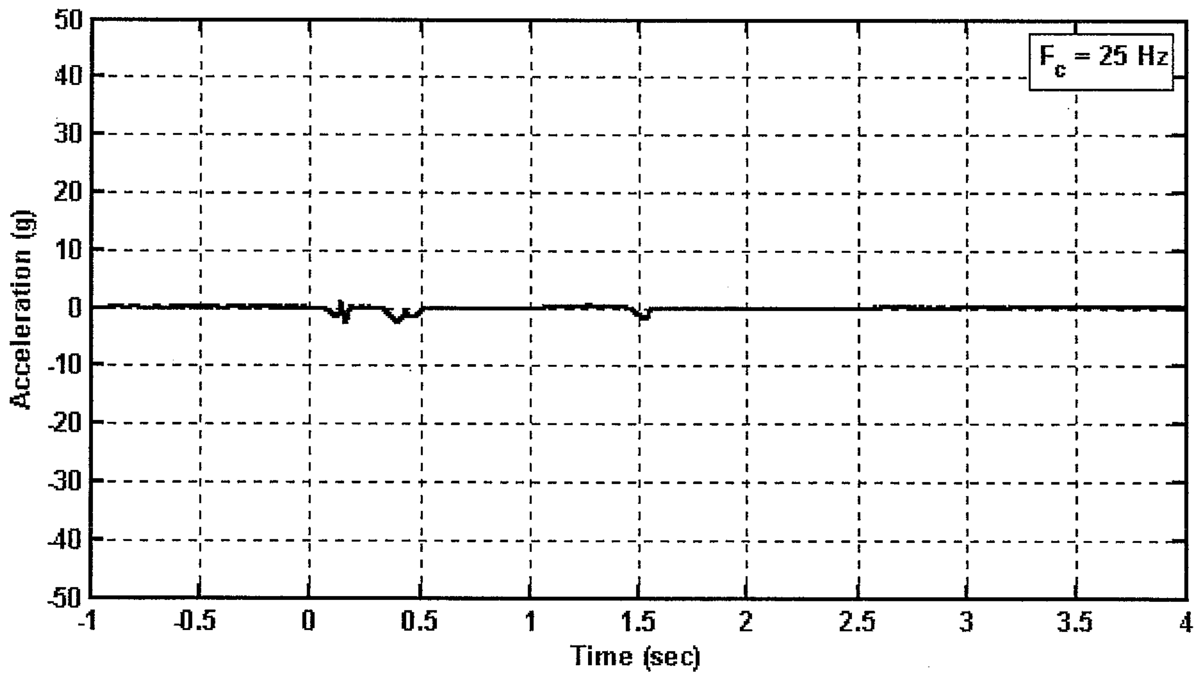


Figure D78. Target car 2, position 1, center sill, longitudinal acceleration
Channel Name: SH2_C1X

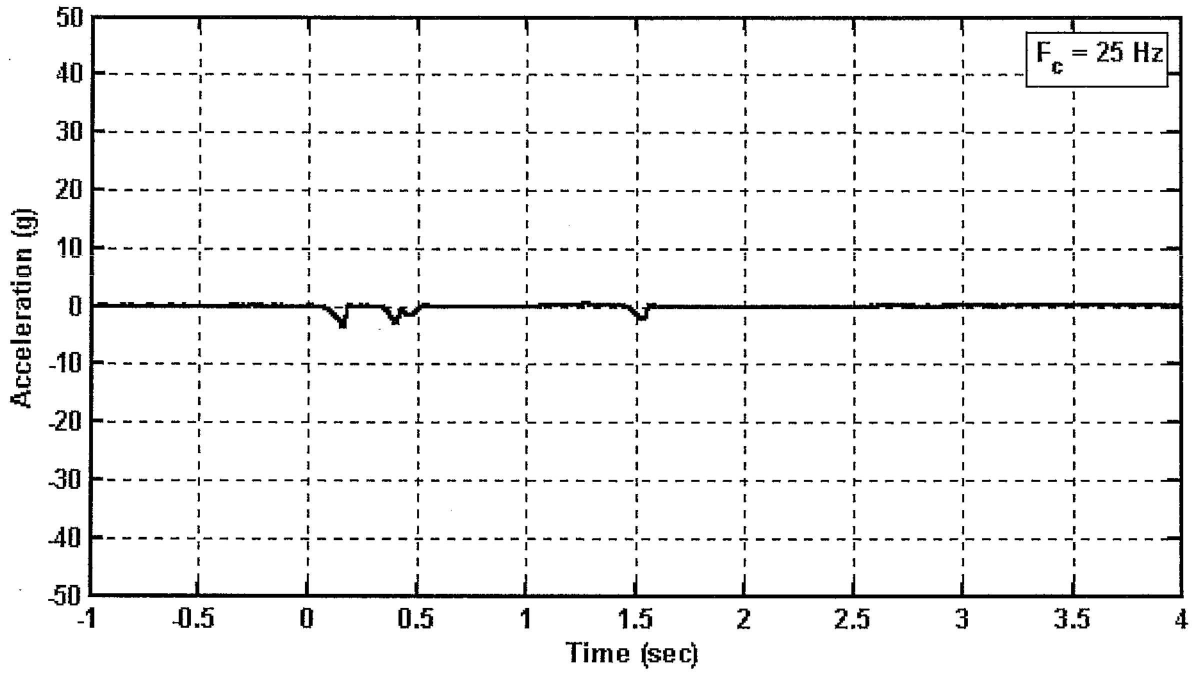


Figure D79. Target car 2, position 2, center sill, longitudinal acceleration
Channel Name: SH2_C2X

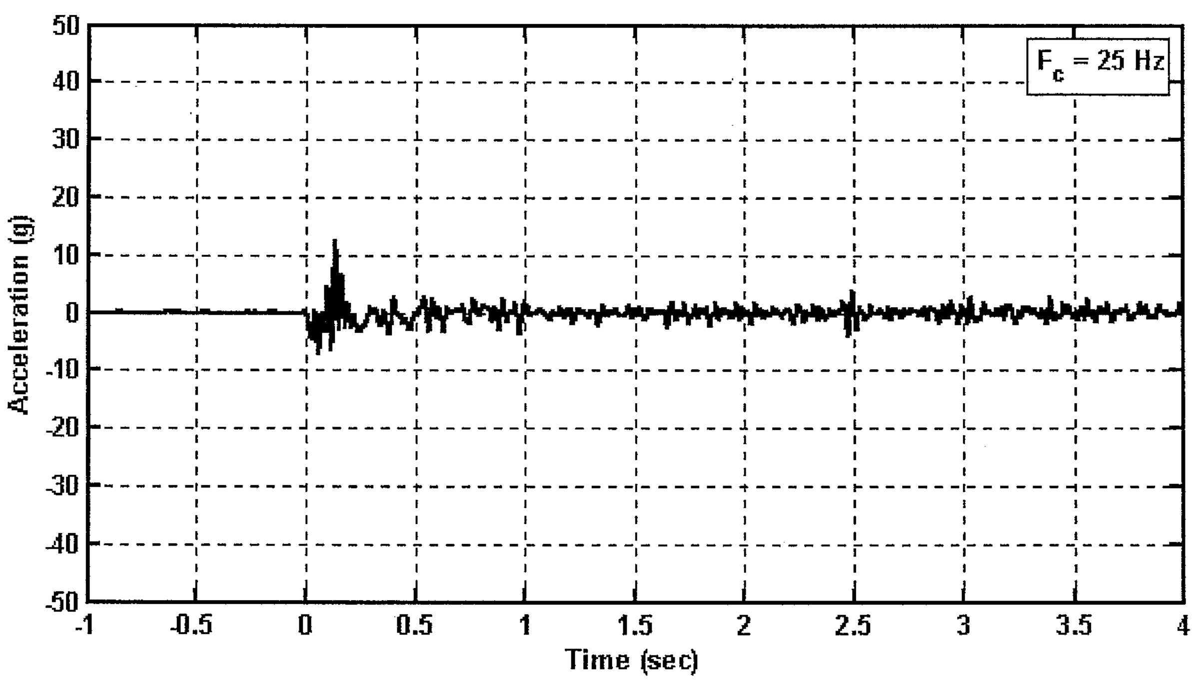


Figure D80. Target locomotive, A truck, longitudinal acceleration
Channel Name: SL_BAX

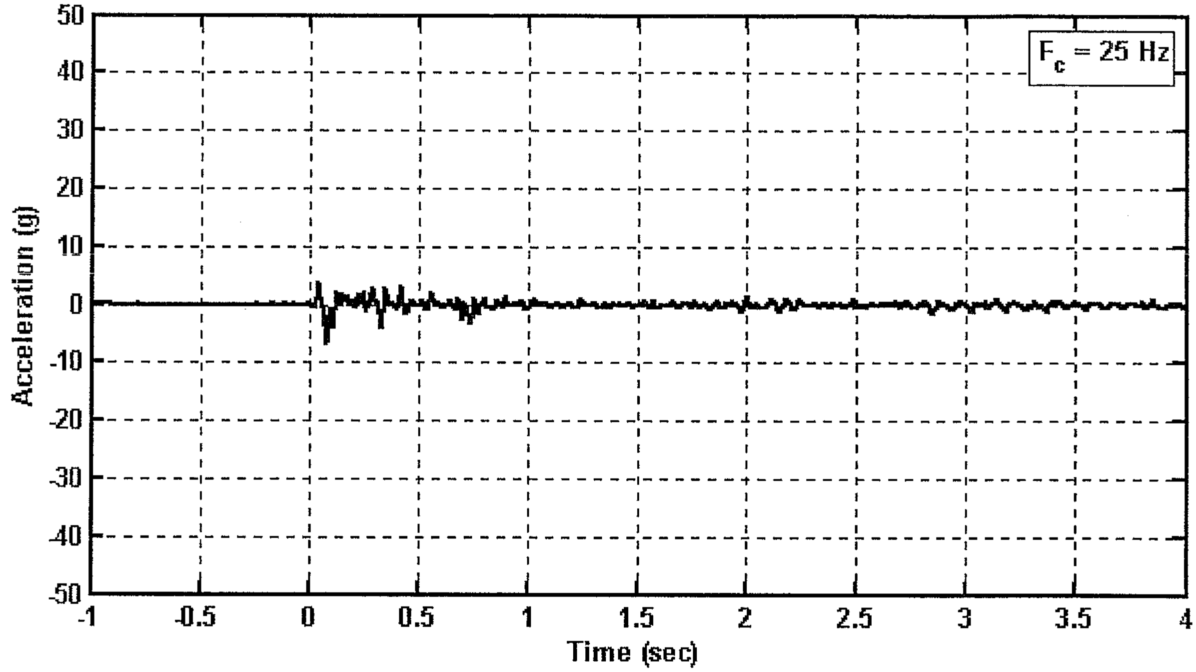


Figure D81. Target locomotive, A truck, lateral acceleration
Channel Name: SL_BAY

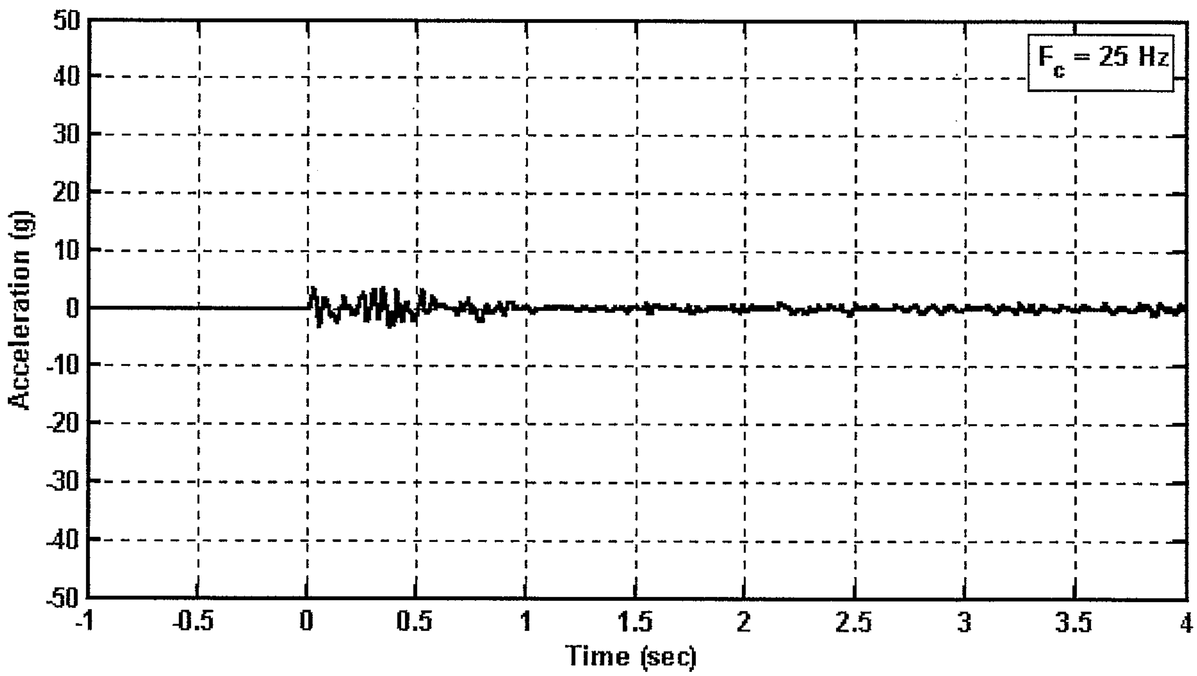


Figure D82. Target locomotive, A truck, vertical acceleration
Channel Name: SL_BAZ

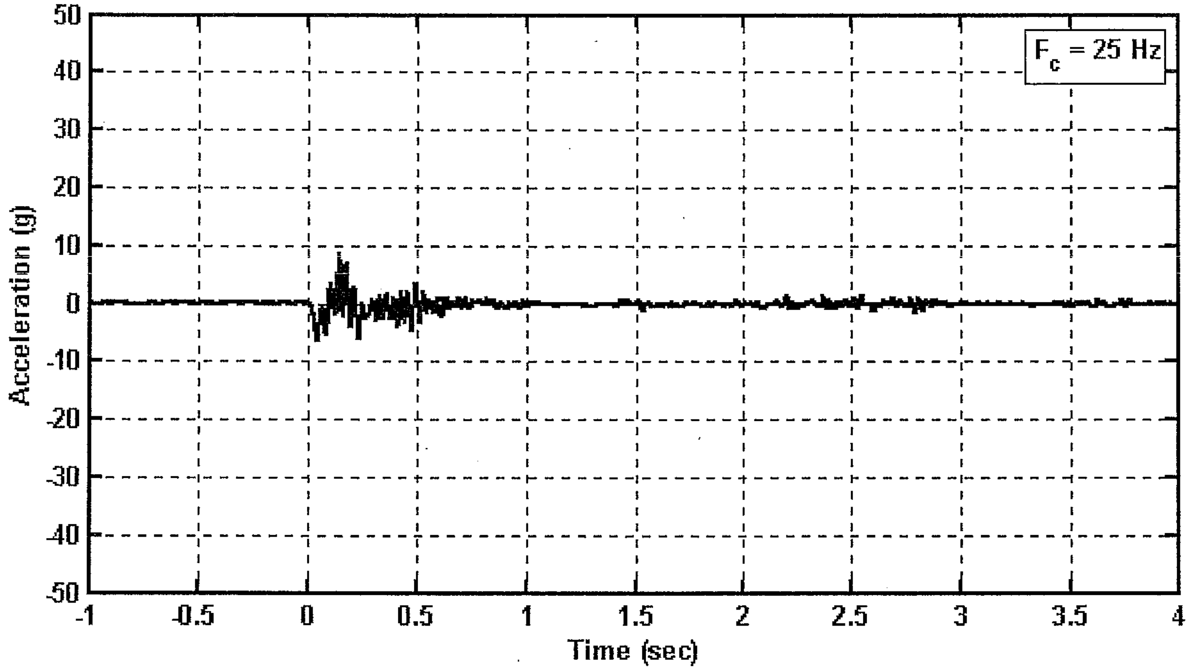


Figure D83. Target locomotive, B truck, longitudinal acceleration
Channel Name: SL_BBX

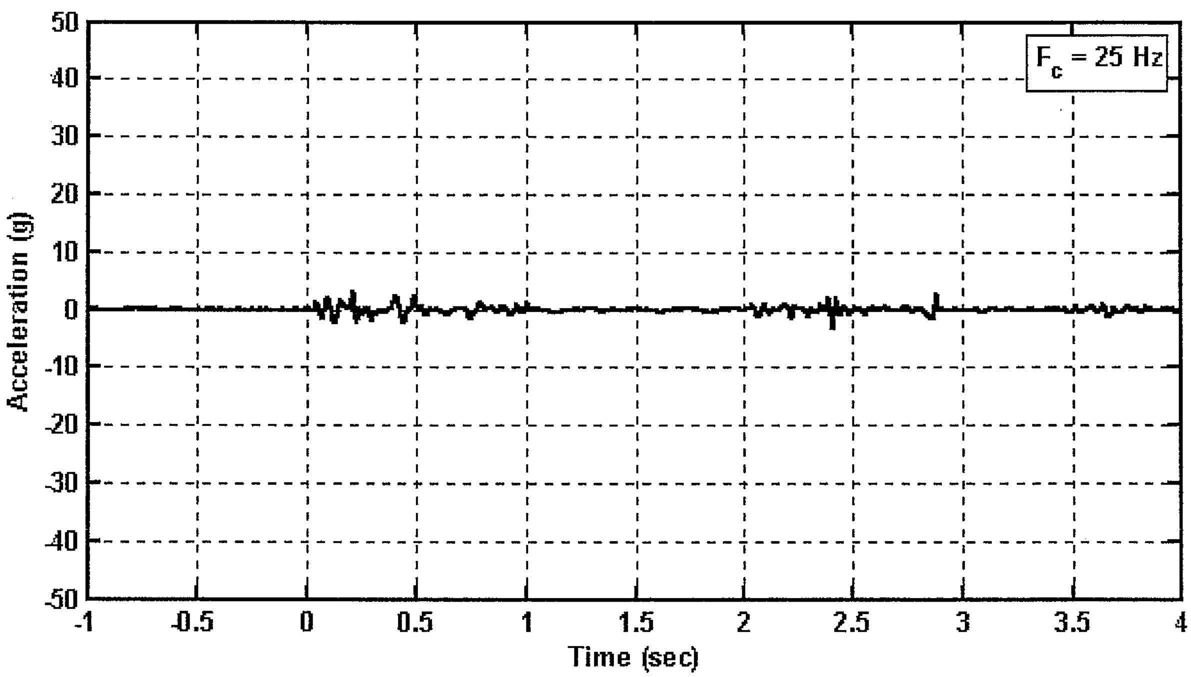


Figure D84. Target locomotive, B truck, lateral acceleration
Channel Name: SL_BBY

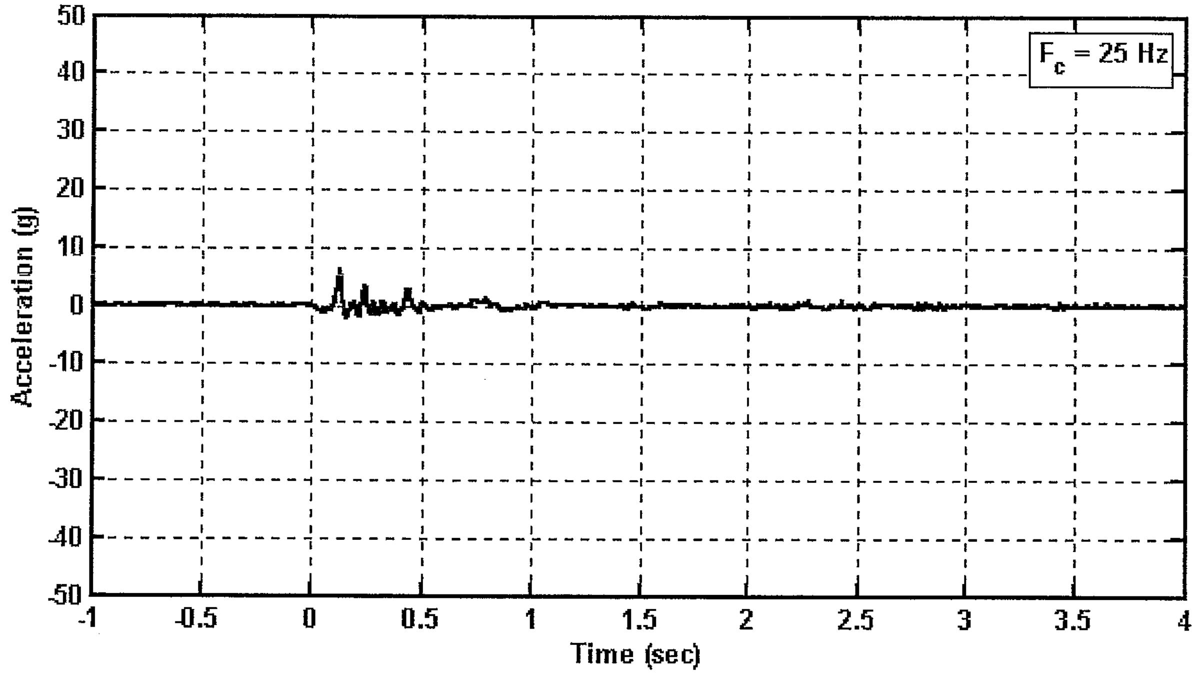


Figure D85. Target locomotive, B truck, vertical acceleration
Channel Name: SL_BBZ

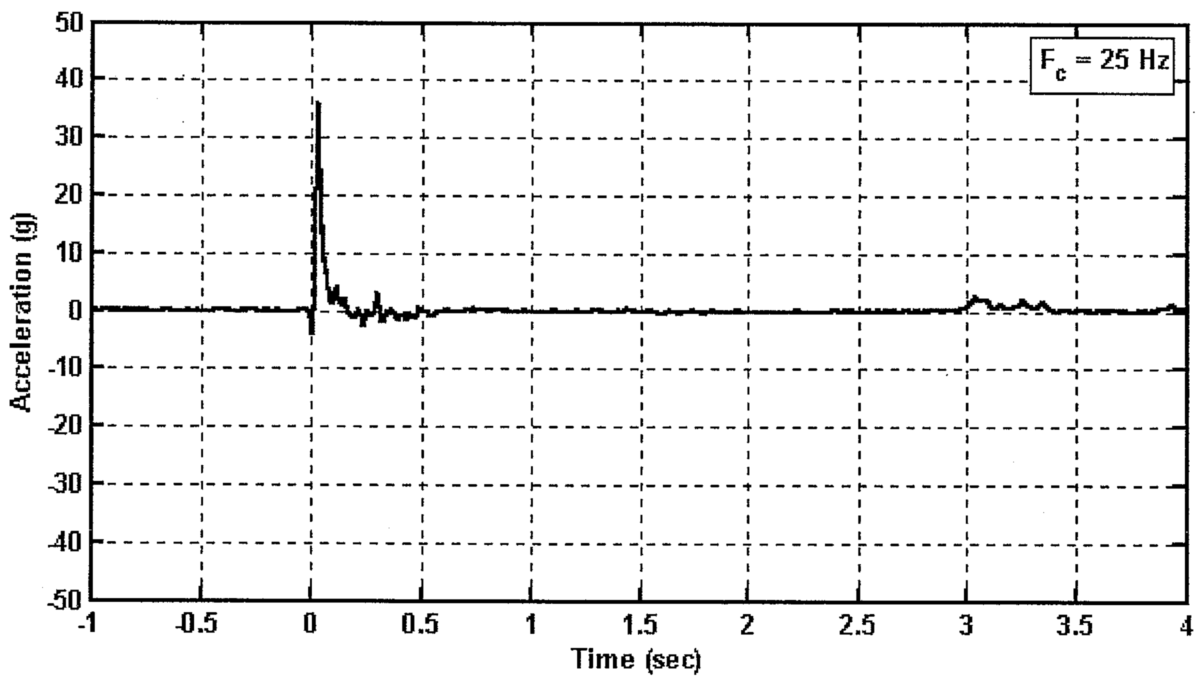


Figure D86. Target locomotive, position 1, center sill, longitudinal acceleration
Channel Name: SL_C1X

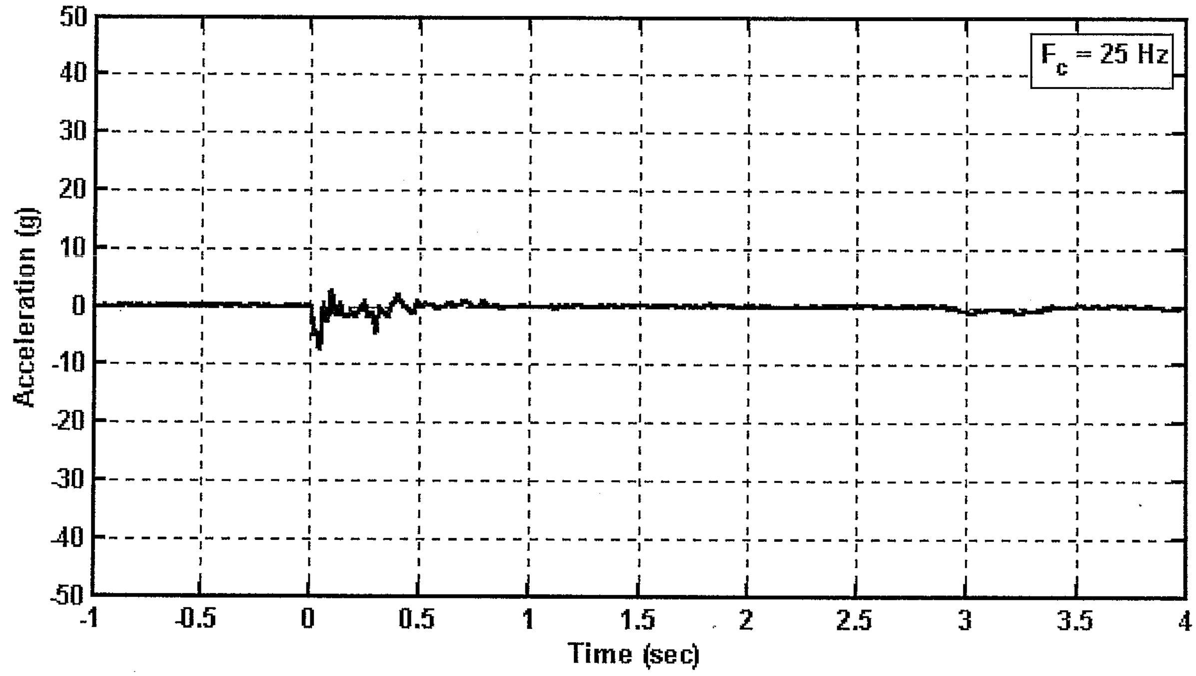


Figure D87. Target locomotive, position 1, center sill, lateral acceleration
Channel Name: SL_C1Y

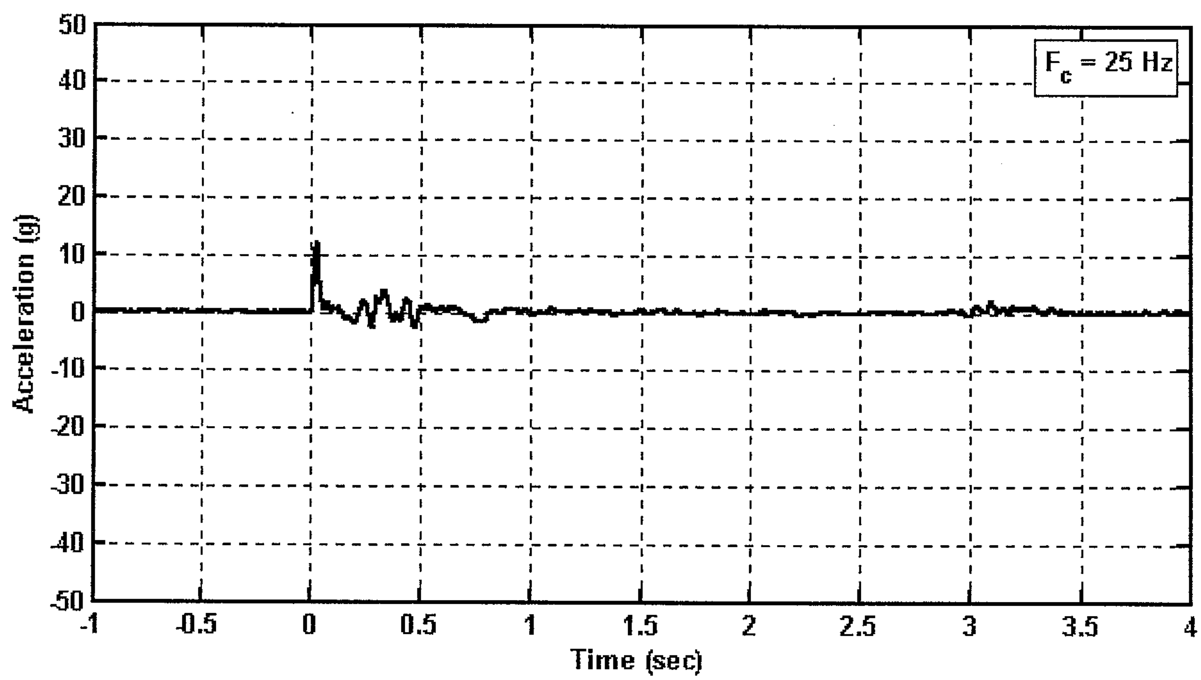


Figure D88. Target locomotive, position 1, center sill, vertical acceleration
Channel Name: SL_C1Z

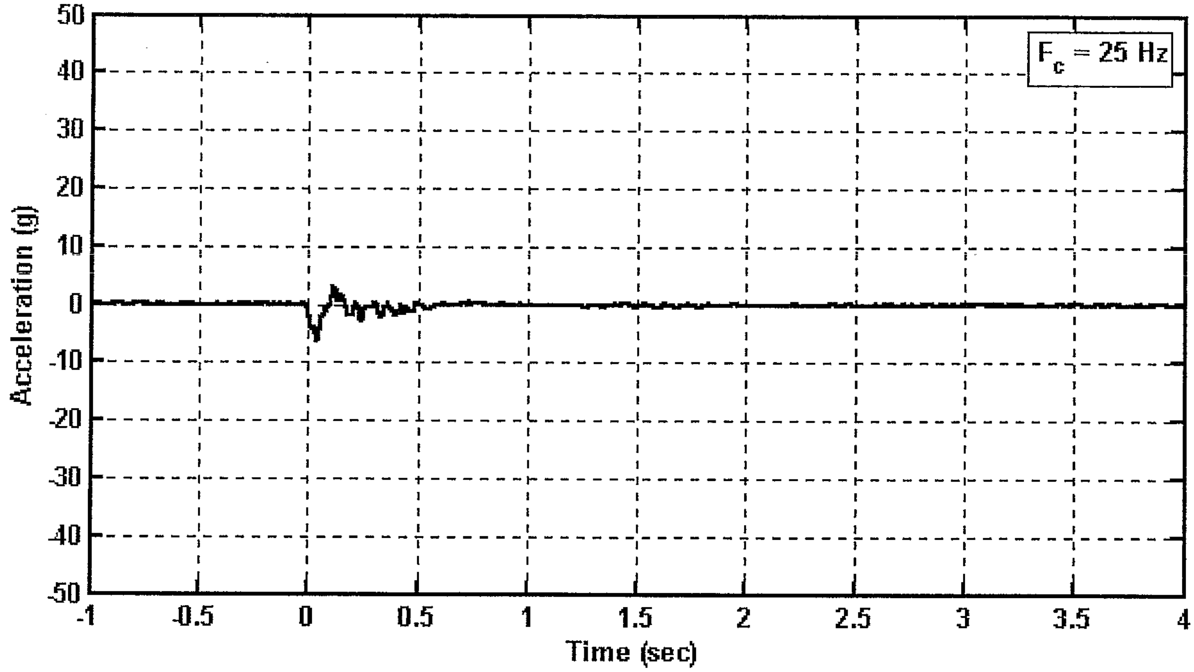


Figure D89. Target locomotive, position 2, center sill, longitudinal acceleration
Channel Name: SL_C2X

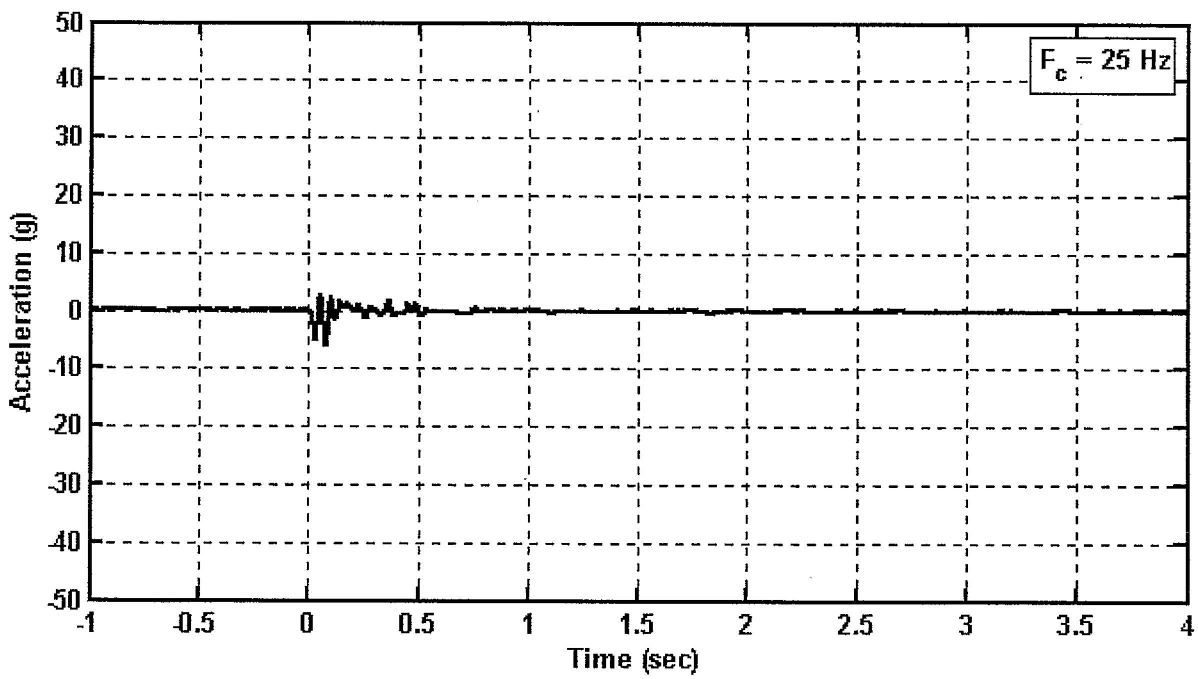


Figure D90. Target locomotive, position 2, center sill, lateral acceleration
Channel Name: SL_C2Y

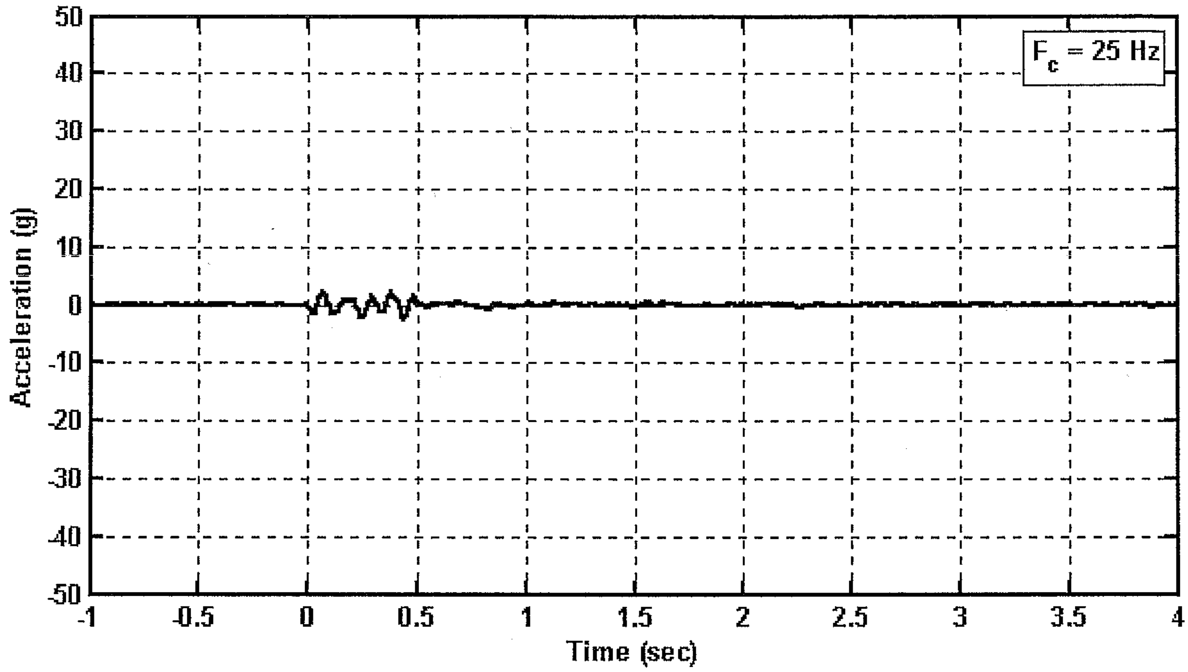


Figure D91. Target locomotive, position 2, center sill, vertical acceleration
Channel Name: SL_C2Z

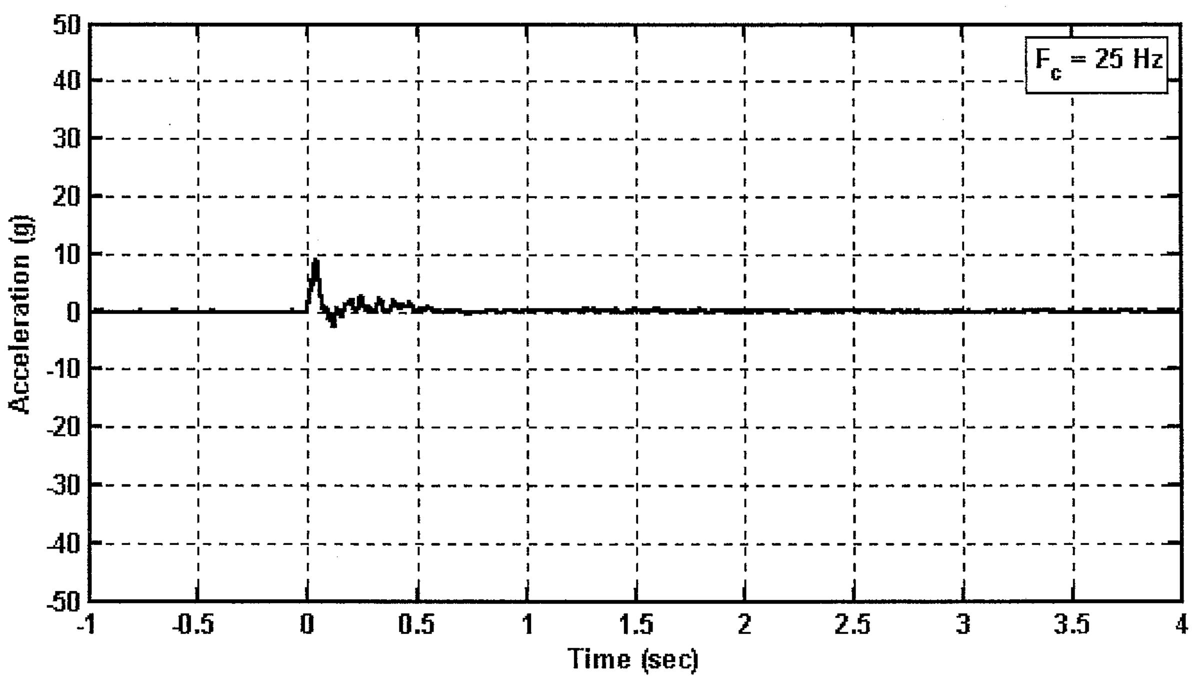


Figure D92. Target locomotive, position 3, center sill, longitudinal acceleration
Channel Name: SL_C3X

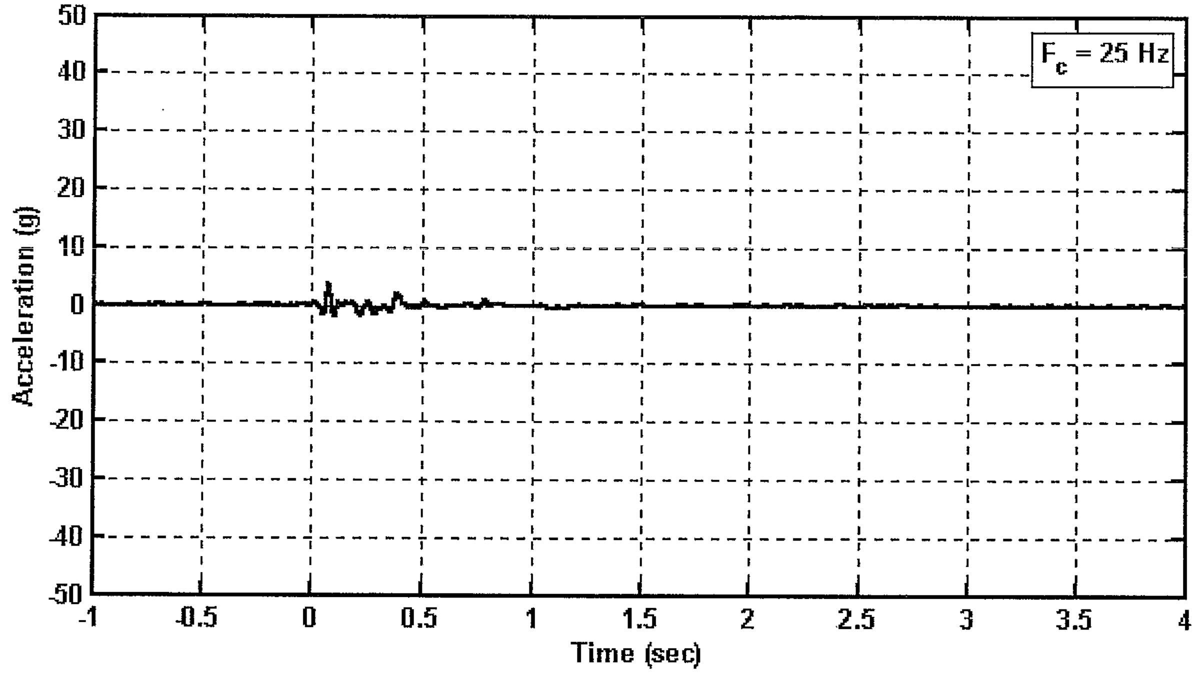


Figure D93. Target locomotive, position 3, center sill, lateral acceleration
Channel Name: SL_C3Y

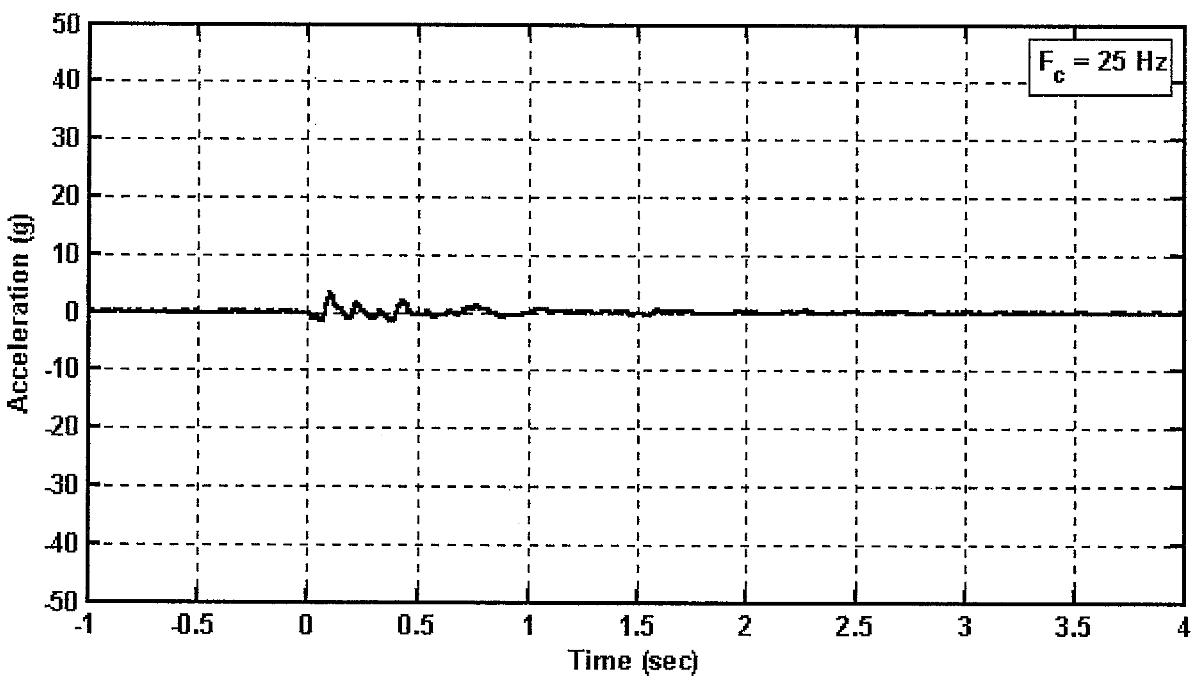


Figure D94. Target locomotive, position 3, center sill, vertical acceleration
Channel Name: SL_C3Z

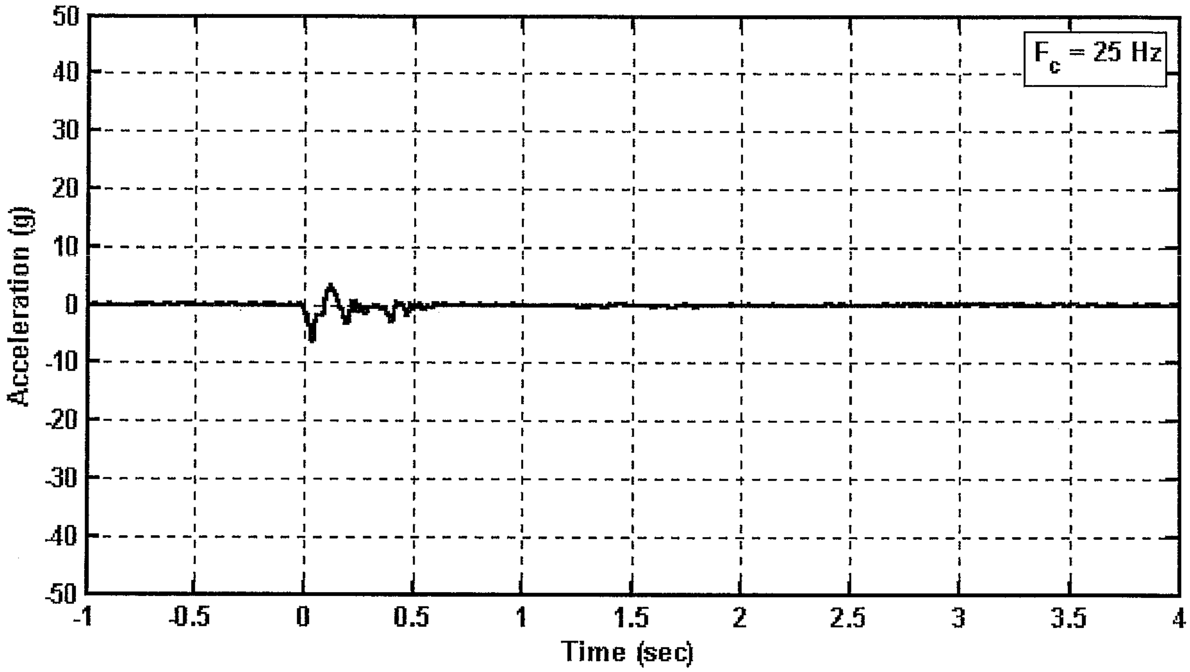


Figure D95. Target locomotive, position 3, cab floor, longitudinal acceleration
Channel Name: SL_F1X

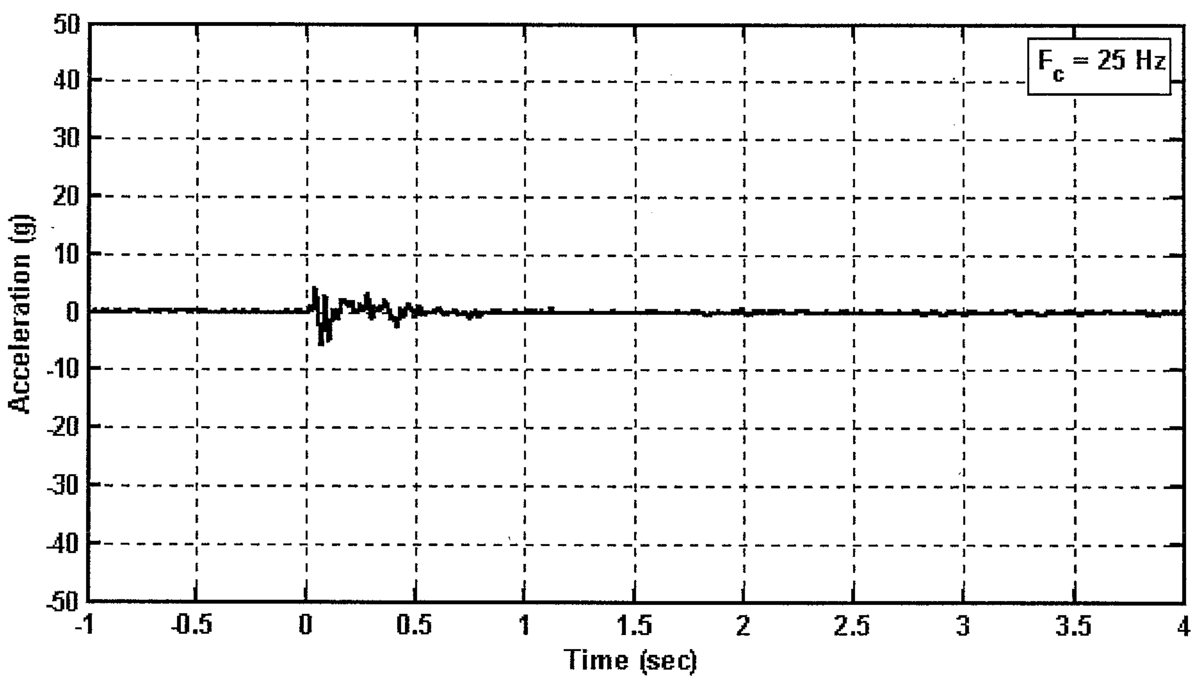


Figure D96. Target locomotive, position 3, cab floor, lateral acceleration
Channel Name: SL_F1Y

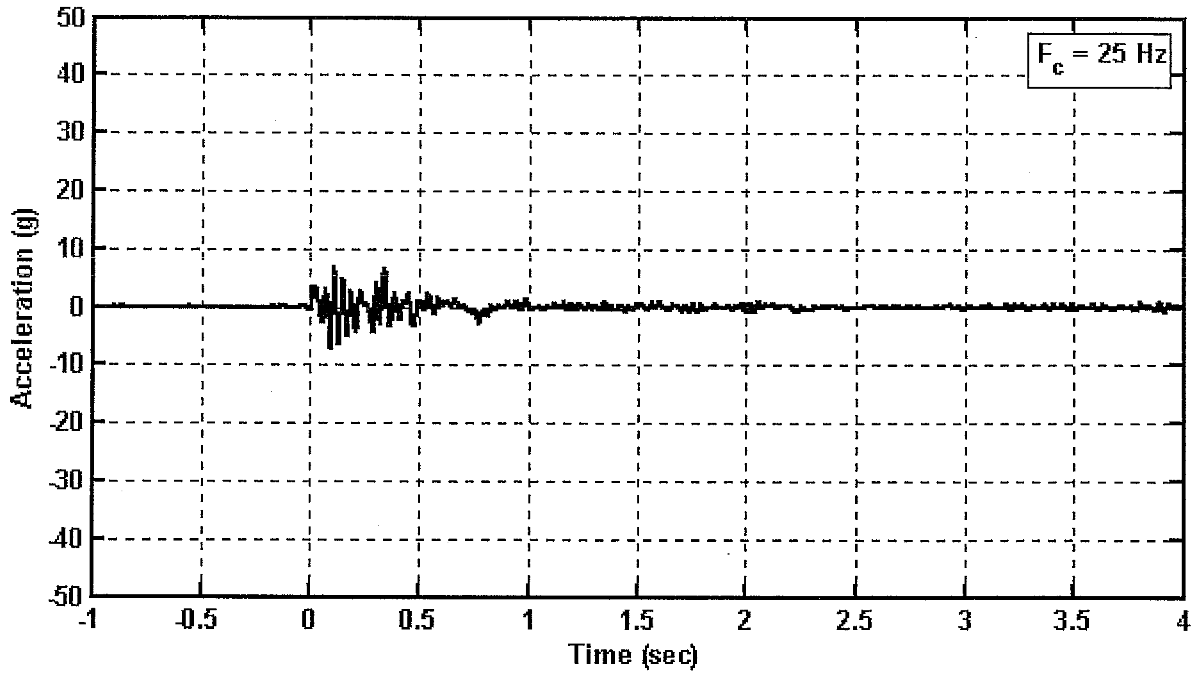


Figure D97. Target locomotive, position 3, cab floor, vertical acceleration
Channel Name: SL_F1Z

APPENDIX E

Displacement and Coupler Force Data

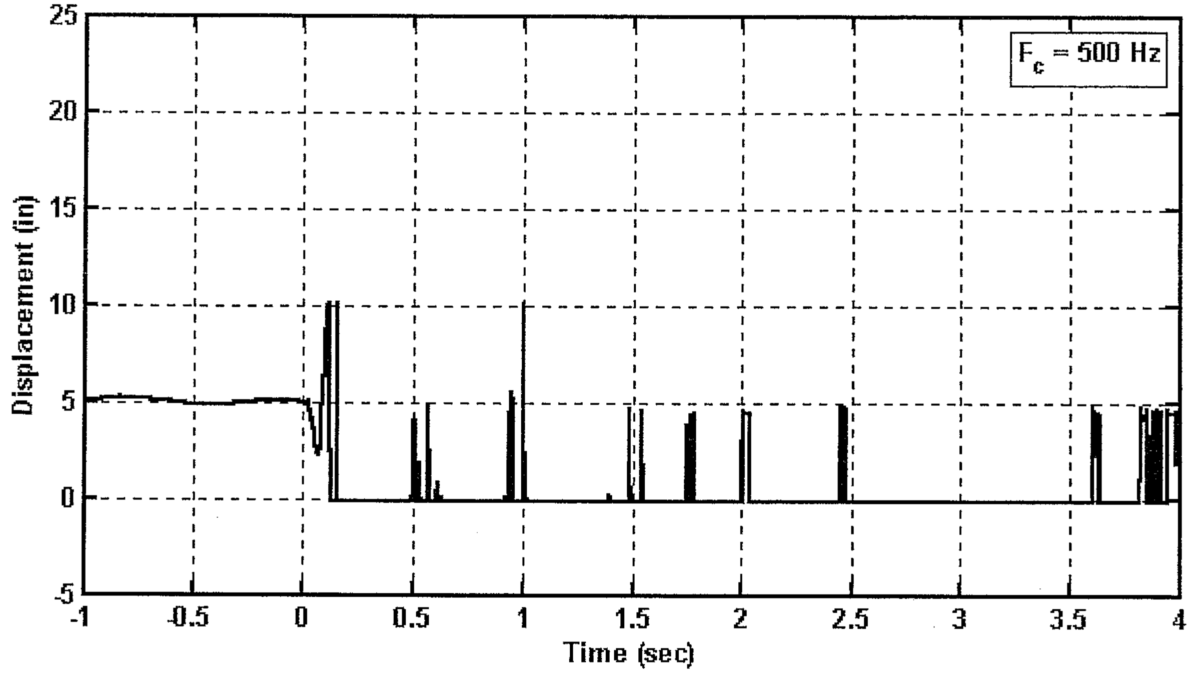


Figure E1. Bullet car 1, A truck, left side secondary suspension, displacement
Channel Name: B1_AL

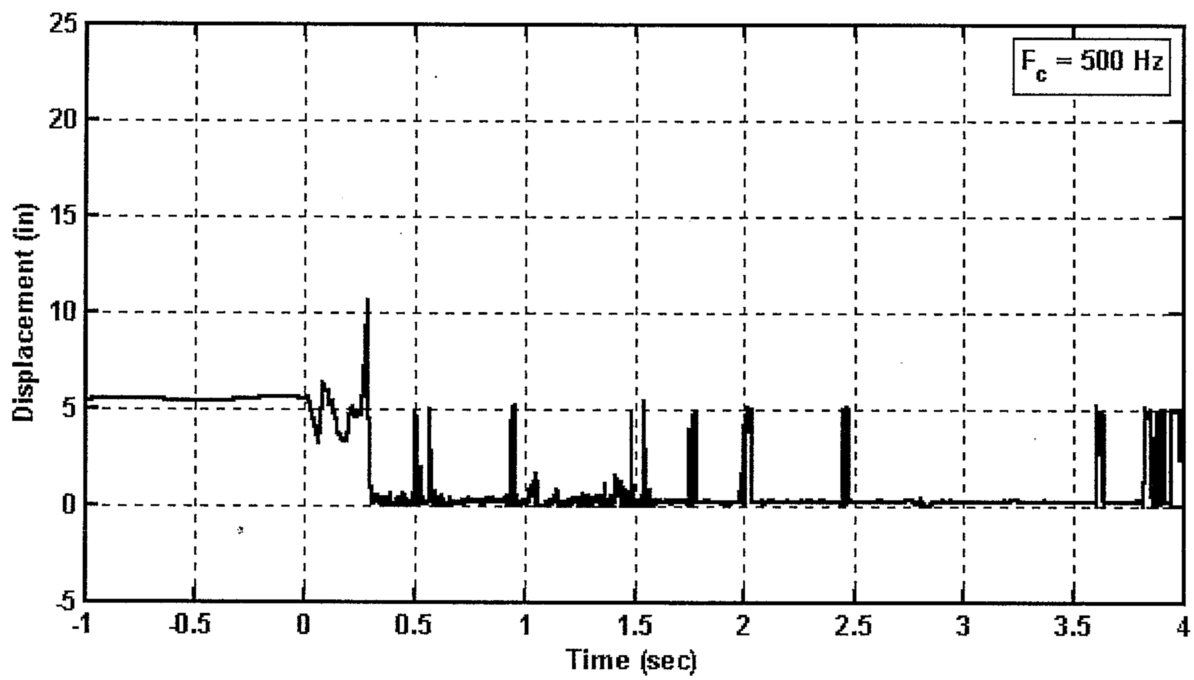


Figure E2. Bullet car 1, A truck, right side secondary suspension, displacement
Channel Name: B1_AR

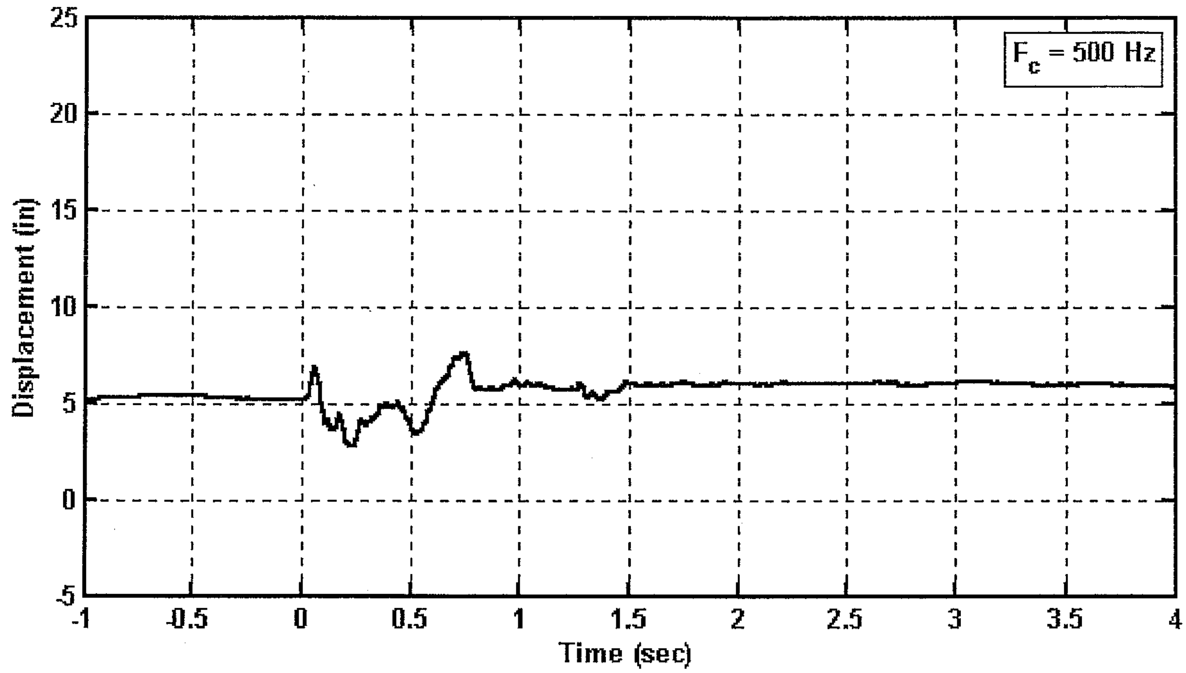


Figure E3. Bullet car 1, B truck, left side secondary suspension, displacement
Channel Name: B1_BL

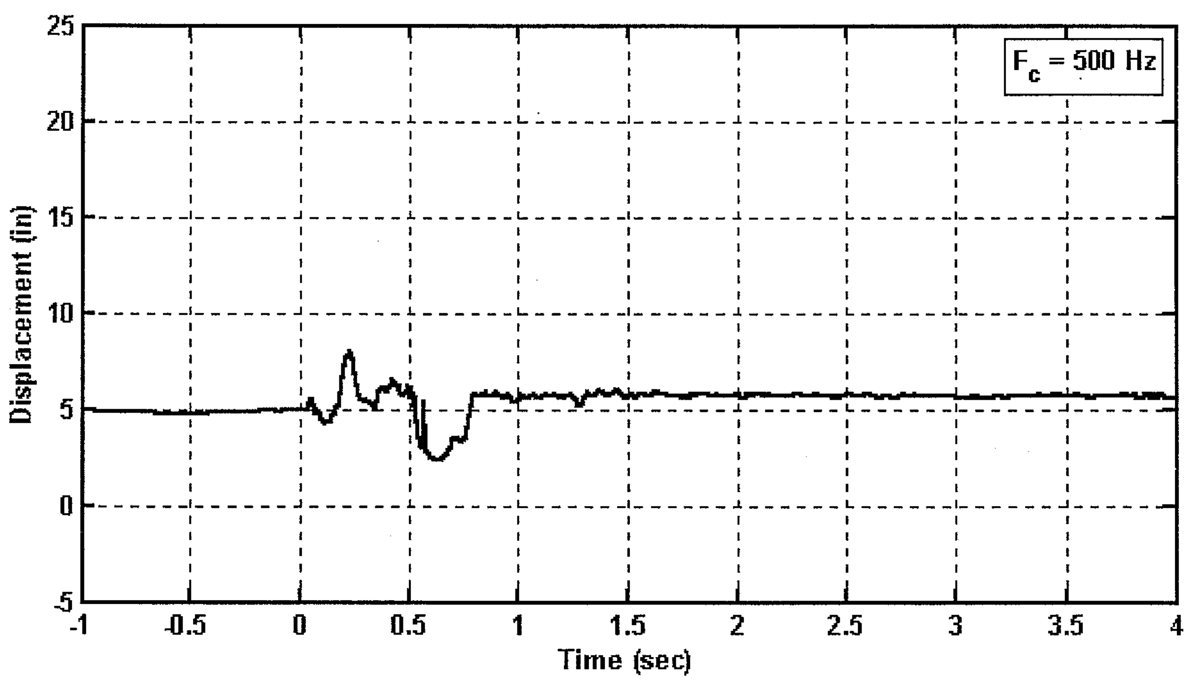


Figure E4. Bullet car 1, B truck, right side secondary suspension, displacement
Channel Name: B1_BR

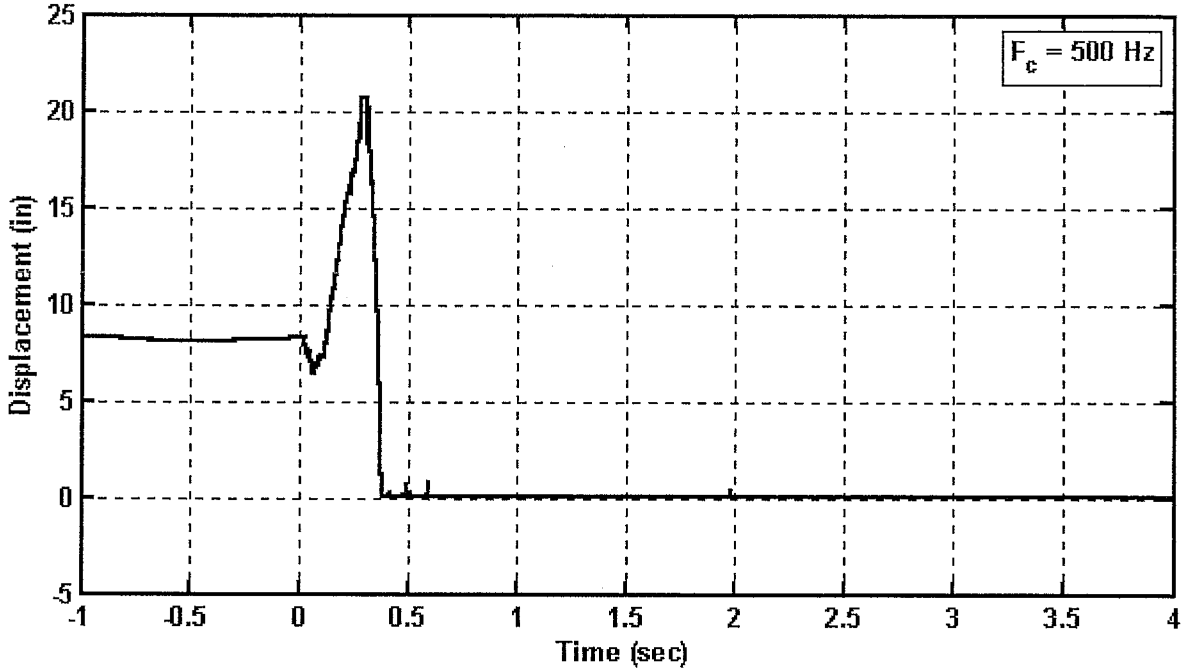


Figure E5. Bullet car 1, B end coupler, longitudinal displacement
Channel Name: B1_CBX

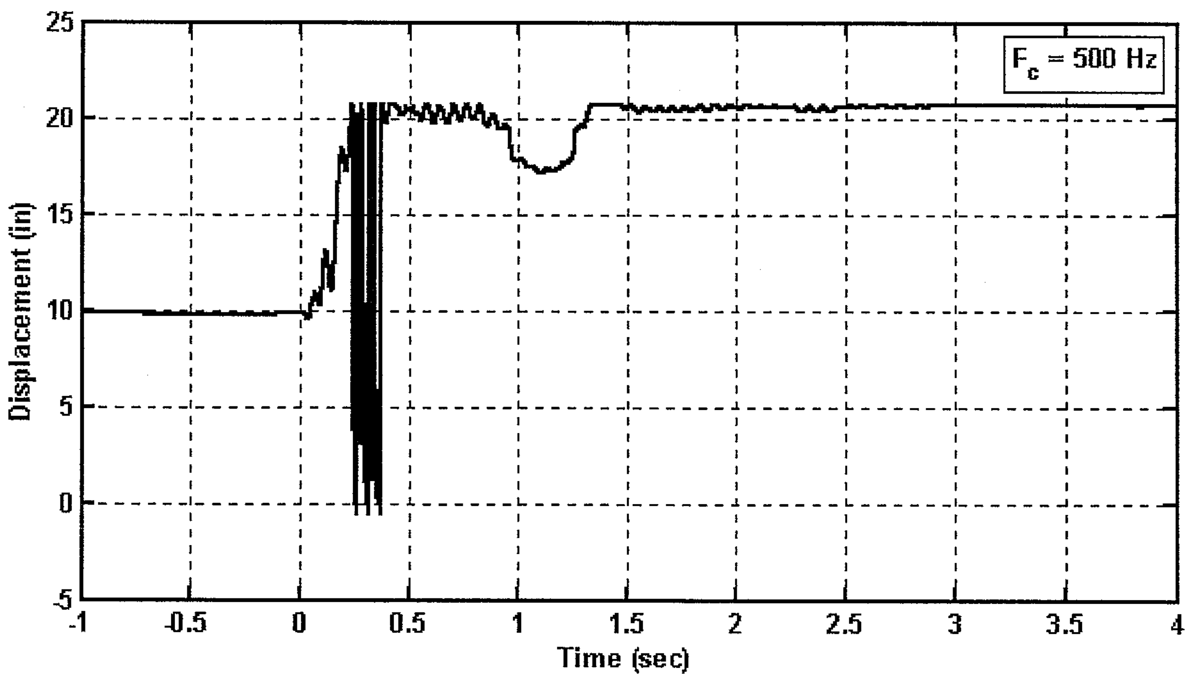


Figure E6. Bullet car 1, B end coupler, lateral displacement
Channel Name: B1_CBY

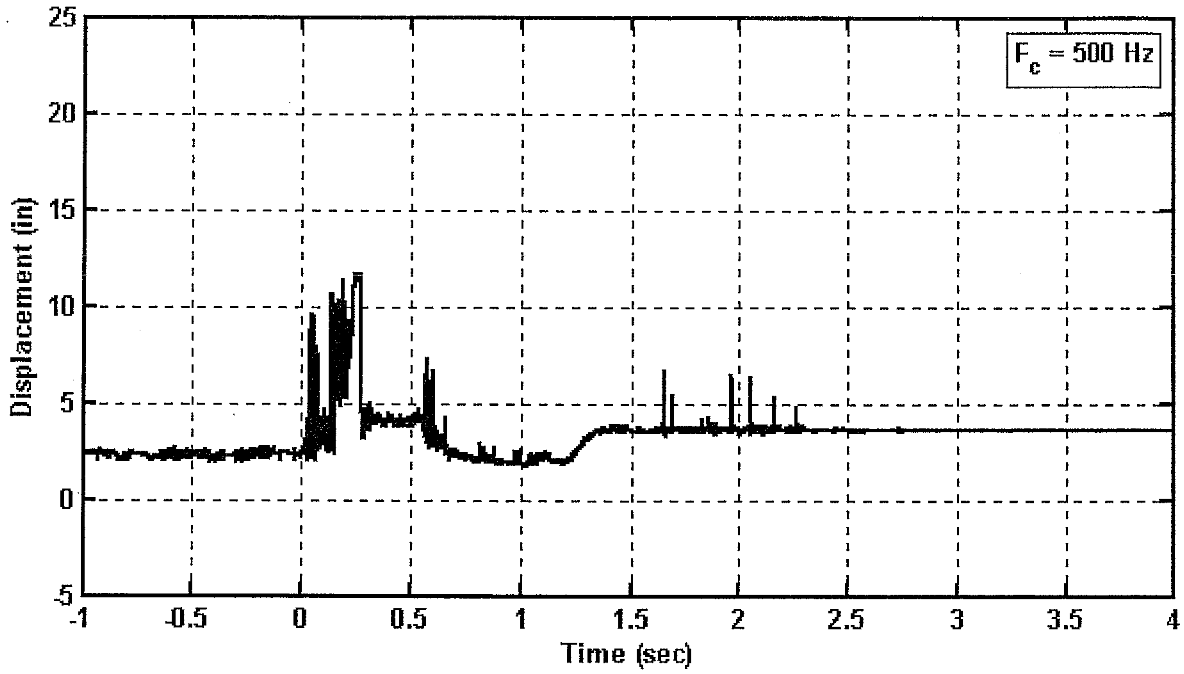


Figure E7. Bullet car 1, B end coupler, vertical displacement
Channel Name: B1_CBZ

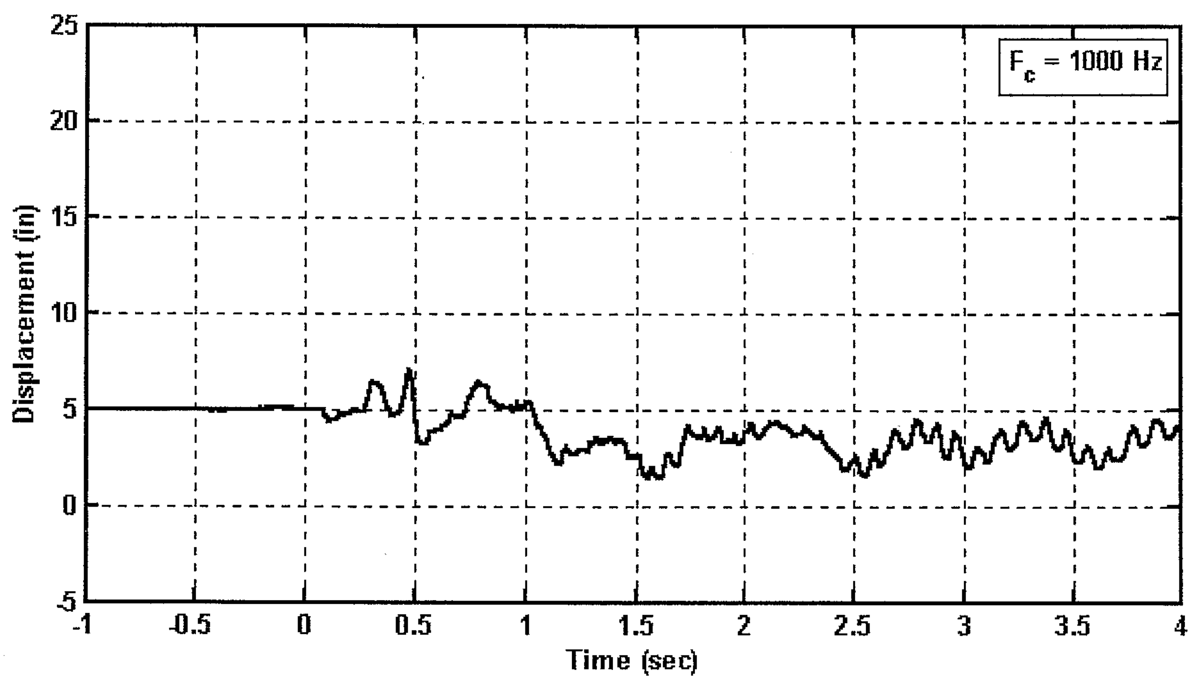


Figure E8. Bullet car 2, A truck, left side secondary suspension, displacement
Channel Name: B2_AL

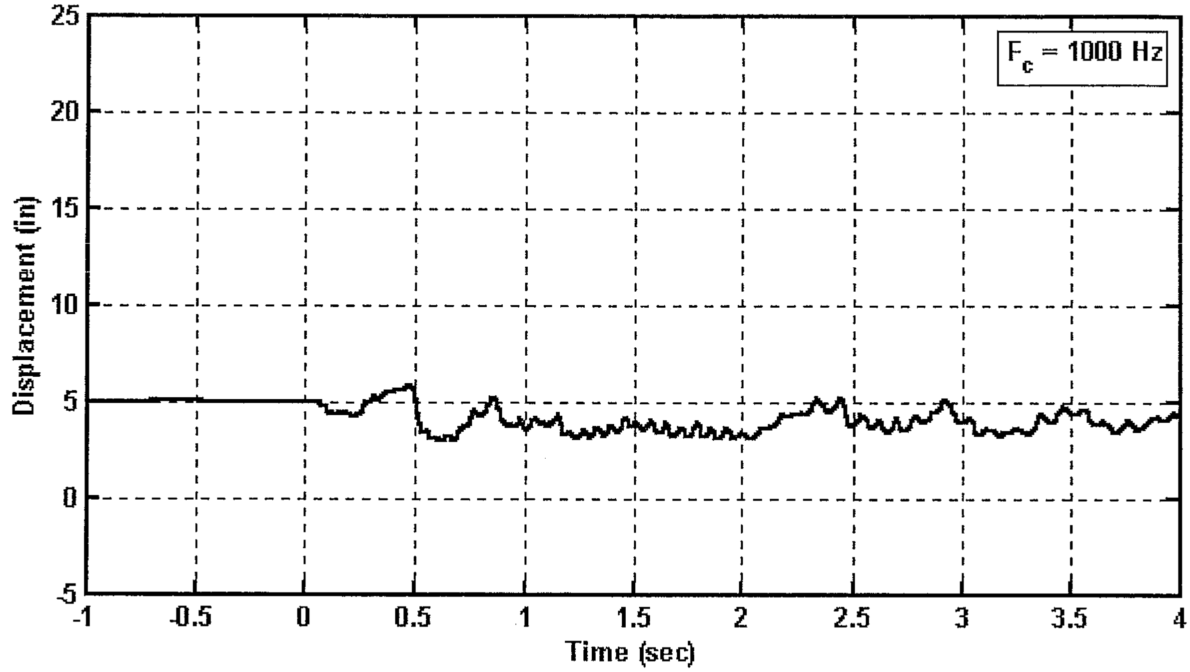


Figure E9. Bullet car 2, A truck, right side secondary suspension, displacement
Channel Name: B2_AR

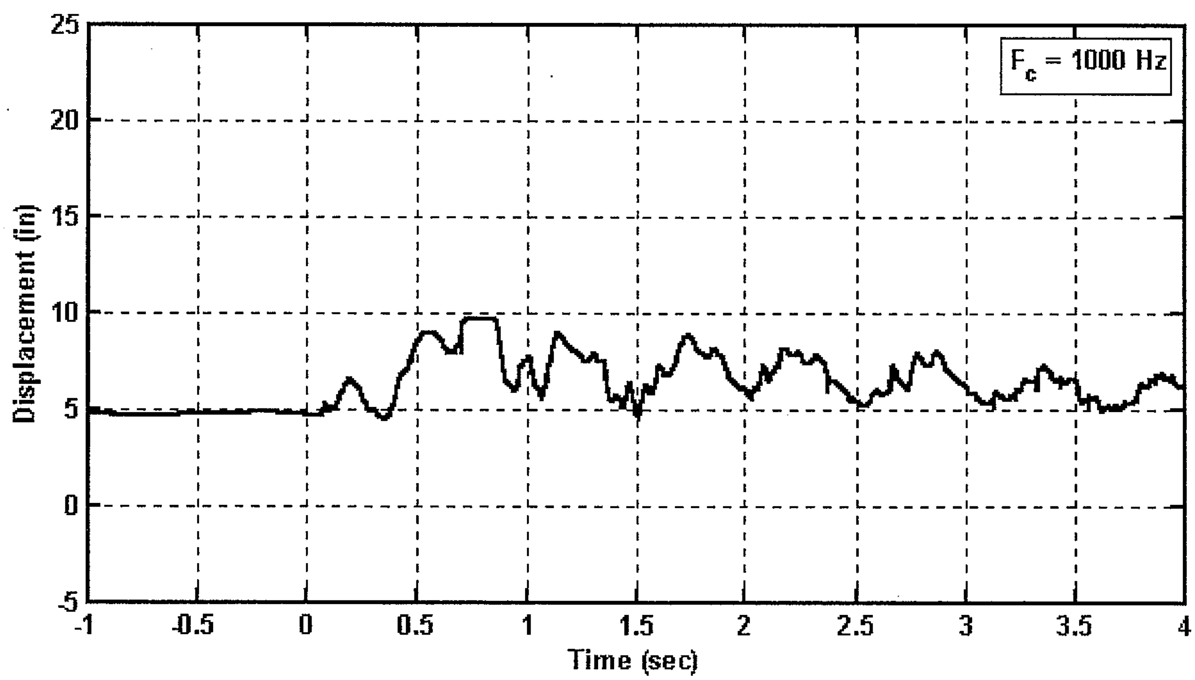


Figure E10. Bullet car 2, B truck, left side secondary suspension, displacement
Channel Name: B2_BL

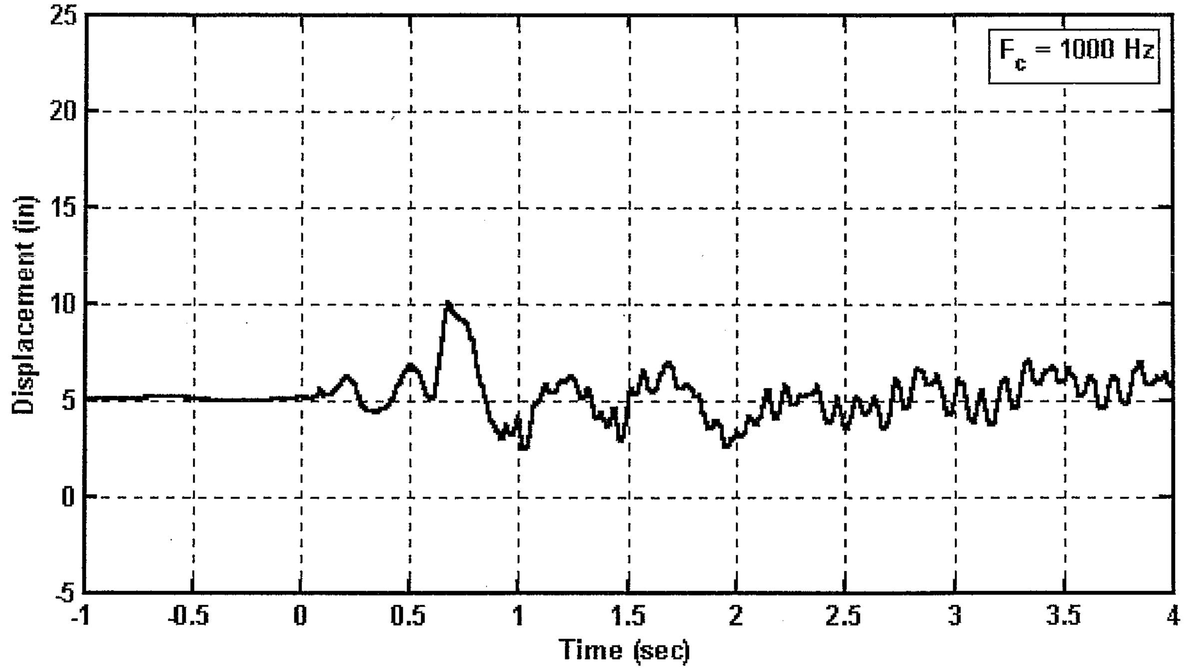


Figure E11. Bullet car 2, B truck, right side secondary suspension, displacement
Channel Name: B2_BR

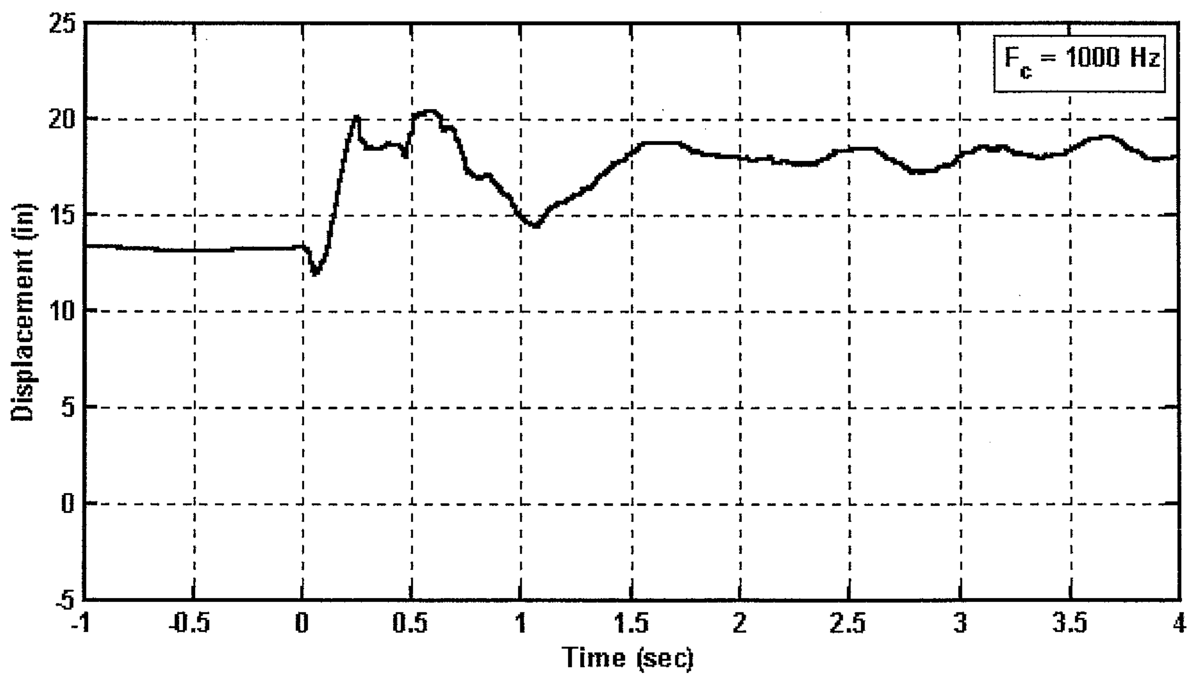


Figure E12. Bullet car 2, A end coupler, longitudinal displacement
Channel Name: B2_CAX

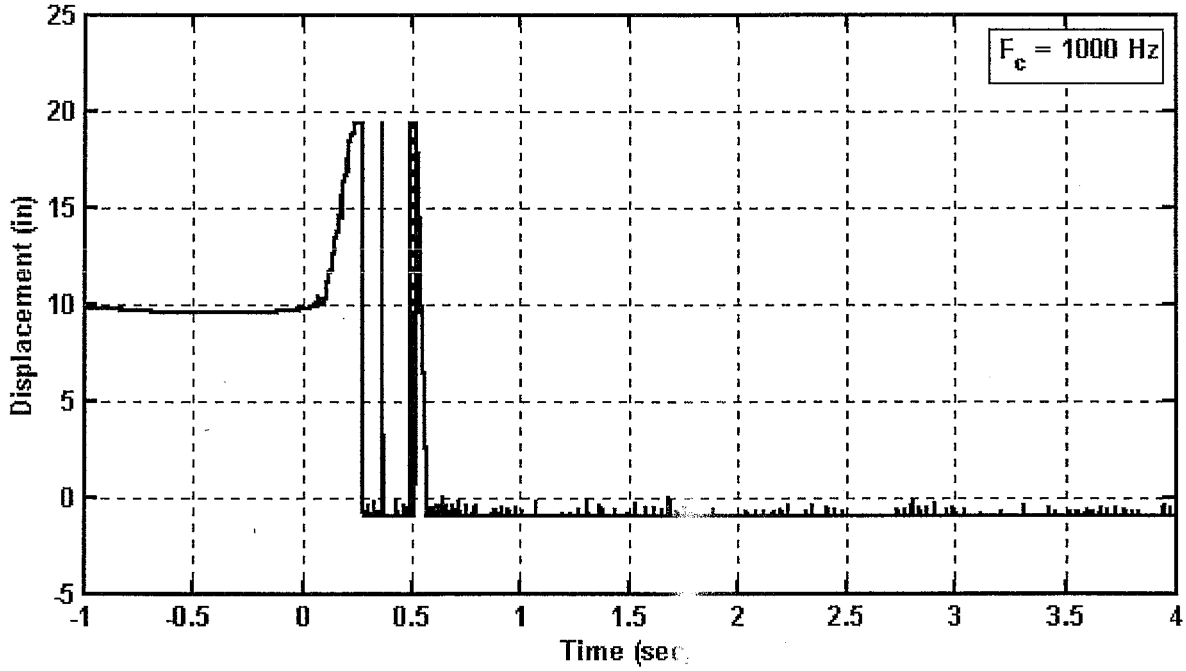
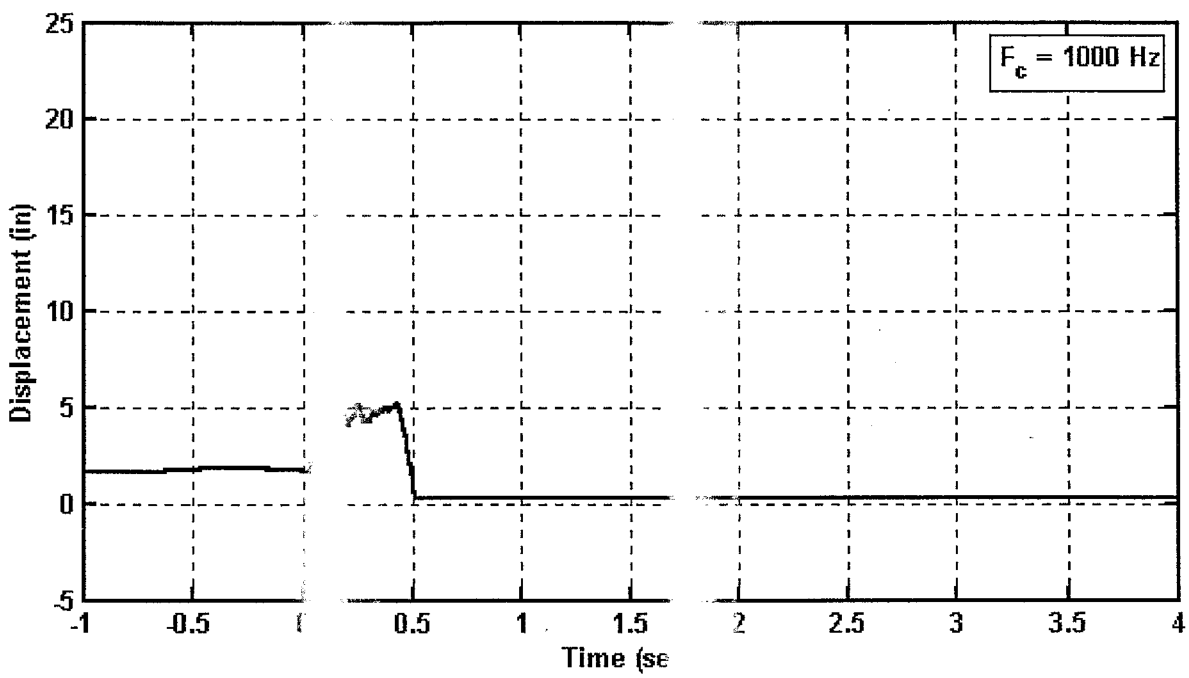


Figure E13. Bullet car 2, A end co pler, lateral displacement
Channel Name: 2_CAY



Figu 4. Bullet car 2, A end cc er, vertical displacement
Channel Name _CAZ

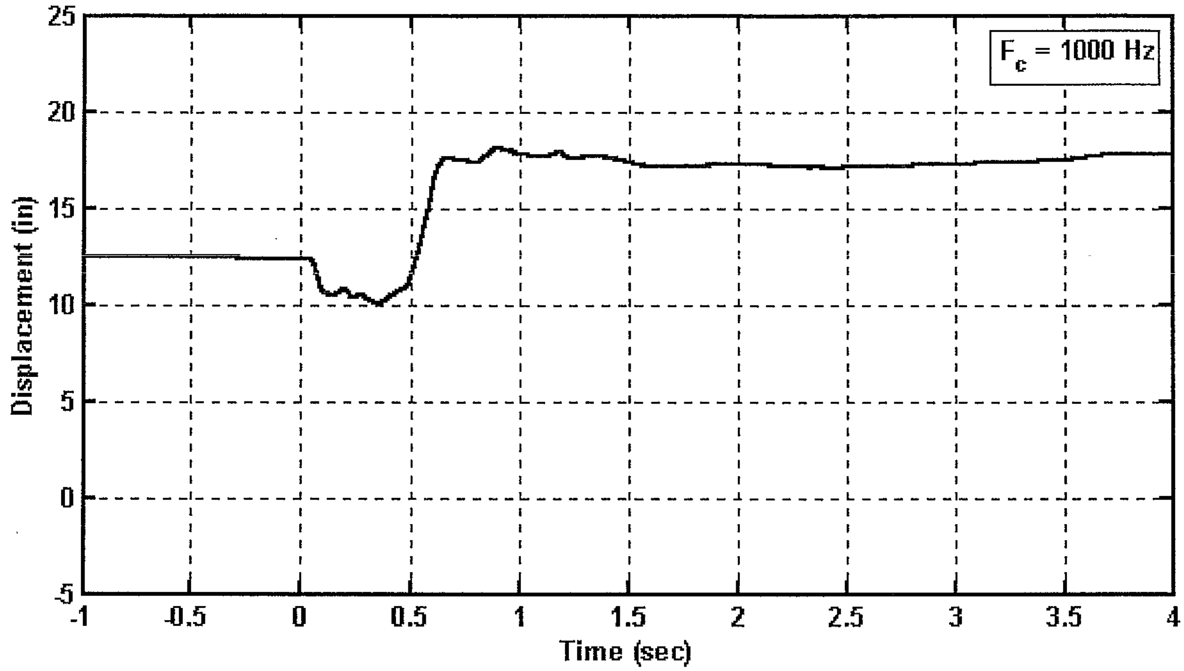


Figure E15. Bullet car 2, B end coupler, longitudinal displacement
Channel Name: B2_CBX

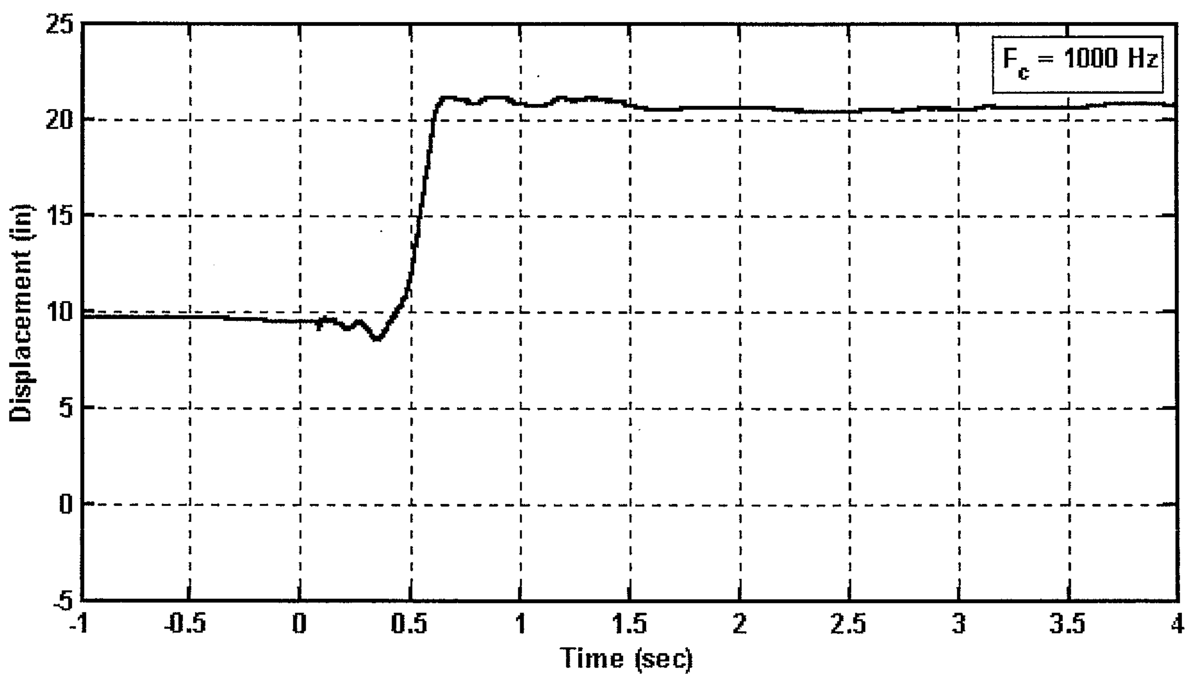


Figure E16. Bullet car 2, B end coupler, lateral displacement
Channel Name: B2_CBY

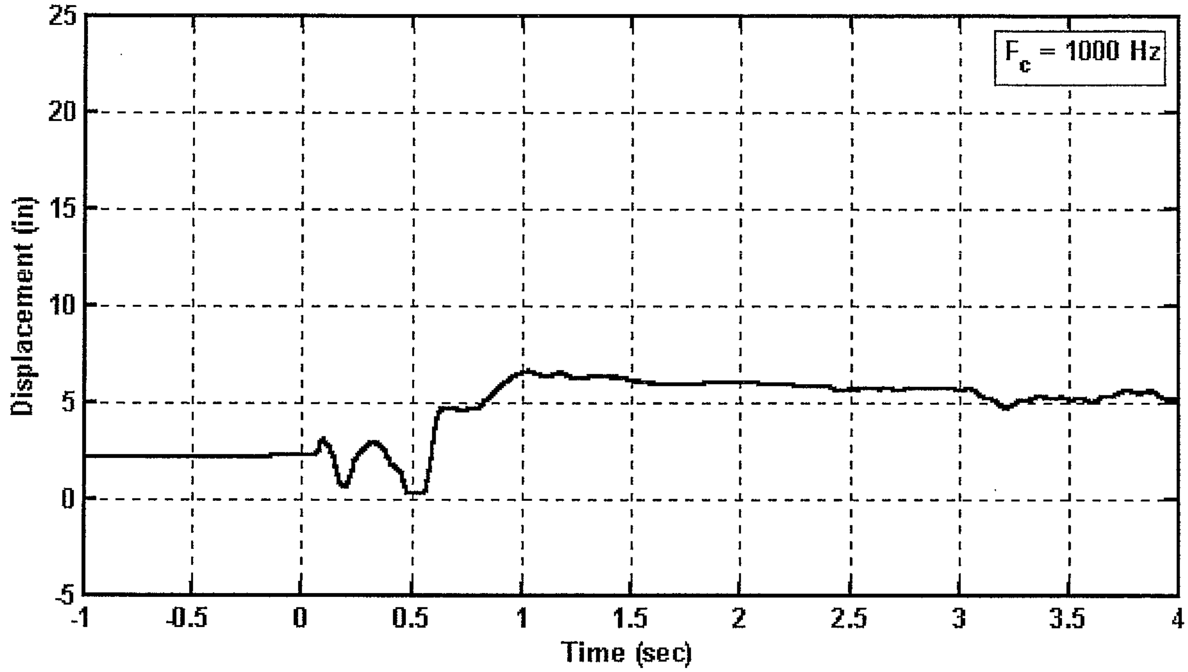


Figure E17. Bullet car 2, B end coupler, vertical displacement
Channel Name: B2_CBZ

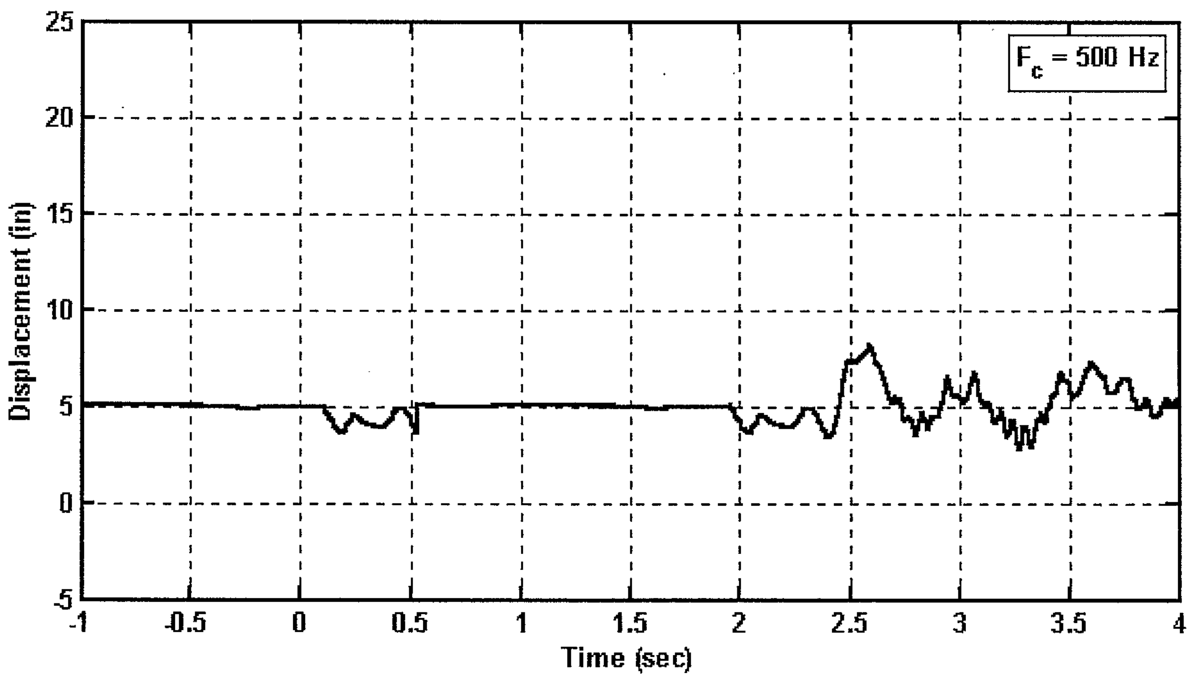


Figure E18. Bullet car 3, A truck, left side secondary suspension, displacement
Channel Name: B3_AL

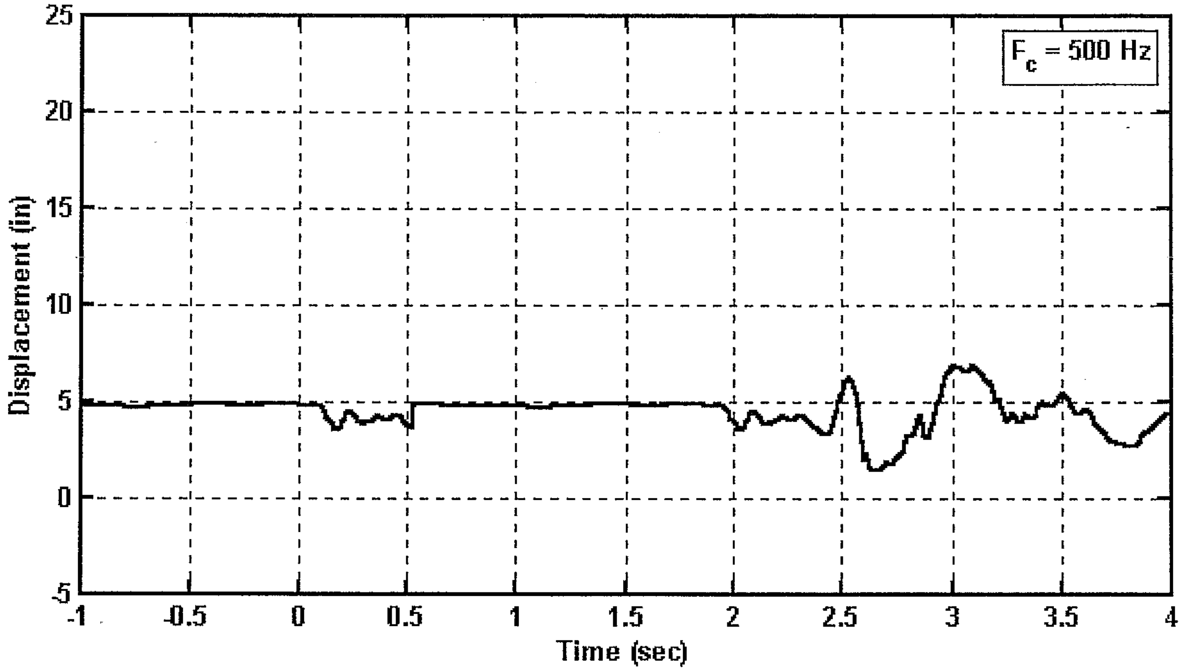


Figure E19. Bullet car 3, A truck, right side secondary suspension, displacement
Channel Name: B3_AR

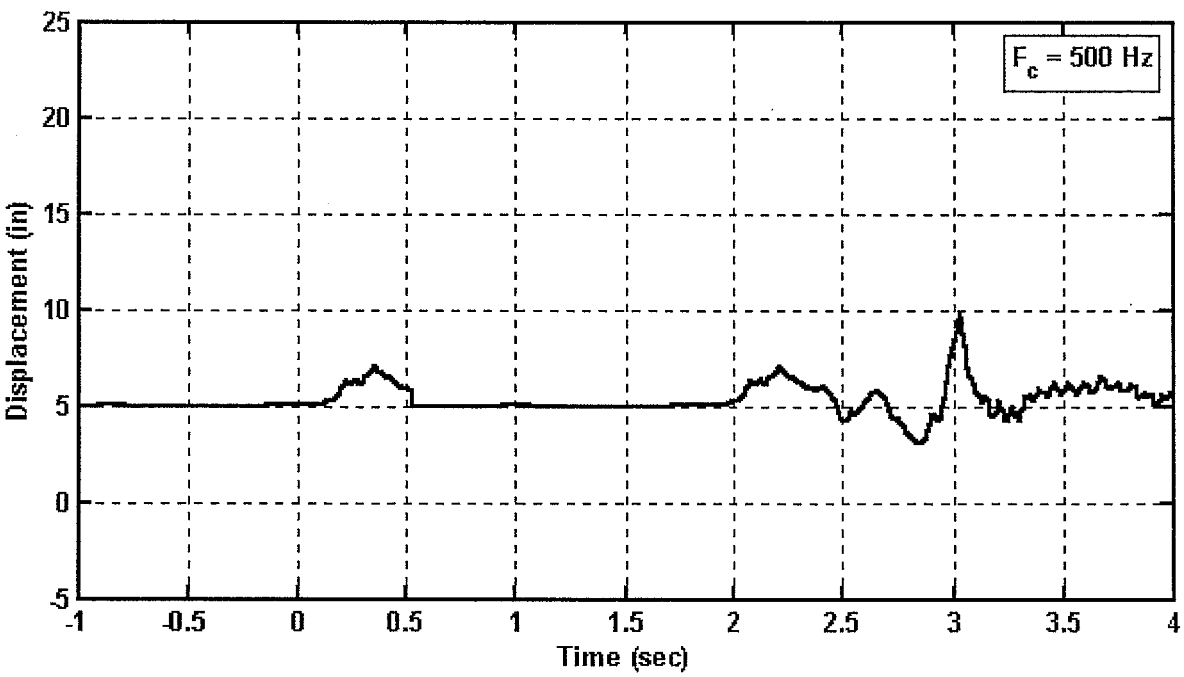


Figure E20. Bullet car 3, B truck, left side secondary suspension, displacement
Channel Name: B3_BL

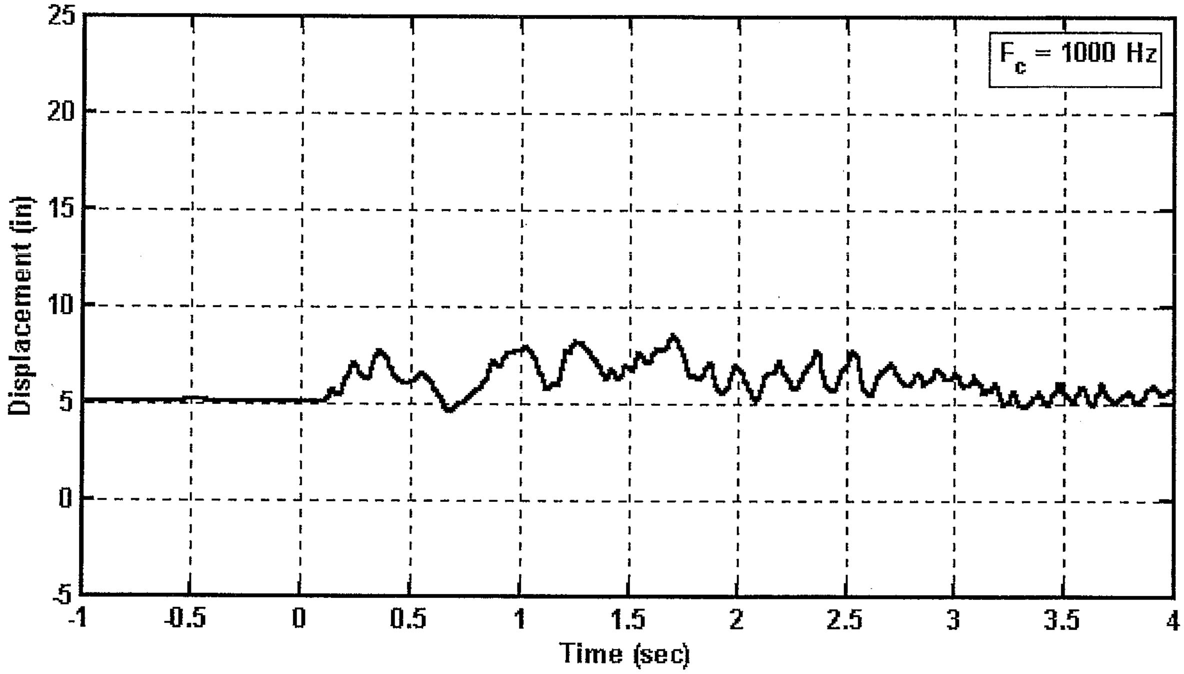


Figure E21. Bullet car 3, B truck, right side secondary suspension, displacement
Channel Name: B3_BR

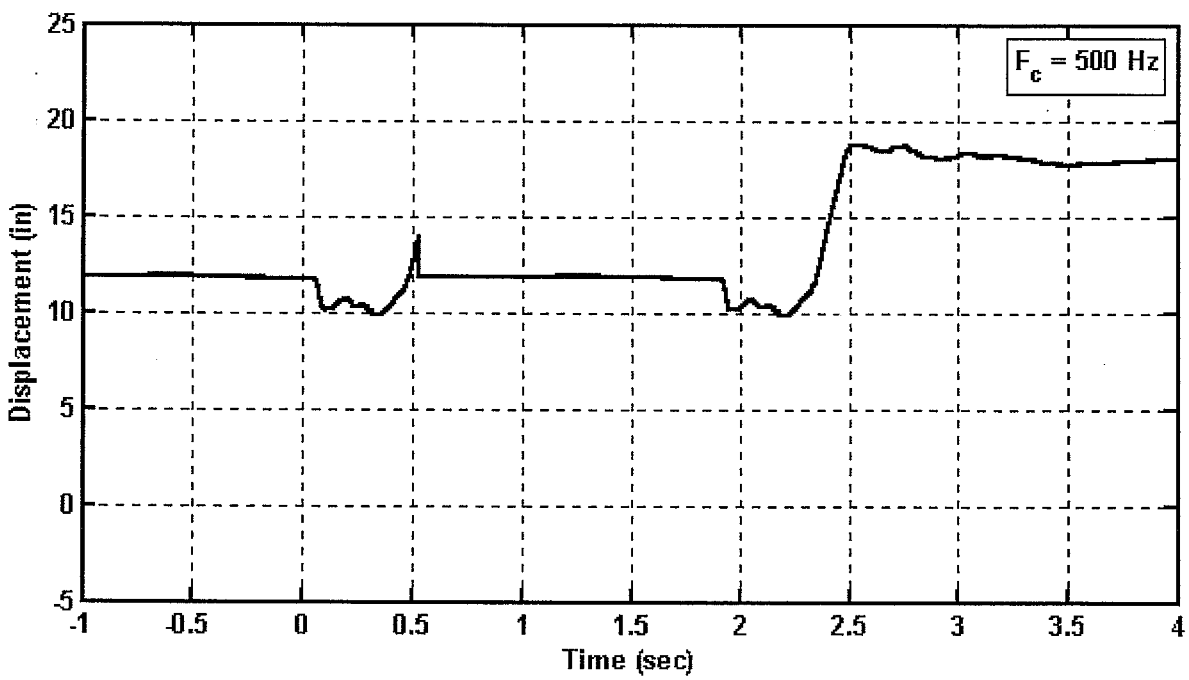


Figure E22. Bullet car 3, A end coupler, longitudinal displacement
Channel Name: B3_CAX

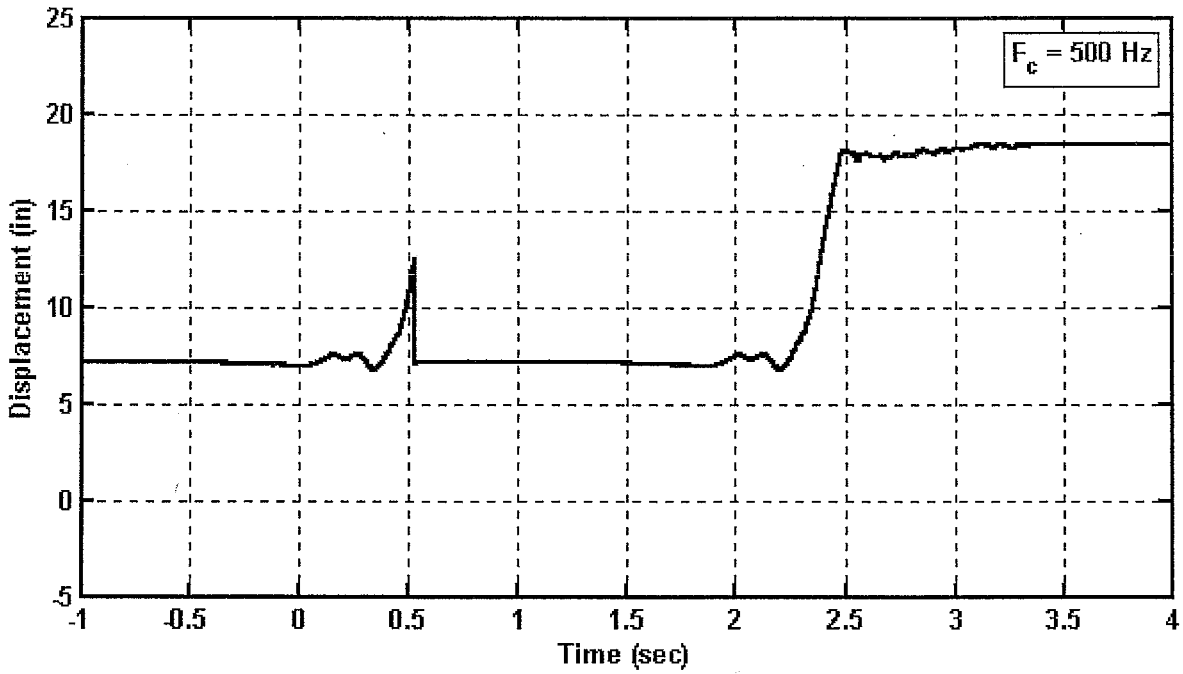


Figure E23. Bullet car 3, A end coupler, lateral displacement
Channel Name: B3_CAY

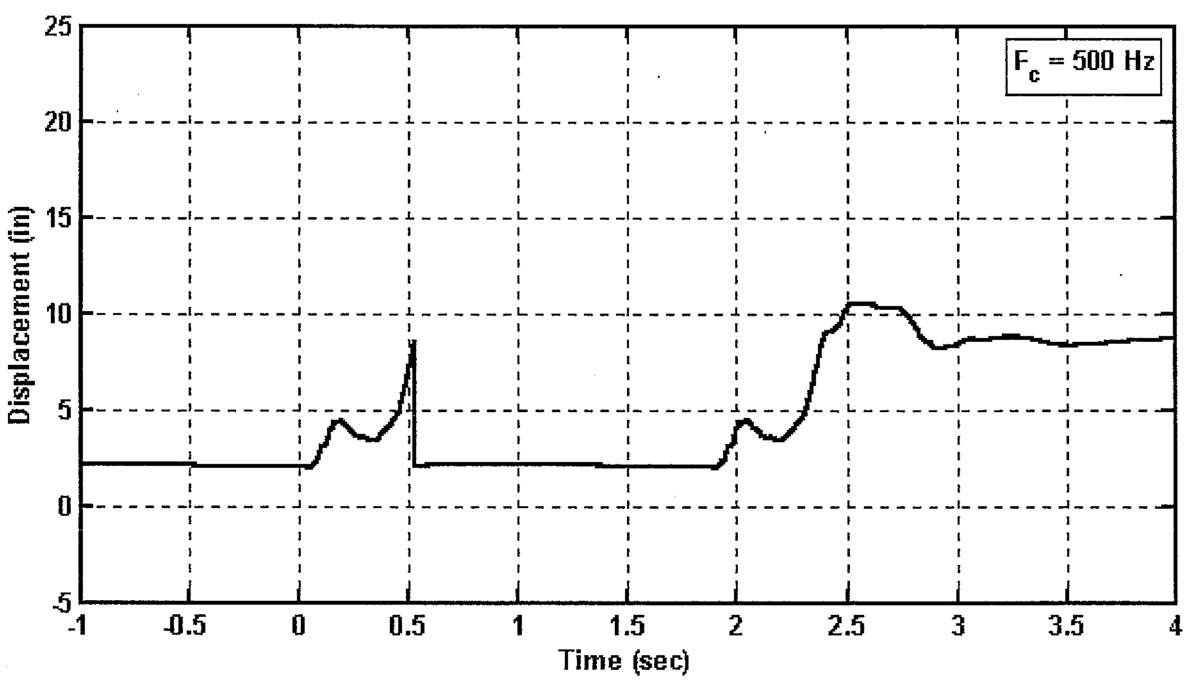


Figure E24. Bullet car 3, A end coupler, vertical displacement
Channel Name: B3_CAZ

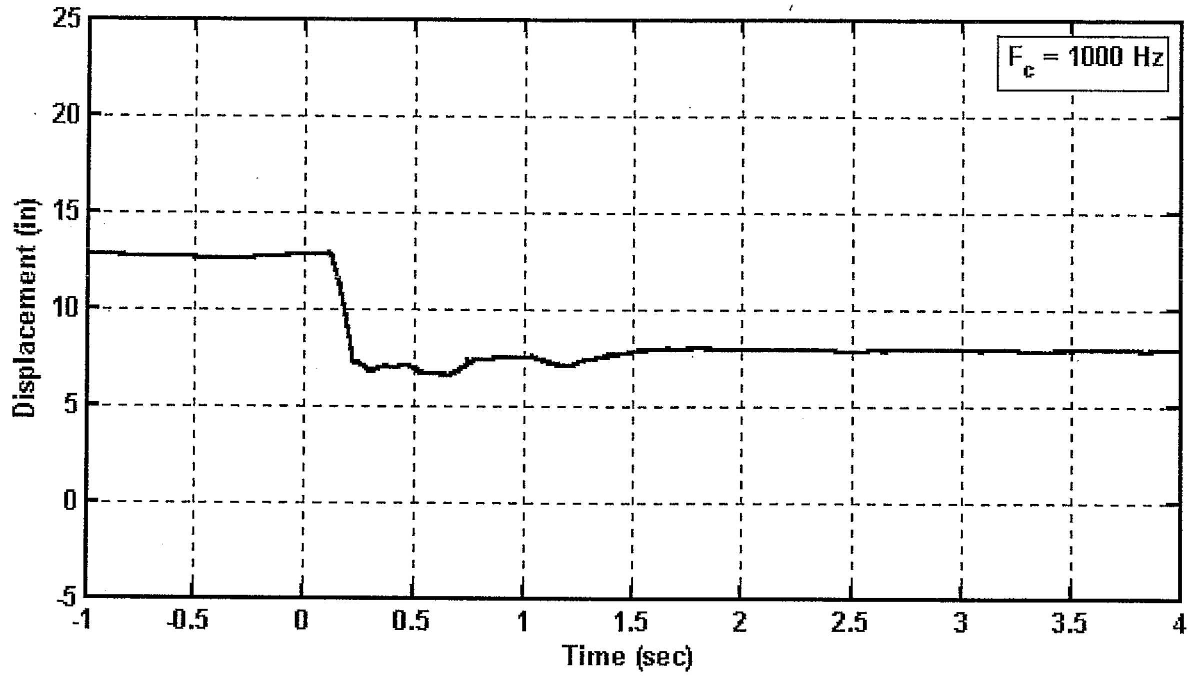


Figure E25. Bullet car 3, B end coupler, longitudinal displacement
Channel Name: B3_CBX

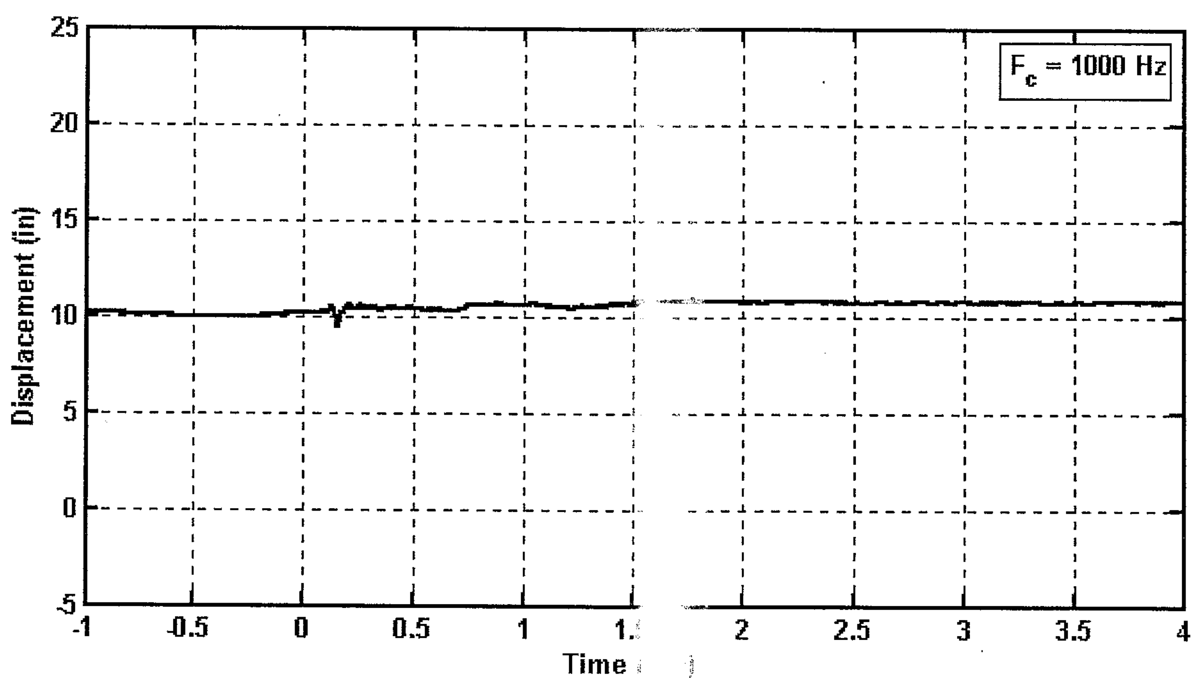


Figure E26. Bullet car 3, B end pler, lateral displacement
Channel Nan B3_CBY

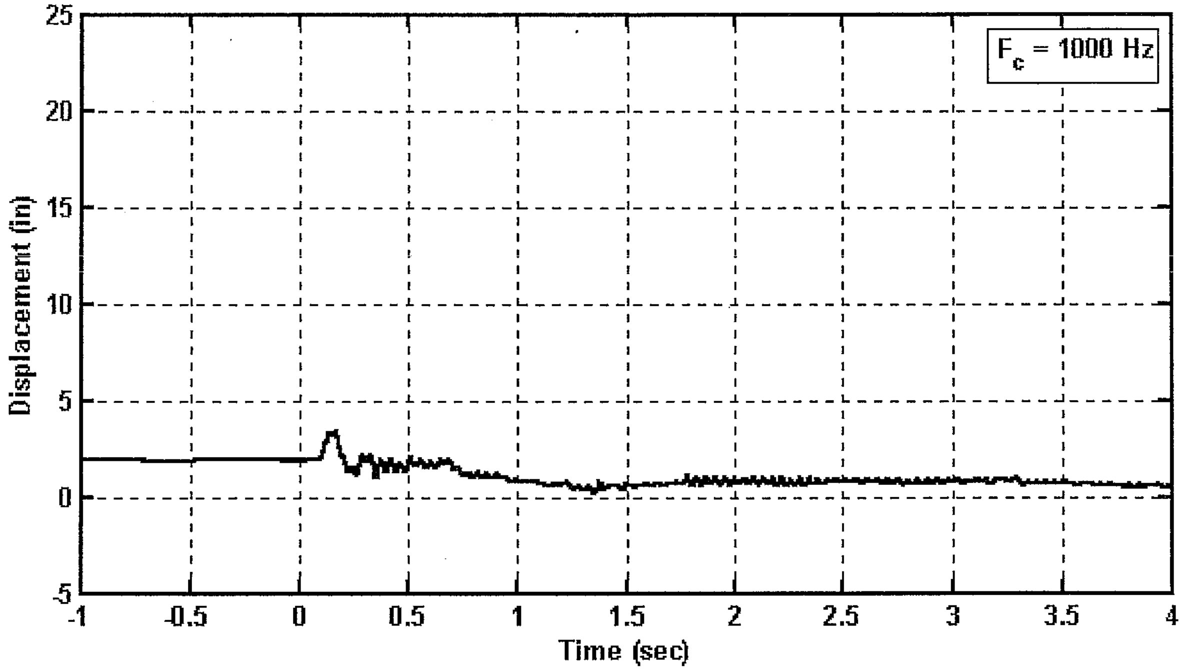


Figure E27. Bullet car 3, B end coupler, vertical displacement
Channel Name: B3_CBZ

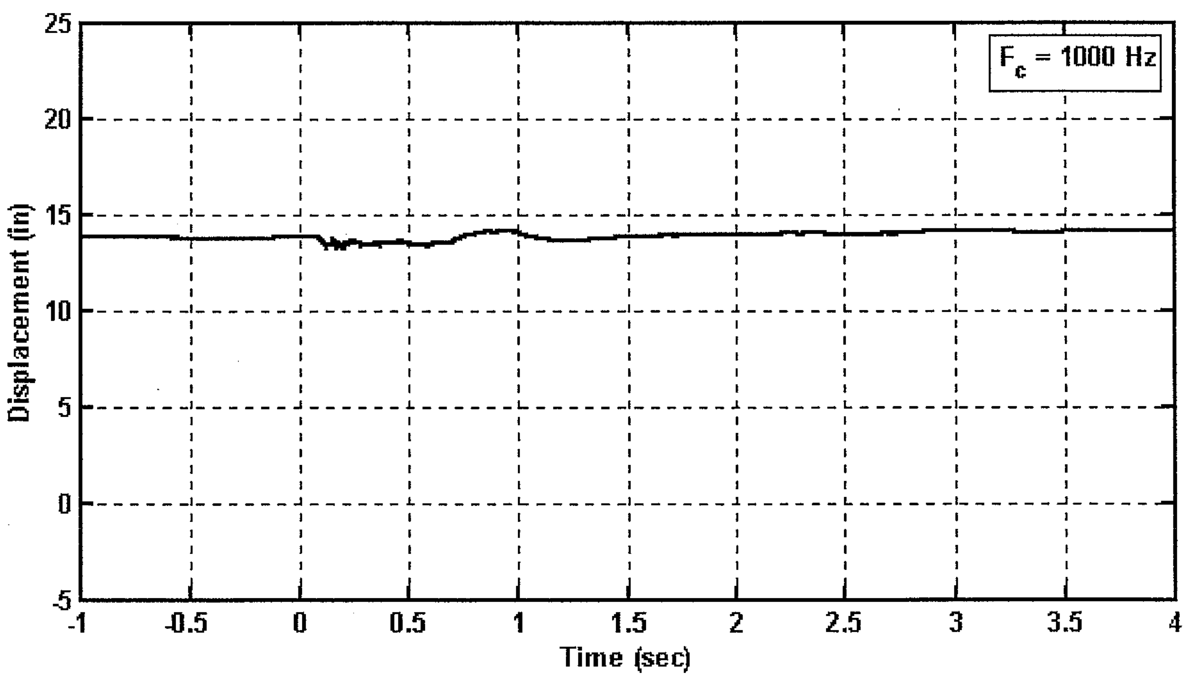


Figure E28. Bullet car 4, A end coupler, longitudinal displacement
Channel Name: B4_CAX

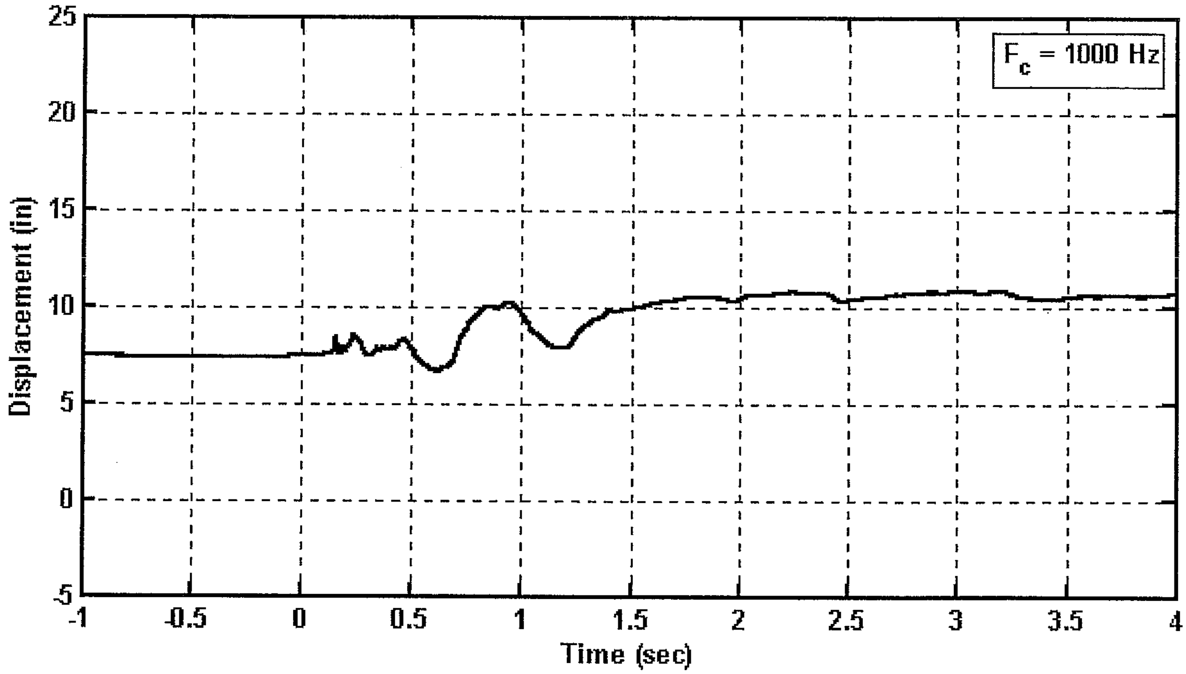


Figure E29. Bullet car 4, A end coupler, lateral displacement
Channel Name: B4_CAY

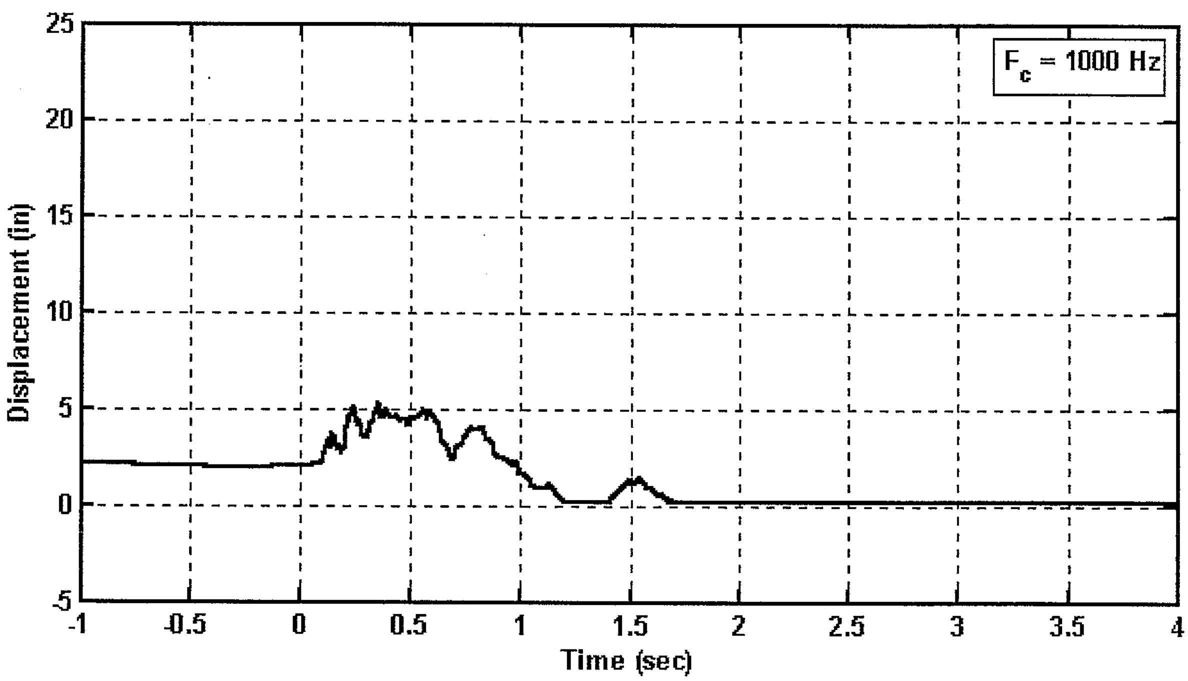


Figure E30. Bullet car 4, A end coupler, vertical displacement
Channel Name: B4_CAZ

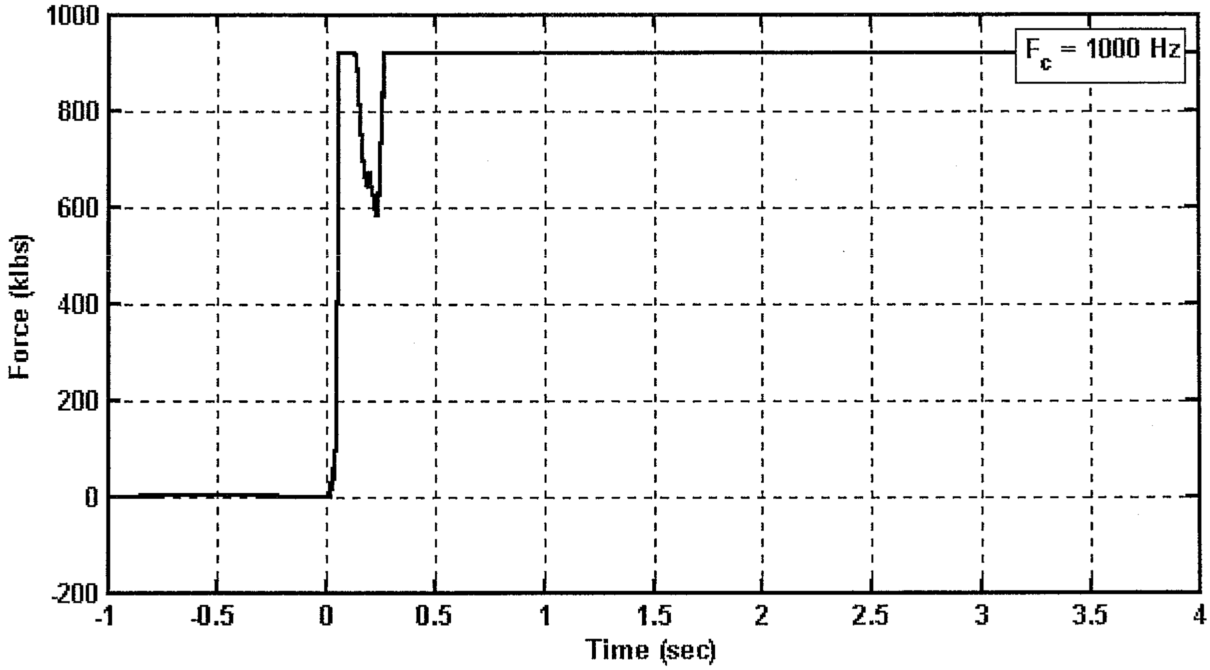


Figure E31. Bullet car 1, B end coupler, force measurement
Channel Name: B1_Cload

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APPENDIX F

Strain Data

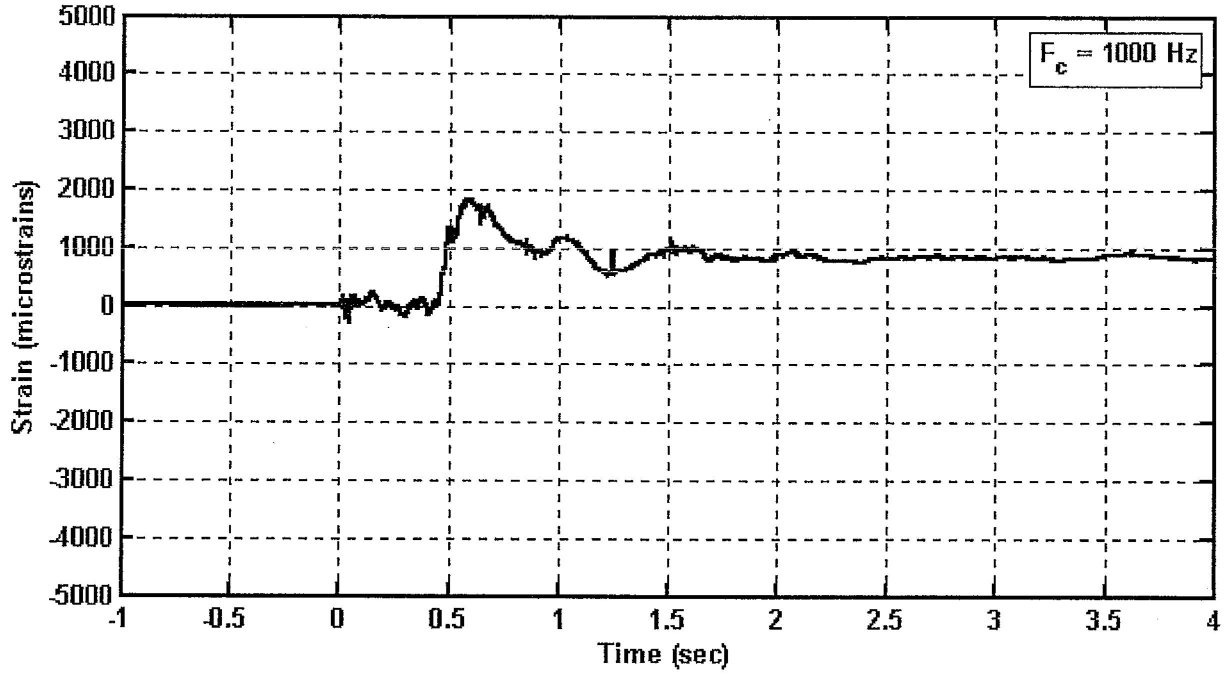

Figure F1. Bullet car 1, cant rail, position 1, left side, strain measurement
Channel Name: B1_CRL1

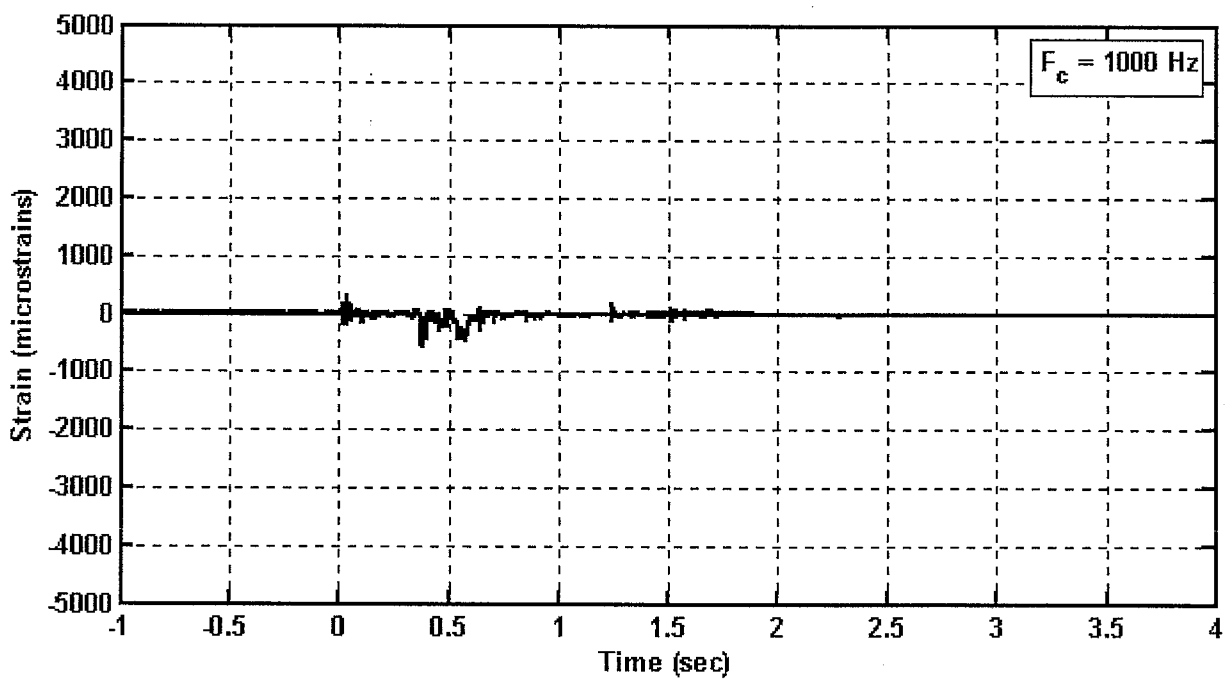

Figure F2. Bullet car 1, cant rail, position 2, left side, strain measurement
Channel Name: B1_CRL2

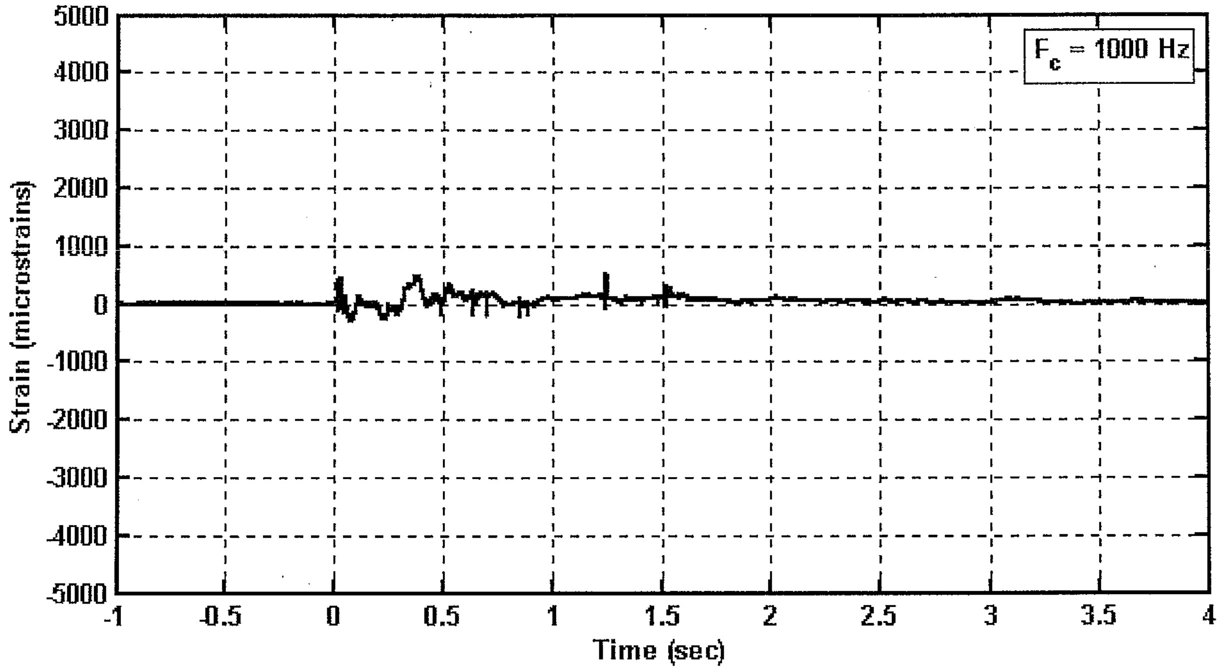

Figure F3. Bullet car 1, cant rail, position 3, left side, strain measurement
Channel Name: B1_CRL3

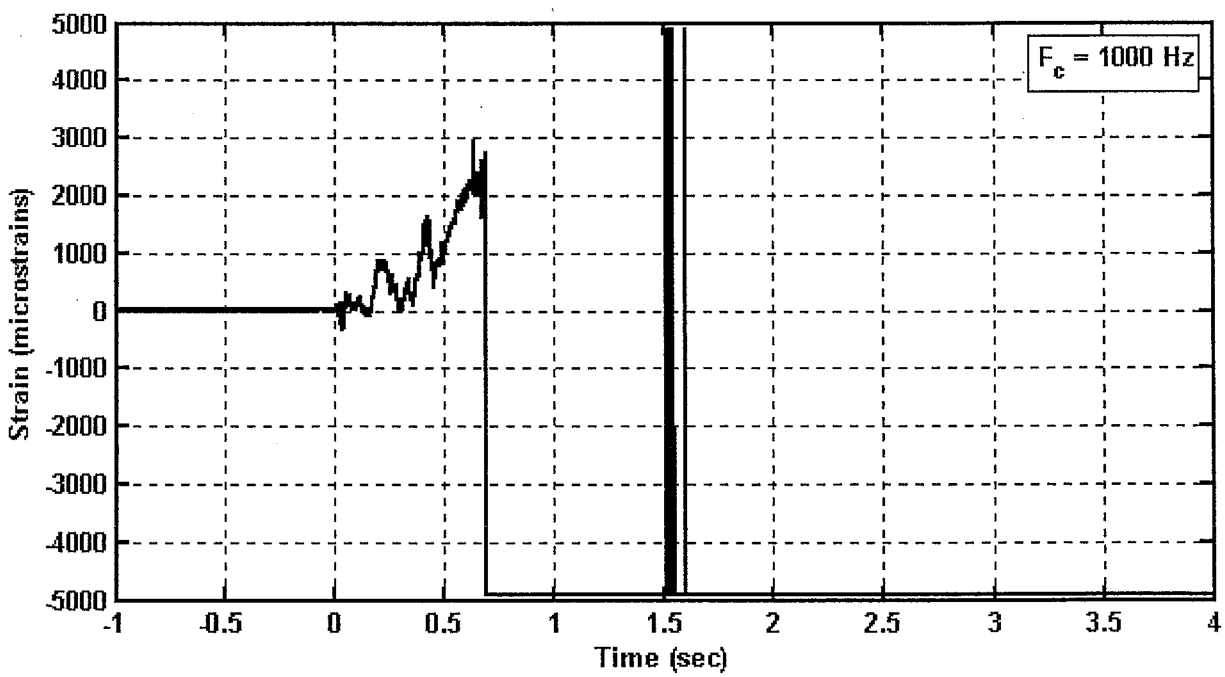

Figure F4. Bullet car 1, cant rail, position 1, right side, strain measurement
Channel Name: B1_CRR1

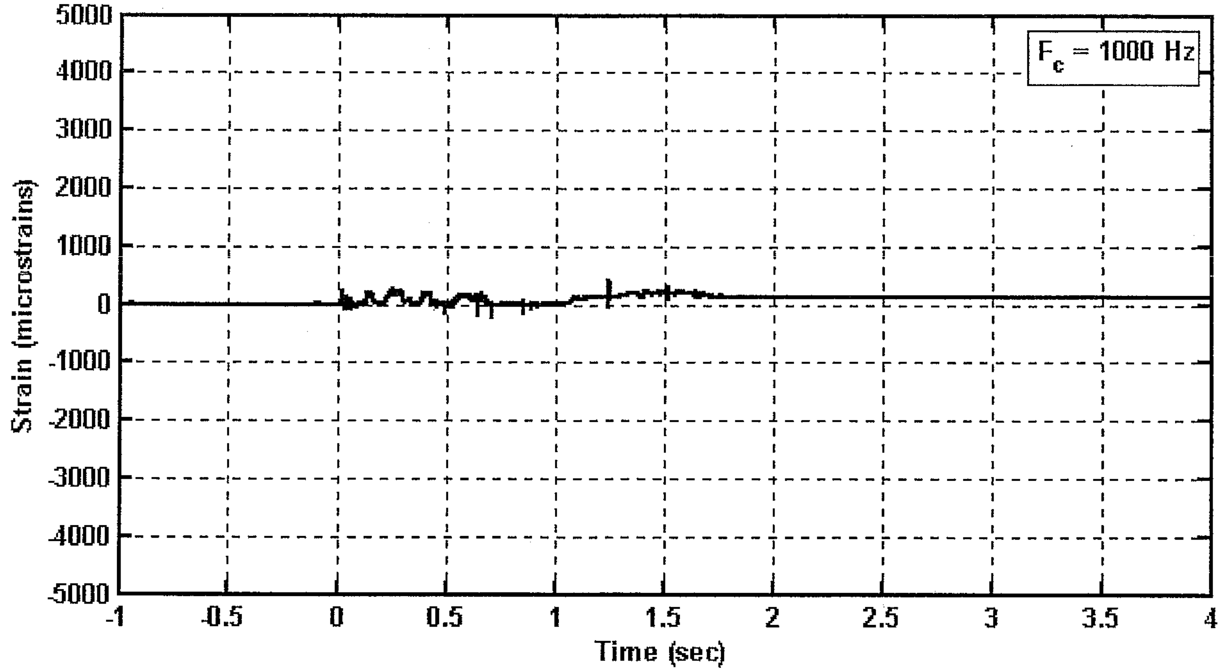

Figure F5. Bullet car 1, cant rail, position 2, right side, strain measurement
Channel Name: B1_CRR2

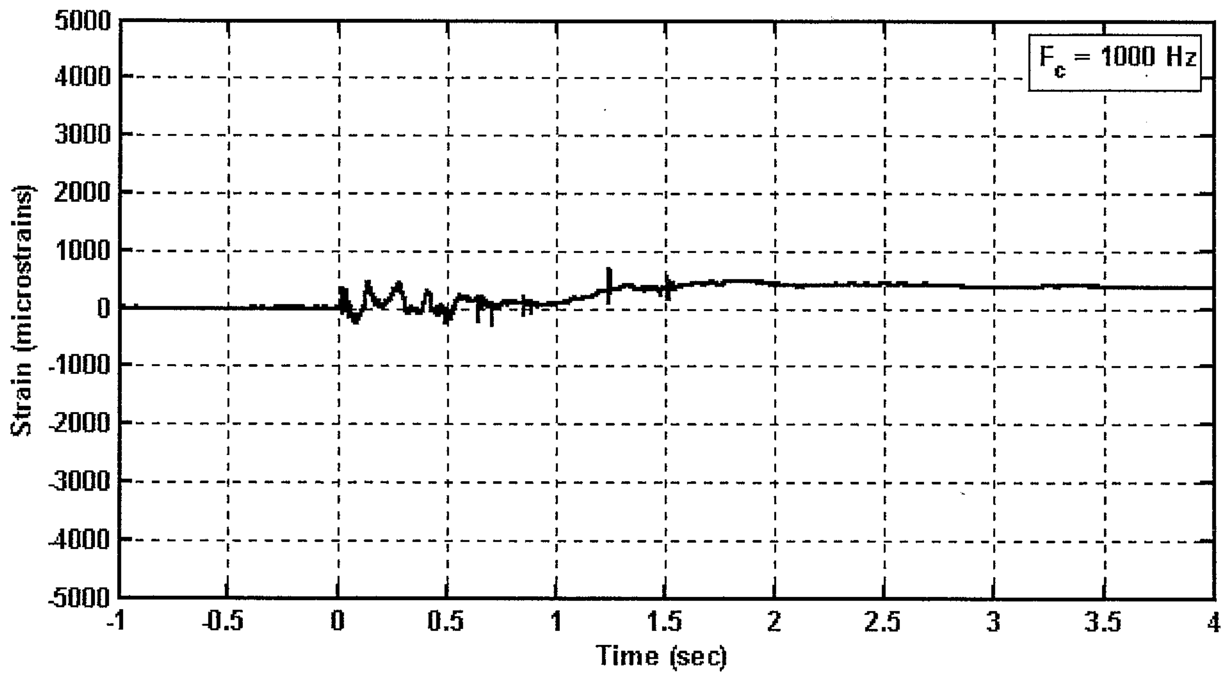

Figure F6. Bullet car 1, cant rail, position 3, right side, strain measurement
Channel Name: B1_CRR3

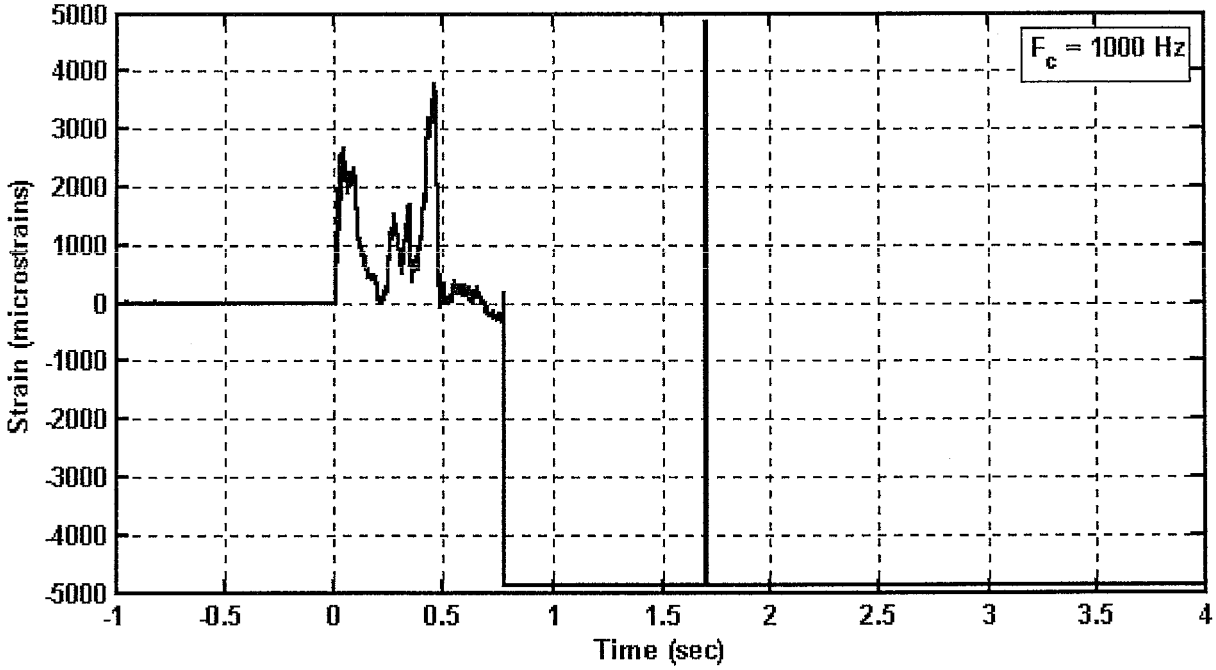

Figure F7. Bullet car 1, center sill, position 1, left side lower, strain measurement
Channel Name: B1_CSL1L

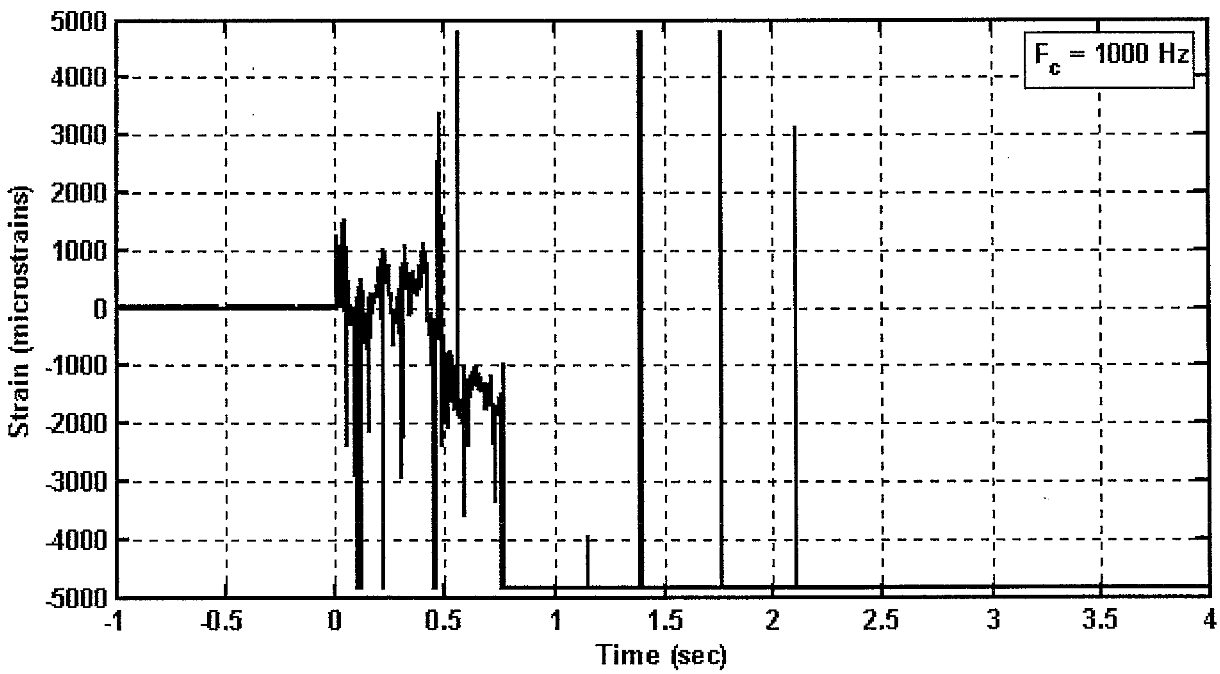

Figure F8. Bullet car 1, center sill, position 1, left side upper, strain measurement
Channel Name: B1_CSL1U

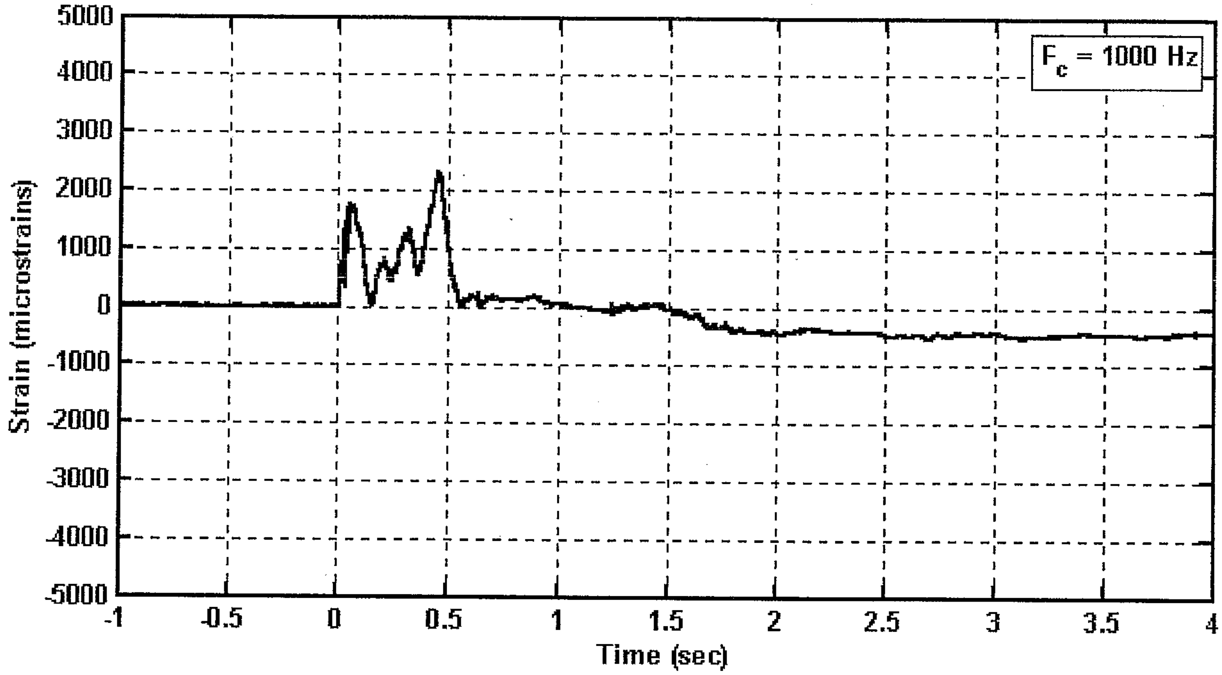

Figure F9. Bullet car 1, center sill, position 2, left side lower, strain measurement
Channel Name: B1_CSL2L

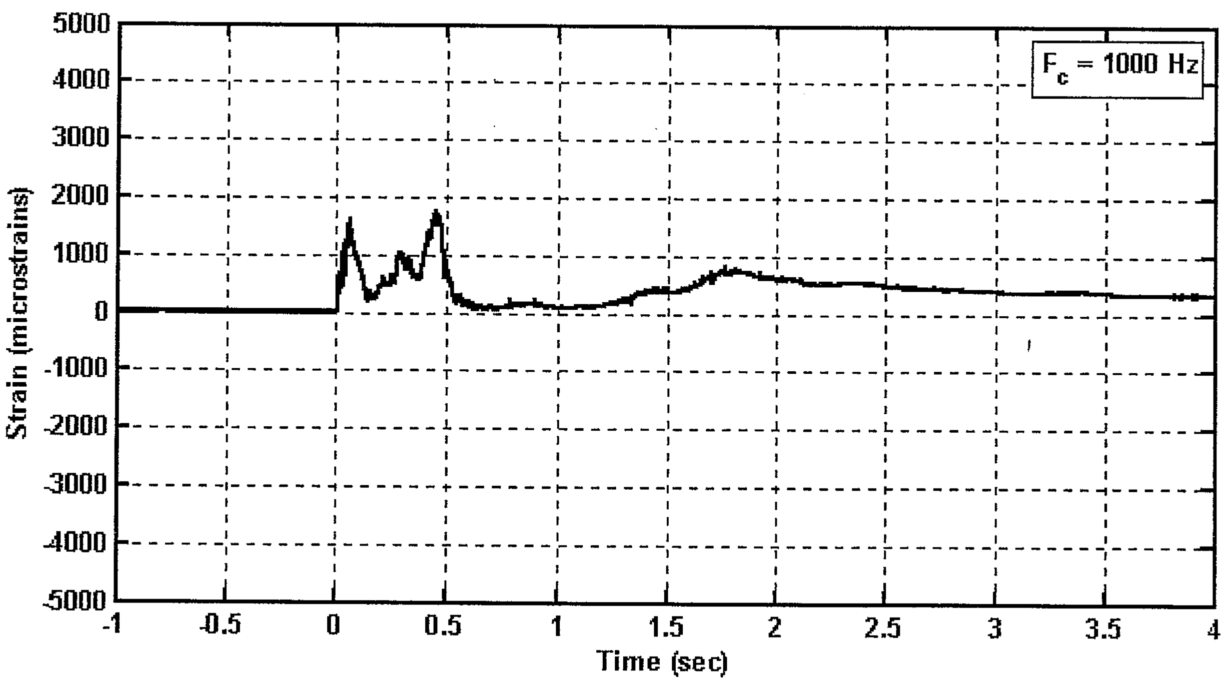

Figure F10. Bullet car 1, center sill, position 2, left side upper, strain measurement
Channel Name: B1_CSL2U

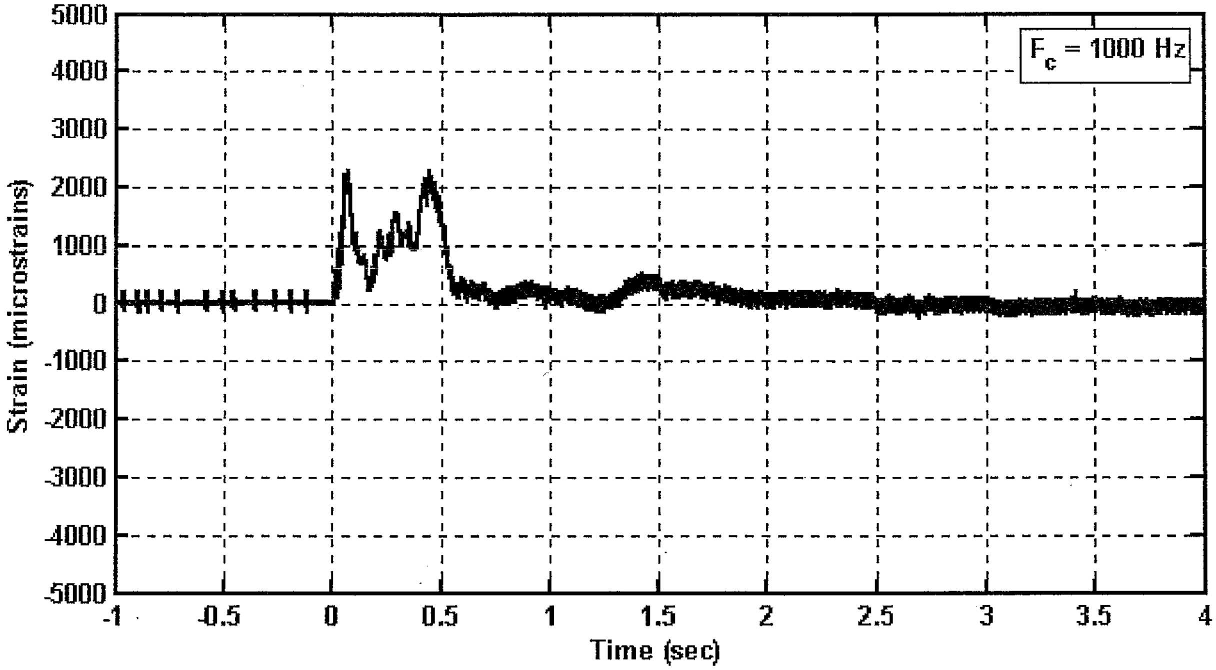

Figure F11. Bullet car 1, center sill, position 3, left side lower, strain measurement
Channel Name: B1_CSL3L

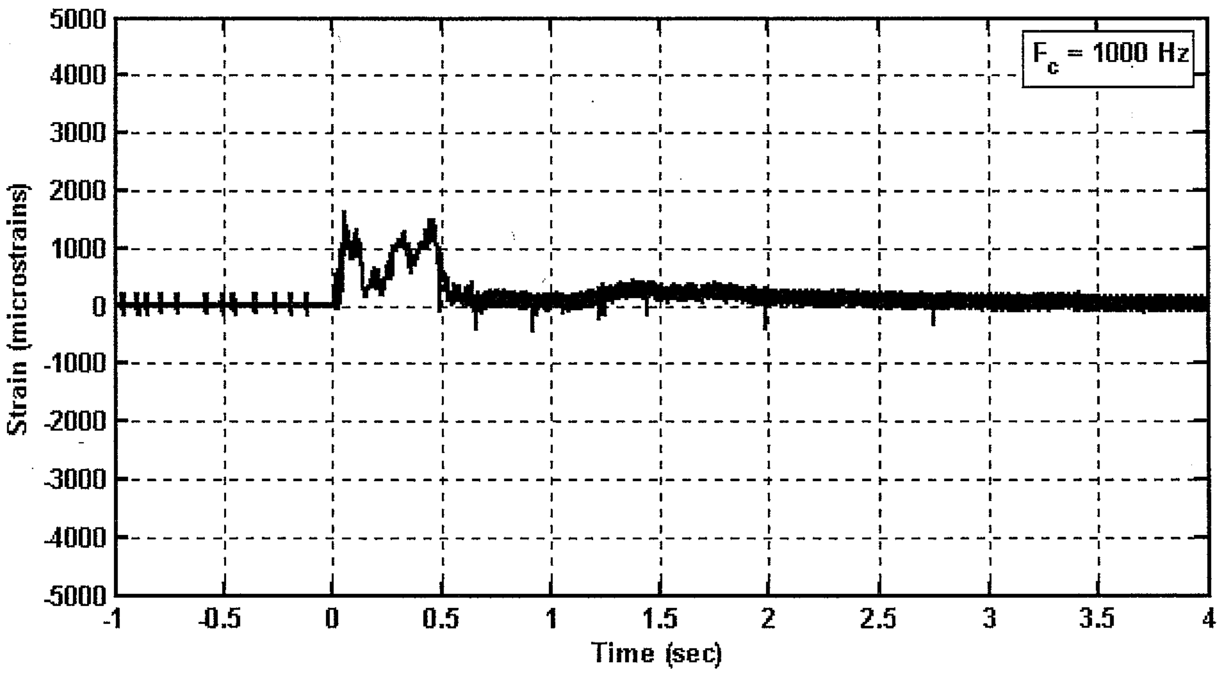

Figure F12. Bullet car 1, center sill, position 3, left side upper, strain measurement
Channel Name: B1_CSL3U

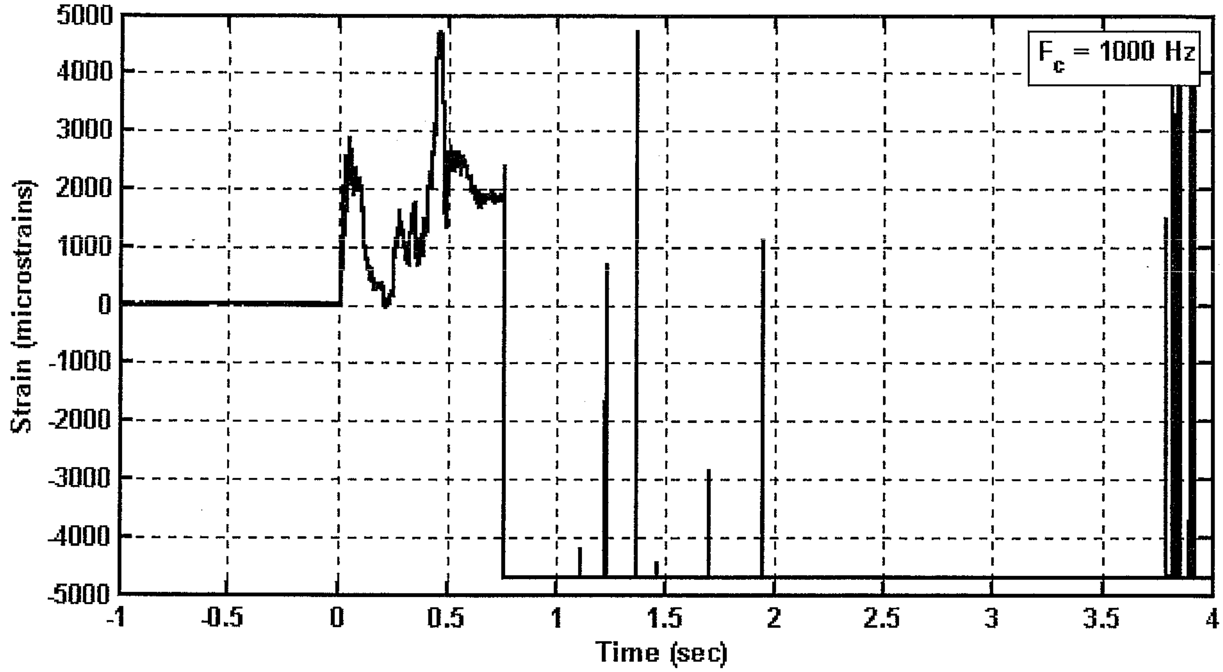

Figure F13. Bullet car 1, center sill, position 1, right side lower, strain measurement
Channel Name: B1_CSR1L

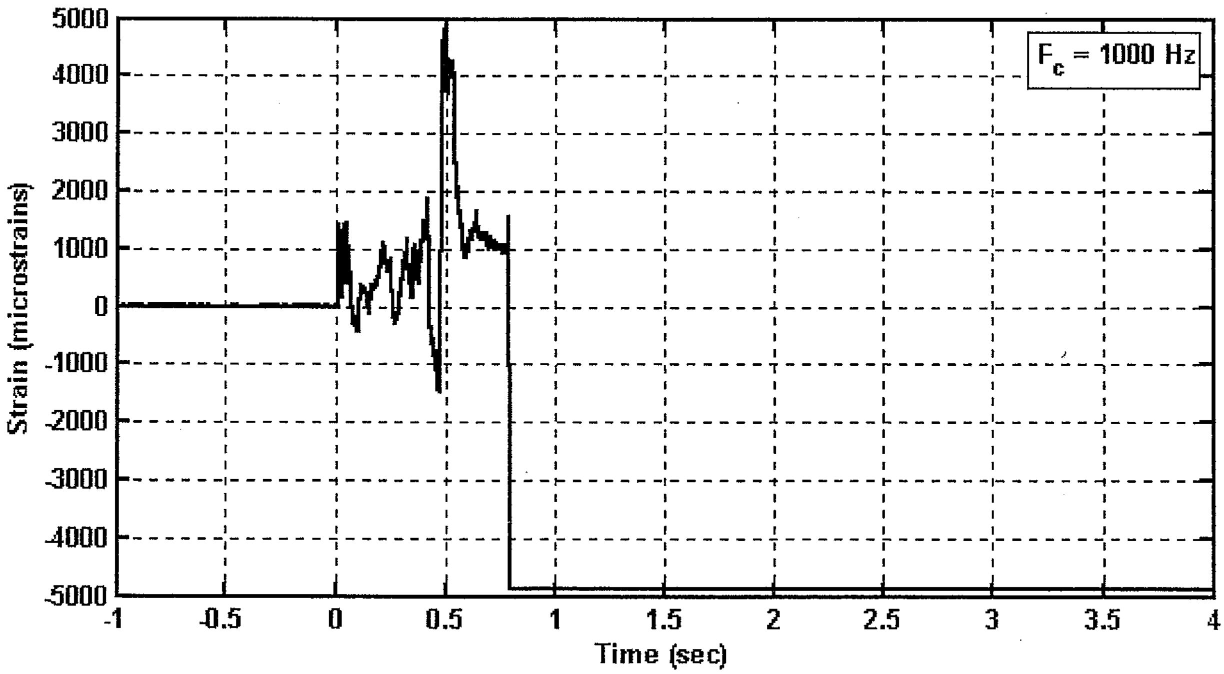

Figure F14. Bullet car 1, center sill, position 1, right side upper, strain measurement
Channel Name: B1_CSR1U

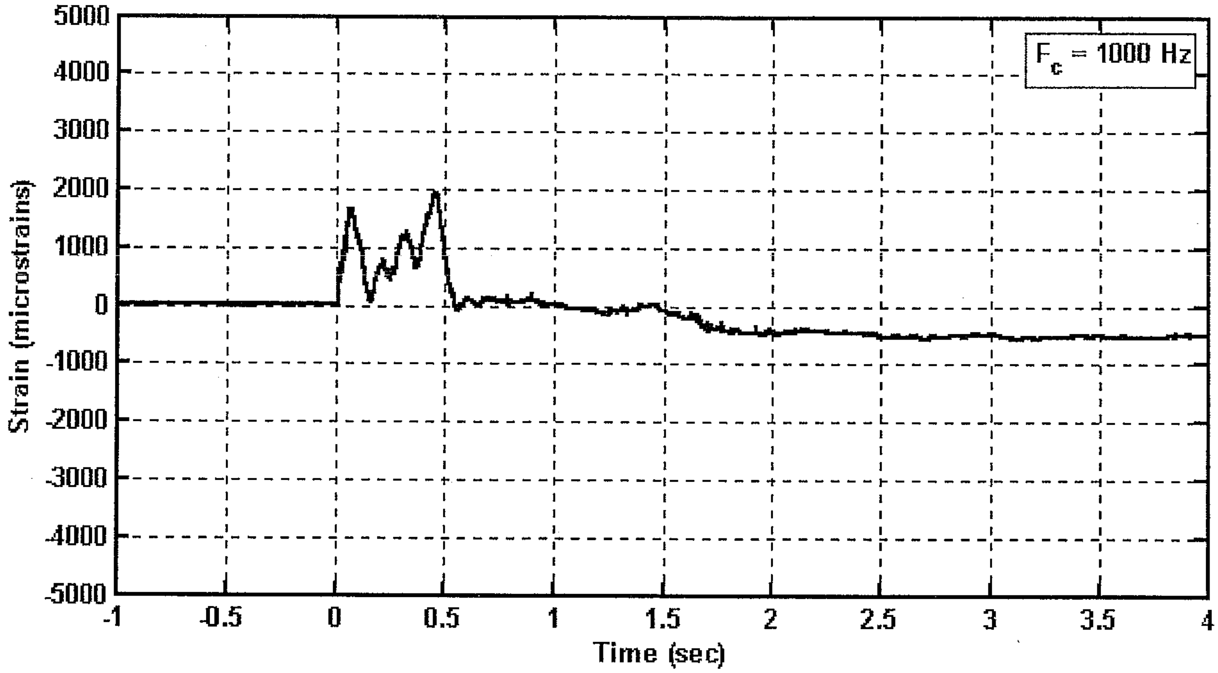

Figure F15. Bullet car 1, center sill, position 2, right side lower, strain measurement
Channel Name: B1_CSR2L

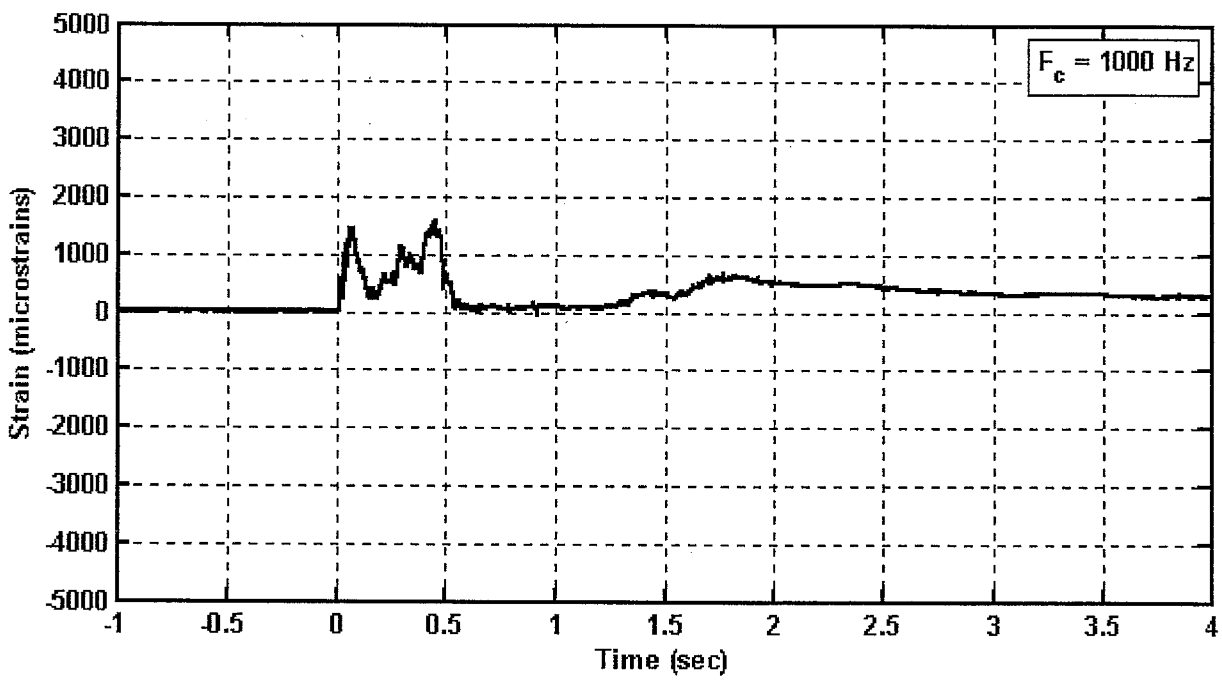

Figure F16. Bullet car 1, center sill, position 2, right side upper, strain measurement
Channel Name: B1_CSR2U

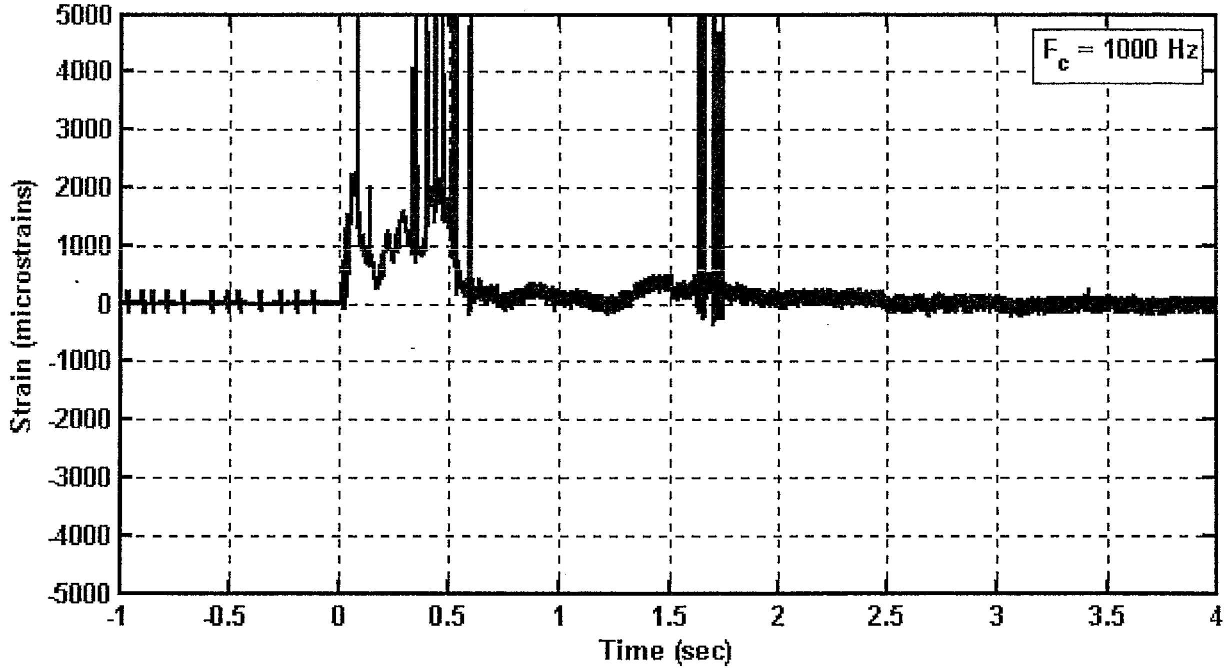

Figure F17. Bullet car 1, center sill, position 3, right side lower, strain measurement
Channel Name: B1_CSR3L

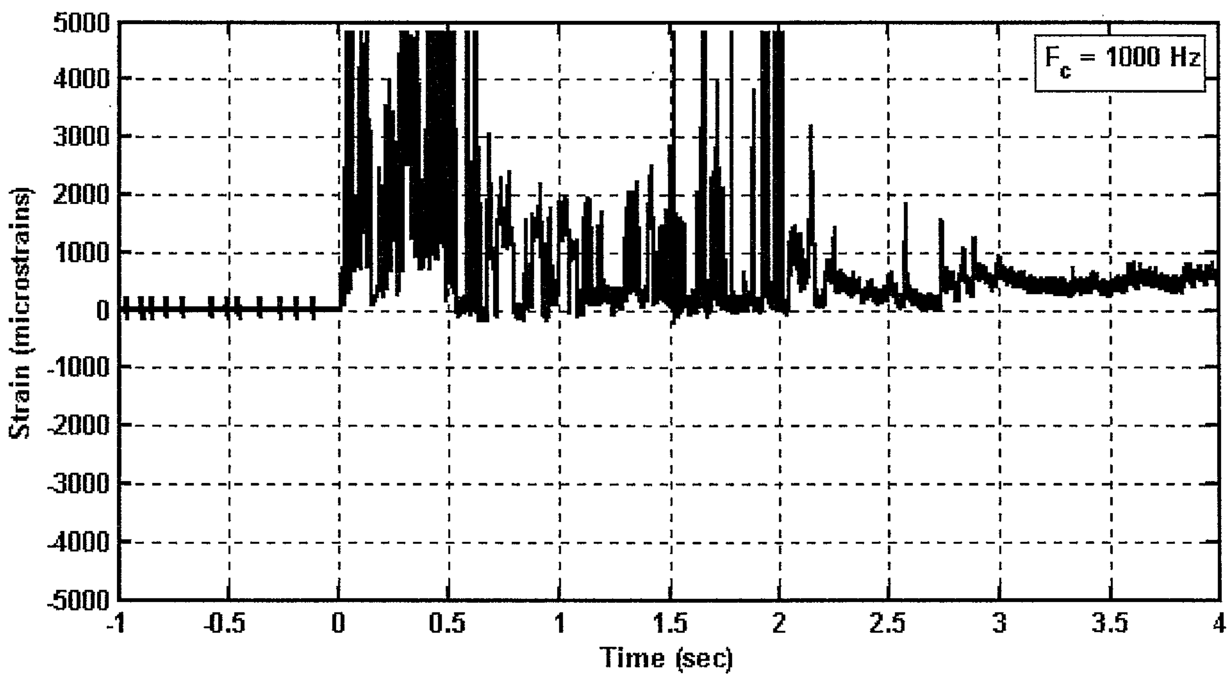

Figure F18. Bullet car 1, center sill, position 3, right side upper, strain measurement
Channel Name: B1_CSR3U

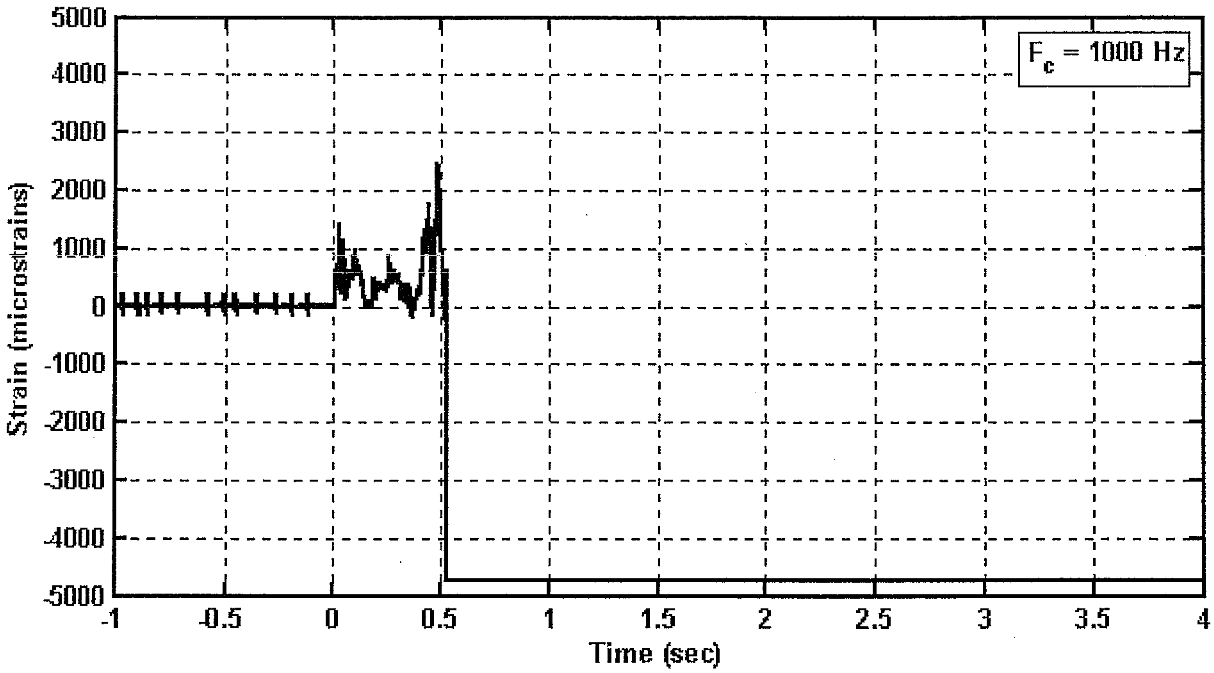

Figure F19. Bullet car 1, side sill, position 1, left side, strain measurement
Channel Name: B1_SSL1

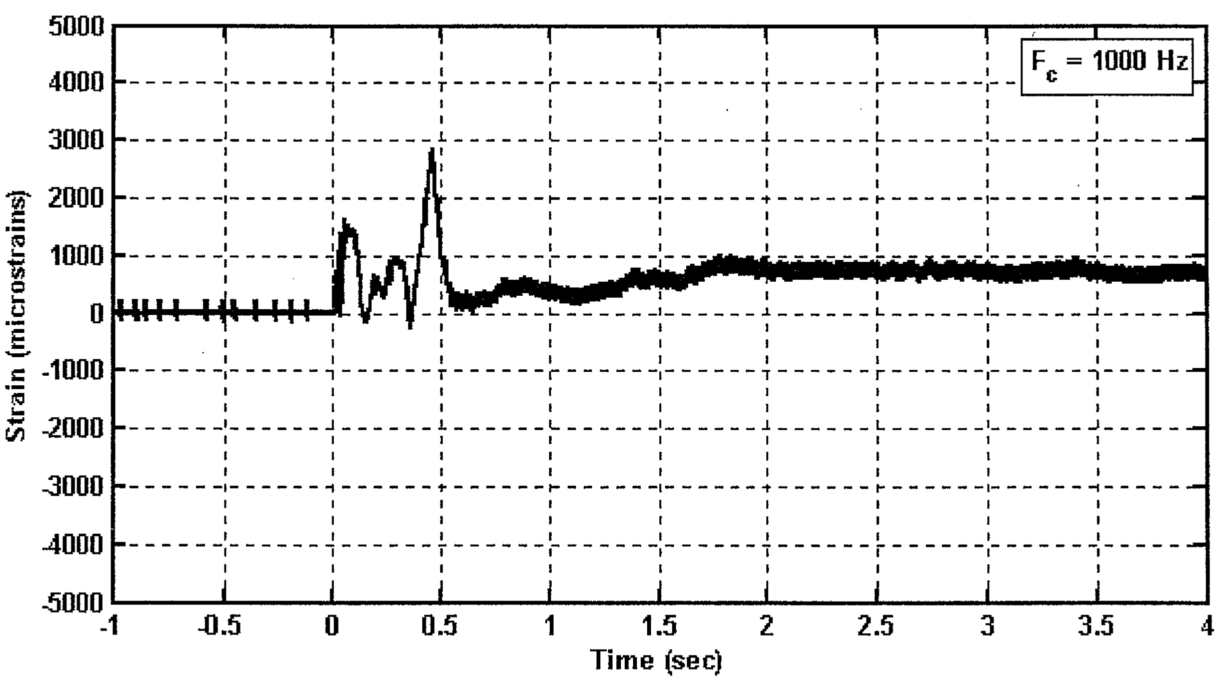

Figure F20. Bullet car 1, side sill, position 2, left side, strain measurement
Channel Name: B1_SSL2

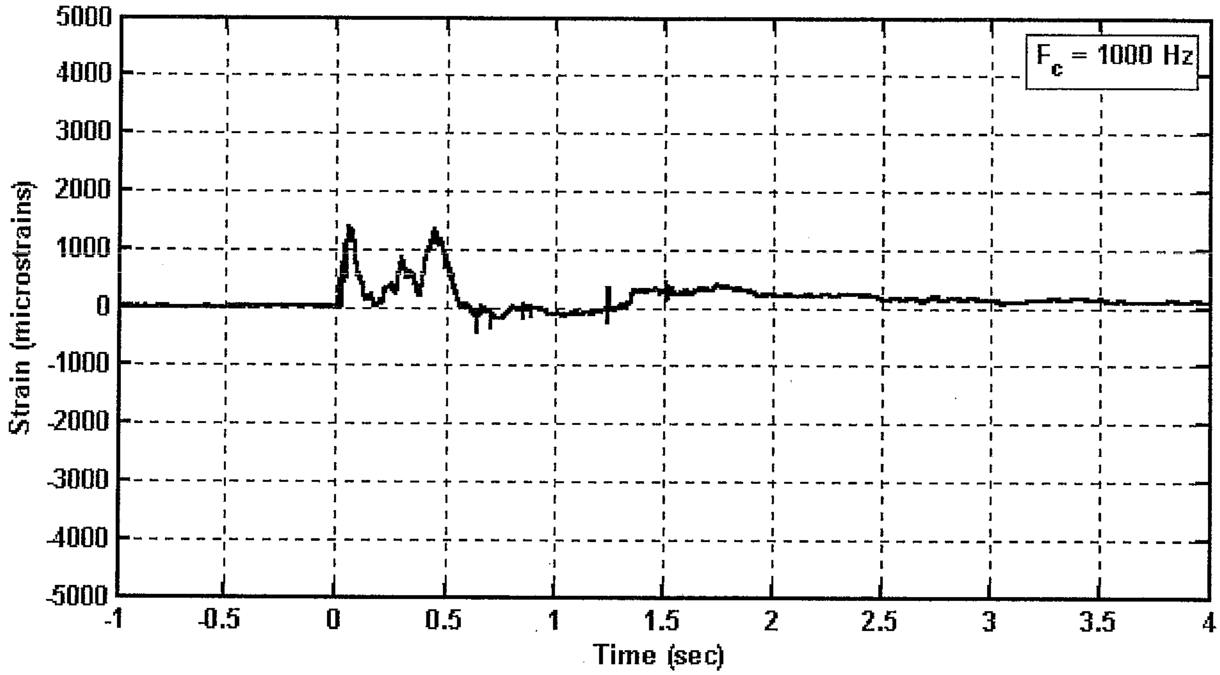

Figure F21. Bullet car 1, side sill, position 3, left side, strain measurement
Channel Name: B1_SSL3

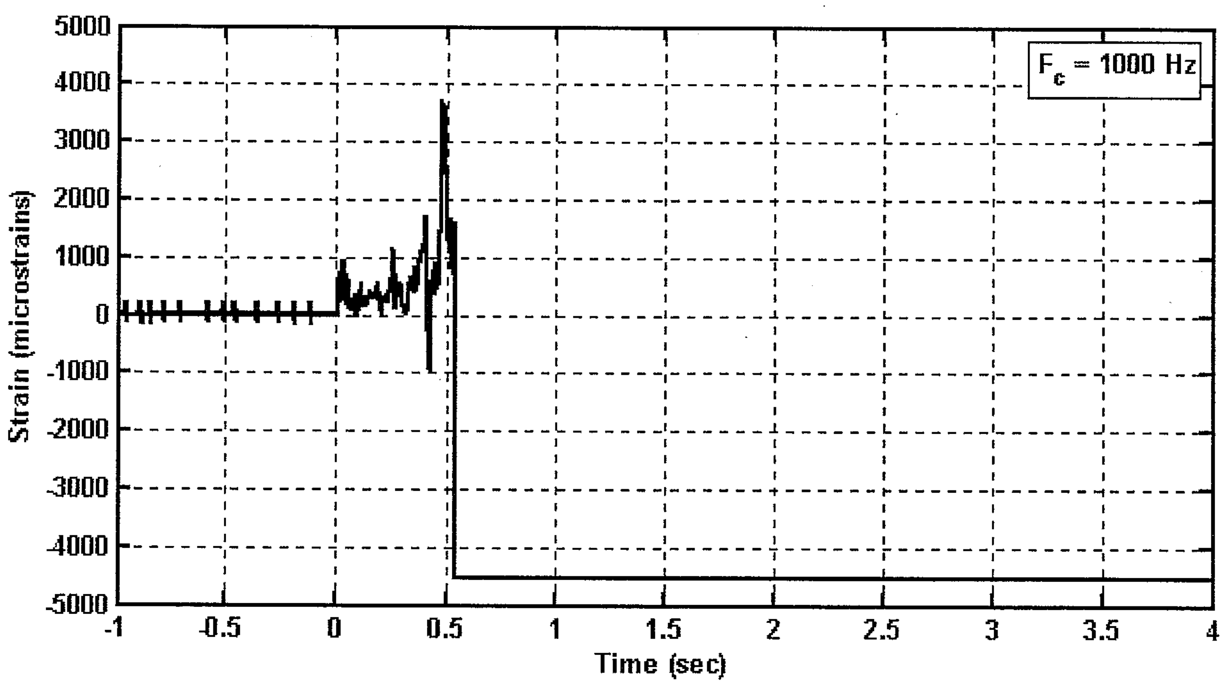

Figure F22. Bullet car 1, side sill, position 1, right side, strain measurement
Channel Name: B1_SSR1

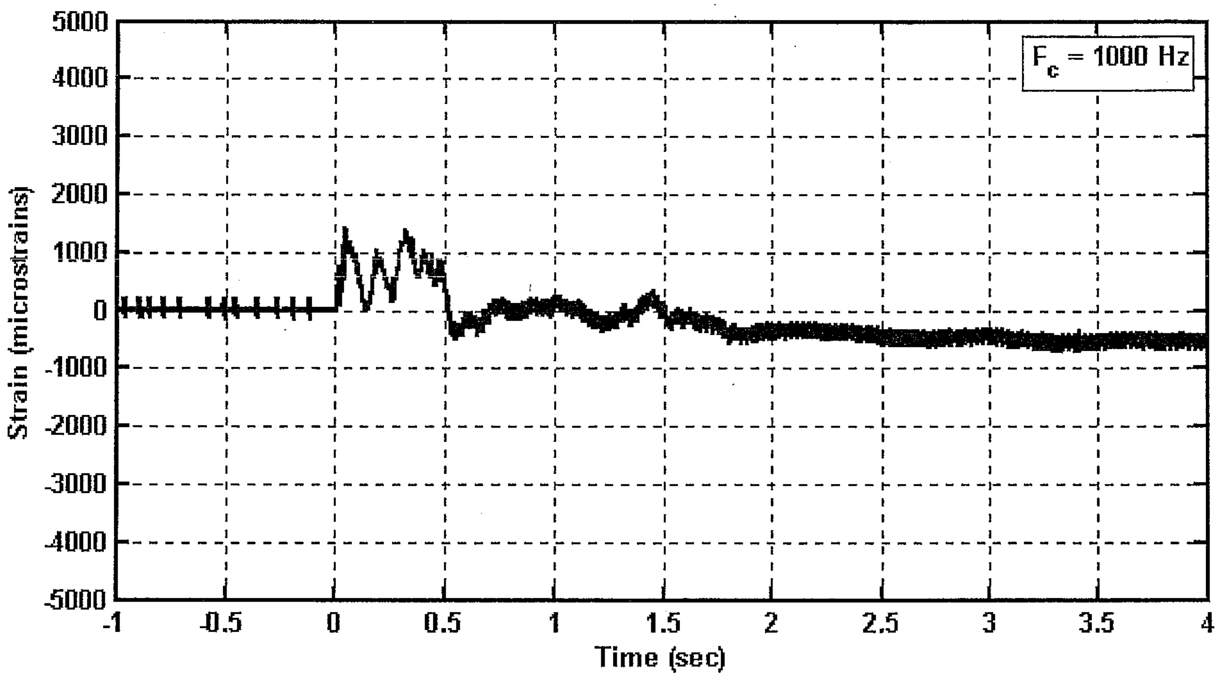

Figure F23. Bullet car 1, side sill, position 2, right side, strain measurement
Channel Name: B1_SSR2

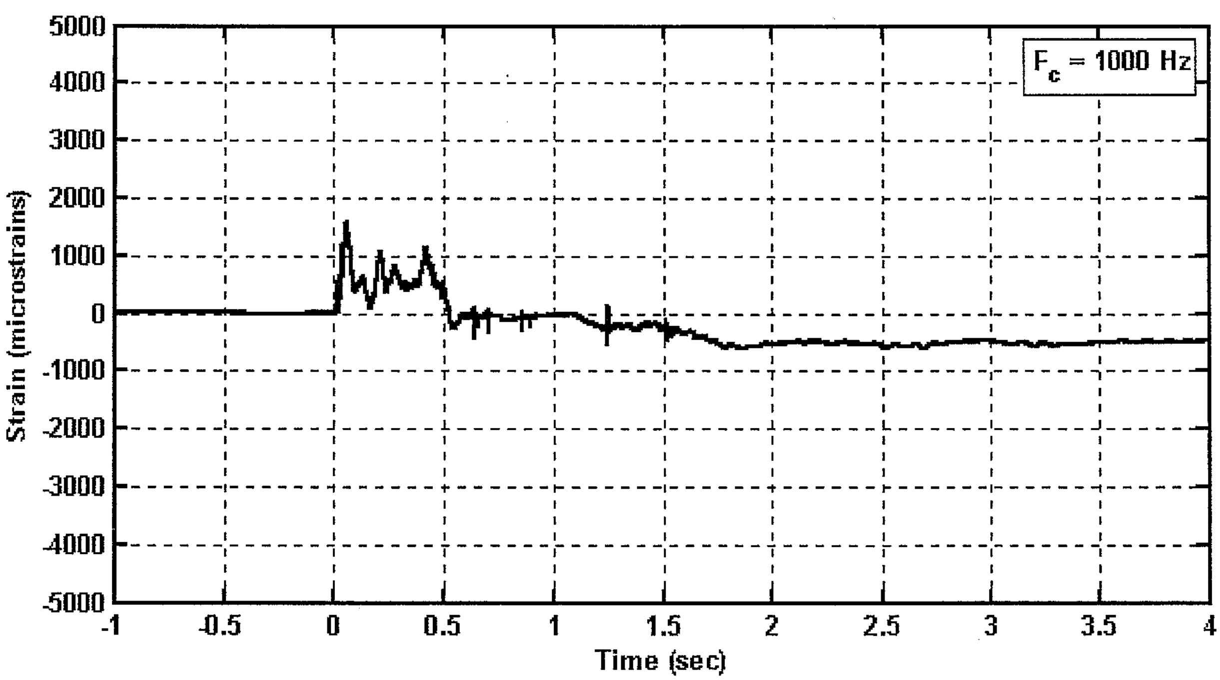

Figure F24. Bullet car 1, side sill, position 3, right side, strain measurement
Channel Name: B1_SSR3

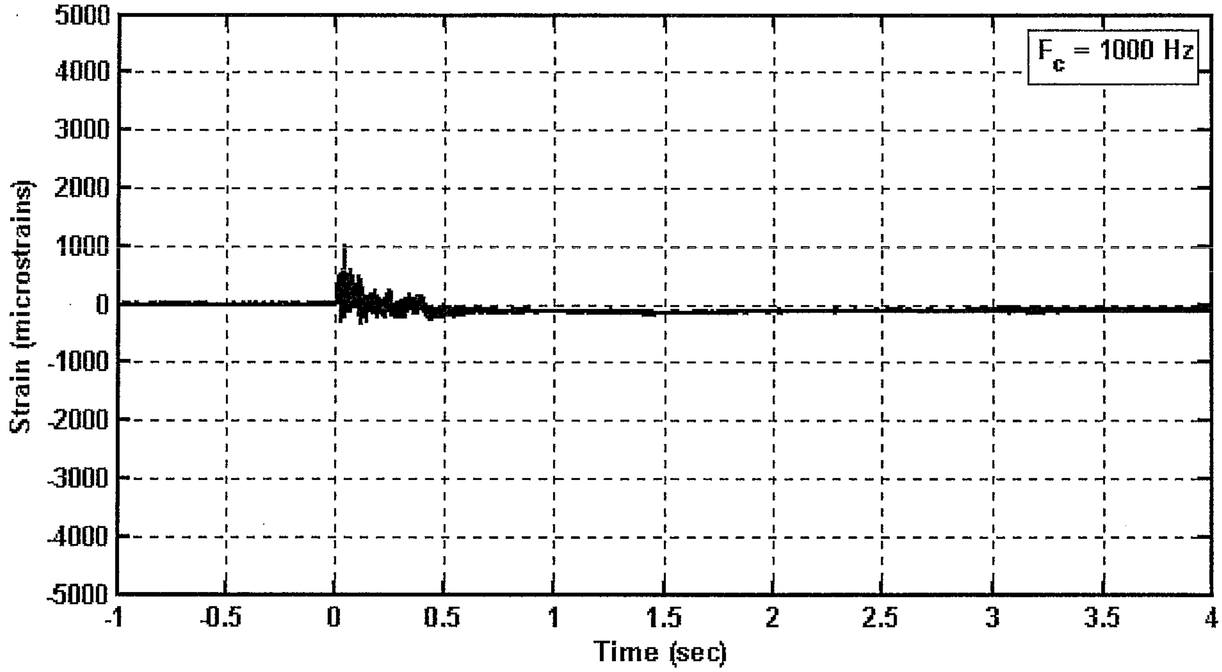

Figure F25. Target locomotive, main sill, position 1, left side lower, strain measurement
Channel Name: SL_MSL1L

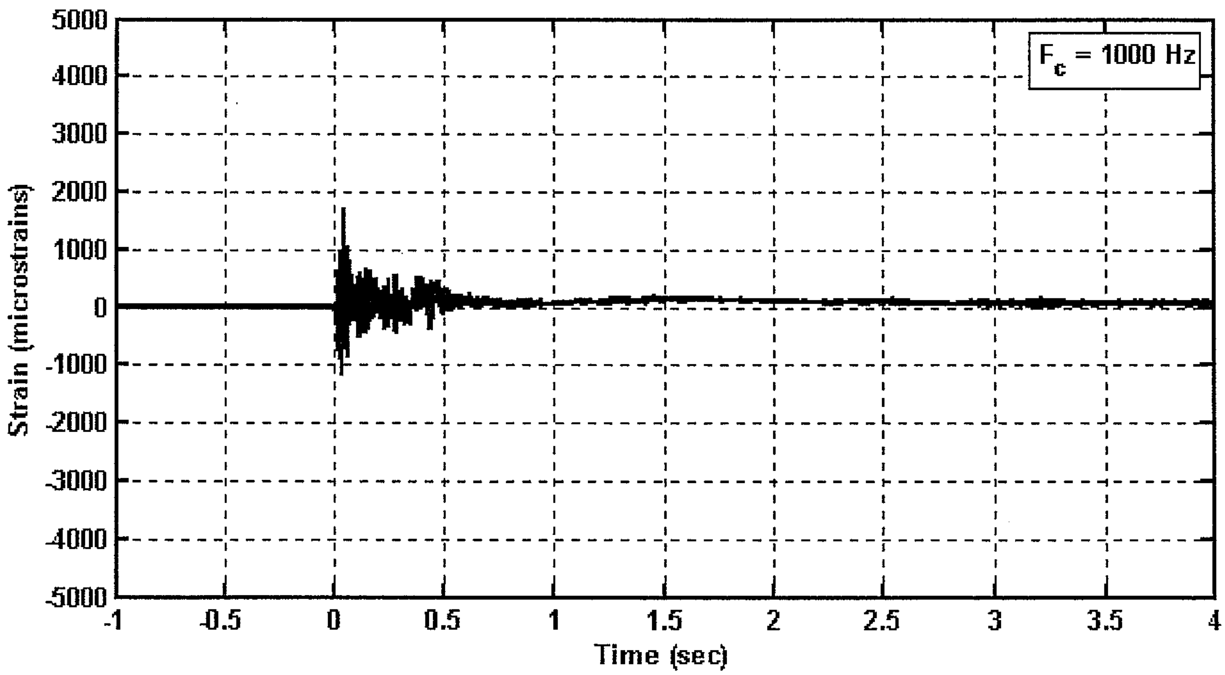

Figure F26. Target locomotive, main sill, position 1, left side upper, strain measurement
Channel Name: SL_MSL1U

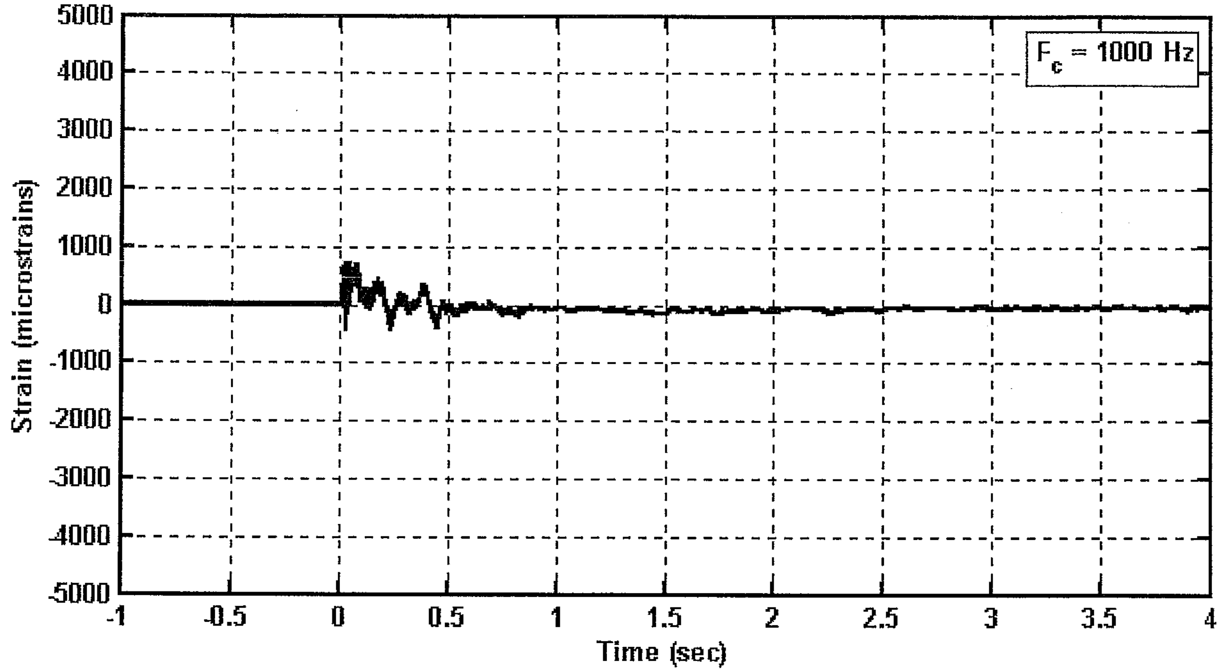

Figure F27. Target locomotive, main sill, position 2, left side lower, strain measurement
Channel Name: SL_MSL2L

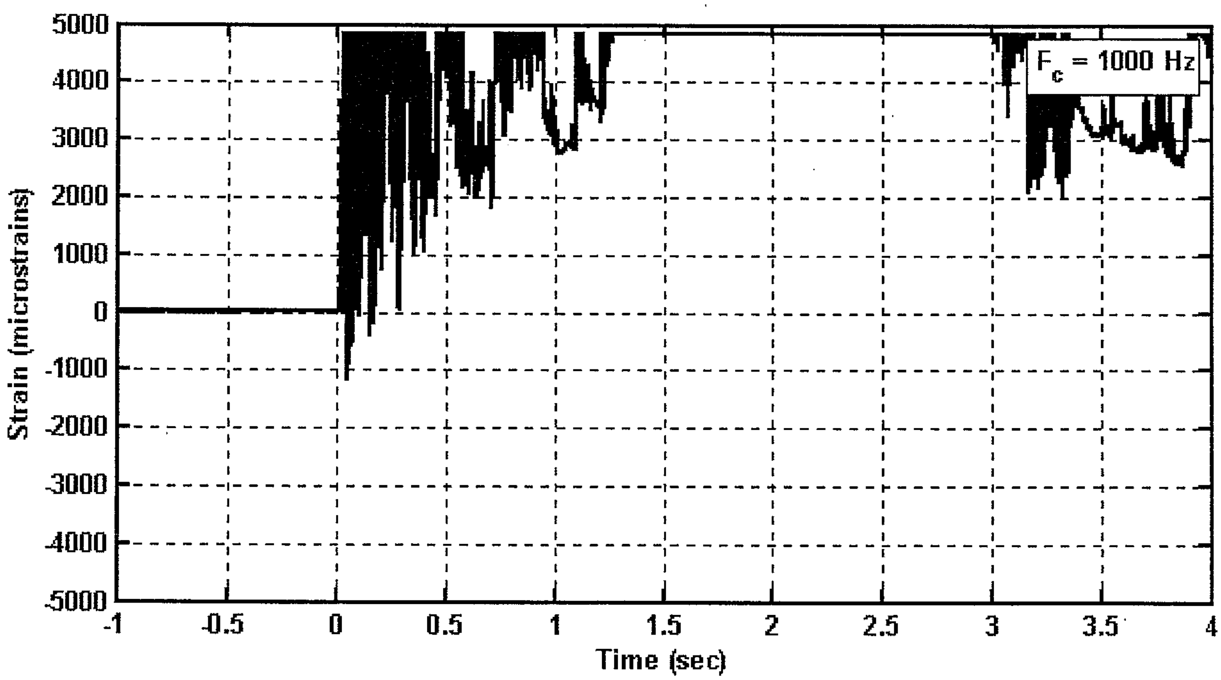

Figure F28. Target locomotive, main sill, position 2, left side upper, strain measurement
Channel Name: SL_MSL2U

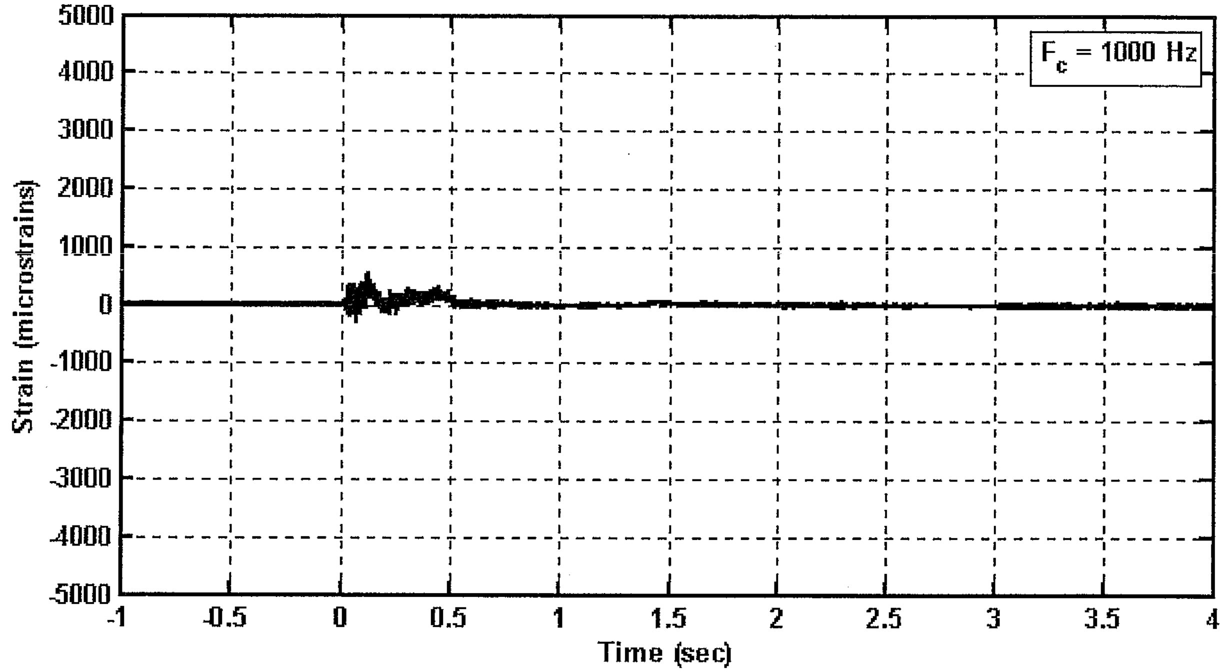

Figure F29. Target locomotive, main sill, position 3, left side lower, strain measurement
Channel Name: SL_MSL3L

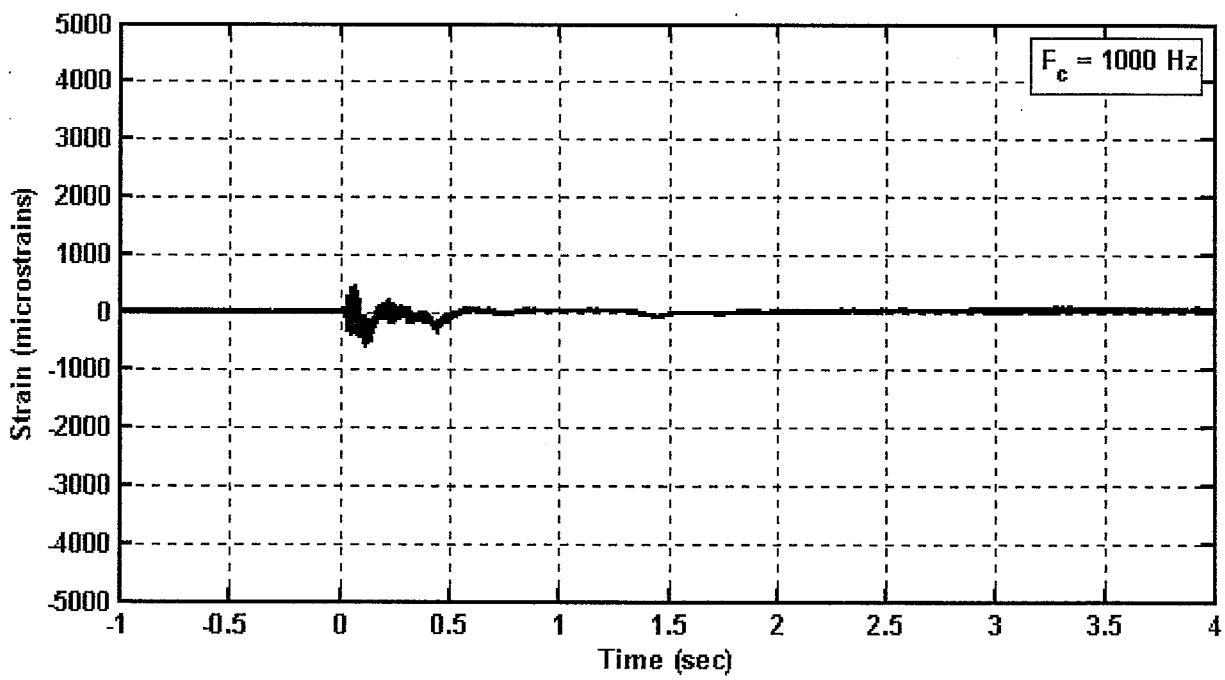

Figure F30. Target locomotive, main sill, position 3, left side upper, strain measurement
Channel Name: SL_MSL3U

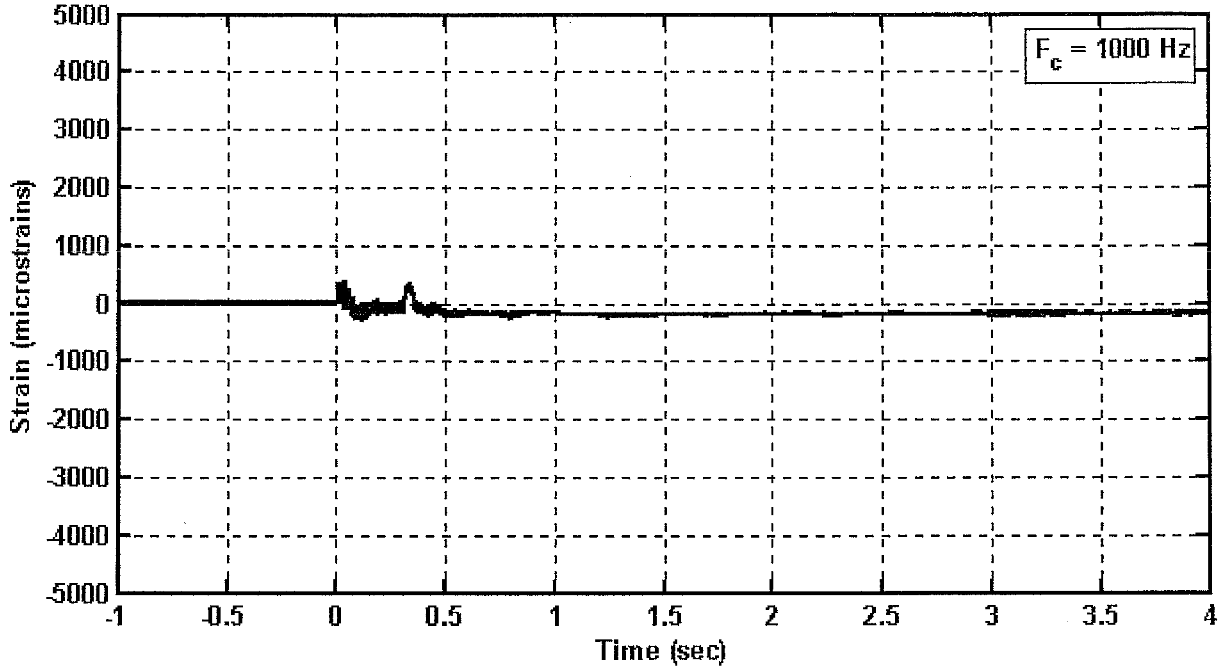

Figure F31. Target locomotive, main sill, position 1, right side lower, strain measurement
Channel Name: SL_MSR1L

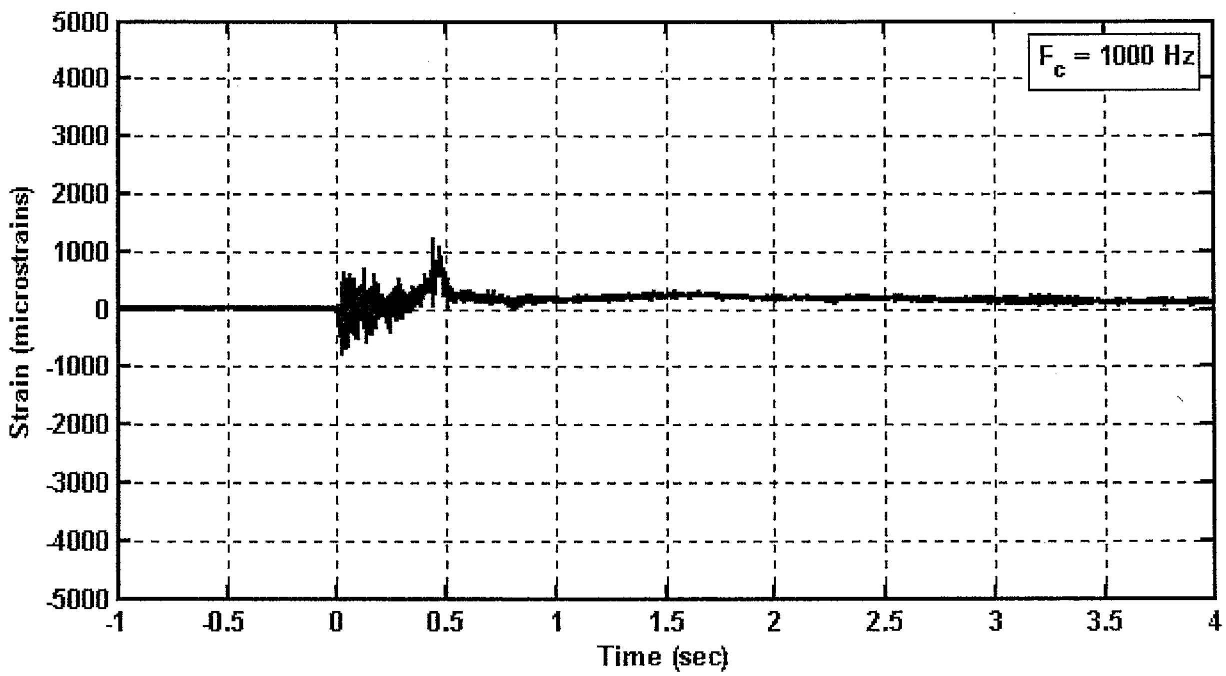

Figure F32. Target locomotive, main sill, position 1, right side upper, strain measurement
Channel Name: SL_MSR1U

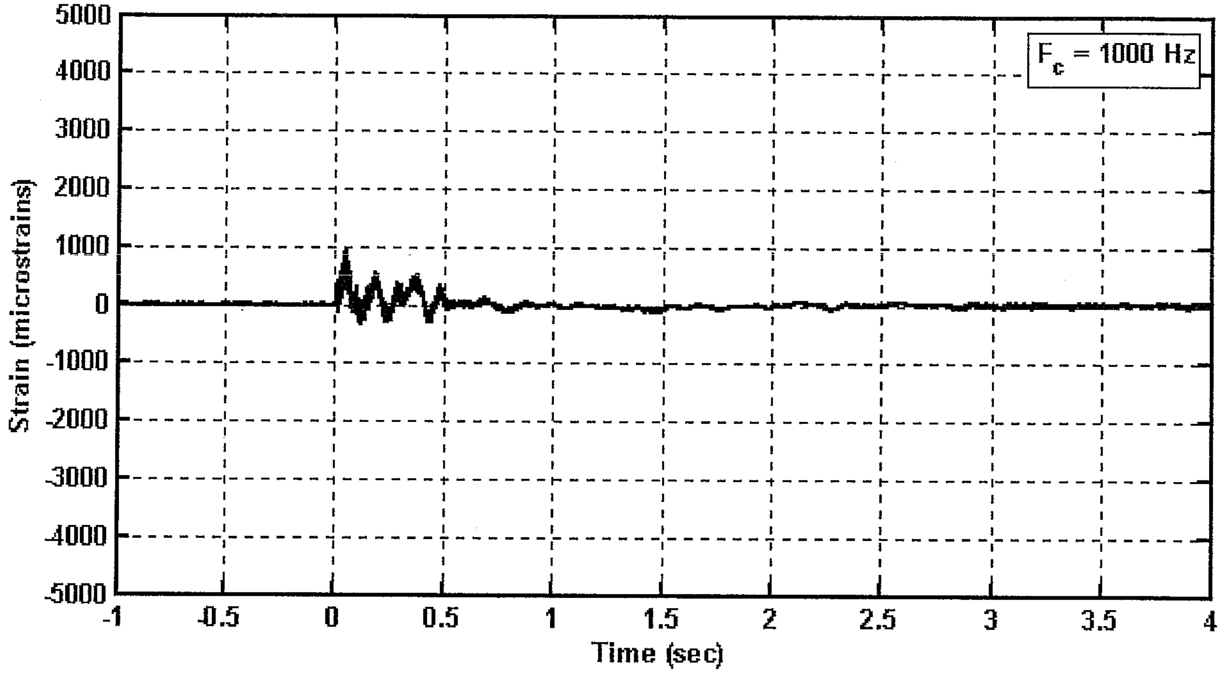

Figure F33. Target locomotive, main sill, position 2, right side lower, strain measurement
Channel Name: SL_MSR2L

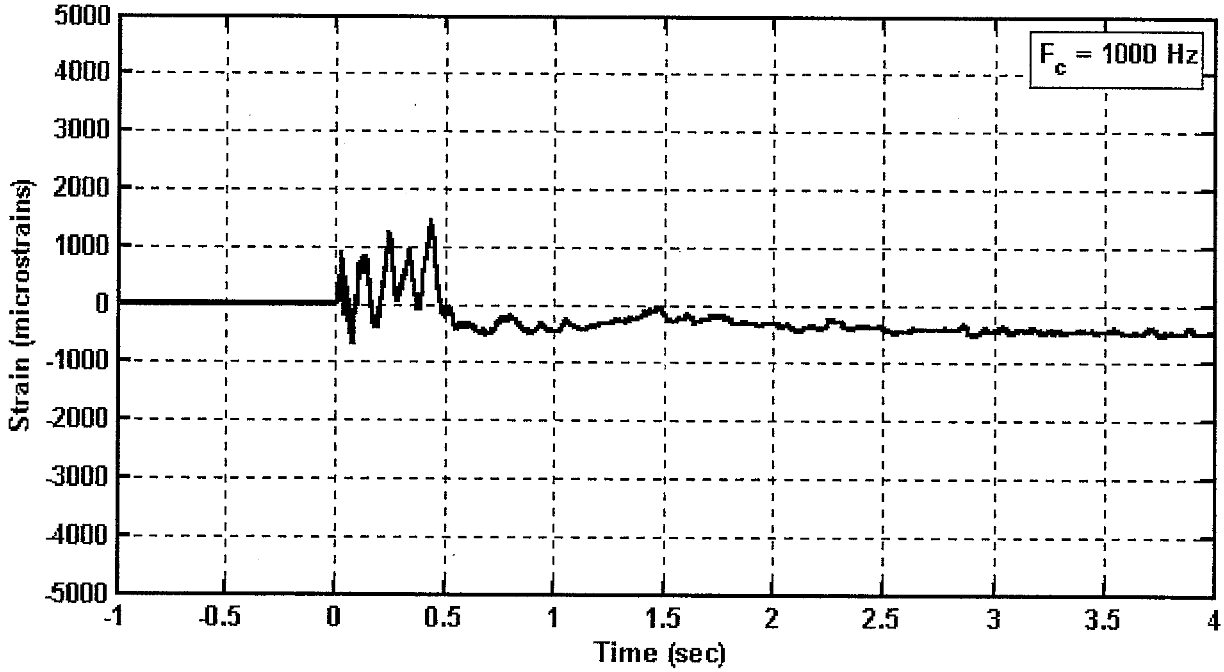

Figure F34. Target locomotive, main sill, position 2, right side upper, strain measurement
Channel Name: SL_MSR2U

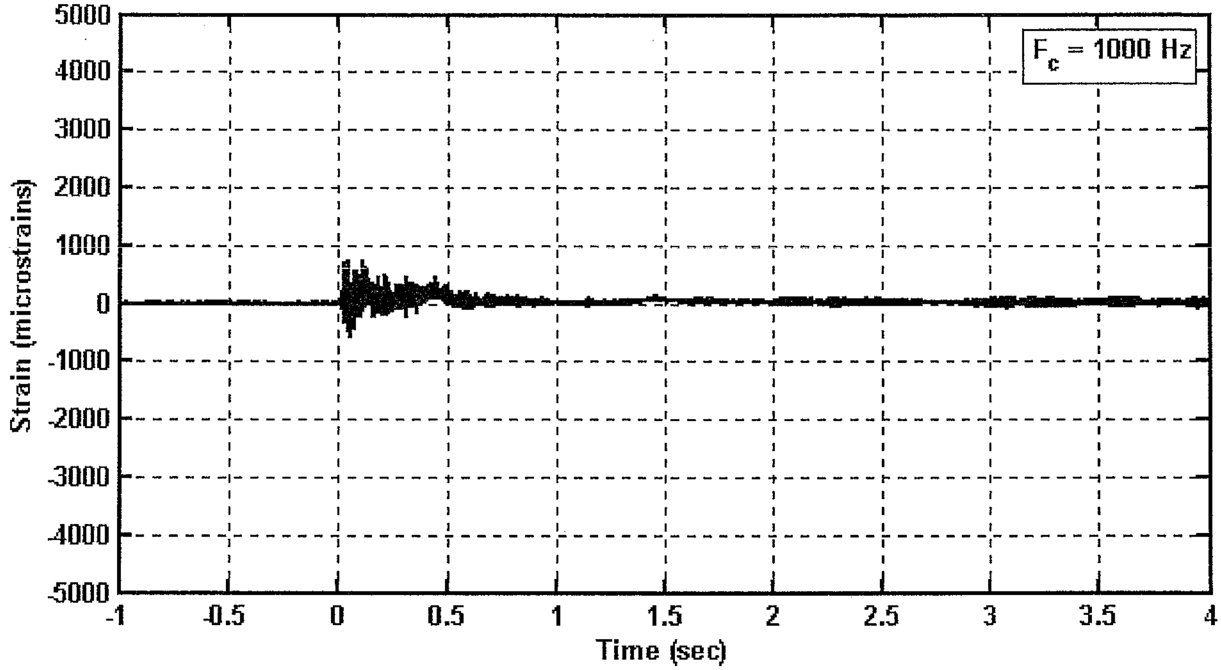

Figure F35. Target locomotive, main sill, position 3, right side lower, strain measurement
Channel Name: SL_MSR3L

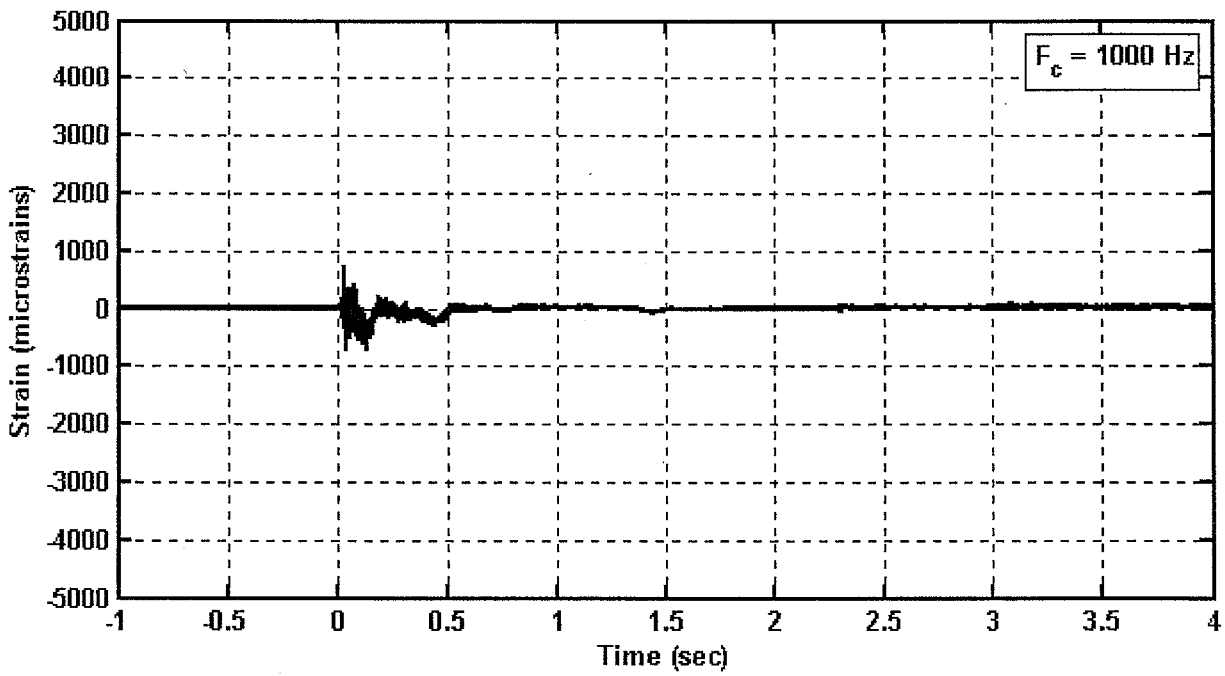

Figure F36. Target locomotive, main sill, position 3, right side upper, strain measurement
Channel Name: SL_MSR3U

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APPENDIX G

Velocity Data

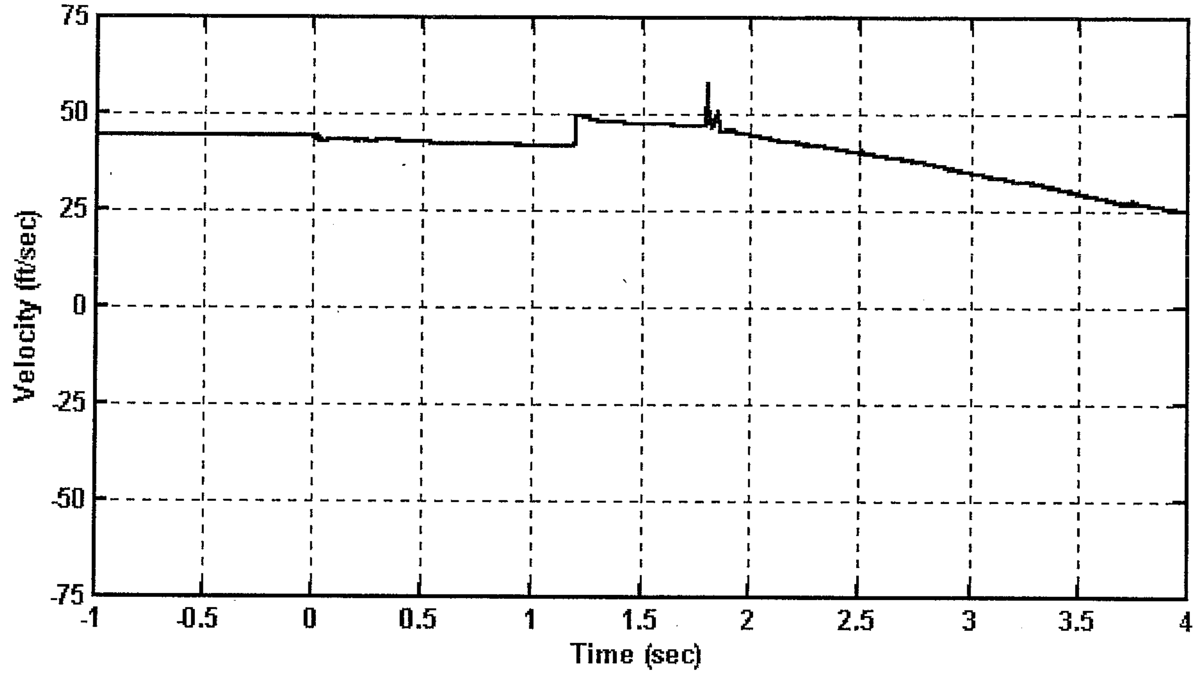

Figure G1. Bullet car 1, position 2, center sill, longitudinal velocity
Channel Name: B1_C2X_Vel

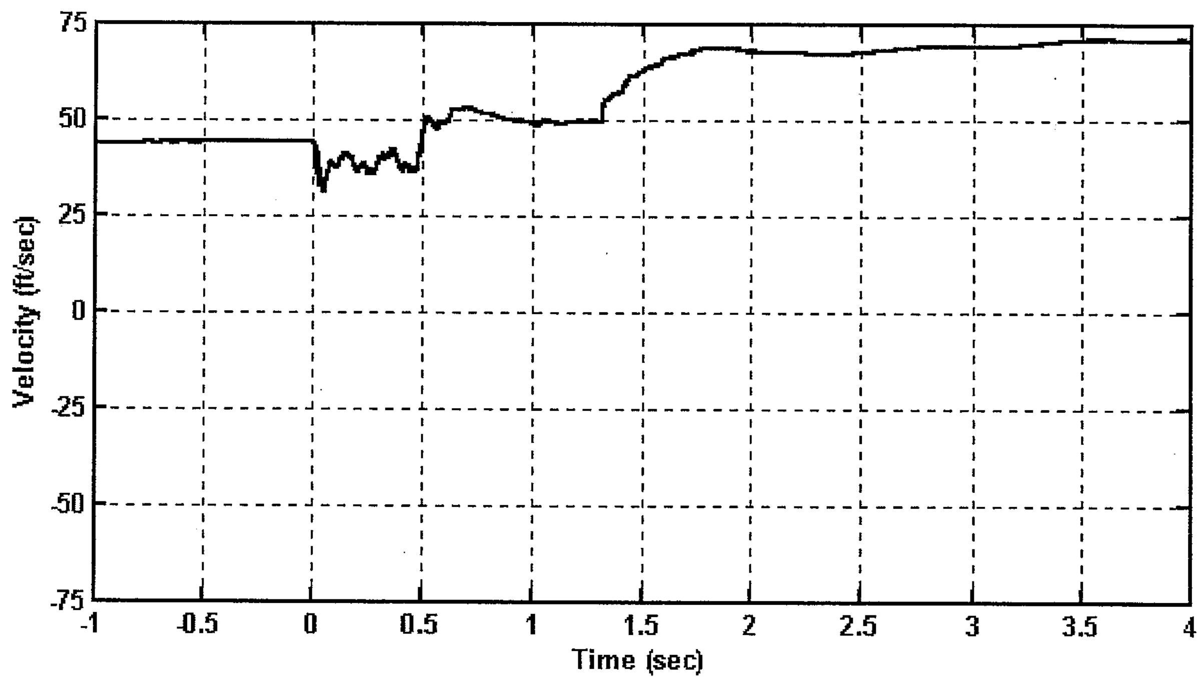

Figure G2. Bullet car 1, position 3, center sill, longitudinal velocity
Channel Name: B1_C3X_Vel

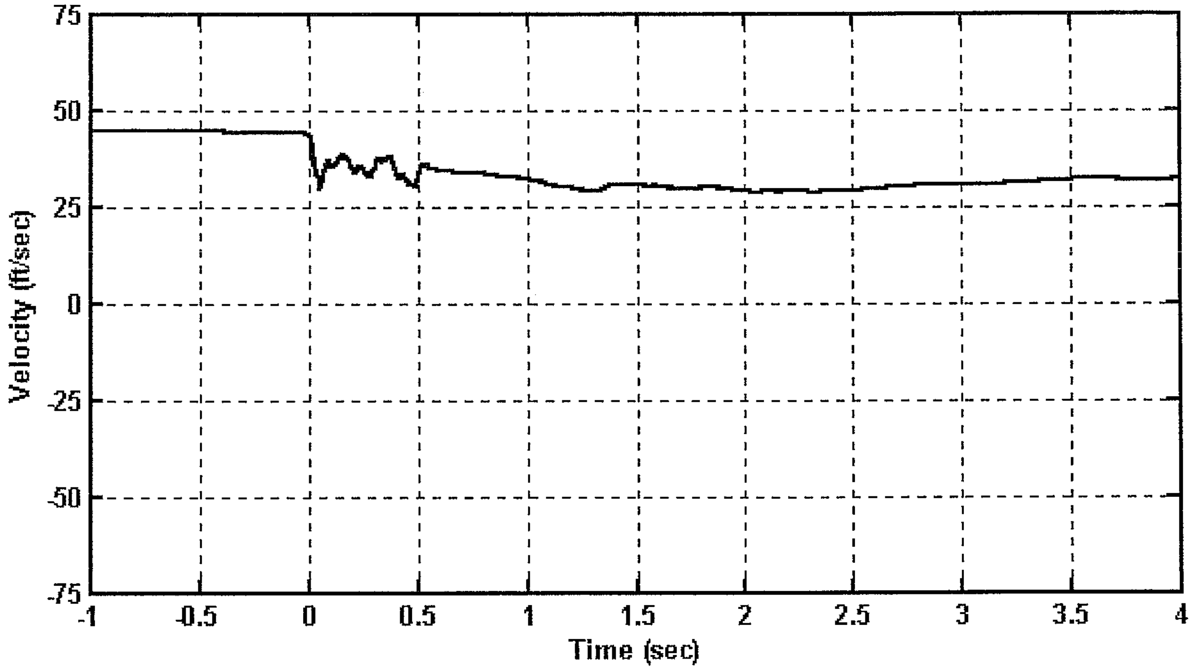

Figure G3. Bullet car 1, position 4, center sill, longitudinal velocity
Channel Name: B1_C4X_Vel

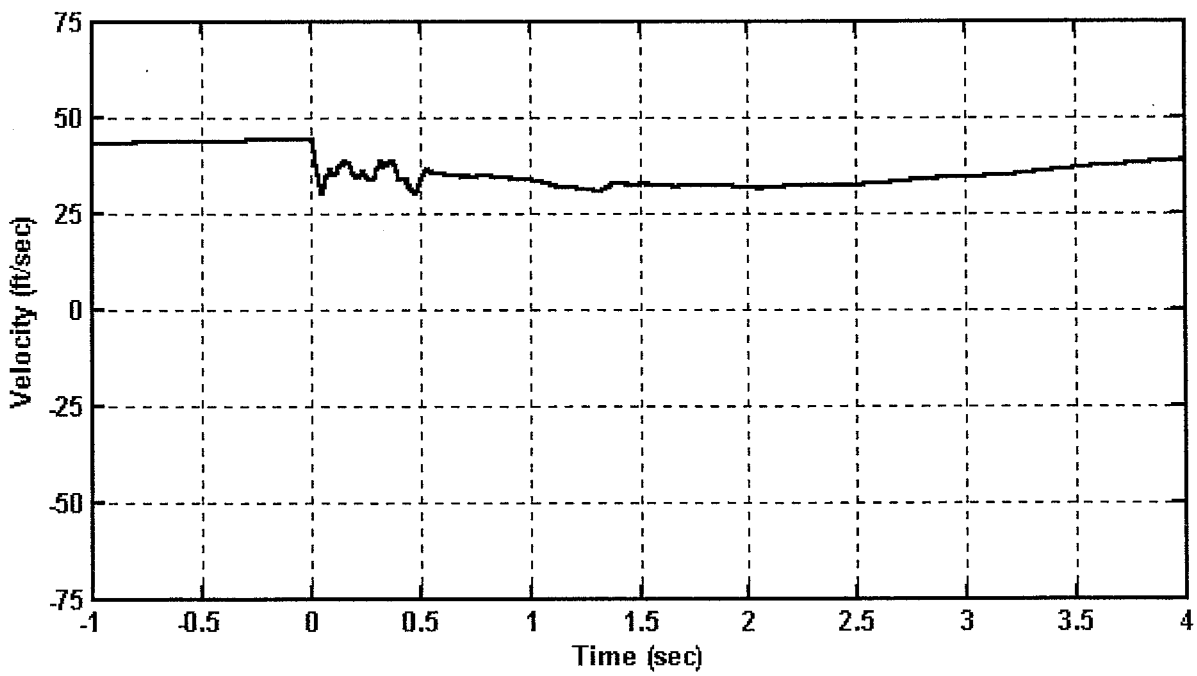

Figure G4. Bullet car 1, position 5, center sill, longitudinal velocity
Channel Name: B1_C5X_Vel

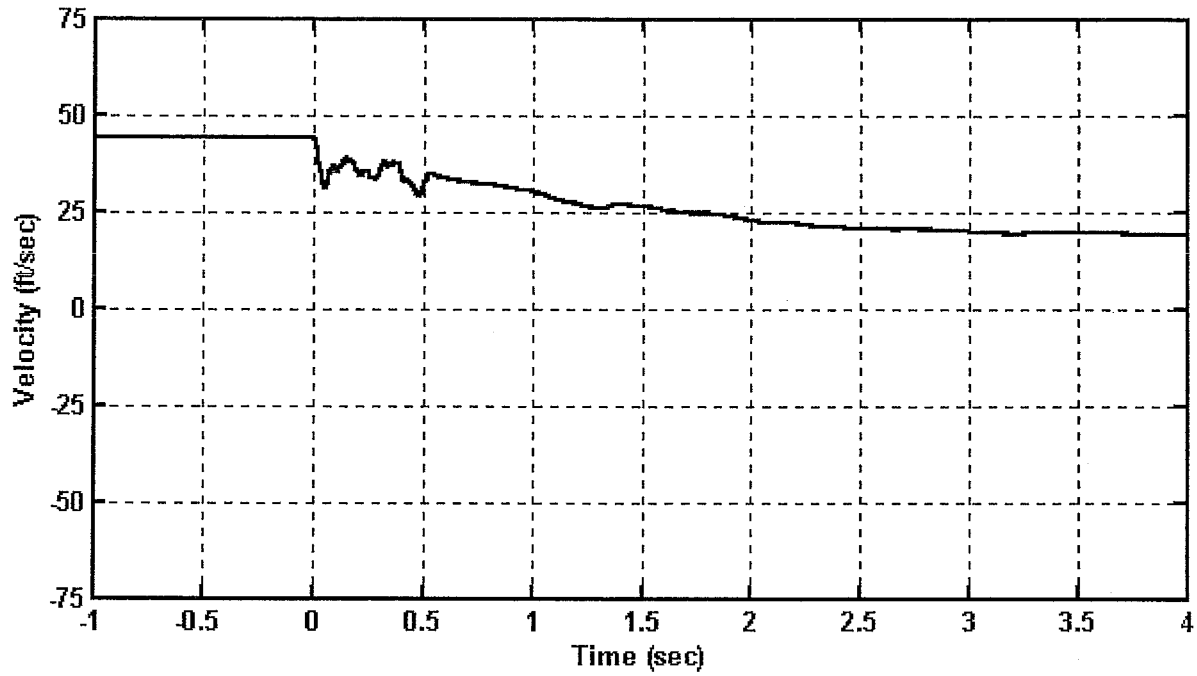

Figure G5. Bullet car 1, position 6, center sill, longitudinal velocity
Channel Name: B1_C6X_Vel

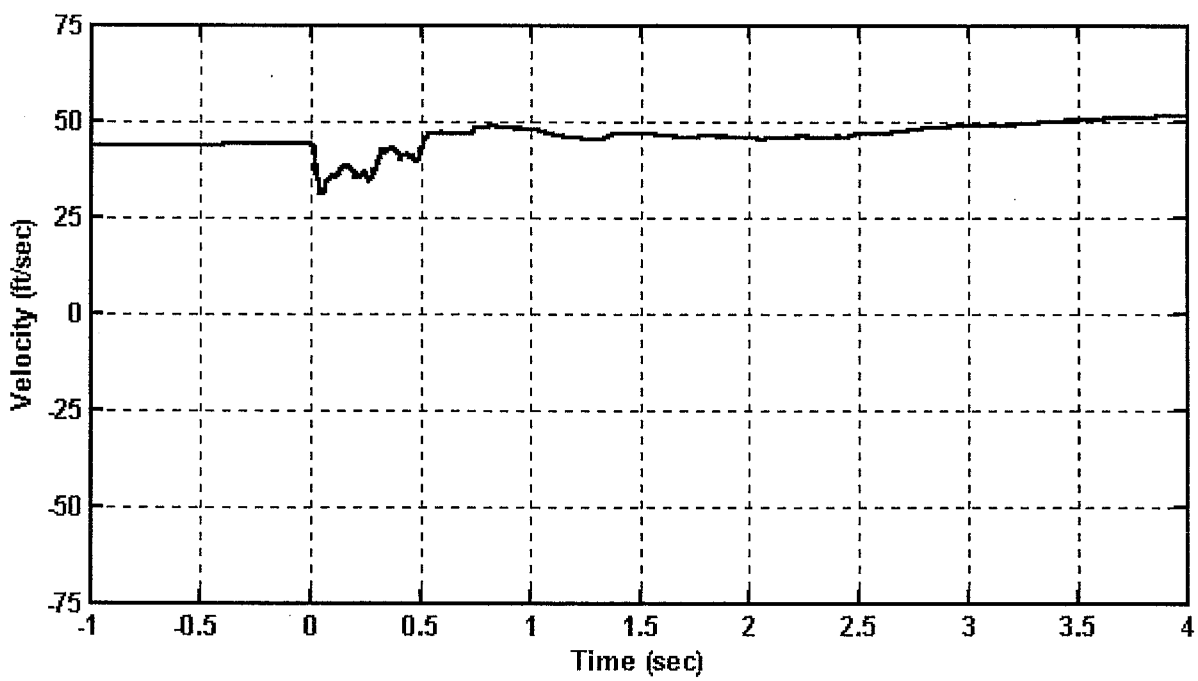

Figure G6. Bullet car 1, position 7, center sill, longitudinal velocity
Channel Name: B1_C7X_Vel

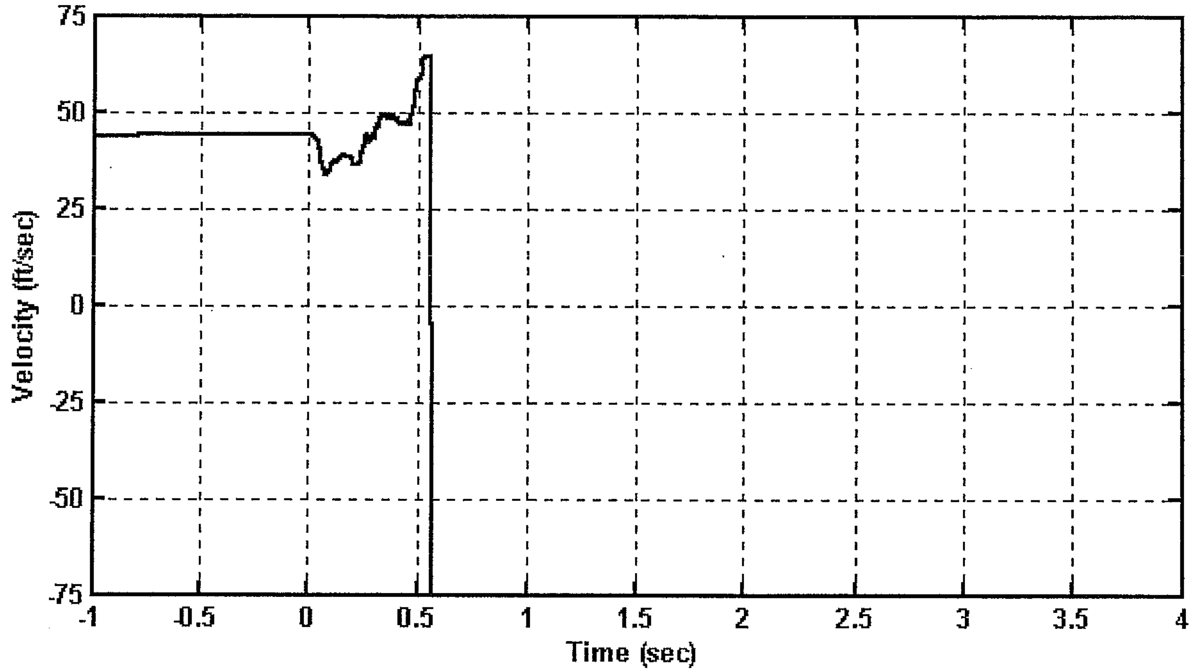

Figure G7. Bullet car 2, position 1, center sill, longitudinal velocity
Channel Name: B2_C1X_Vel

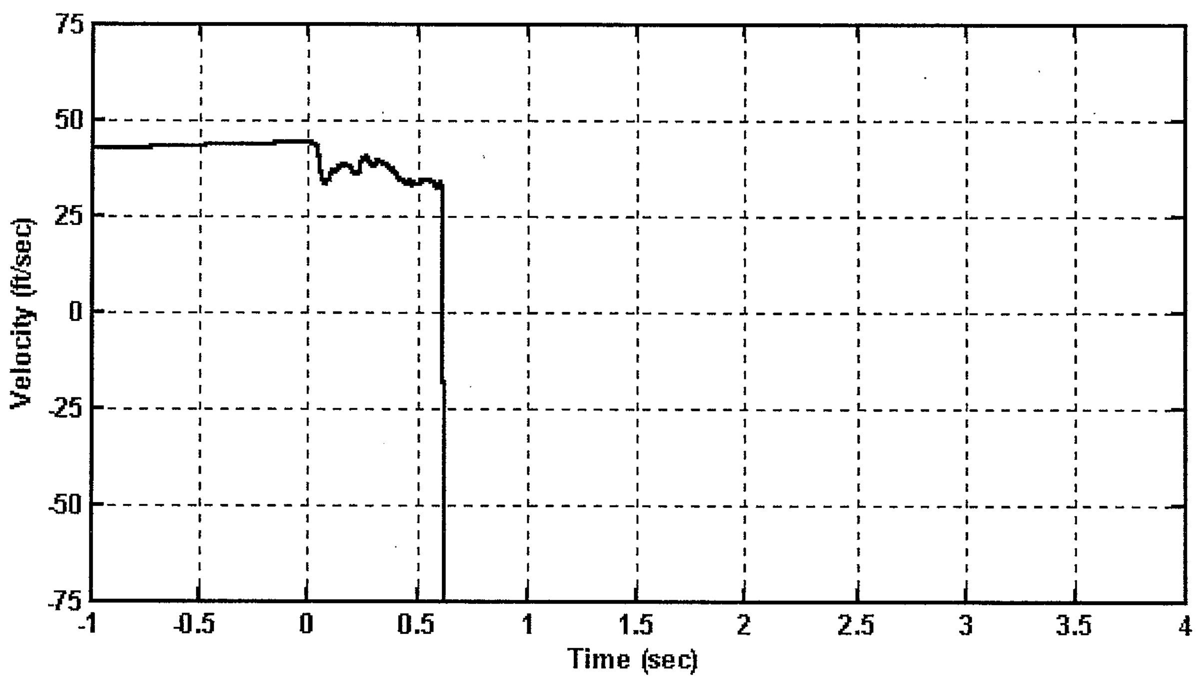

Figure G8. Bullet car 2, position 2, center sill, longitudinal velocity
Channel Name: B2_C2X_Vel

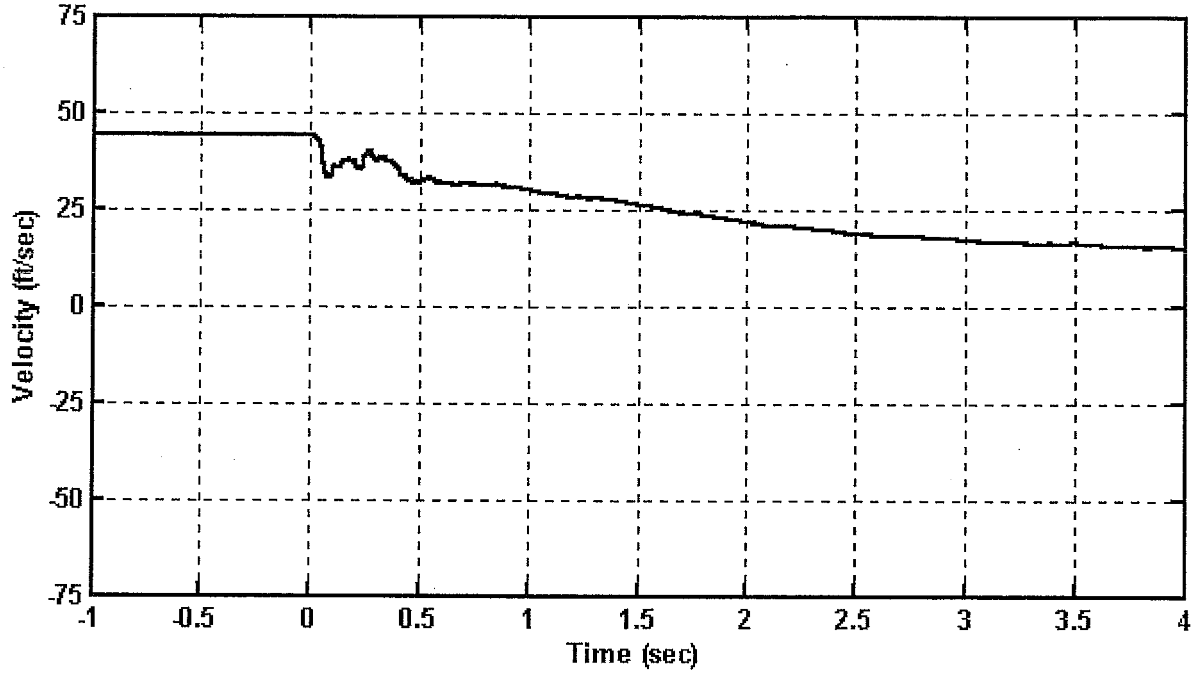

Figure G9. Bullet car 2, position 3, center sill, longitudinal velocity
Channel Name: B2_C3X_Vel

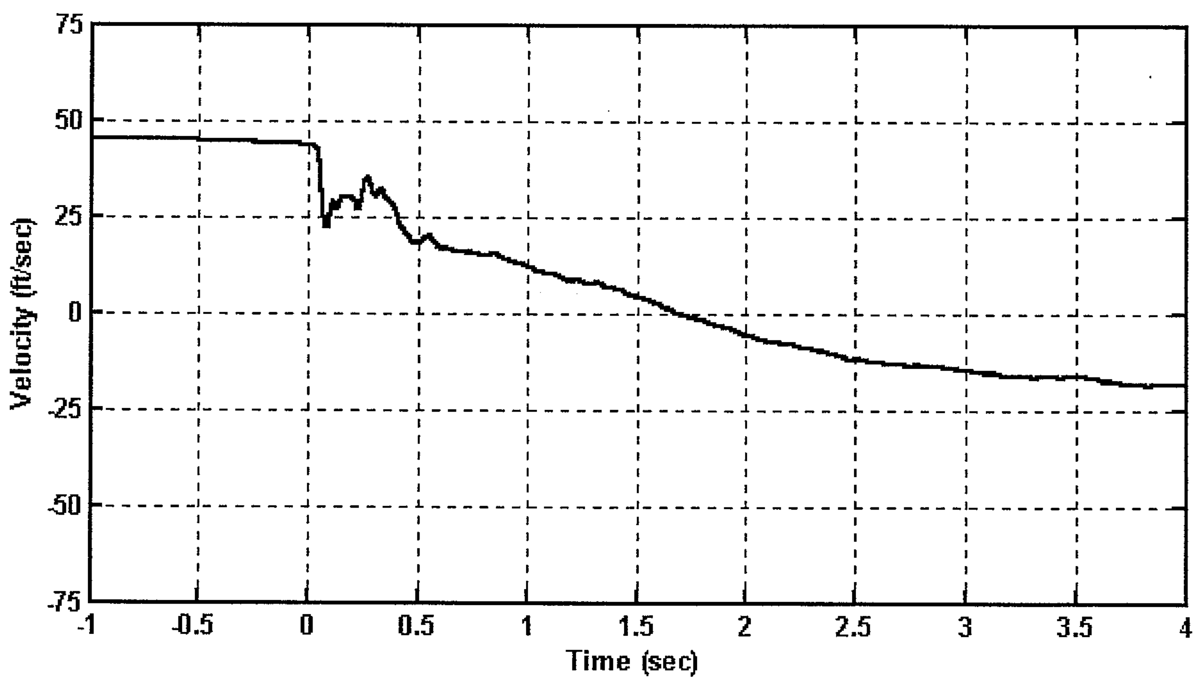

Figure G10. Bullet car 2, position 4, center sill, longitudinal velocity
Channel Name: B2_C4X_Vel

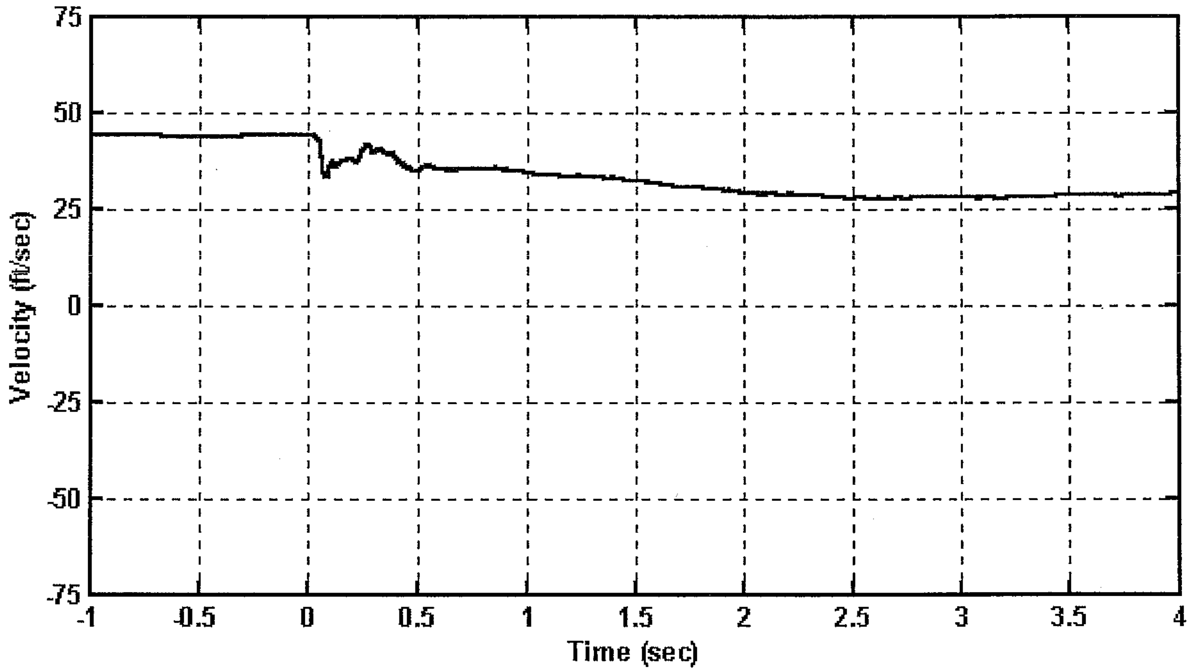

Figure G11. Bullet car 2, position 5, center sill, longitudinal velocity
Channel Name: B2_C5X_Vel

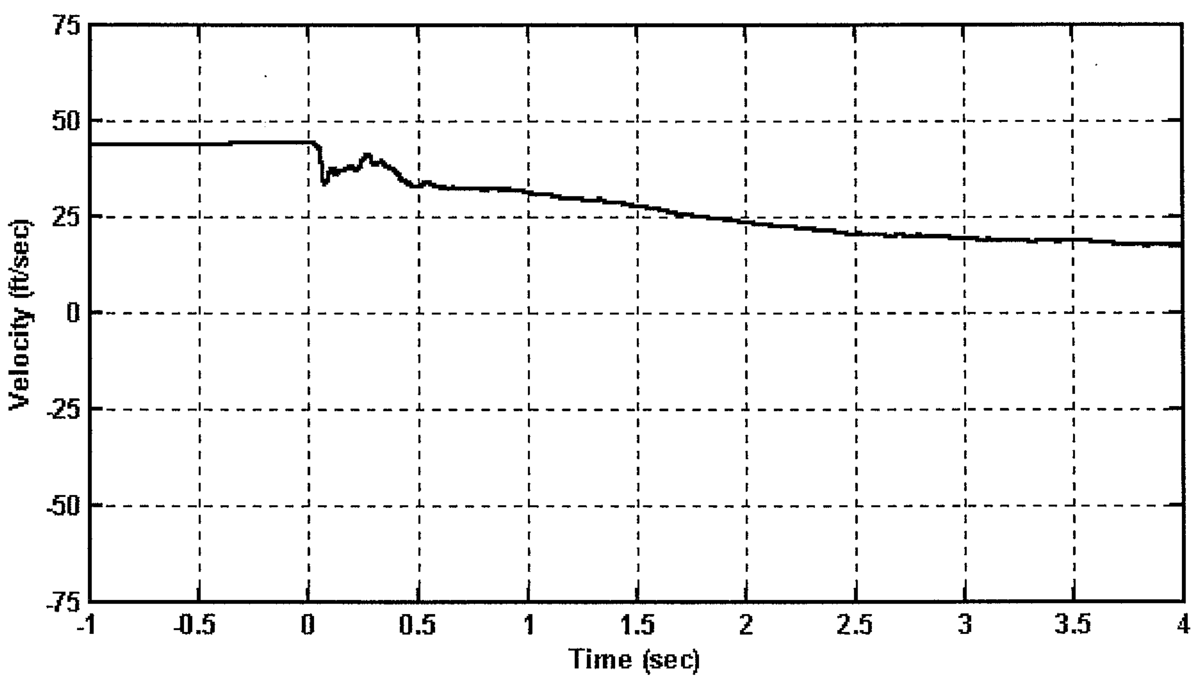

Figure G12. Bullet car 2, position 6, center sill, longitudinal velocity
Channel Name: B2_C6X_Vel

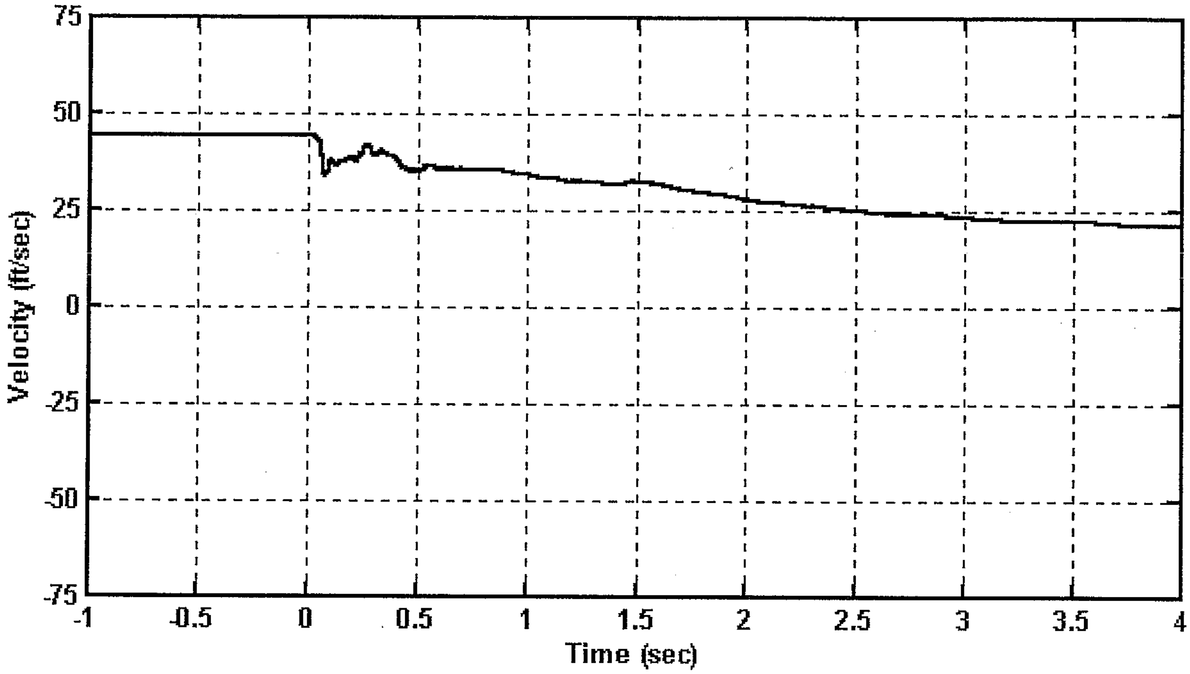

Figure G13. Bullet car 2, position 7, center sill, longitudinal velocity
Channel Name: B2_C7X_Vel

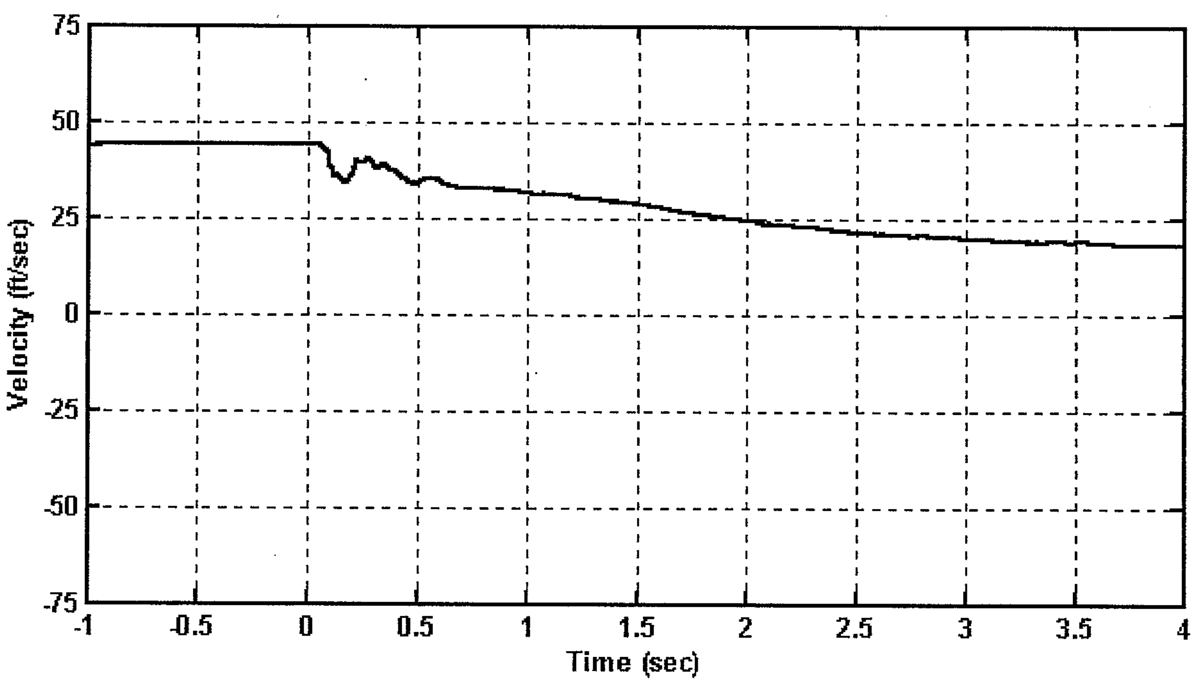

Figure G14. Bullet car 3, position 1, center sill, longitudinal velocity
Channel Name: B3_C1X_Vel

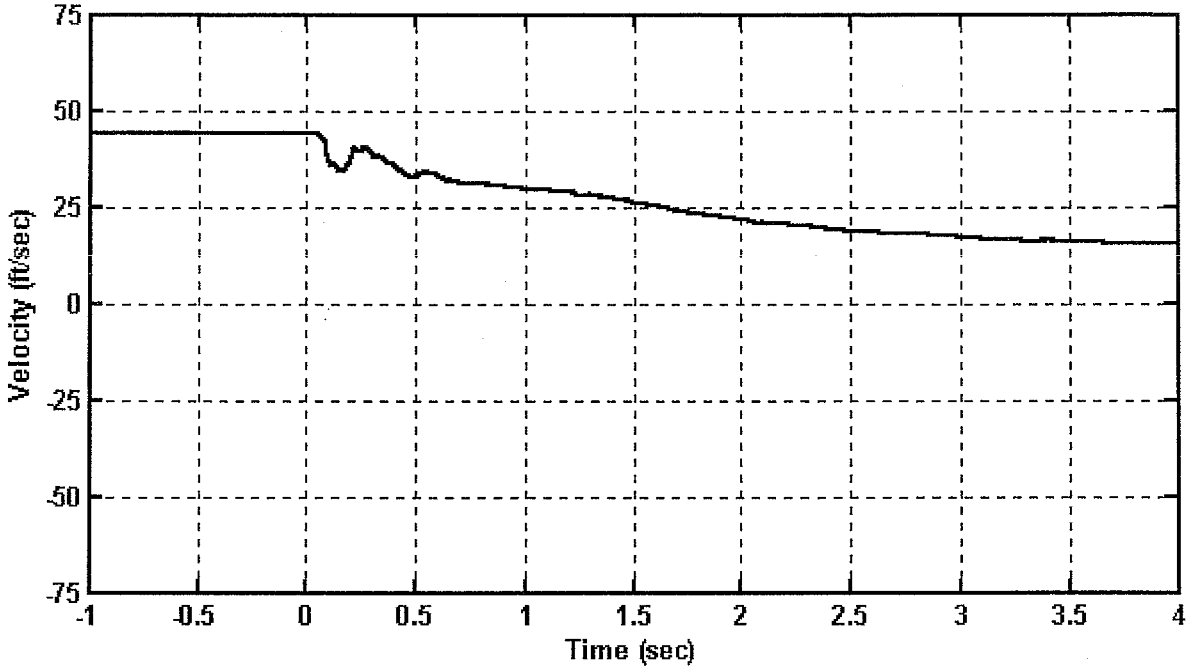

Figure G15. Bullet car 3, position 2, center sill, longitudinal velocity
Channel Name: B3_C2X_Vel

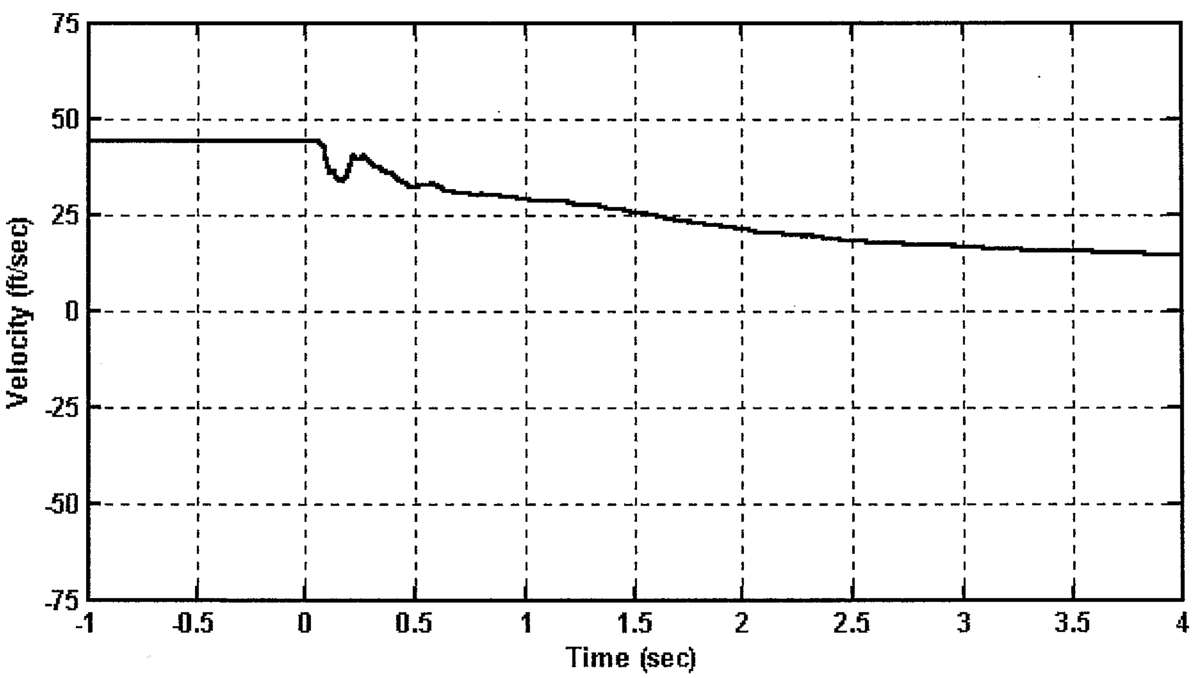

Figure G16. Bullet car 3, position 3, center sill, longitudinal velocity
Channel Name: B3_C3X_Vel

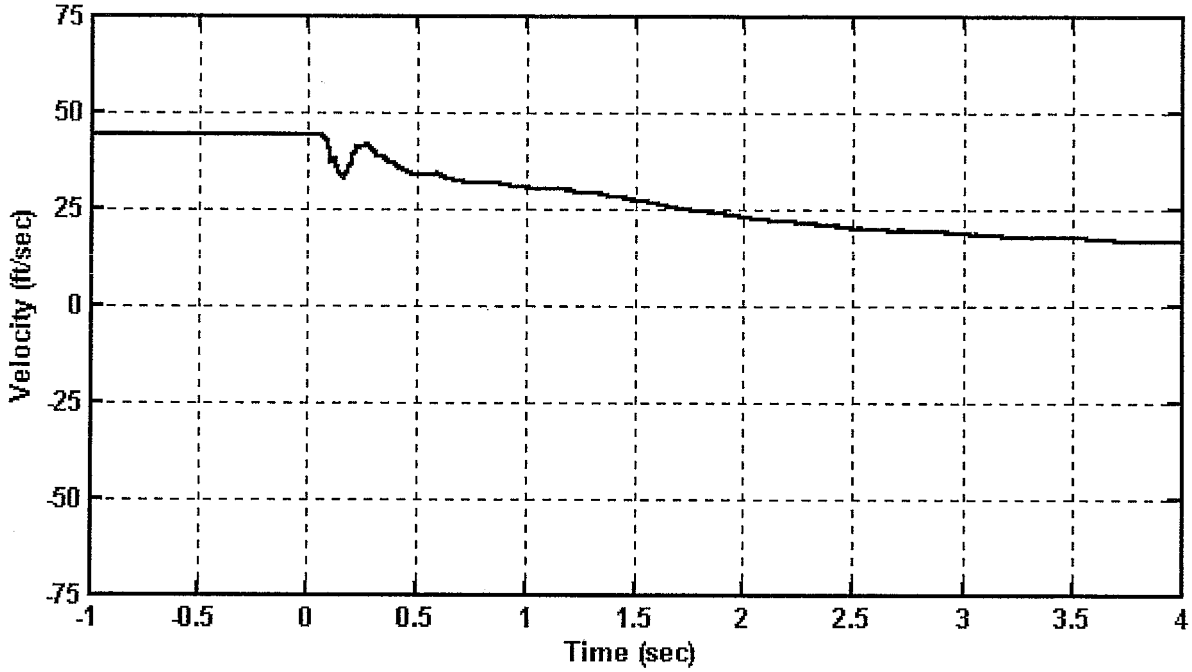

Figure G17. Bullet car 3, position 4, center sill, longitudinal velocity
Channel Name: B3_C4X_Vel

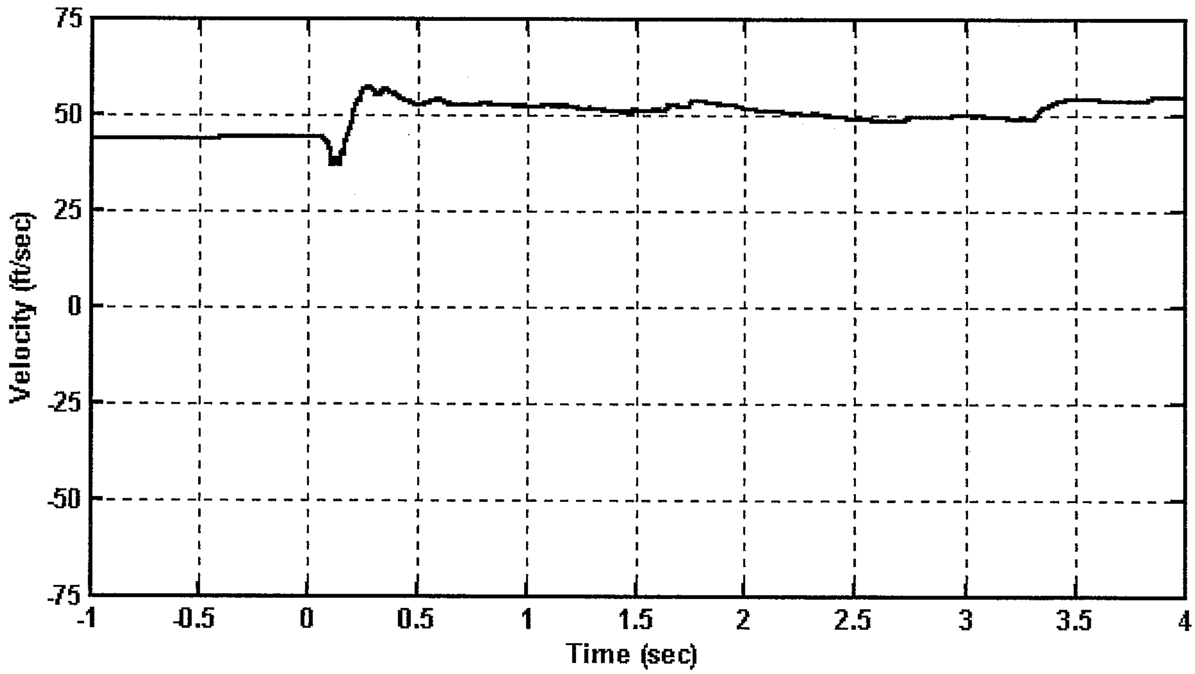

Figure G18. Bullet car 3, position 5, center sill, longitudinal velocity
Channel Name: B3_C5X_Vel

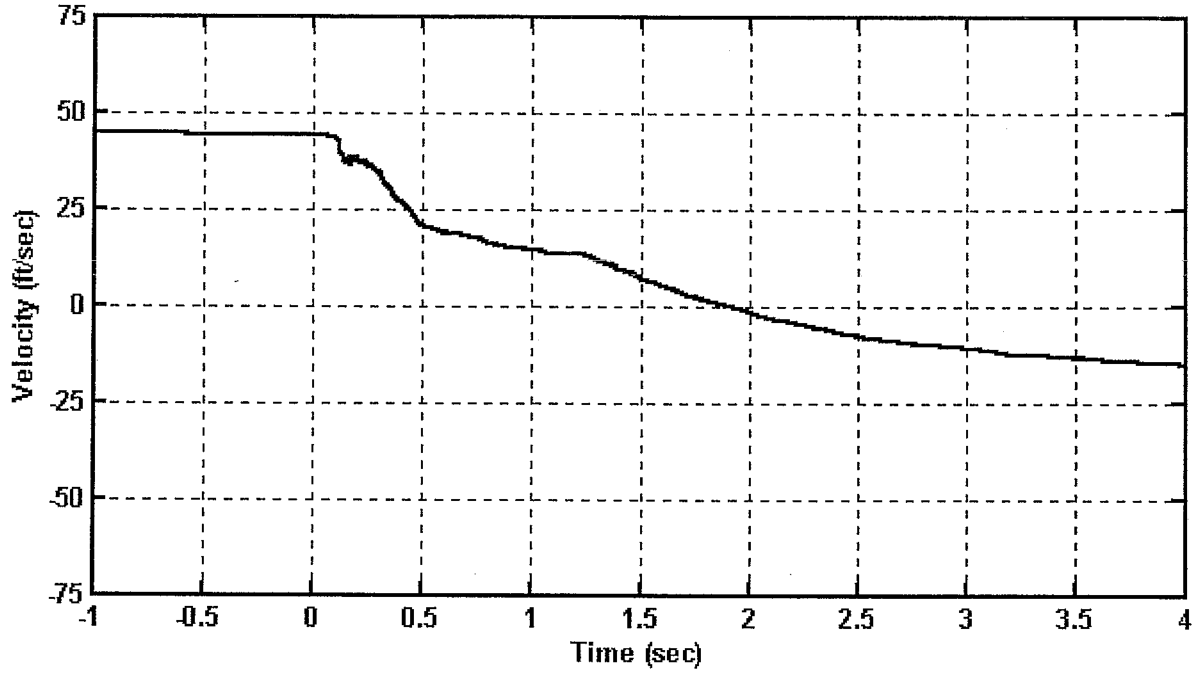

Figure G19. Bullet car 4, position 1, center sill, longitudinal velocity
Channel Name: B4_C1X_Vel

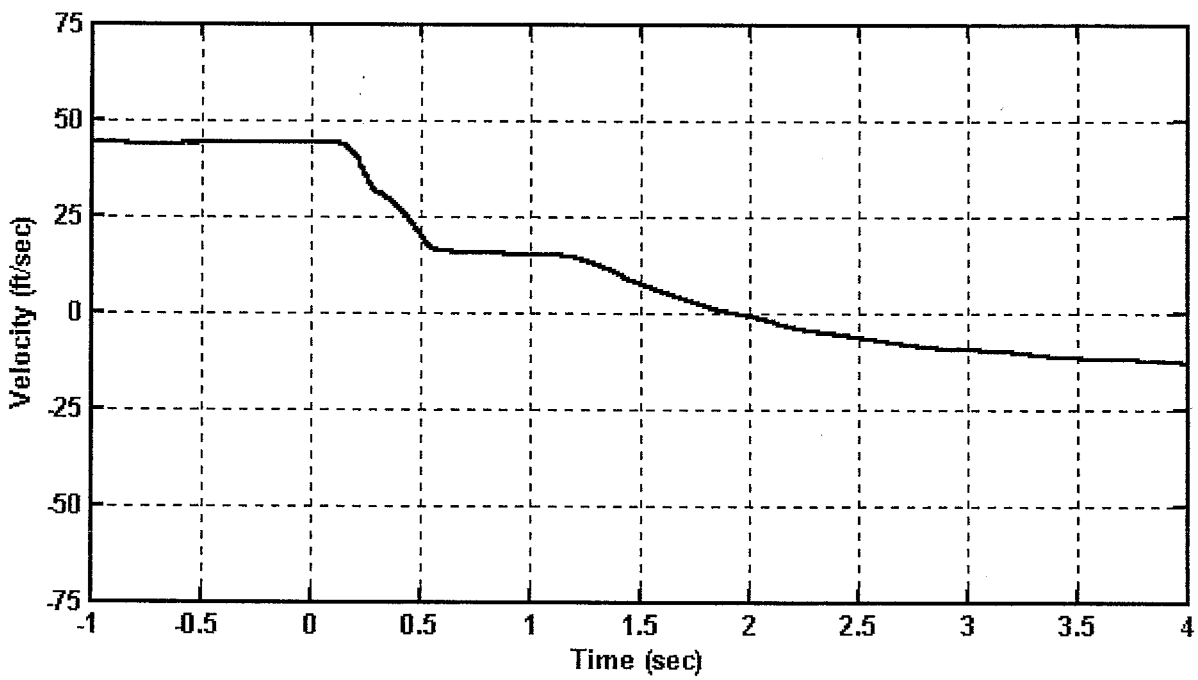

Figure G20. Bullet locomotive, position 1, center sill, longitudinal velocity
Channel Name: BL_C1X_Vel

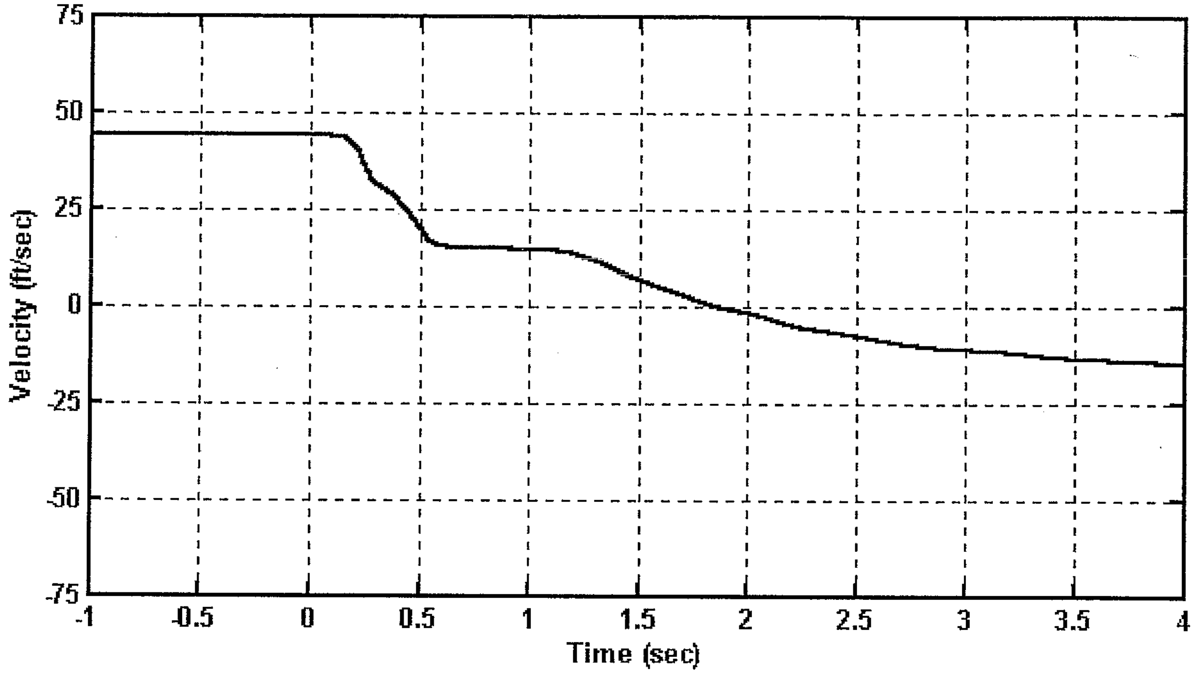

Figure G21. Bullet locomotive, position 2, center sill, longitudinal velocity
Channel Name: BL_C2X_Vel

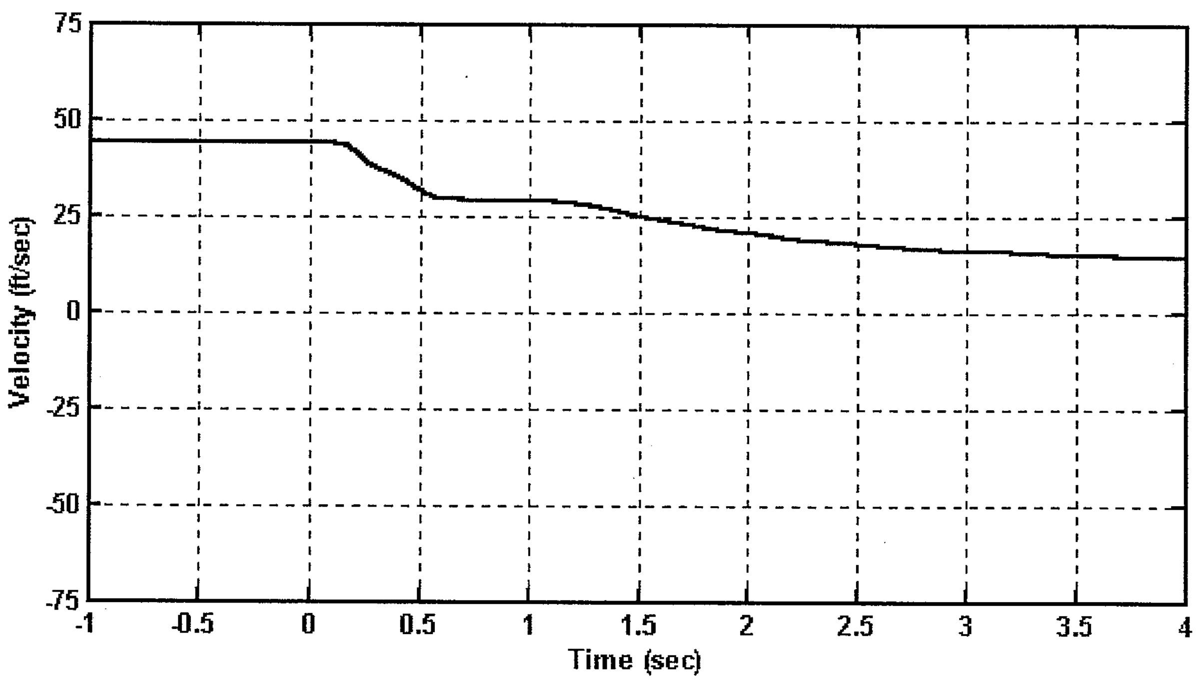

Figure G22. Bullet locomotive, position 3, center sill, longitudinal velocity
Channel Name: BL_C3X_Vel

APPENDIX H

Camera Set-up Sheets

High-Speed Film Camera Set Up

Location	Camera View	Camera Serial #	Frame Speed	Lens (mm)	Lens Serial #	F-stop
F1	Westside-Overall	Milliken 7332-1	300	16	570	4.5
F2	Overhead-Impact	Milliken 6893	500	10	050	4.0
F3	Eastside – Overall	Milliken 6970	300	25	894154	4.5
F4	Eastside	Milliken 7169	300	25	6821	4.5
F5	Eastside	Milliken 7341	300	25	882012	4.5
F6	Eastside	Milliken 7486	300	25	14512	4.5
F7	Eastside	Milliken 7348	300	12	pen.-tv	4.5
F8	Overhead-Rear	Milliken 7410	300	25	-	4.5
F9	Eastside-Panning	Milliken 6967-1	120	25	048	8.0
F10	Eastside-Close-up	Locam 1280	500	50	3853	4.0

High Speed Film Camera Set-up

Location	Camera View	Camera Type	Camera Serial #	Frame Rate	Lens (mm)
V1	Overhead-Impact	Hi-8	240	30	3.6
V2	Overhead-Rear View	Hi-8	026	30	3.6
V3	Overhead-Front View	Hi-8	248	30	3.6
V4	Southeast-Angle View	Hi-8	044	30	3.6
V5	Eastside-Overall View	8mm	868	30	w/a lens
V6	Eastside-Panning	S-VHS	259	30	8
V7	Northeast-Angle View	3ccd-dig.	455	30	4.2
V8	Overhead-Rear View	Hi-8	321	30	3.6
V9	Northwest-Angle View	VHS	223	30	12
V10	Westside-View	Dig.8	759	30	3.7
V11	Westside-Panning	DV	-	30	-
V12	Westside-Panning HS	DV	167	120	5.0
V13	Westside-Overall View	Hi-8	701	30	w/a lens
V14	Westside-View	Dig.8	690	30	3.7
V15	Southwest-Angle View	Hi-8	857	30	3.6