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16. Abstract

A full-scale impact test was performed November 16, 1999, at the Federal Railroad Administration's Transportation Technology Center, Pueblo, Colorado, by Transportation Technology Center, Inc., a subsidiary of the Association of American Railroads. The test was performed on a Budd Company Pioneer-type commuter passenger car. The purpose of the test was to measure strains, accelerations and displacements during the impact and validate the computational and kinematic models of the vehicle impacting a rigid barrier.

Other test objectives were to determine the crash-force pulse shape throughout the vehicle and to provide a greater understanding of occupant kinematics in crash situations. Simula Technologies Inc. provided the occupant kinematics experiments which included a number of instrumented Anthropomorphic Test Devices in different seat configurations.

This report describes the test car and the methodology used to carry out the impact test, together with a description of all the instrumentation used to measure the structural deformation of the car during the impact.

The impact was recorded by a number of high speed film and video cameras. The report contains a description of the cameras used, their position. and the subsequent film analysis carried out to measure the displacement and velocity of the test car during the impact.

The strain, acceleration, velocity and displacement time histories from all the transducers are presented in the report.

The speed of the test car at impact with the rigid barrier was 35.1 mph and the amount of crush was about 4.5 feet.

17. Key Words Impact Test, commuter rail passenger car, computational and Kinematic models, speed	**18. Distribution Statement** This document is available through National Technical Information Service Springfield, VA 22161

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Executive Summary

A full-scale impact test was performed November 16, 1999, at the Federal Railroad Administration's Transportation Technology Center, Pueblo, Colorado, by Transportation Technology Center, Inc., a subsidiary of the Association of American Railroads. The test was performed on a Budd Company Pioneer-type commuter passenger car. The purpose of the test was to measure strains, accelerations, and displacements during the impact so that computational and kinematic models of the vehicle impacting a rigid barrier can be validated.

Other test objectives were to determine the crash-force pulse shape throughout the vehicle and to provide a greater understanding of occupant kinematics in crash situations.

The measurements taken before, during and after impact indicate that:

- The speed of the test car at impact with the barrier was 35.1 mph. This was within 0.3 percent of the target speed of 35 mph.
- The amount of crush was about 4.5 feet as measured from the reduction in length of the vehicle after the test. The film analysis showed the maximum displacement in the longitudinal direction of 5.5 feet. The accelerometer data, double integrated, shows a maximum displacement of about 5.5 feet. (Both the film analysis and the integrated accelerometer data include elastic deformation of the car body.) The test requirement was for at least 3 feet of crush.
- The data acquisition system comprised 12 Data Bricks each collecting 8 channels of data. One of the Data Bricks did not trigger, and the 8 strain gage channels feeding signals into this Data Brick were lost. All these strain gages were on the left hand side of the center sill. All other strain gages provided information.
- All the accelerometers provided some information. Two of the lateral and two of the vertical accelerometers saturated. The accelerometer at the front of the vehicle, Center Sill – Position 1, recorded a maximum longitudinal acceleration of 70 g, filtered to SAE CFC 60, before its cable failed at 0.1 s.

- A maximum vertical deflection of 3.5 inches was recorded on the A-end, right-hand side string potentiometer.
- All video and film cameras successfully recorded the impact of the test car from both sides, overhead, underneath, on board and a general view. The film was analyzed frame-by-frame, and the displacement and velocity calculated throughout the impact.

The test car was structurally complete, although the original seats were removed together with other under-floor auxiliary equipment. The interior of the car was modified with a number of prototype seats fitted in different configurations. Approximately 10,000 pounds of ballast was added to the car body. The coupler was left installed at the impact end.

The impact test was performed by pushing the test car with a locomotive, releasing it at a pre-determined point, and then letting it run down the inclined track and into the barrier. The release distance and the speed of the locomotive at release were calculated from a series of speed calibration tests carried out before the actual impact test.

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A full-scale impact test was performed using a Budd Company Pioneer-type commuter passenger car November 16, 1999, at the Federal Railroad Administration's Transportation Technology Center, Pueblo, Colorado. The impact test was conducted to measure strains, accelerations, and displacements during the impact to validate computational and kinematic models of the vehicle impacting a rigid barrier.

Additional objectives were to determine crash-force pulse shape throughout the vehicle and to gain greater understanding of occupant kinematics in crash situations.

This report describes the test procedure, the instrumentation used in the test, and a complete set of results.

2.0 DESCRIPTION OF TEST CAR

A Budd Company Pioneer-type commuter passenger car (Figure 1), donated by Southeastern Pennsylvania Transportation Authority (SEPTA), was used in the impact. The car body was structurally complete. The original seats were removed together with other underfloor and auxilary equipment. The interior of the car was modified with a number of prototype seats fitted in different configurations. To compensate for the weight removed, approximately 10,000 pounds of concrete was added to the car body, mostly under the floor in the center of the car. Both couplers were left installed.

Figure 1. Test Car

The trucks fitted to the test car were not equipped with motors. The secondary air suspension was pumped up to its normal inflated height before impact.

The brakes were primed to release if the brake pipe was cut on impact. A cutter device was fitted to the front of the car to ensure that the brake pipe was cut on impact. An orifice was installed in the pipe to delay brake action. This was done so that the car would hit the barrier, roll back, and stop, and not roll forward into the barrier again.

3.0 TEST METHODOLOGY

The test was performed by Transportation Technology Center, Inc. to procedures outlined in the "Test Implementation Plan (TIP) for Single Car Dynamic Crush Test," November 16, 1999, which is included as Appendix A.

The inclined tangent track leading to the impact barrier has a constant gradient of 0.86 percent and is parallel to the Precision Test Track (PTT), which has exactly the same gradient. The barrier itself is constructed of re-inforced concrete and steel and has an estimated weight of 1,350 tons. It is capable of withstanding an impact force of 3,000,000 pounds (13.4M N). The front face of the barrier is 2-feet thick reinforced concrete faced with a 3-inch thick steel plate . A schematic of the impact barrier is shown in Figure 2a and a front view of the barrier is shown in Figure 2b.

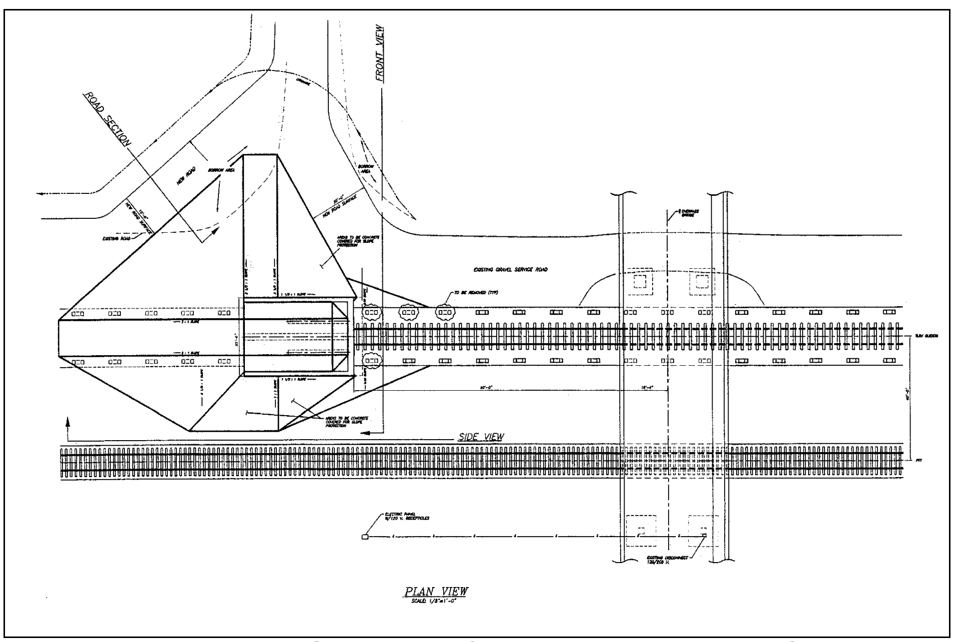


Figure 2a. Schematic of Impact Barrier at the TTC

Figure 2b. Impact barrier at the TTC

The impact test was performed by pushing the test car with a locomotive, releasing it at a pre-determined point, and then letting it run down the inclined track and into the barrier. The release distance, and the speed of the locomotive at release, was calculated from a series of speed calibration tests carried out on the PTT track and on the track leading to the barrier. The target for the impact speed at the wall was 35 mph.

4.0 RESULTS

4.1 MEASUREMENTS TAKEN BEFORE TEST

4.1.1 Longitudinal and Vertical Distances (A-end = Impact End)

- Length of car from buffer beam to buffer beam = 84 .5 ft
- Longitudinal distance from buff stop to body bolster , A-end = 6.76 ft
- Longitudinal distance from buff stop to body bolster , B-end = 6.72 ft
- Longitudinal distance between body bolsters = 57.17 ft
- Vertical distance between mid point of car (center sill) and a line extending between body bolsters = 10.34 in.
- Vertical distance between buffer beam and a line extending between body bolsters, A-end = 17.63 in.
- Vertical distance between buffer beam and a line extending between body bolsters, B-end = 15.44 in.

Appendix B contains the complete longitudinal and vertical distances measured before and after the impact test.

4.1.2 Weight of Test Car

The test car was weighed just prior to the impact test using the TTC computerized scale. The test car was uncoupled from the locomotive for these measurements and each truck in turn moved onto the weigh bridge. Total weight included the weight of the car body, trucks, added weight, anthropomorphic dummies, seats, and all instrumentation.

Weight of A-end	= 33,585 lb
Weight of B-end	= 40,704 lb
Total weight	= 74,289 lb

(The accuracy of the weigh bridge is + or – 50 lb; therefore, the accuracy of the vehicle weight is + or – 100 lb)

4.1.3 Height of Center of Gravity of Car Body

A characterization test was carried out on the loaded car to provide an estimate of the height of the center of gravity of the car body (see Appendix C for a full description of techniques used for this test).

From these results, the height of the center of gravity of the car body is estimated to be between 69.7 and 76.7 inches from the top of the rail.

4.1.4 Weather Conditions

Weather conditions at test time:

- Temperature 76°F
- Wind speed 5 mph from the SE

4.2 MEASUREMENTS TAKEN DURING TEST

4.2.1 Speed

From a complete stop, the car was accelerated by a locomotive and released at a point 1,550 feet from the barrier. Measured by the laser-based speed trap, the speed of the test car just before impact was:

Laser 1	51.52 ft/s
Laser 2	51.42 ft/s
Average:	51.47 ft/s = 35.1 mph

The amount of energy (E) absorbed by the vehicle on impact with the rigid barrier can be calculated from the speed of the car just before impact, V_0 = 51.47 ft/s, and the mass of the test car, m = 74,289 lb, according to the formula:

$$E = ½.m.V_0^2$$

$$E = 3.06 \times 10^6 \text{ ft.lb (4.15 MJ)}$$

4.2.2 Strains

The Test Implementation Plan in Appendix A contains the positions of the strain gages. Figures 3 through 42 (Figures 3 through 188 are placed at the end of this document) show the strain time histories over the range –0.1 s to 0.6 s. In these figures positive values represent compression.

The Society of Automobile Engineers (SAE) frequency class indicating the filter frequency used for processing the recorded data is shown on each figure. SAE frequency classes are defined in SAE J211/1 (R) "Instrumentation for Impact Testing," Part 1 Electronic Instrumentation, March 1995. For the strain results, SAE CFC 1000 is equivalent to the raw data.

The data acquisition system for both strains and accelerations comprised 12 Data Bricks each collecting 8 channels of data. When the system was triggered on impact with the wall each Data Brick stored 0.1 s of information before the impact and 1.4 s of information after the impact. The strain time histories over the complete range recorded by the Data Bricks (-0.1 s to 1.4 s) are shown in Appendix D.

One of the Data Bricks did not trigger properly and none of its 8 channels recorded data. These channels were set up to record the following strain channels:

CS-L-1-U	CS-L-2-U	CS-L-3-U	CS-L-4-U
CS-L-5-U	CS-L-6-U	CS-L-7-U	CS-L-1-L

4.2.3 Accelerations

The positions of the accelerometers are shown in the Test Implementation Plan, Appendix A. Figures 43 through 83 show the acceleration time histories over the range –0.1 s to 0.6 s. These results are recorded acceleration time histories filtered according to SAE CFC 1000 specifications. As for strain, SAE CFC 1000 is equivalent to the raw data. Figures 84 through 124 show the filtered accelerations for SAE CFC 60. The algorithm defining SAE CFC 60 is given in Appendix C of SAE J211/1 (R). Essentially SAE CFC 60 is a Low-pass filter with a cut-off frequency of 100 Hz.

Low-pass filtered acceleration time histories with a cutoff frequency of 25 Hz (Fc = 25 Hz) are shown in Figures 125 to 165.

The acceleration time histories over the complete range recorded by the Data Bricks (-0.1 s to 1.4 s) are presented in Appendix E.

Note that some of the high accelerations shown in the SAE CFC 1000 results (Figures 43-83) represent high frequency, short duration peaks, and do not represent the acceleration that would be experienced by an occupant sitting in the car at impact.

4.2.4 Displacements

The vertical displacement across the secondary suspension was measured using string potentiometers between the car body and the truck. The unfiltered results are plotted in Figures 166 through 169. It may be noted that the maximum displacement of approximately 3.5 inches occurred at the A-end.

The string potentiometer on the right hand side at the B-end failed to record data.

4.2.5 Longitudinal Velocity and Displacement

The X-axis acceleration time histories of the center sill accelerometers have been integrated to give velocity and plotted against time in Figures 170 through 174.

These same acceleration time histories have been double integrated to give crush displacement and plotted against time in Figures 175 through 179.

4.2.6 High-Speed and Video Photography

The impact test was recorded using an array of high-speed and video cameras. Camera coverage was selected to provide views of both left and right sides of the vehicle, overhead views, an underside view, an onboard view, and an overall view of the impact. (Camera coverage is depicted in Figure 6-3-1 of the Test Implementation Plan in Appendix A). The side views and overhead view had redundant coverage to obtain photo-documentation in the event of an individual camera failure.

All the cameras worked successfully and the film analysis described in the next section was conducted after the film had been processed.

4.2.7 Film Analysis

The film analysis was conducted on film from high-speed fixed cameras located on the west and east sides of the barrier.

For the analysis, the film was projected frame-by-frame onto a digitizer pad. The location of three vehicle-mounted and three ground-based targets was selected with the crosshairs of a cursor, and corresponding x and y coordinates were stored in a computer. The analysis was started before impact and continued throughout maximum crush to the vehicle rebound. The average position of the onboard targets relative to the ground-based targets was computed by

$$d = \frac{s_1 + s_2 + s_3 - s_4 - s_5 - s_6}{3}$$

where d is the relative position, and s_1 through s_6 are the locations of the three onboard and three ground-based targets, respectively. The distance reference was the distance between the two extreme ground-based targets, which was 88 inches.

Vehicle speed was computed by

$$v_i = \frac{d_i - d_{i+1}}{\Delta t}$$

where the subscripts represent the film frame number, and Δt is the time duration between frames.

Film speed was obtained directly from the 100-Hz timing marks on the film. The nominal speed of the fixed cameras was 500 fps.

Car-body displacement was set to zero at impact. The displacement data is relatively smooth in its raw, as collected, form. Figures 152 and 153 show the car-body displacements in the longitudinal and vertical directions computed from the west-side stationary camera and the east-side stationary cameras, respectively. These show a maximum displacement in the longitudinal direction of about 5 feet 6 inches. Figure 154 is a compilation of these two plots.

Figures 155 to 158 show car body velocities in the longitudinal and vertical directions, computed from each of the two high-speed stationary camera films. The raw velocity data was computed as indicated above. Smoothed data was low-pass filtered with a phaseless 4^{th}-order Butterworth filter having a cutoff frequency of approximately 23 Hz. Phaseless filtering introduces no time lags into the filtered data, so the time relationship with other events and measurements in the crash test is maintained. Before smoothing, the velocity at impact was set to 51.5 ft/s, the average velocity obtained from the laser speed traps.

Figures 159 and 160 compare smoothed car-body velocities from the two stationary cameras in the longitudinal and vertical directions, respectively.

4.3 MEASUREMENTS TAKEN AFTER TEST

4.3.1 Longitudinal and Vertical Distances (A-end = Impact End)

- Length of car from buffer beam to buffer beam = 79.89 ft
  (Difference = 4.61 ft)
- Longitudinal distance from buff stop to body bolster, A-end = 2.25 ft
  (Difference = 4.51 ft)
- Longitudinal distance from buff stop to body bolster, B-end = 6.72 ft
  (Difference = 0.0 ft)
- Longitudinal distance between body bolsters = 57.17 ft
  (Difference = 0.0 ft)
- Vertical distance between mid point of car (center sill) and a line extending between body bolsters = 10.50 in.
  (Difference = 0.16 in.)
- Vertical distance between buffer beam and a line extending between body bolsters, A-end = 15.5 in.
  (Difference = 2.13 in.)
- Vertical distance between buffer beam and a line extending between body bolsters, B-end = 15.44 in.
  (Difference = 0.0 in.)

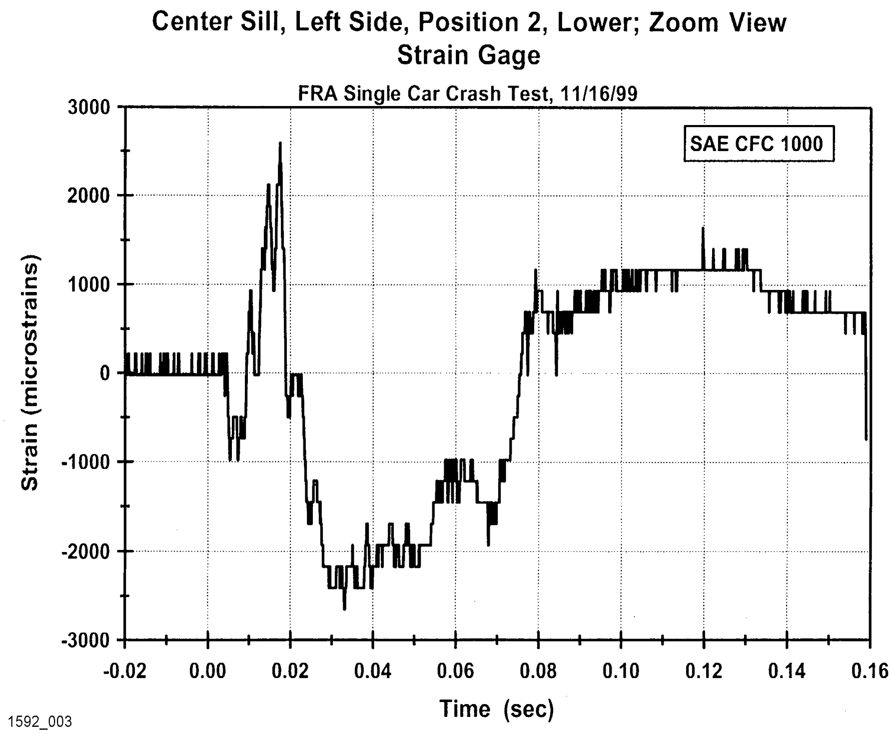
Appendix B contains the complete longitudinal and vertical distances measured before and after the impact test.

5.0 CONCLUSIONS

- The speed of the test car at impact was 35.1 mph. This was within 0.3% of the desired speed of 35 mph.
- The crush measured about 4.5 feet from the reduction in length of the vehicle after the test. The film analysis showed the maximum displacement in the longitudinal direction of 5.5 feet. The accelerometer data, double integrated, shows a maximum displacement of about 5.5 feet. Both the film analysis and the integrated accelerometer data include elastic deformation of the car body. The test requirement was for at least 3 feet of crush.

- One of the Data Bricks (out of 12) did not trigger, and the 8 strain-gage channels feeding signals into this Data Brick were lost. All these strain gages were on the left hand side of the center sill. Apart from this, all the strain gages provided information.
- The accelerometer at the front of the vehicle, center sill at position 1, recorded a maximum longitudinal acceleration of 180 g before its cable failed at 0.1 s. When this signal was filtered to SAE CFC 60 (Low-pass filter with a cut-off frequency of 100 Hz), the peak acceleration was reduced to 70 g.
- The maximum longitudinal acceleration recorded on the center sill was 434 g at position 2. When filtered to SAE CFC 60, the peak acceleration reduced to 70 g.
- The maximum longitudinal acceleration of 734 g was recorded on the right-side sill at position 1. When filtered to SAE CFC 60, the peak acceleration reduced to 50 g.
- The 100-g accelerometers at both the left sill, position 1 (lateral), and right sill at position 1 (lateral) saturated.
- The maximum vertical acceleration recorded on the center sill was 180 g at position 2. When filtered to SAE CFC 60, the acceleration reduced to 51 g.
- The 200-g accelerometer at the right sill, position 1 (vertical), saturated and the 50-g accelerometer at the right sill, position 2 (vertical), also saturated.
- The string potentiometer at the B-end, right-hand side, failed. The other three potentiometers measured vertical displacement across the airbags. A maximum deflection of 3.5 inches was recorded on the A-end, right hand side transducer.
- All the video and film cameras successfully recorded the impact of the test car from both sides, overhead, underneath, on board, and a general view.
- The film was analyzed frame-by-frame, and the displacement and velocity of the vehicle through the impact calculated. This provided an independent check of the velocity and displacement during impact.
- The amount of energy absorbed by the vehicle on impact with the wall was 3.06×10^6 ft.lb. (4.15 MJ)

Figures 3 through 188



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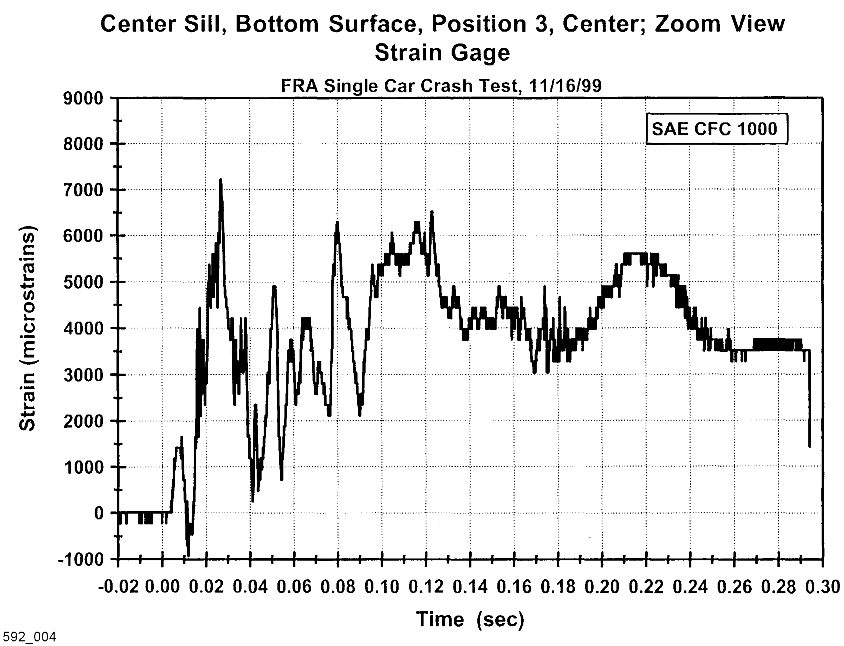

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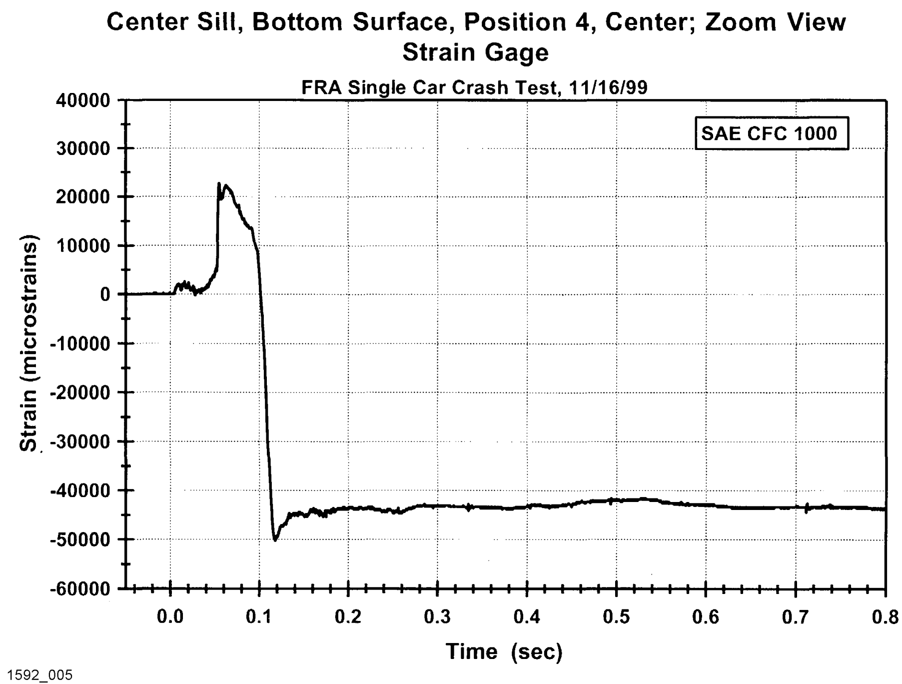

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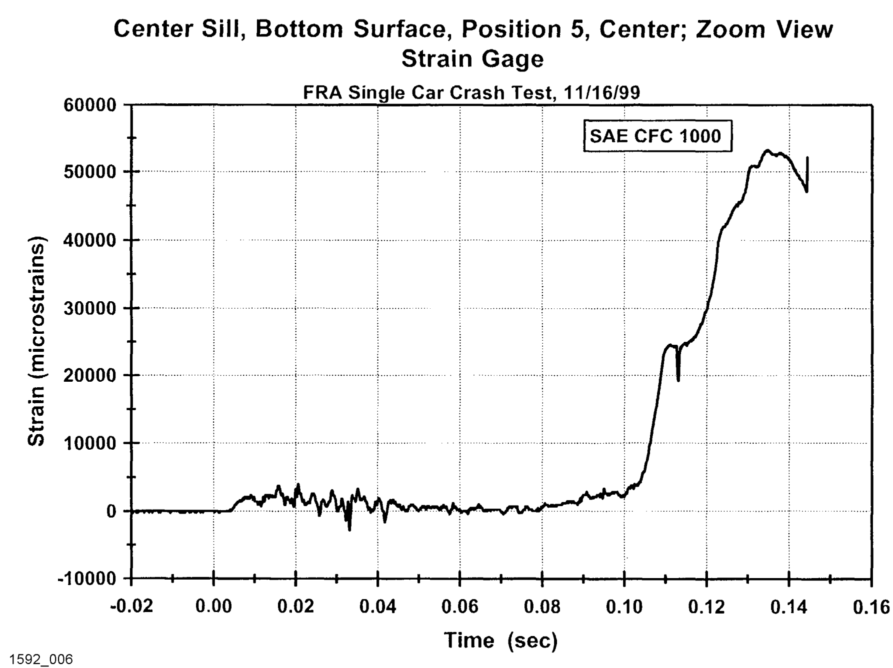

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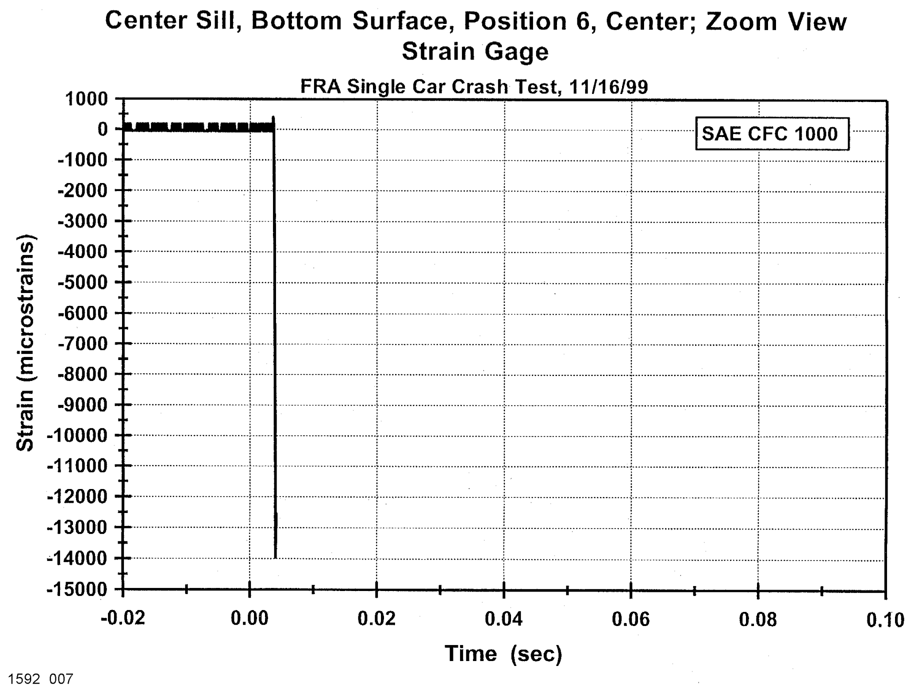

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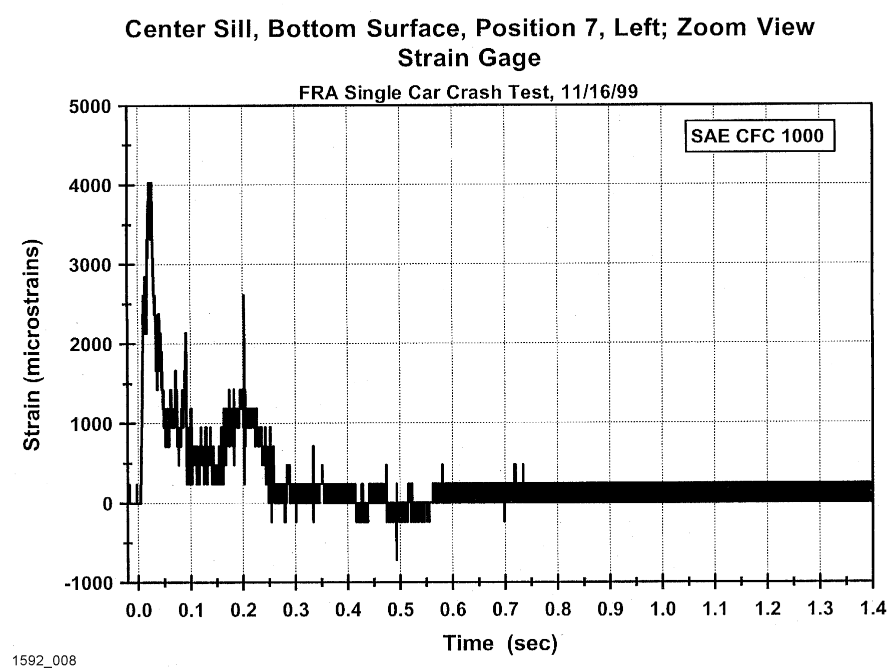

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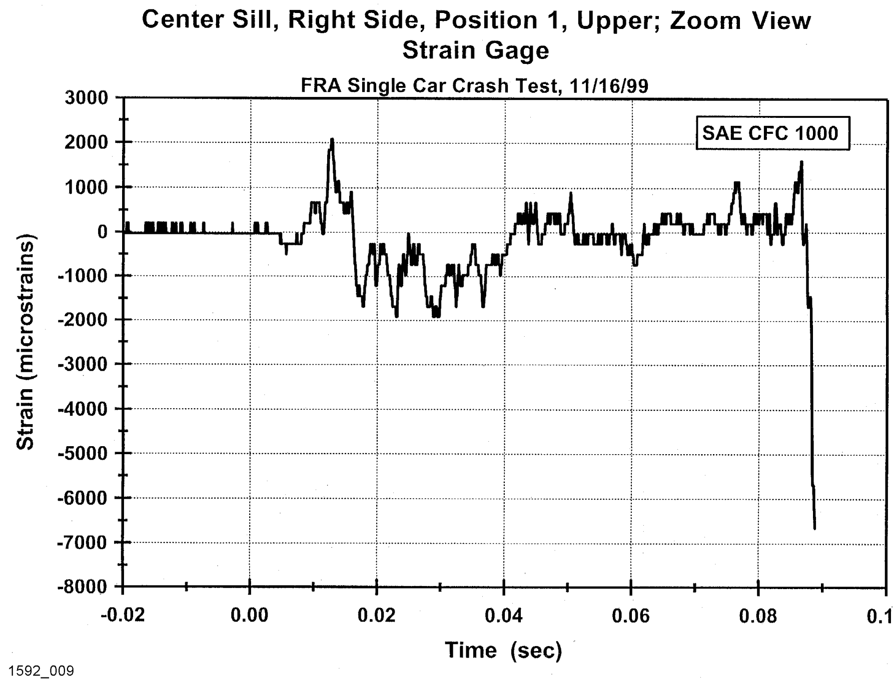

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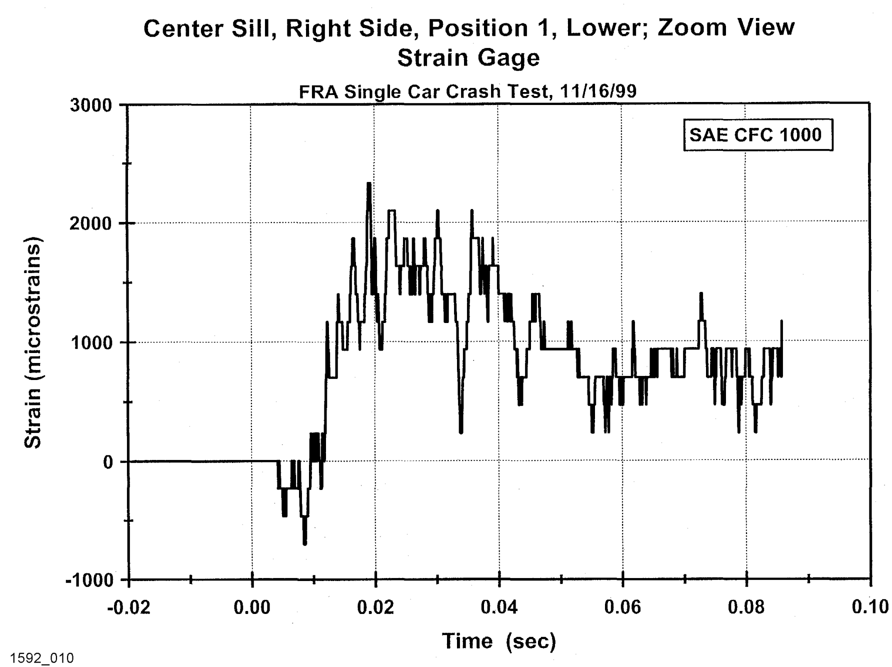


Figure 10.

Center Sill, Right Side, Position 2, Upper; Zoom View
Strain Gage

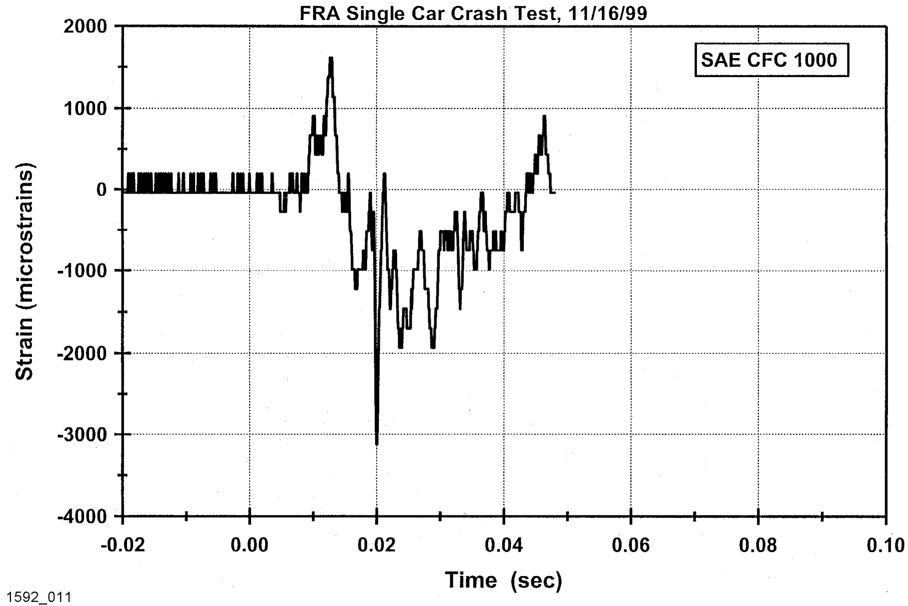
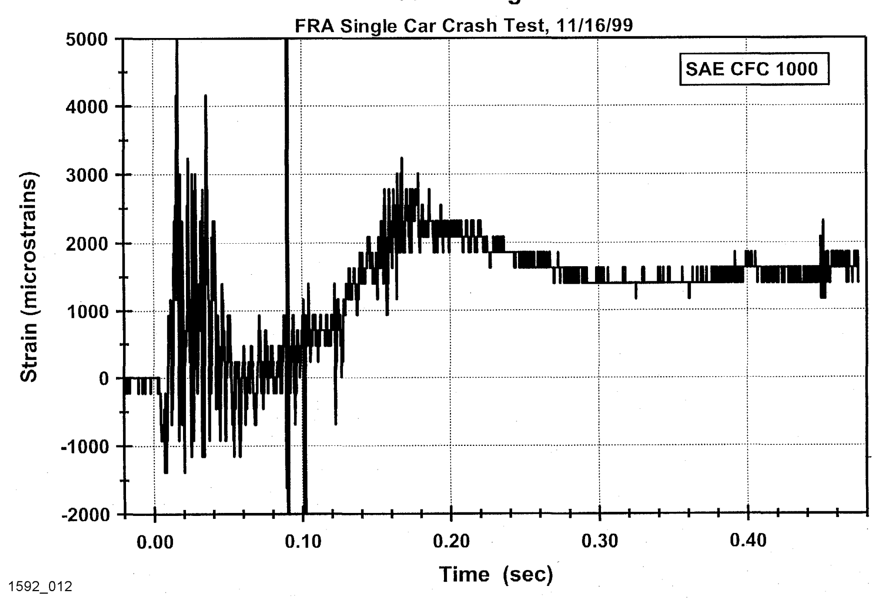


Figure 11.

Center Sill, Right Side, Position 2, Lower; Zoom View
Strain Gage



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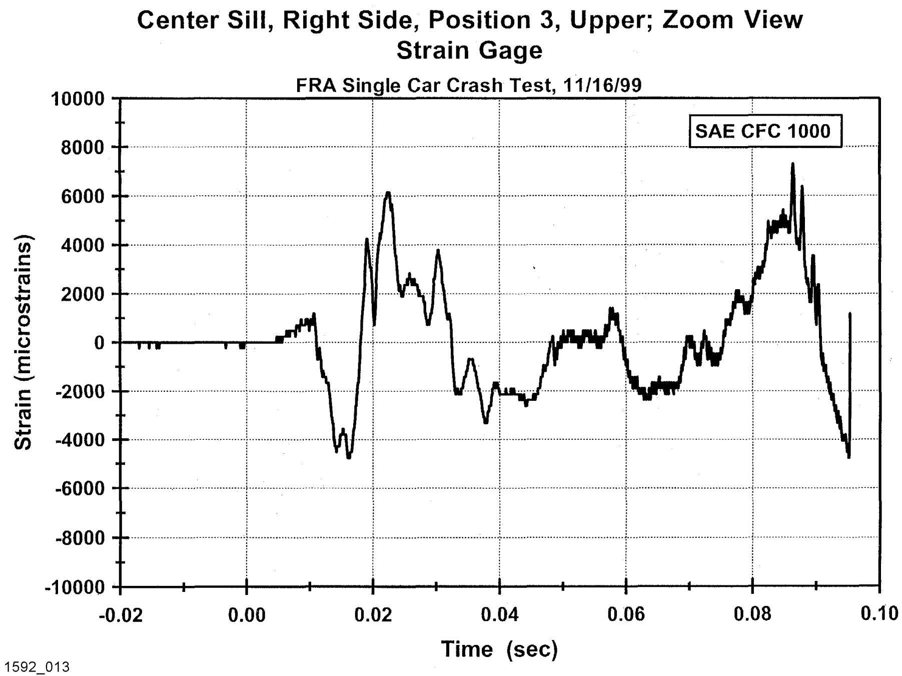

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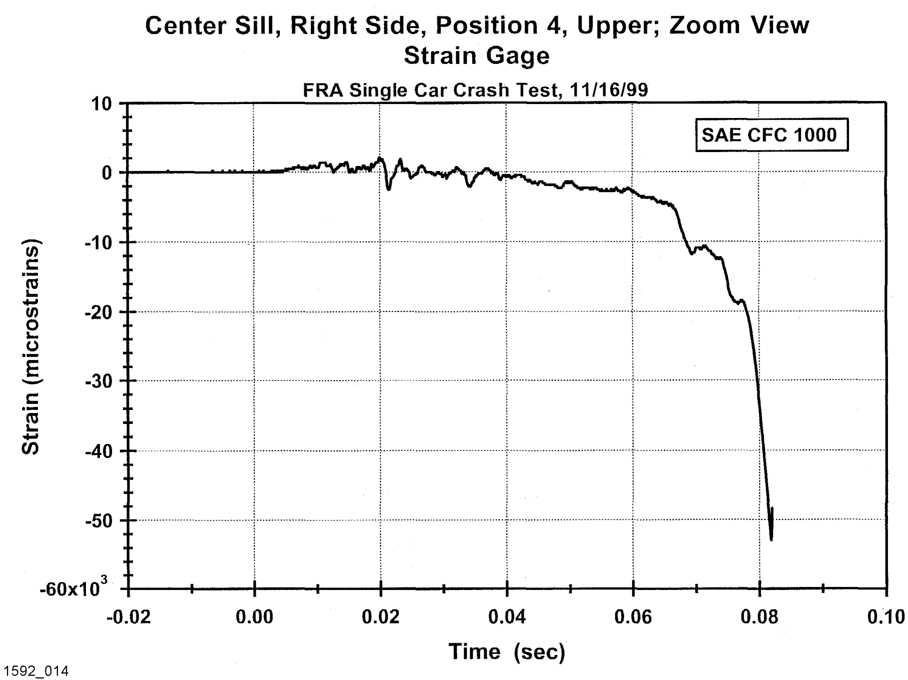

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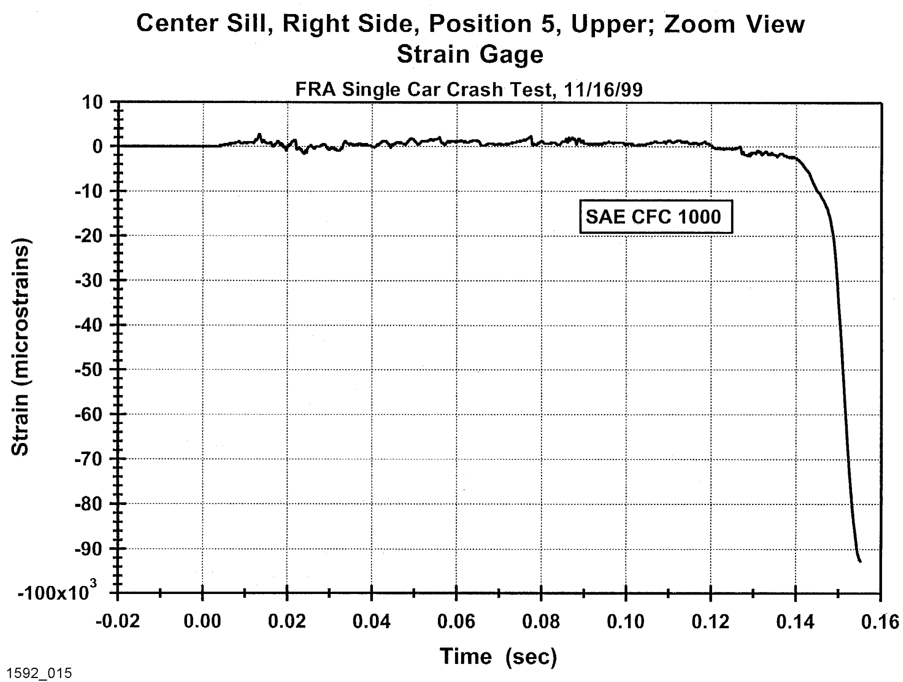

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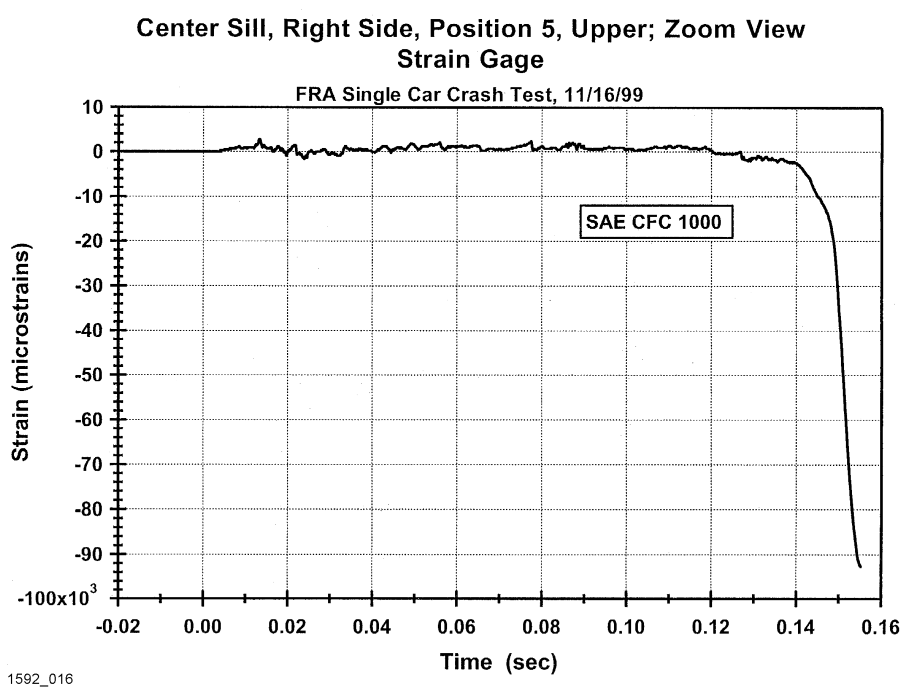

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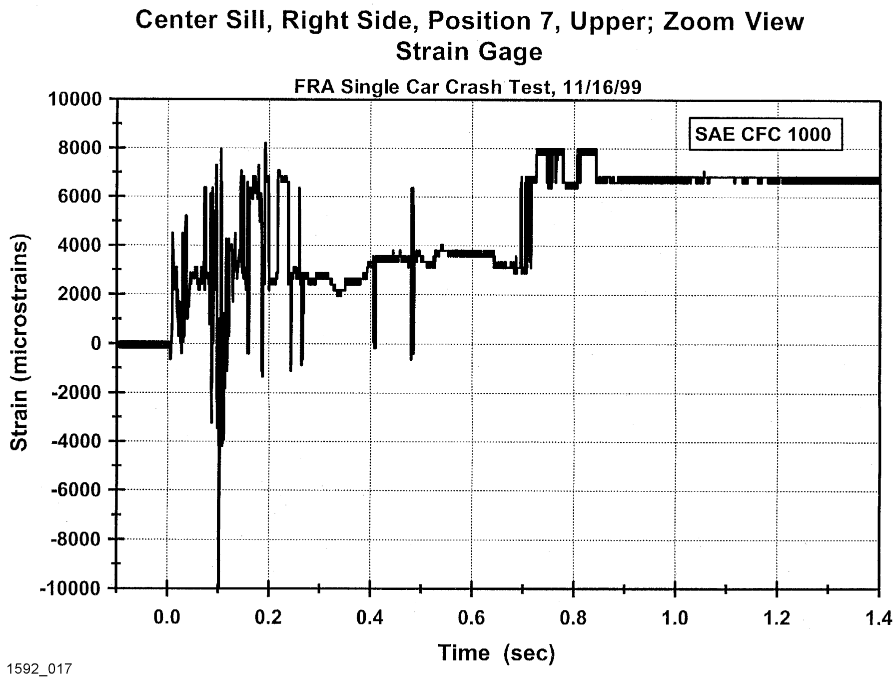

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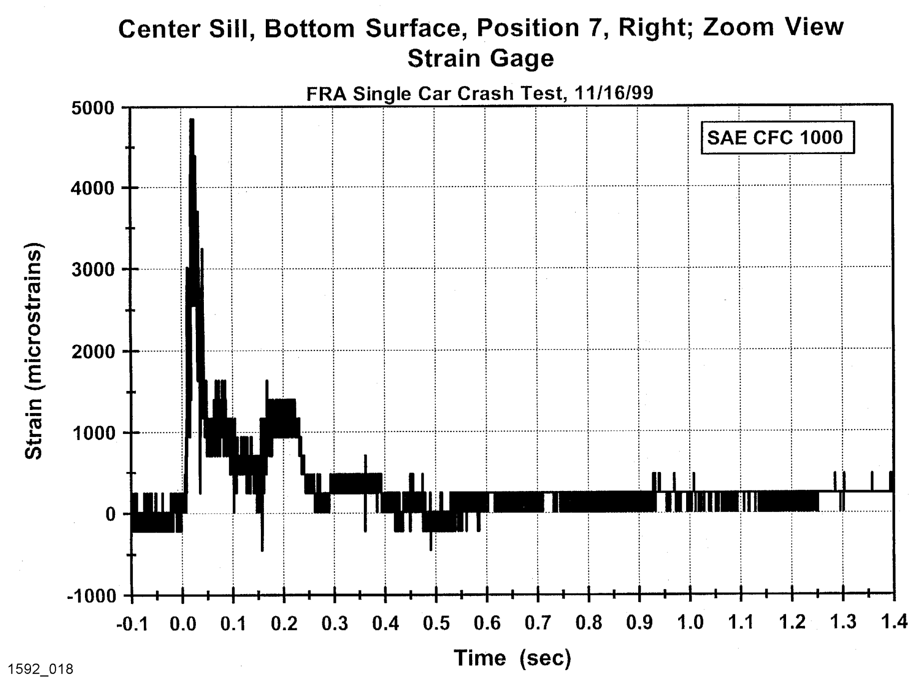

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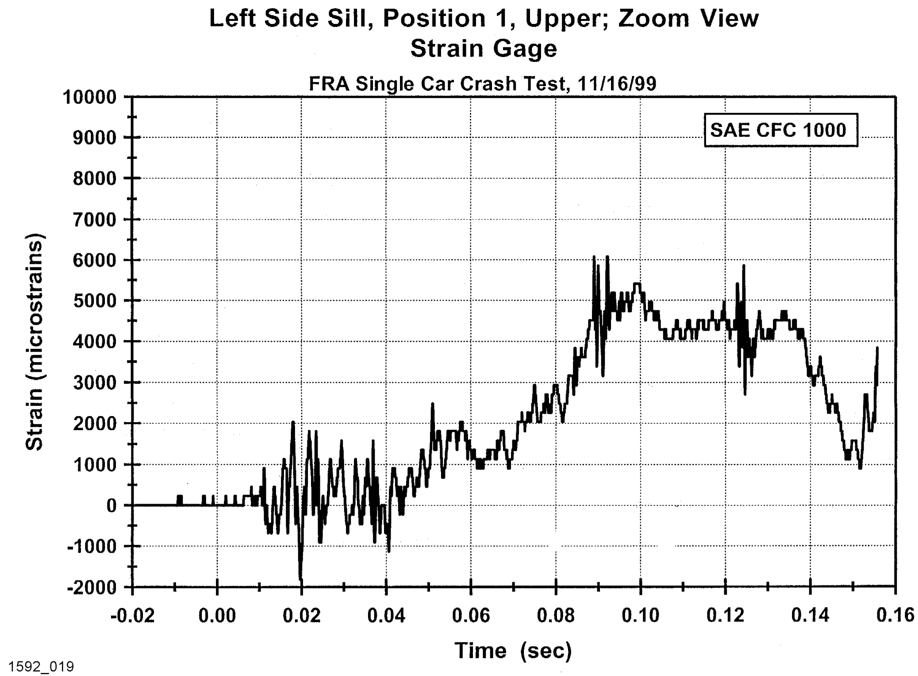

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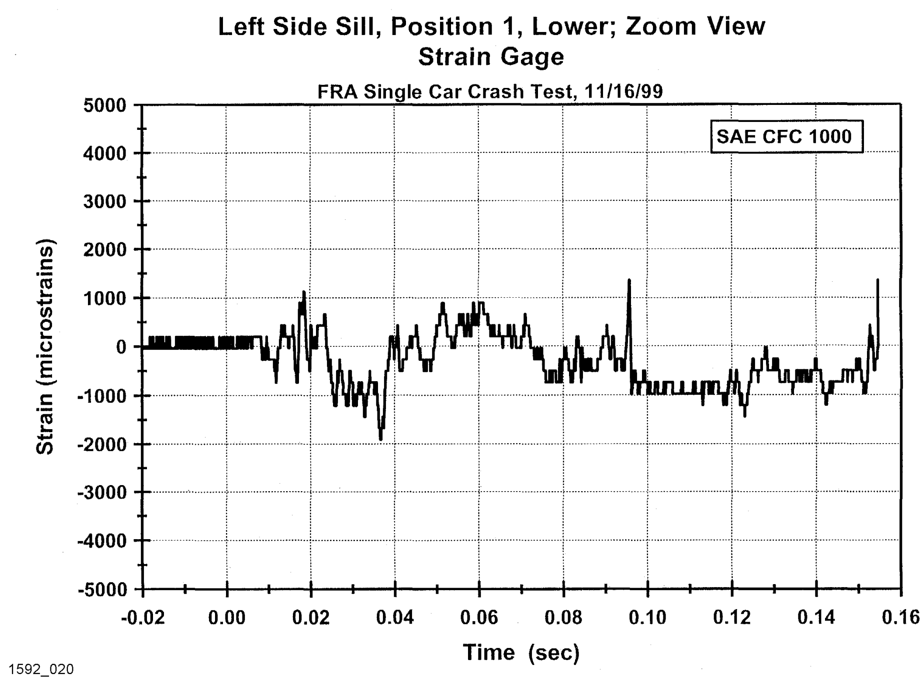

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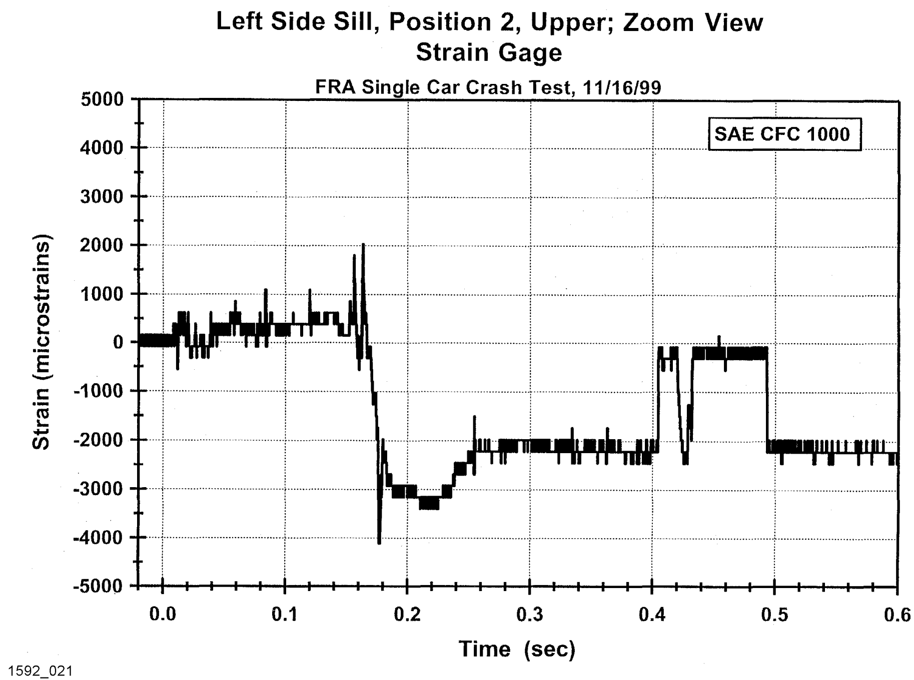

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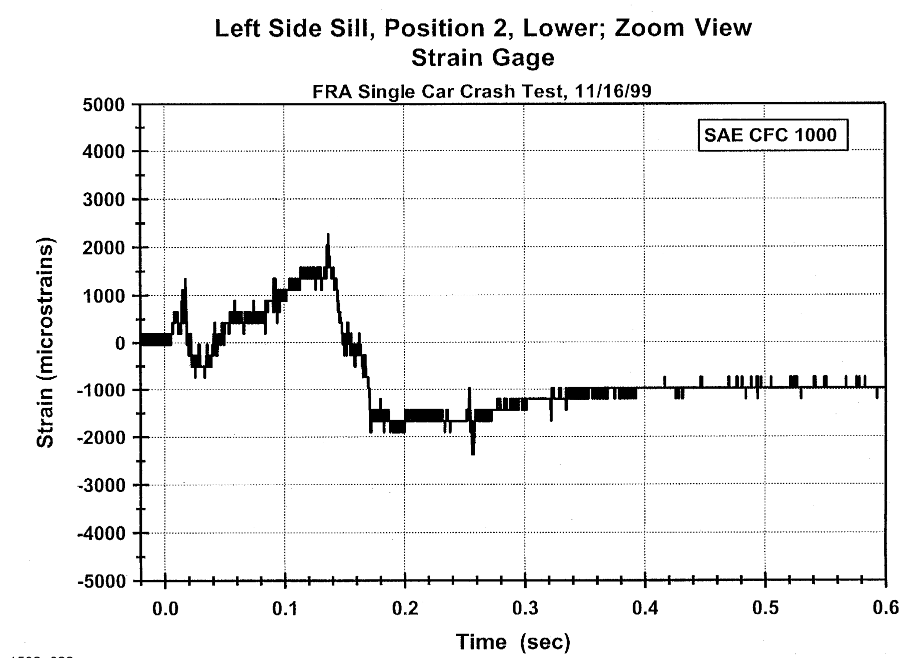

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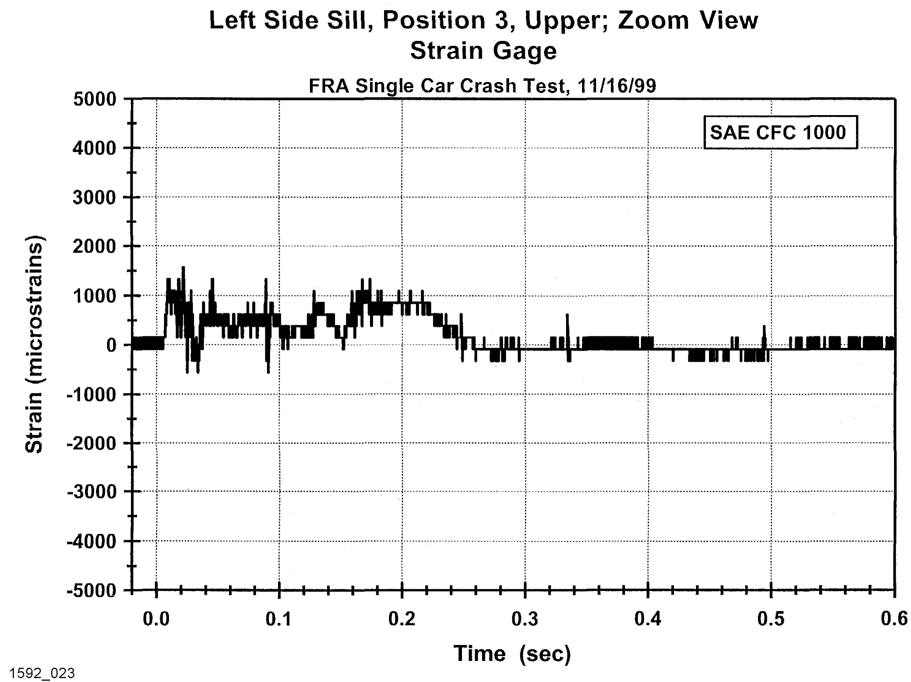

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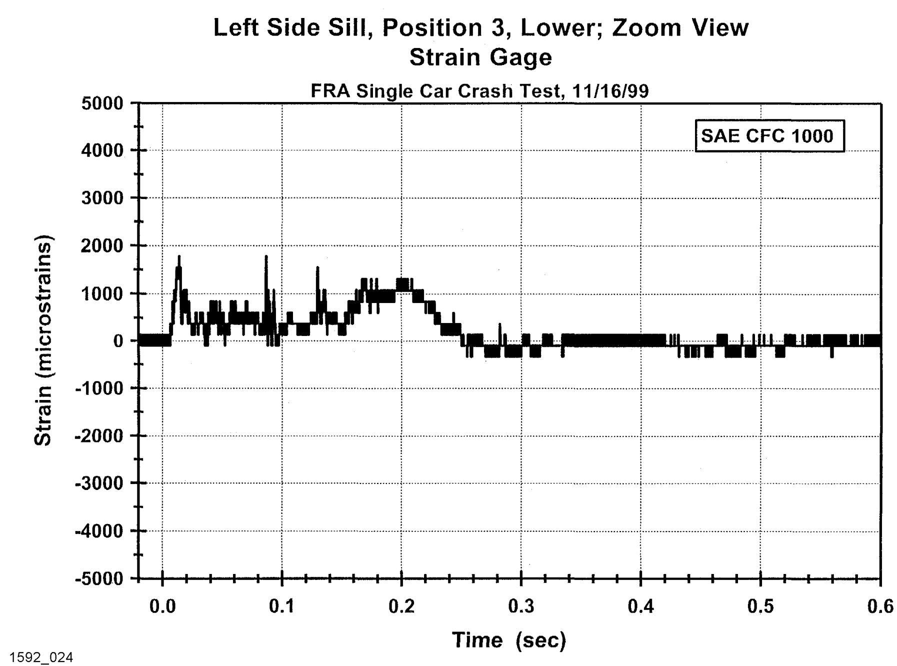

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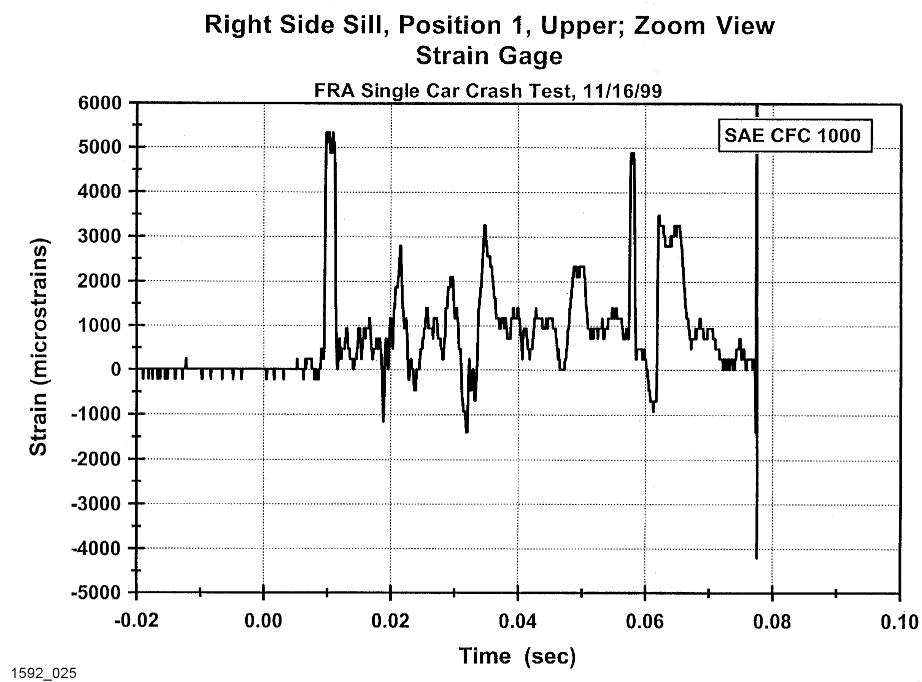

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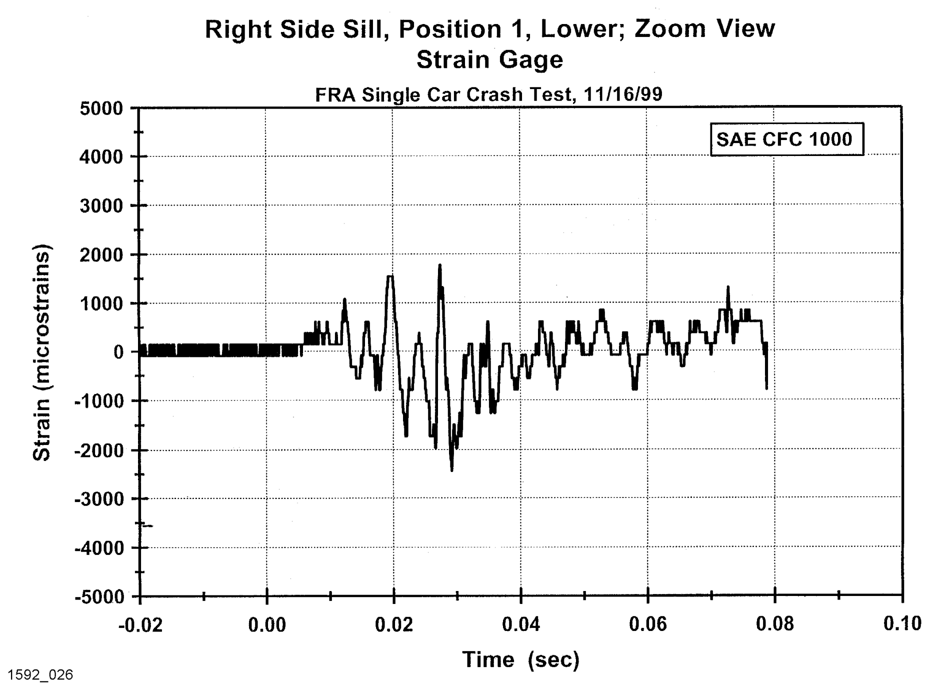

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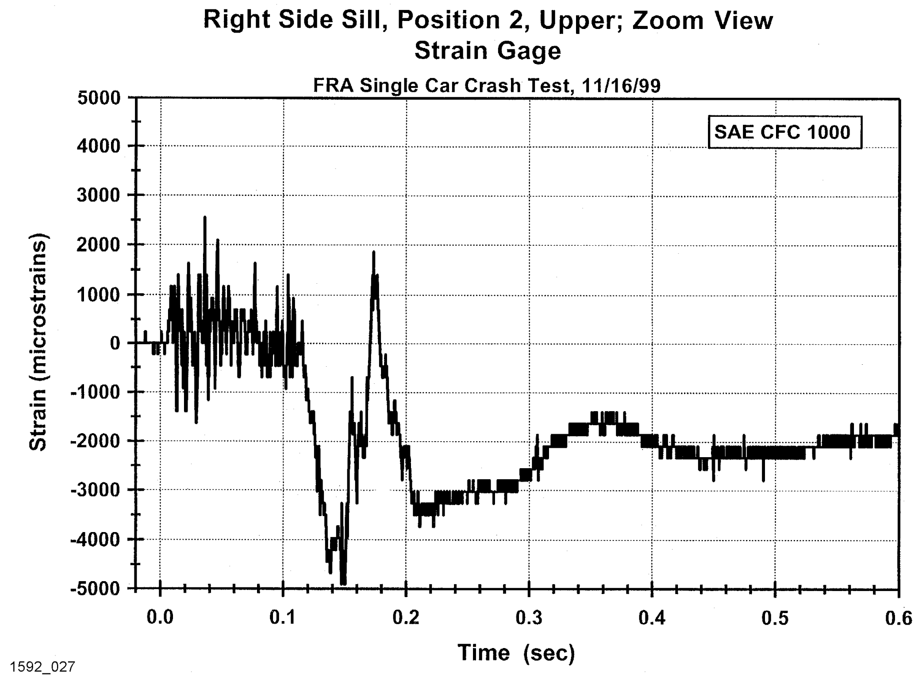

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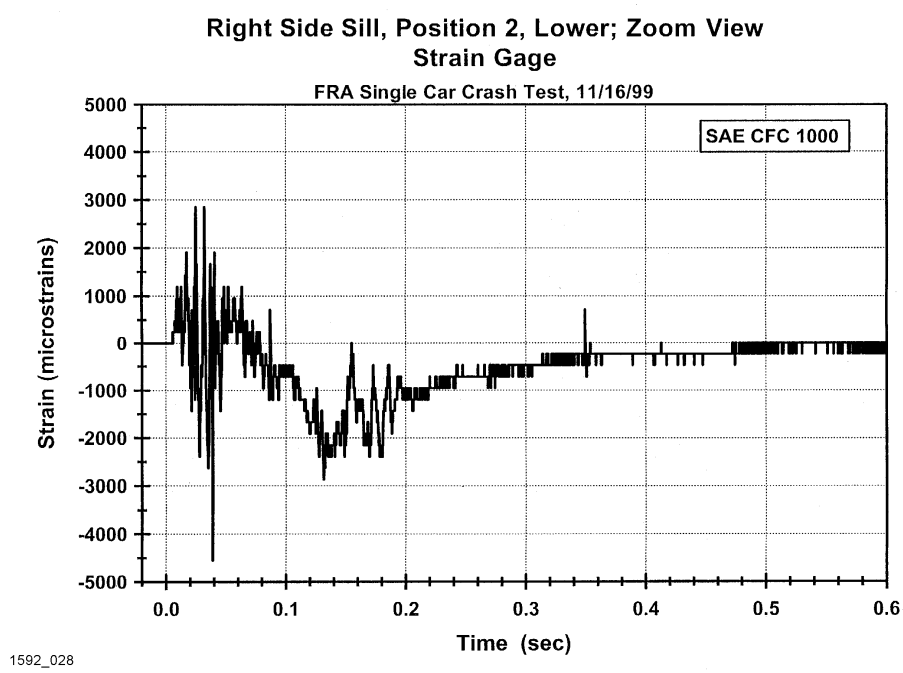

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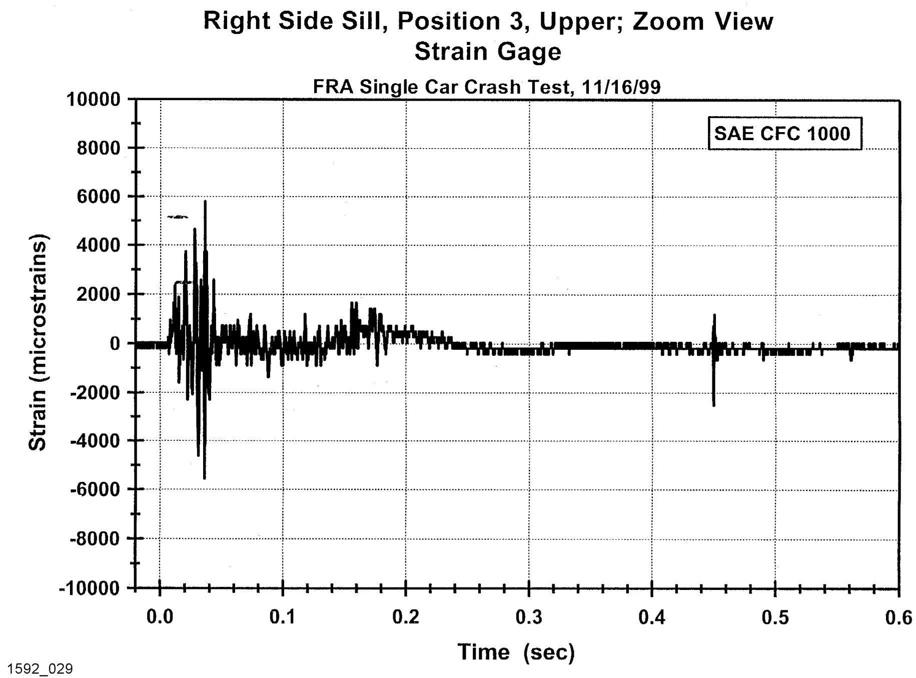
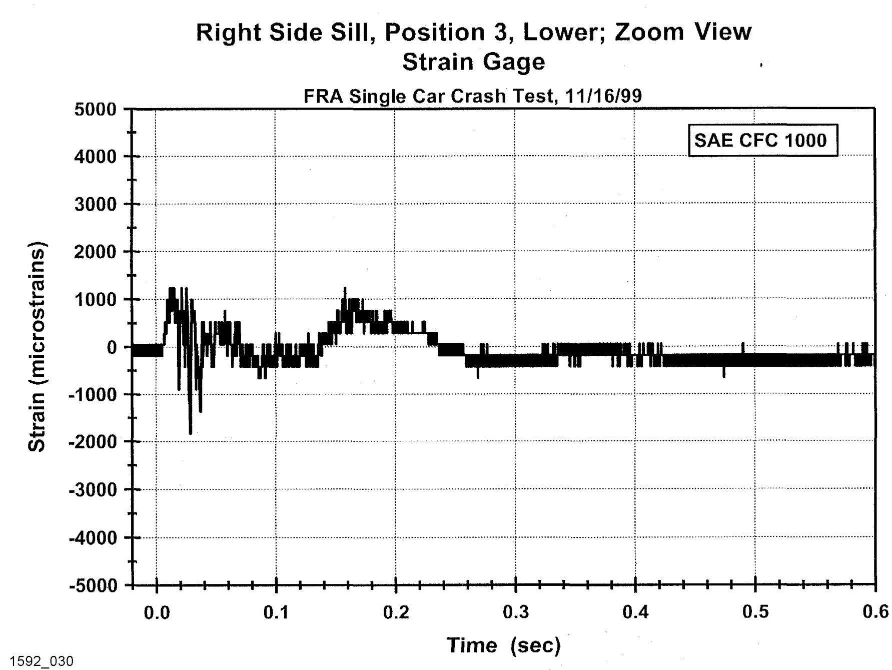


Figure 29.



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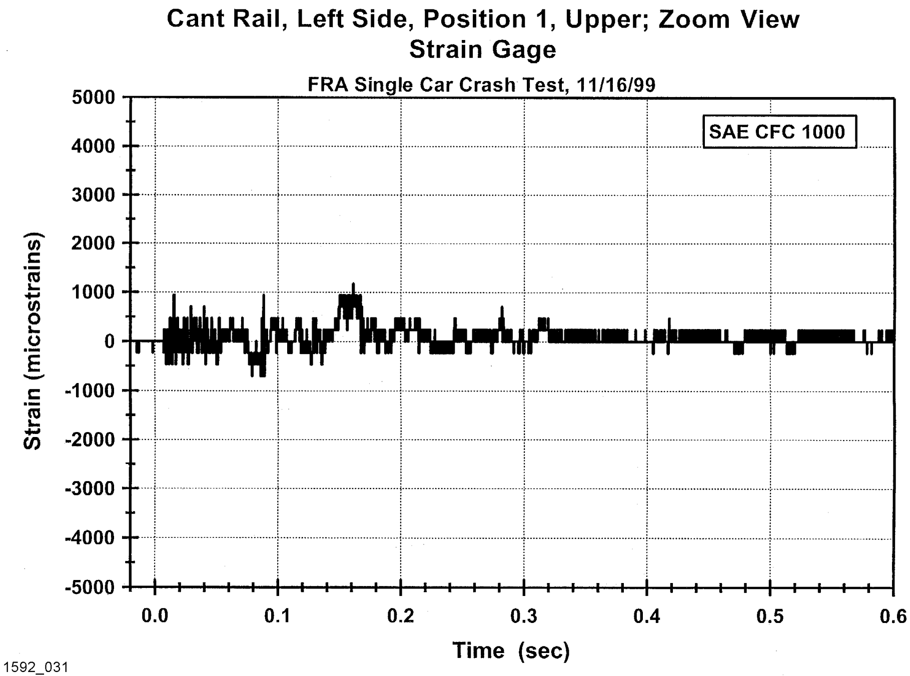

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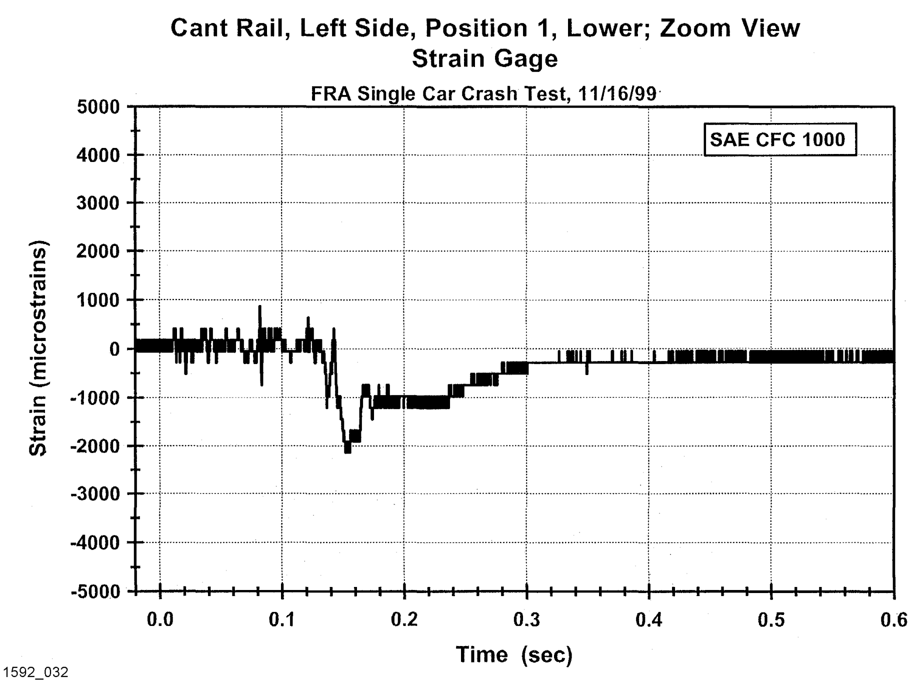

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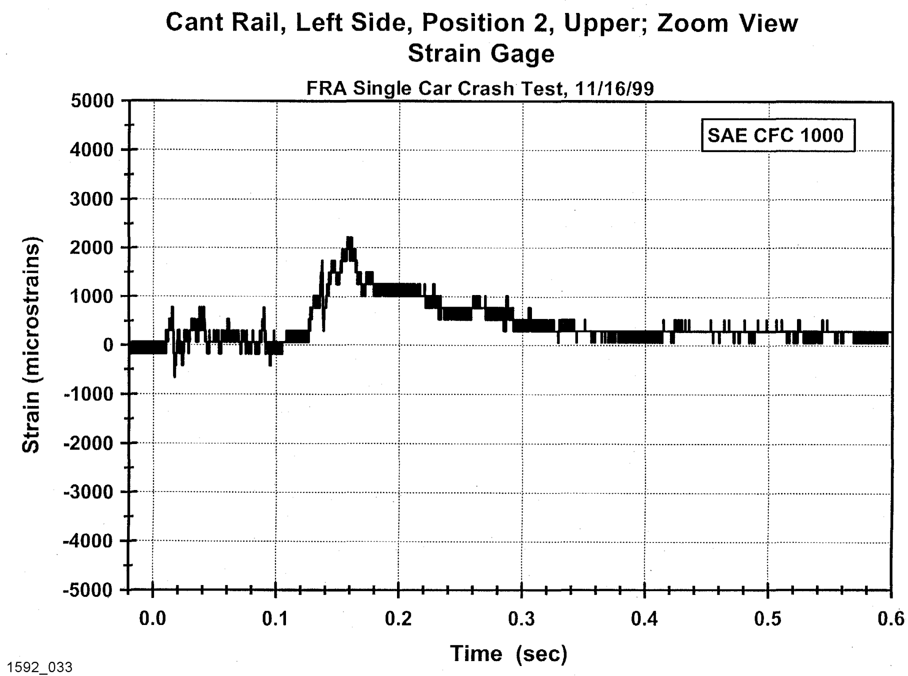

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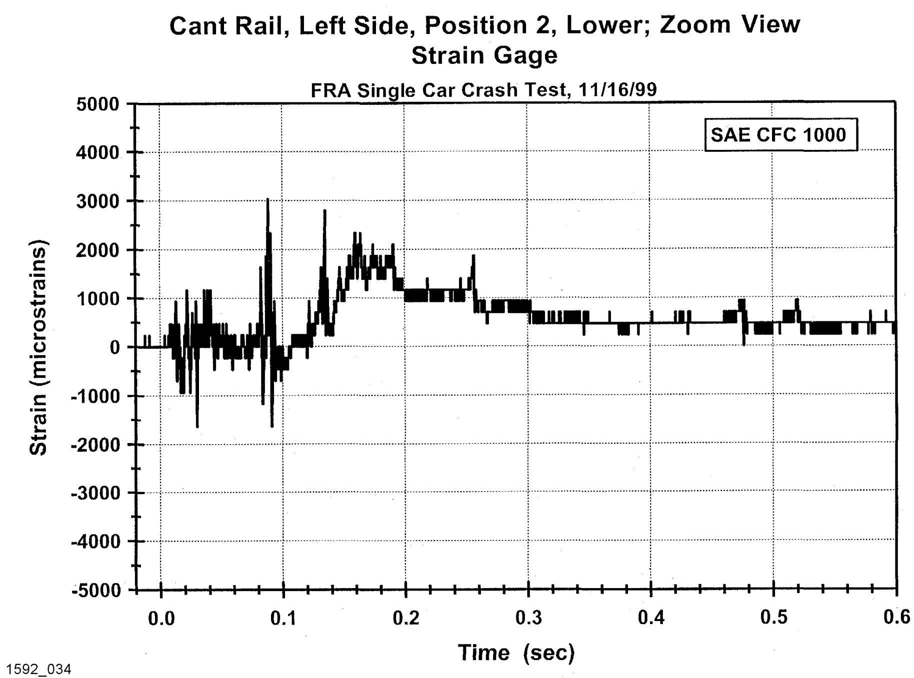

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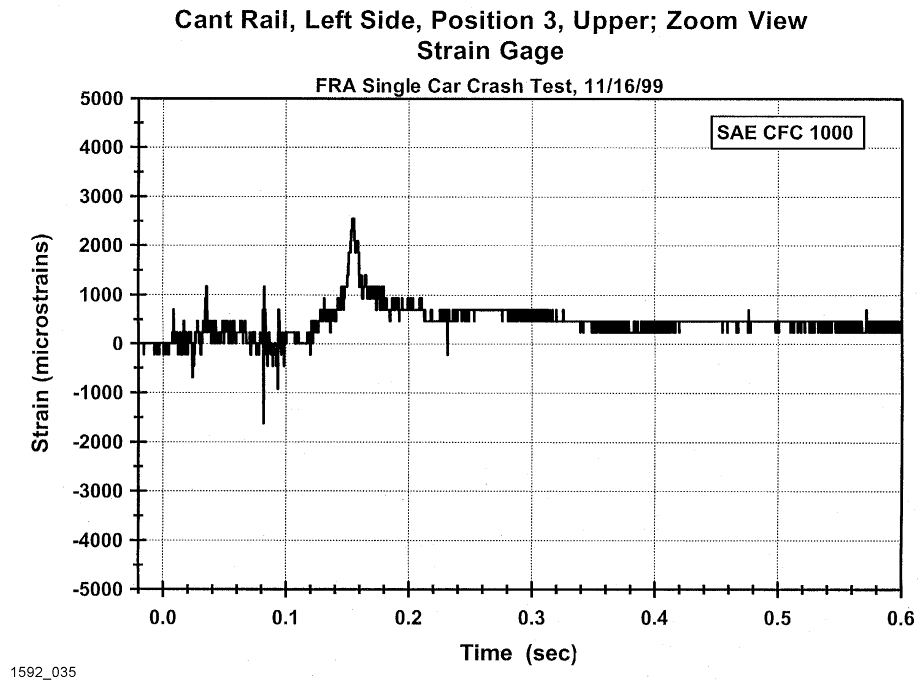

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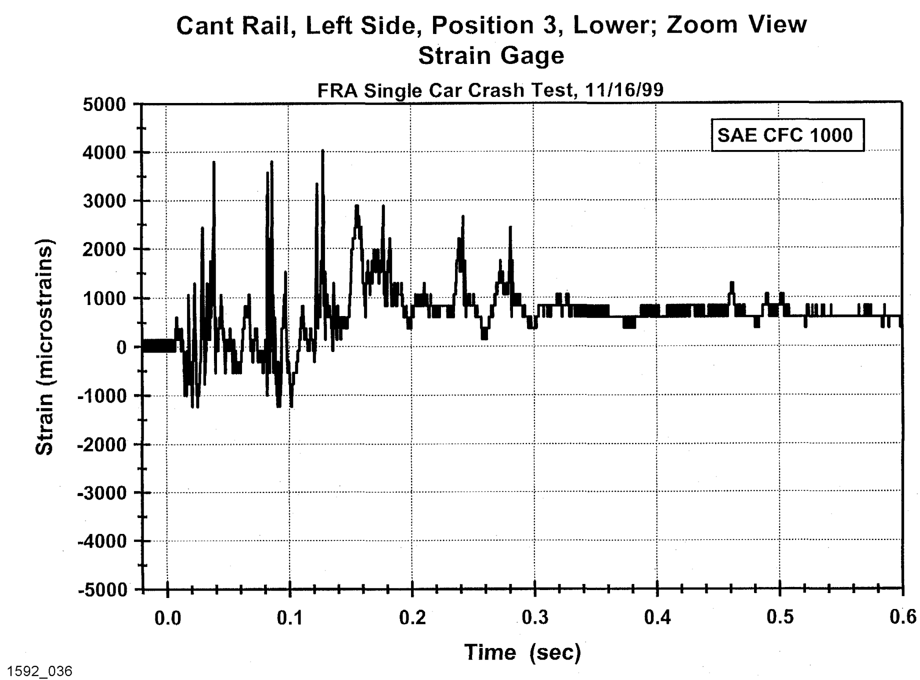

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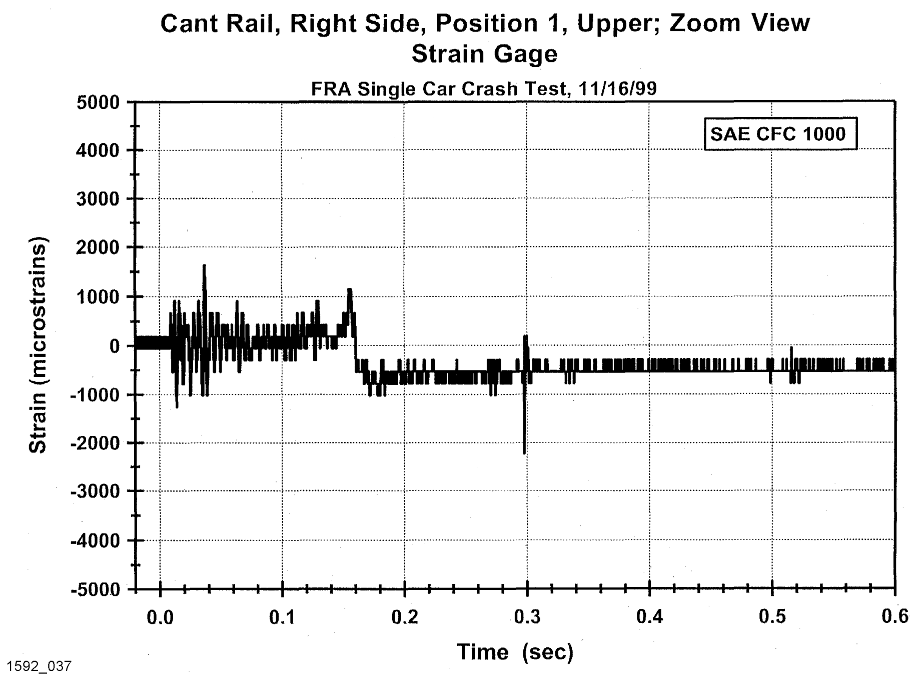

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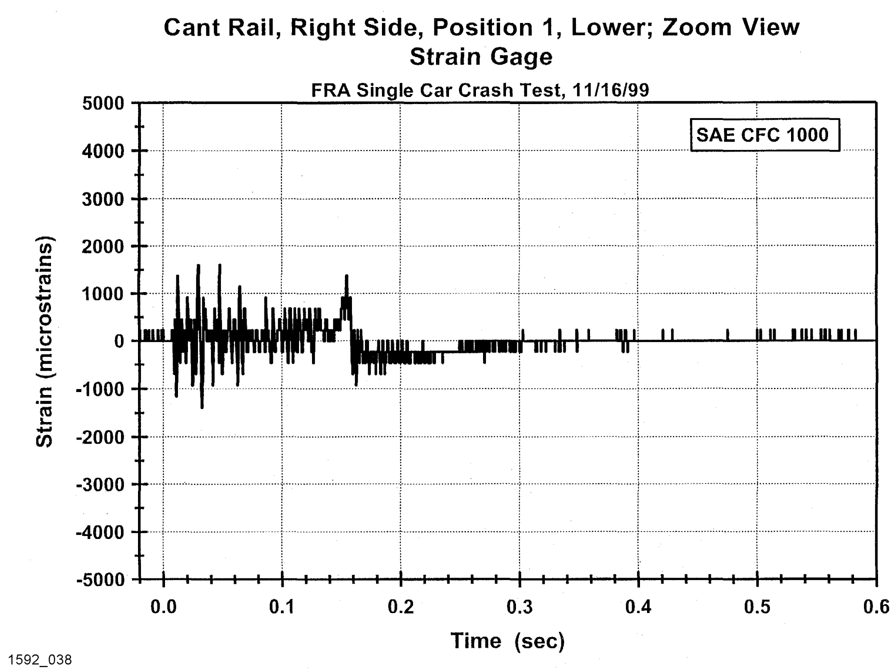

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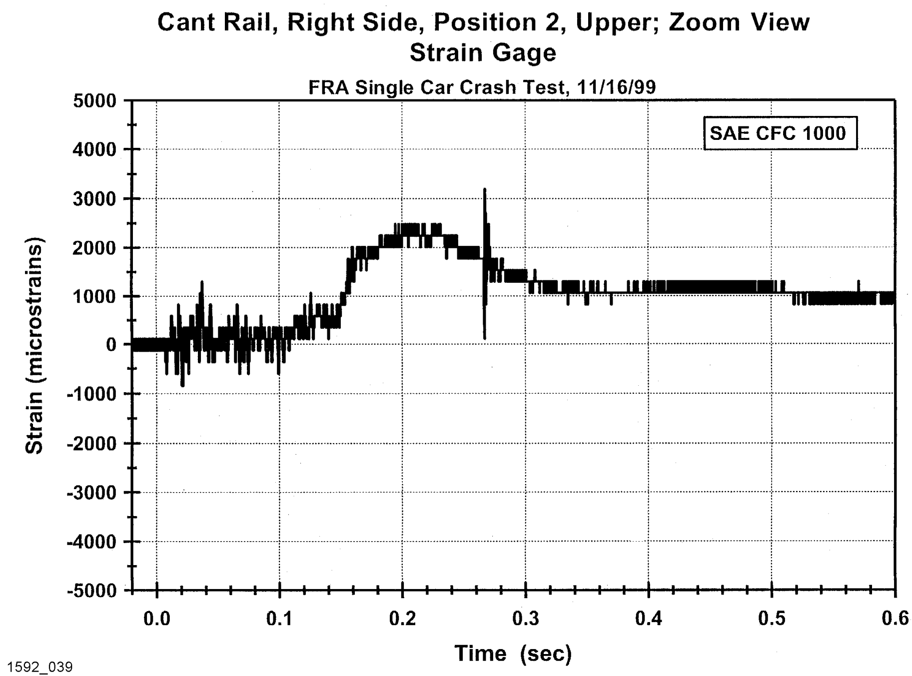

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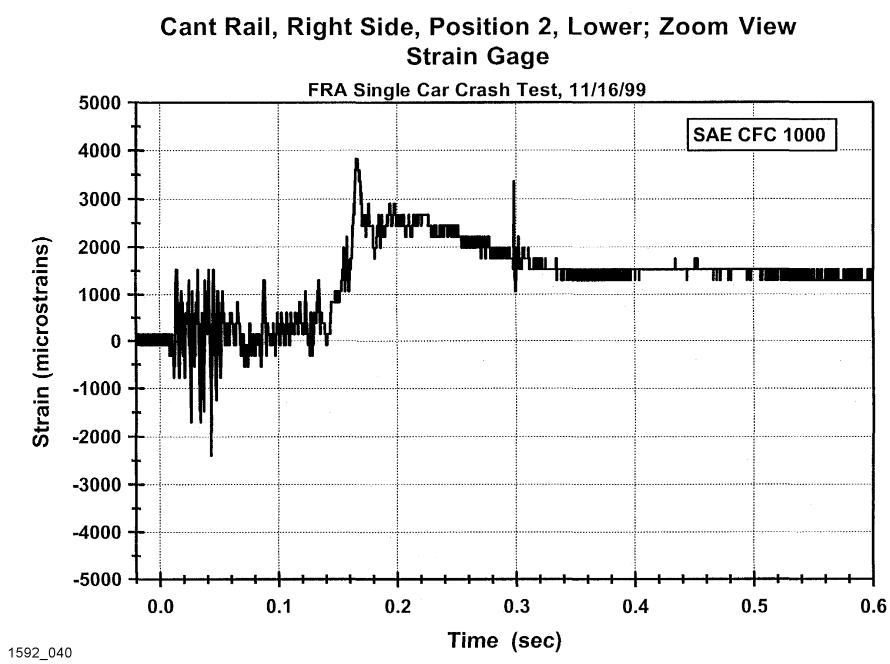

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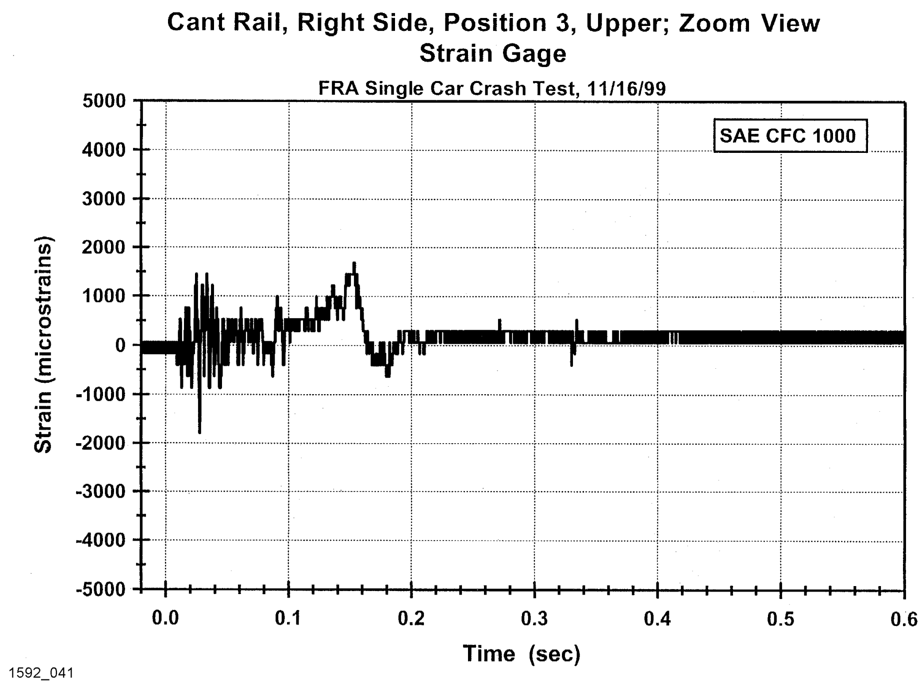

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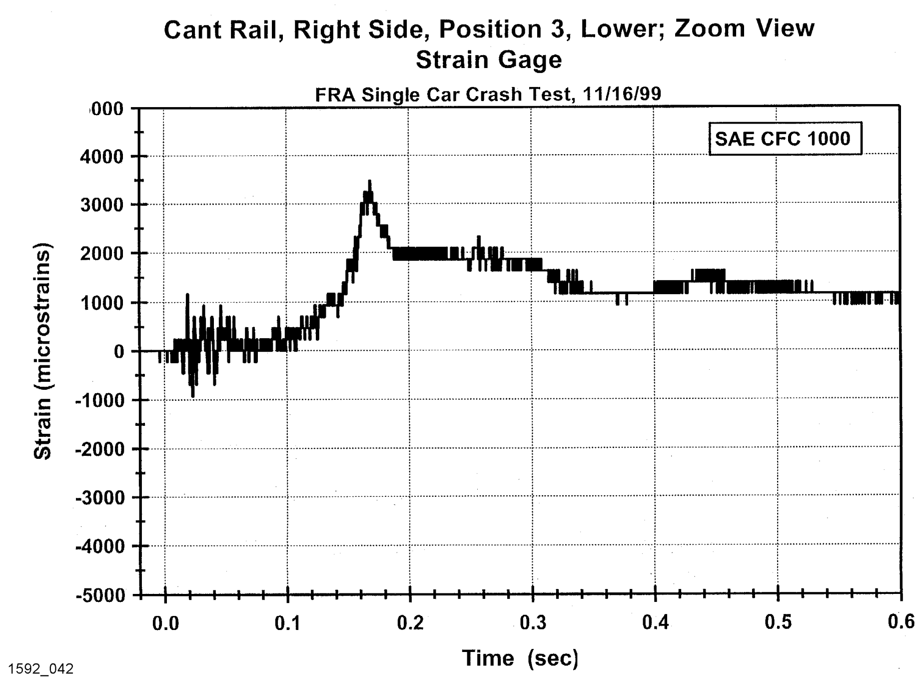

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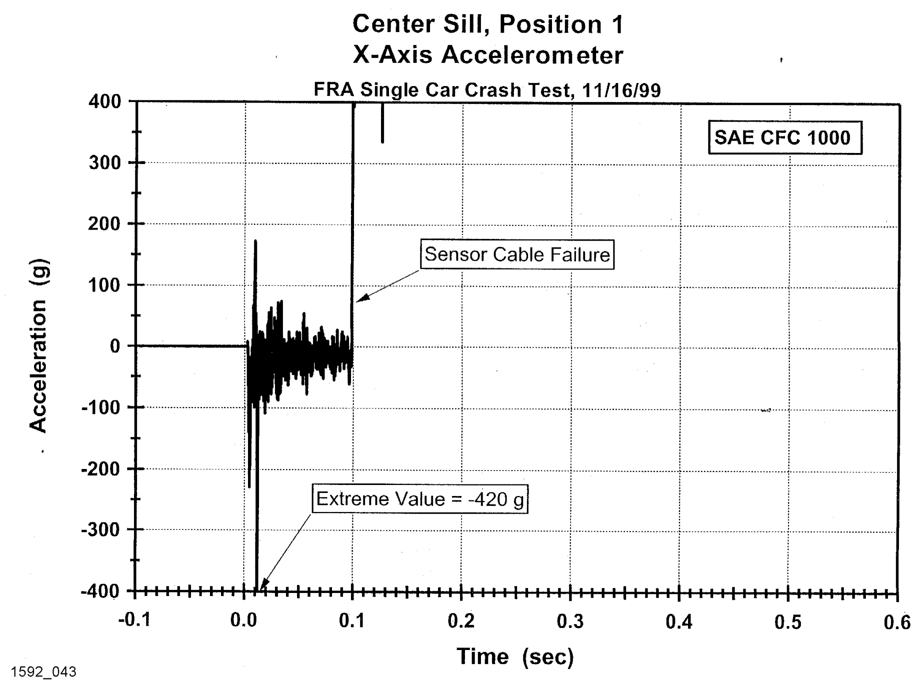

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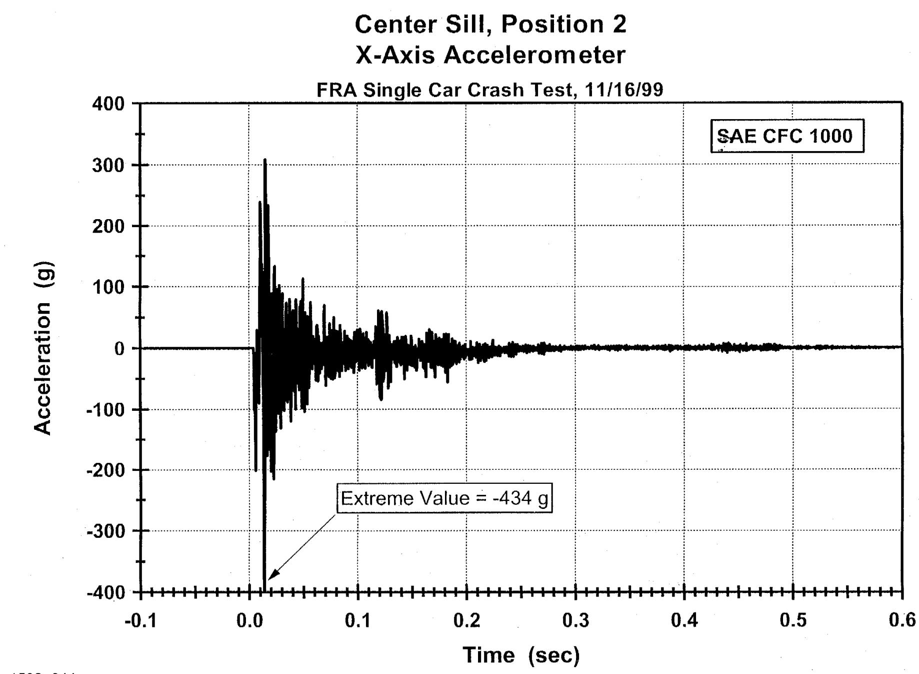

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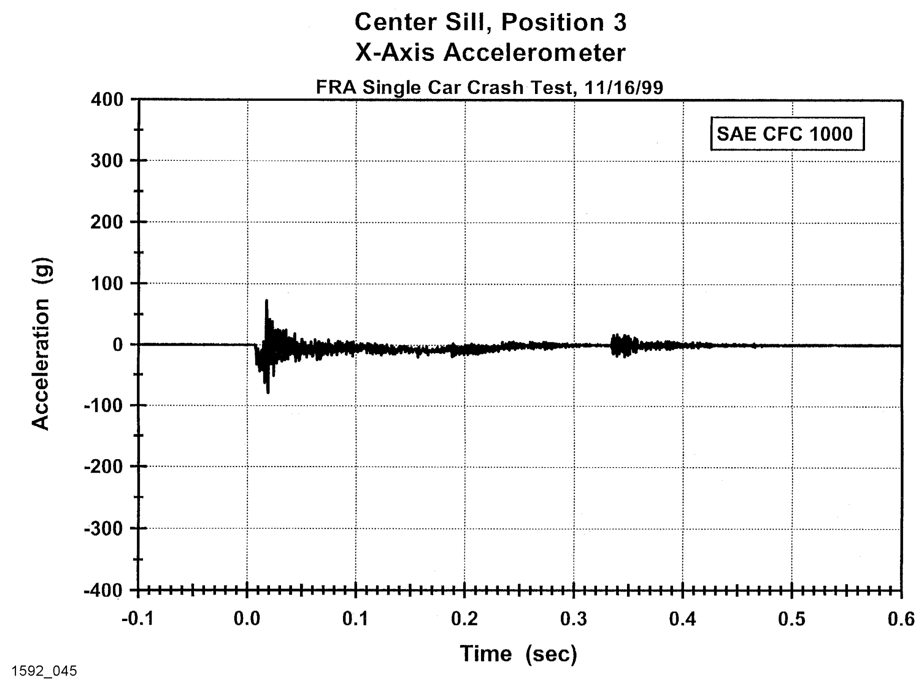

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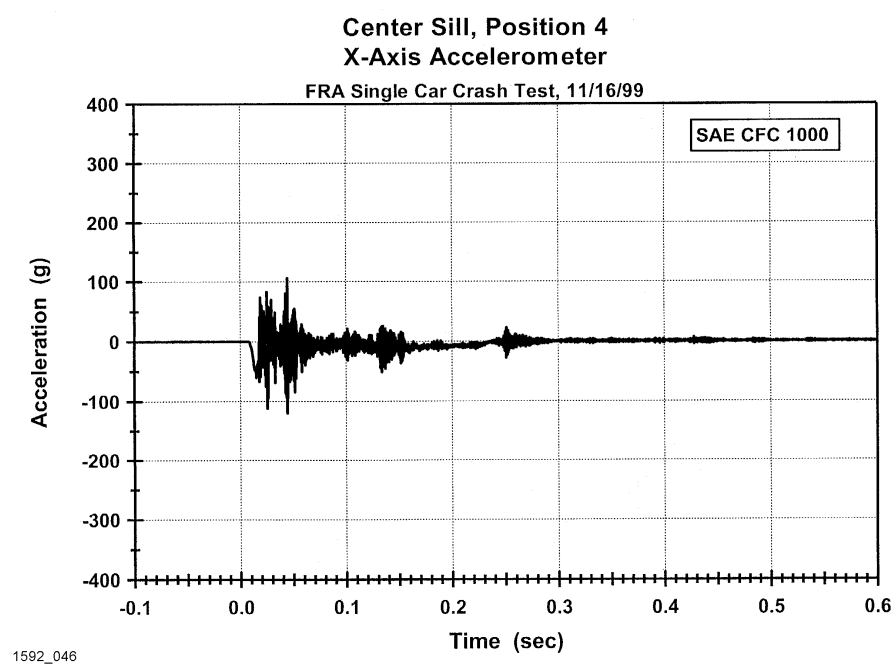

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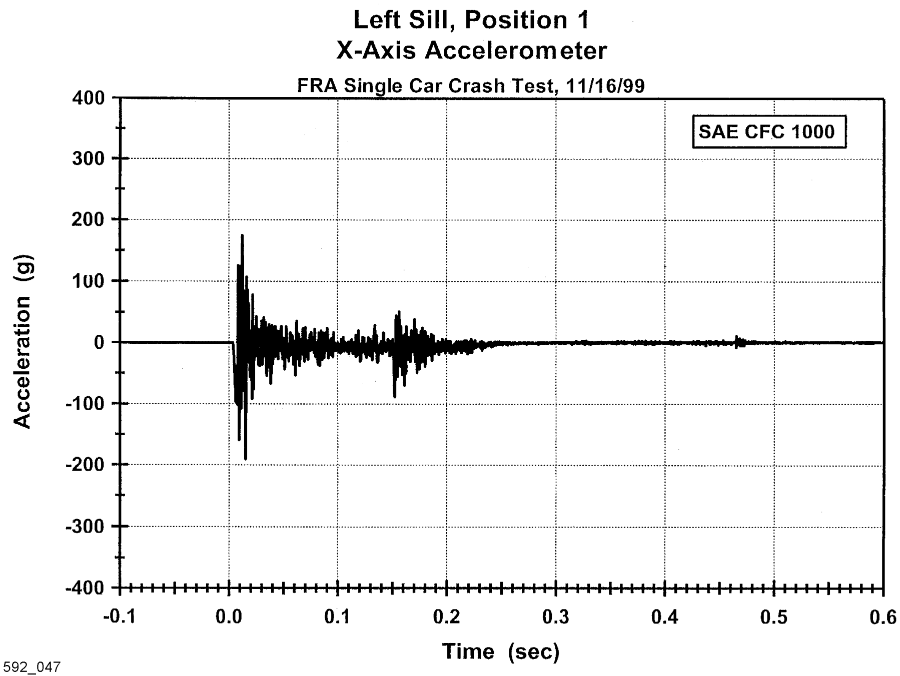

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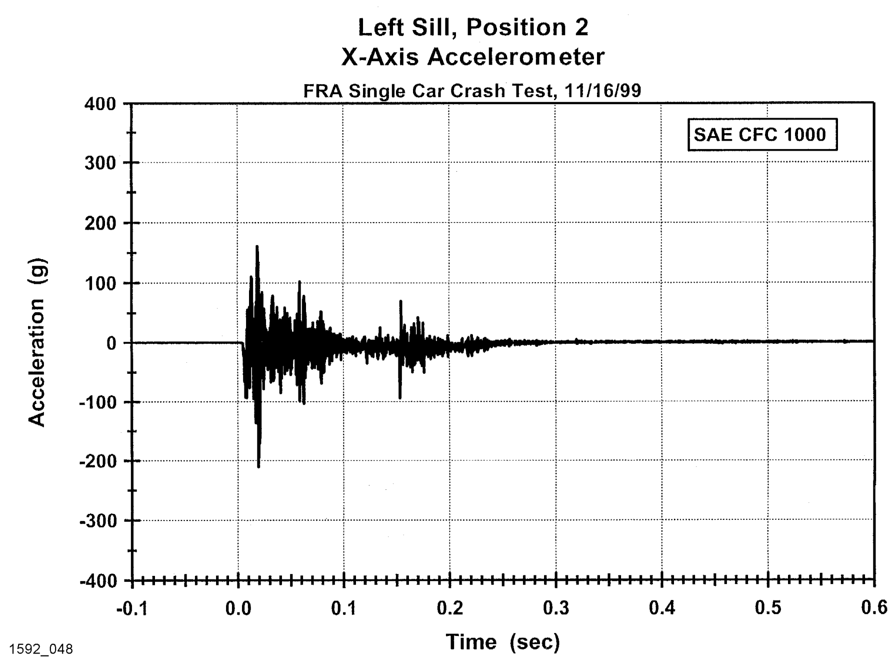

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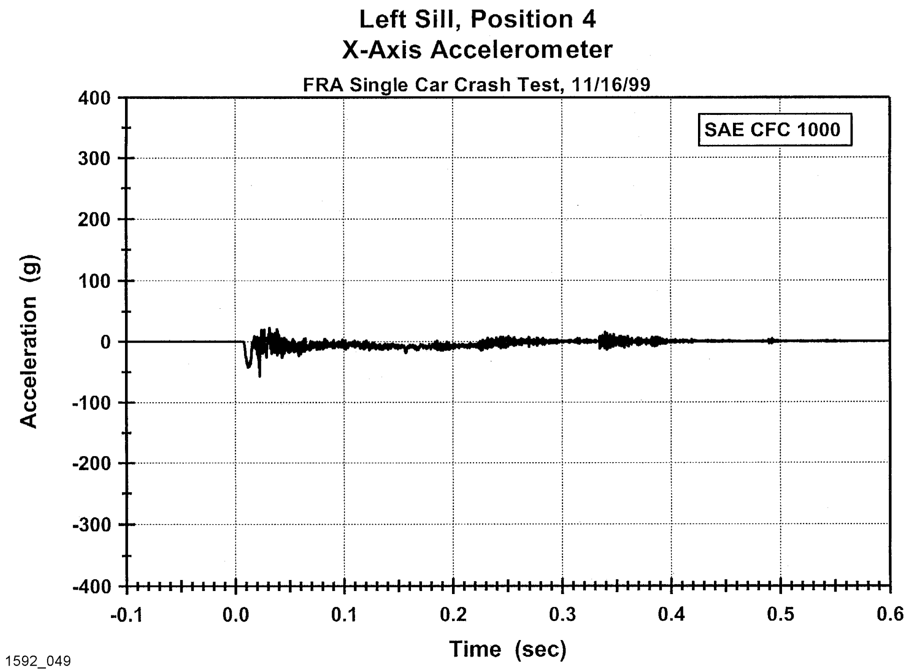

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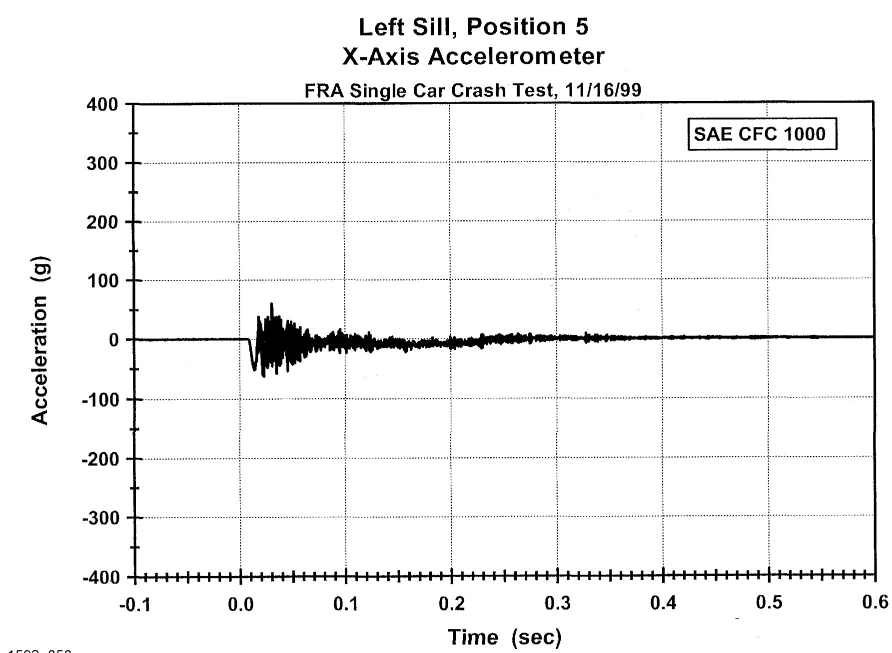

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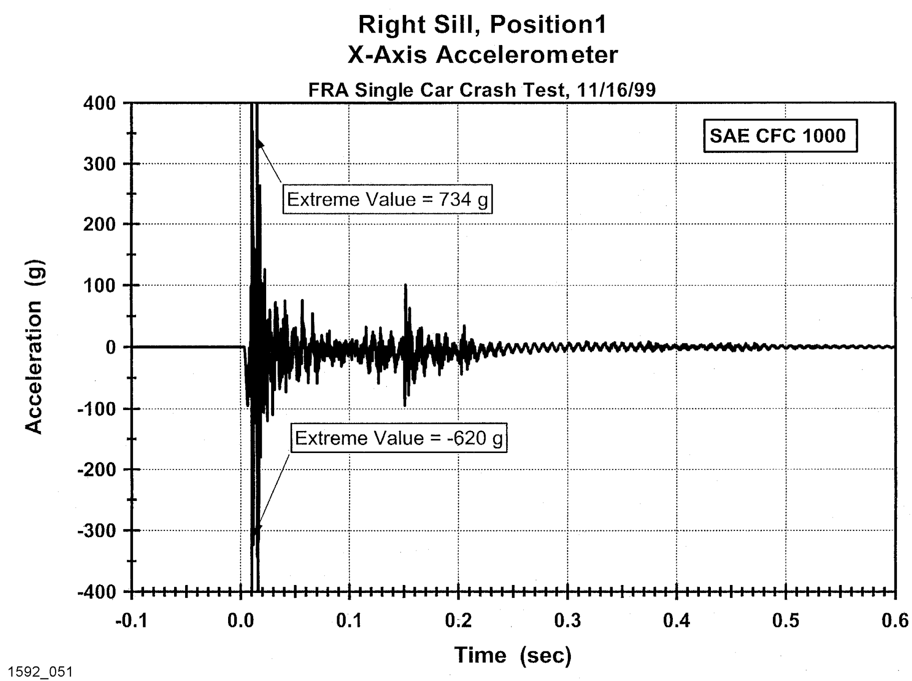

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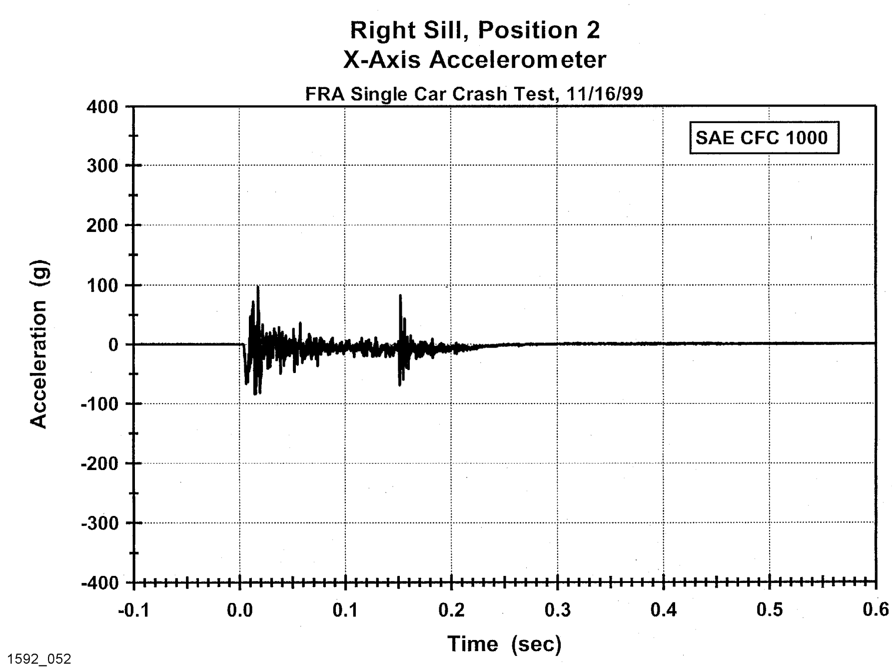

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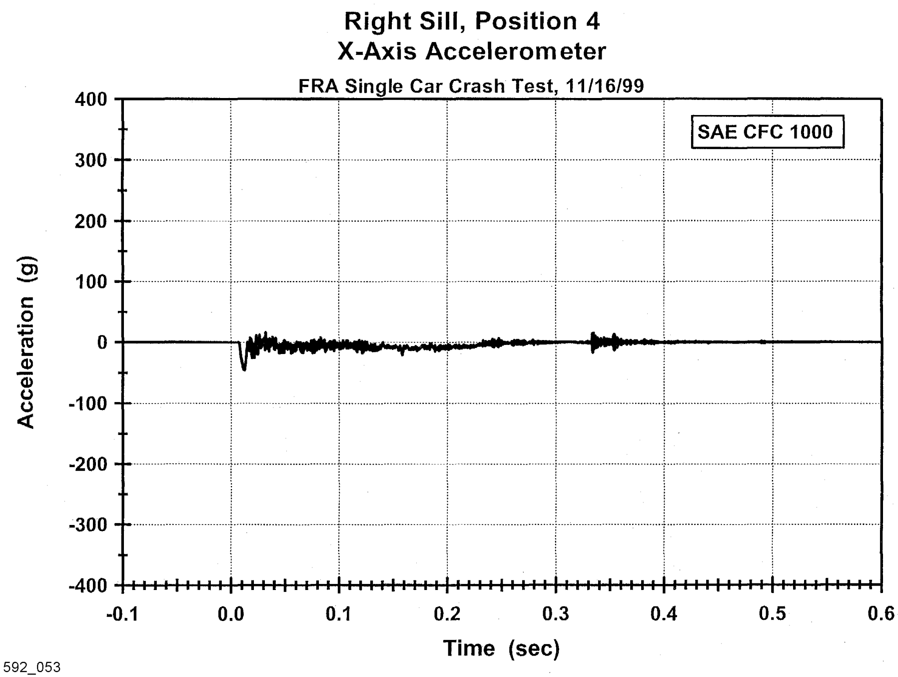

1592_053

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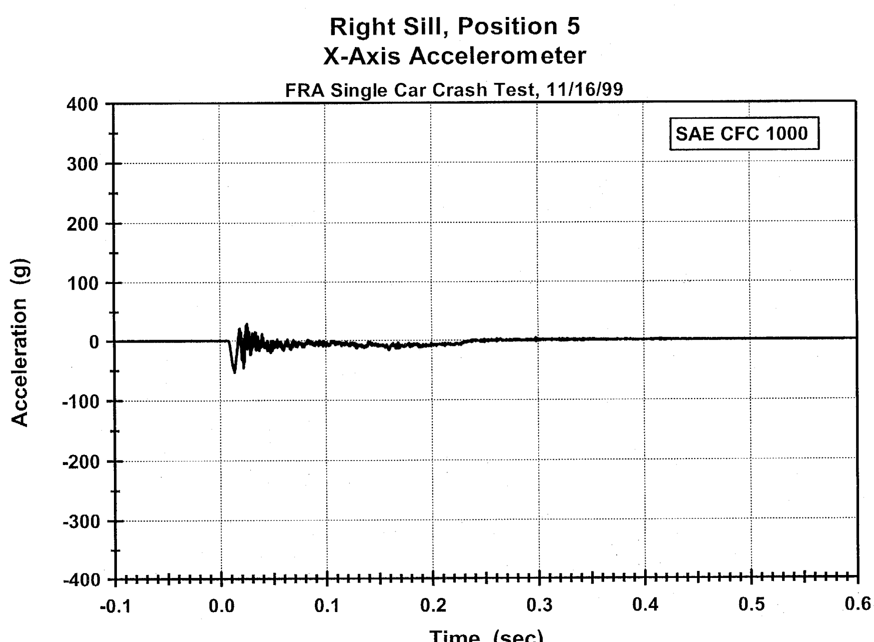

1592_054

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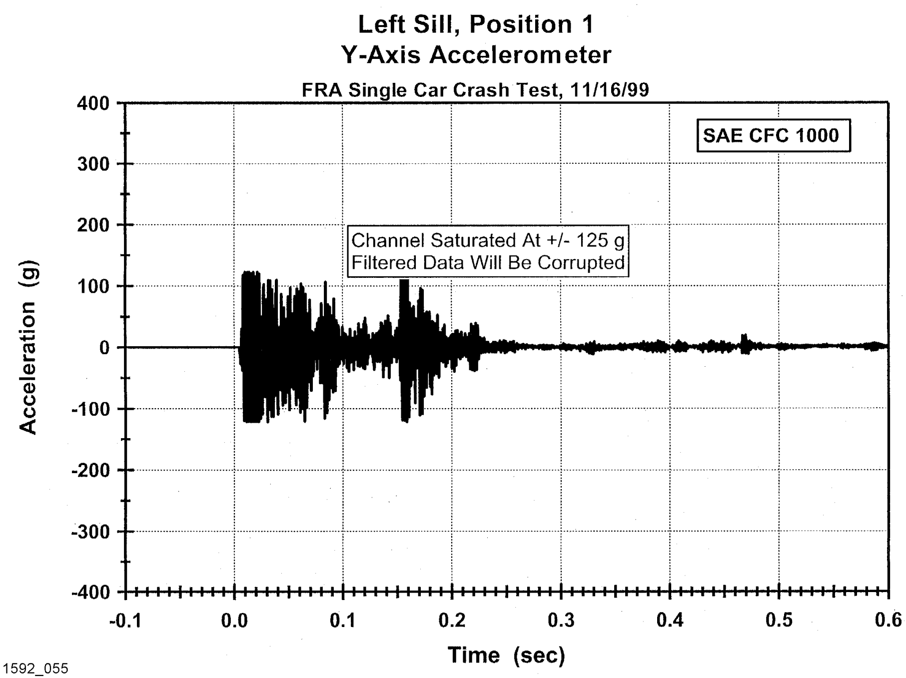

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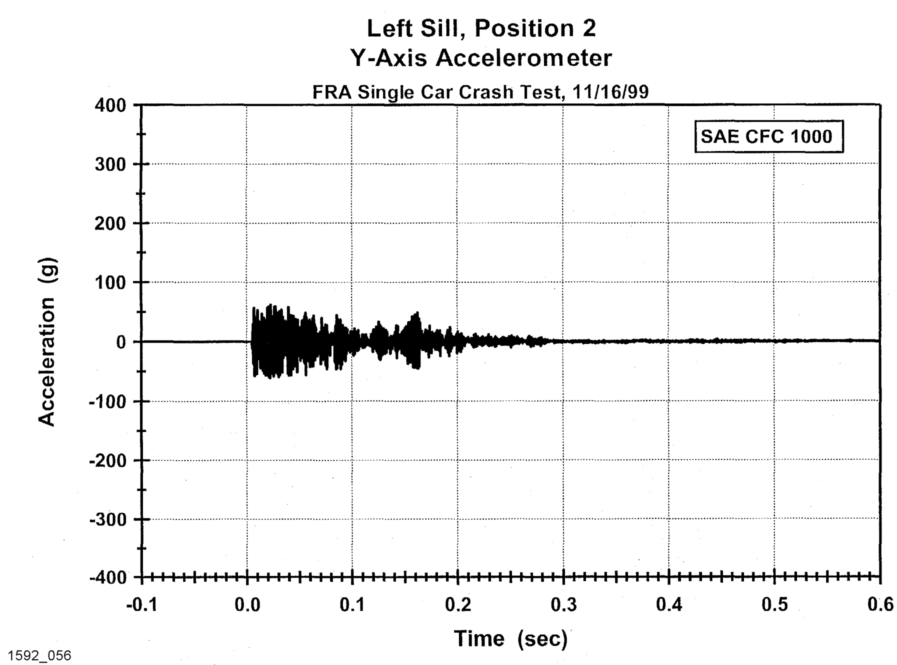

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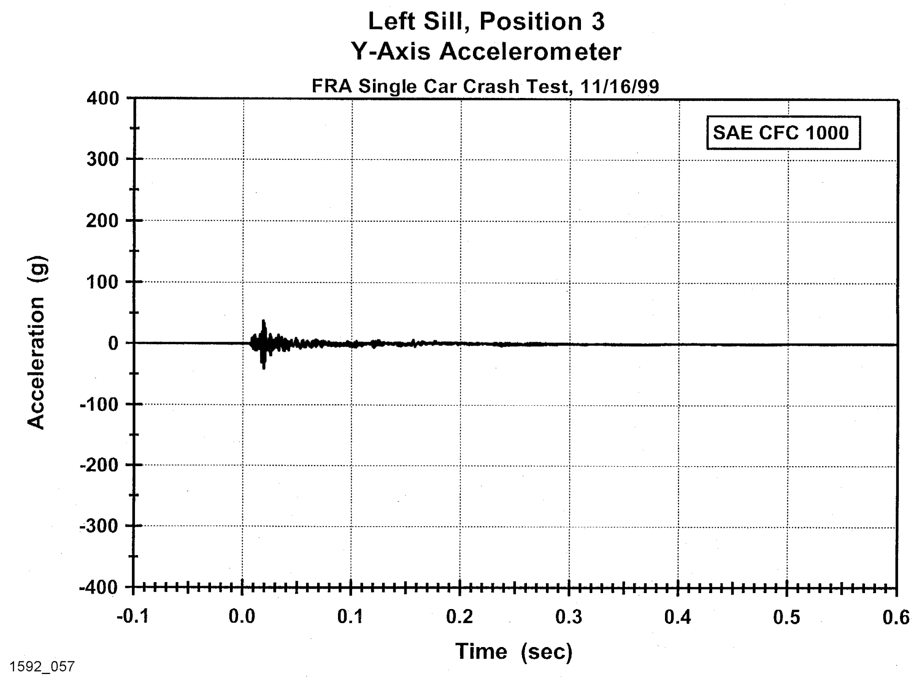

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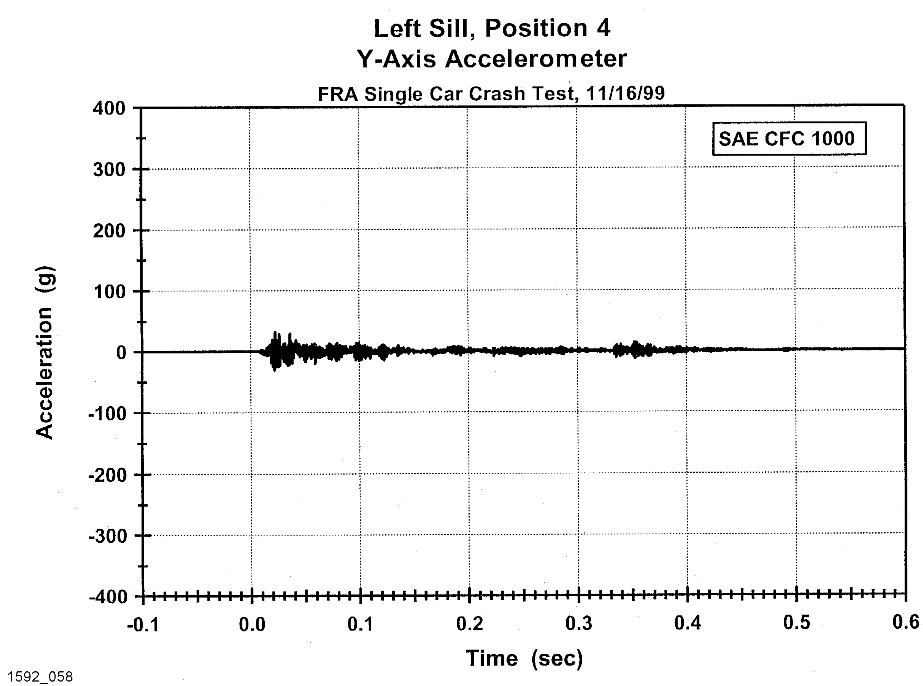

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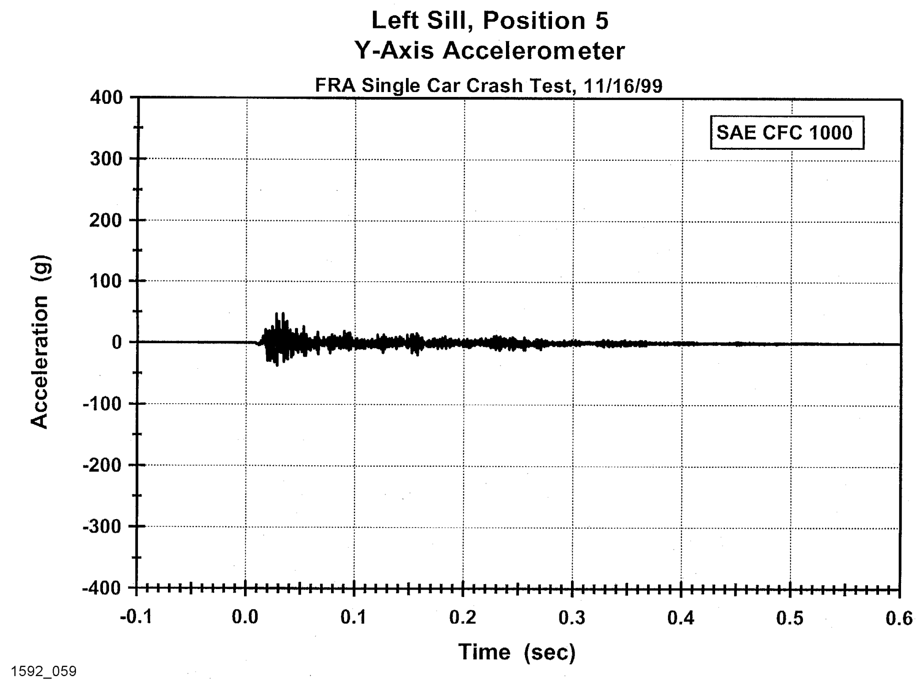

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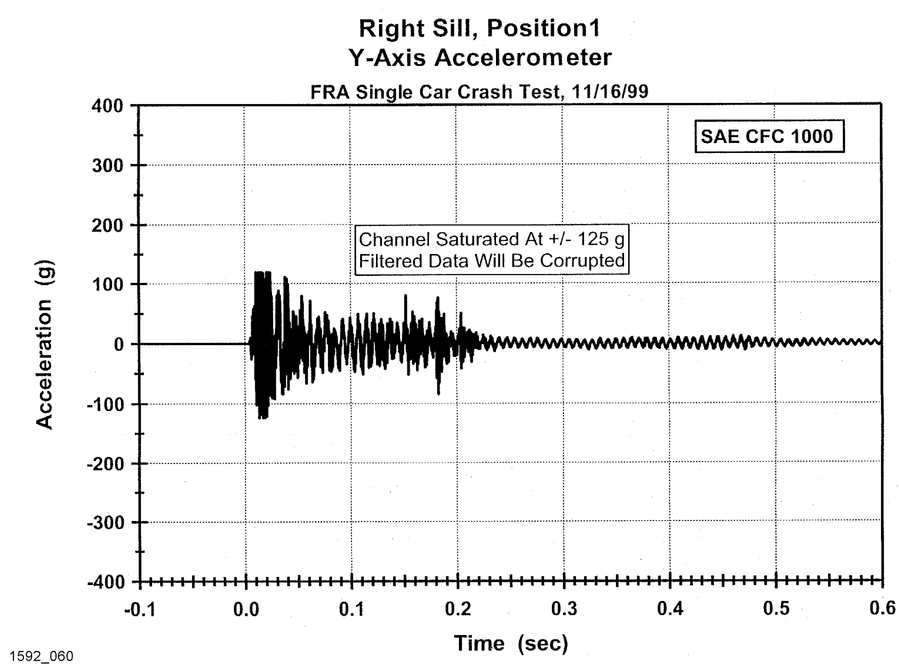

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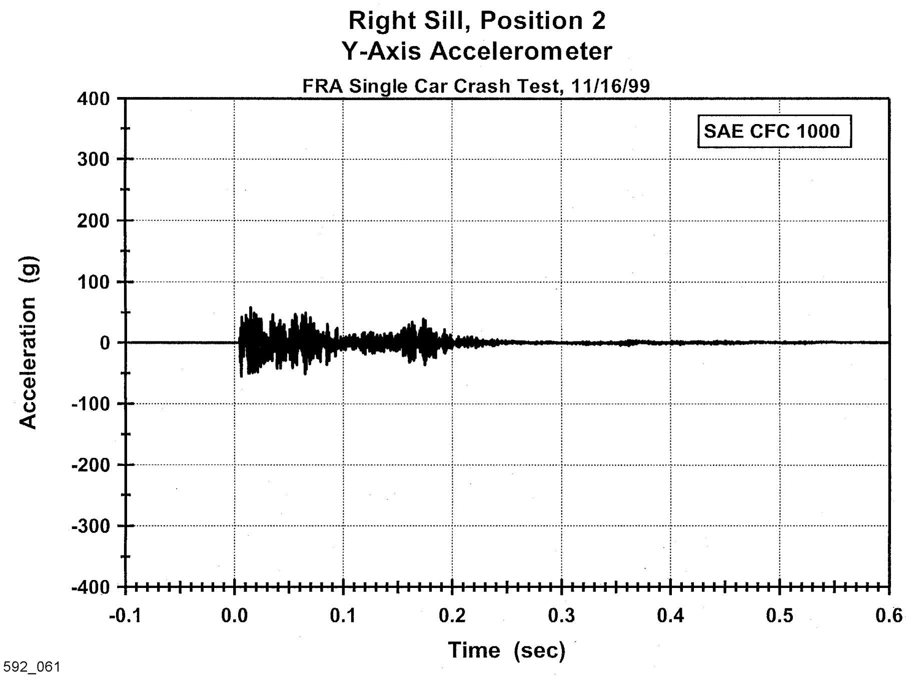

1592_061

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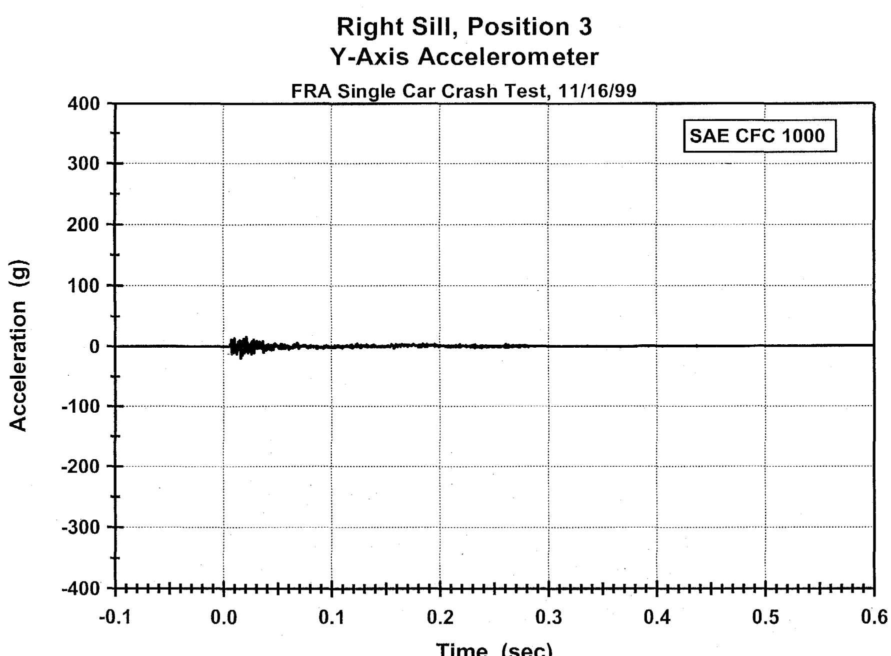

1592_062

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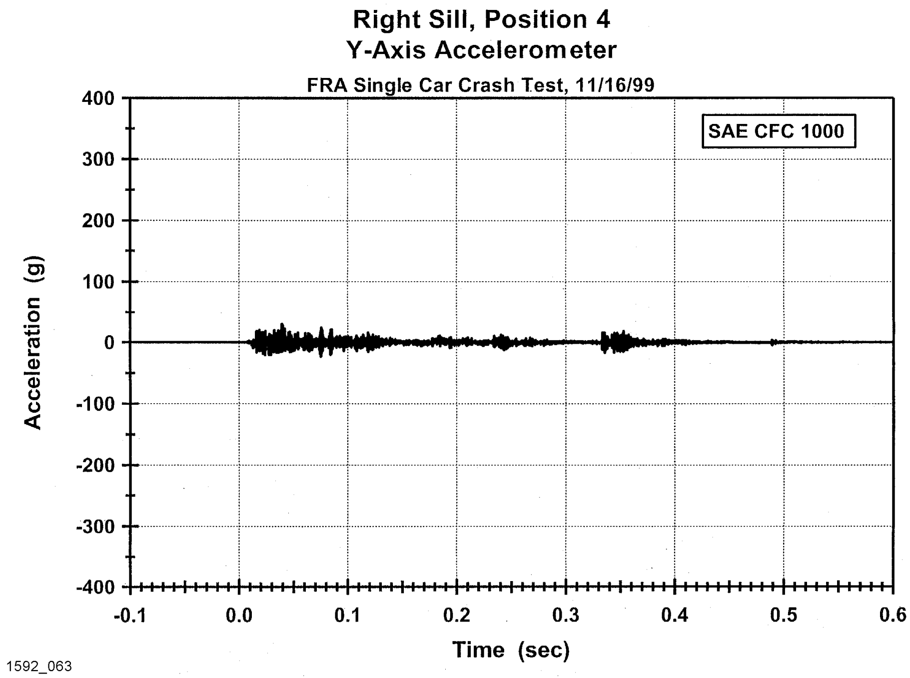

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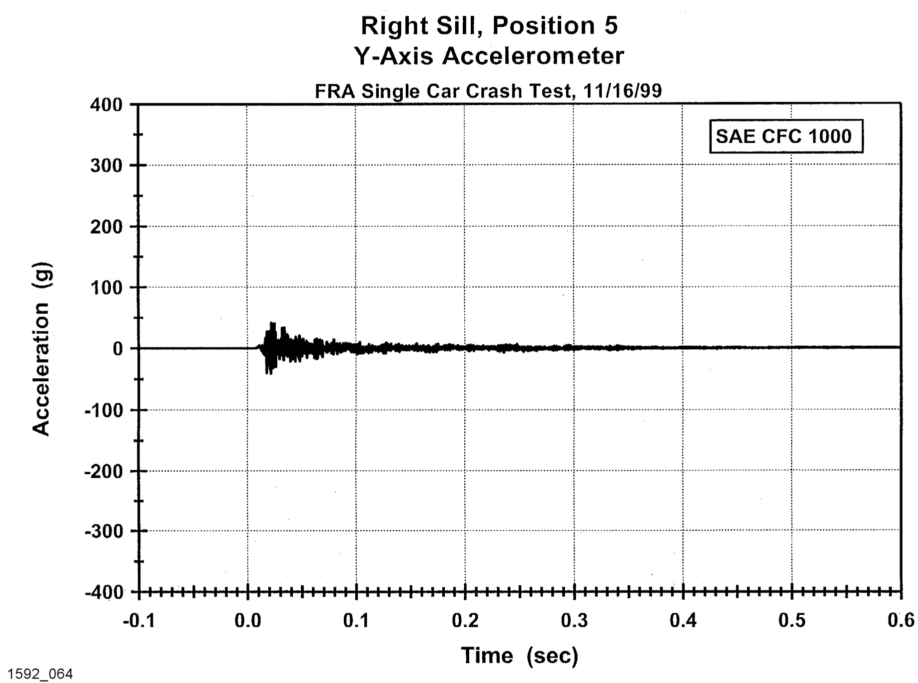

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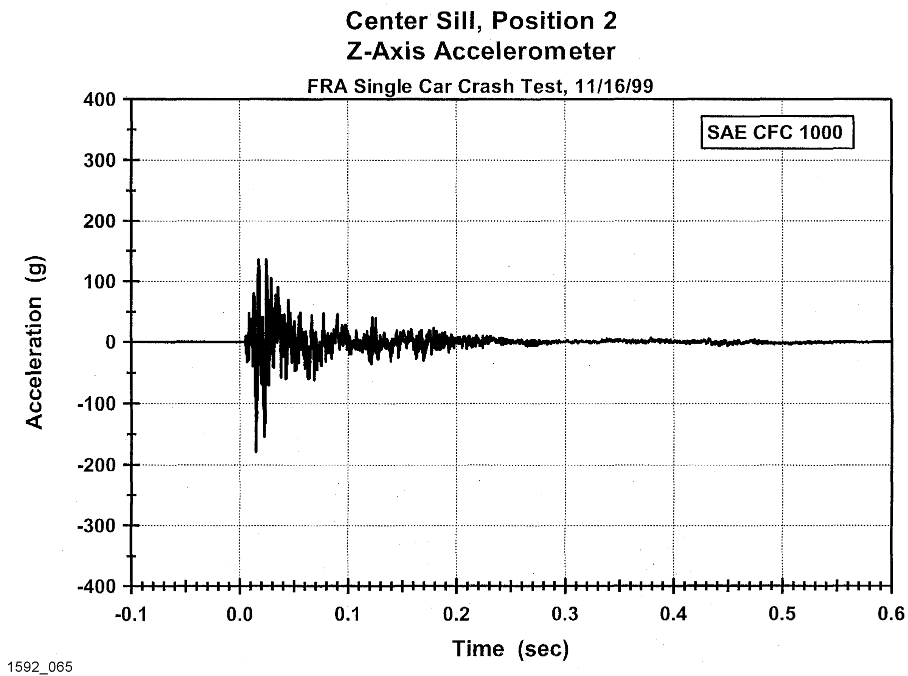

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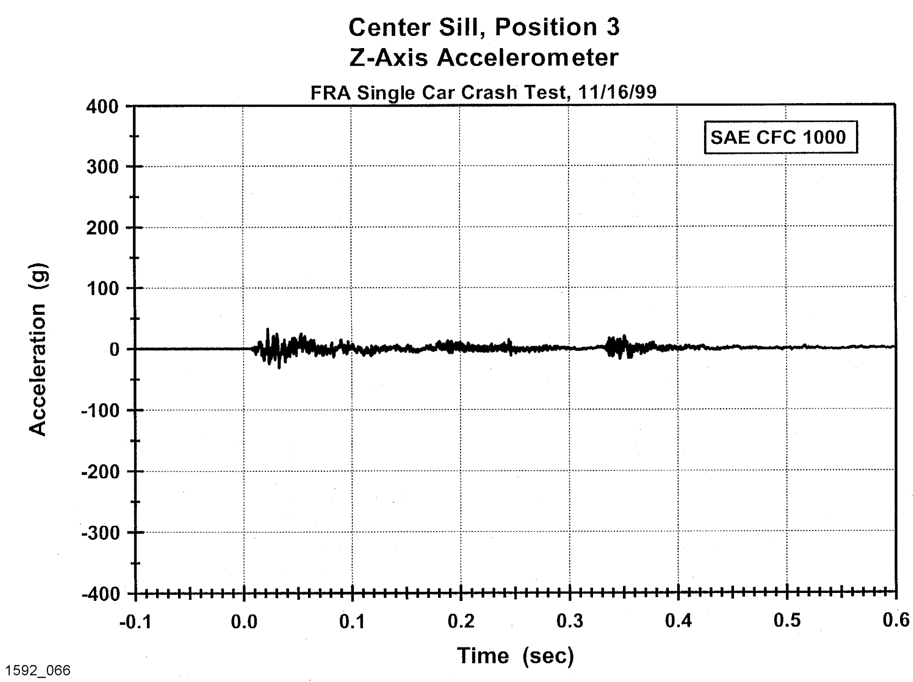

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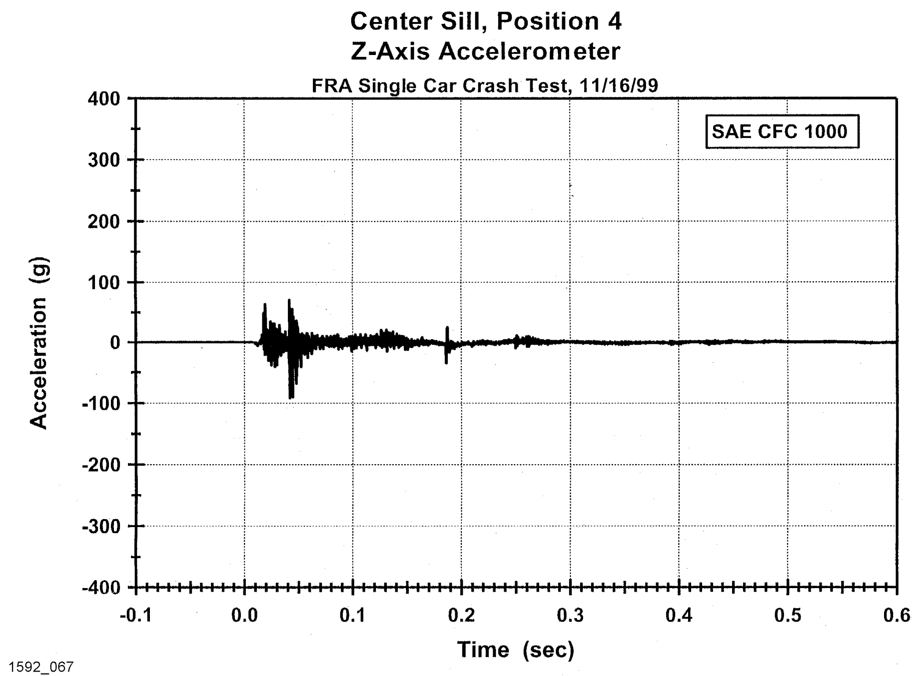

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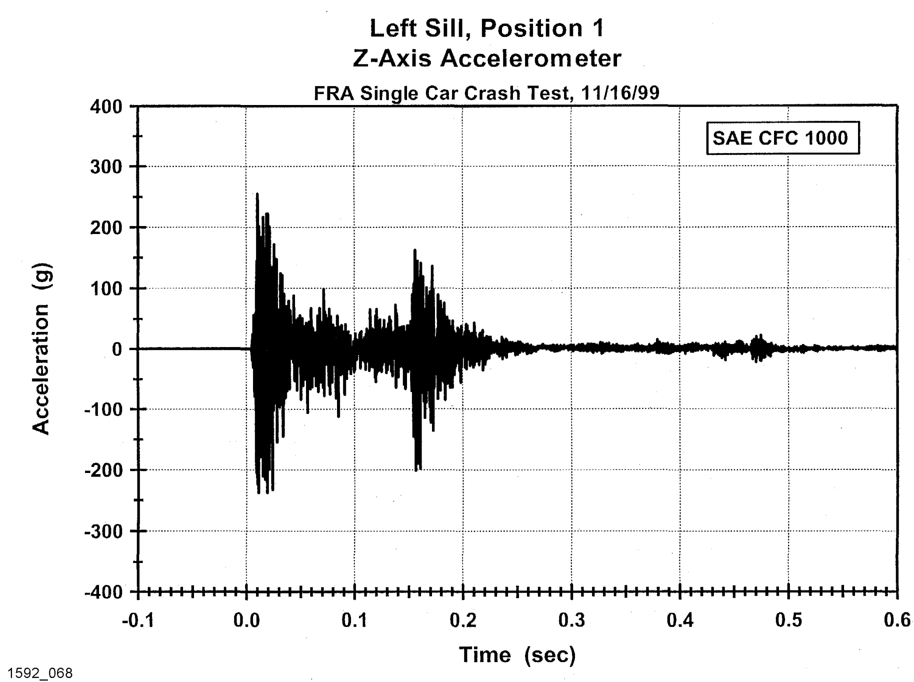

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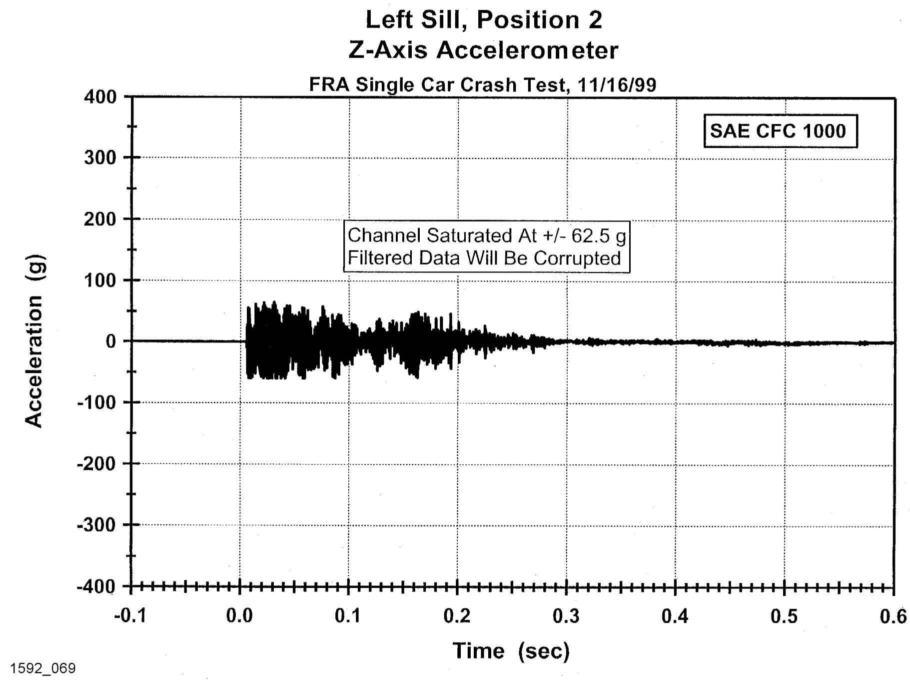

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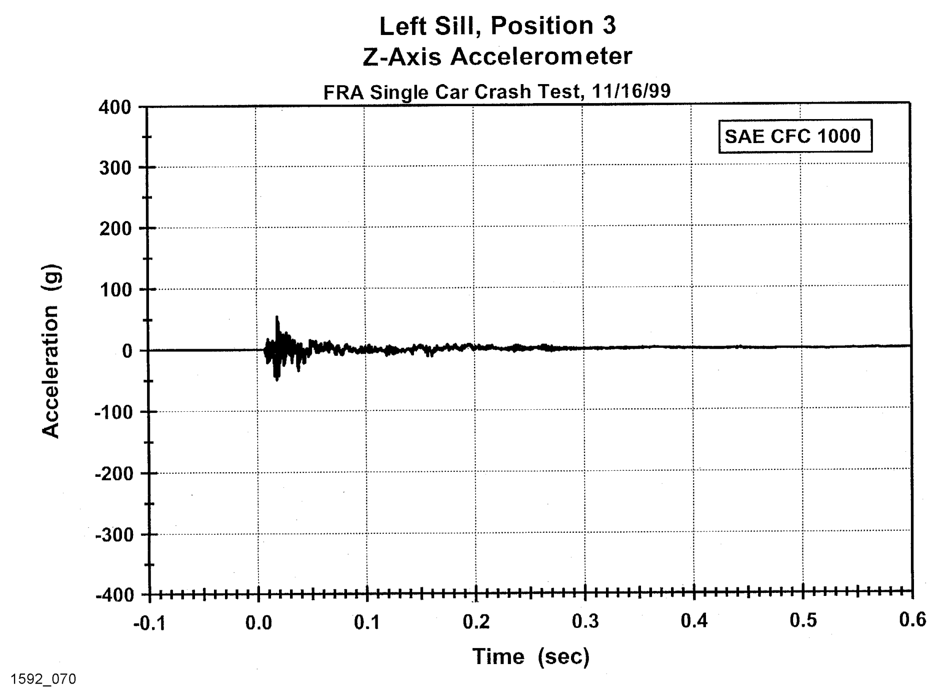

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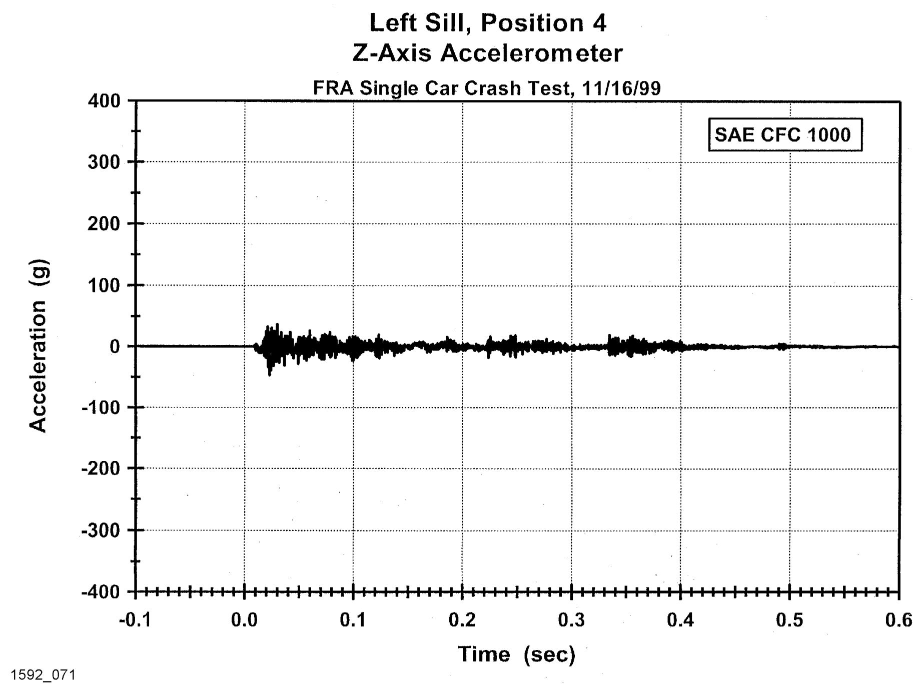

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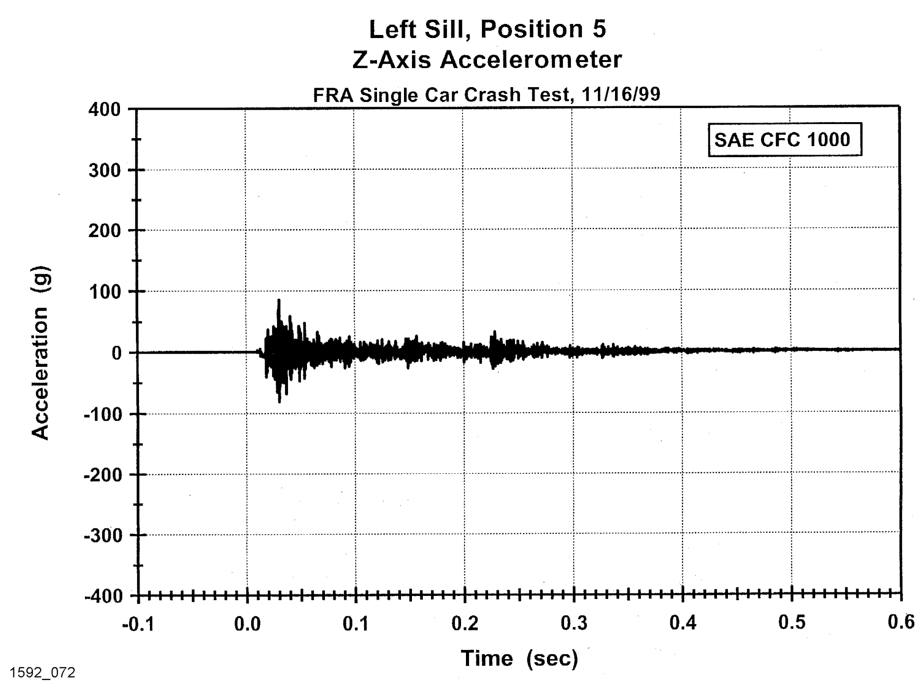

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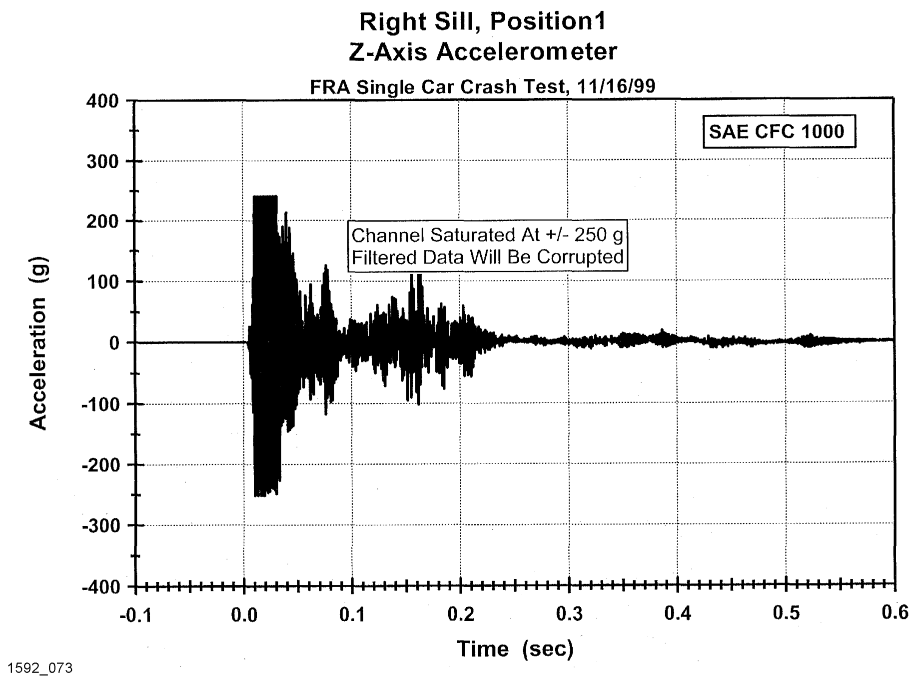

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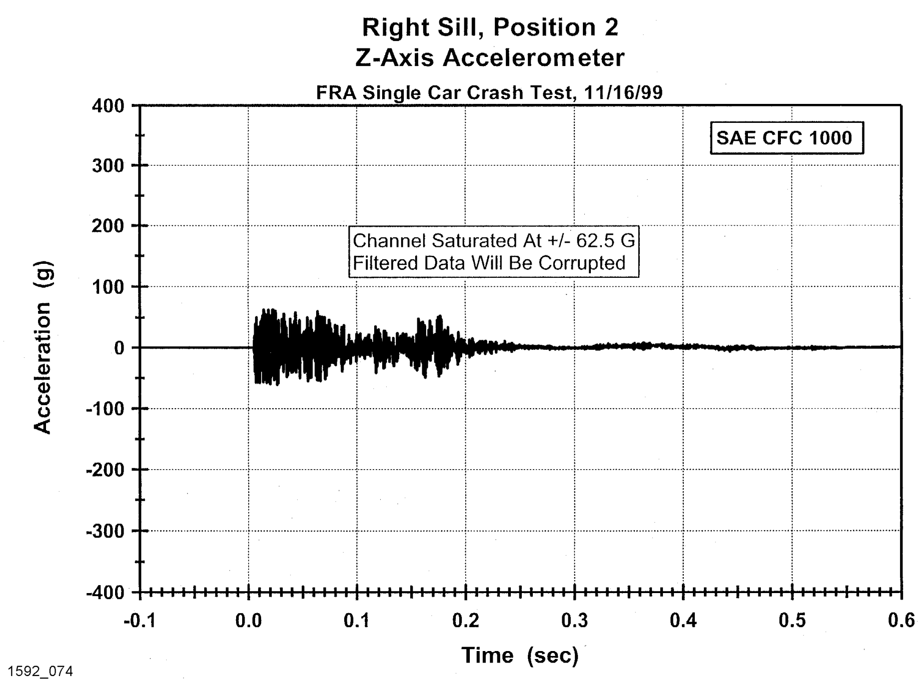

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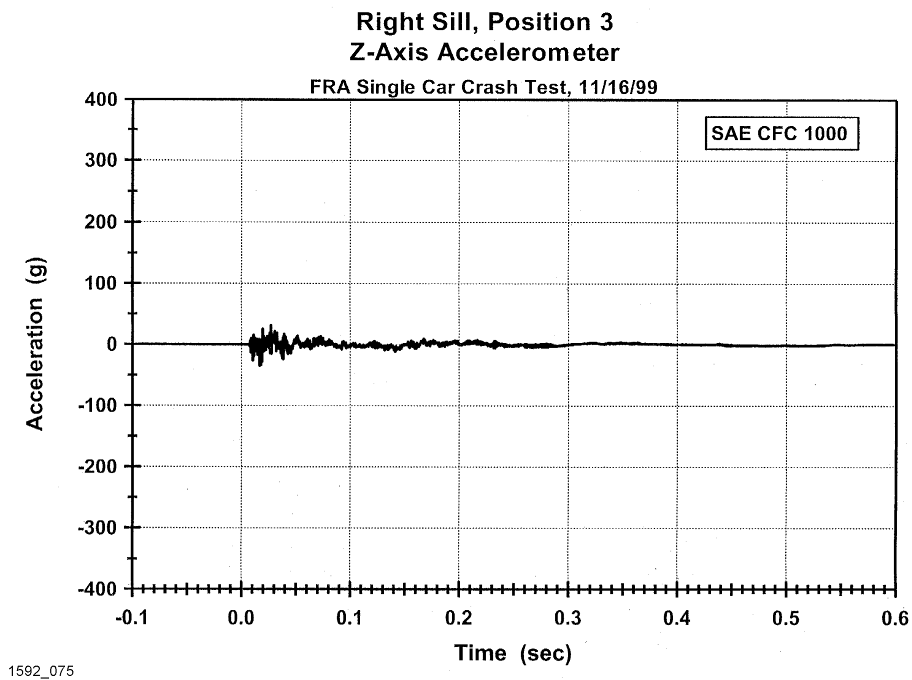

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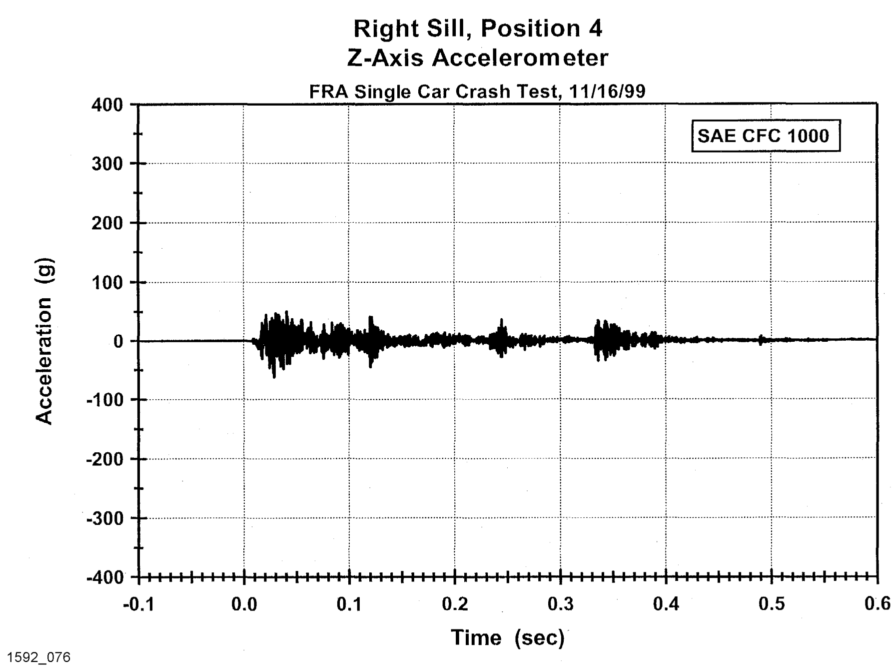

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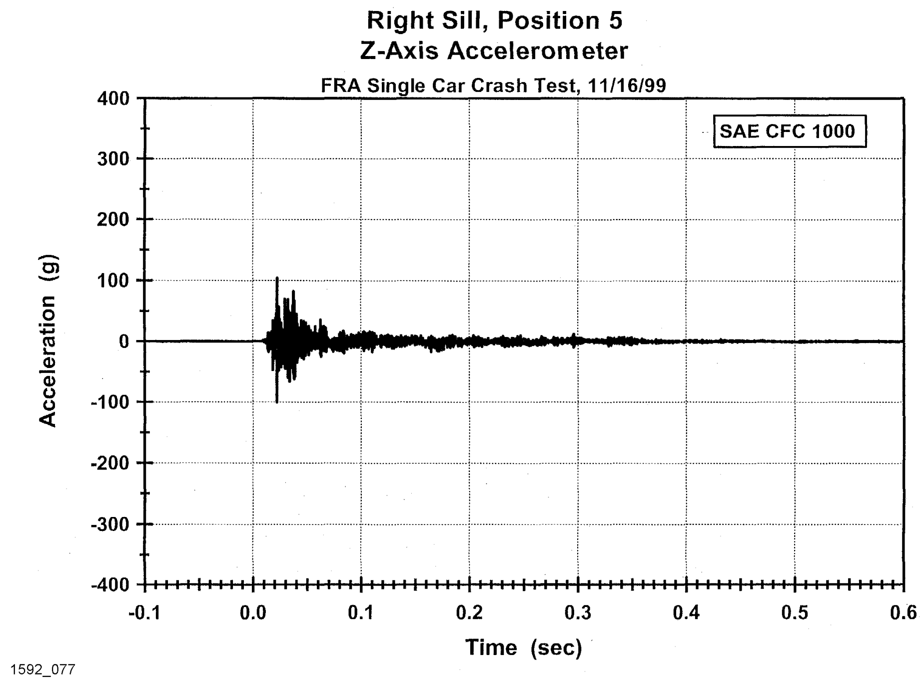

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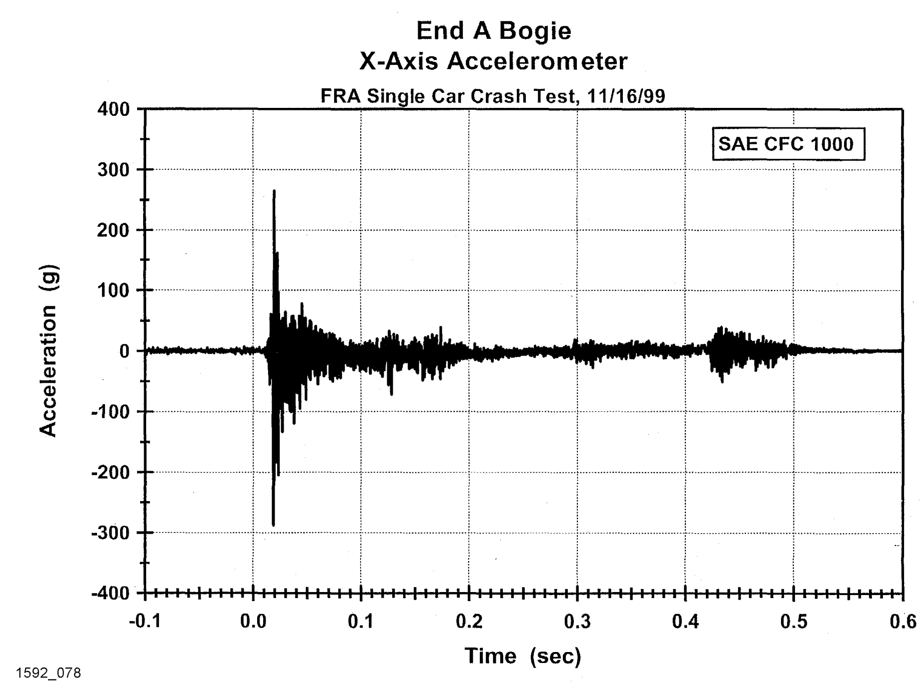

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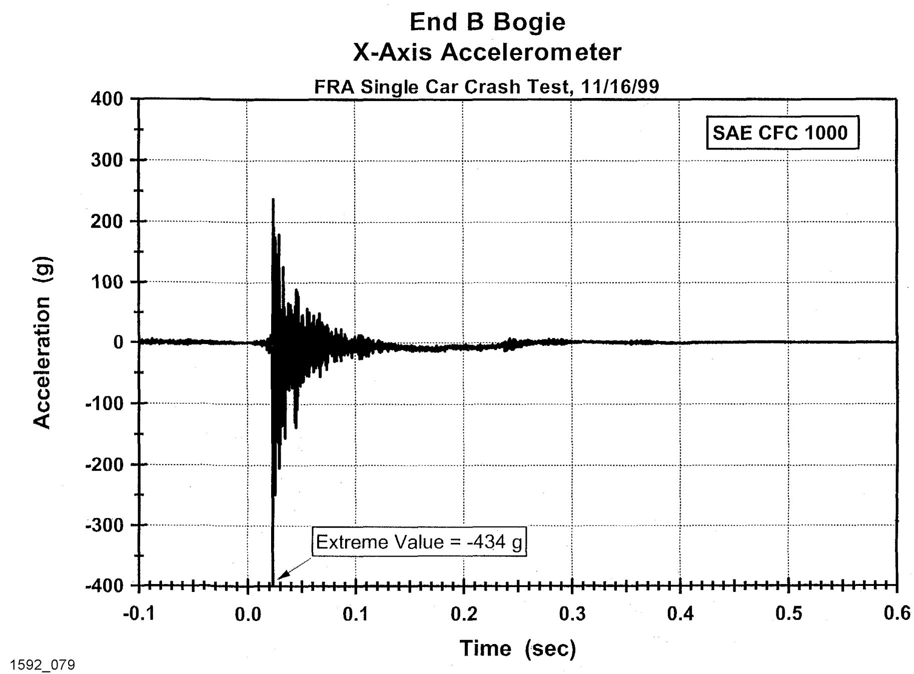

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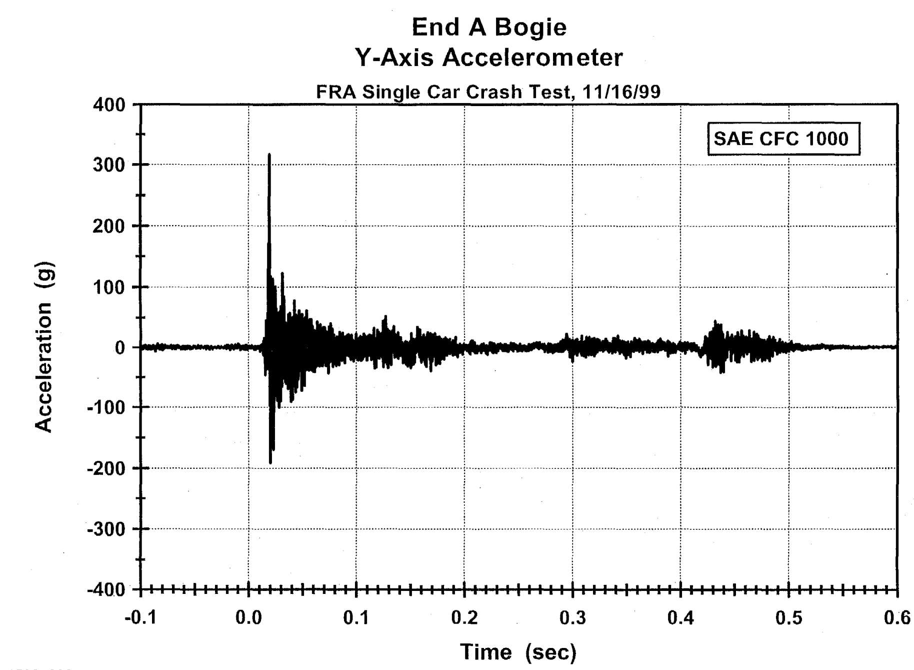

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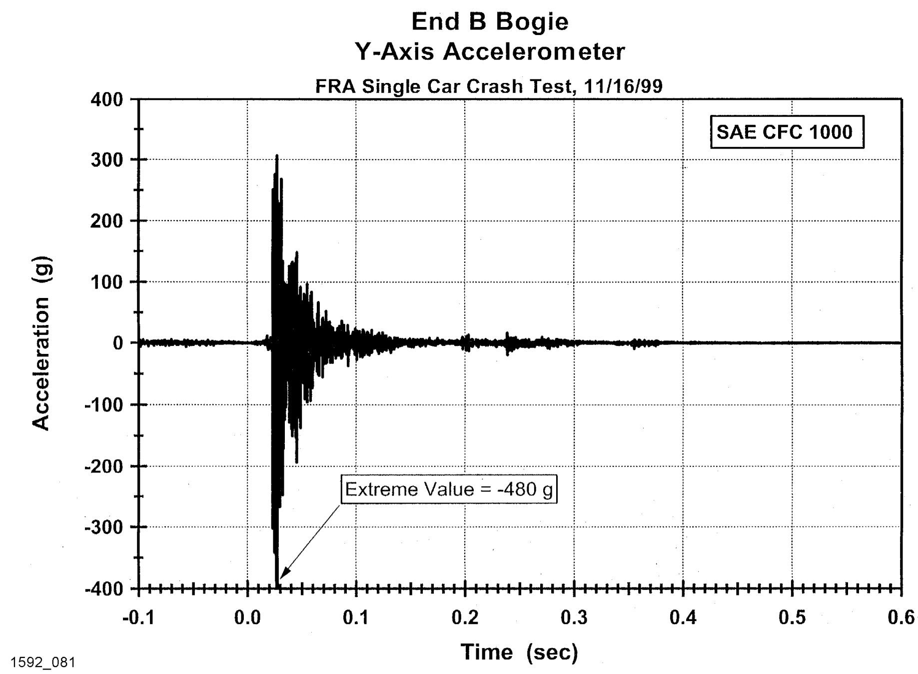

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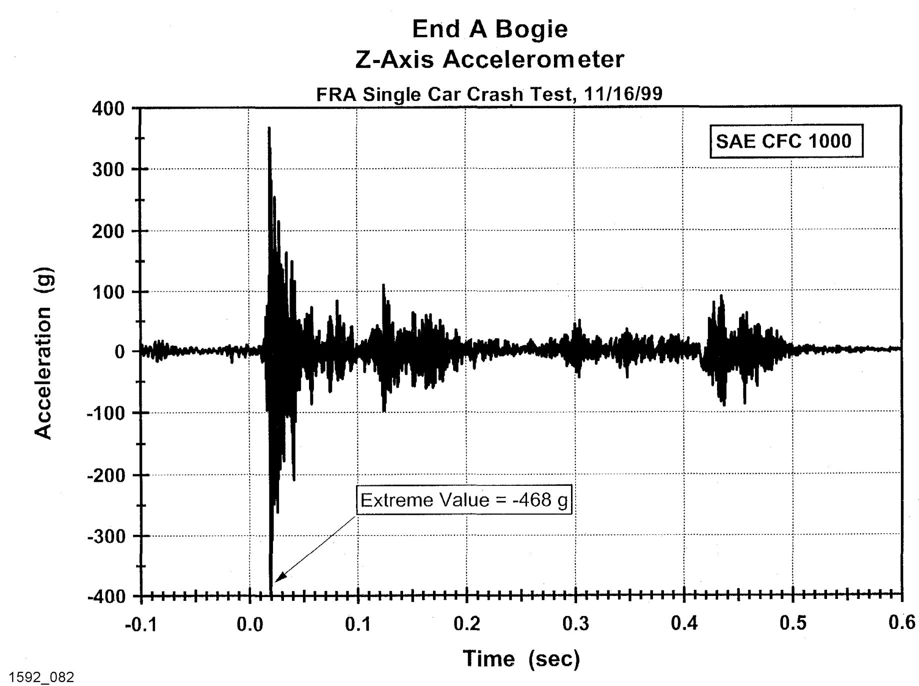

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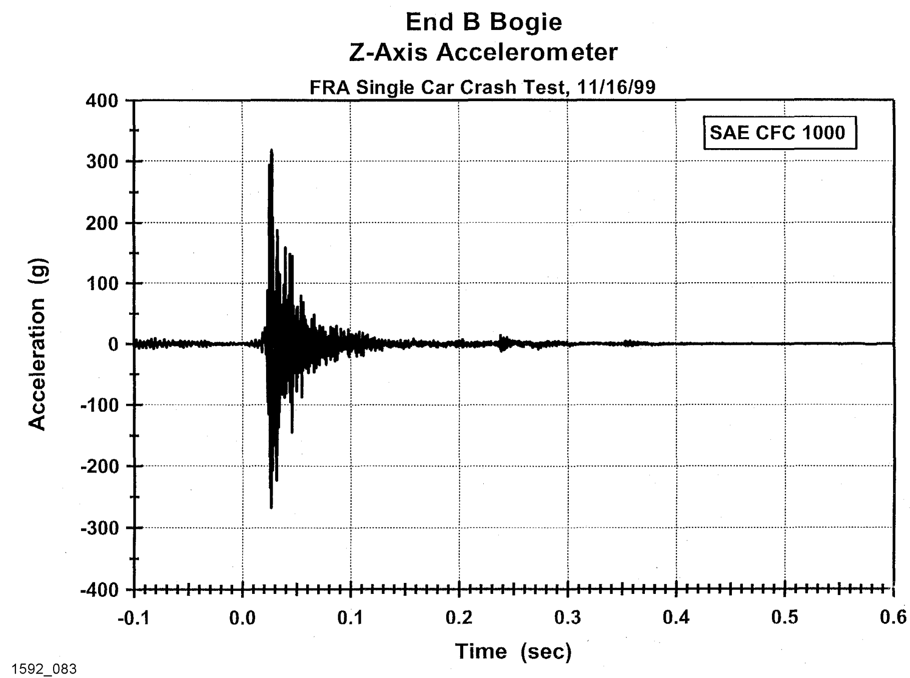

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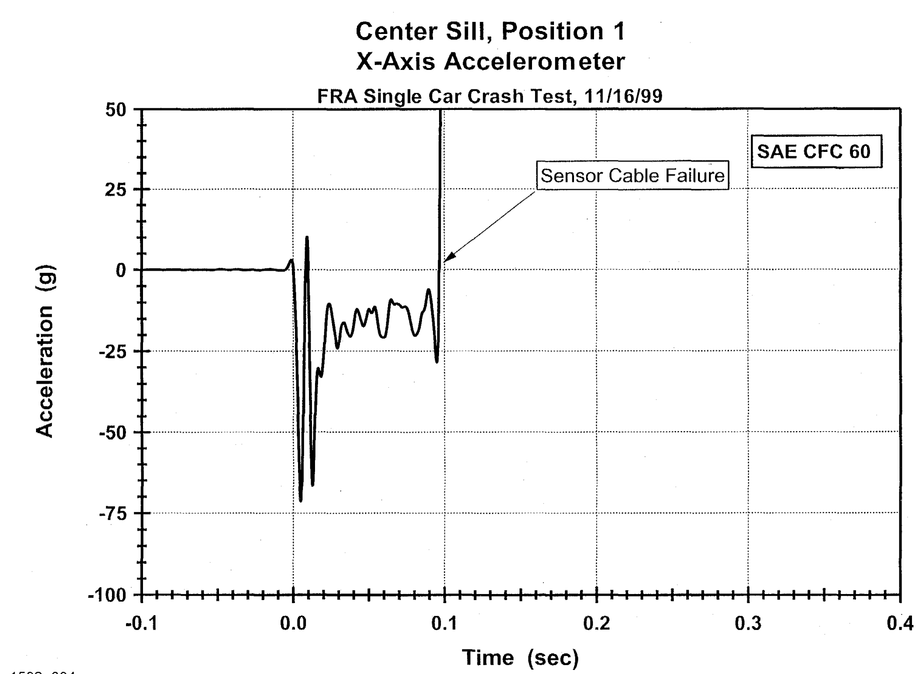

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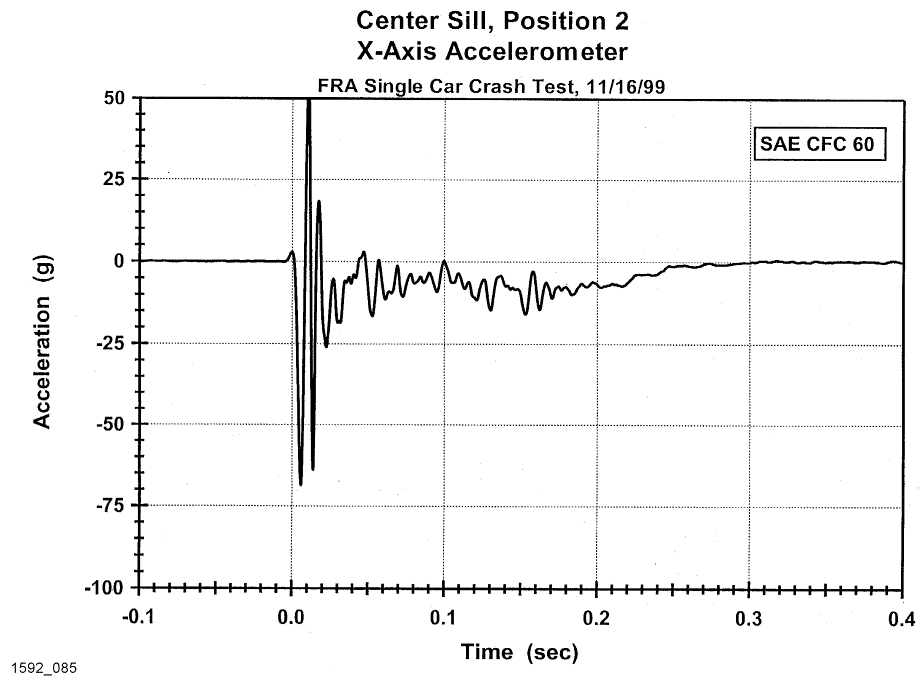

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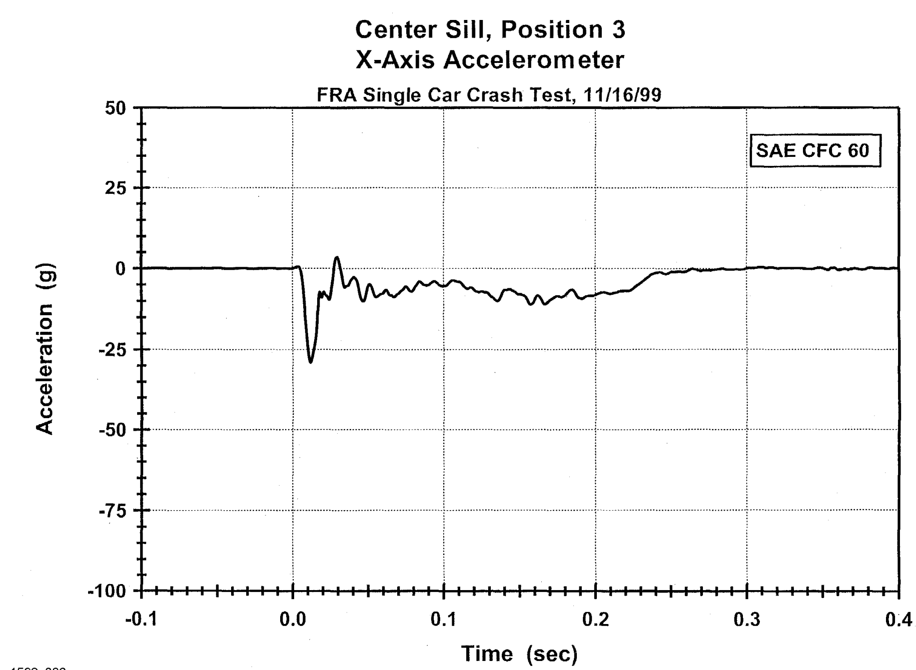

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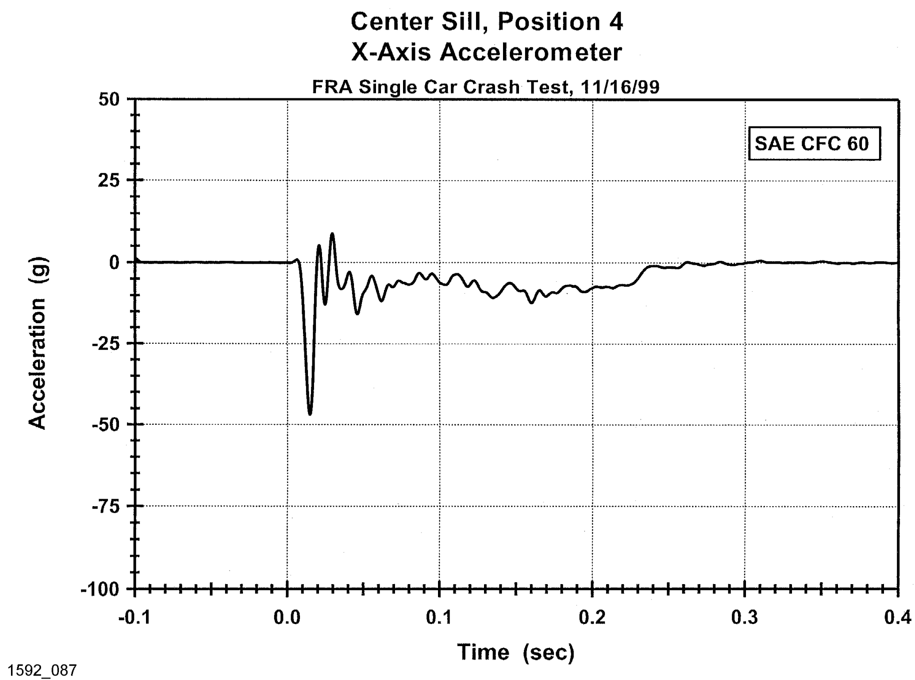

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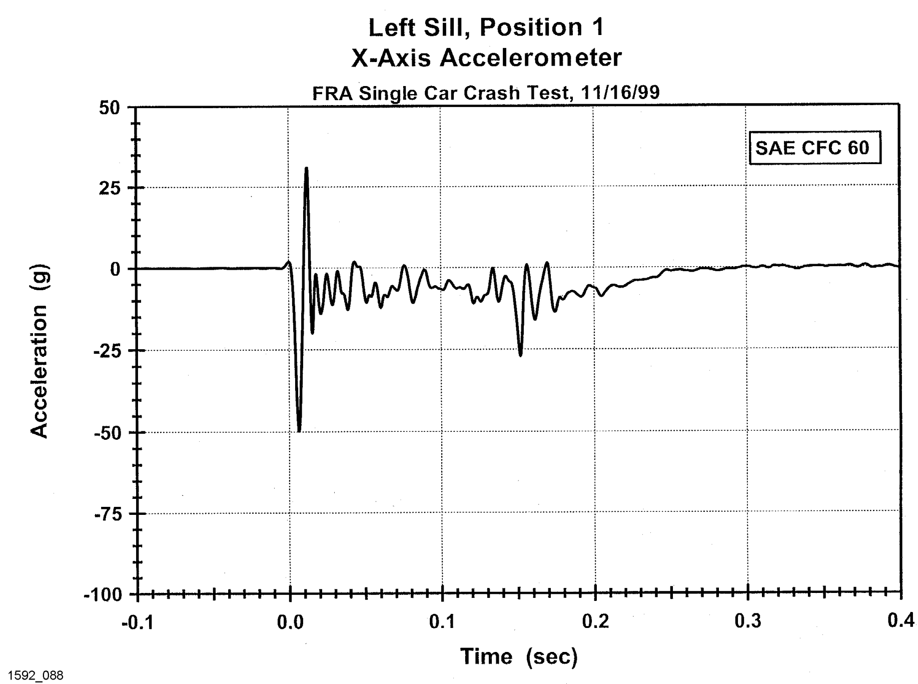

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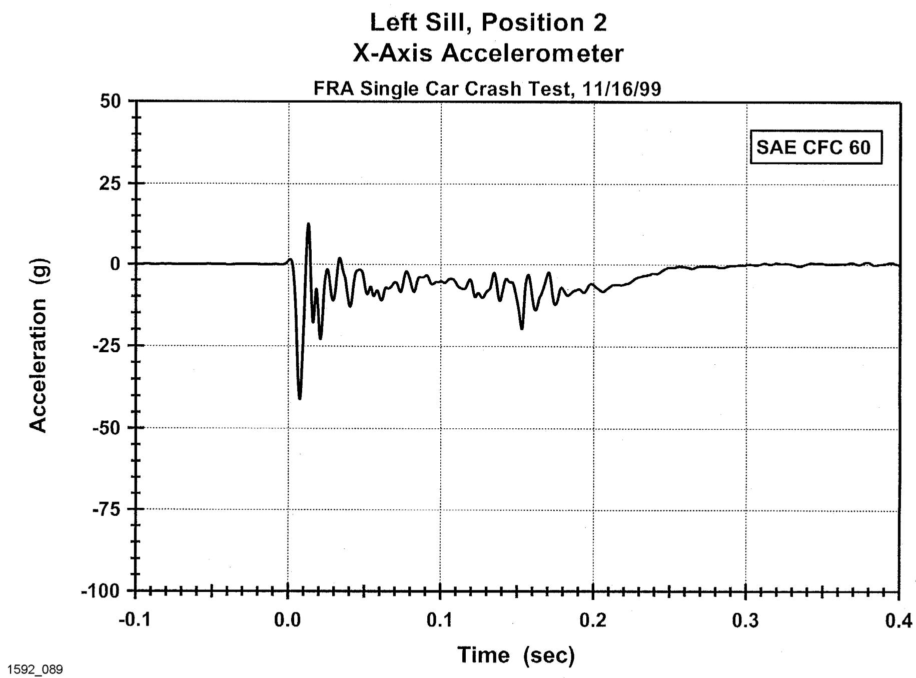

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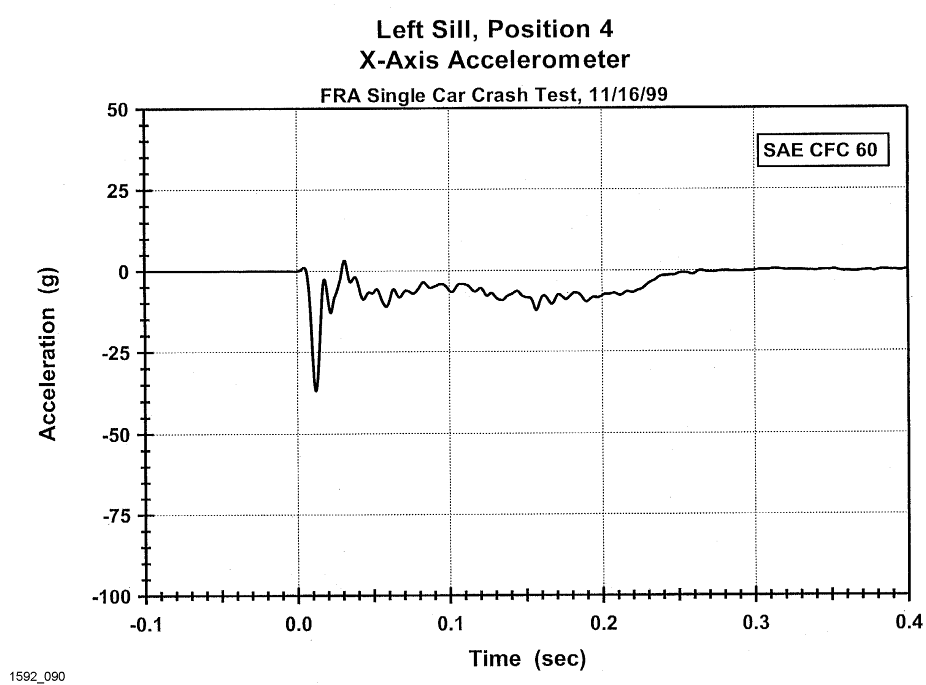

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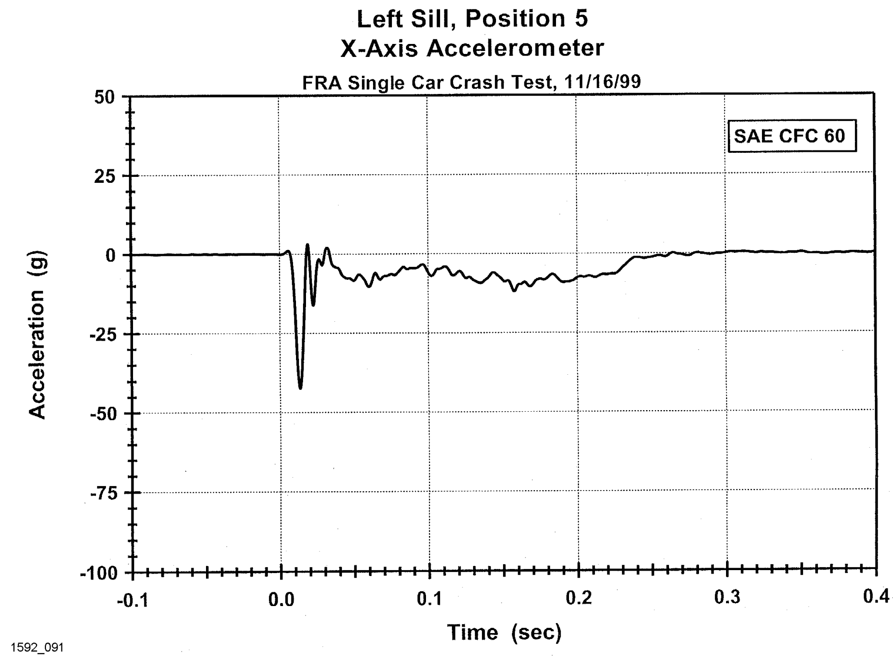

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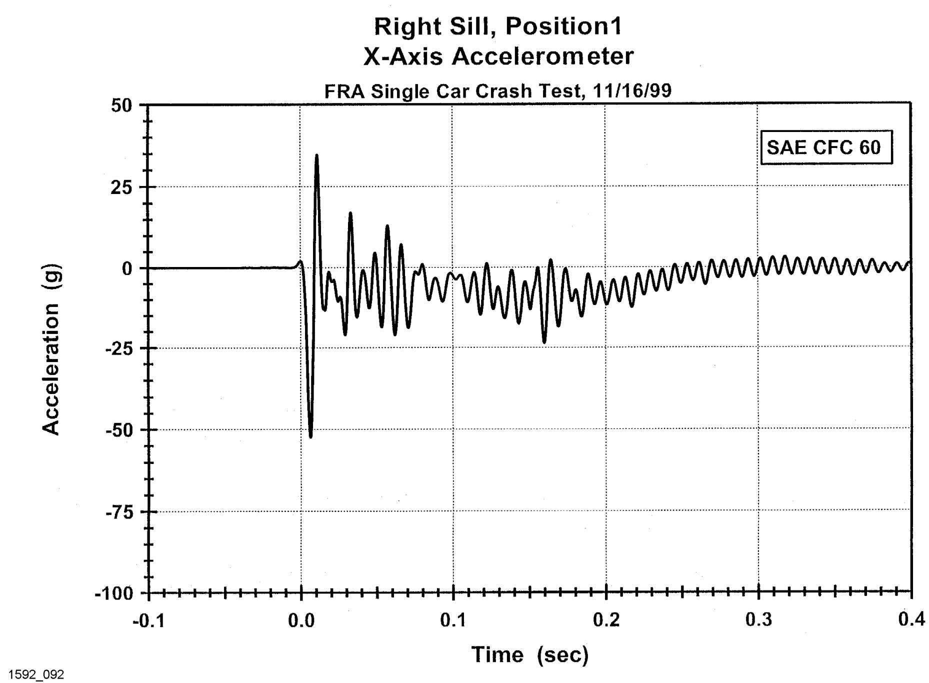

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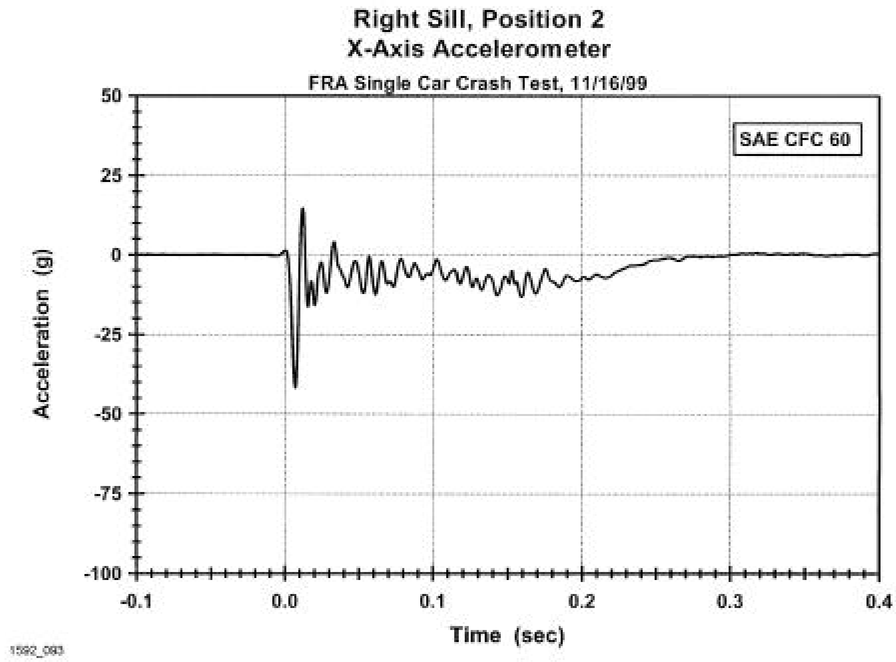

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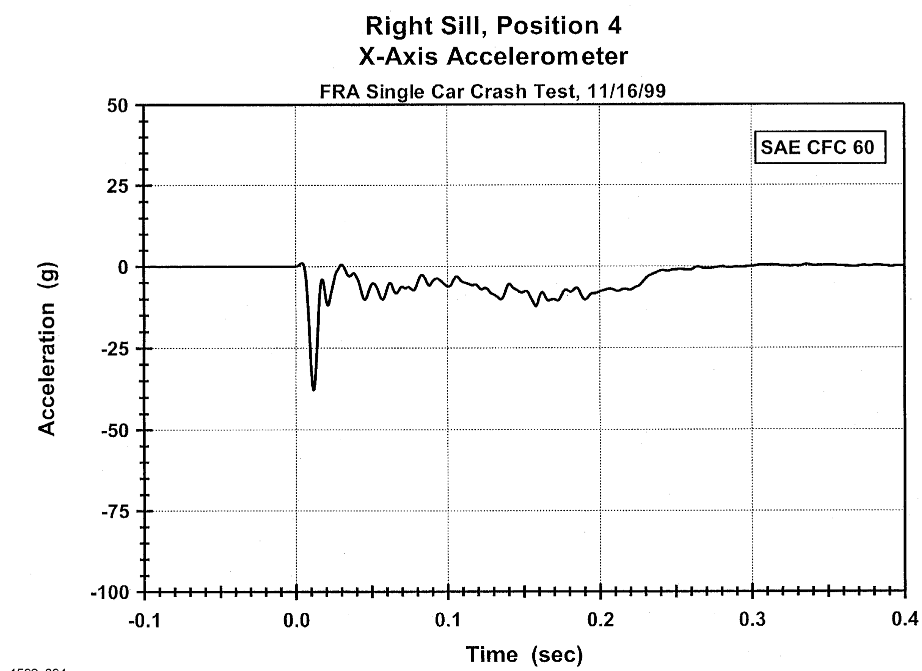

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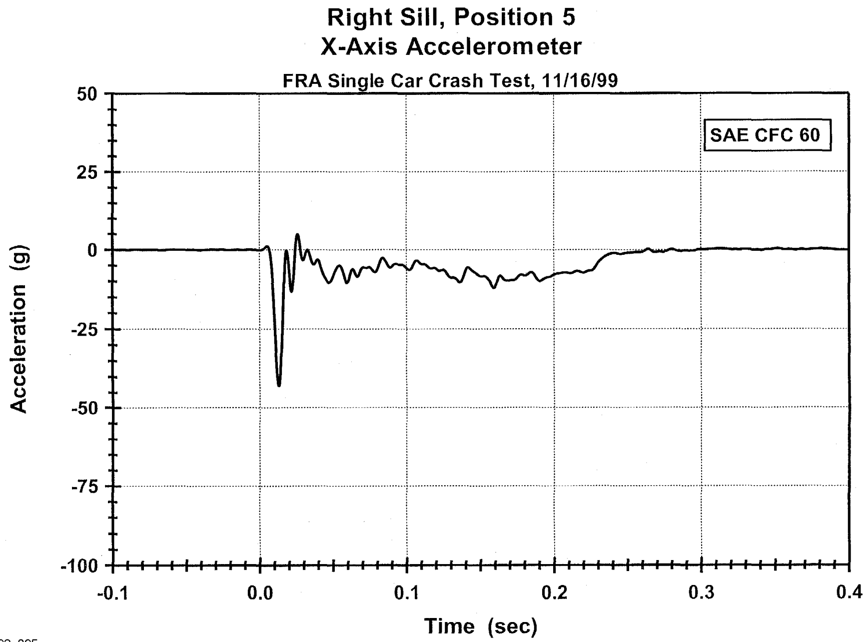

1592_095

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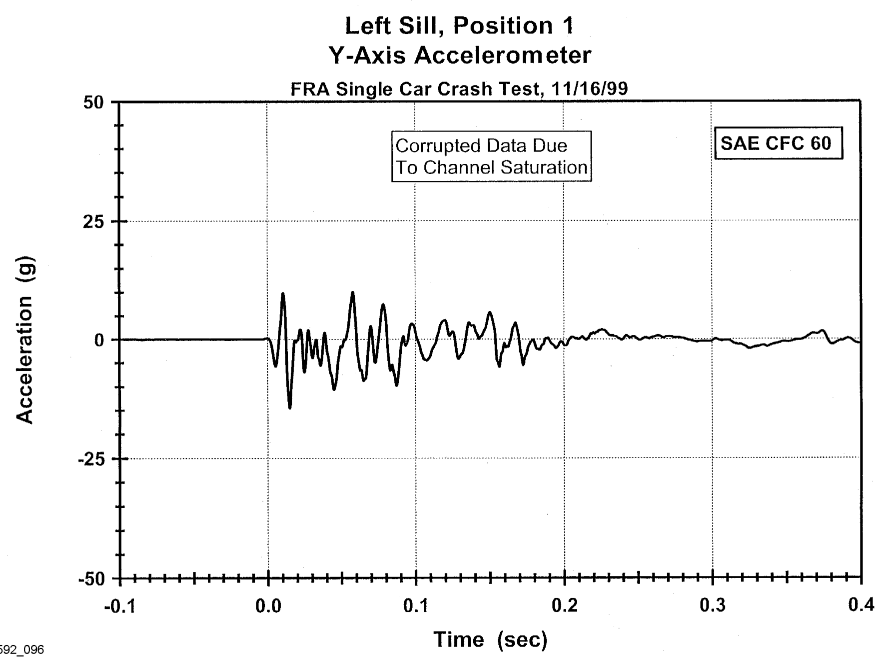

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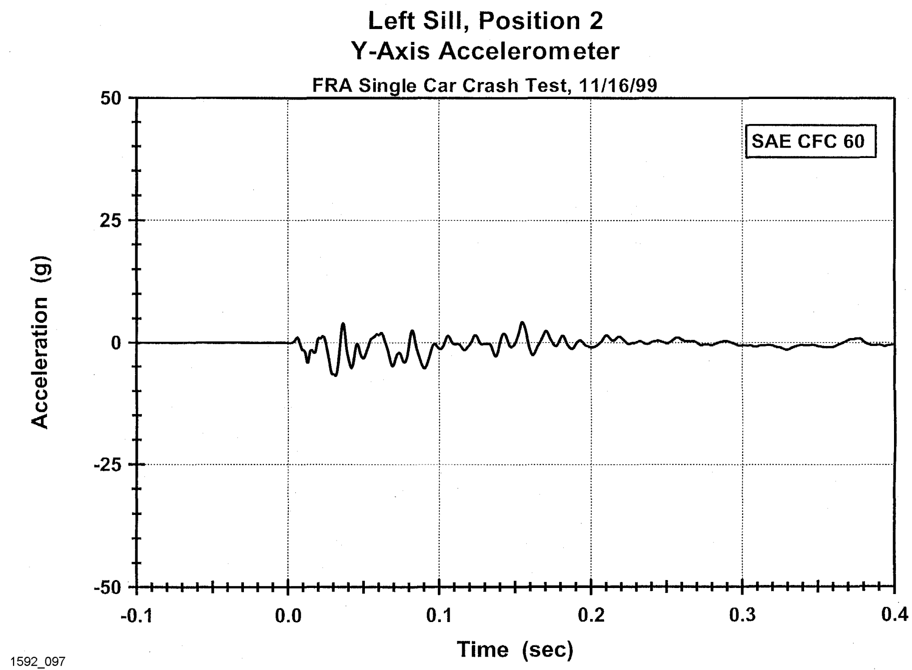

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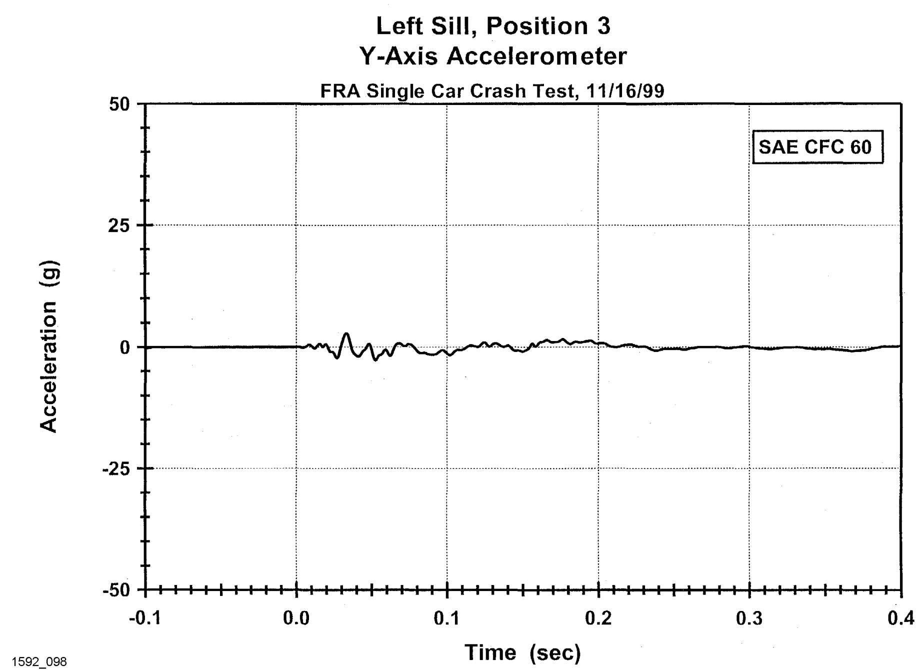

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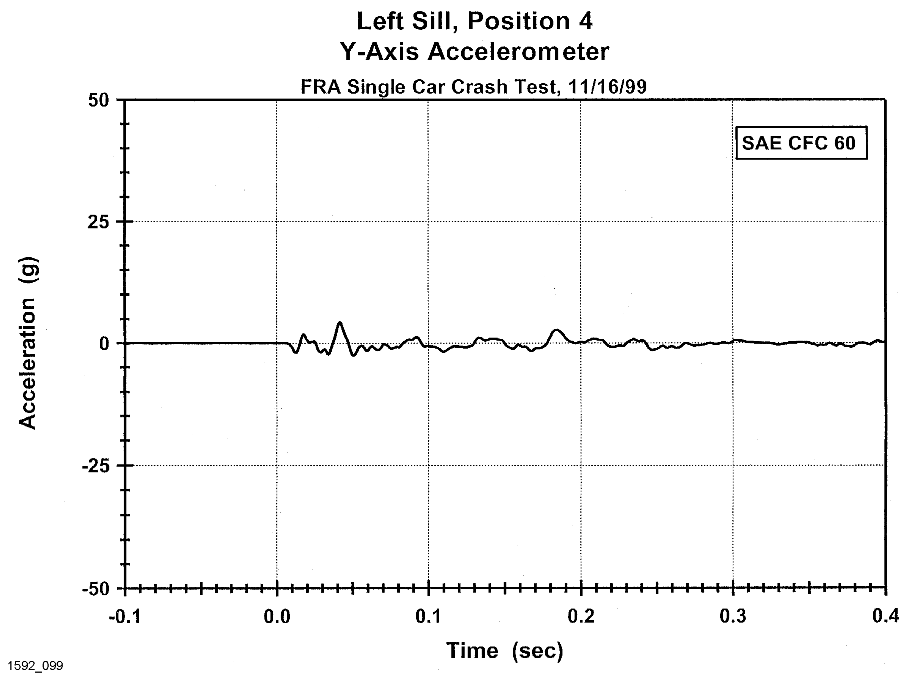

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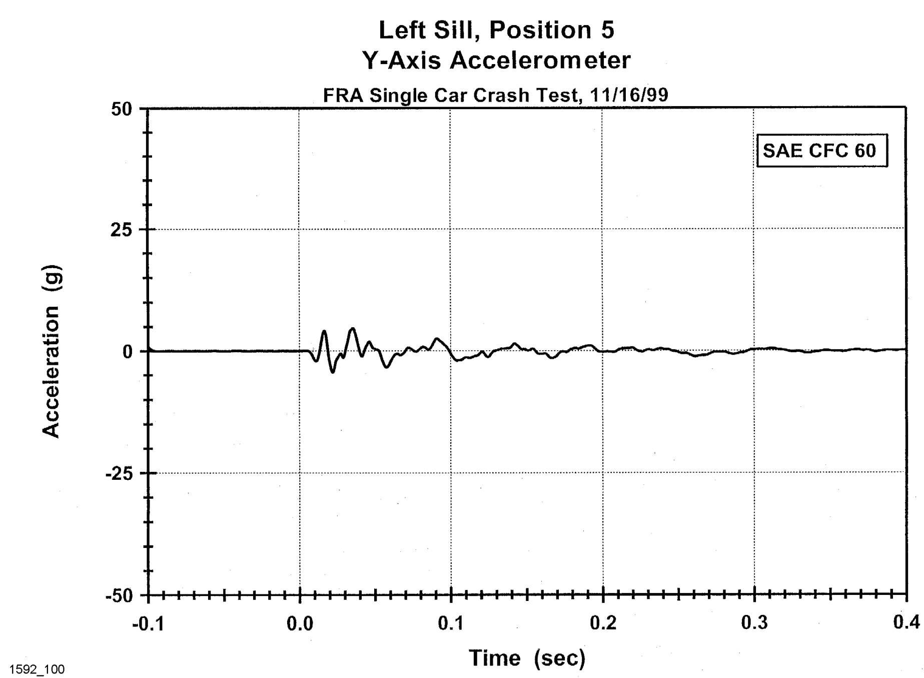

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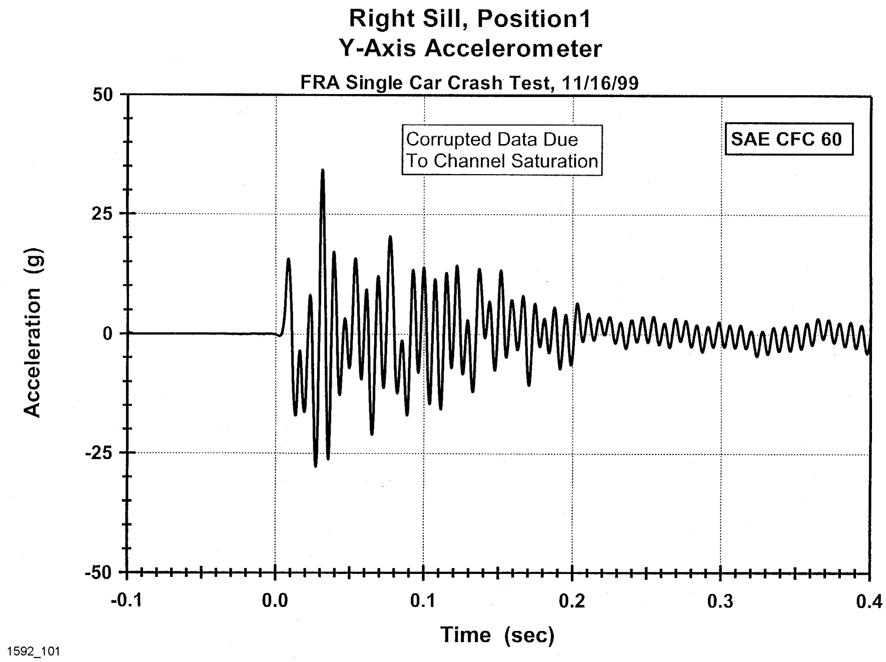

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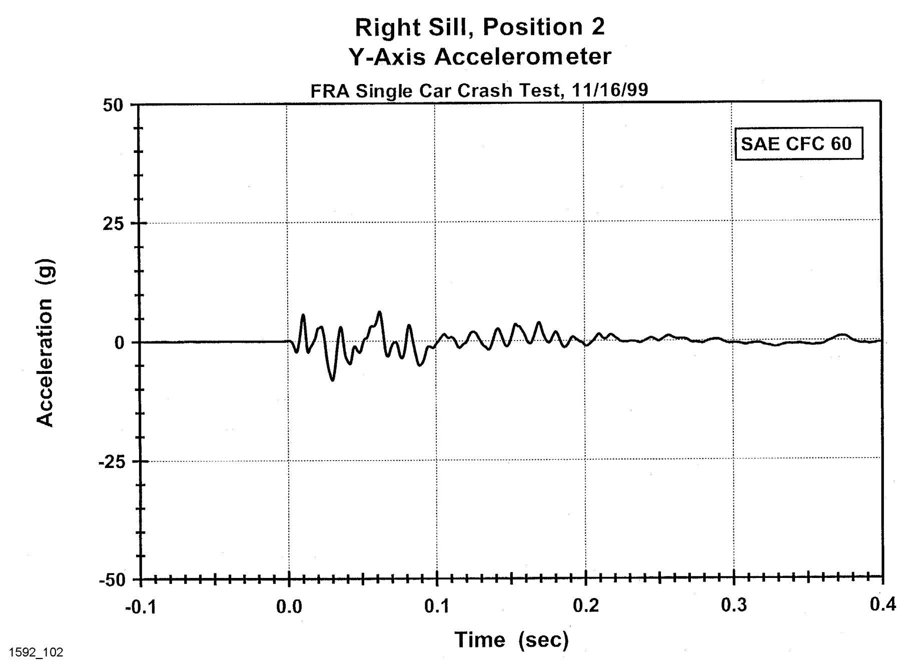

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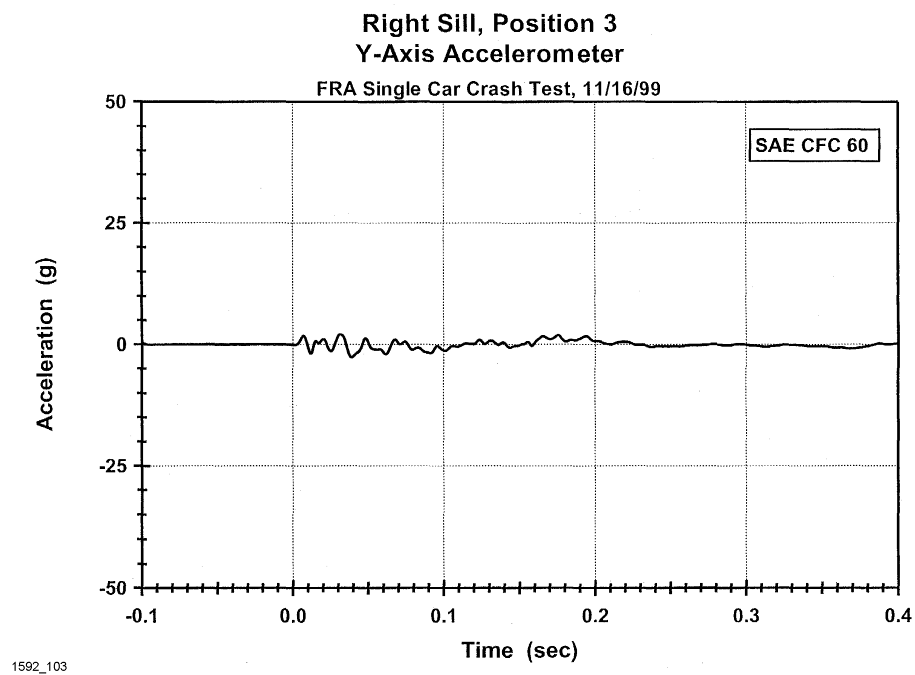


Figure 103.

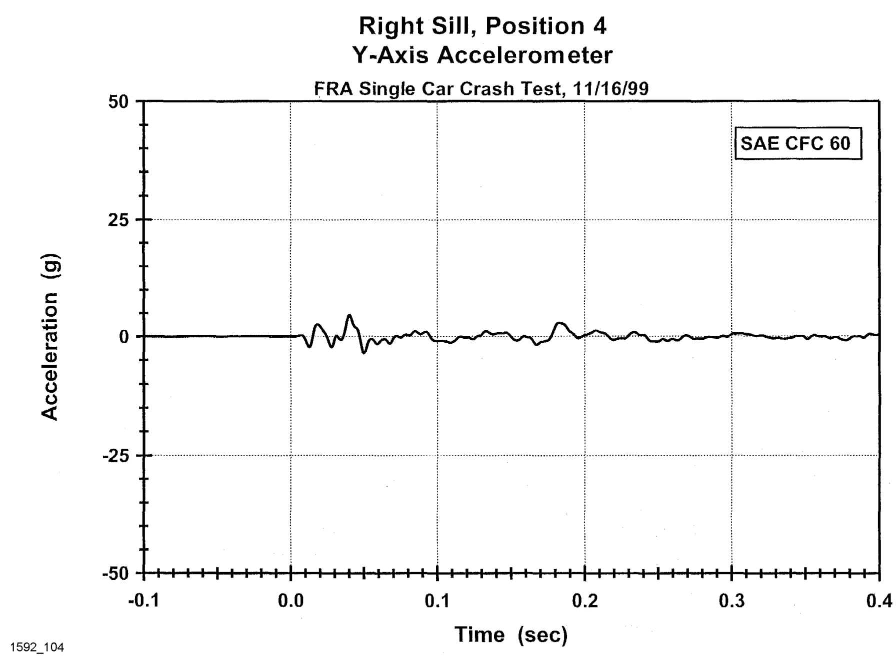


Figure 104.

Right Sill, Position 5
Y-Axis Accelerometer

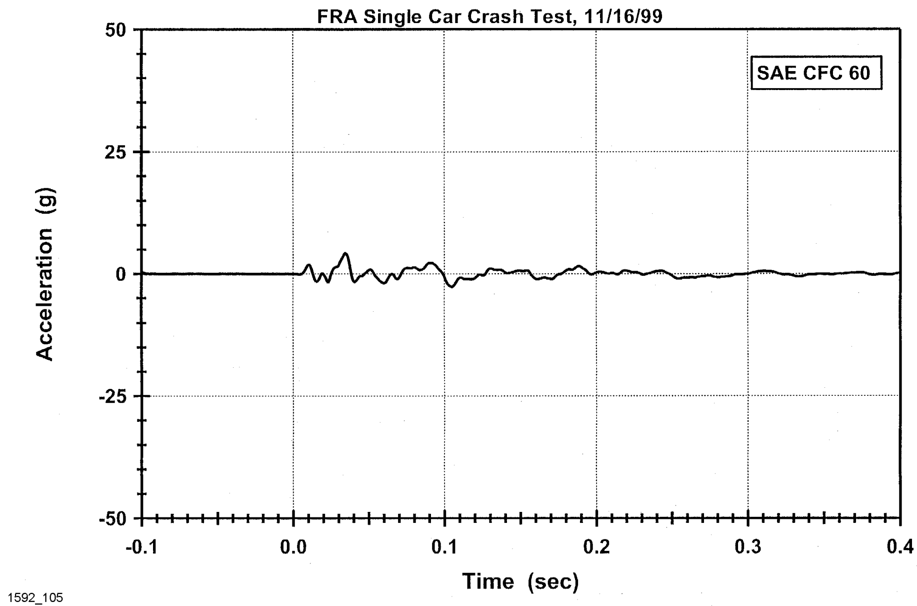
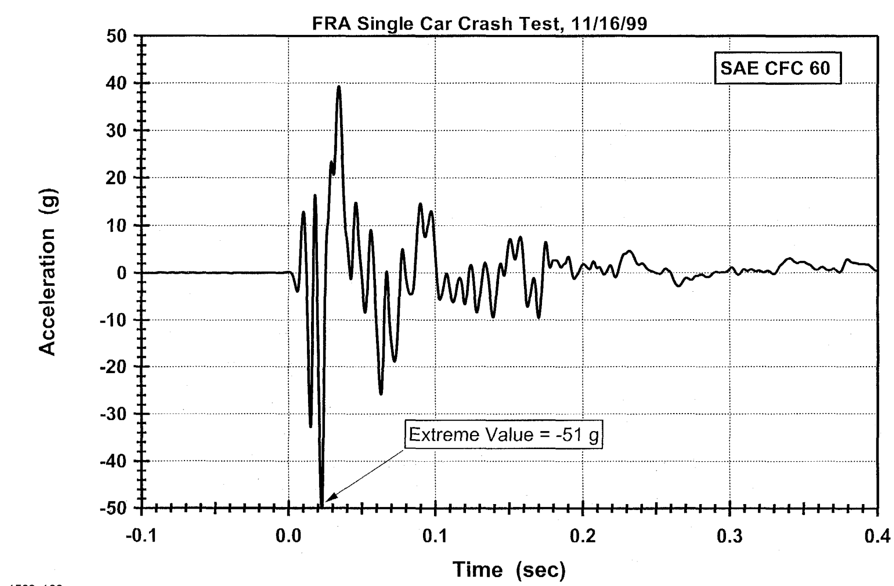


Figure 105.

Center Sill, Position 2
Z-Axis Accelerometer



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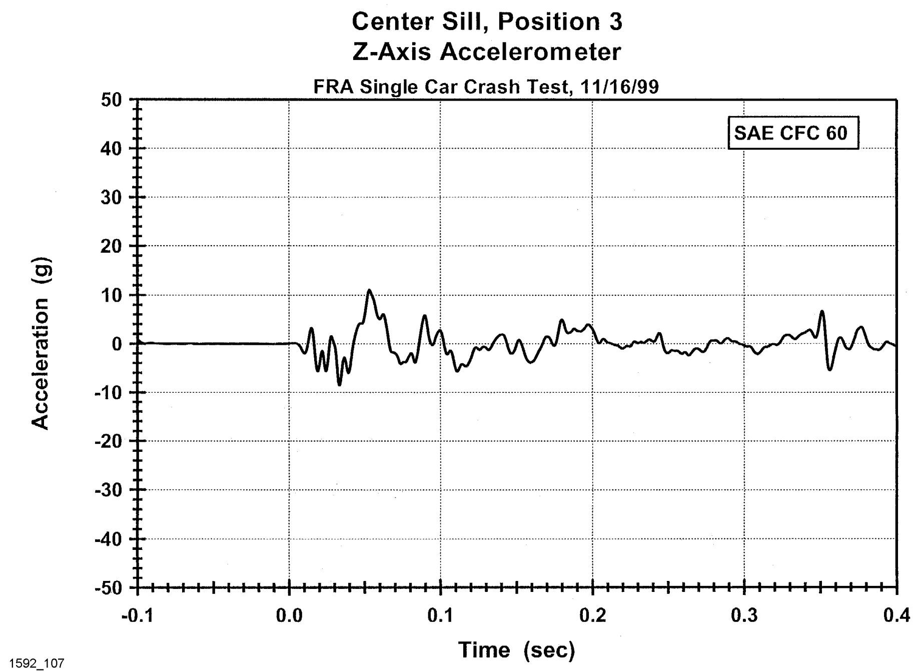

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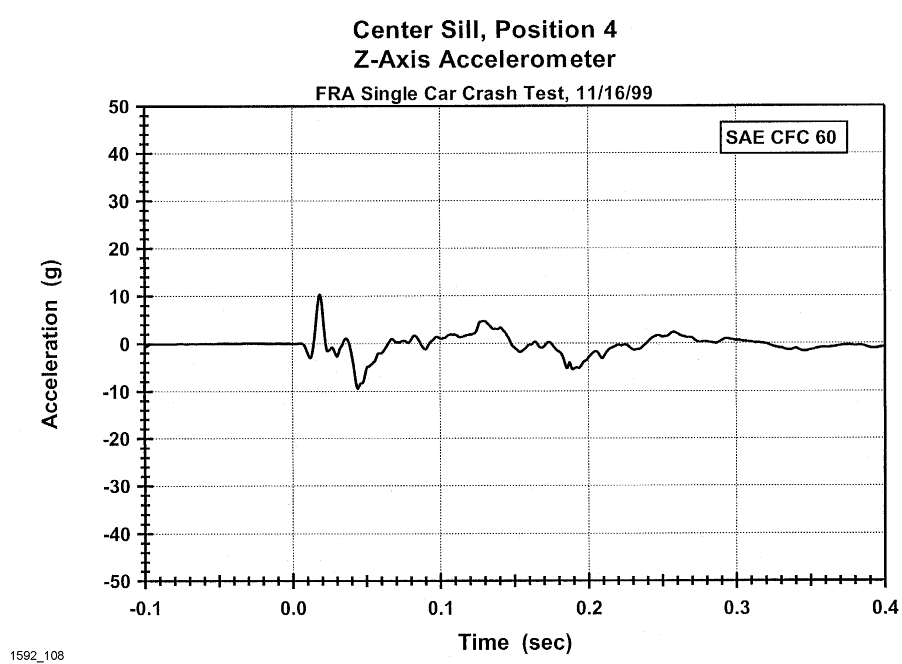

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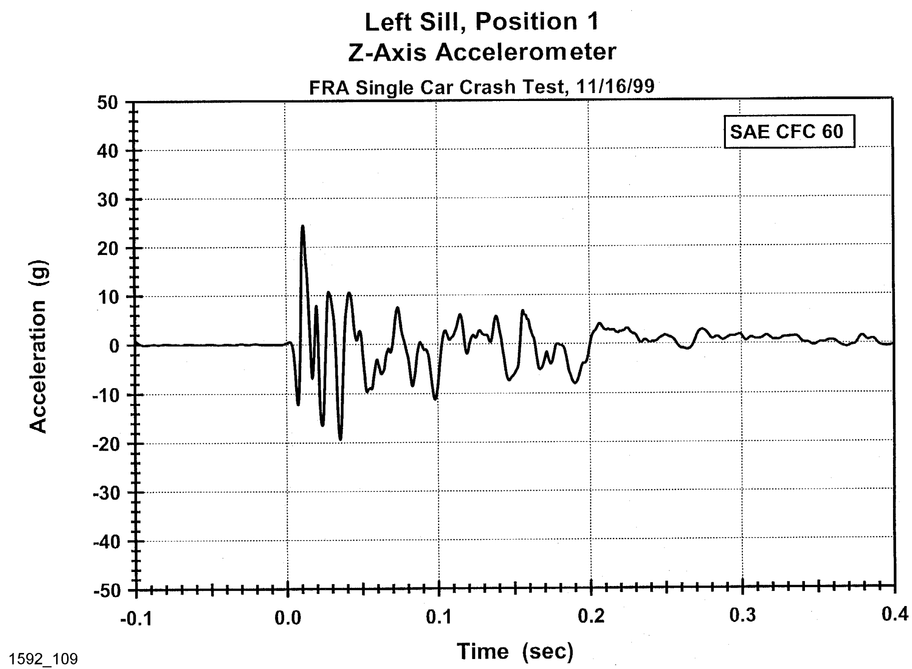

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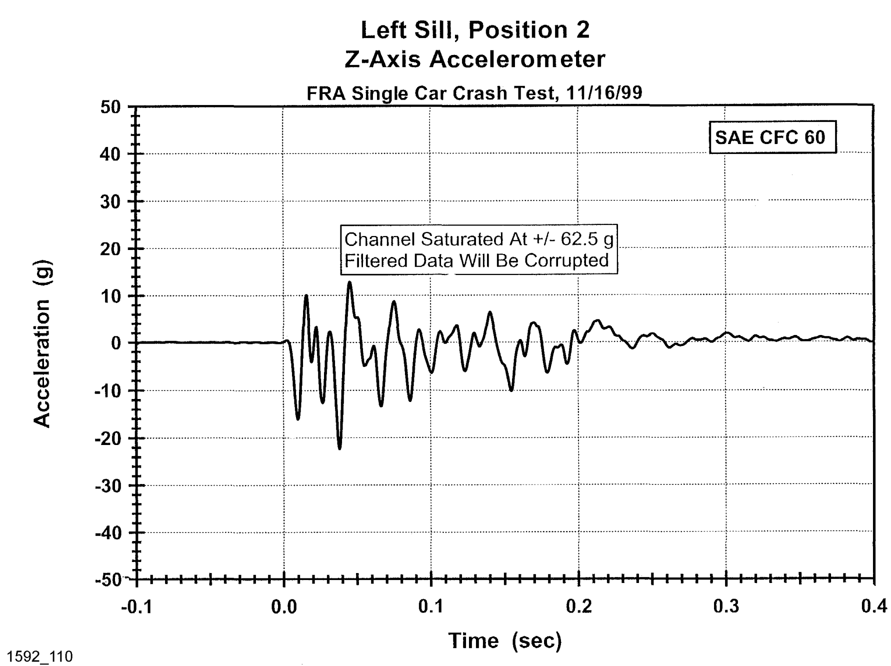

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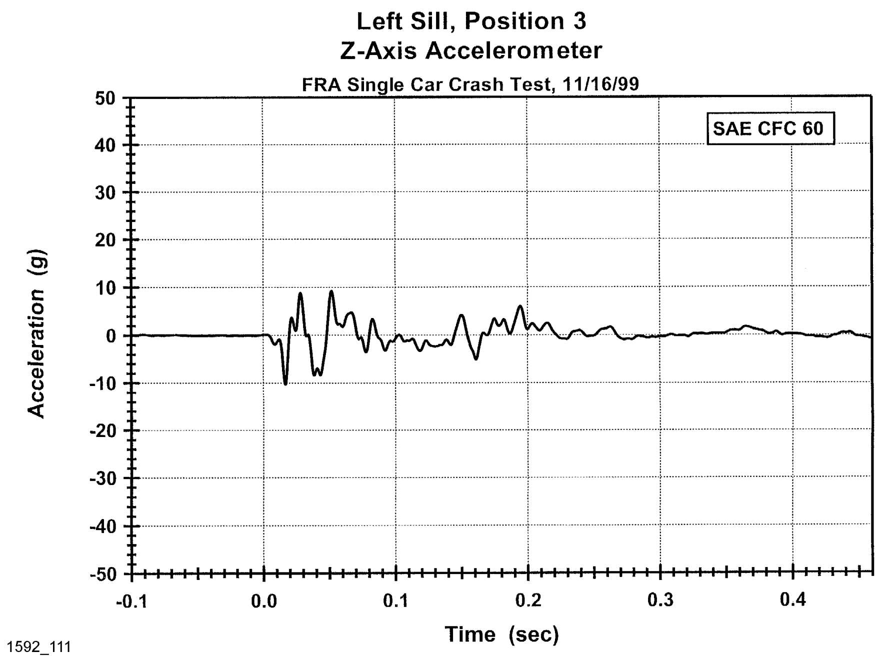

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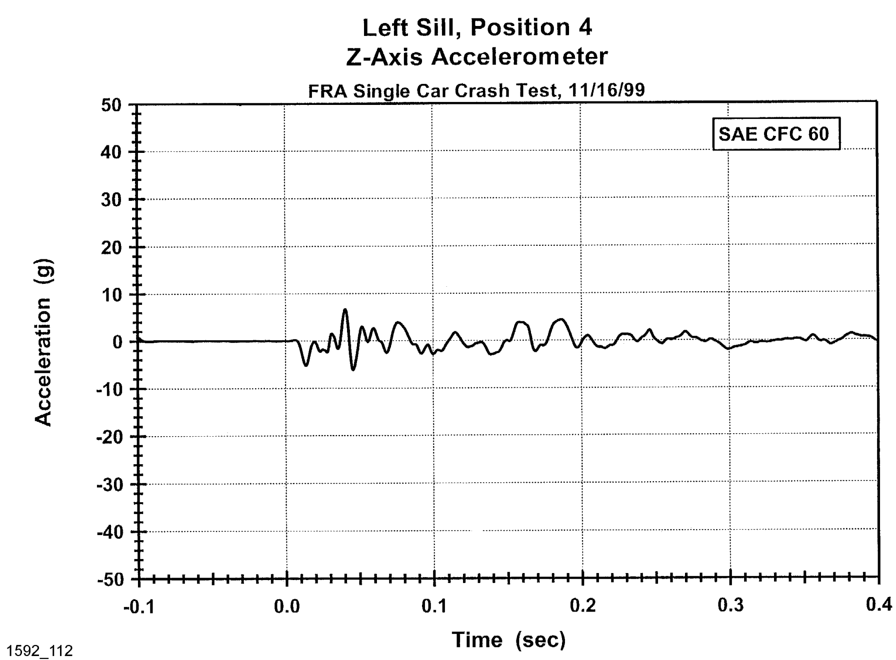

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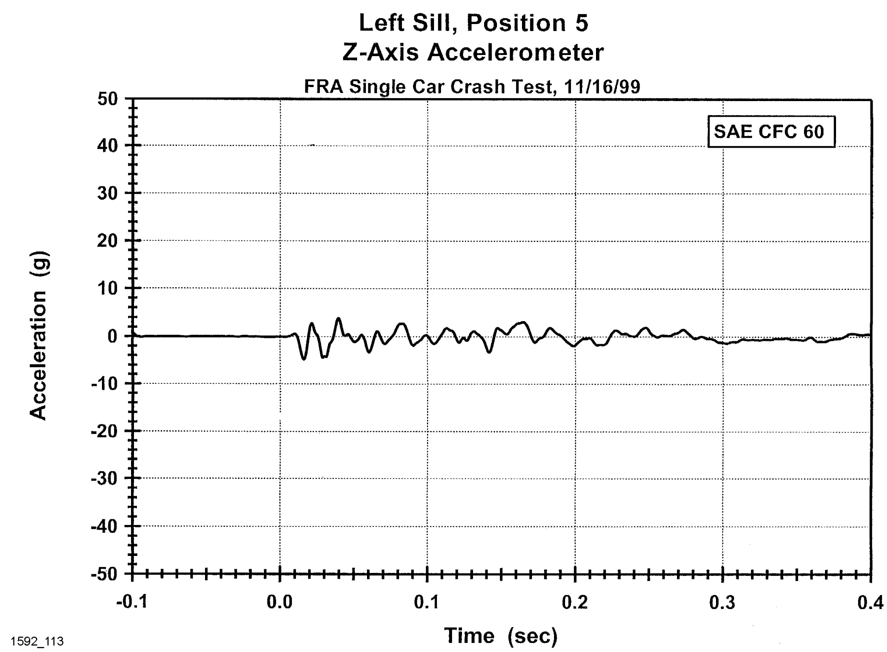

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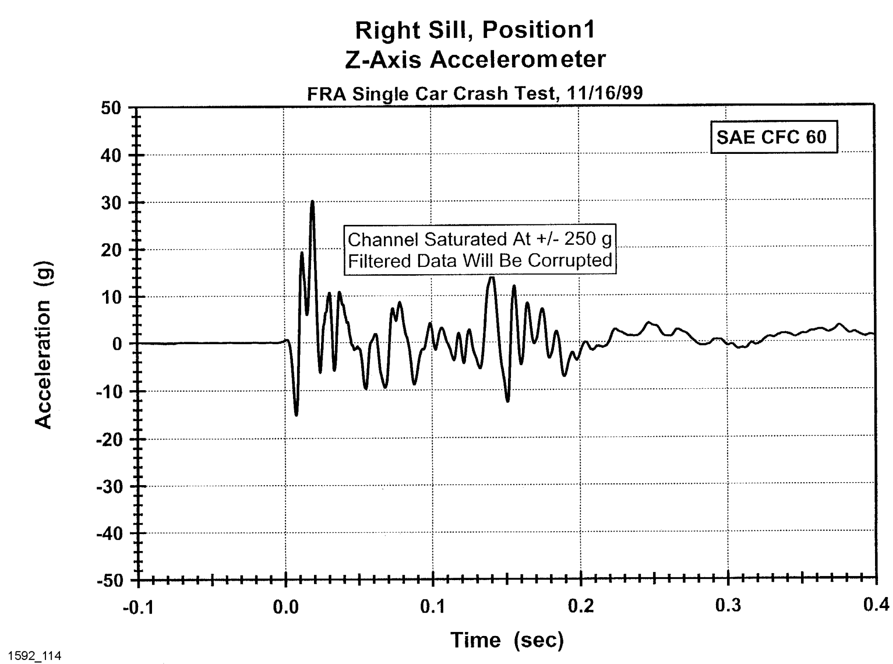

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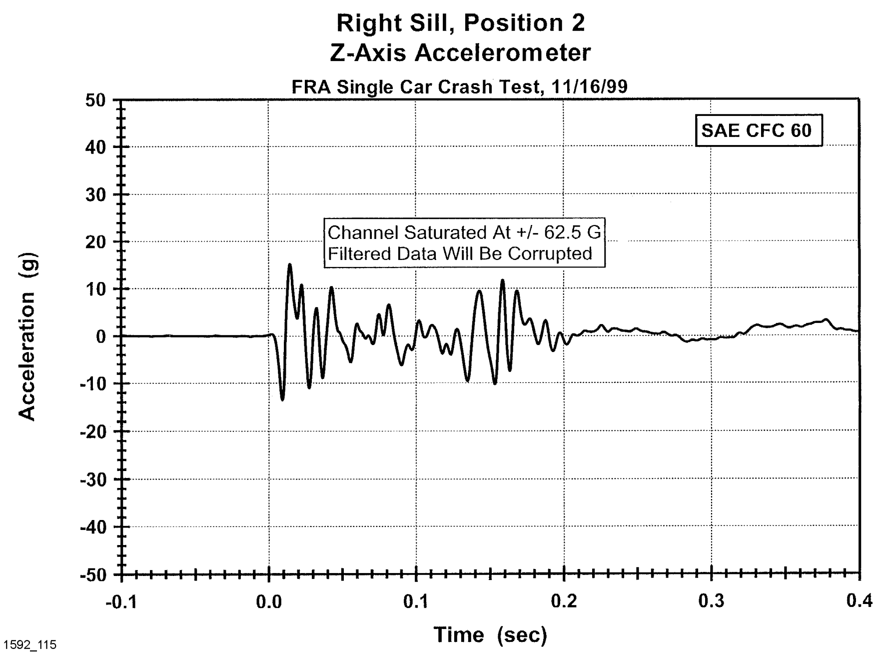

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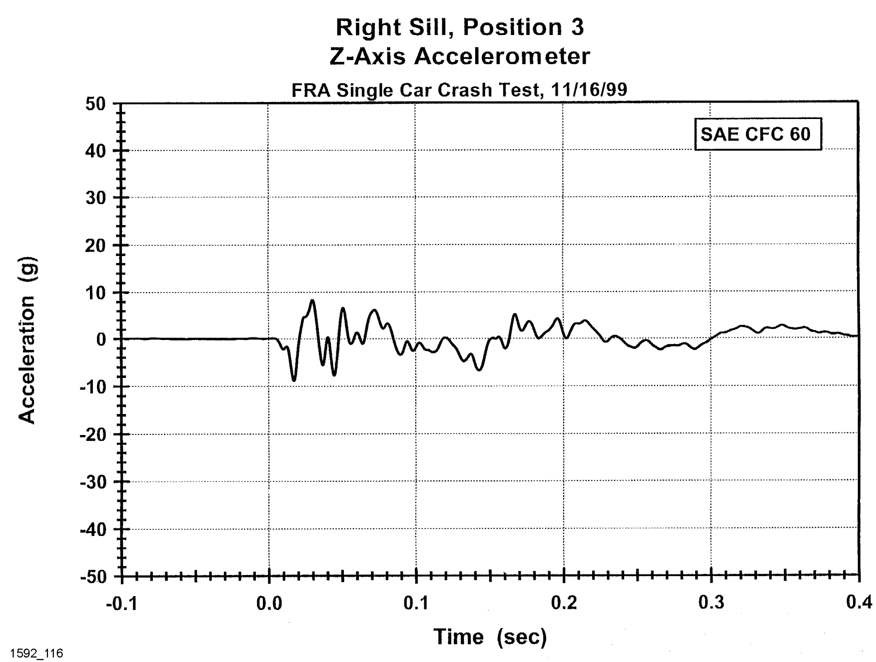

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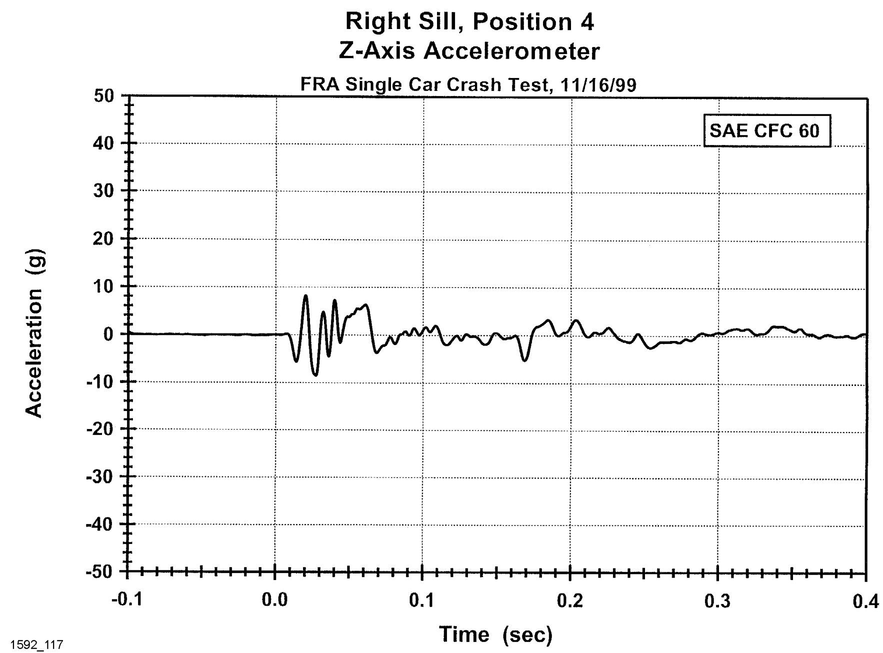

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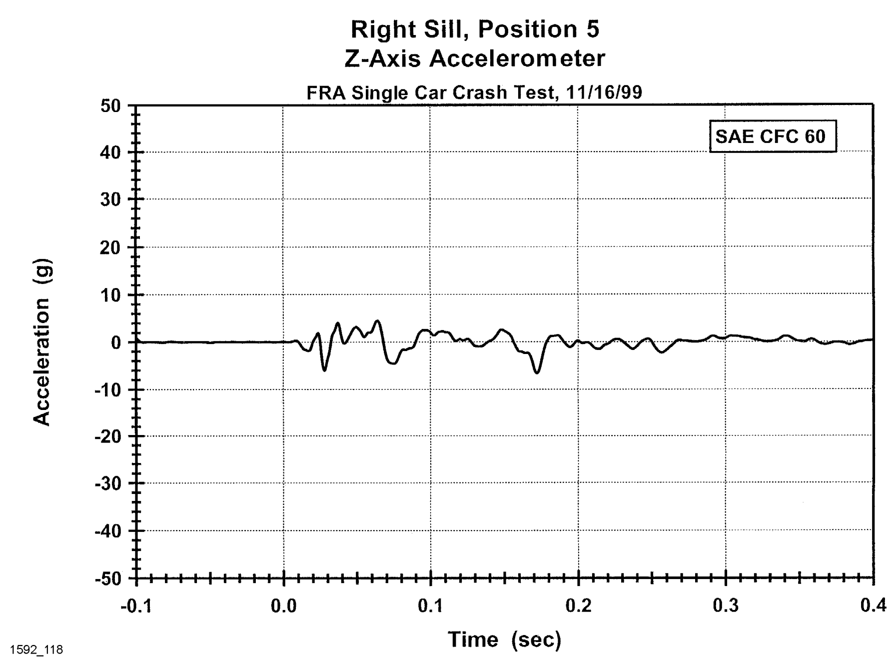

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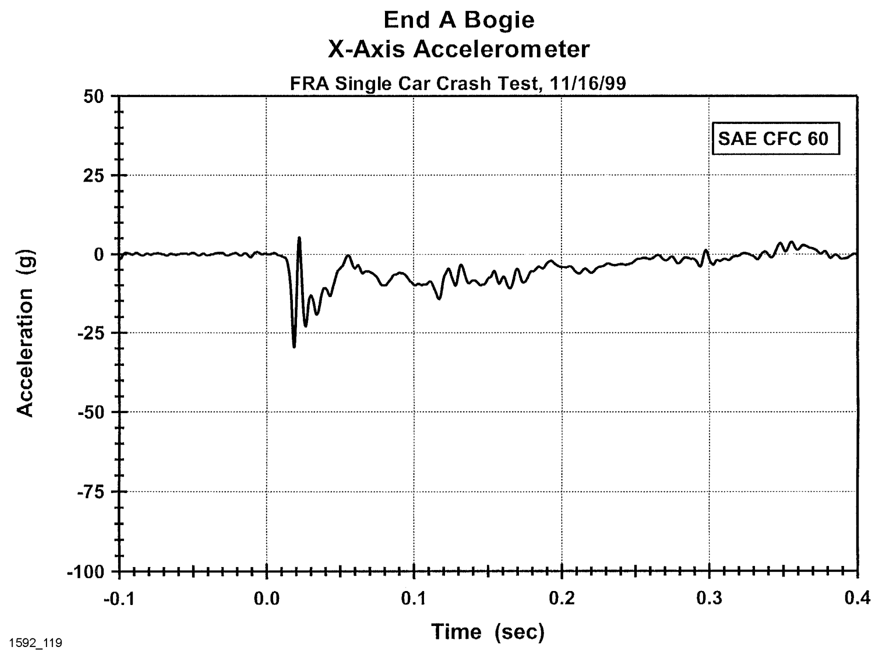

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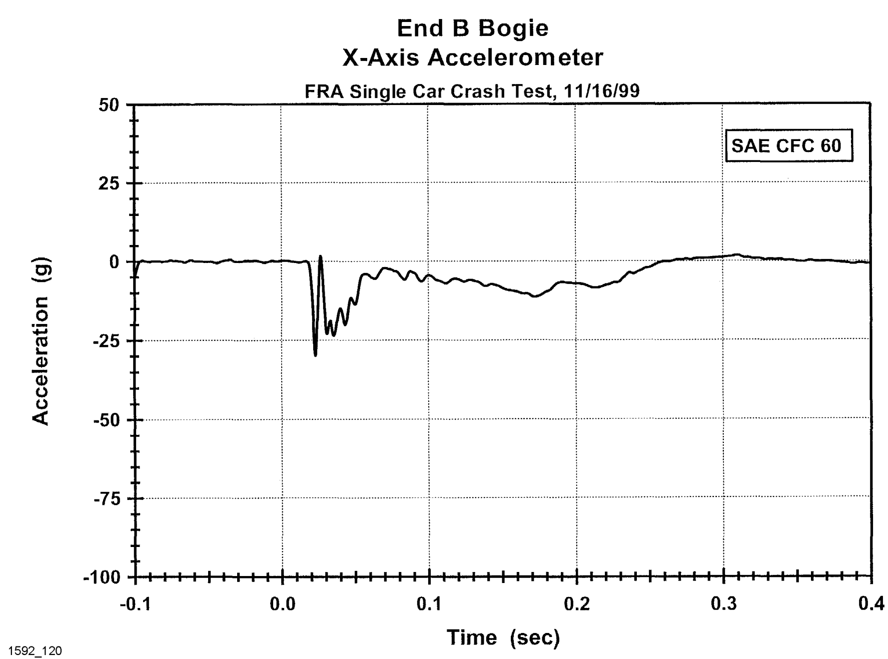

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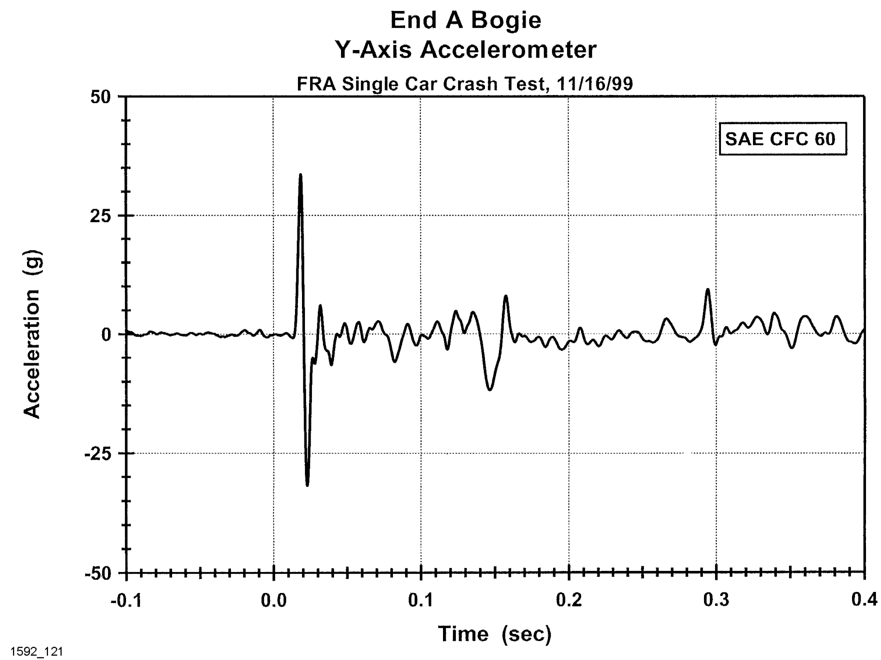

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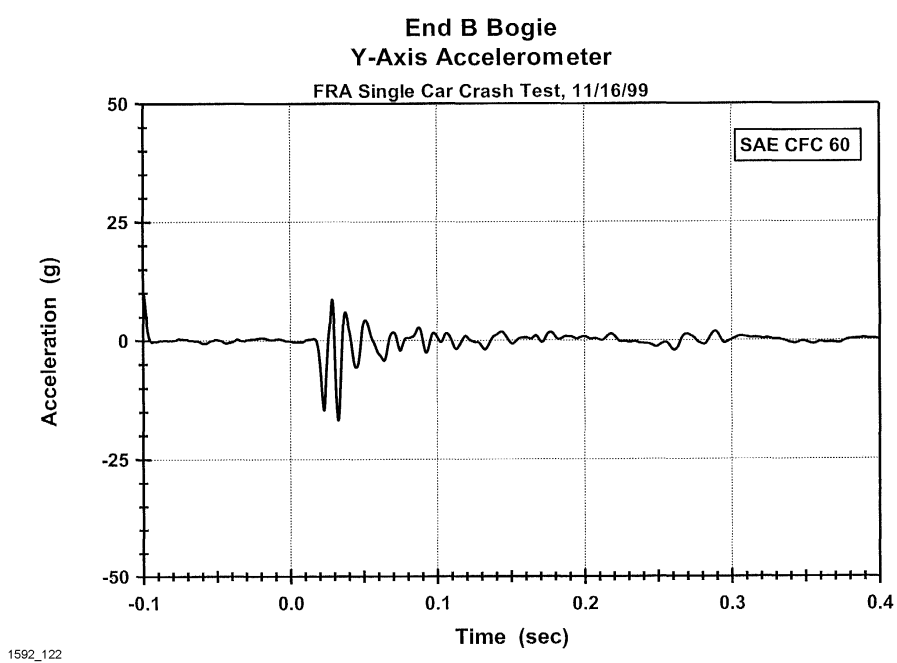

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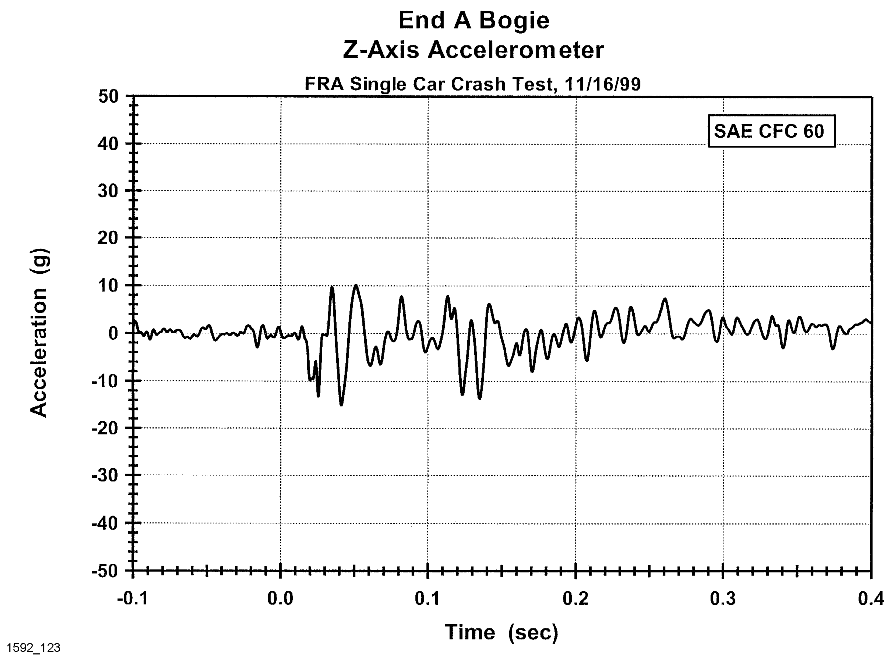

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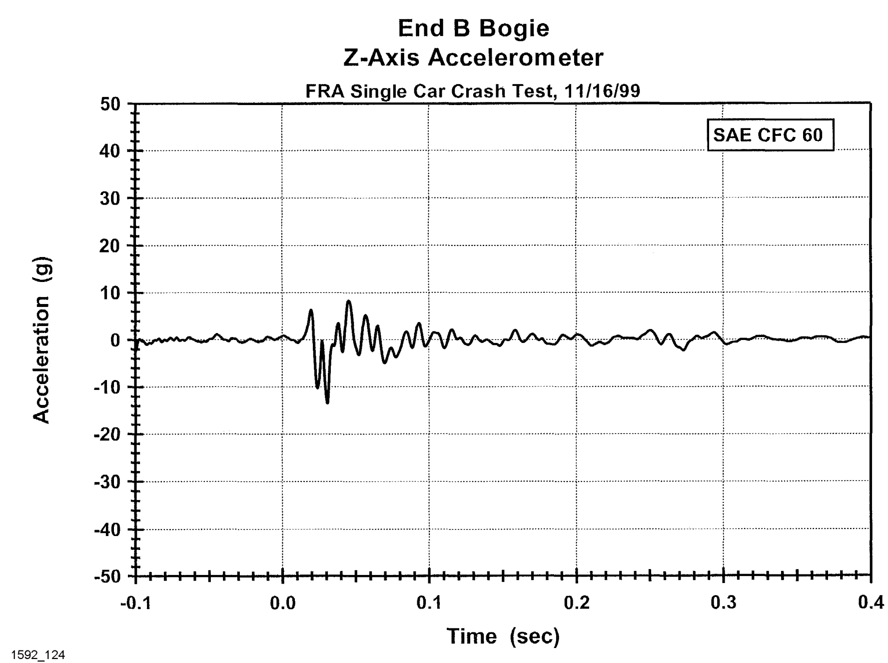

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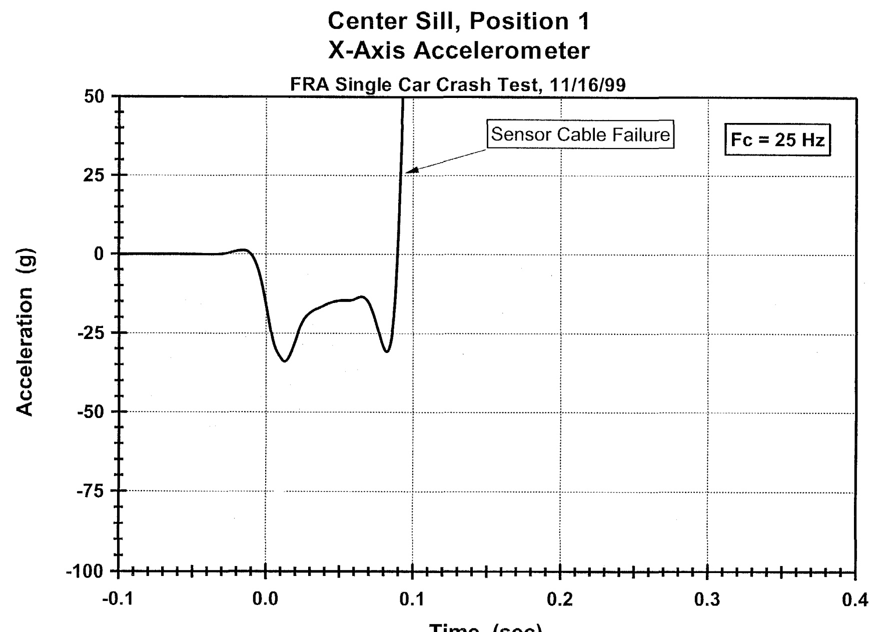
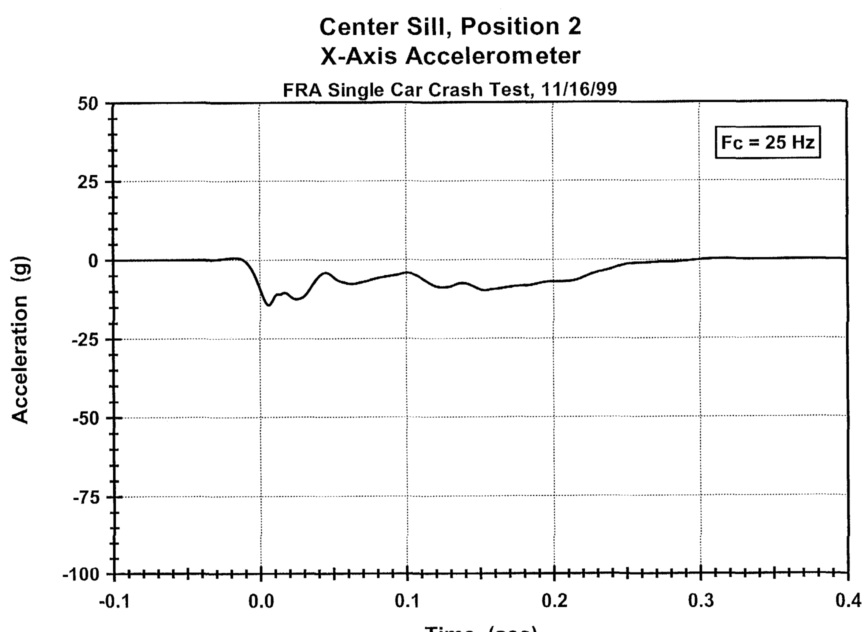


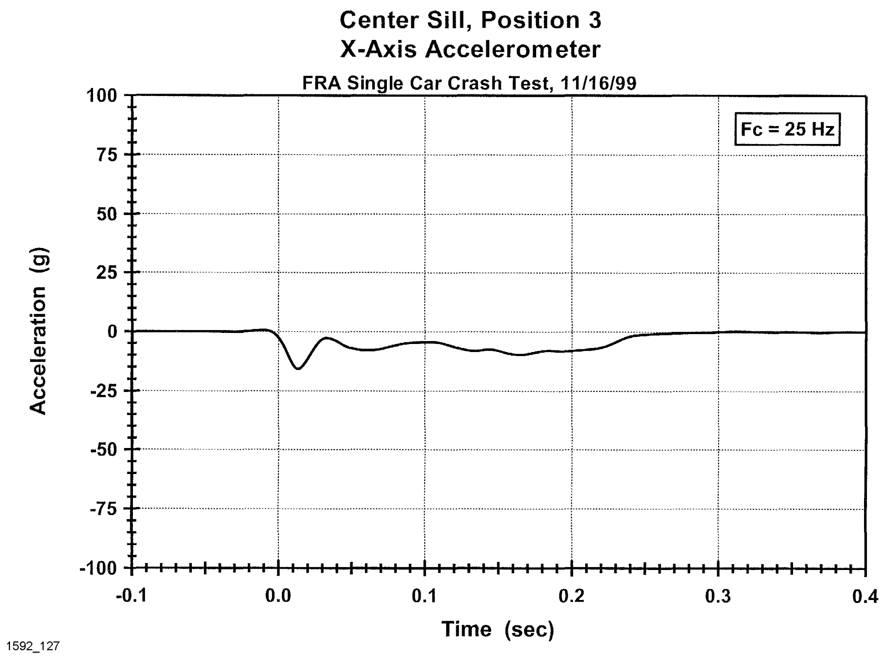
1592_125

Figure 125.



1592_126

Figure 126.



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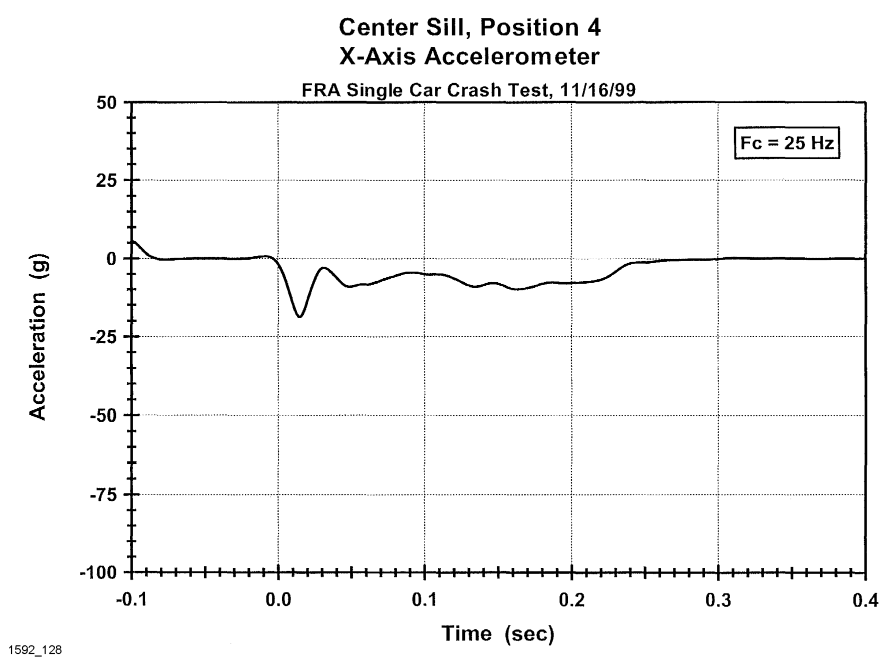

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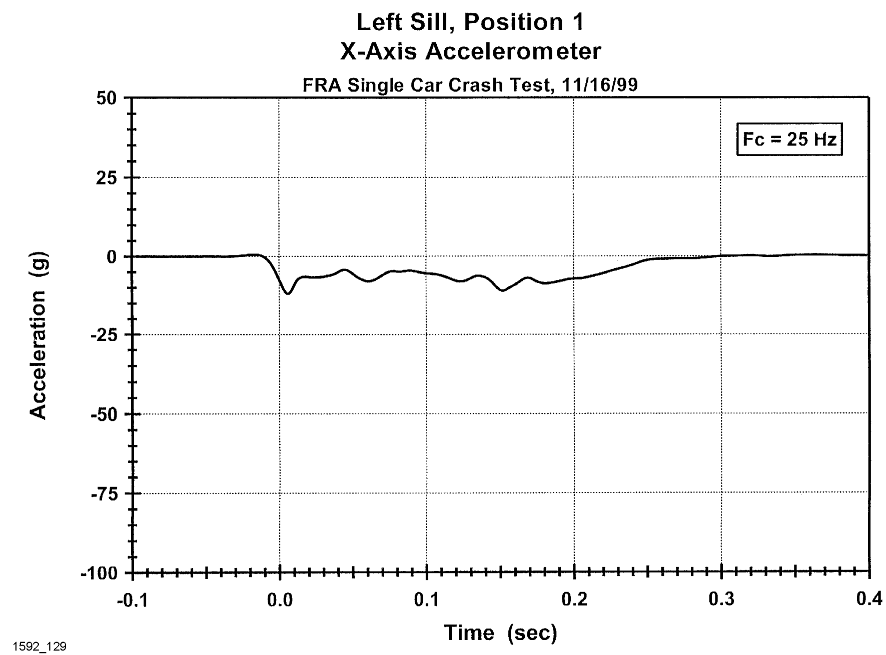

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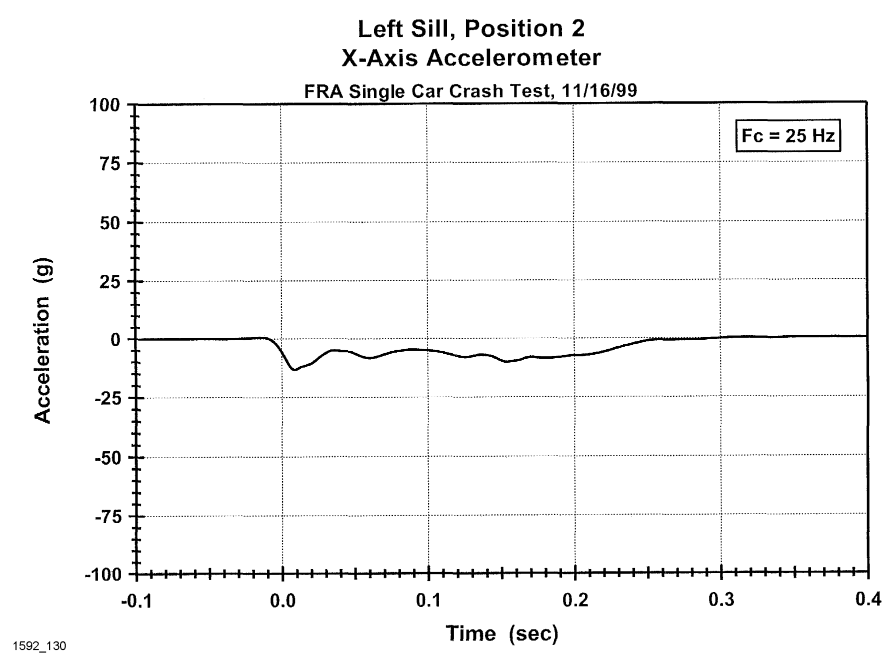

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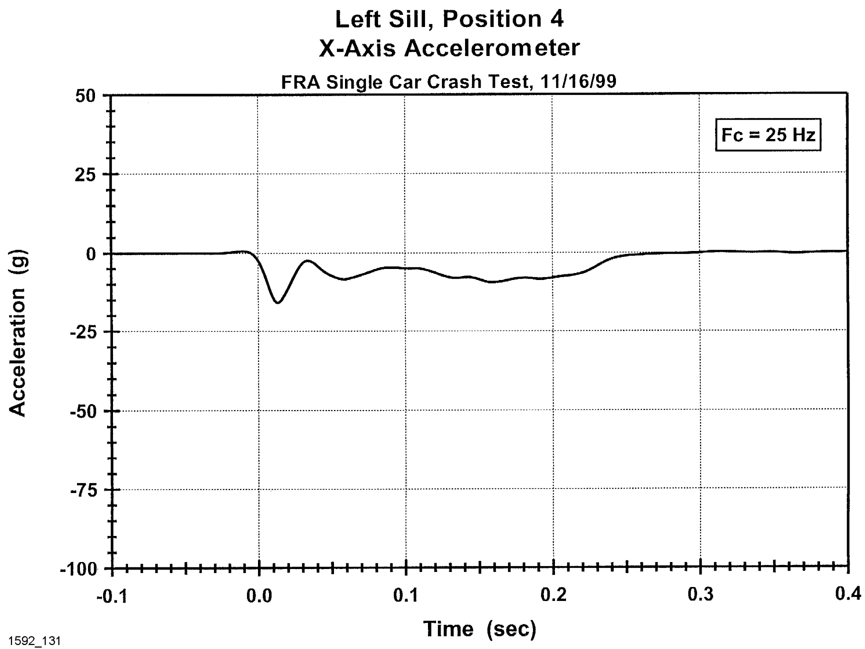

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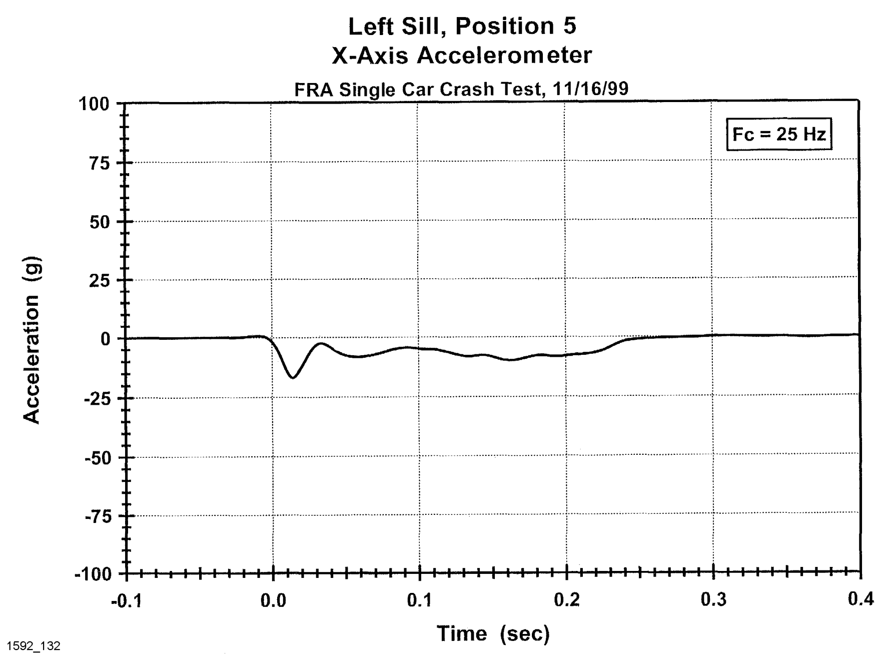

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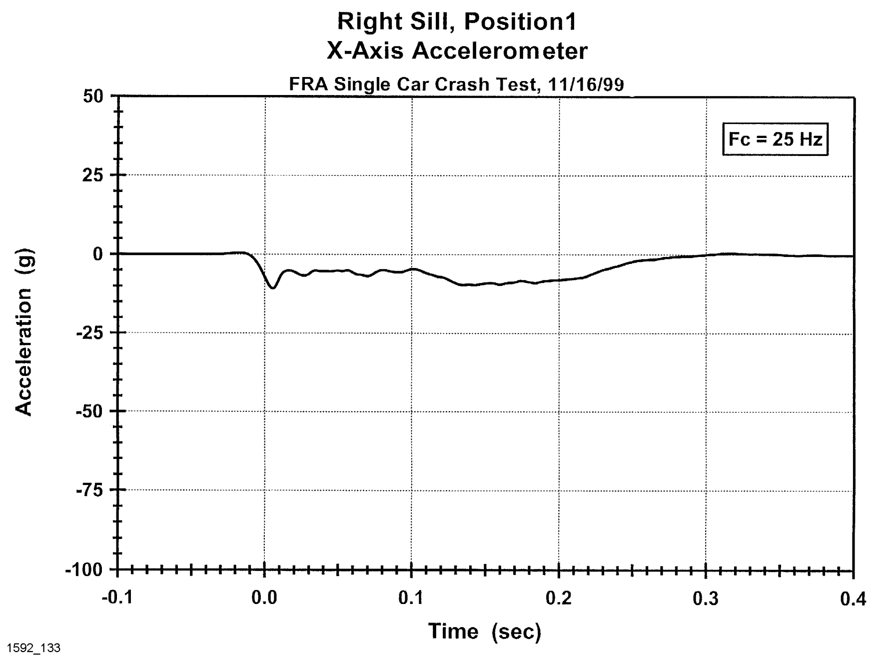

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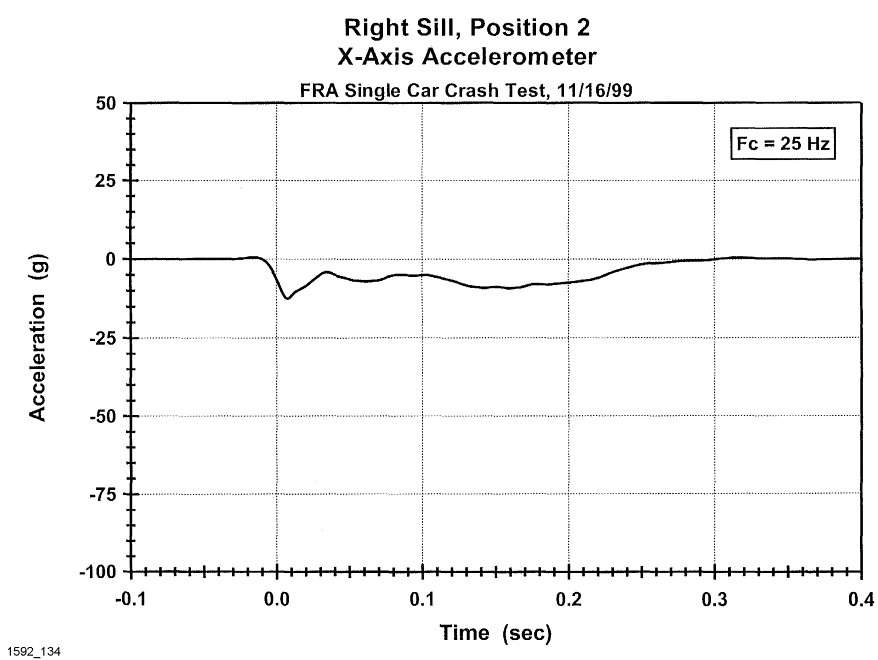

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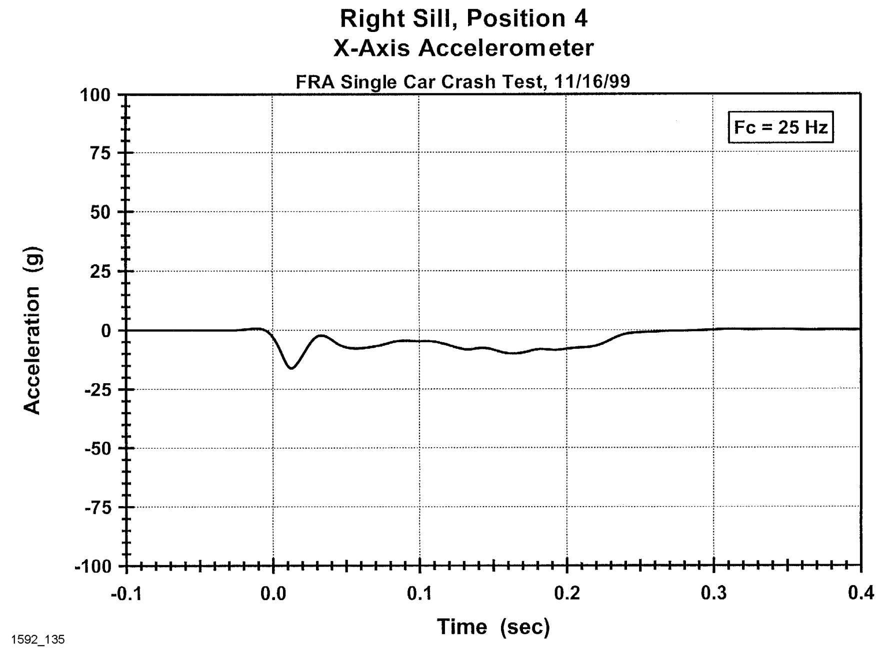

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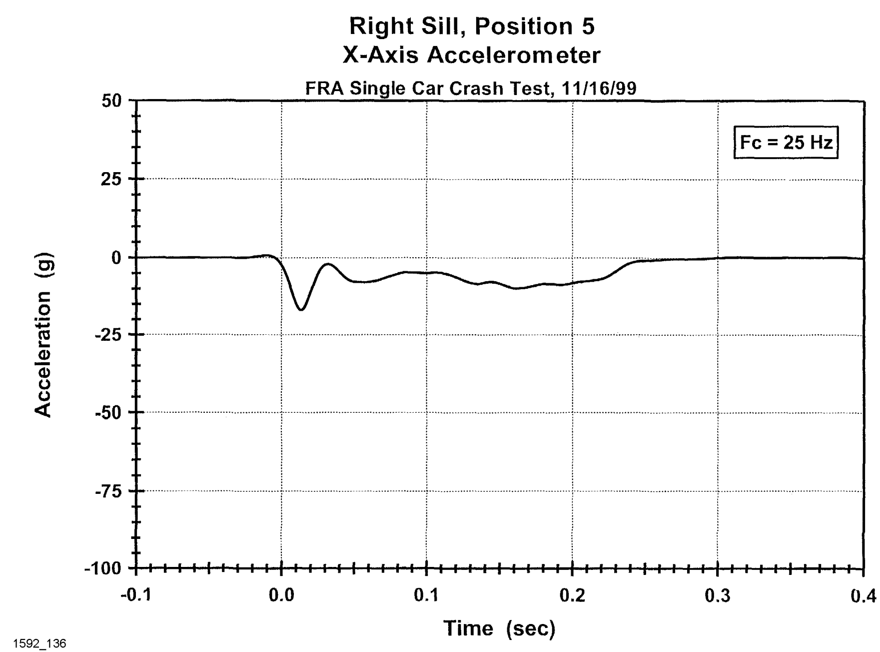

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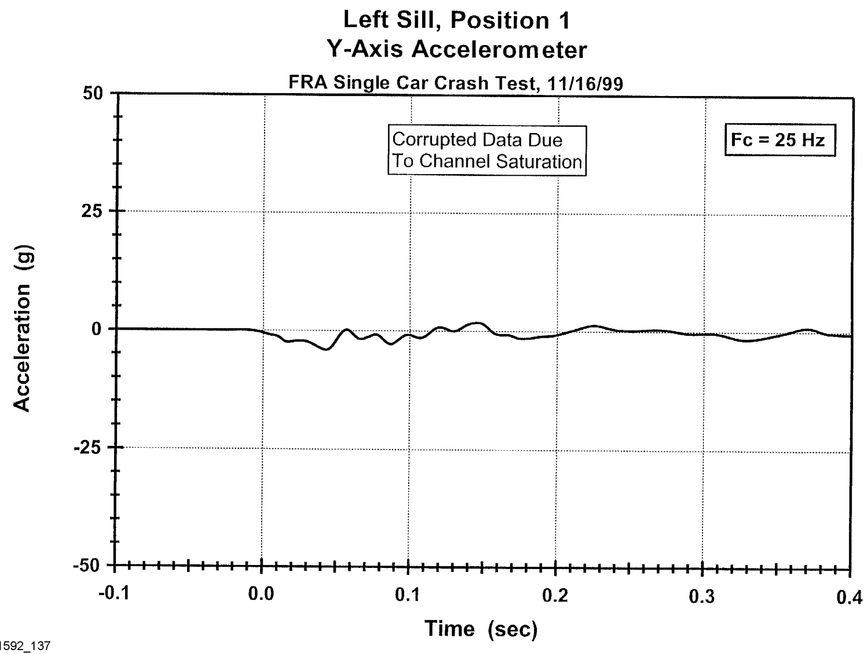

1592_137

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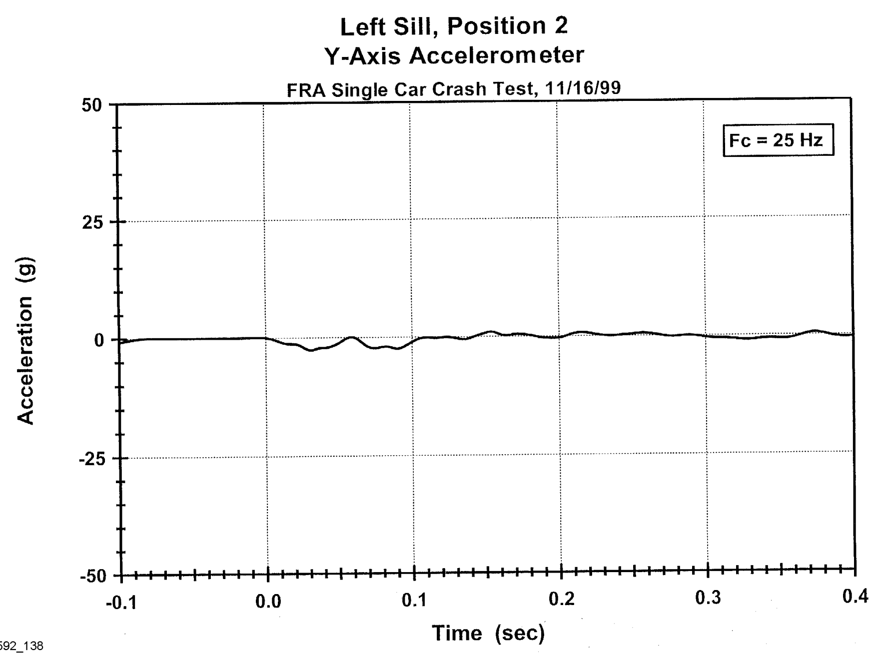

1592_138

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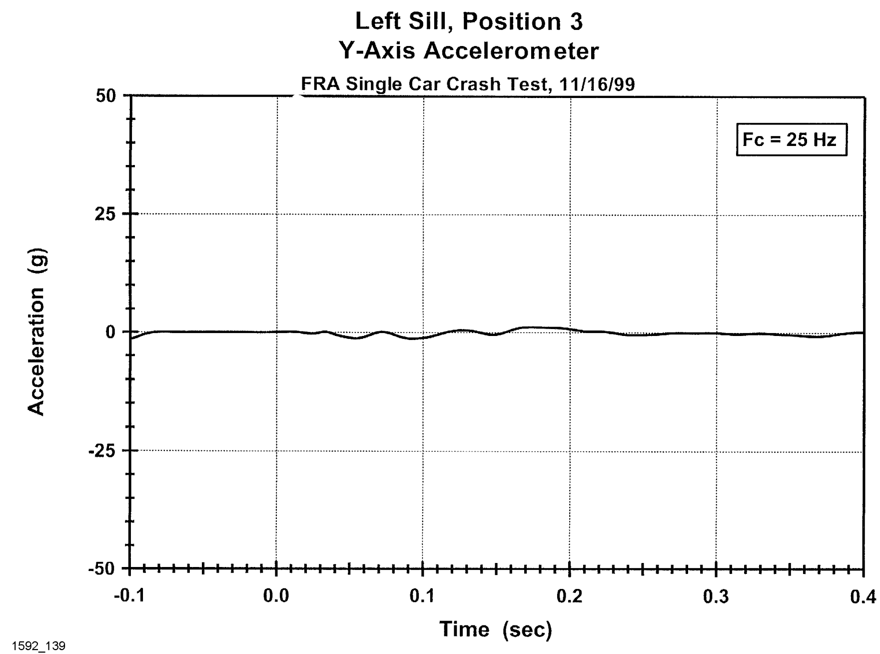

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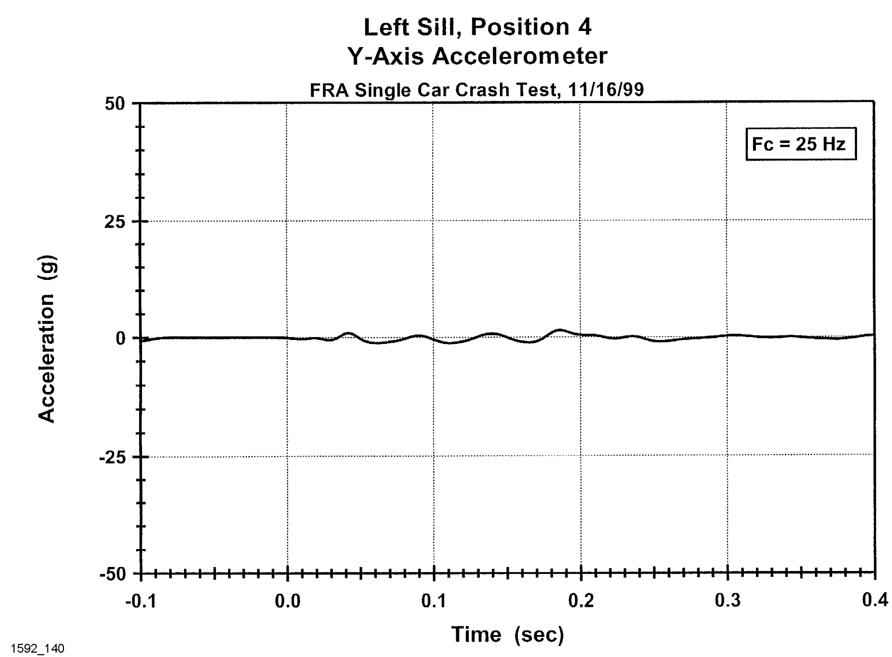

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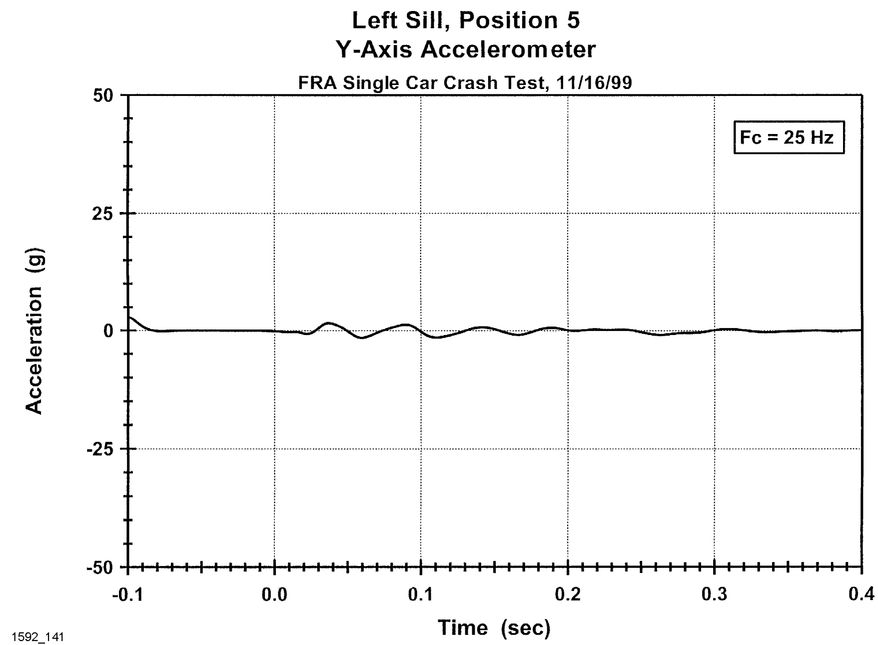

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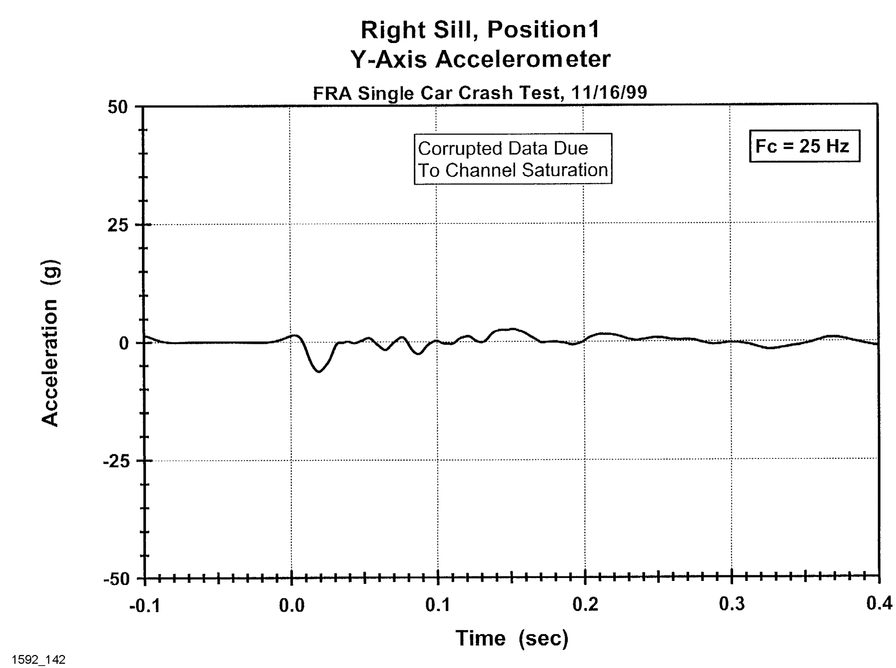

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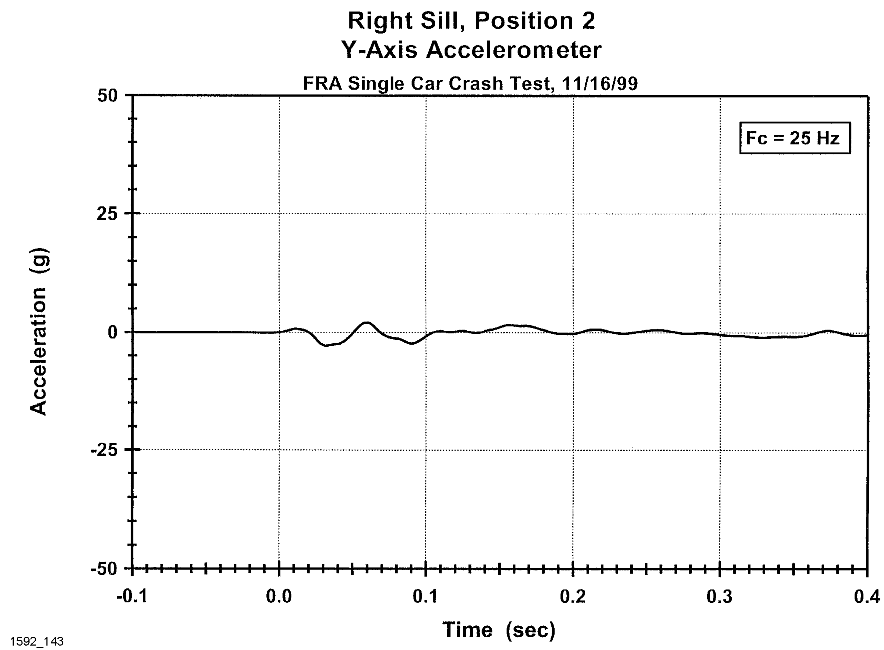

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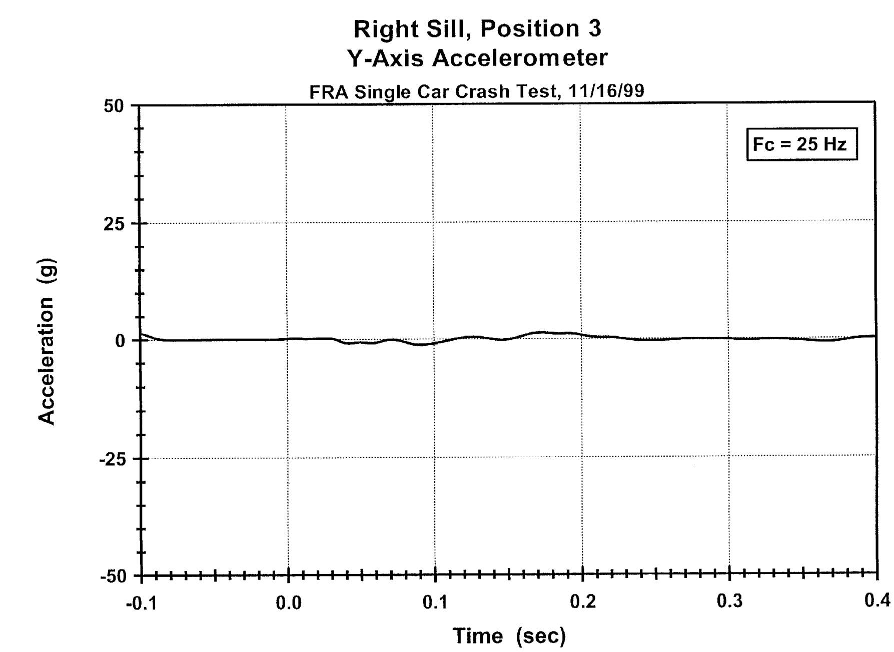

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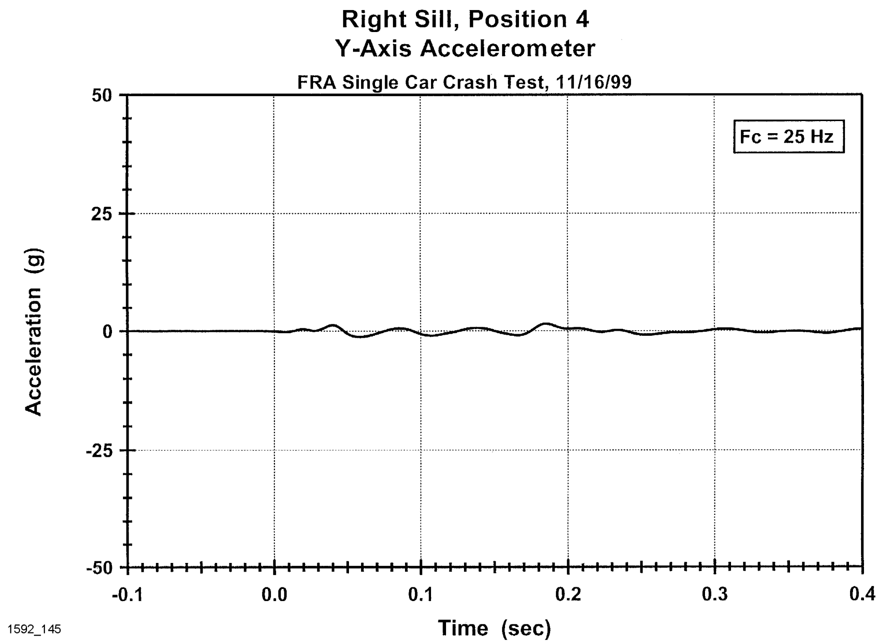

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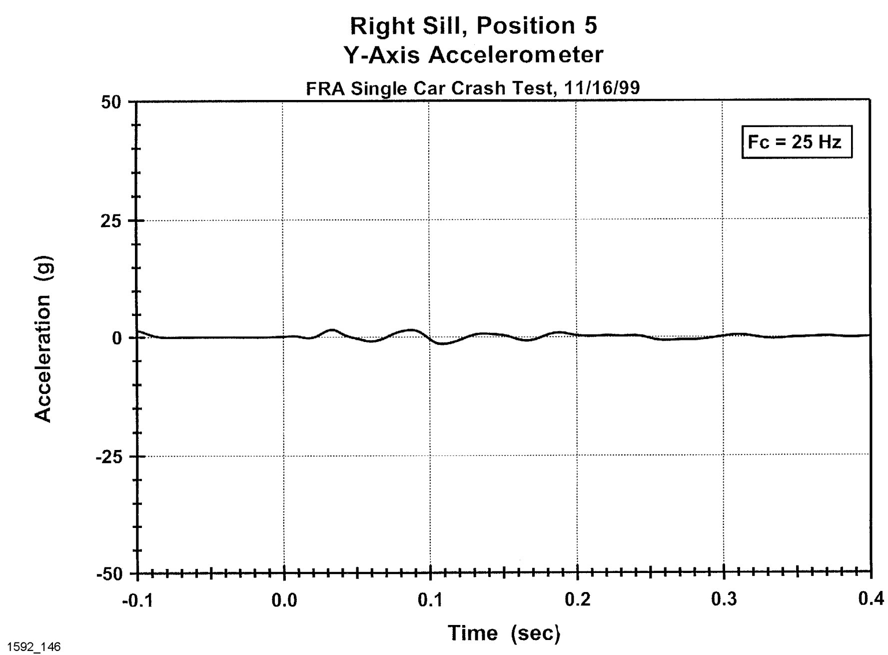

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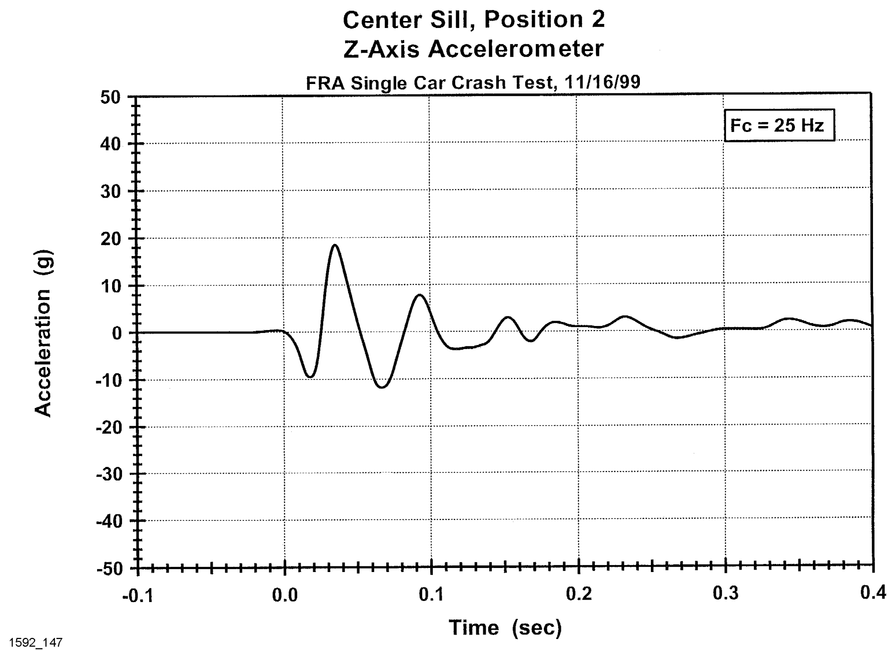

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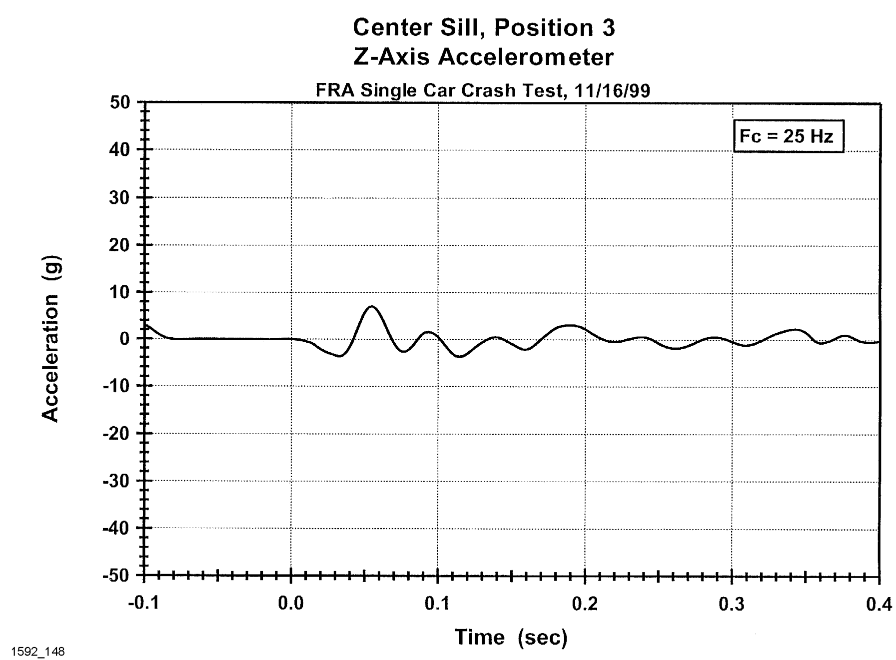

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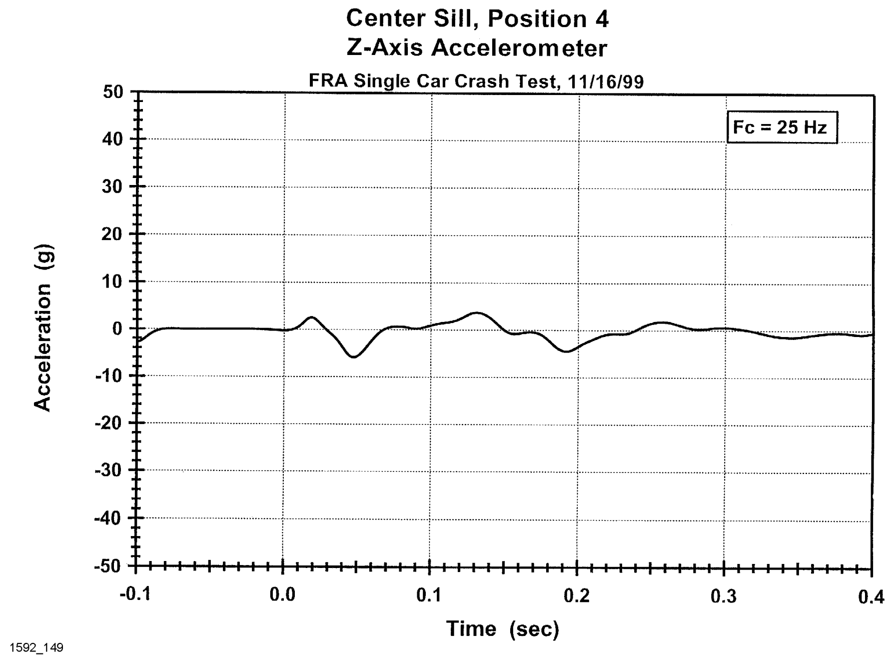

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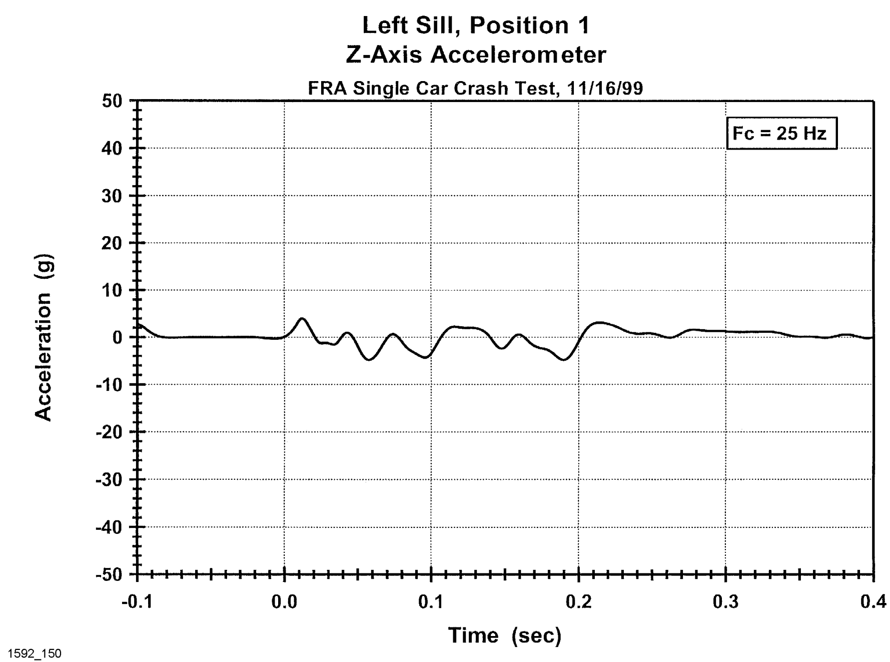

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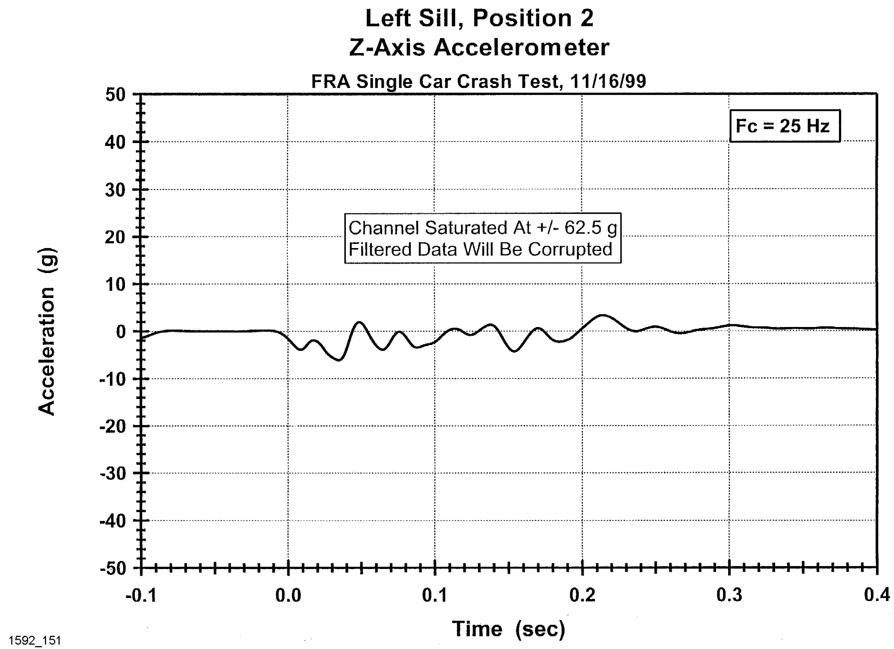

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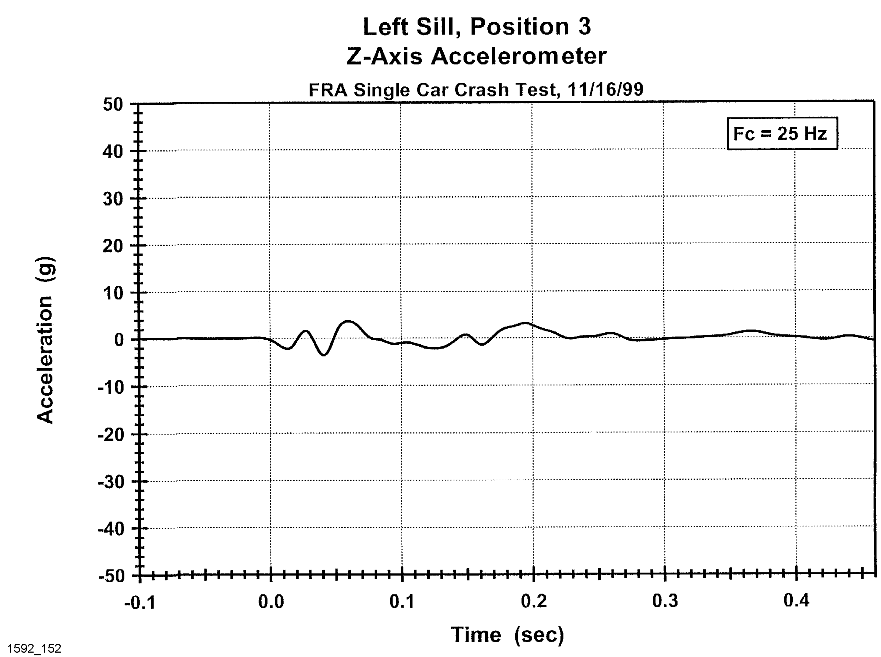

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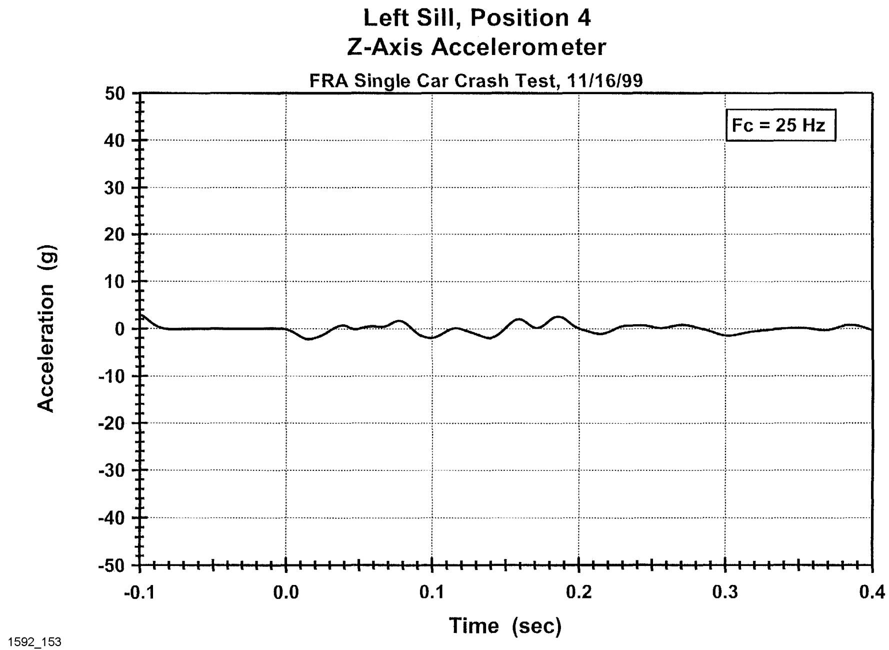

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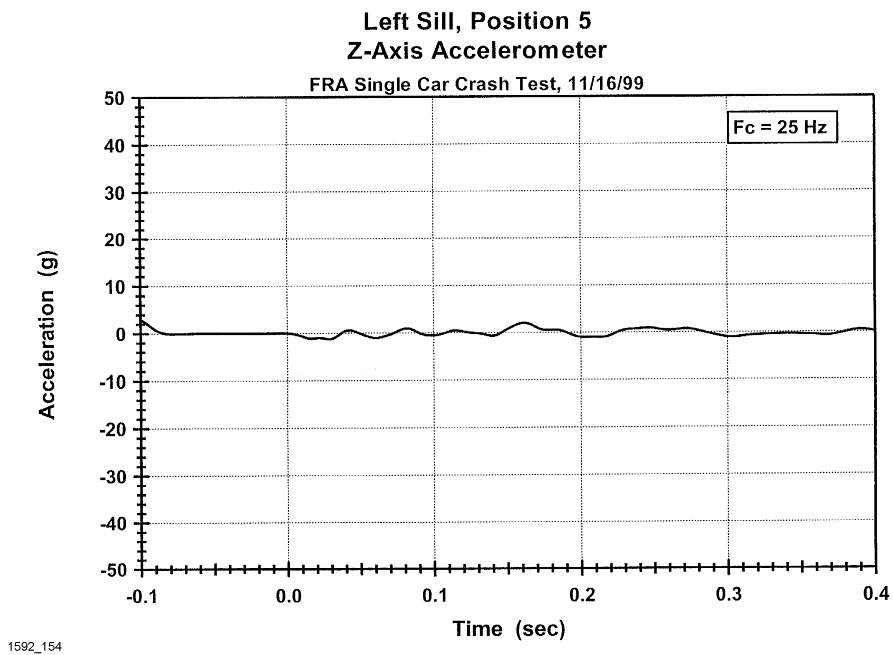

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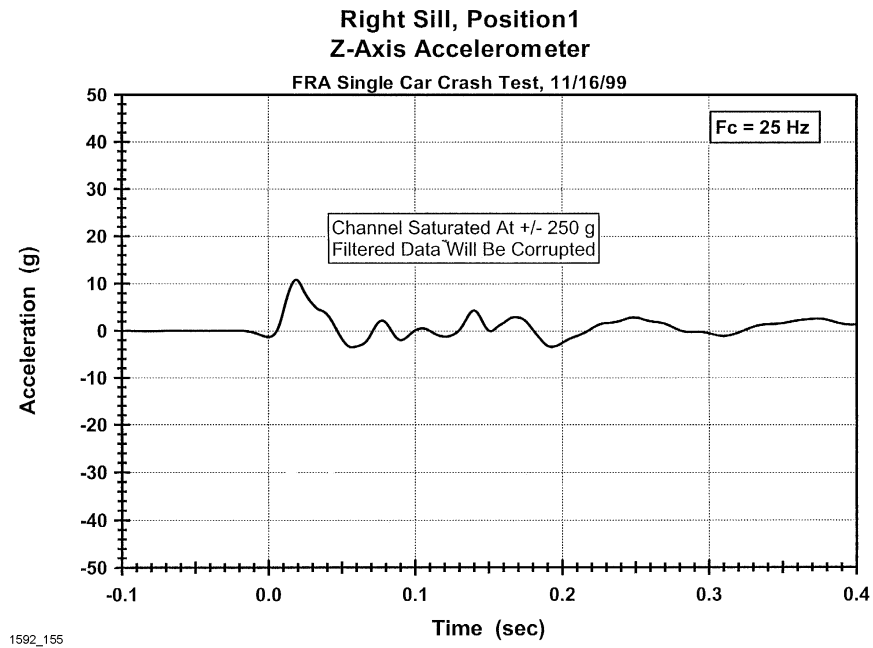

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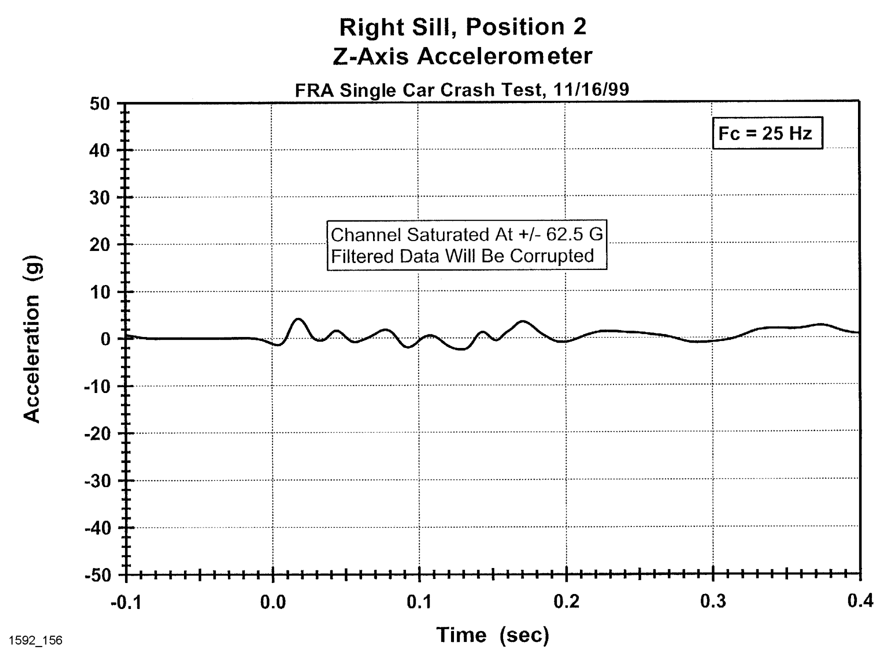

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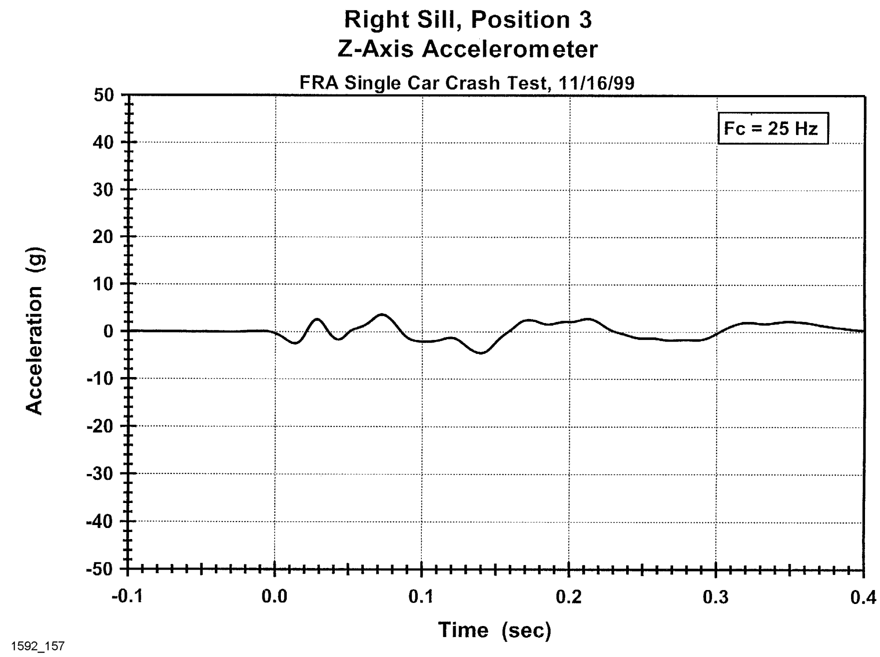

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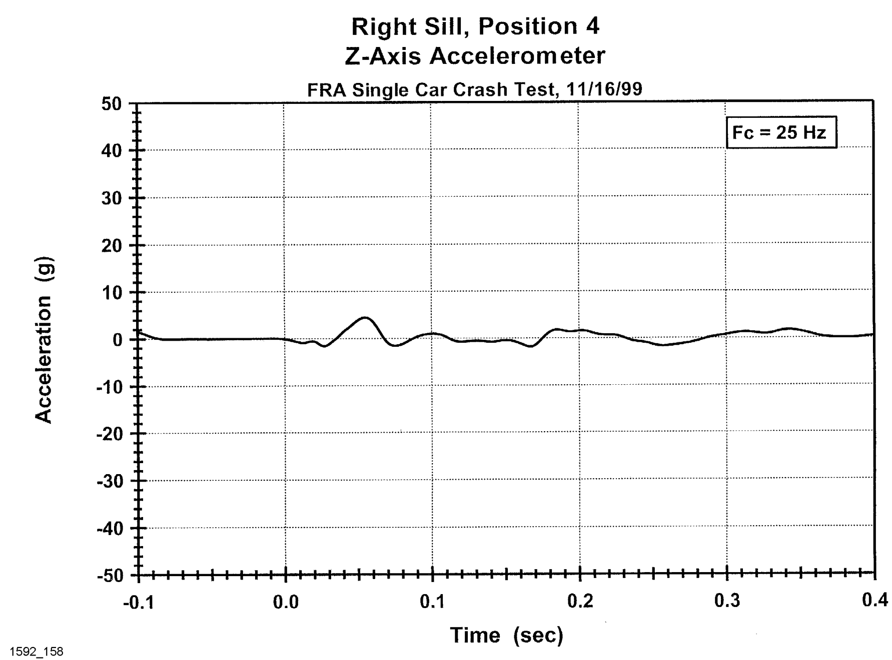

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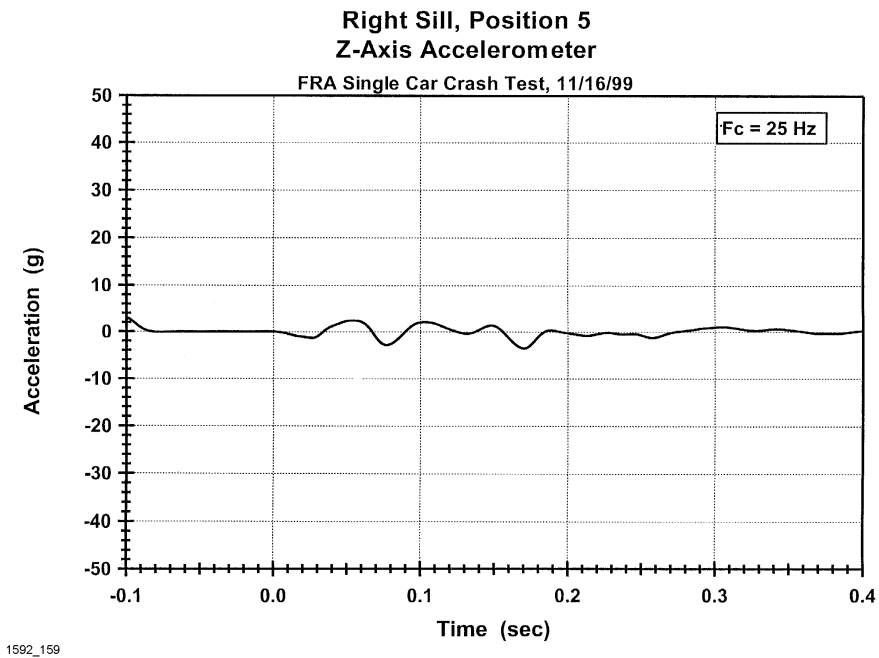

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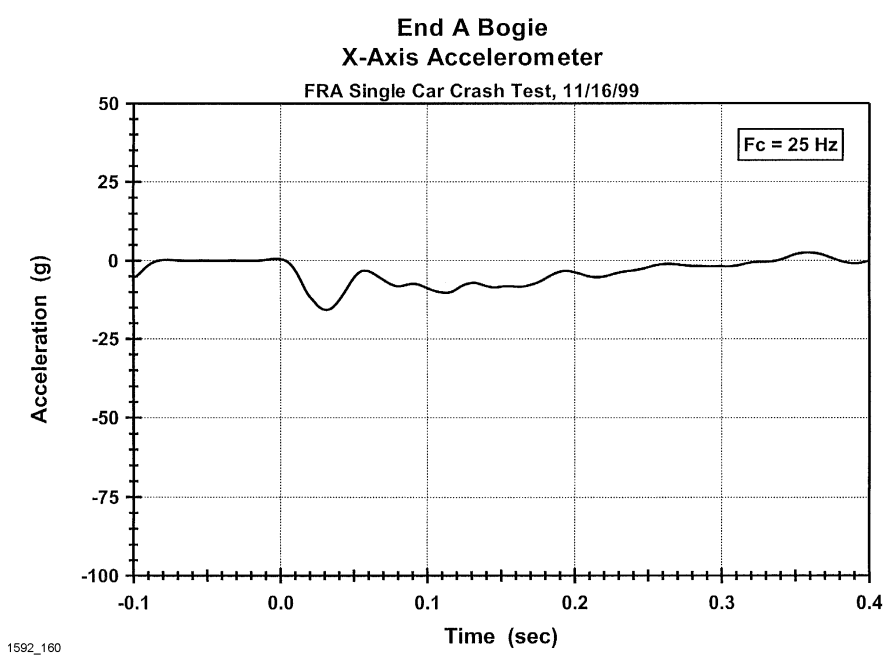

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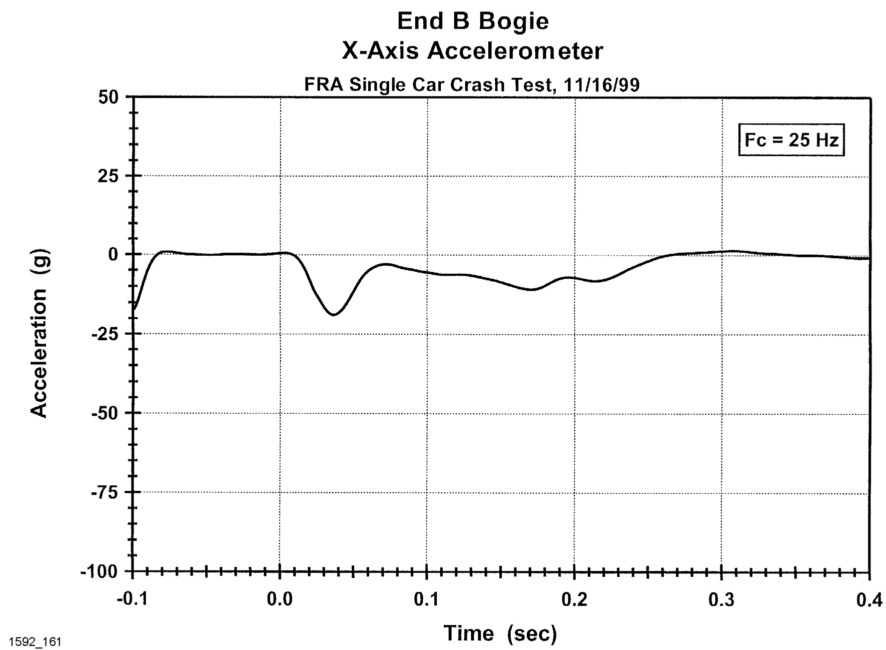

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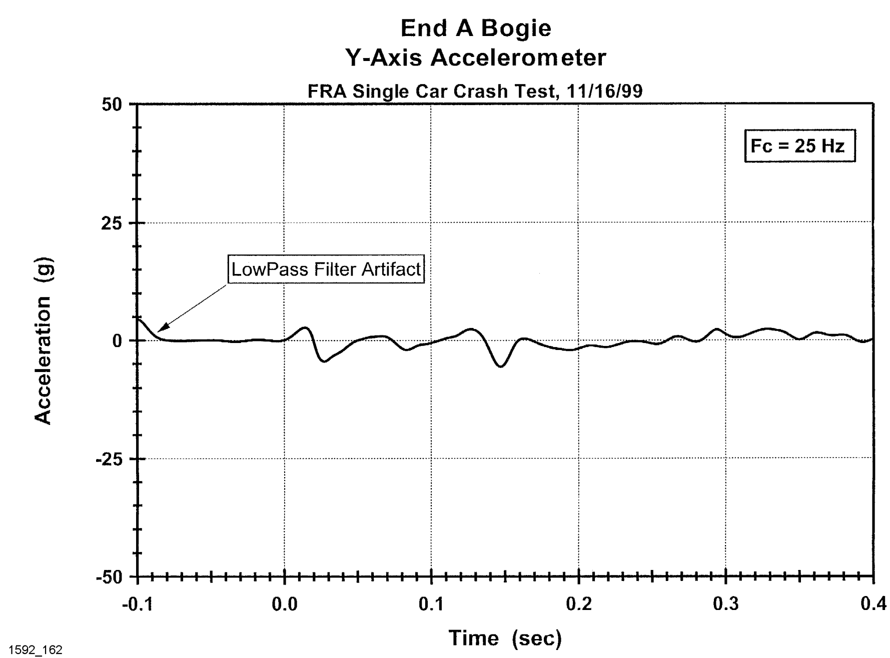

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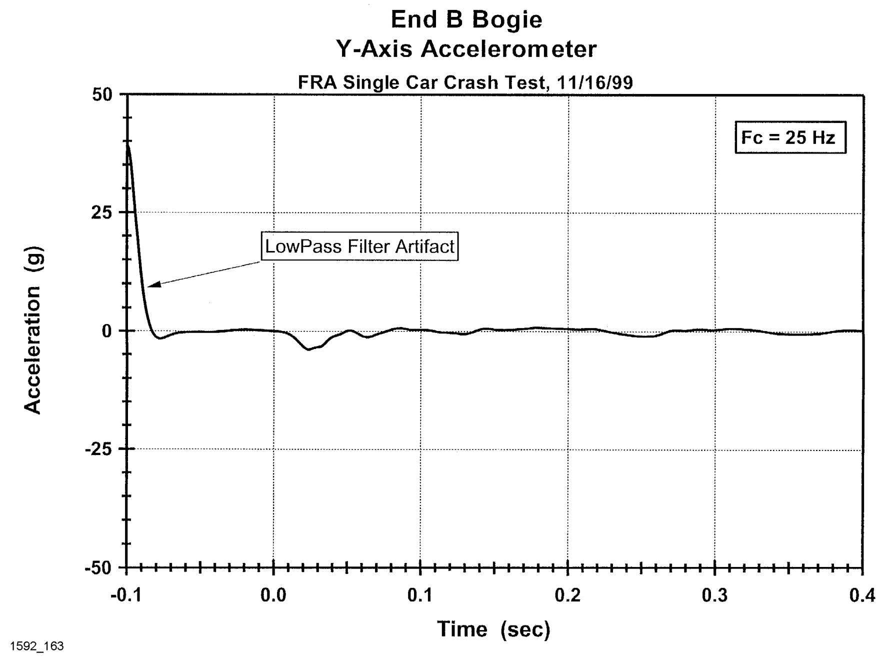

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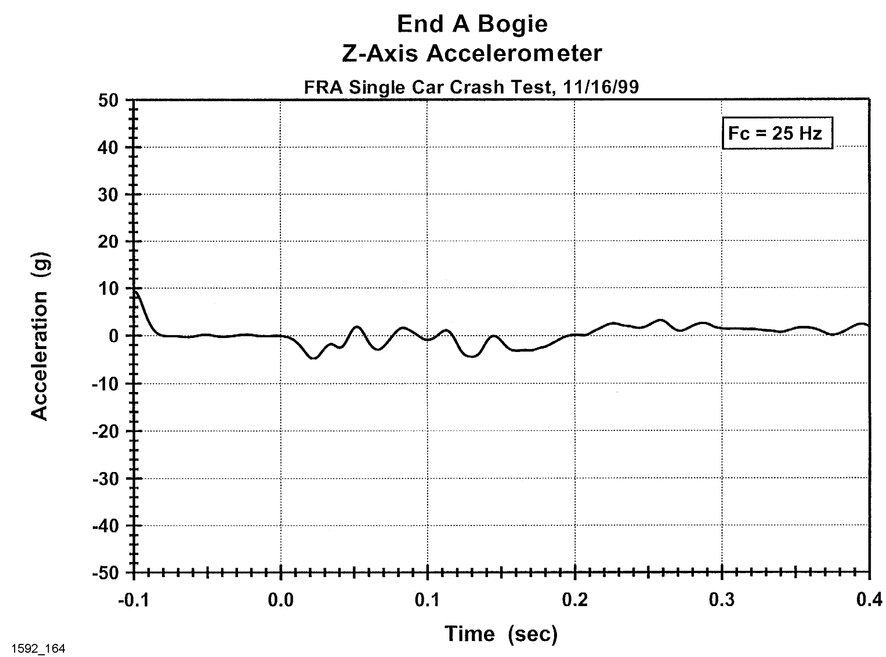

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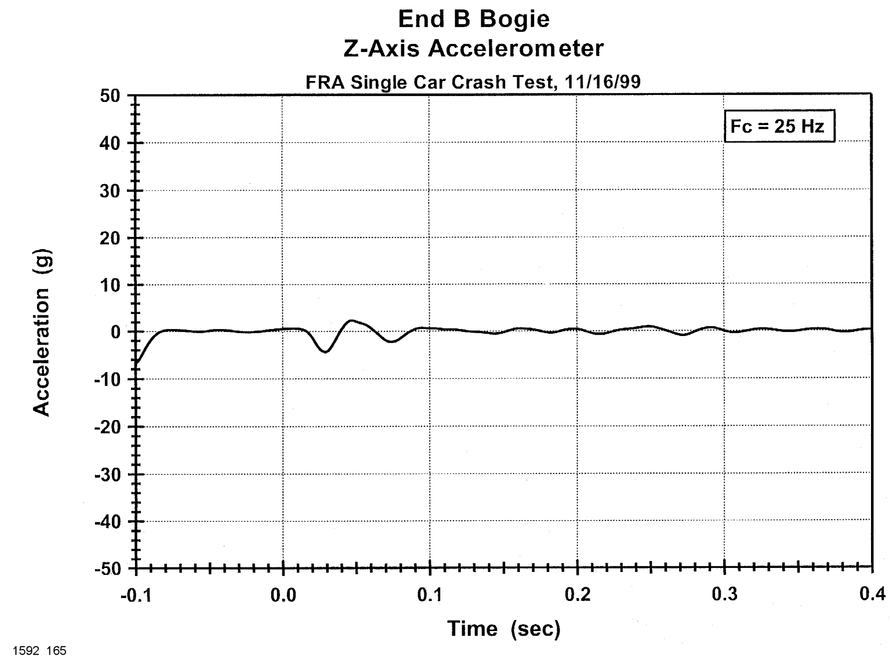

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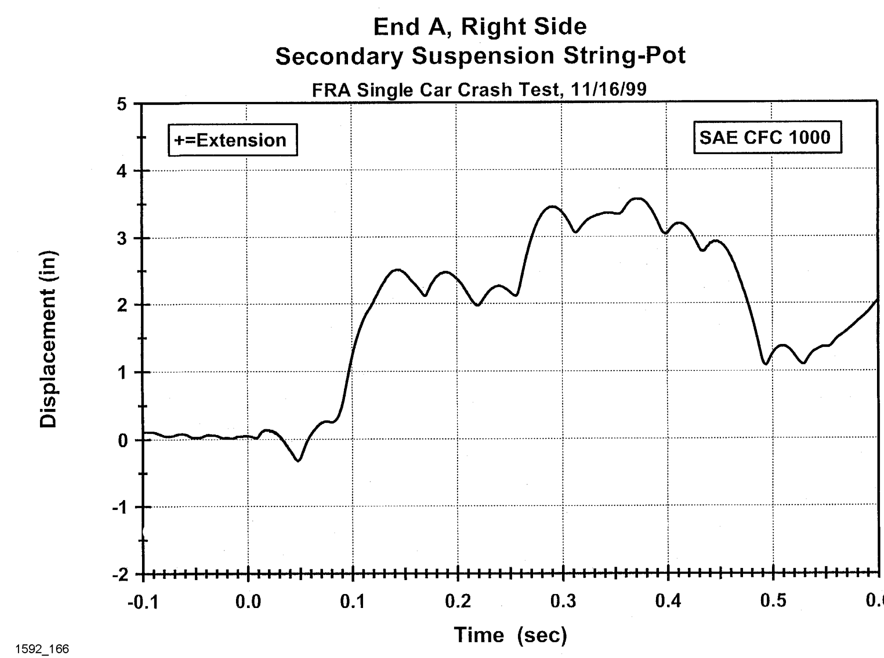

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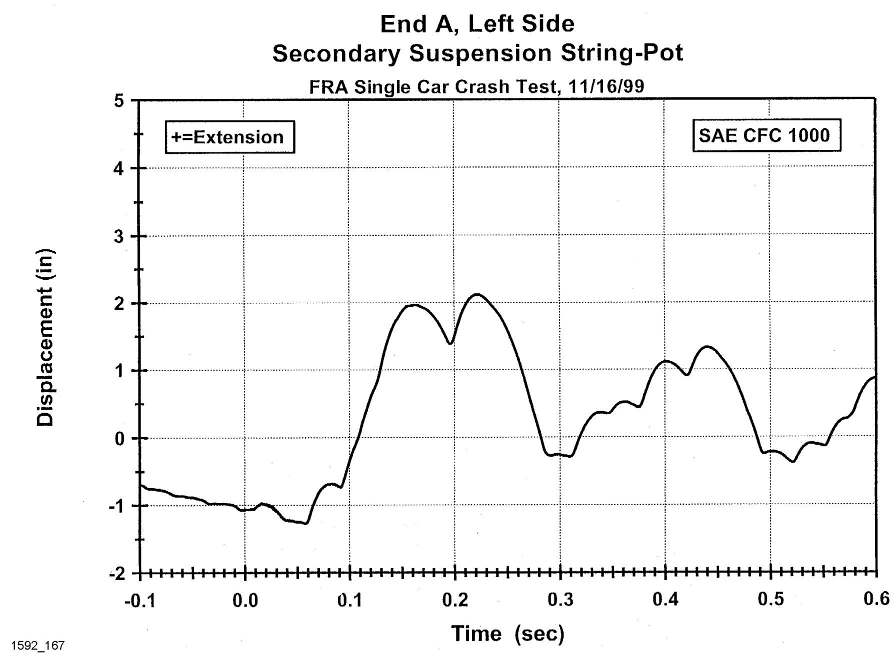

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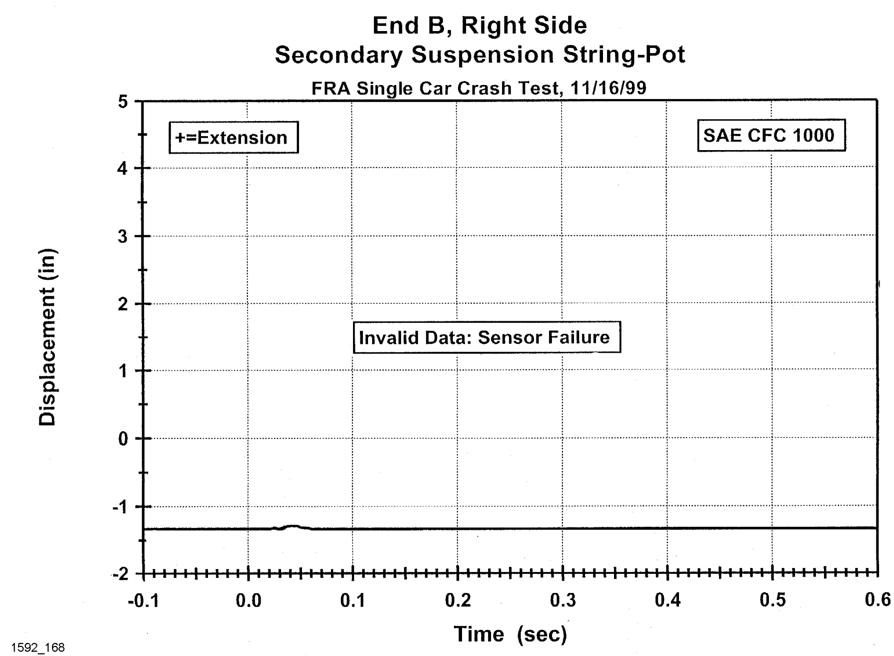

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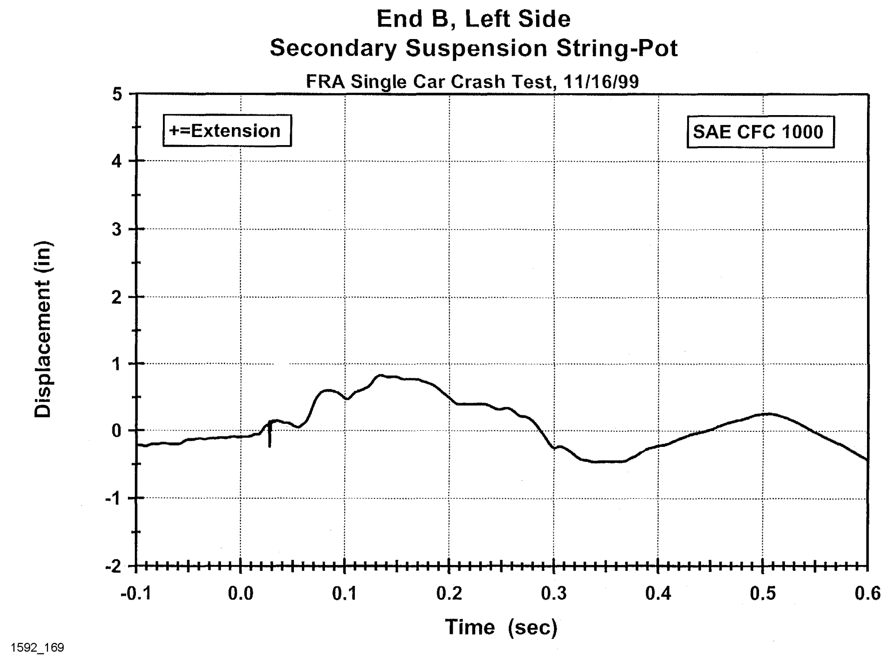

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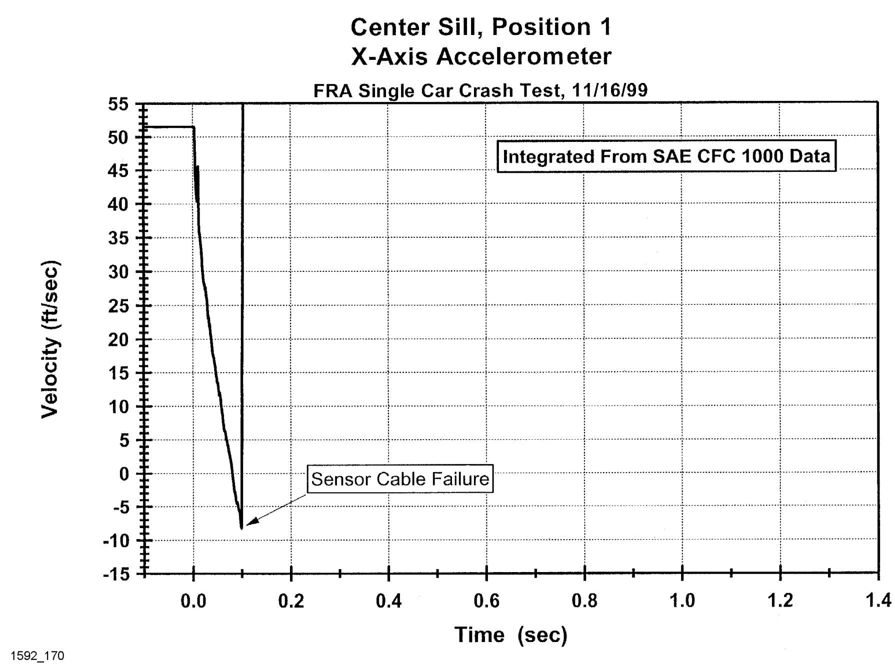

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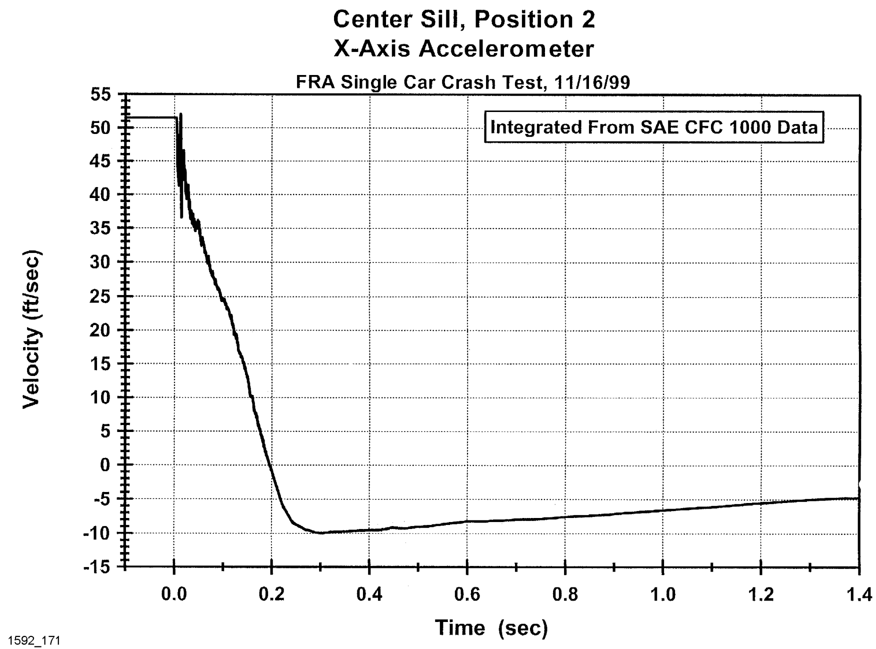

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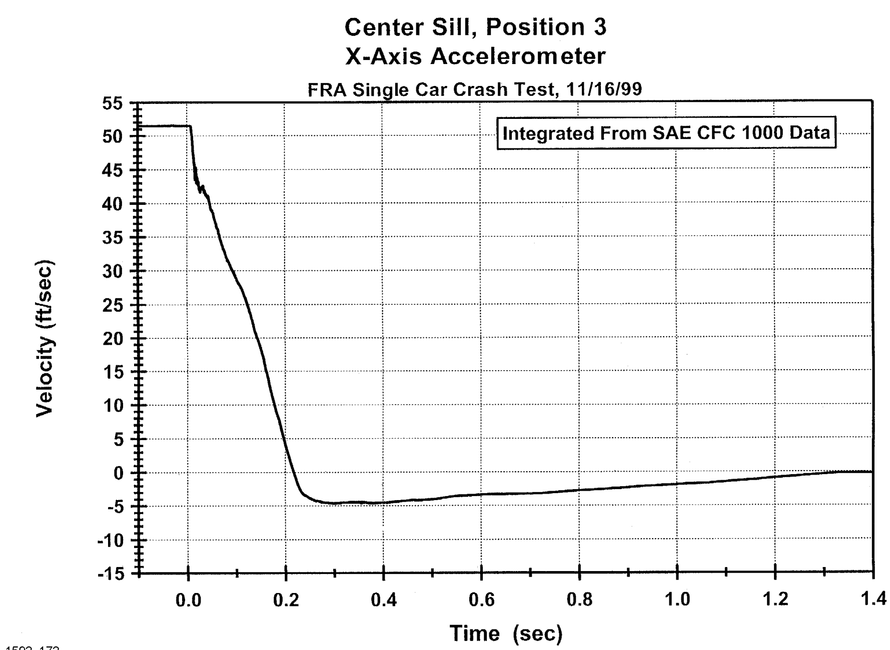

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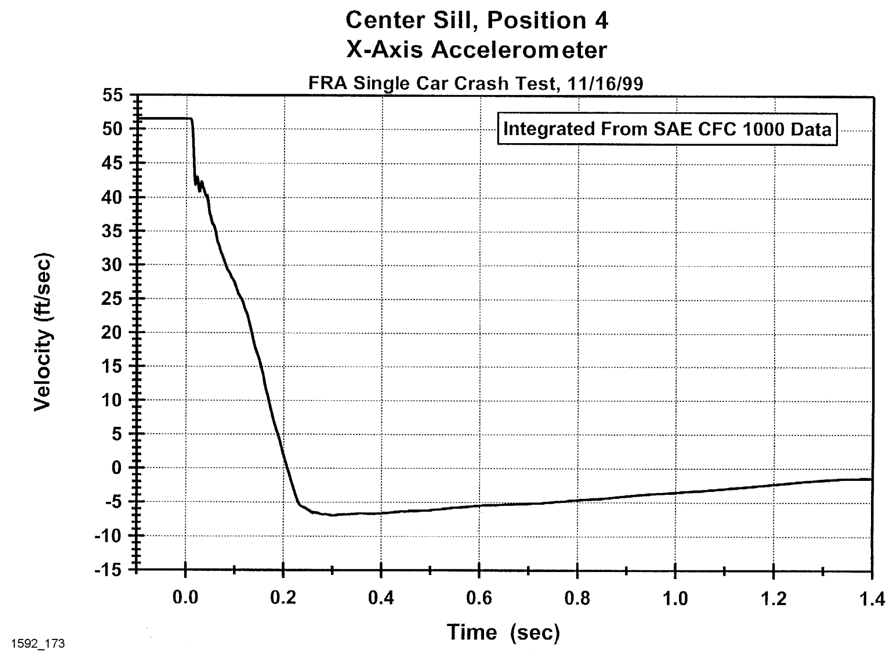

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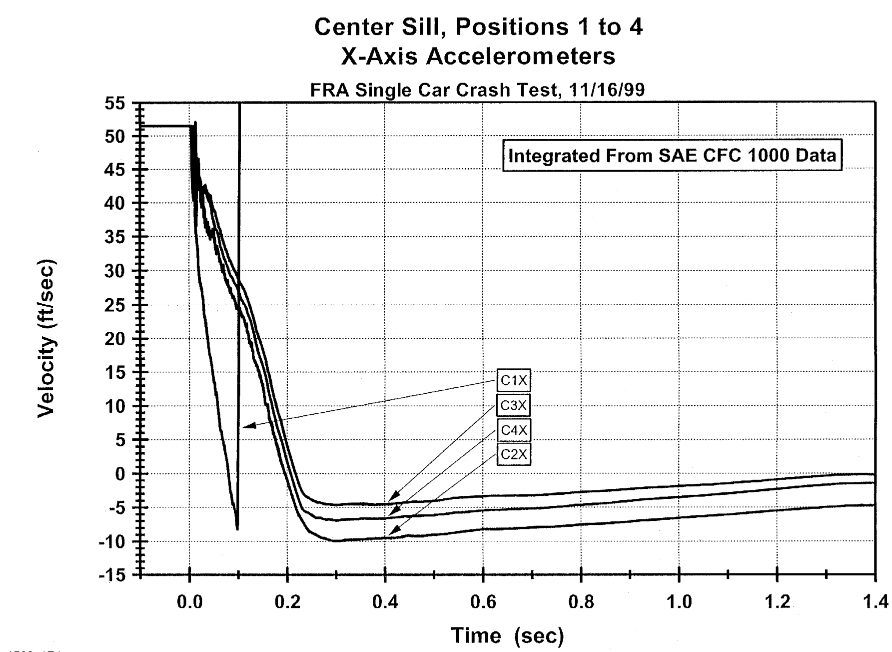

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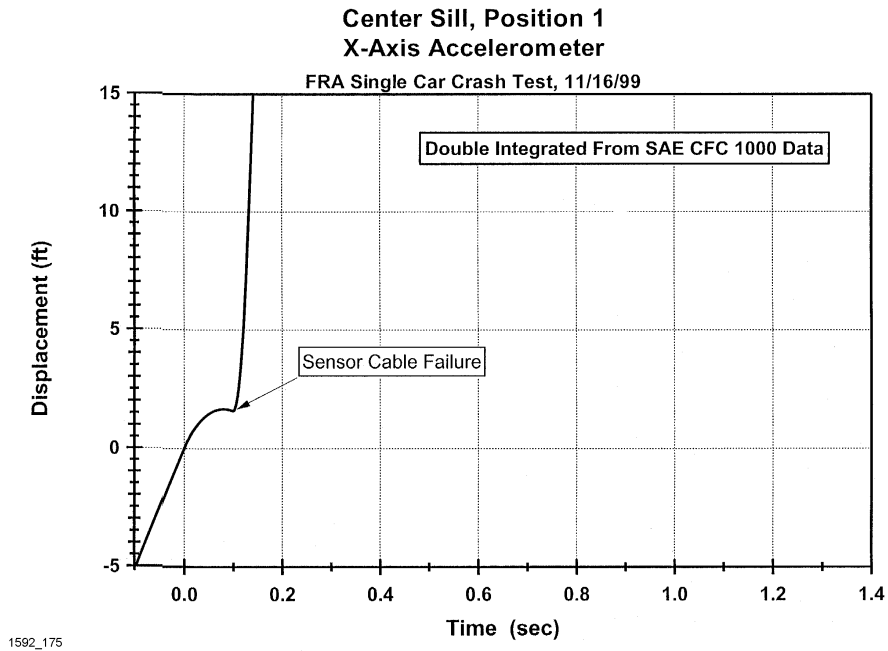

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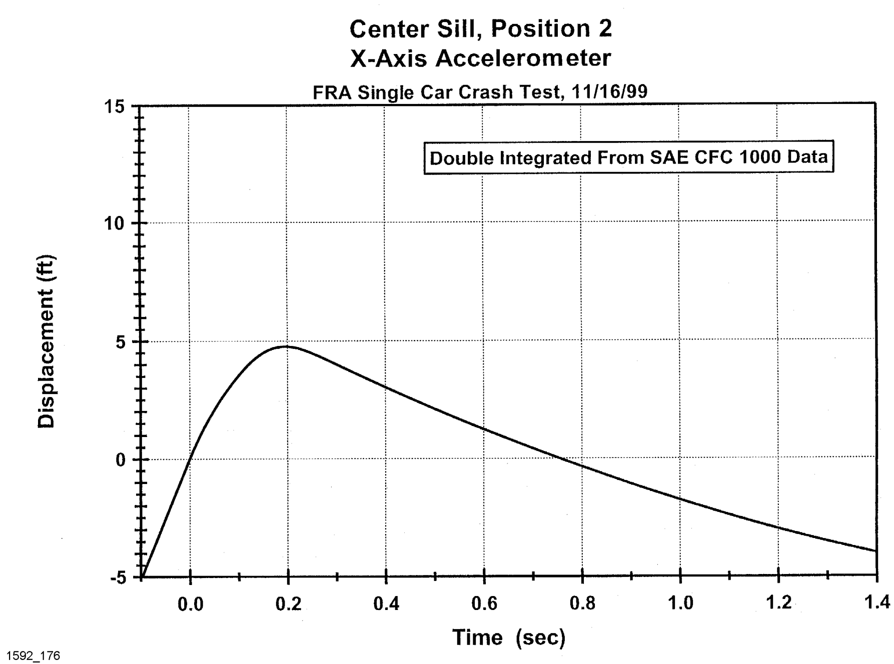
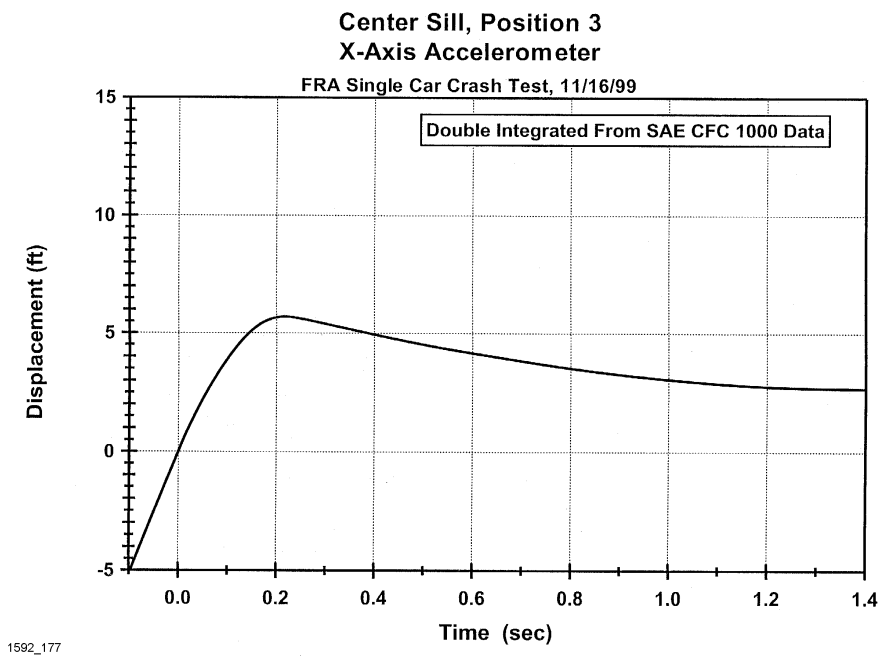


Figure 176.



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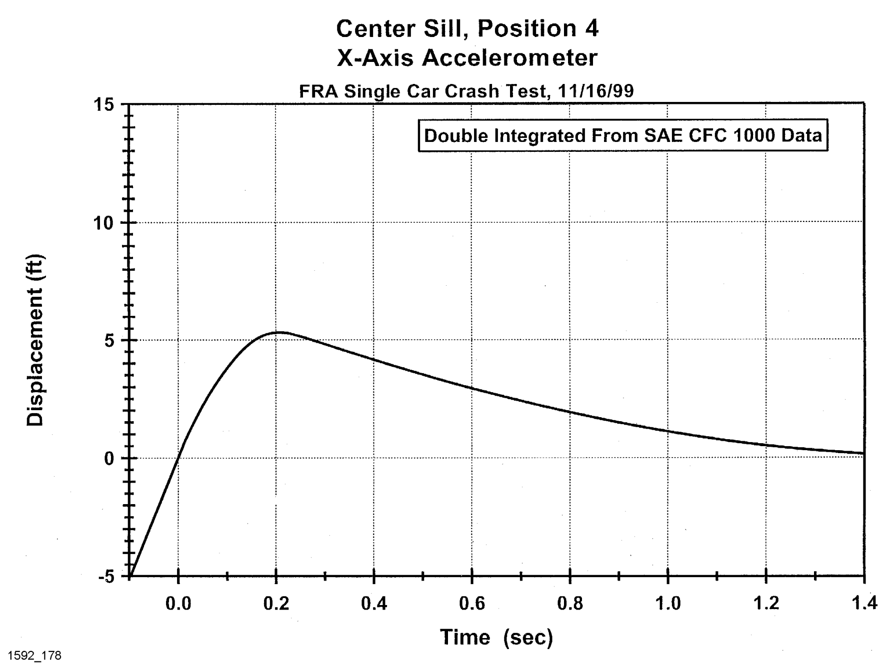

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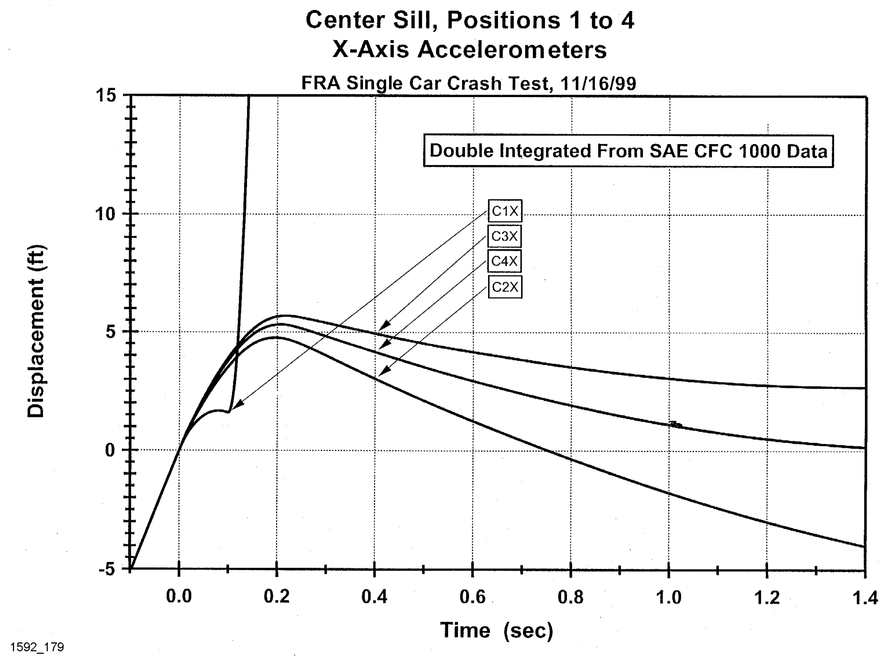

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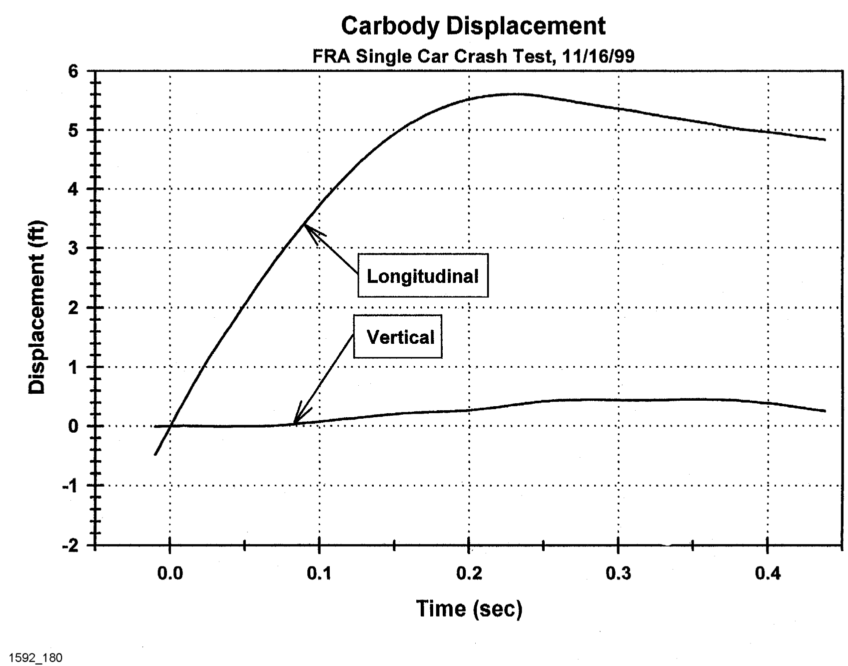

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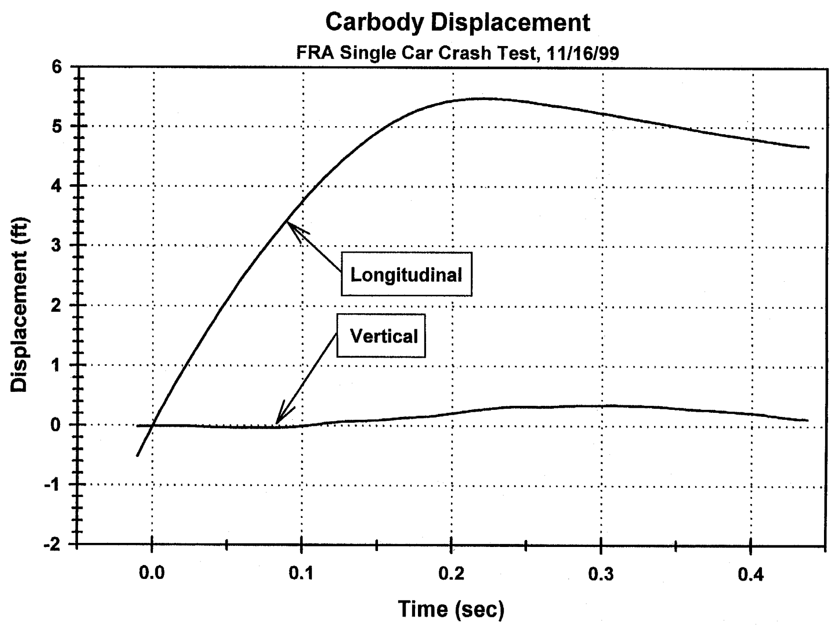
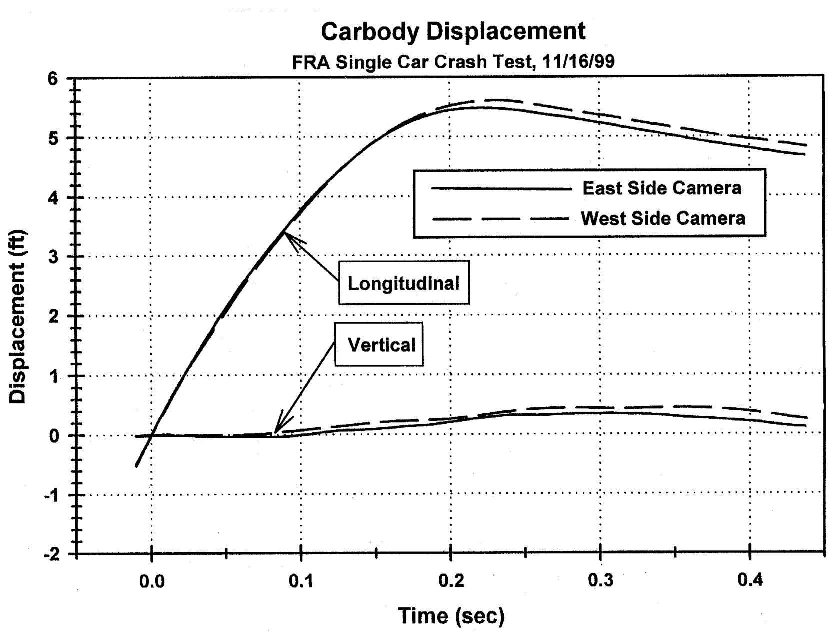


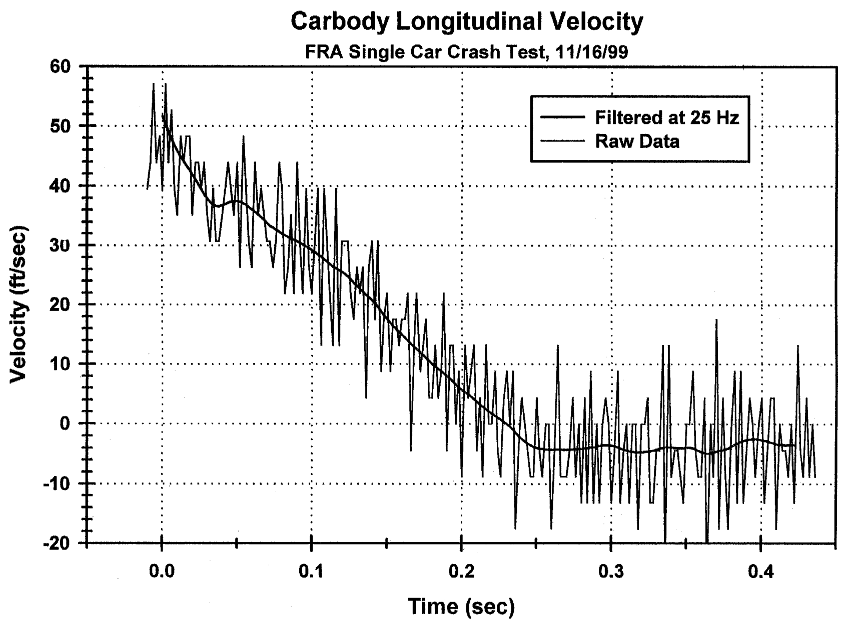
1592_181

Figure 181.



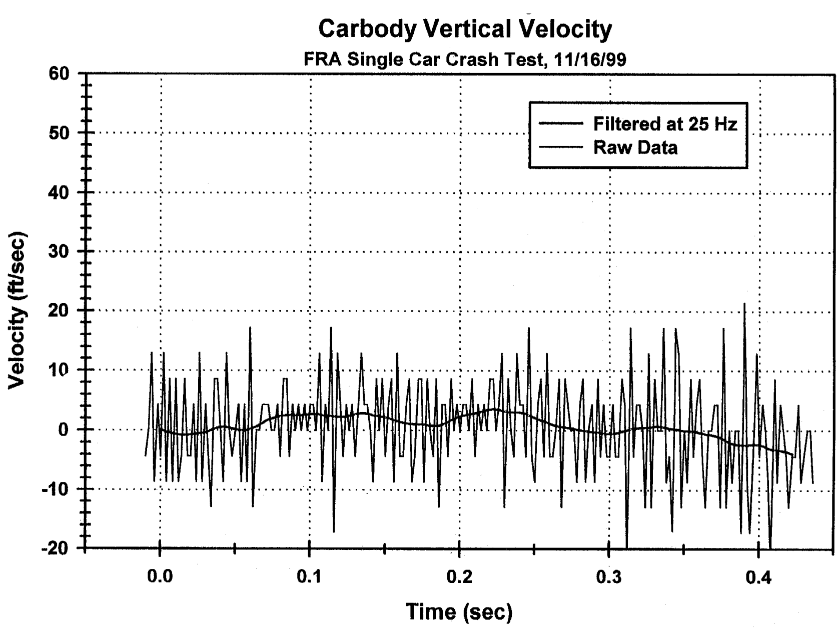
1592_182

Figure 182.



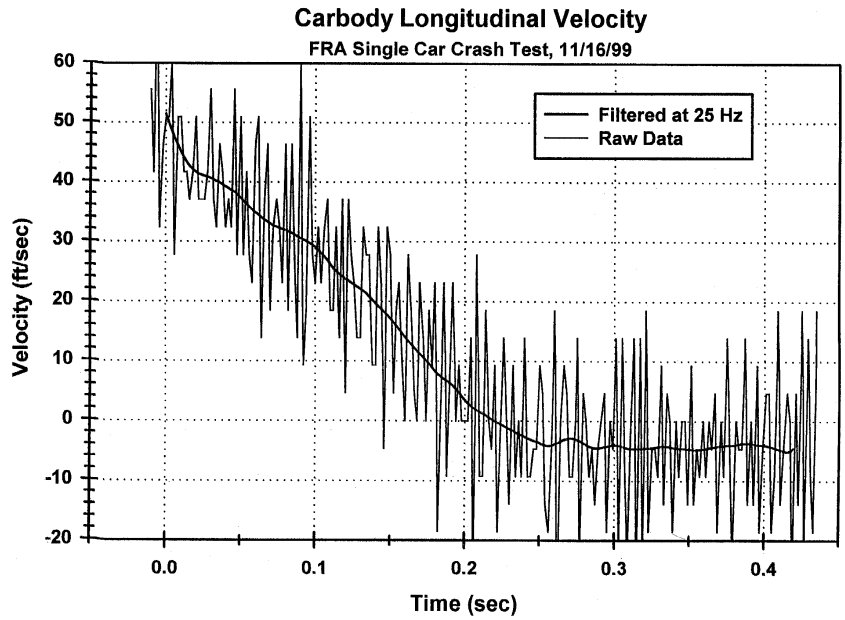
1592_183

Figure 183.



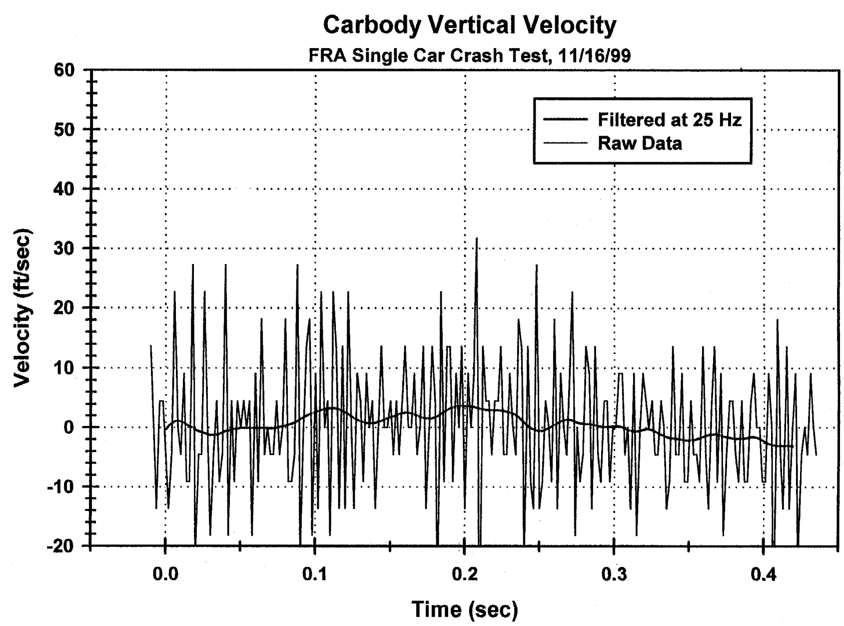
1592_184

Figure 184.



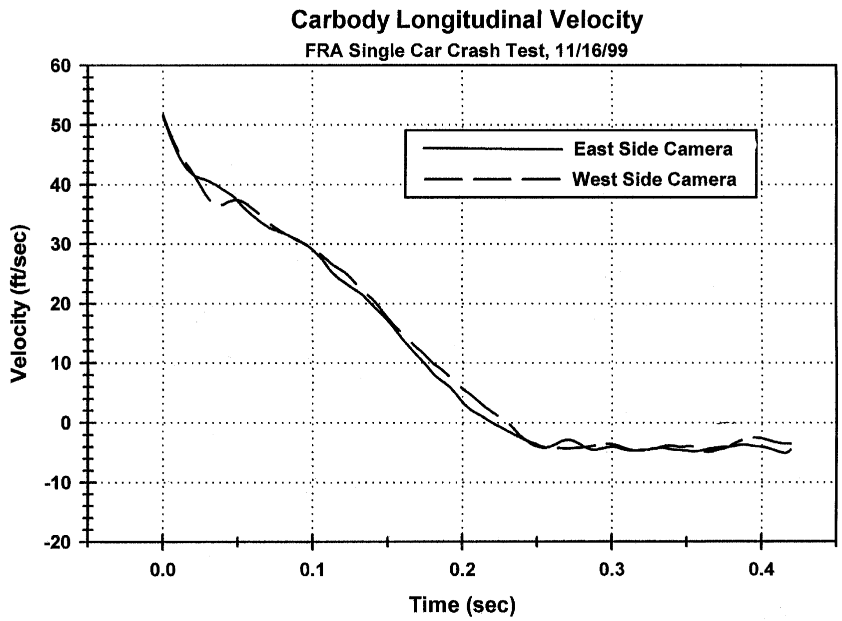
1592_185

Figure 185.



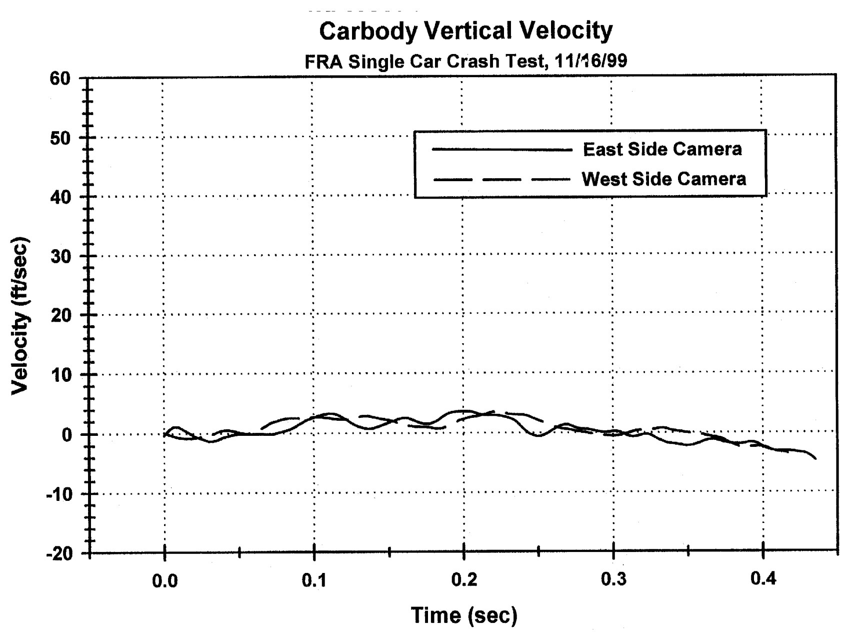
1592_186

Figure 186.



1592_187

Figure 187.



1592_188

Figure 188.

APPENDIX A

Test Implementation Plan for Single Car Dynamic Crush Test – 11/16/99

1.0 Purpose

To indirectly measure the force necessary to crush the main structure of the passenger car at least a distance of three feet under dynamic crush conditions, and measure material strains, structural accelerations and structural displacements throughout the vehicle in sufficient quantity to allow correlation with analytical predictions.

2.0 Requirements

To impact a single passenger car into a rigid barrier at a speed of 35 mph (+ or – 2 mph).

3.0 Test Car

The test will be conducted on a Pioneer type commuter passenger car to be provided by SEPTA.

The test car will be modified internally so that it is fitted with the following seats:

1. 3-place M-style (back row)
2. 3-place M-style (front row)
3. 2-place intercity seat without RS (back row)
4. 2-place intercity seat with lap and shoulder belts (front row)
5. 3-place rear-facing M-style

The following Anthropomorphic Test Devices (ATD) will be provided by Simula and placed in the seats as indicated:

1. 3-place M-style (back row)
   Hybrid III 50^{th} - percentile in window seat
   Hybrid II 50^{th} - percentile in middle seat
   Hybrid II 50^{th} - percentile in aisle seat

2. 2-place intercity seat without RS (back row)
   Hybrid III 95^{th} – percentile in window seat
   Hybrid III 95^{th} – percentile in aisle seat

3. 2-place intercity seat with lap and shoulder belts (front row)
   Hybrid III 5^{th} – percentile in aisle seat
   Hybrid III 95^{th} – percentile in window seat

4. 3-place rear-facing M-style
   Hybrid III 95^{th} – percentile in window seat
   Hybrid III 95^{th} – percentile in middle seat
   Hybrid III 95^{th} – percentile in aisle seat

Weights will be added to the test car so that it is brought up to AW0 condition with the center of gravity in approximately the correct position.

4.0 Test Method

The test will be performed at TTC by impacting the test car into a rigid barrier at a speed of 35 mph. This will be carried out by pushing the test car with a locomotive and then releasing it and allowing it to roll down a constant gradient slope into the rigid barrier. The release distance and the speed of the locomotive at the release point will be determined from a series of calibration runs carried out on a parallel track to the impact track. Both tracks have the same slope.

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

On-board instrumentation will record accelerations, displacements and strains at various points on the test car during the impact. High speed film cameras will be used to record the impact.

5.0 Measured Items

The following items will be measured before the test:

1. Car length, measured from buffer-beam to buffer-beam.
2. Longitudinal distance from buff stop to body bolster, at both ends of car.
3. Longitudinal distance between body bolsters.
4. Vertical distance between mid-point of car and a line extending between body bolsters.
5. Vertical distance between buffer beam and a line extending between body bolsters.
6. The weight of the test car.
7. The height of the center of gravity of the test car.

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 test vehicle. The following items will be measured during the test:

1. The speed of the car just before impact using a laser based speed trap.
2. Longitudinal strains at draft sill, center sill, side sills and cant rails (48 strain gages).
3. Acceleration of left and right side sills, draft sill and at the mid point of each body bolster (35 accelerometers).
4. Acceleration of each truck (6 accelerometers)
5. Displacement across each secondary suspension (4 string potentiometers)

This amounts to a total of 48 + 35 + 6 + 4 = 93 channels

High speed 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 of the vehicle during impact.

The following items will be measured after the test:

1. Car length, measured from buffer-beam to buffer-beam.
2. Longitudinal distance from buff stop to body bolster, at both ends of car.
3. Longitudinal distance between body bolsters.
4. Vertical distance between mid-point of car and a line extending between body bolsters.
5. Vertical distance between buffer beam and a line extending between body bolsters.

6.0 Instrumentation

6.1 Strain measurements

Substantial crush of the car is expected to occur in the end of the car nearest the rigid wall. Figure 6.1.1 schematically illustrates the areas of plastic deformation that may potentially occur during the test. The side sills and cant rails are also expected to have plastic deformations in corresponding areas.

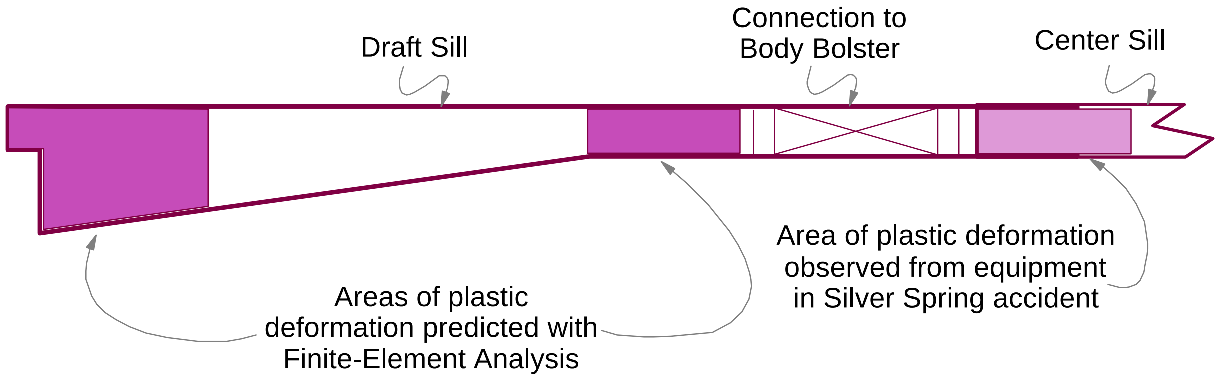


Figure 6.1.1 Potential areas of plastic deformation, draft sill and center sill.

Figure 6.1.2 shows the general arrangement of high-elongation (up to 20% strain) strain gages intended to capture the plastic deformation of the end of the car nearest the wall during the test. The strain gages are to be located on the draft sill and center sill, the side sills, and the cant rails.

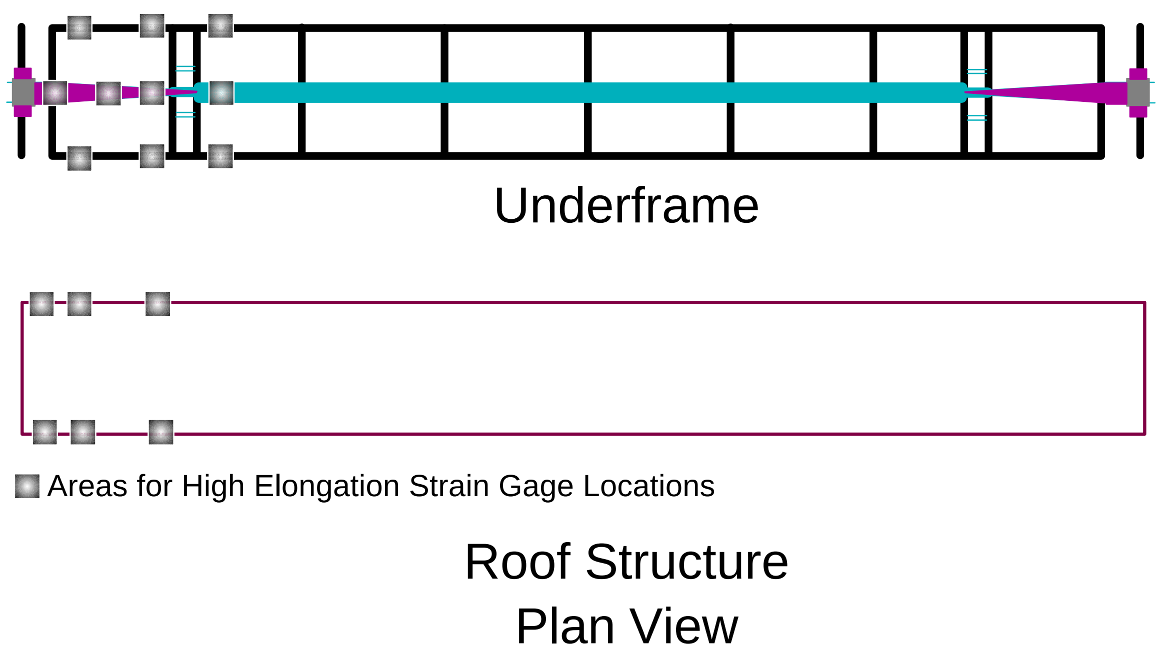


Figure 6.1.2 General Arrangement of High Elongation Strain Gages.

Figure 6.1.3 shows the detailed arrangement of the high elongation strain gages on the left side draft sill and center sill. The strain gages shown along the lower part of the sill are actually located on the bottom surface of the sill. Table 6.1.1. lists the locations and strain gage types for all the strain gages on the draft sill and center sill. A total of twenty one high elongation strain gages are to be used on the draft sill and center sill.

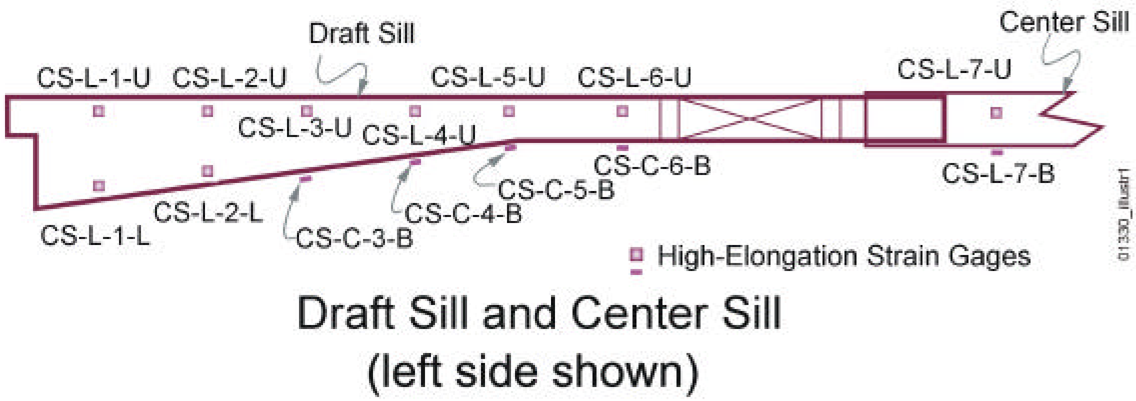


Figure 6.1.3 Detailed arrangement of high elongation strain gages on the left side of the draft sill and center sill.

Table 6.1.1 Strain gage location and type, Draft Sill and Center Sill

Location	**Strain Gage**	**Channel**
Center Sill Right - 1-Upper CS-R-1-U	High Elongation (200,000 maximum strain)	1
CS-R-2-U	High Elongation	2
CS-R-3-U	High Elongation	3
CS-R-4-U	High Elongation	4
CS-R-5-U	High Elongation	5
CS-R-6-U	High Elongation	6
CS-R-7-U	High Elongation	7
CS-L-1-U	High Elongation	8
CS-L-2-U	High Elongation	9
CS-L-3-U	High Elongation	10
CS-L-4-U	High Elongation	11
CS-L-5-U	High Elongation	12
CS-L-6-U	High Elongation	13
CS-L-7-U	High Elongation	14
CS-L-1-L	High Elongation	15
CS-L-2-L	High Elongation	16
CS-R-1-L	High Elongation	17
CS-R-2-L	High Elongation	18
CS-C-3-B	High Elongation	19
CS-C-4-B	High Elongation	20
CS-C-5-B	High Elongation	21
CS-C-6-B	High Elongation	22
CS-L-7-B	High Elongation	23
CS-R-7-B	High Elongation	24
Total Number of Channels		24

Figure 6.1.4. shows the detailed arrangement of the high elongation strain gages on the left side sill. Table 6.1.2. lists the locations and strain gage types for all the strain gages on the side sills. A total of twelve high elongation strain gages are to be used on both side sills.

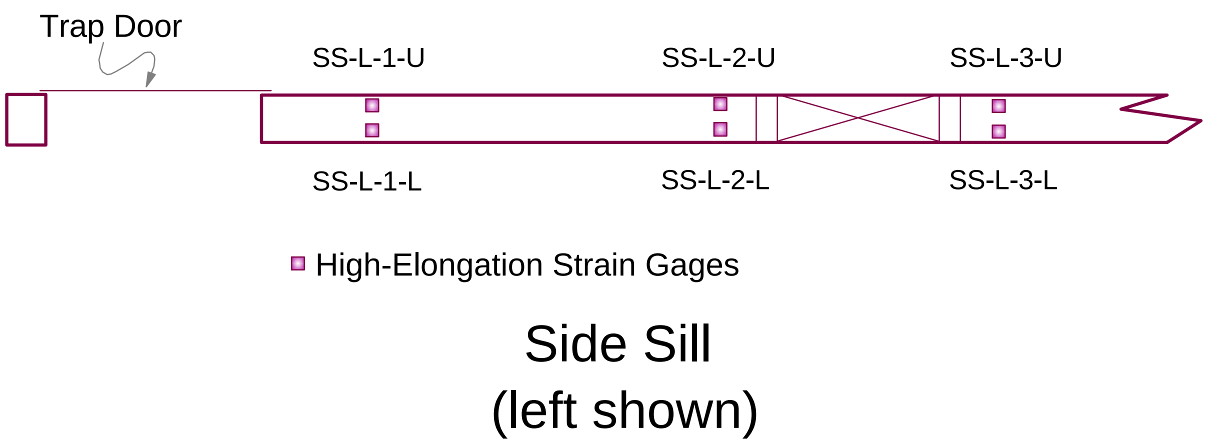


Figure 6.1.4 Detailed arrangement of high elongation strain gages on the left side sill.

Table 6.1.2   Strain gage location and type, Side Sills

Location	**Strain Gage**	**Channel**
Side Sill Left –1- Upper SS-L-1-U	High Elongation (200,000 maximum strain)	1
SS-L-2-U	High Elongation	2
SS-L-3-U	High Elongation	3
SS-L-1-L	High Elongation	4
SS-L-2-L	High Elongation	5
SS-L-3-L	High Elongation	6
SS-R-1-U	High Elongation	7
SS-R-2-U	High Elongation	8
SS-R-3-U	High Elongation	9
SS-R-1-L	High Elongation	10
SS-R-2-L	High Elongation	11
SS-R-3-L	High Elongation	12
Total Number of Channels		12

Figure 6.1.5 shows the detailed arrangement of the high elongation strain gages on the left cant rail. Table 6.1.3 lists the locations and strain gage types for all the strain gages on the cant rails. A total of twelve high elongation strain gages are to be used on both cant rails.

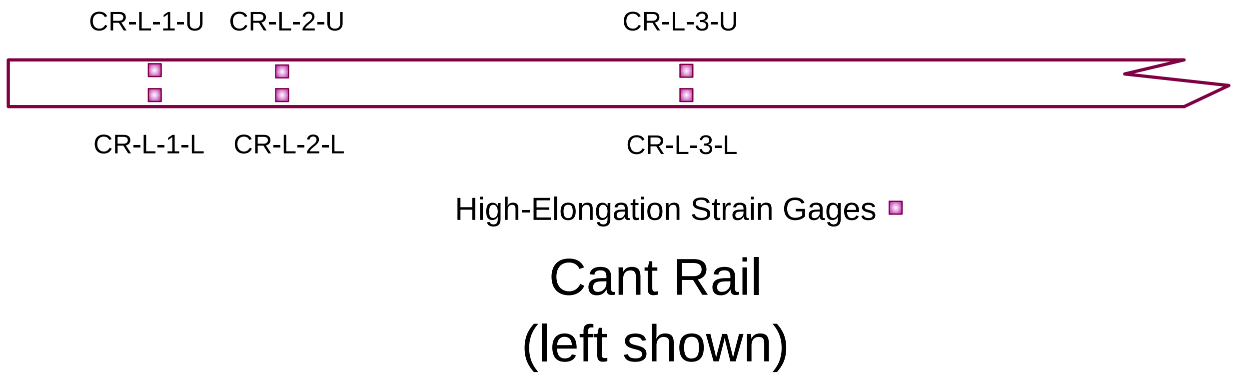


Figure 6.1.5 Detailed arrangement of high elongation strain gages on the left cant rail.

Table 6.1.3 Strain gage location and type, Cant rails

Location	**Strain Gage**	**Channel**
Cant Rail Left –1- Upper CR-L-1-U	High Elongation (200,000 maximum strain)	1
CR-L-2-U	High Elongation	2
CR-L-3-U	High Elongation	3
CR-L-1-L	High Elongation	4
CR-L-2-L	High Elongation	5
CR-L-3-L	High Elongation	6
CR-R-1-U	High Elongation	7
CR-R-2-U	High Elongation	8
CR-R-3-U	High Elongation	9
CR-R-1-L	High Elongation	10
CR-R-2-L	High Elongation	11
CR-R-3-L	High Elongation	12
Total Number of Channels		12

Table 6.1.4 lists a summary of the structural members and the total number of strain gages.

Table 6.1.4 Structural Members and Numbers of Strain Gages

Structural Member	**Number of Strain Gages**
Draft and Center Sills	24
Side Sills	12
Cant Rails	12
Total Number of Strain Gages	48

6.2 Acceleration measurements
The car-body gross and flexible motions will be measured using accelerometers. The gross motions of the car body are the longitudinal, lateral, and vertical translational displacements, as well as the pitch, yaw and roll angular displacements. The gross motions of the car shall be measured in or near the operator's control stand, and in the passenger volume. The flexible modes of concern include vertical and lateral bending as well as torsional displacement about axis of the car. Measurements of these motions are required to fully characterize the secondary collision environment.

Figure 6.2.1 shows the location of the accelerometers schematically. Table 6.2.1 lists the accelerometer locations, accelerometer types, and data channels.

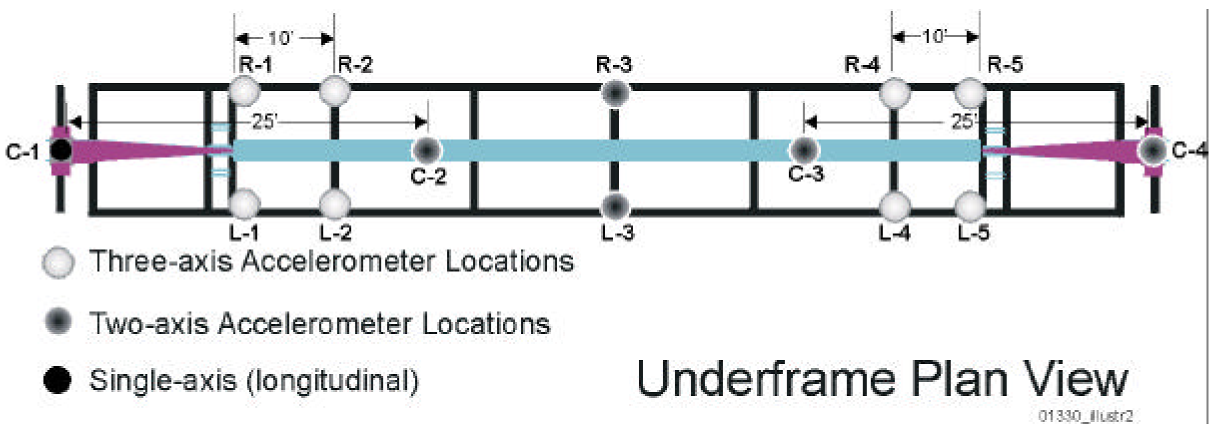


Figure 6.2.1 Schematic Diagram of Accelerometer Locations.

Table 6.2.1 Accelerometer measurements

Location	Accelerometer	Measurement	Channel
C-1	Single axis	Longitudinal 400g	1
C-2	Two axis	Vertical 200g	2
		Longitudinal 400g	3
C-3	Two axis	Vertical 200g	4
		Longitudinal 400g	5
C-4	Two axis	Vertical 200g	6
		Longitudinal 400g	7
R-1	Three axis	Vertical 200g	8
		Lateral 100g	9
		Longitudinal 1000g	10
R-2	Three axis	Vertical 50g	11
		Lateral 50g	12
		Longitudinal 400g	13
R-3	Two axis	Vertical 200g	14
		Lateral 100g	15
R-4	Three axis	Vertical 100g	16
		Lateral 50g	17
		Longitudinal 100g	18
R-5	Three axis	Vertical 200g	19
		Lateral 100g	20
		Longitudinal 400g	21
L-1	Three axis	Vertical 200g	22
		Lateral 100g	23
		Longitudinal 1000g	24
L-2	Three axis	Vertical 50g	25
		Lateral 50g	26
		Longitudinal 400g	27
L-3	Two axis	Vertical 200g	28
		Lateral 100g	29
L-4	Three axis	Vertical 100g	30
		Lateral 50g	31
		Longitudinal 100g	32
L-5	Three axis	Vertical 200g	33
		Lateral 100g	34
		Longitudinal 400g	35
B-1	Three axis	Vertical 400g	36
		Lateral 400g	37
		Longitudinal 400g	38
B-2	Three axis	Vertical 400g	39
		Lateral 400g	40
		Longitudinal 400g	41

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.

6.3 String Potentiometers

Four string potentiometers will be fixed across each secondary suspension between body bolster and bogie bolster to measure the relative vertical displacement.

6.4 High-speed and real-time photography

Eight high-speed film cameras and three real-time video cameras will document the impact test. Locations of the cameras appear in Fig. 6-3-1. Coverage and frame rates appear in Table 6-3-1. Cameras 1,3,6 and 7 will view from just below the top of the rail to just above the car-body. Thus the height of the view at the side of the car-body will be approximately 12 ft, and the width of the view will be approximately 18 ft. The cameras will be located approximately 25 ft away from the side of the car-body that they are viewing, and about 5 ft from the front of the barrier. The cameras are equipped with sights that allow the photographer to view the expected image. Thus the final siting will be done at the time of camera setup to achieve the views described above. Adjustments will be made, if necessary, to the above distances to achieve the desired 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.

One high-speed camera (No. 9) to be provided in the recess between rails to look up at the end sill deformation during crash. Supplemental lighting will be necessary to obtain good exposure.

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. Film for the on-board camera will be Kodak 16-mm 7249, ISO 500, for tungsten on 100-ft spools.

Four-in. diameter targets will be placed on the vehicle 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. Yellow and black are sometimes used, as are red and white. The color scheme has not yet been finalized. At least three targets will be placed on each side of the vehicle and the ground. During film analysis, the longitudinal and vertical coordinates of the targets are determined from projections on a film analyzer or ground glass plate 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.

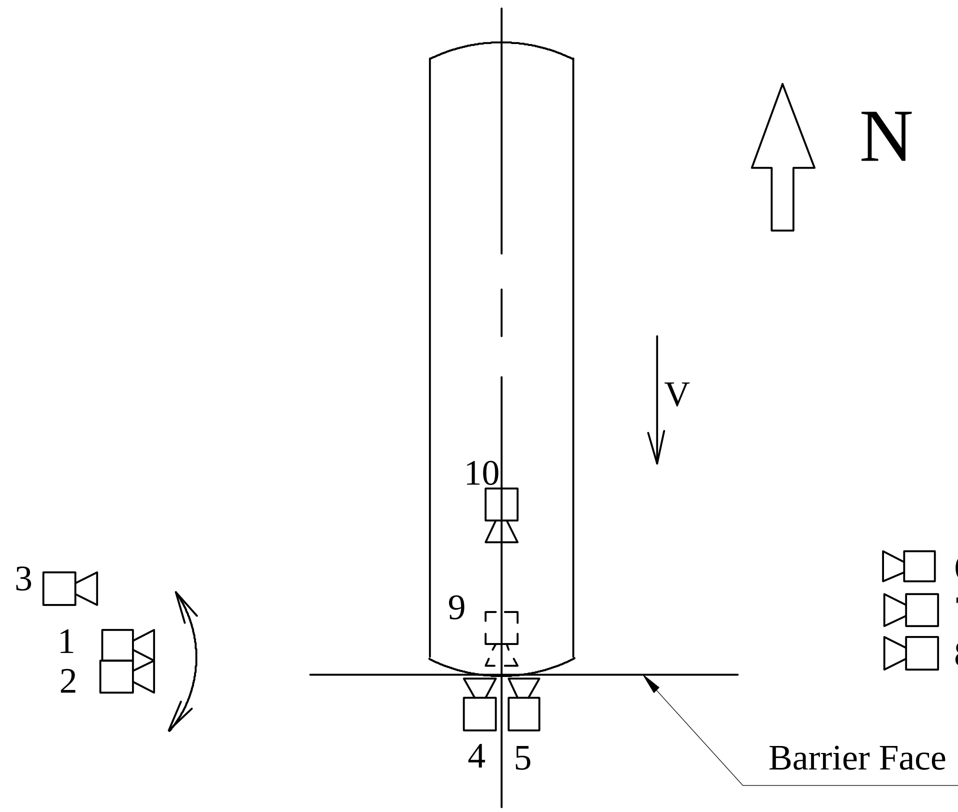


Fig. 6 -3-1 Camera placement

The on-board high-speed camera will be started automatically by a trip wire attached to the test vehicle. On-board lights will be turned on before the vehicle motion begins. When the trip wire engages a trip stake placed to start the camera 102 ft before barrier contact, a relay will close energizing the camera. The ground-based cameras will be started simultaneously from a central relay box triggered manually when the front of the car body passes a mark 102 feet from the barrier. This will allow about 2 seconds for the cameras to get up to speed and to start filming the event. The cameras running at a nominal speed of 1000 frames per second will run for about four seconds before the100-ft film is entirely exposed.

Table 6-3-1 Camera information

No.	Type	Manufacturer Model	Speed	Coverage	Location	Lens
1	Video	(S-VHS)	Real Time	Panning	Ground	
3	Film	Hycam 41-0064	500fps	Close	Ground	25 mm
4	Video	Digital	Real Time	Close	Barrier	4.2-50.4 mm zoom
5	Film	Hycam 41-0064	500 fps	Close	Barrier	10 mm
6	Video	HI 8	Real Time	Close	Ground	
7	Film	Hycam 41-0064	500 fps	Close	Ground	25 mm
9	Film	Locam –mirror	500 fps	Close	Under	8 mm
10	Film	Milliken DBM55	500 fps	Close	On-Board	10 mm

6.5 Data Acquisition

Twelve 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 front of the vehicle in the leading contact position. Closure of these switches at impact will indicate contact between the test vehicle and the barrier. The switch closures will trigger each Data Brick. At least 50 ms of pre-trigger data will be recorded. Separate Tape Switches will also be attached at the front of the vehicle and at a corresponding location on the barrier to fire flash bulbs and to synchronize film cameras. The tape switches will be manufactured by Tapeswitch Corporation, model 1201-131-A.)

6.7 Speed Trap
A dual channel speed trap will accurately measure impact speed of the test vehicle within 0.5 meter of the barrier. 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 vehicle. Final rod location will be determined prior to installation.

7.0 Test Procedure

(1) The car body will be modified internally with the appropriate seating arrangement.

(2) Strain gages will be attached on the side sills and draft sills of the car body.

(3) The car length will be measured from buffer beam to buffer beam. The longitudinal distance from buff stop to body bolster will be measured at both ends of the car. The longitudinal distance body bolsters will be measured. The vertical distance between the mid-point of the car and a line extending between body bolsters will be measured. The vertical distance between buffer beam and a line extending between the body bolsters will be measured.

(4) The mass of the car will be calculated by measuring the weight of each end of the car on a weigh bridge (Elevation of the TTC = 5,013 ft., g = 32.14 ft/sec^2) .

(5) The vertical height of the center of gravity will be estimated using the technique described in Appendix A.

(6) Speed calibration runs will be carried out using the test car. These will be carried out on the PTT track, which is parallel to the track leading to the barrier. This track has the same gradient as the track leading to the barrier and both are tangent. The test car will pushed by a locomotive and then released at points of varying distance from the crash barrier and allowed to run freely down the slope. The speed of the test car will be measured as it passes the crash barrier using a laser speed trap. These runs will be carried out at different ambient temperatures and wind speeds. Having passed the barrier, the test car will be stopped by a locomotive catching it up, catching the coupler, and then slowing down and bringing it 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) Calibration runs will be carried out with the test car on the track leading to the crash barrier in a similar manner to those described above except that the vehicle will not be allowed to travel as far as the crash barrier. A calibration chart of speed versus distance will be produced.

(8) The test equipment including the accelerometers and data acquisition system will be mounted on the test vehicle. The strain gages will be connected to the data acquisition system and tested.
(9) The cameras will be set up.
(10) The weight of the test car will be measured.
(11) A check on the calibration speed will be run on the PTT track.
(12) All instruments will be calibrated and a zero reading carried out.
(13) A trial low speed soft impact (less than 1 mph) of the test car will be carried out into the barrier to confirm all the instruments work properly.
(14) The instruments will be re-calibrated, the Tape switches replaced and the test car pulled back.
(15) The test car will be released at the appropriate distance from the barrier, triggering the cameras and the instrumentation just before impact.
(16) After the test the longitudinal and vertical distances mentioned in paragraph (3) will be re-measured.
(17) Visual inspection of the car body structure will be carried out. Photographs will be taken of the car body.

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 client 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.

The amount of energy absorbed by the vehicle on impact with the rigid barrier (E) will be calculated from the speed of the car just before impact (V_0) and the mass of the test car (m), according to the formula:

$$E = ½. m.V_0^2$$

The longitudinal and vertical distances measured before and after the test will be presented in tabular form.

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.

APPENDIX A (of Appendix A)

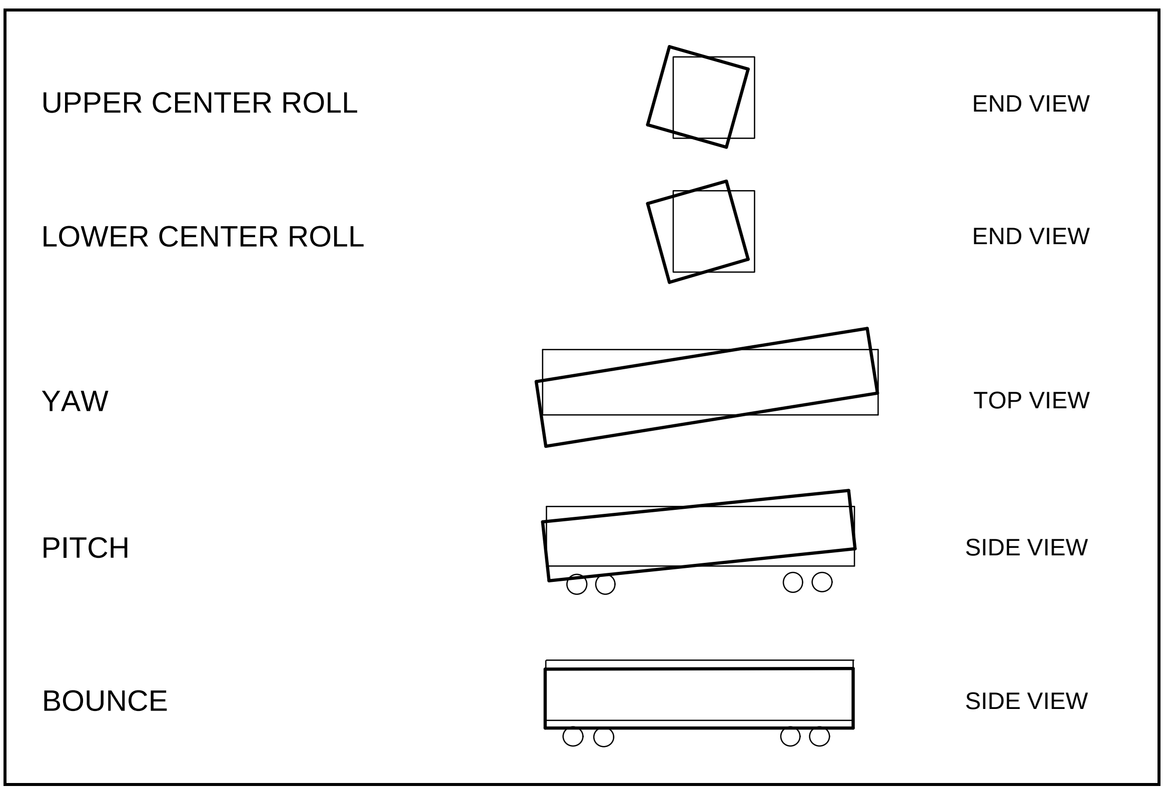
To Obtain Vertical Height of Center of Gravity of Car Body

1. Remove secondary suspension dampers between bolster and car body.

2. Mount tri-axial accelerometers at the top and bottom of each end of the car body.

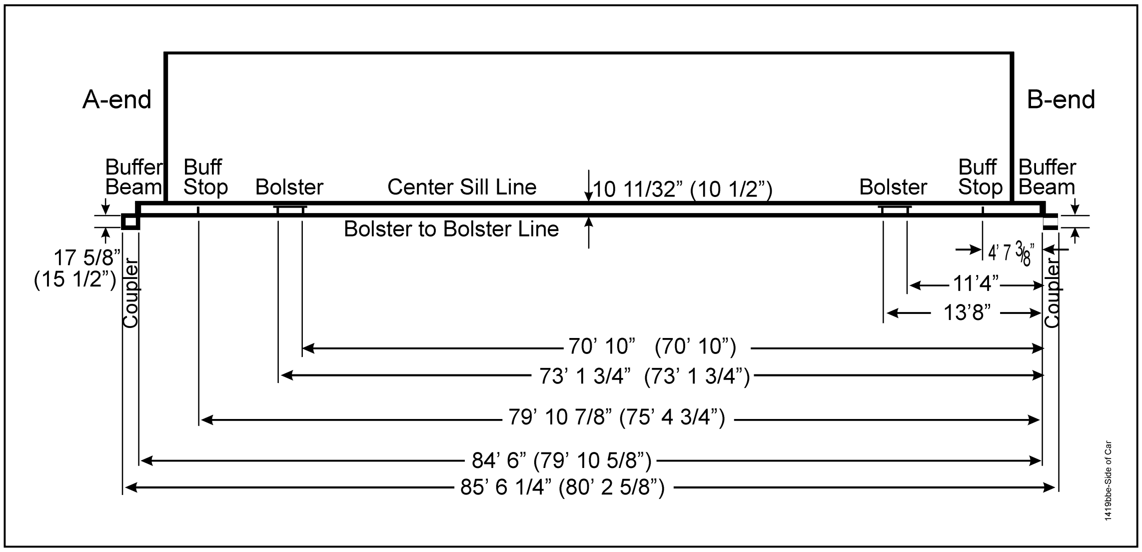
3. Carry out a car-body resonance test to excite each of the rigid body modes, shown below, in turn. (Shake and Bake Test). Record the frequency of each mode.

4. Calculate the vertical center of gravity height



APPENDIX B
PRE- AND POST-TEST LONGITUDINAL AND VERTICAL MEASUREMENTS

(A-End = Impact End)



Measurements Pre-Test (Measurements Post-Test)

Wheel Base

A-End Left	8.51 ft (8.51 ft)	B-End Left	8.48 ft (8.48 ft)
A-End Right	8.5 ft (8.5 ft)	B-End Right	8.48 ft (8.48 ft)

Truck Spacing (Pre-test)

Left 59.40 ft Right 59.42 ft

Height of Air spring Center to Rail (Pre-test)

A-End Left	38.13 inches	B-End Left	37.0 inches
A-End Right	37.25 inches	B-End Right	37.5 inches

APPENDIX C
To Obtain Vertical Height of Center of Gravity of Car Body

On Saturday November 14th, a characterization test was performed on the SEPTA car that was subsequently used for the impact test. The objective of the characterization test was to provide an estimate of the center of gravity height of the vehicle.

Two different methods were used for performing the characterization test. Initially, a standard "Shake and Bake" test method was used, which involved hand excitation of the vehicle. This provided a measure of all of the car on secondary suspension modal frequencies other than upper center roll, which we were unable to excite.

Subsequently, the vehicle was excited using a forklift truck as the means of excitation. Tests were done with excitation in the vertical and lateral directions at one end of the car. The method of excitation involved an initial displacement of the vehicle on its secondary suspension using the forklift truck followed by a rapid release. The ensuing oscillation of the car was measured using six carefully located accelerometers. For both test methods, the rotary lateral dampers were removed from the vehicle.

The accelerometer time histories were combined to provide outputs in each of the principal car body degrees of freedom. Car body modal frequencies were determined through an FFT analysis of the degree of freedom time histories. The modal frequencies that were obtained by this method were in close agreement with those produced by the traditional "Shake and Bake" method. However, the upper center roll mode and the longitudinal mode were also excited using the forklift truck, whereas, they could not be excited by hand excitation. The reason for the difficulty with the upper center roll mode is the close proximity of the frequencies of the pitch, yaw and upper center roll modes.

The measured frequencies are shown in Table A.1.

Table A.1. Measured Car Body Modal Frequencies

Mode	Frequency(Hz)
Longitudinal	2.50
Bounce	1.19
Pitch	1.28
Yaw	1.25
Upper Center Roll	1.30
Lower Center Roll	0.57

The total car weight determined by weighing was 74,289 lb. The weight of each truck was initially estimated to be 12,700 lb. This gave a car body weight of 48,889 lb.

A number of different cases were considered to estimate the car body CG height. For Case 1, because the hand brake was applied on one truck, it was assumed that the longitudinal frequency was due to the car body mass on a longitudinal stiffness provided by the traction rods and shear of the air springs on one truck.

Using these assumptions, the car body mass and inertia properties and secondary suspension characteristics that were derived from the measured frequencies are as follows:

<u>Case 1:</u>
Car Body weight = 126.63 lb-sec^2/in
Car Body Roll Inertia = 556,300 lb-in-sec^2
Car Body Pitch & Yaw Inertia = 13,910,000 lb-in-sec^2
Secondary Vertical Stiffness = 1,770 lb/in per spring
Secondary Lateral Stiffness = 1,375 lb/in per spring
Traction Rod Longitudinal Stiffness = 13,000 lb/in

This gave a car body CG height of 39.2 in above the secondary suspension roll center height. The secondary suspension roll center height was determined by measurement to be approximately 37.5 in above rail. Therefore, the car body CG is estimated to be 76.7 in above rail.

For Case 2, the longitudinal frequency is assumed to be due to the longitudinal stiffness provided by the traction rods and shear of the air springs on both trucks, the following mass and stiffness characteristics were derived:

<u>Case 2:</u>
Car Body weight = 126.63 lb-sec^2/in
Car Body Roll Inertia = 663,000 lb-in-sec^2
Car Body Pitch & Yaw Inertia = 13,910,000 lb-in-sec^2
Secondary Vertical Stiffness = 1,770 lb/in per spring
Secondary Lateral Stiffness = 1,560 lb/in per spring
Traction Rod Longitudinal Stiffness = 4,700 lb/in
This gave a car body CG height above rail of 72.7 in.

For Case 3, the traction rod longitudinal stiffness is neglected in the analysis, then the following mass and stiffness characteristics were derived:

<u>Case 3:</u>
Car Body weight = 126.63 lb-sec^2/in
Car Body Roll Inertia = 716,000 lb-in-sec^2
Car Body Pitch & Yaw Inertia = 13,910,000 lb-in-sec^2
Secondary Vertical Stiffness = 1,770 lb/in per spring
Secondary Lateral Stiffness = 1,665 lb/in per spring
Traction Rod Longitudinal Stiffness = 0 lb/in

This gave a car body CG height above rail of 69.7 in.

The sensitivity of the car body CG height estimate to car body weight was also investigated. This was necessary because the car body weight that was used was based on an estimated truck weight. It proved to be too difficult to remove one of the trucks from the vehicle to obtain an accurate truck weight. To determine the sensitivity of car body CG height to car body weight, the car body weight was varied up by 10% for Case 4 and down by 10% for Case5. The traction rod stiffness was neglected.

The following mass and stiffness properties were derived for these cases:

<u>Case 4:</u>
Car Body weight = 139.29 lb-sec^2/in
Car Body Roll Inertia = 728,000 lb-in-sec^2
Car Body Pitch & Yaw Inertia = 15,300,000 lb-in-sec^2
Secondary Vertical Stiffness = 1,950 lb/in per spring
Secondary Lateral Stiffness = 1,830 lb/in per spring
Traction Rod Longitudinal Stiffness = 0 lb/in

This gave a car body CG height above rail of 69.7 in.

<u>Case 5:</u>
Car Body weight = 113.97 lb-sec^2/in
Car Body Roll Inertia = 596,000 lb-in-sec^2
Car Body Pitch & Yaw Inertia = 12,5200,000 lb-in-sec^2
Secondary Vertical Stiffness = 1,590 lb/in per spring
Secondary Lateral Stiffness = 1,500 lb/in per spring
Traction Rod Longitudinal Stiffness = 0 lb/in

This gave a car body CG height above rail of 69.7 in.

The results from Cases 4 and 5 indicate that the car body CG height estimate is not sensitive to car body weight within a reasonable range of uncertainty.

A summary of the above results is given in Table A.2

Table A.2. Car Body CG Height Estimates.

Case	Car Body CG Height above Rail (in)
1	76.7
2	72.7
3	69.7
4	69.7
5	69.7

One other uncertainty in the analysis is associated with the air spring arrangement on the Budd Pioneer trucks used on this vehicle. The two air springs on each truck have separate reservoir volumes and a common leveling valve. There is an air passage between each air spring and its own reservoir and the reservoir associated with the adjacent air spring. The rate of air flow along each of these passageways is controlled by orifices. As a result of this arrangement, there will be air flowing between adjacent airsprings when the vehicle is rolling. The flow rate will tend to be higher at lower frequencies and will probably be most significant at the lower center roll frequency, which is only 0.57 Hz.

This air spring arrangement could not be properly modeled because neither the air spring and reservoir volumes nor the orifice sizes were known. These parameters could only have been determined by disassembling a truck, which was considered to be too difficult. Accordingly, the vehicle model used to make the estimates of car body CG height discussed previously, assumed that the air springs were not interconnected. This situation is likely to have caused the CG height estimate to be somewhat higher than is actually the case.

APPENDIX D

Strain Gage Results for the Complete Range Recorded

-0.1s TO 1.4 s SAE CFC1000 Hz

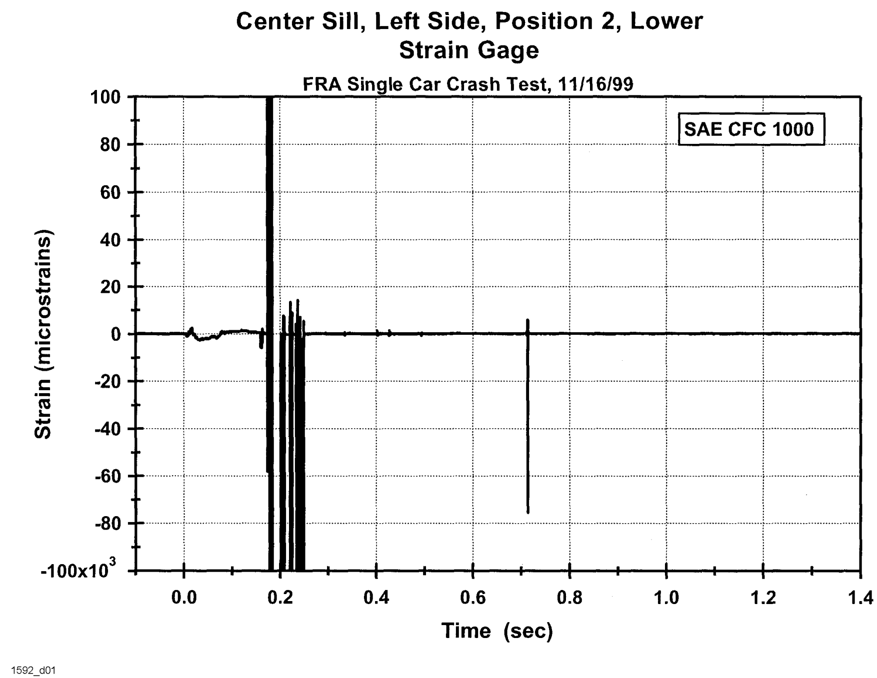


Figure D.1.

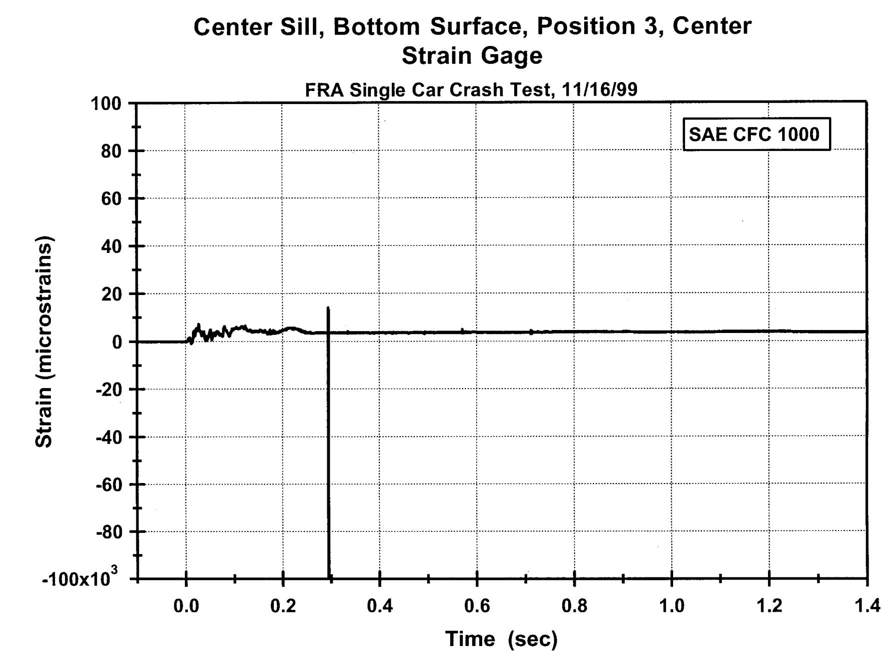
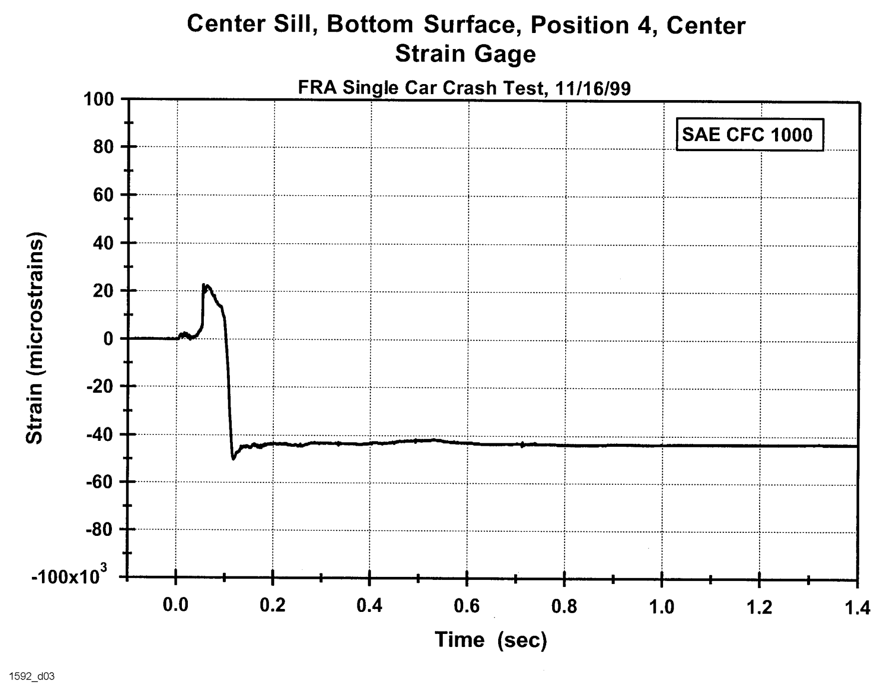


Figure D.2.



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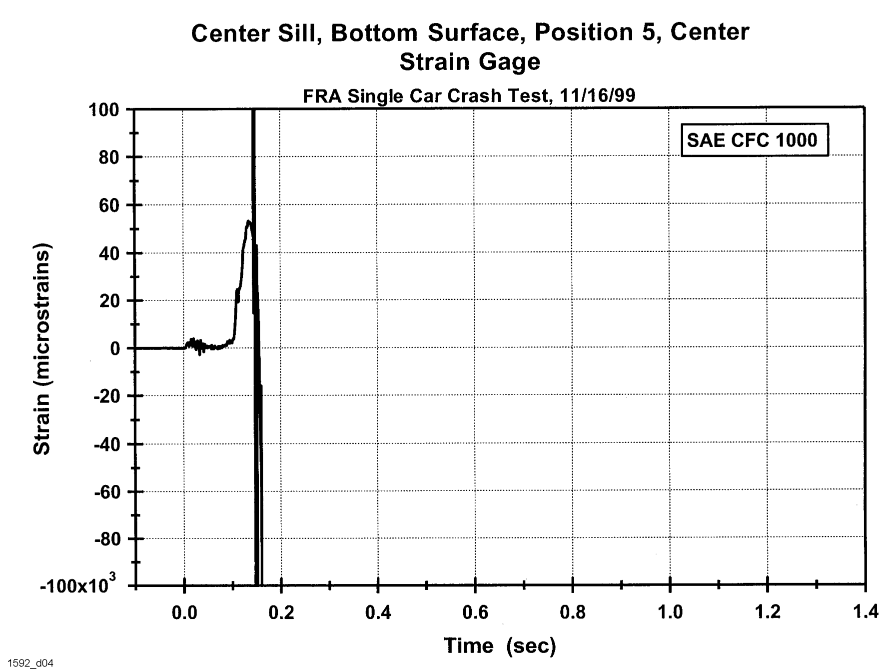

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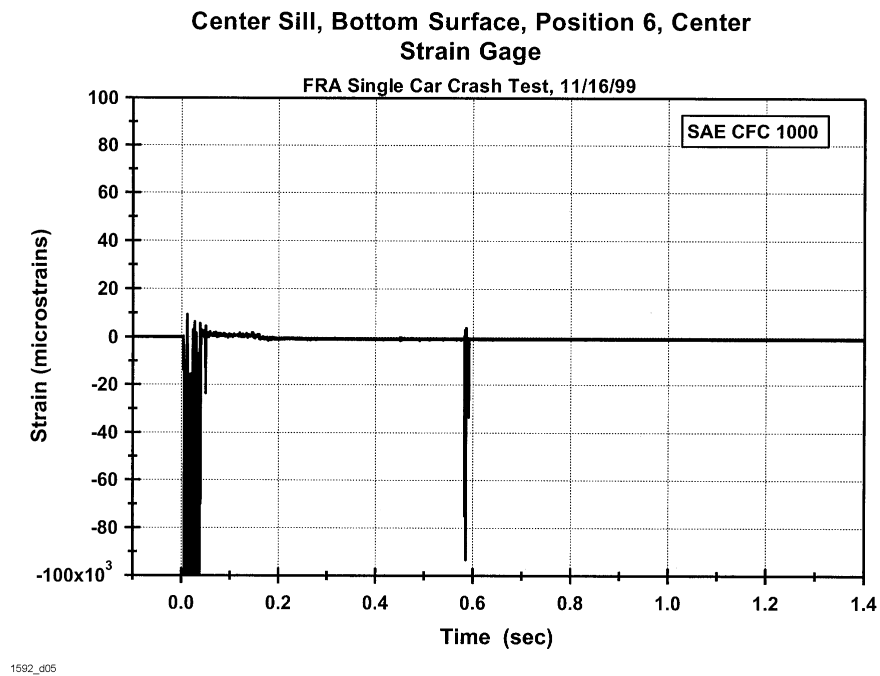


Figure D.5.

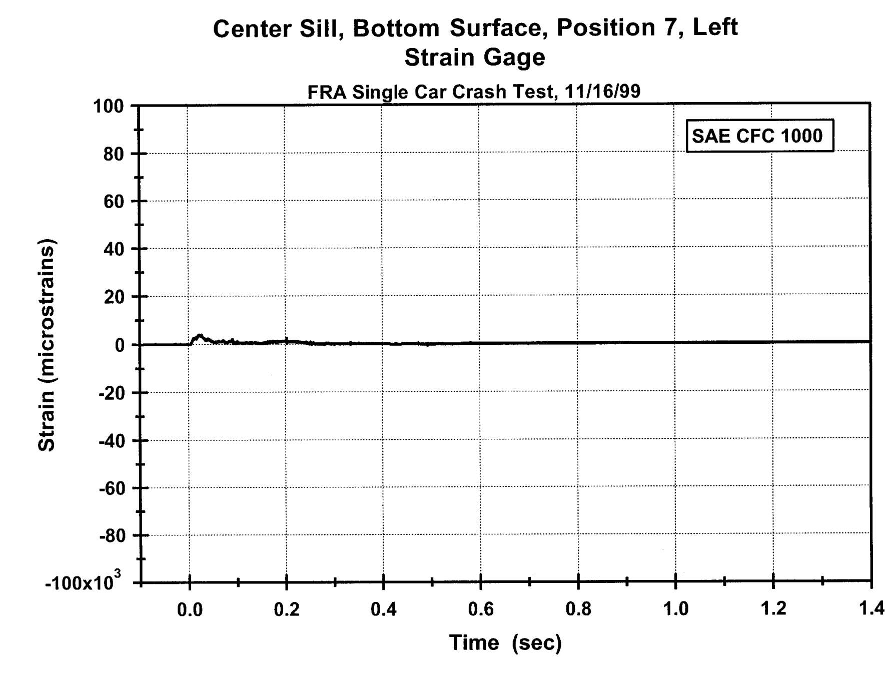
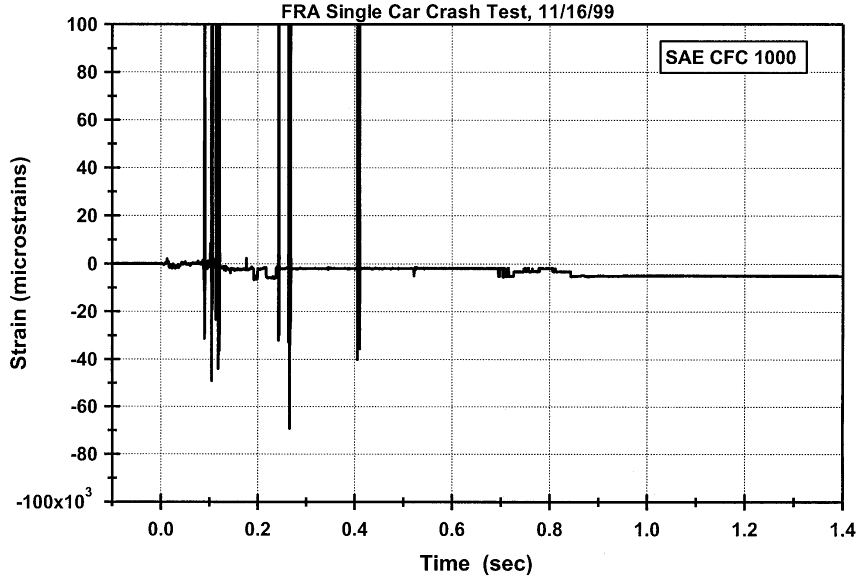


Figure D.6.

Center Sill, Right Side, Position 1, Upper Strain Gage

FRA Single Car Crash Test, 11/16/99

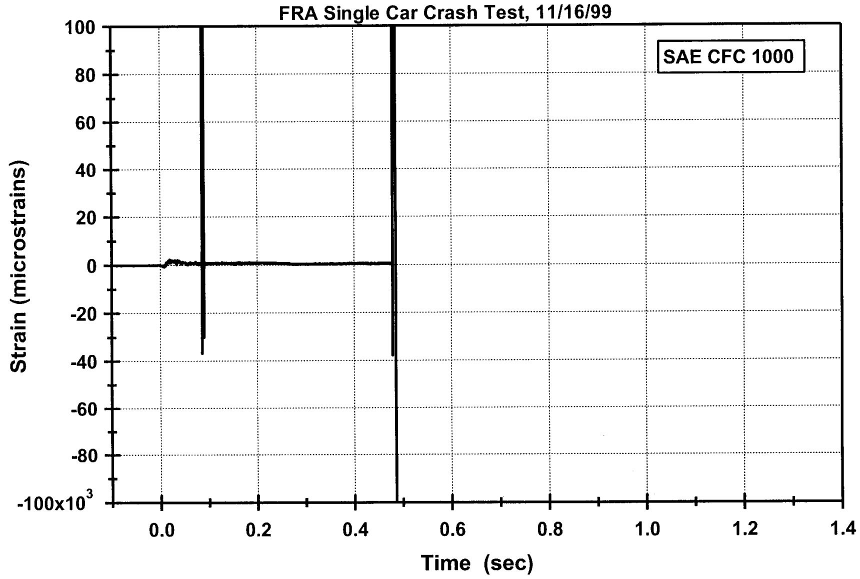


1592_d07

Figure D.7.

Center Sill, Right Side, Position 1, Lower Strain Gage

FRA Single Car Crash Test, 11/16/99



1592_d08

Figure D.8.

Center Sill, Right Side, Position 2, Upper Strain Gage

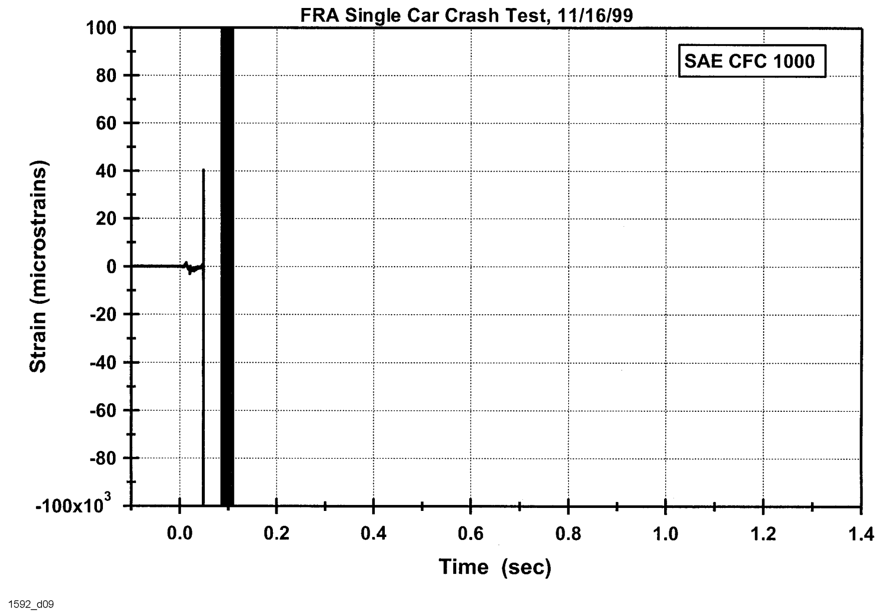


Figure D.9.

Center Sill, Right Side, Position 2, Lower Strain Gage

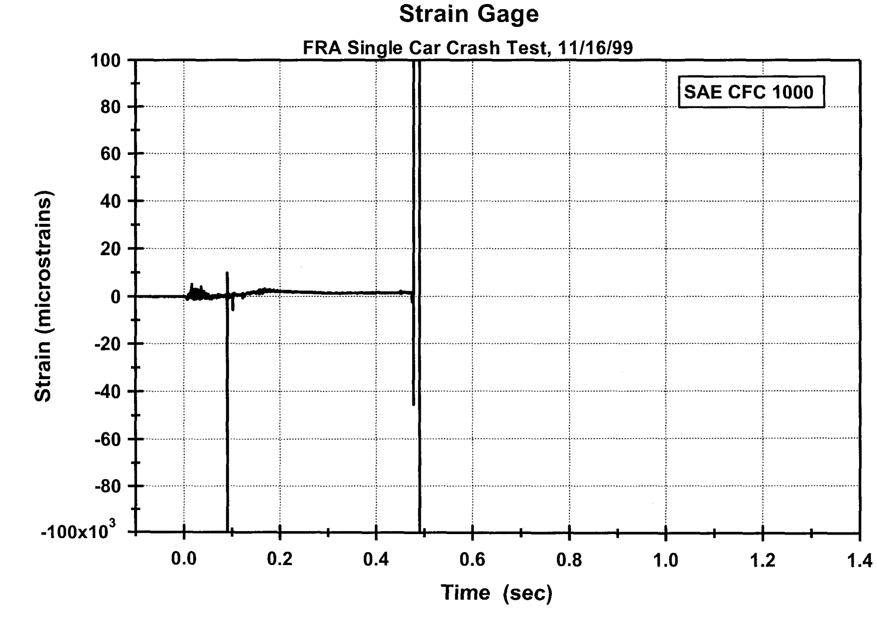
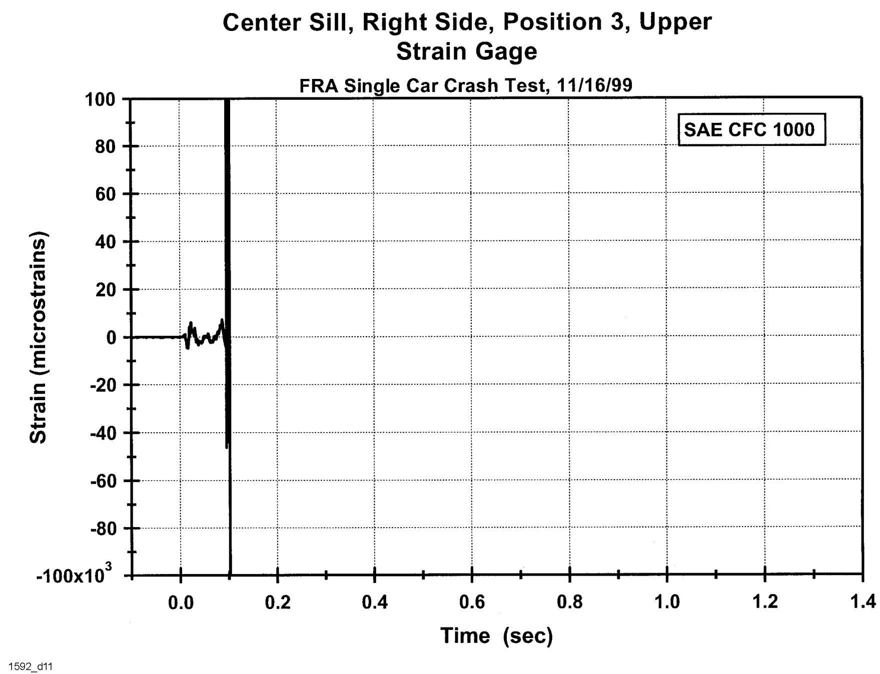


Figure D.10.



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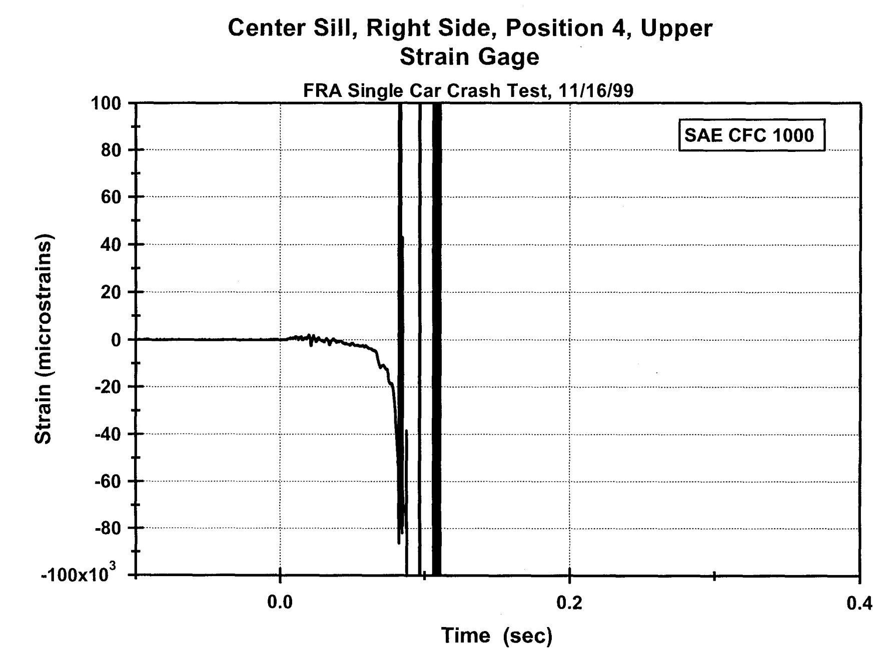
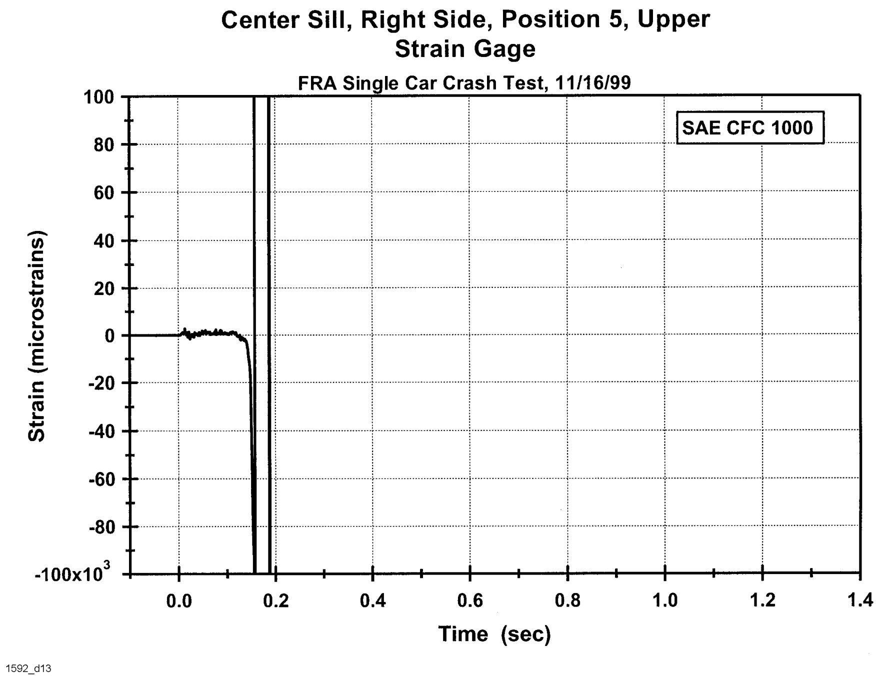


Figure D.12.



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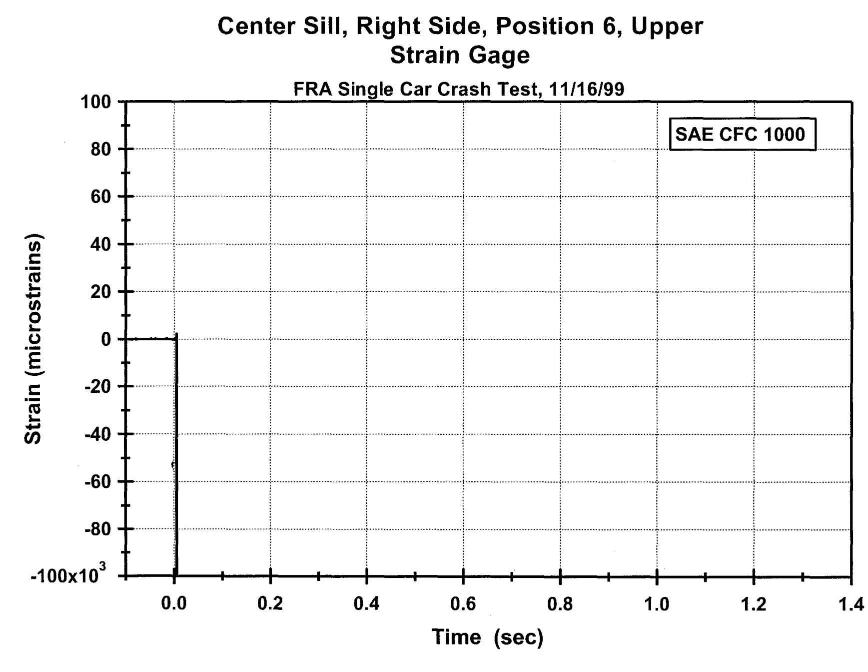


Figure D.14.

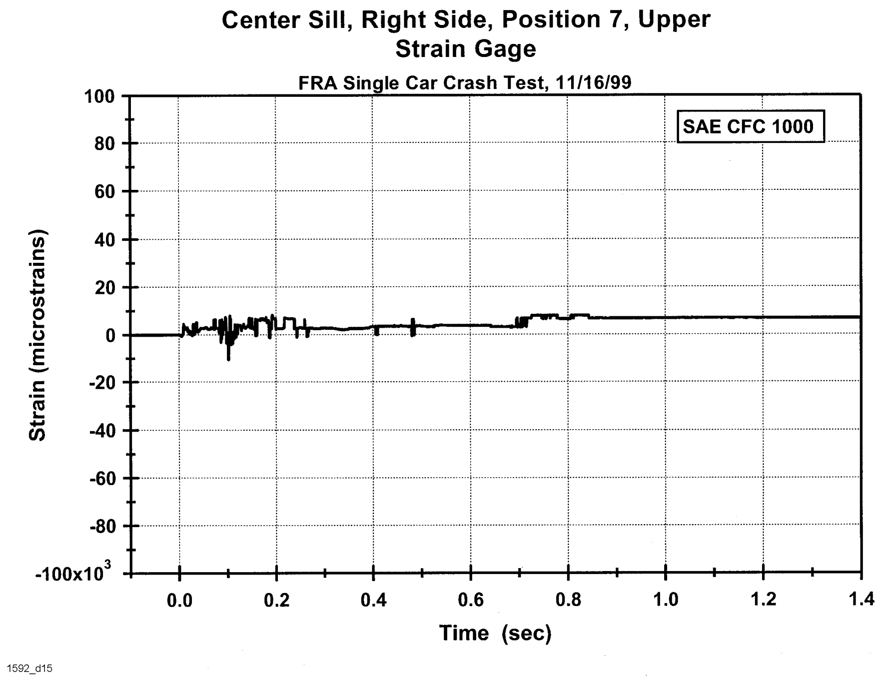


Figure D.15.

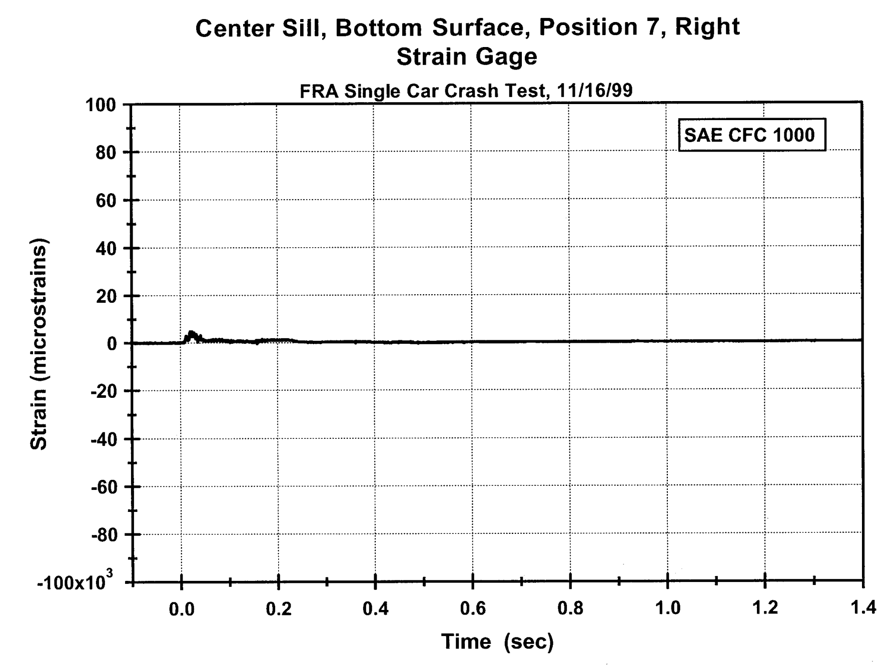


Figure D.16.

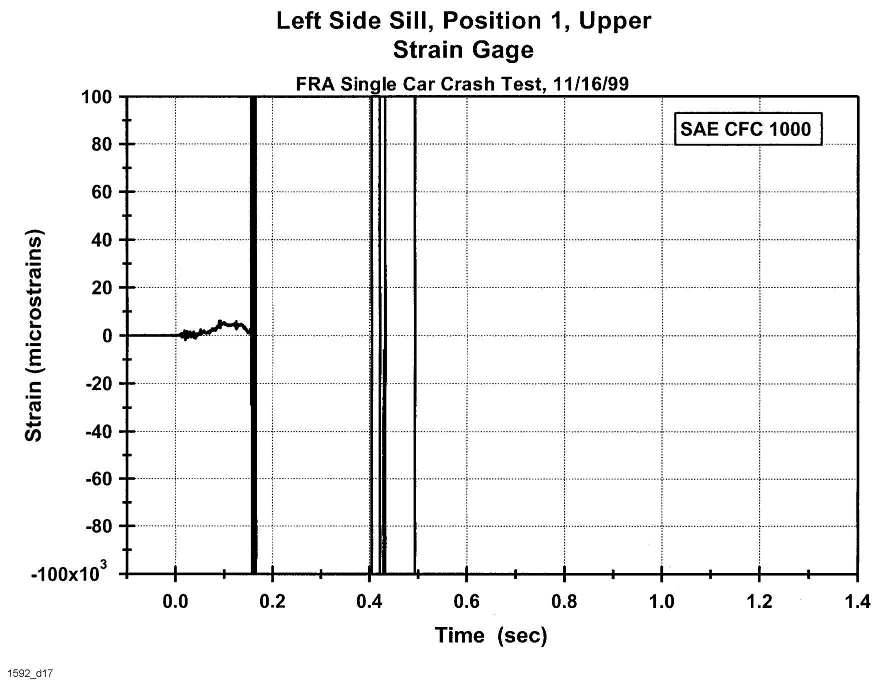


Figure D.17.

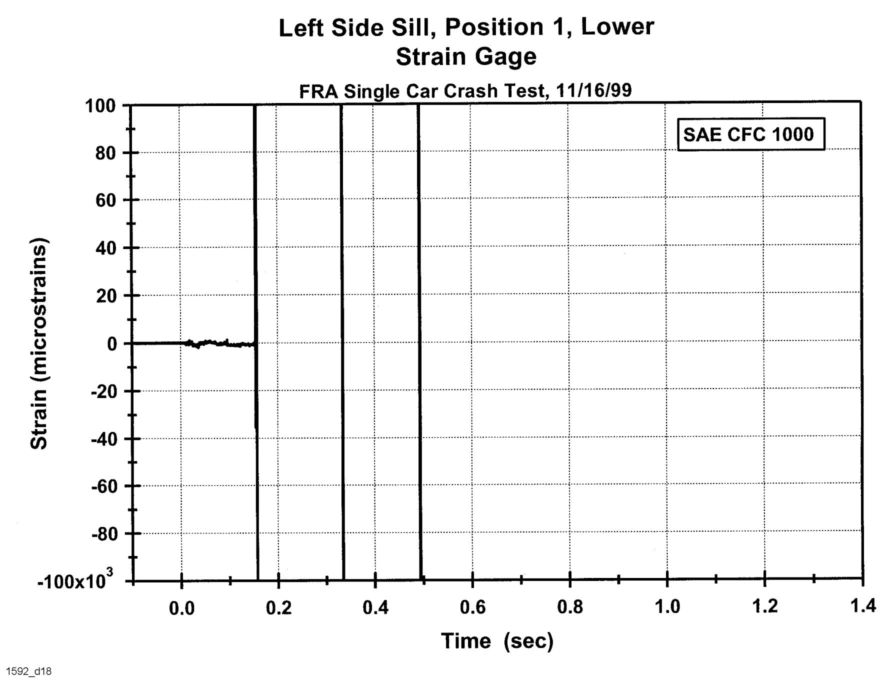


Figure D.18.

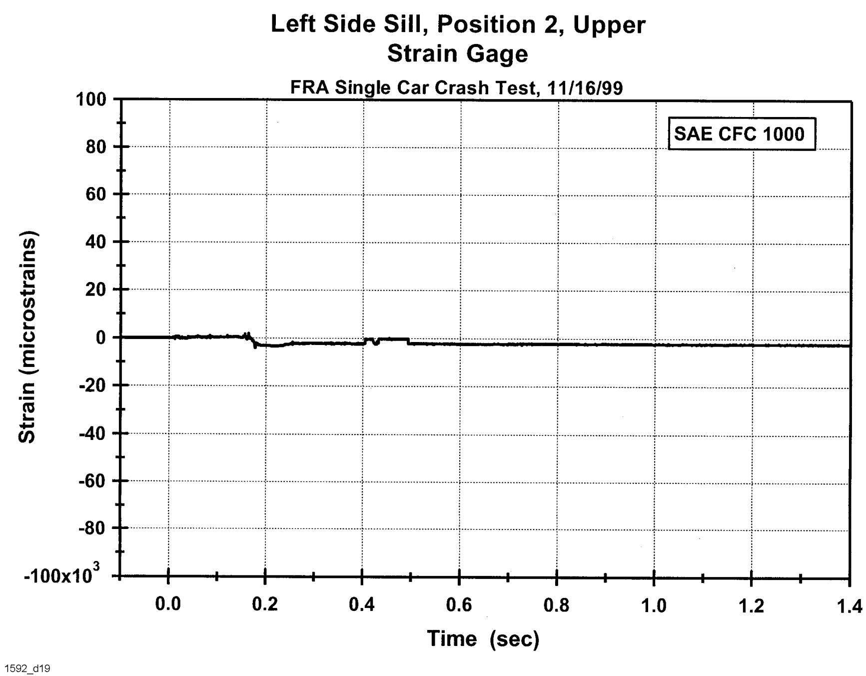


Figure D.19.

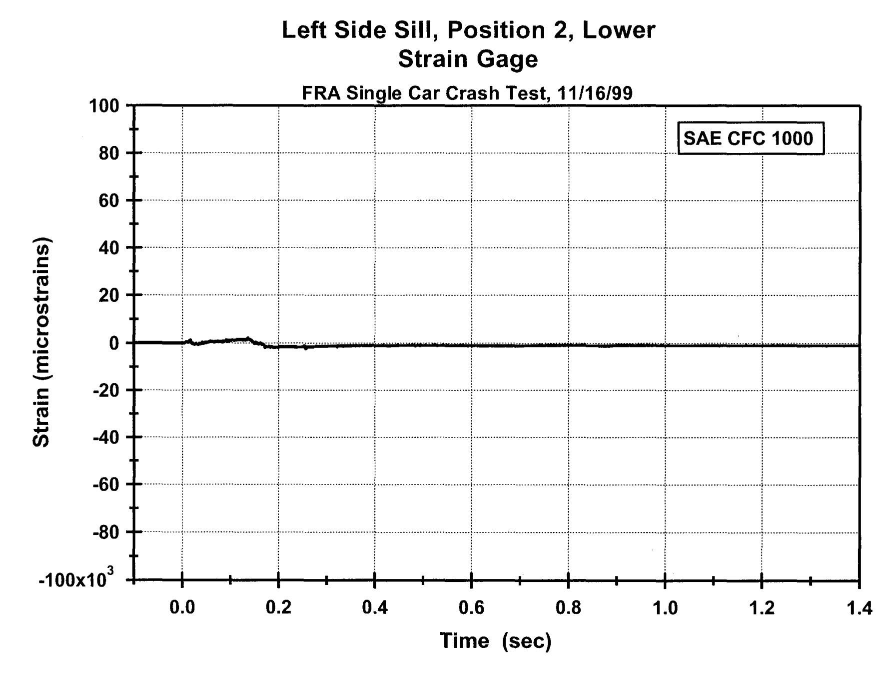


Figure D.20.

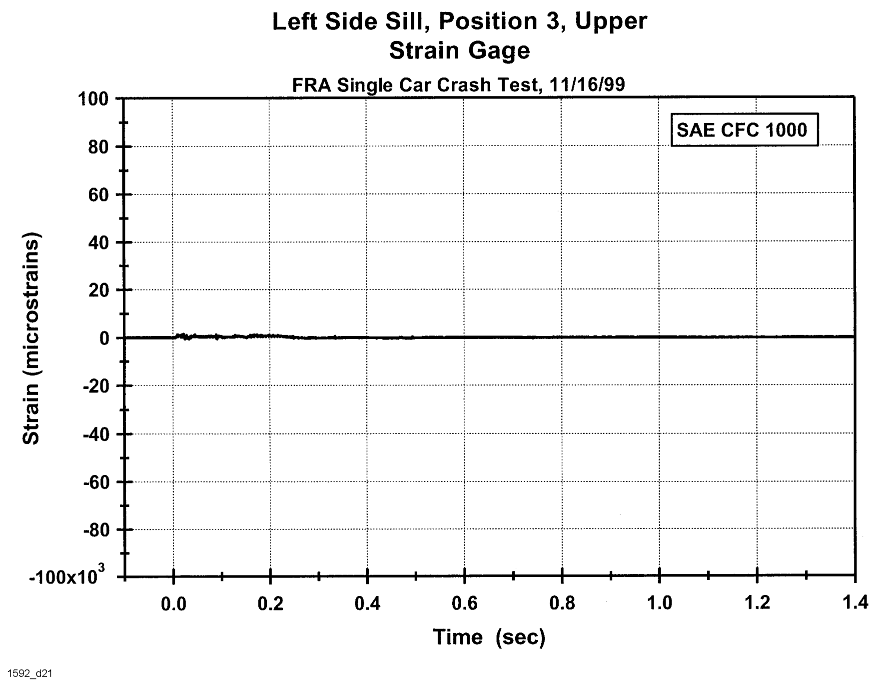
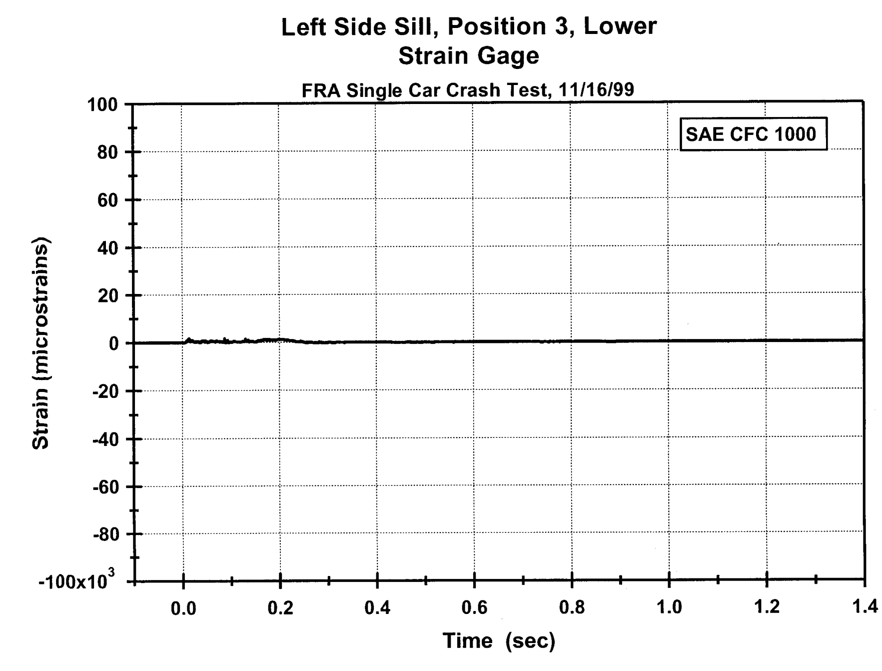


Figure D.21.



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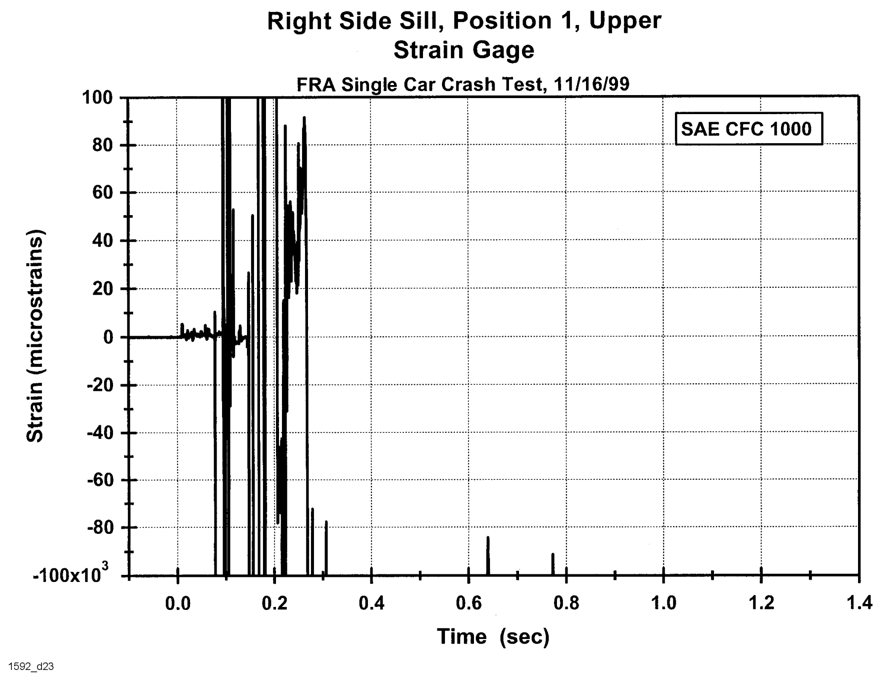

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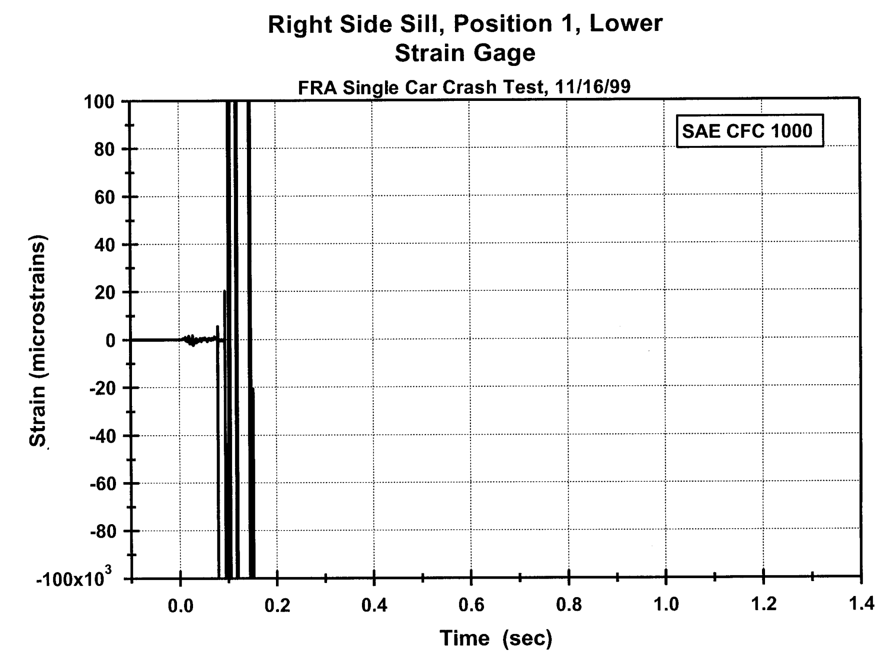

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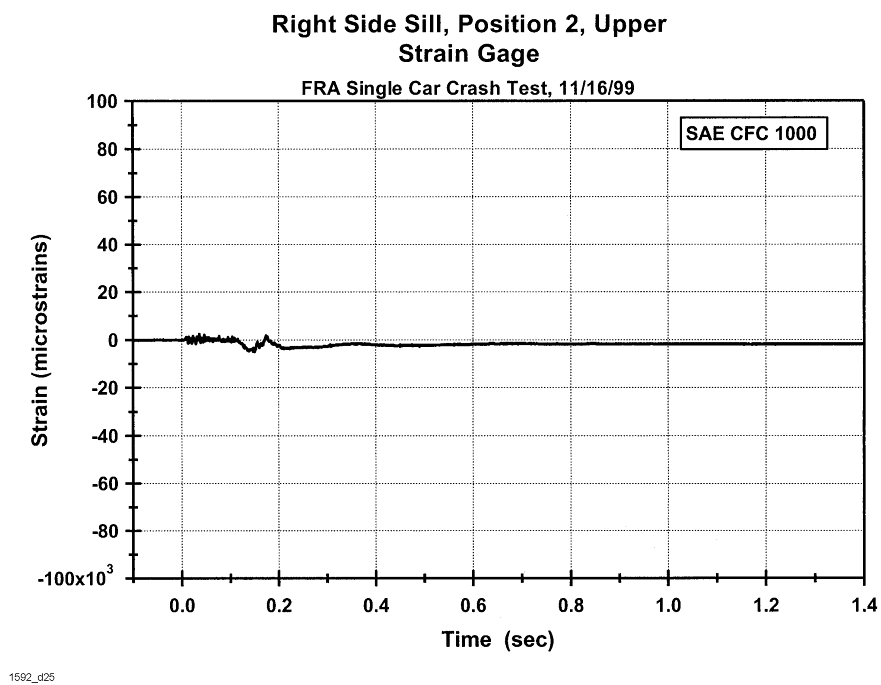

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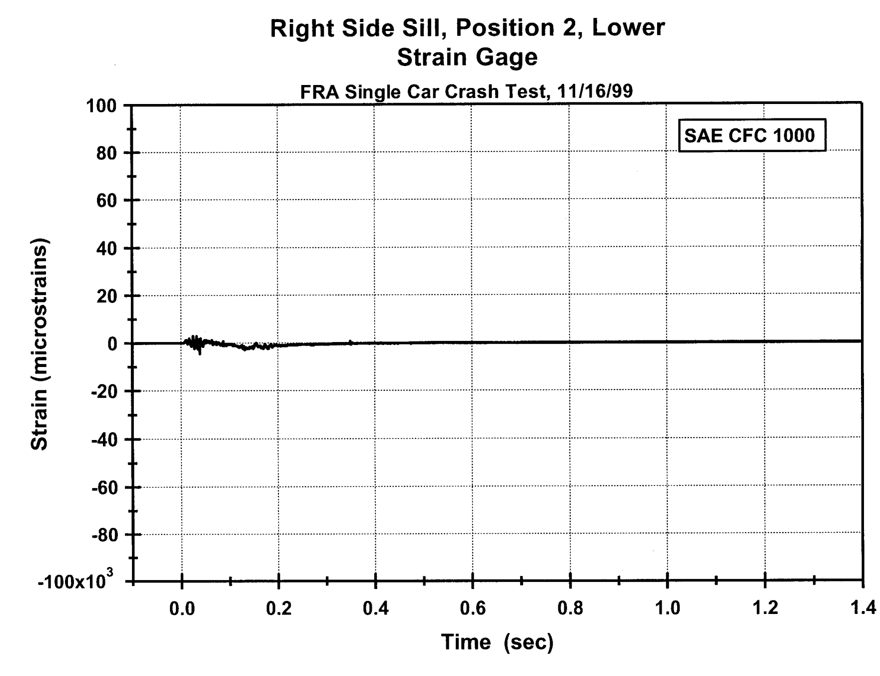
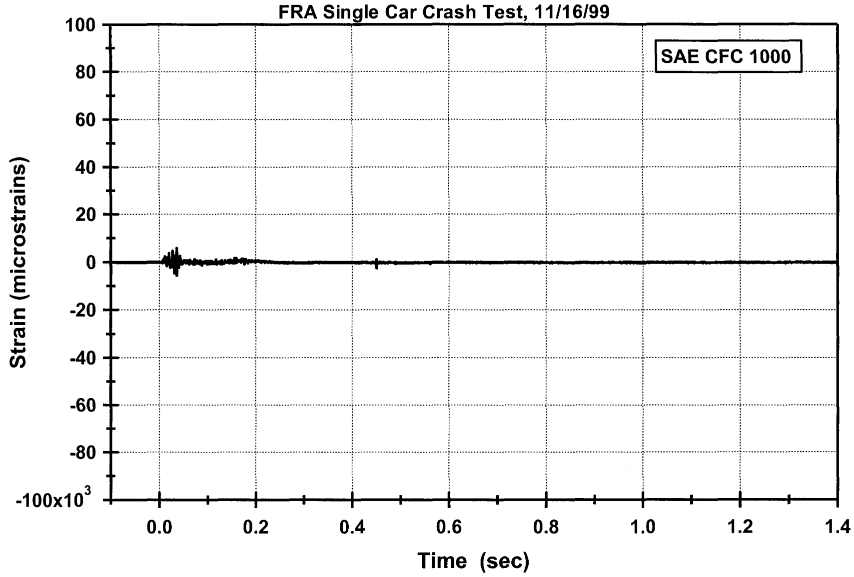


Figure D.26.

Right Side Sill, Position 3, Upper Strain Gage

FRA Single Car Crash Test, 11/16/99

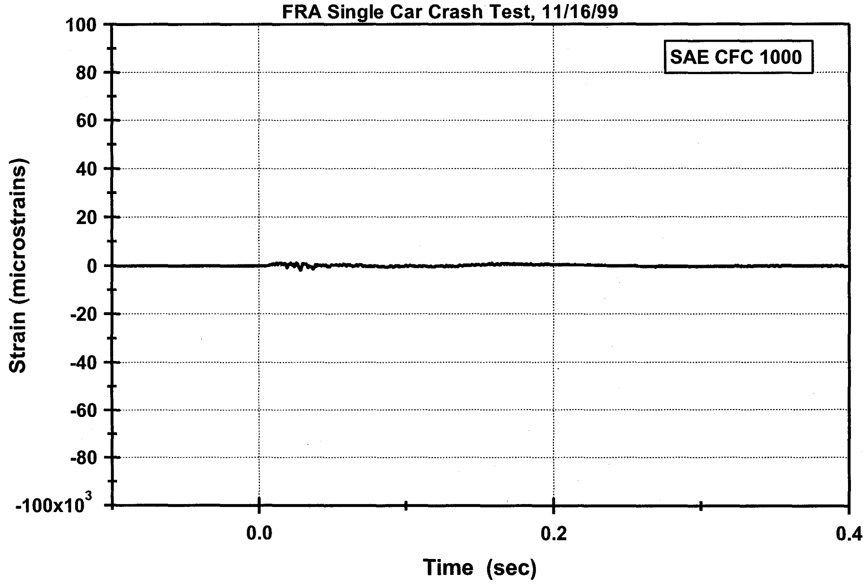


1592_d27

Figure D.27.

Right Side Sill, Position 3, Lower Strain Gage

FRA Single Car Crash Test, 11/16/99



1592_d28

Figure D.28.

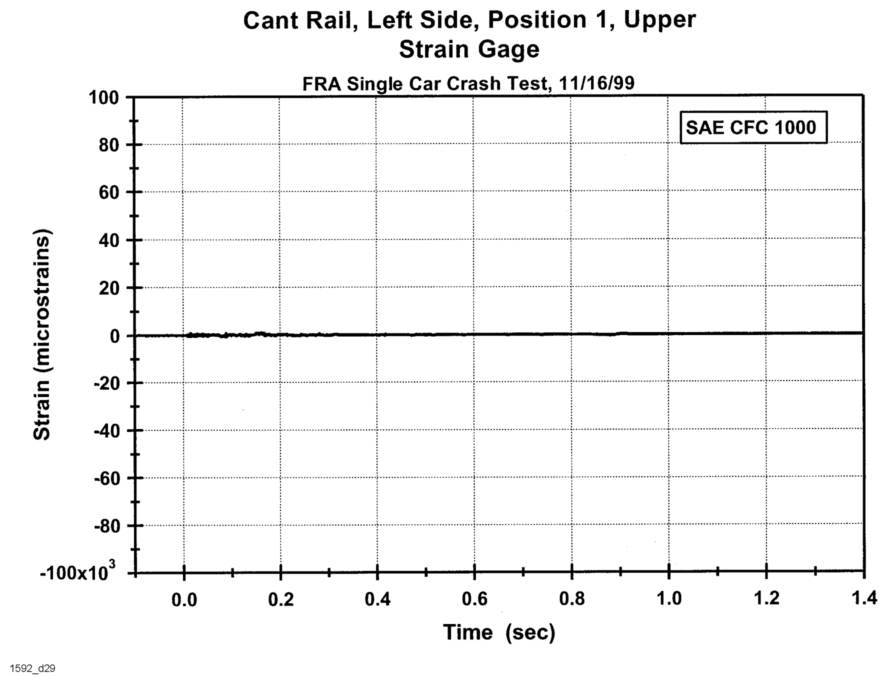


Figure D.29.

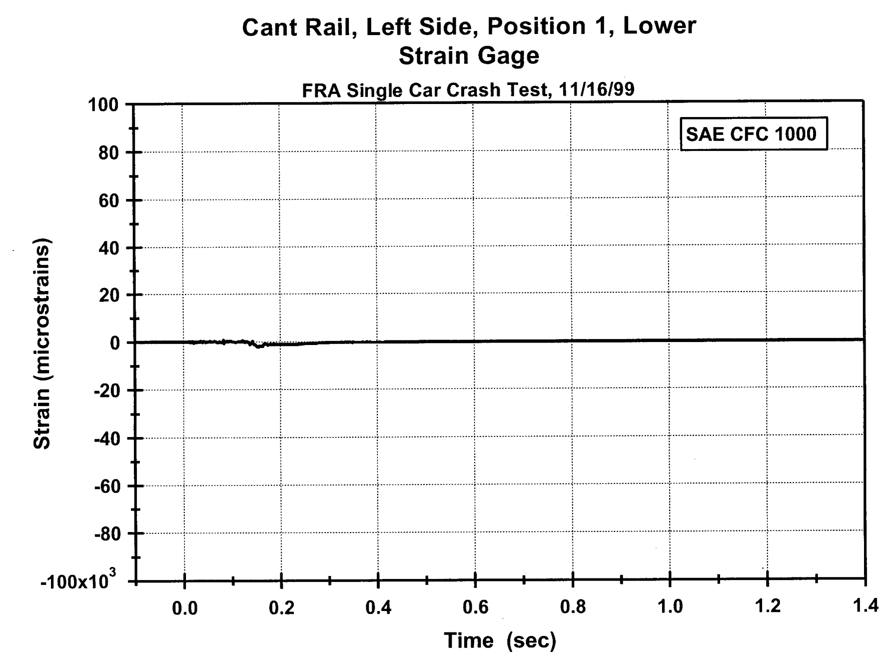
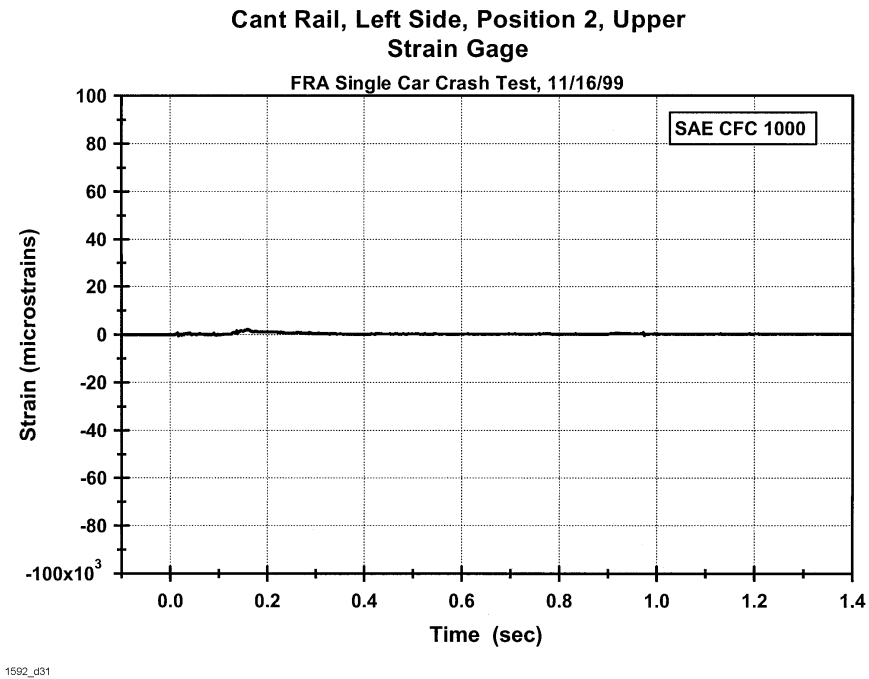


Figure D.30.



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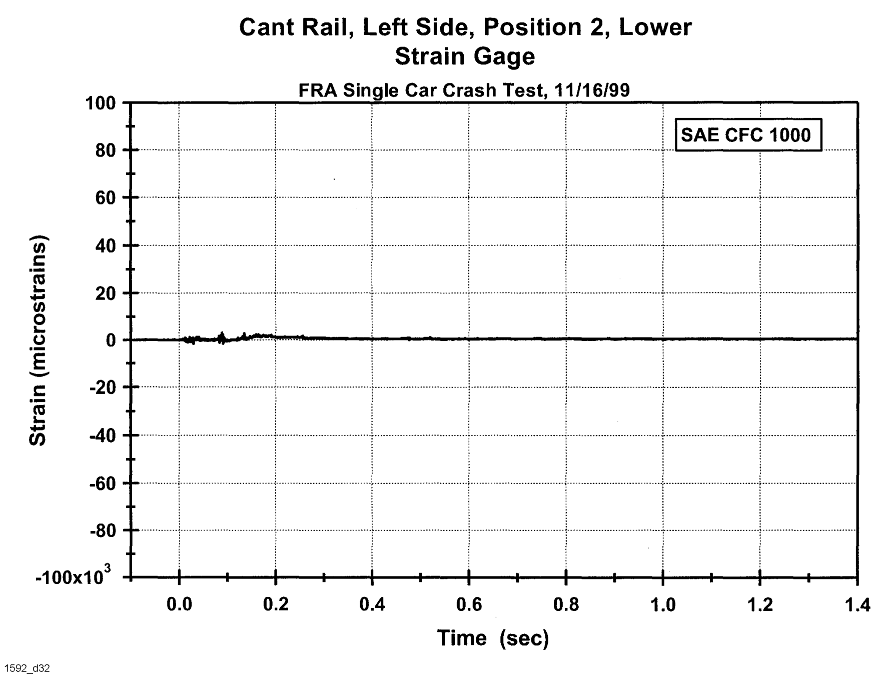


Figure D.32.

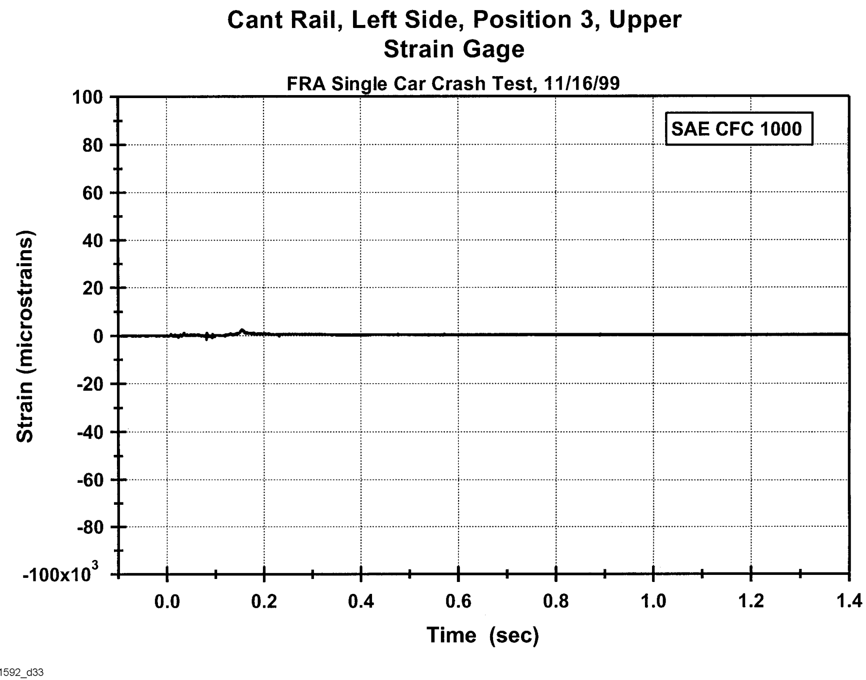


Figure D.33.

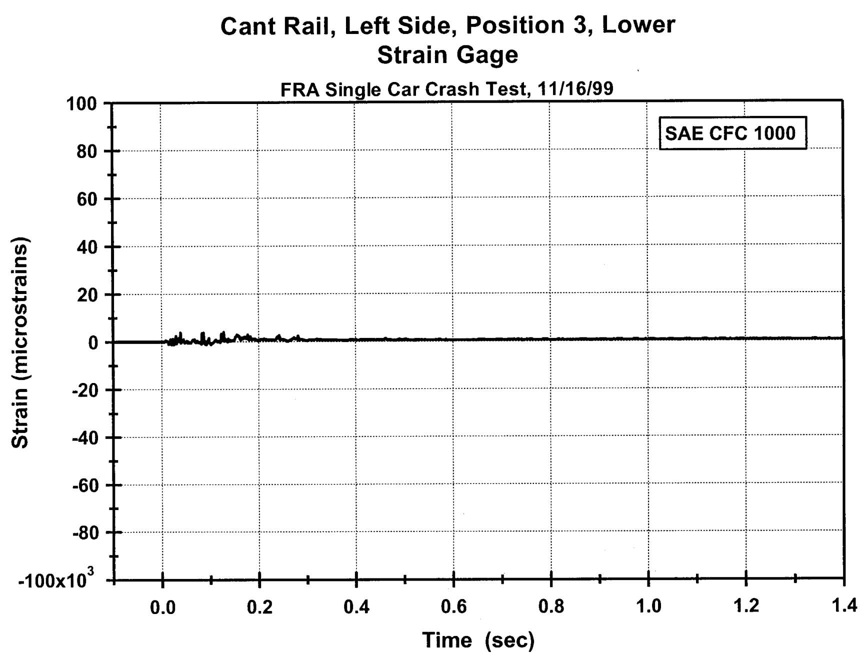


Figure D.34.

Cant Rail, Right Side, Position 1, Upper Strain Gage

FRA Single Car Crash Test, 11/16/99

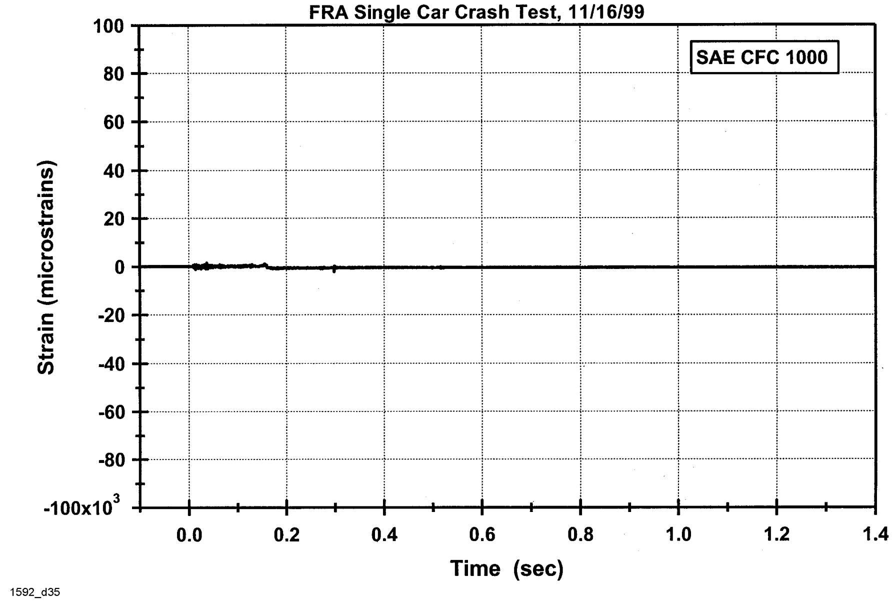


Figure D.35.

Cant Rail, Right Side, Position 1, Lower Strain Gage

FRA Single Car Crash Test, 11/16/99

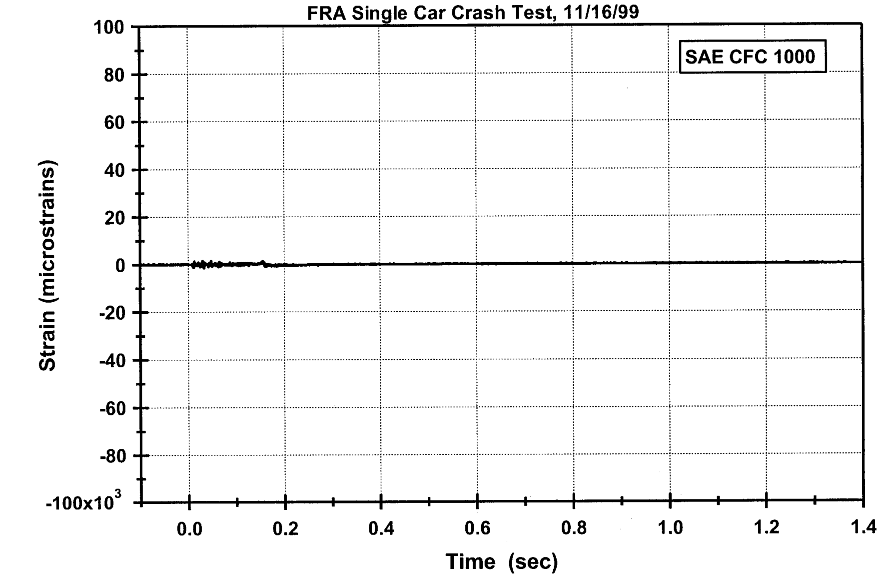


Figure D.36.

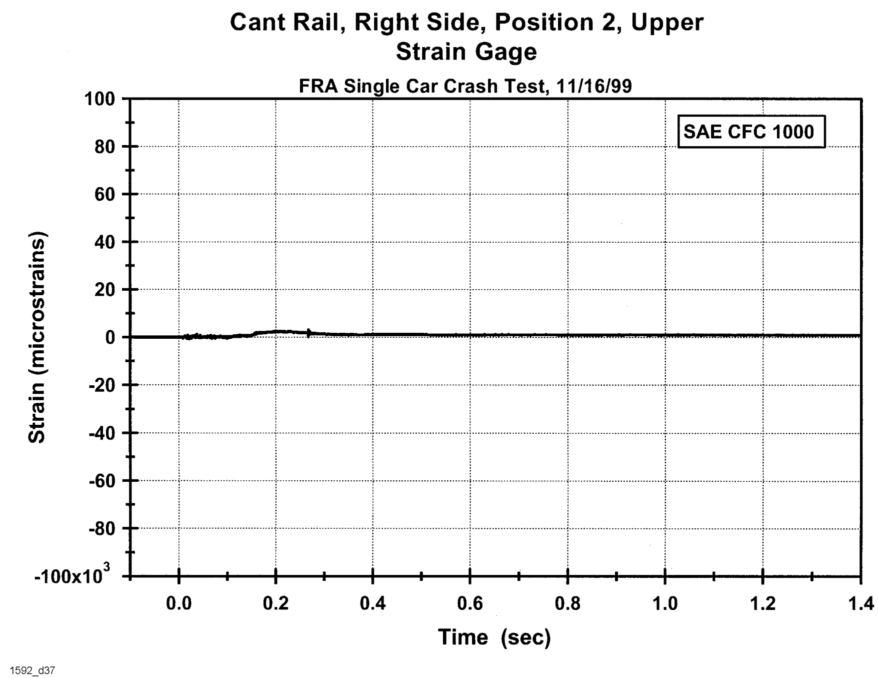


Figure D.37.

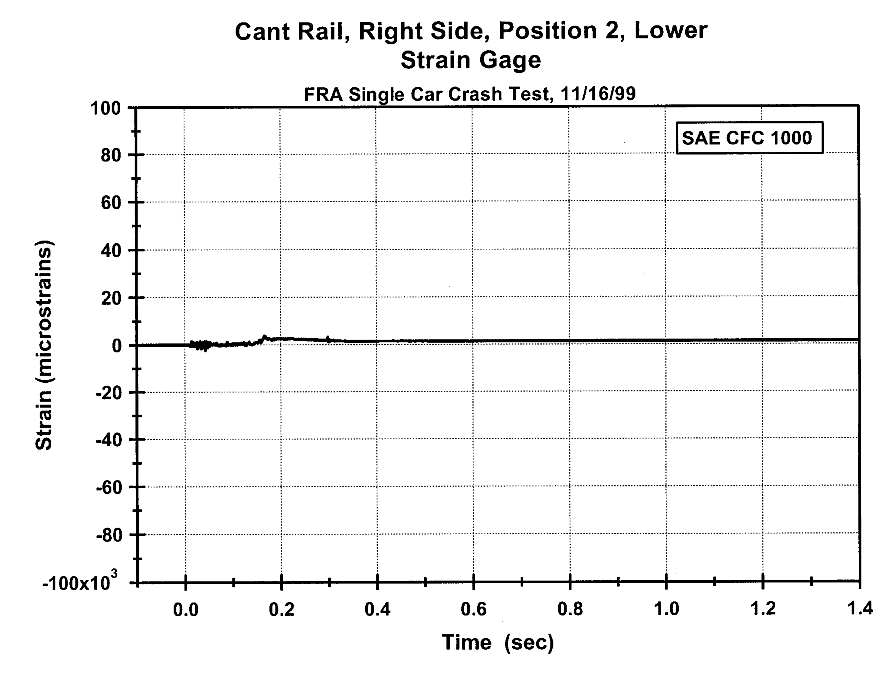
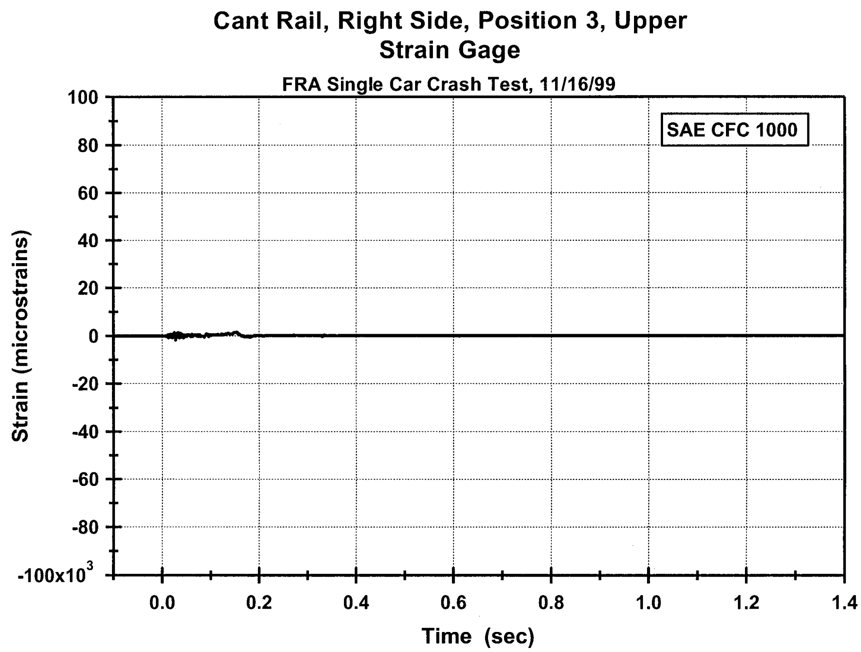
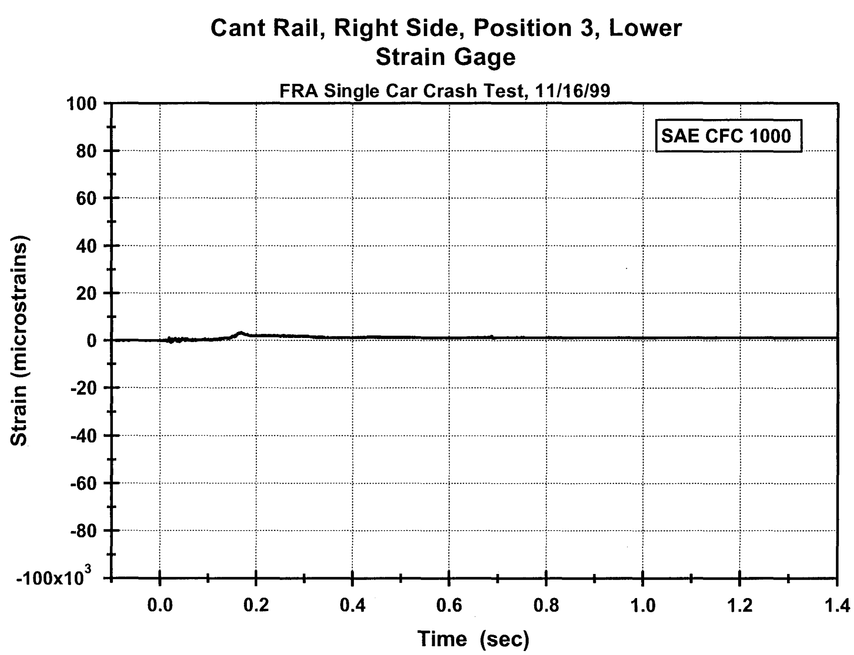


Figure D.38.



1592_d39

Figure D.39.



1592_d40

Figure D.40.

APPENDIX E
Accelerations for the Complete Range Recorded
-0.1s TO 1.4 s

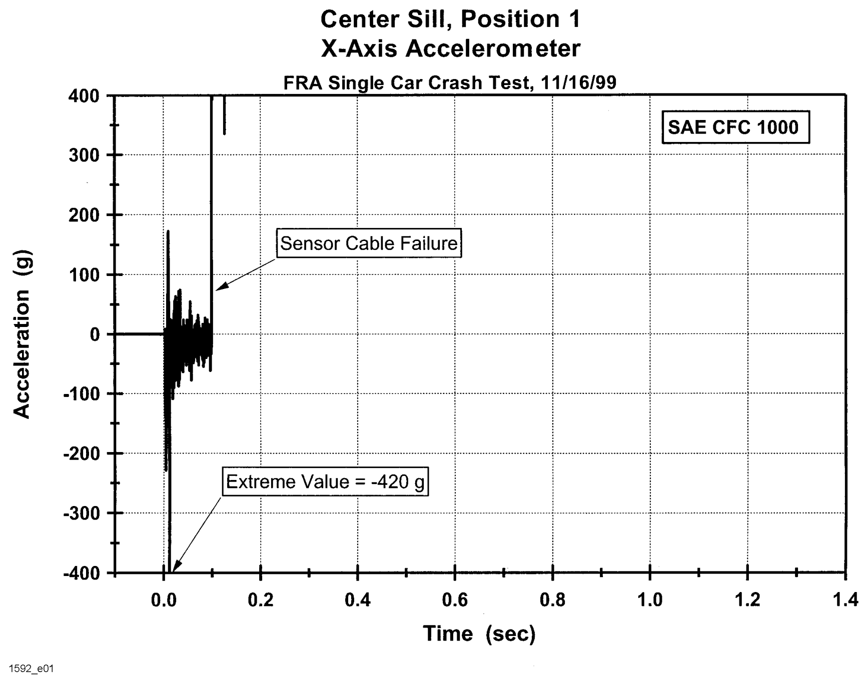


Figure E.1.

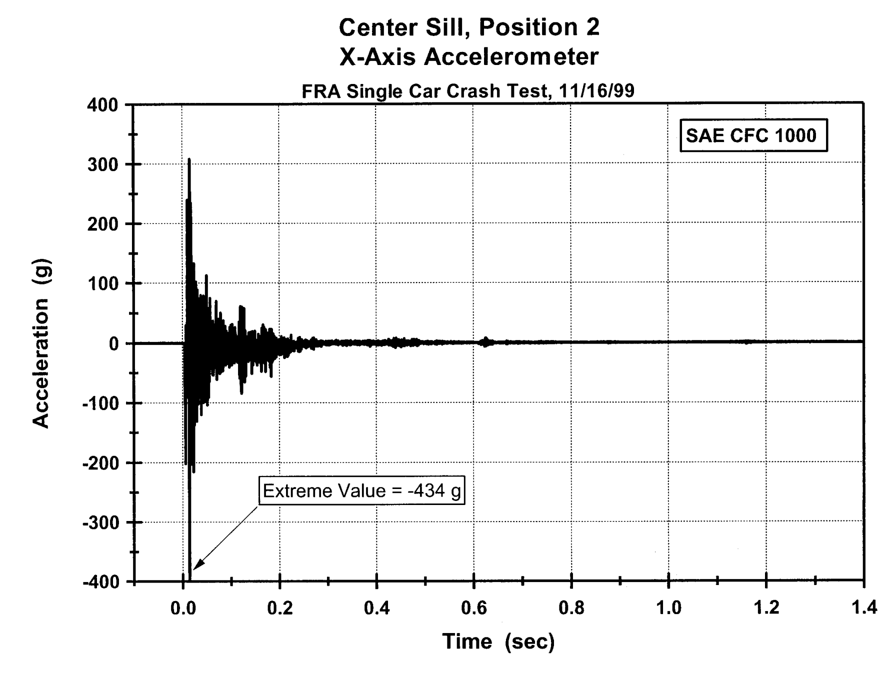
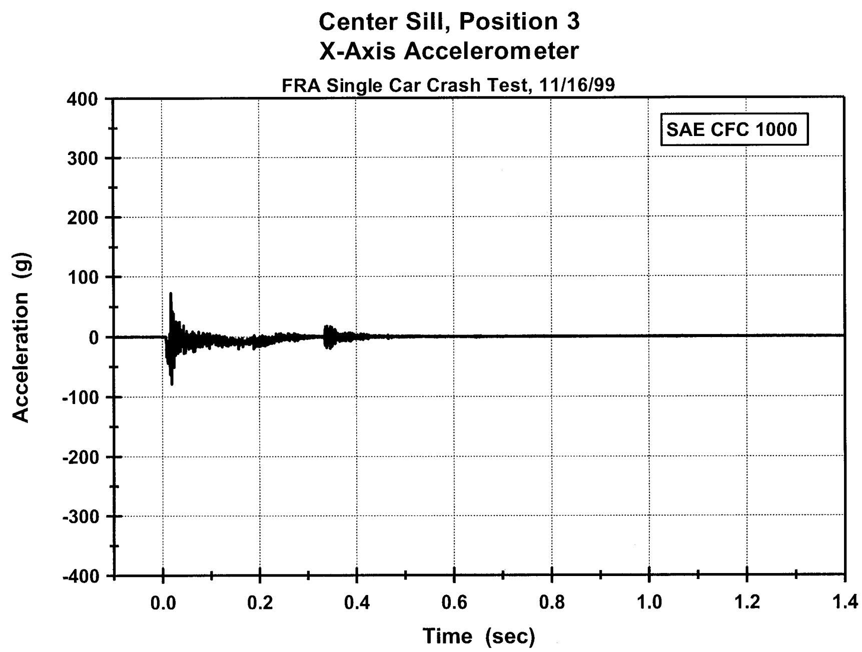


Figure E.2.



1592_e03

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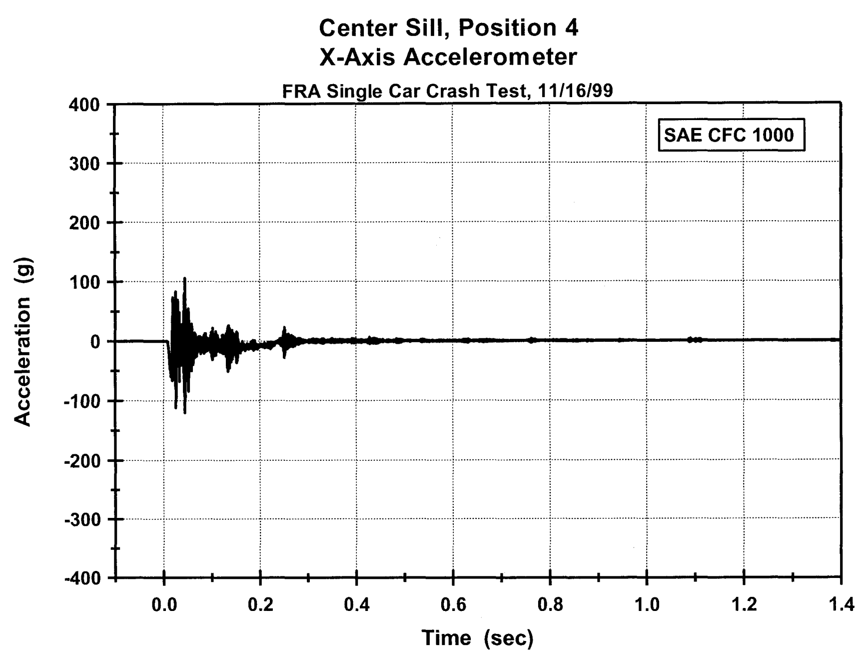
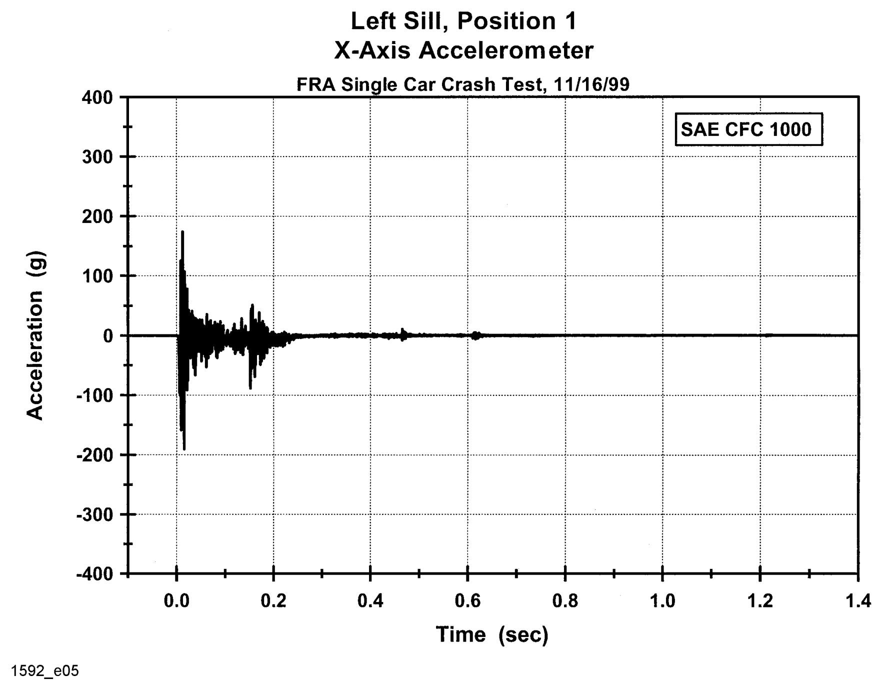


1592_e04

Figure E.4.



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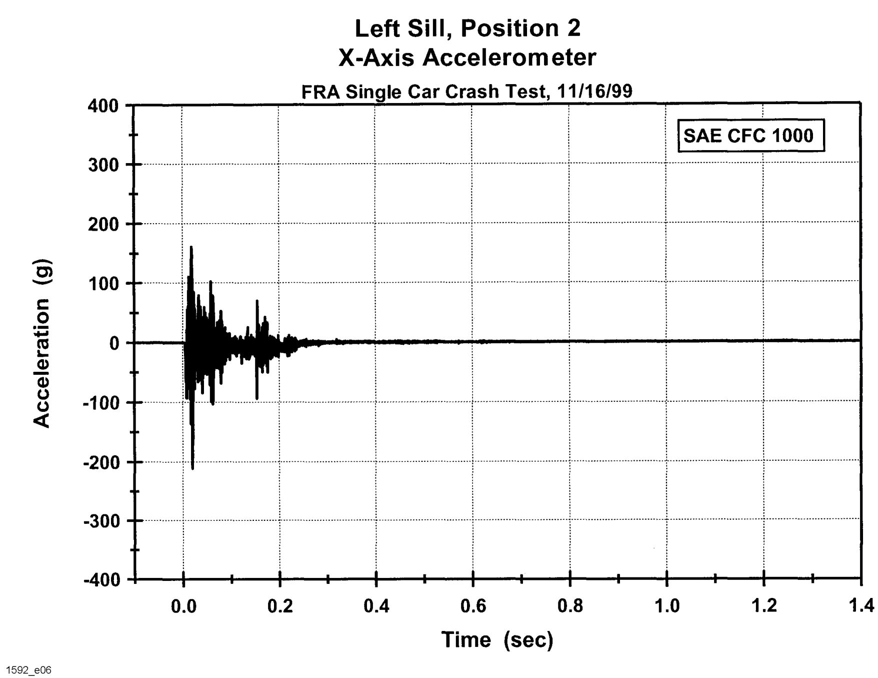

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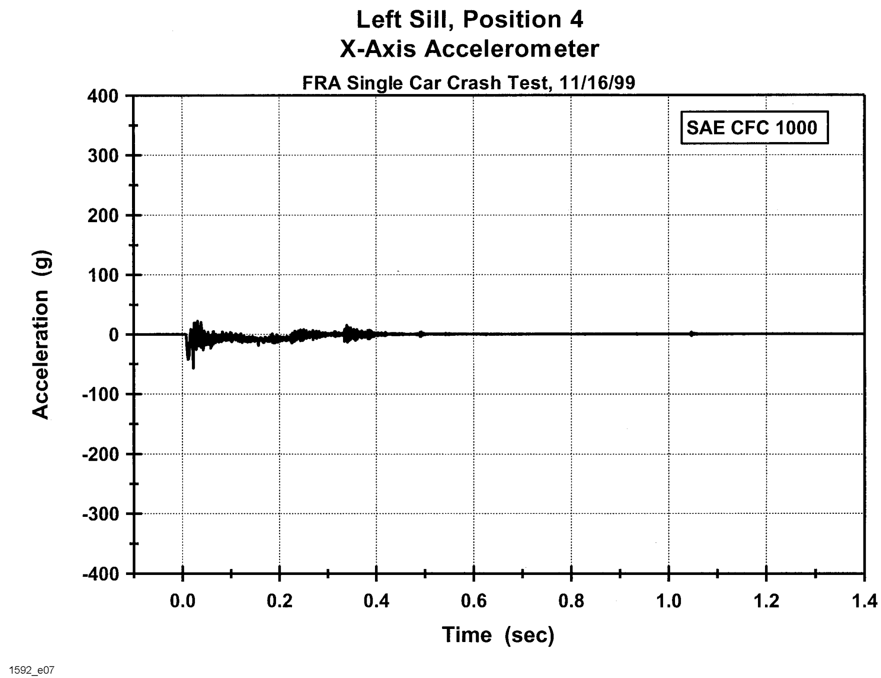

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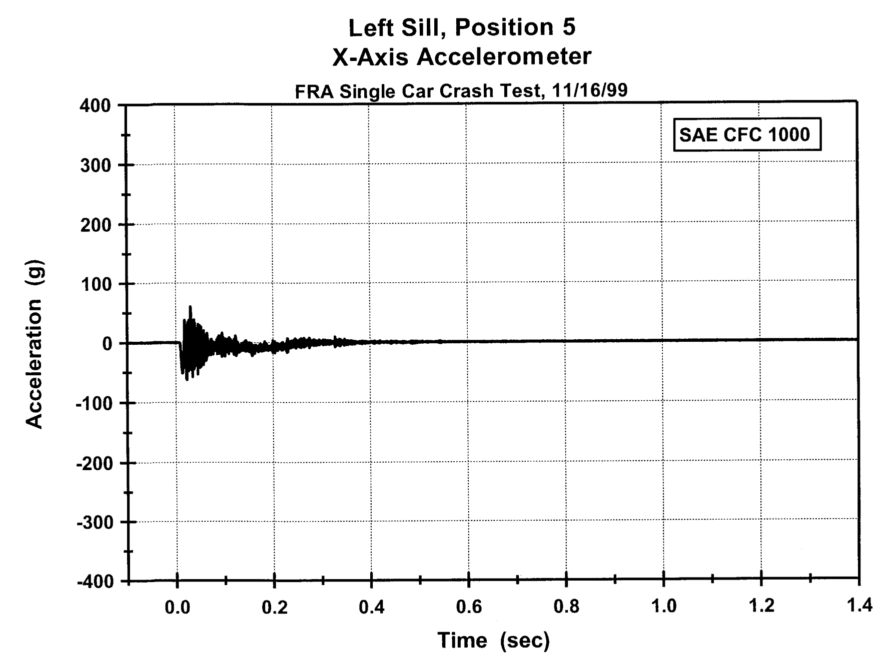

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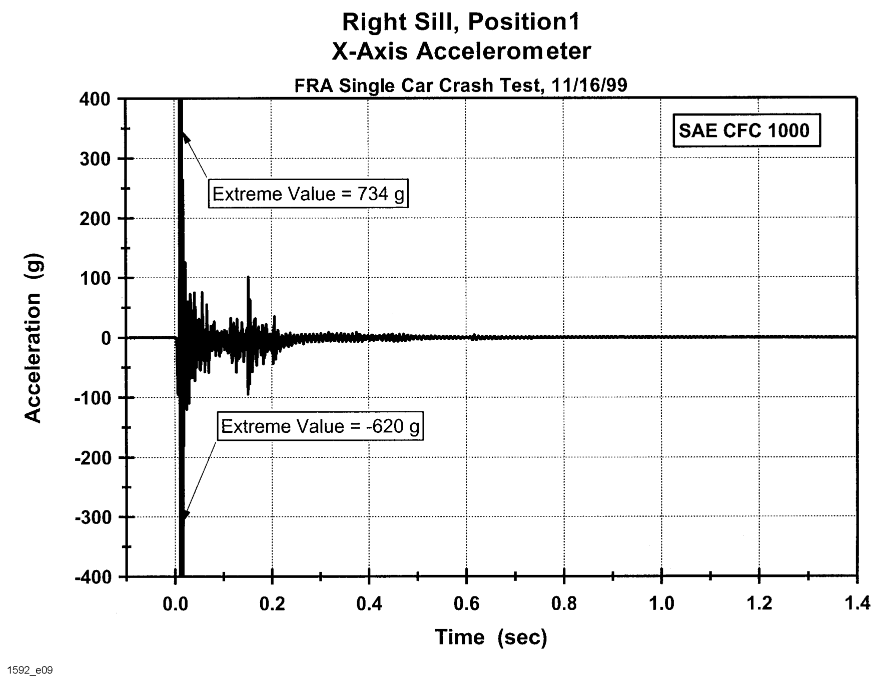

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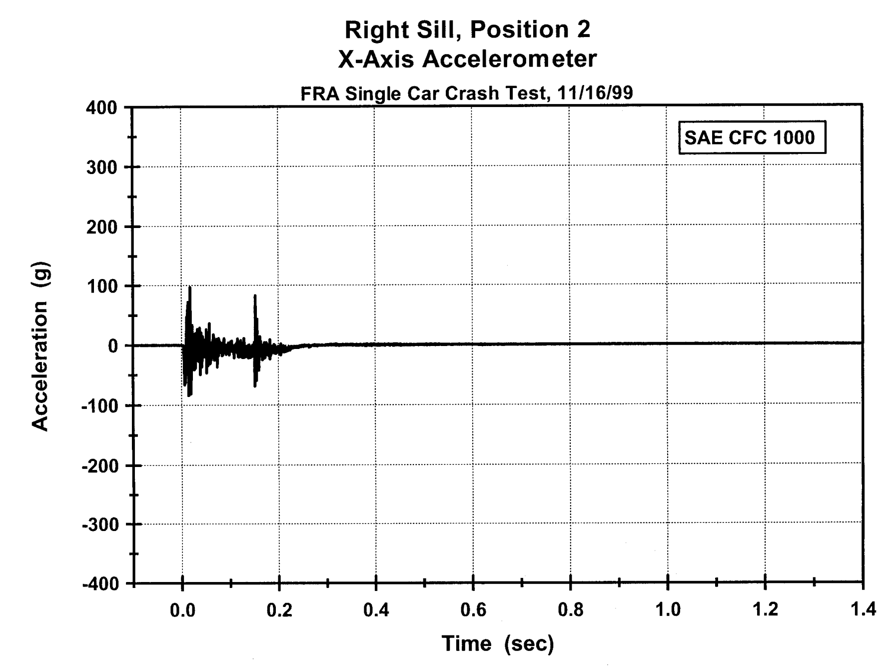

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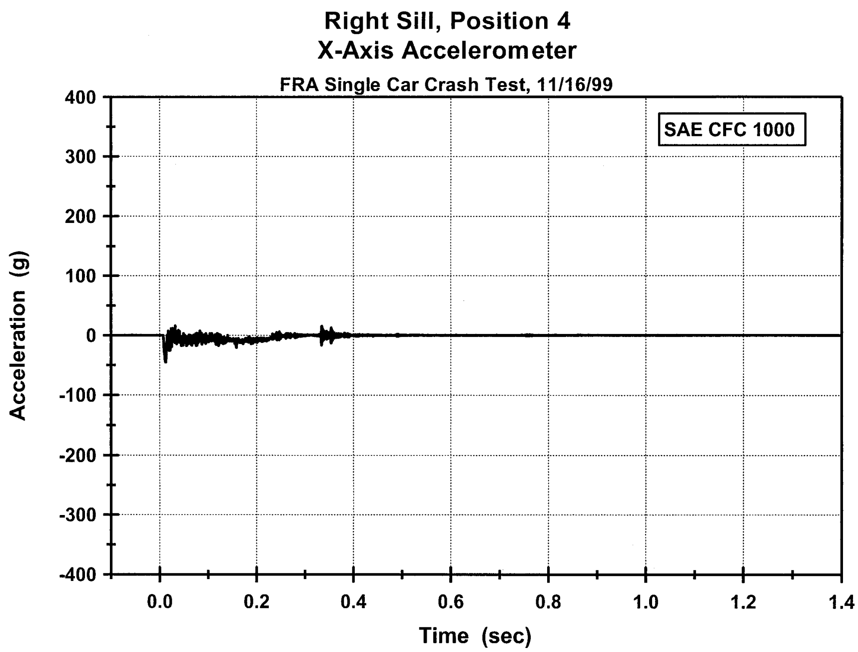
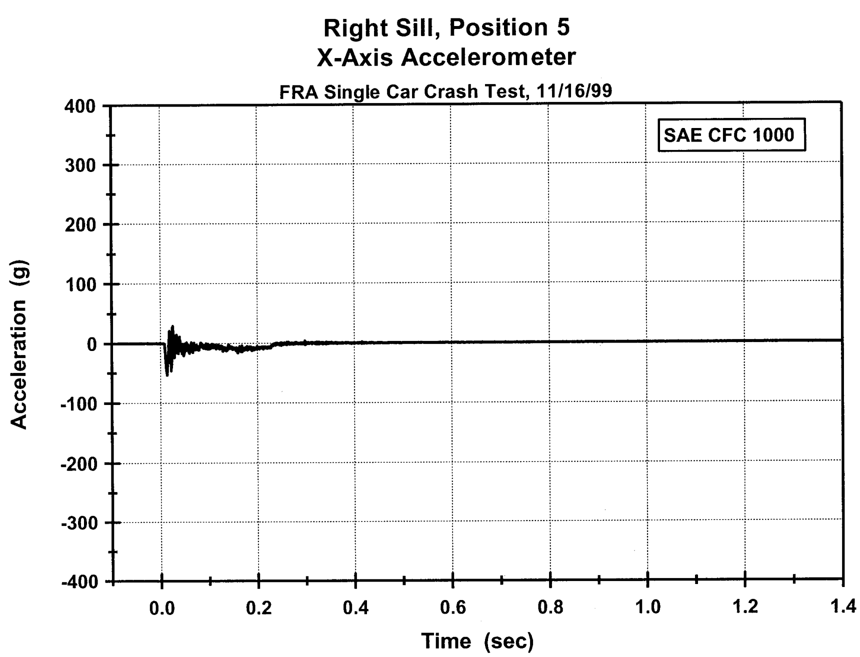


1592_e11

Figure E.11.



1592_e12

Figure E.12.

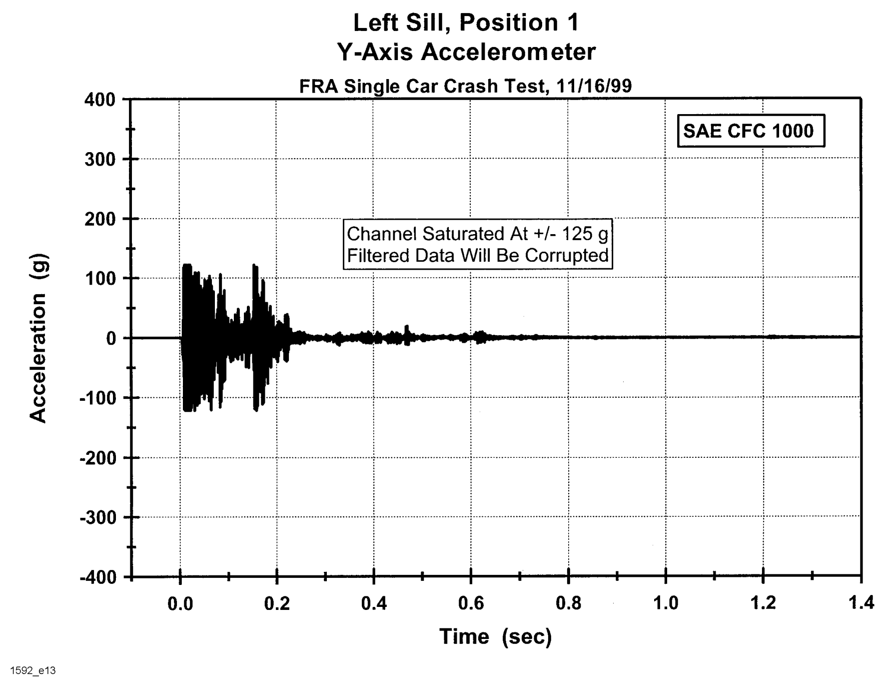


Figure E.13.

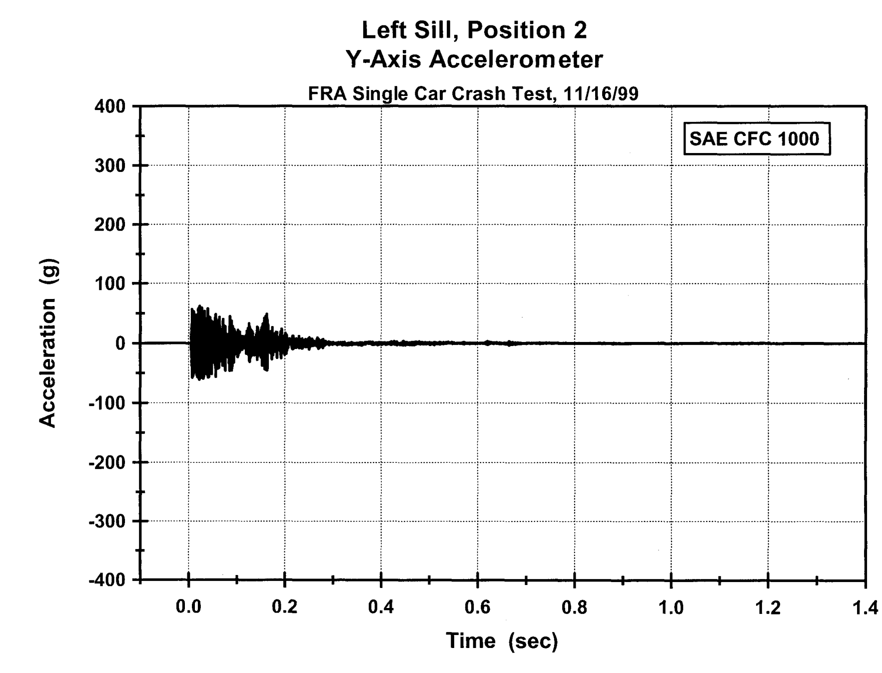
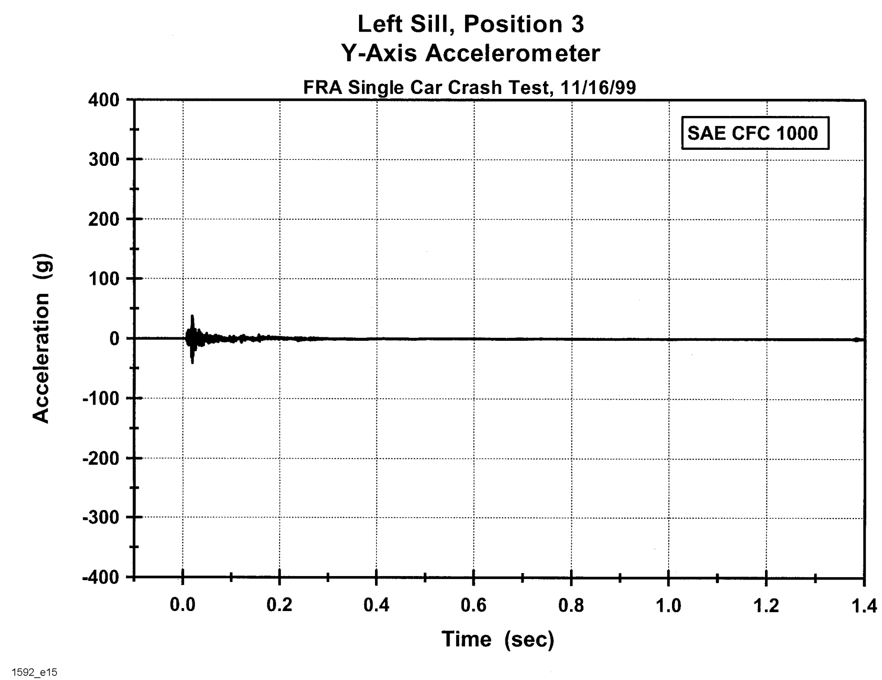


Figure E.14.



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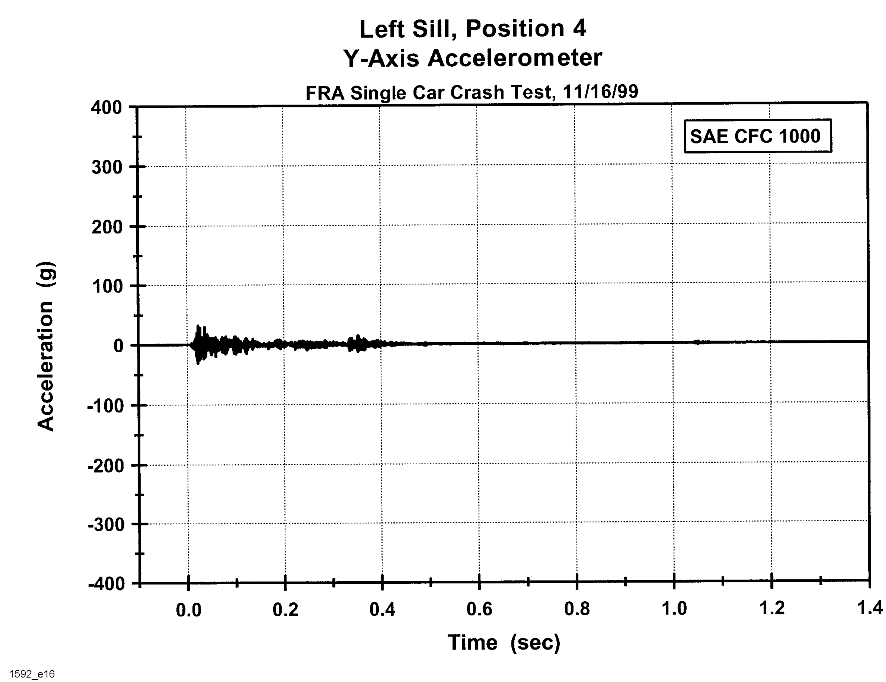

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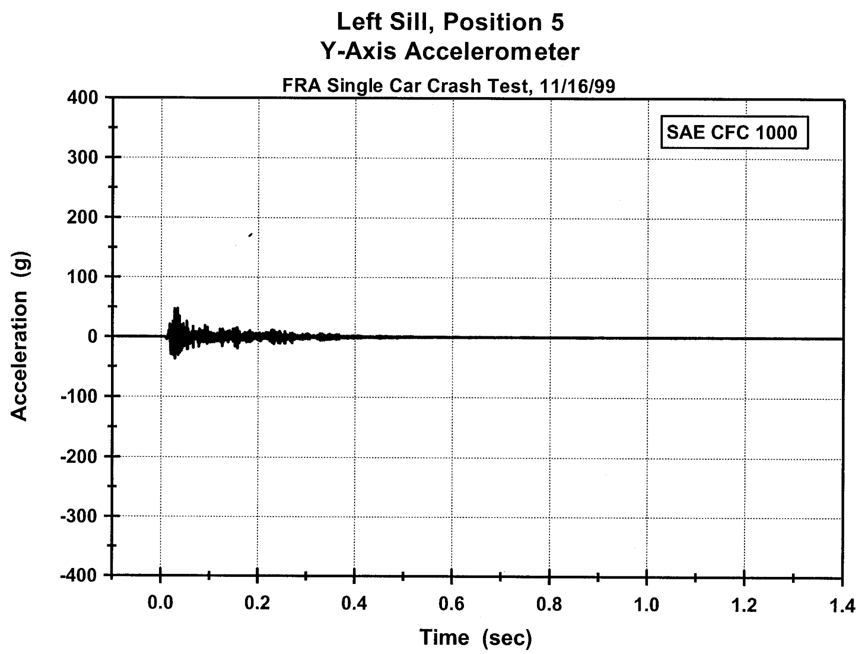
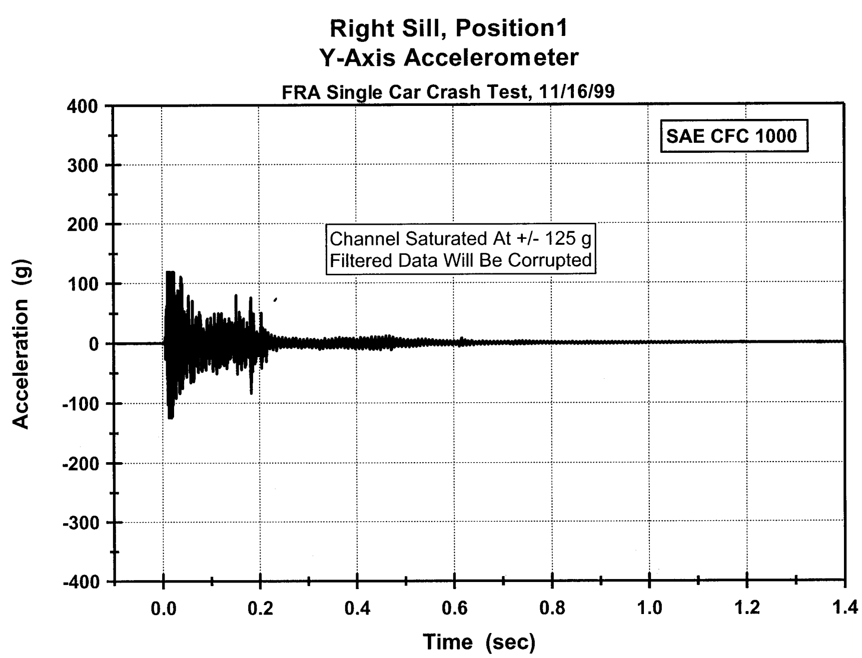


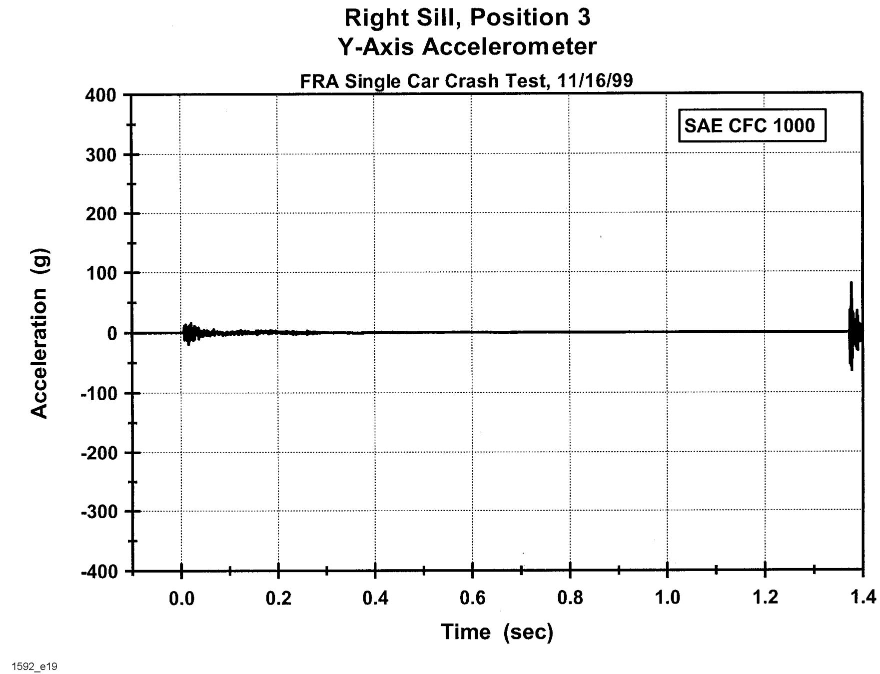
1592_e17

Figure E.17.



1592_e18

Figure E.18.



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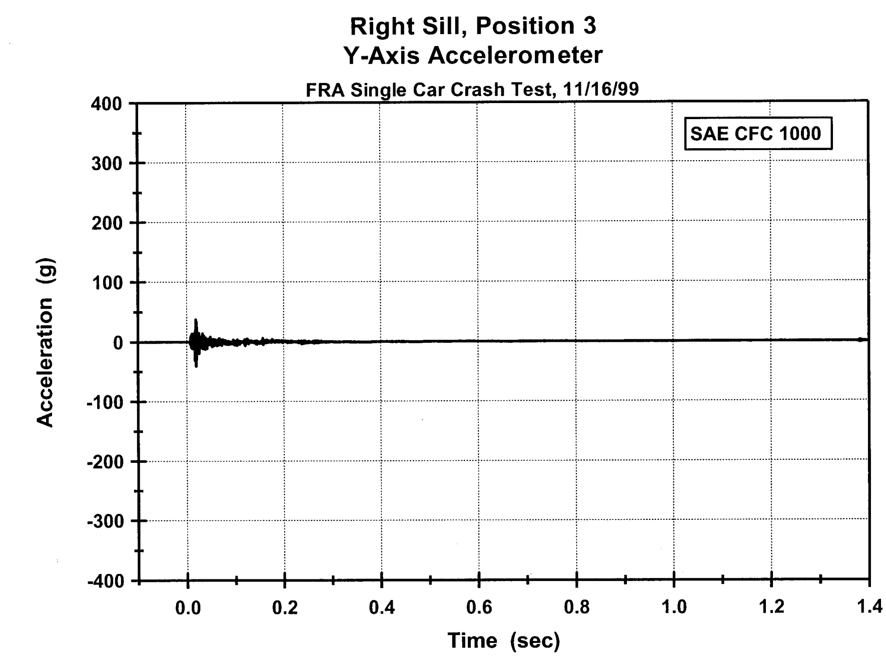

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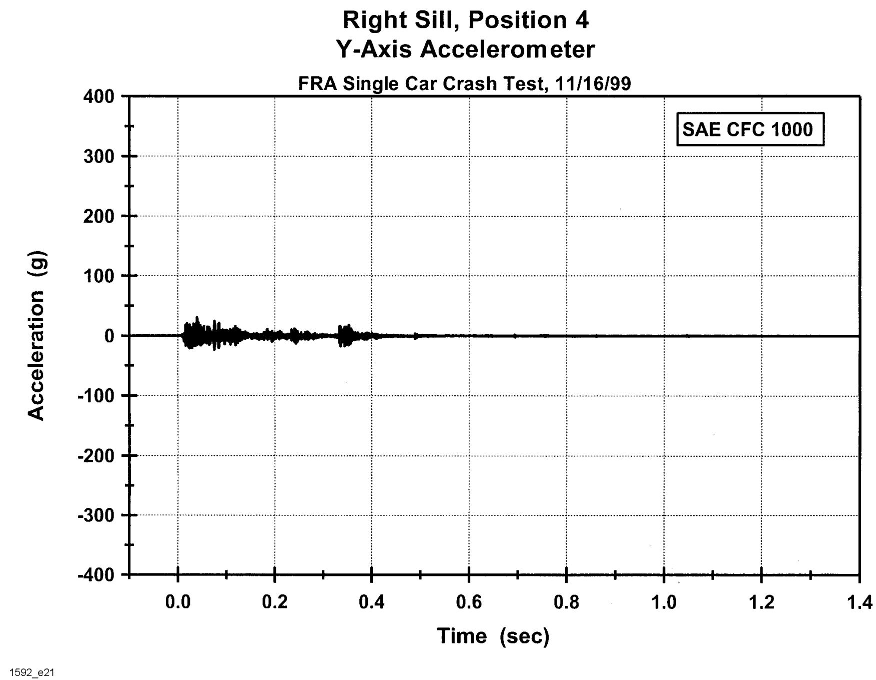

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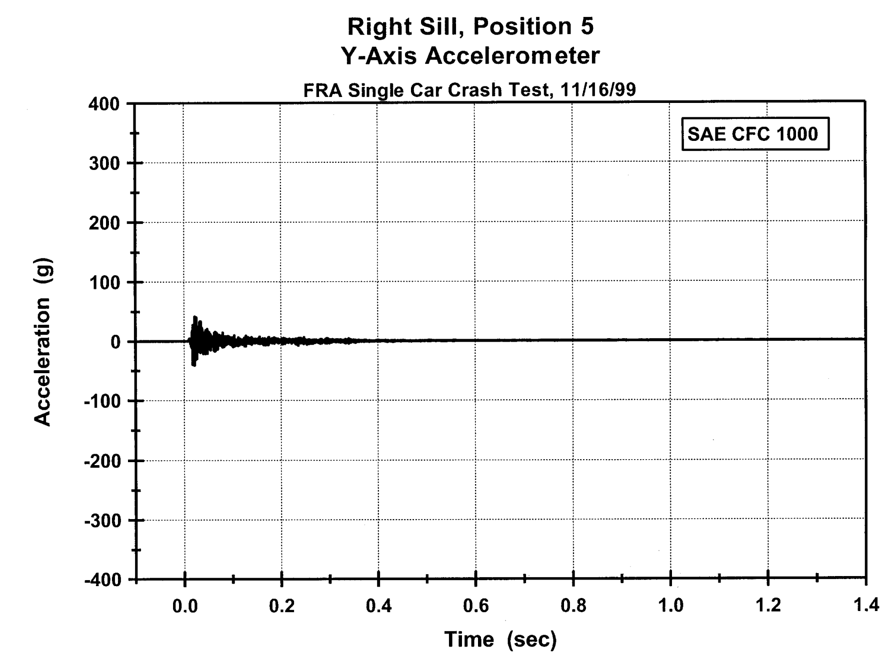

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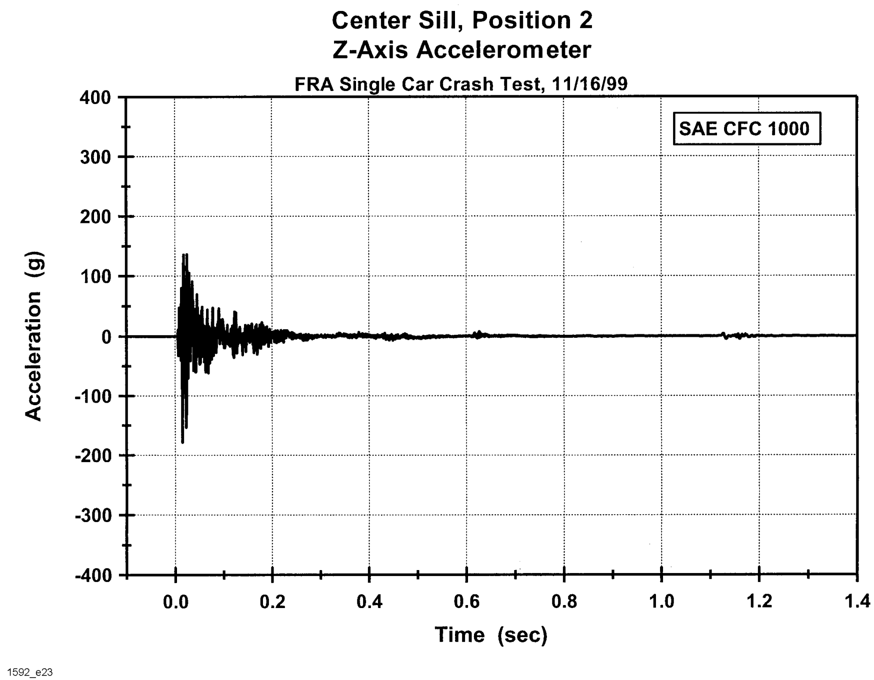

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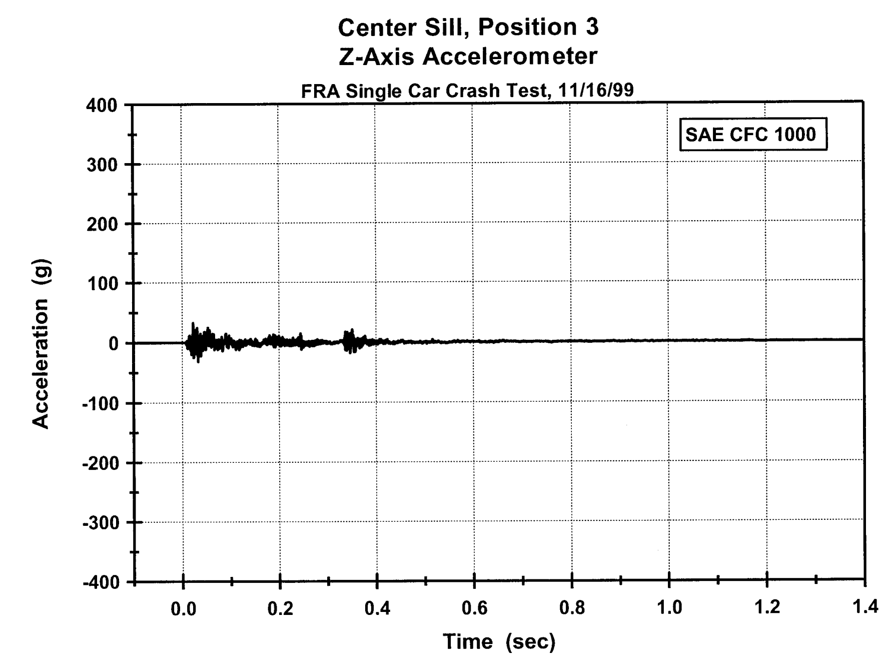

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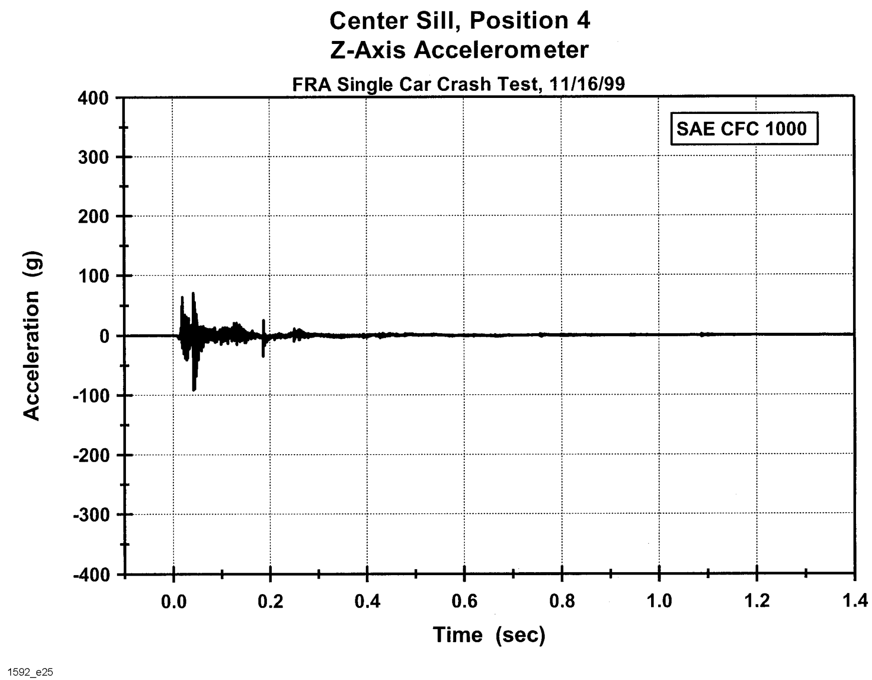

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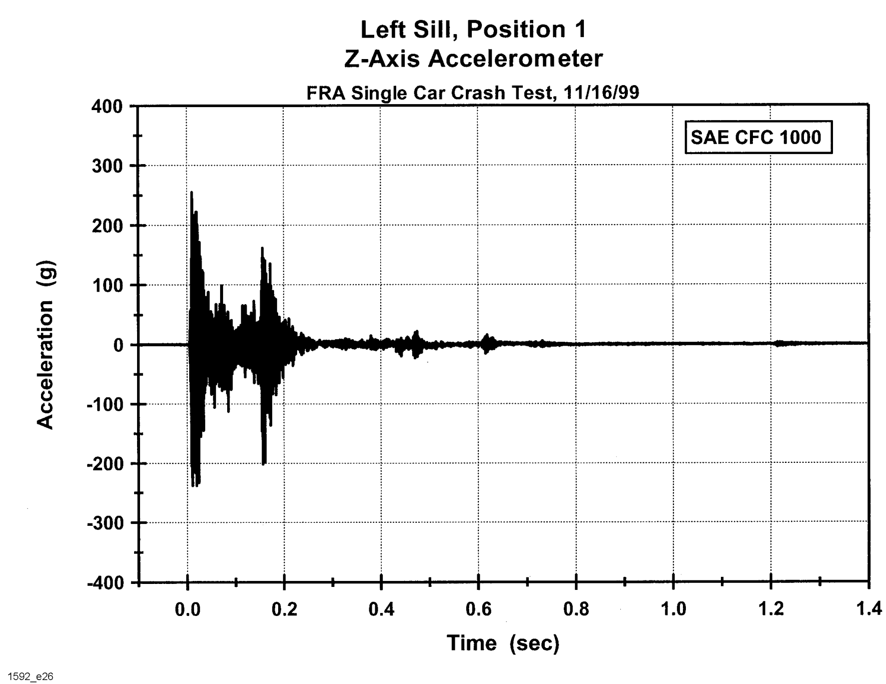

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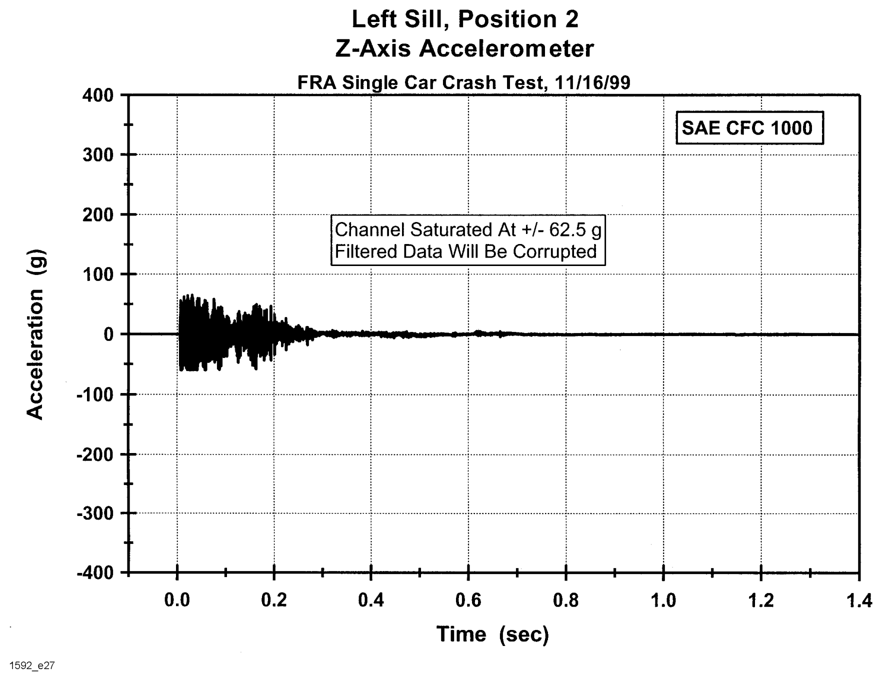

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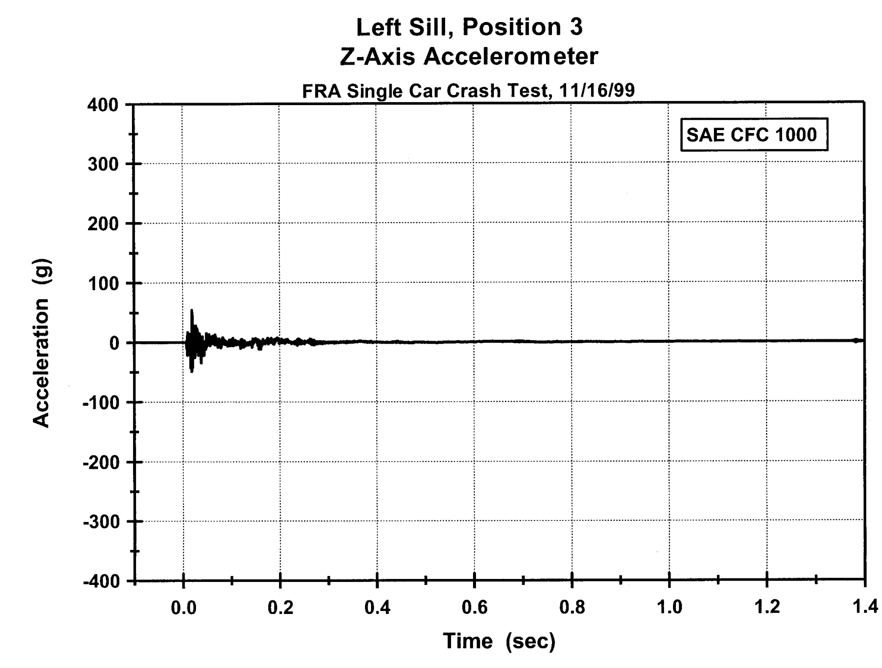

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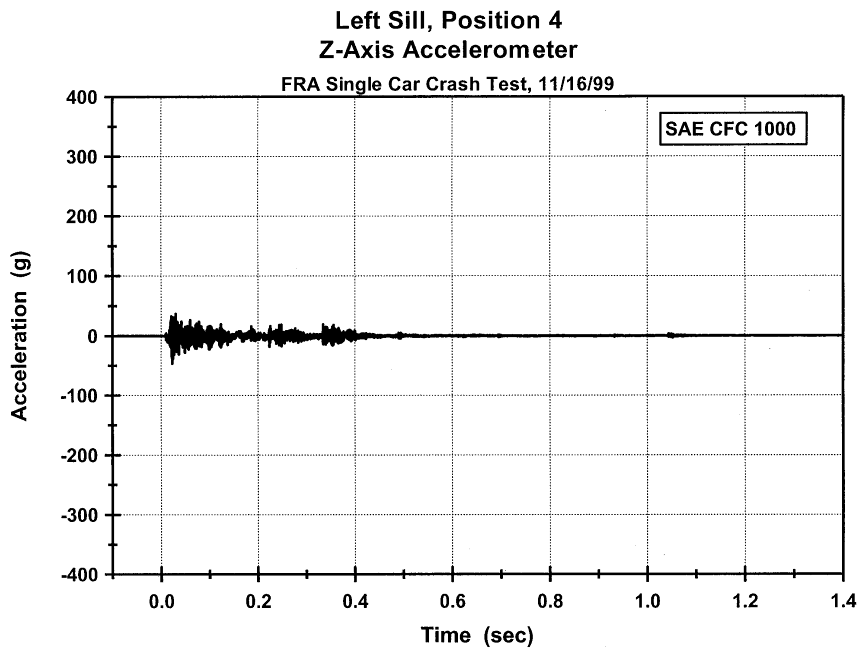
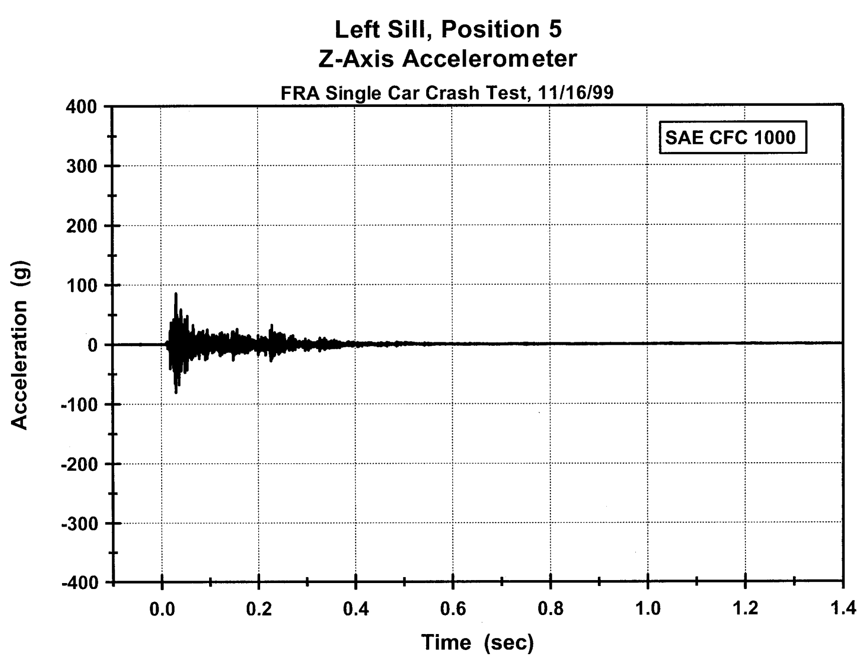


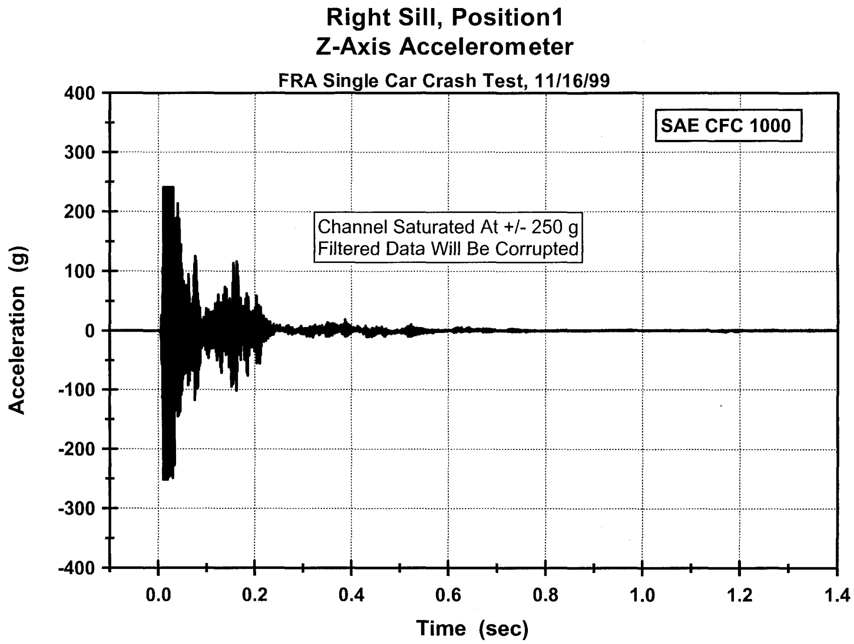
1592_e29

Figure E.29.



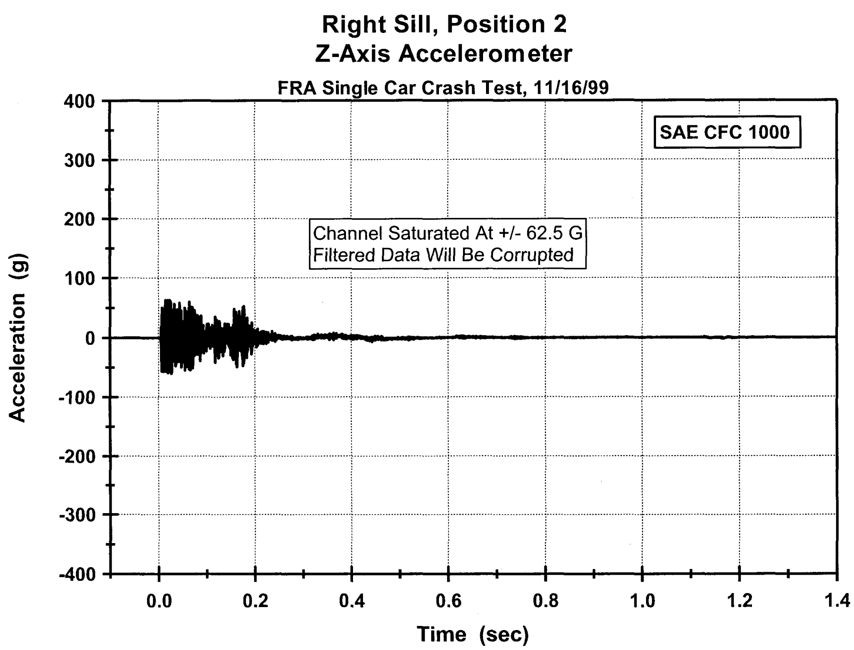
1592_e30

Figure E.30.



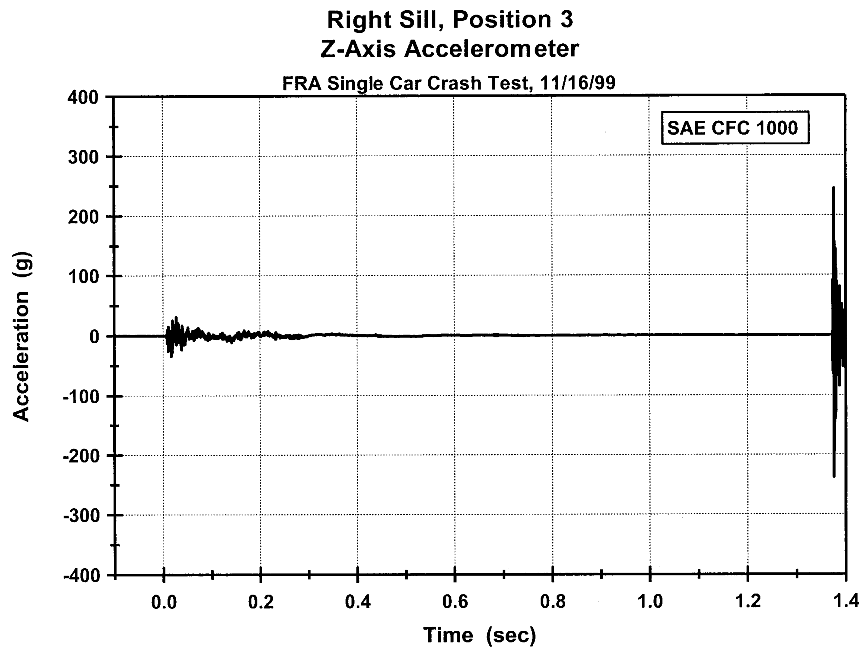
1592_e31

Figure E.31.



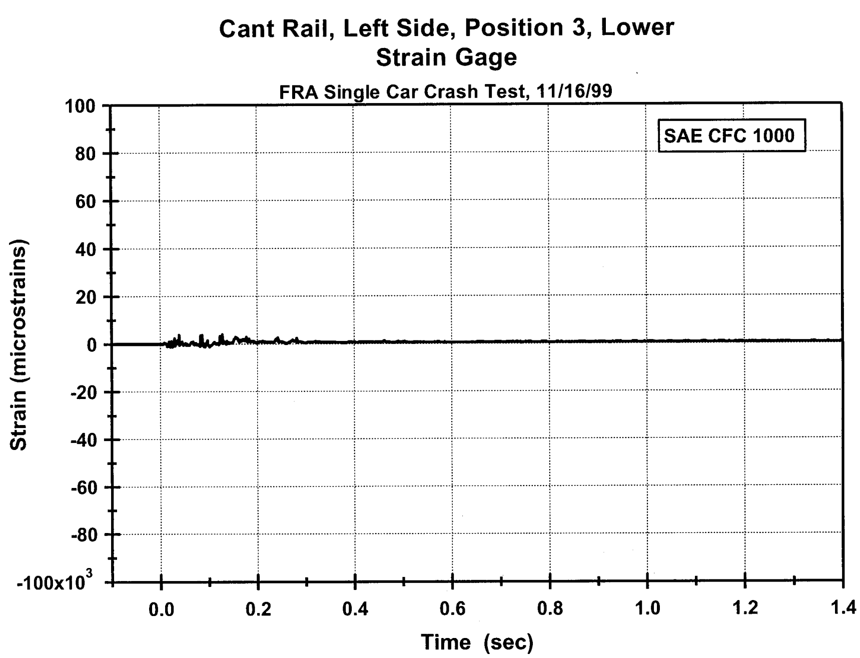
1592_e32

Figure E.32.



1592_e33

Figure E.33.



1592_d34

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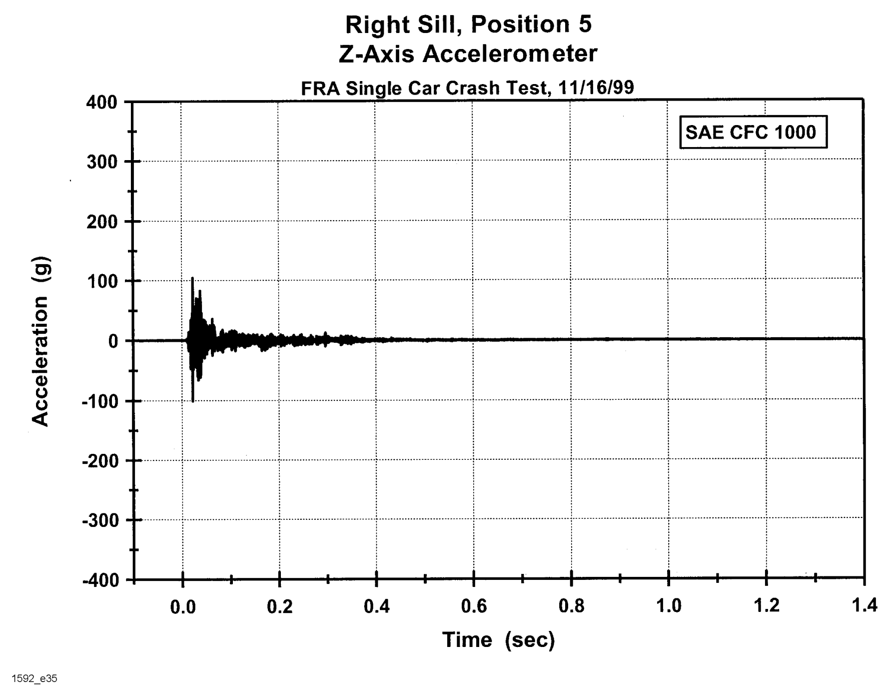

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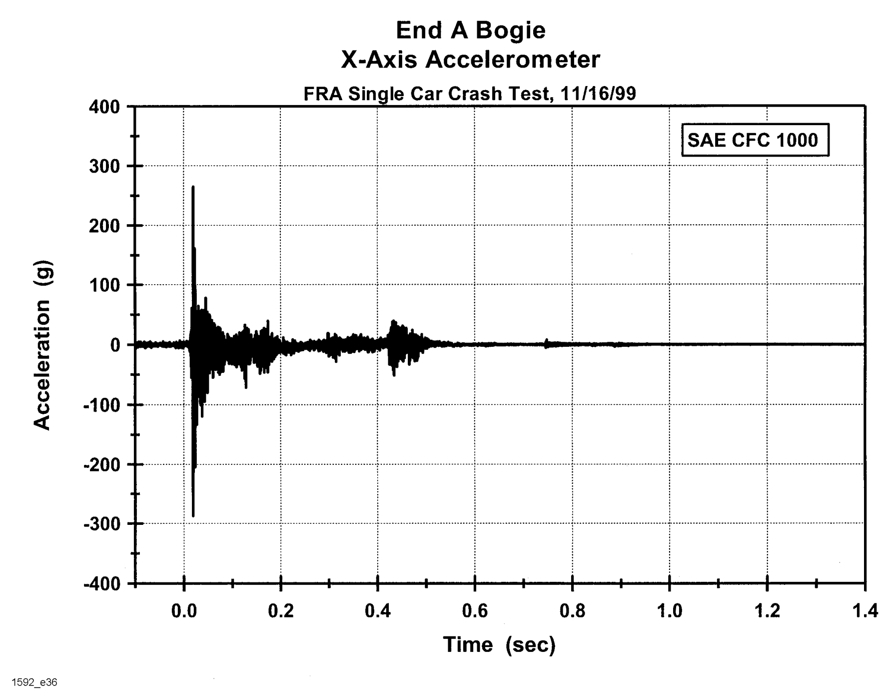

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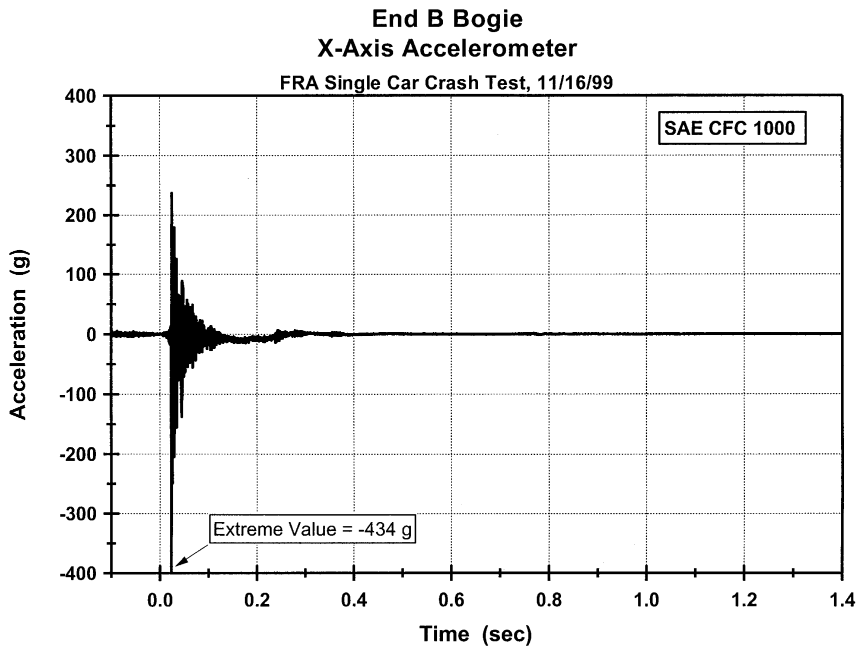
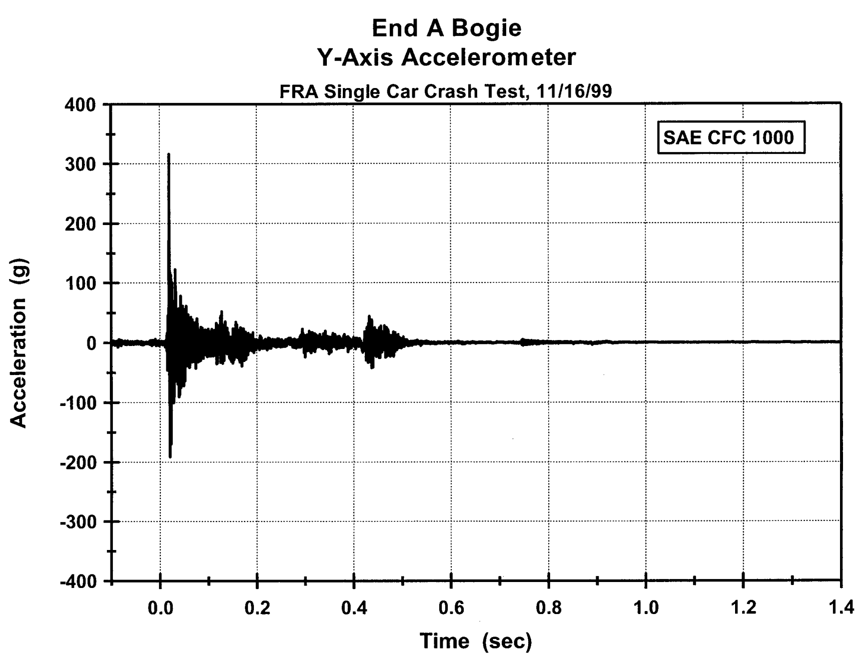


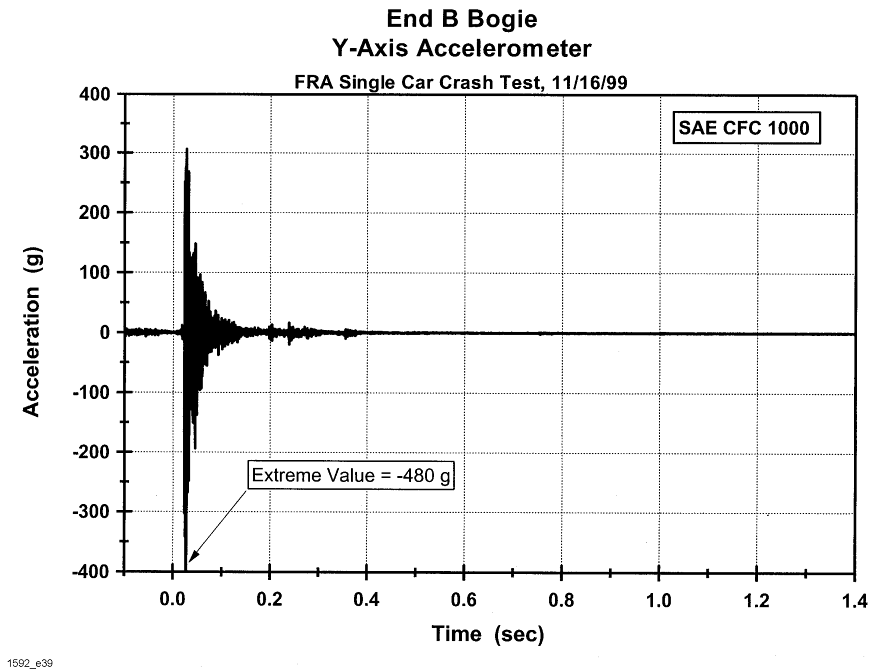
1592_e37

Figure E.37.



1592 e38

Figure E.38.



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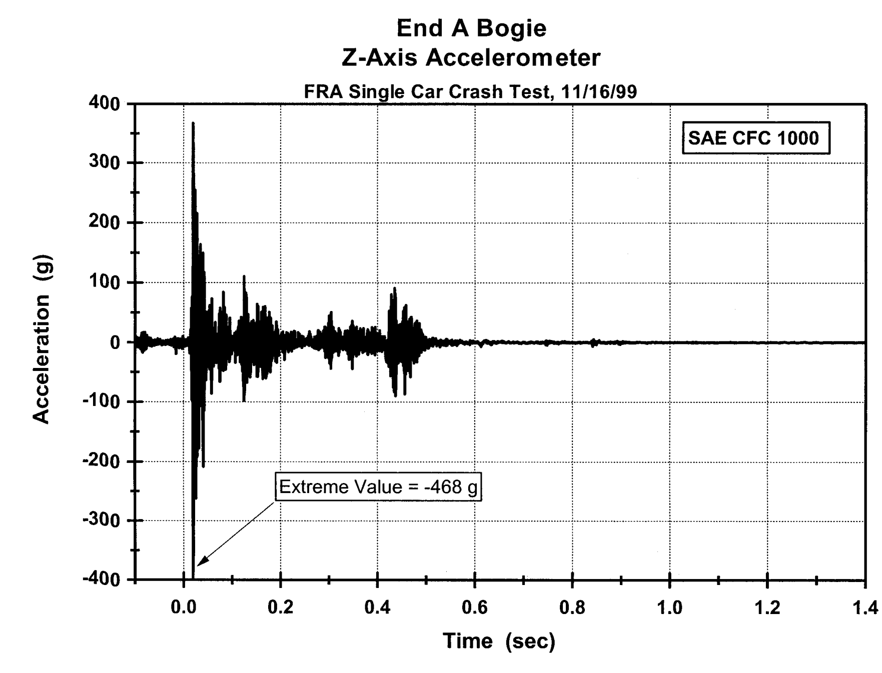

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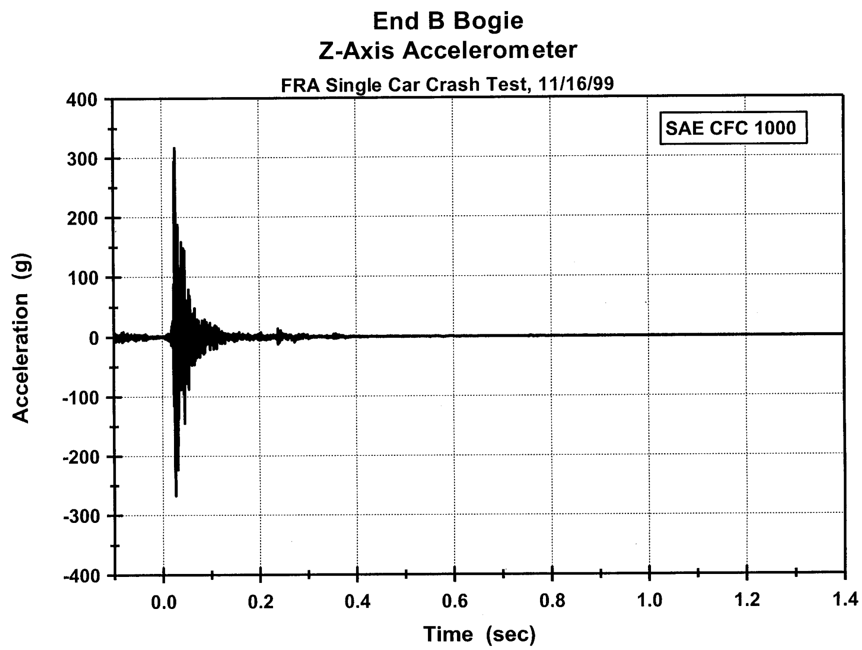


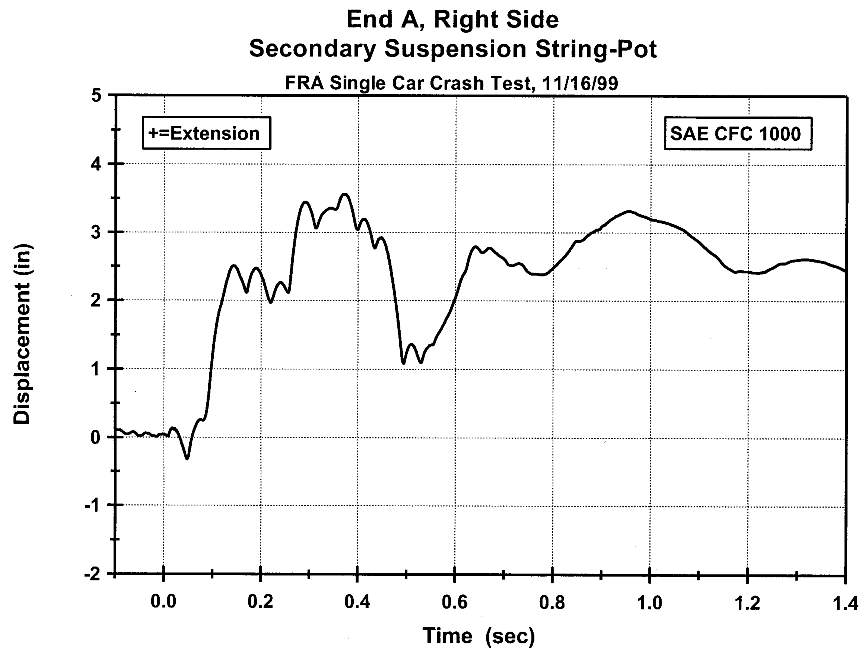
1592_e41

Figure E.41.

Displacements for the Complete

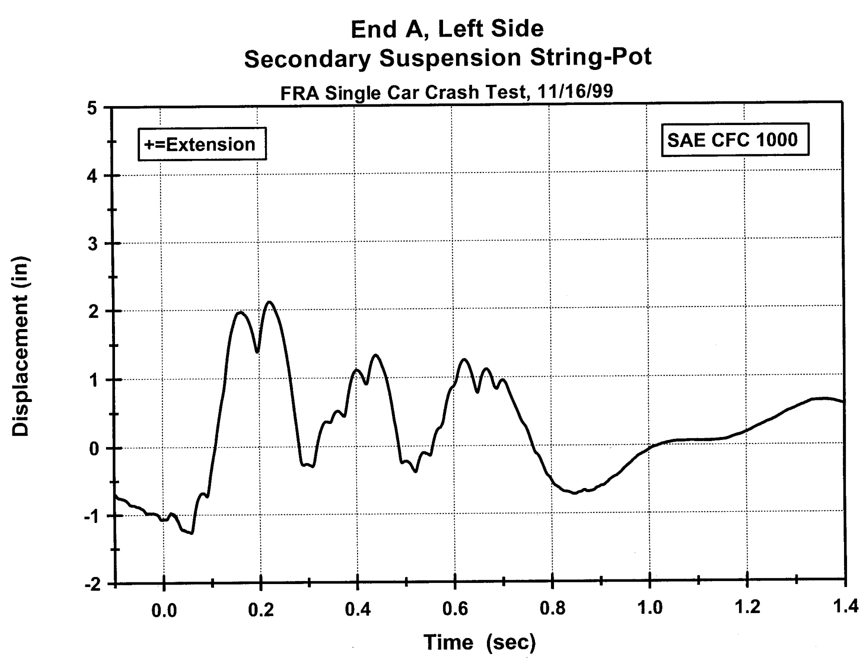
Range Recorded

-0.1s TO 1.4 s



1592_f01

Figure F.1.



1592_f02

Figure F.2.

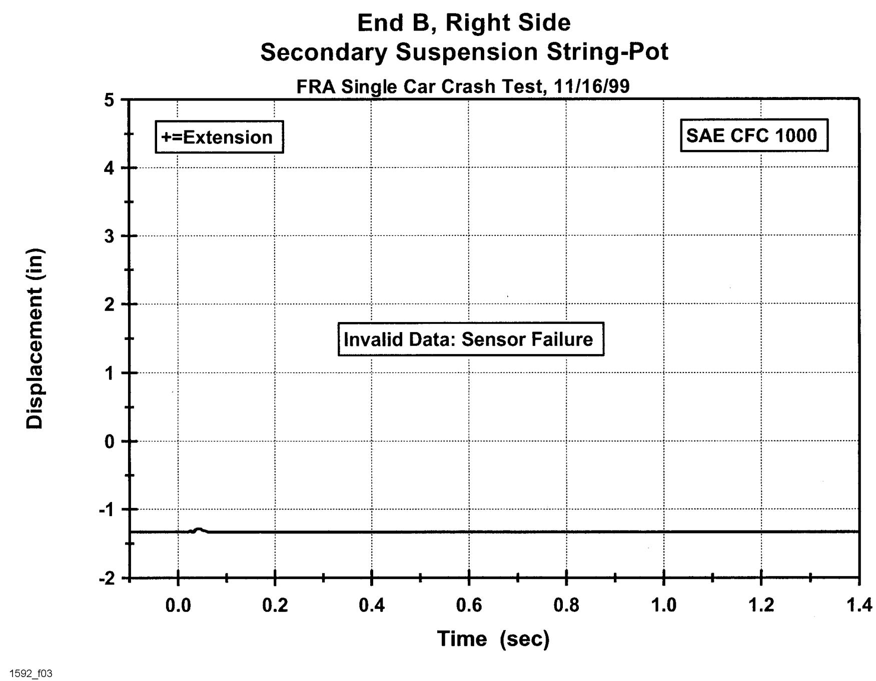


Figure F.3.

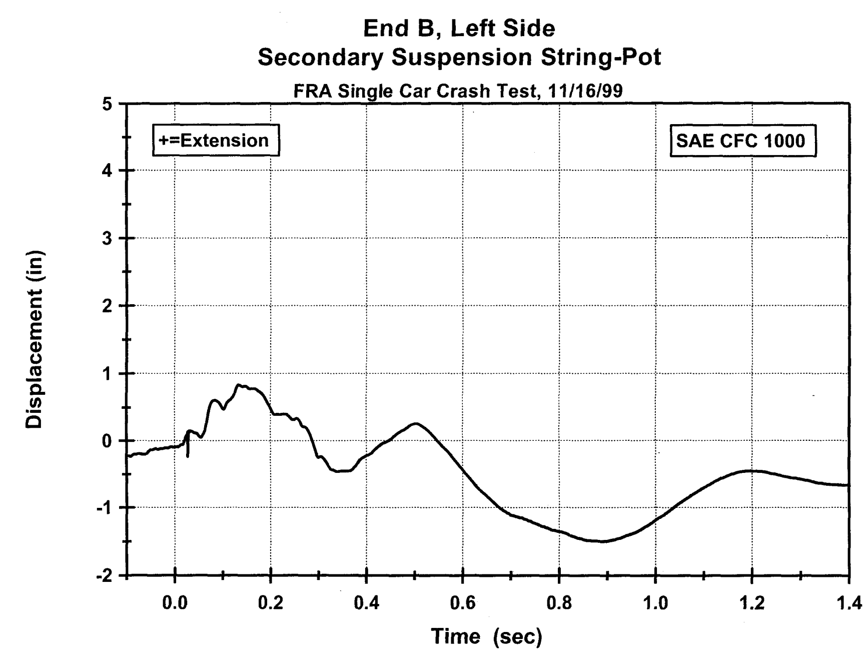


Figure F.4.

Acknowledgments

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, Director, Transportation Test Center, Federal Railroad Administration, directed and coordinated the activities of all the parties involved in the test.

Dave Tyrell, Program Manager, Volpe National Transportation Systems Center, coordinated technical requirements. Caroline Van Ingen-Dunn, Senior Engineer, Simula Technologies, Inc., implemented the occupant protection tests. Ed Murphy, Chief Mechanical Officer, Southeastern Pennsylvania Transit Authority (SEPTA), arranged for the donation of the cars in the test effort. Doug Karan of Amtrak arranged for the donation of the intercity passenger seats. Gordon Campbell, Senior Engineer, LDK Engineering, Inc., arranged for a copy of the Pioneer car structural drawings from Bombardier, Inc. Tom Peacock of the American Public Transit Association coordinated the test with members of the passenger rail transportation industry. TTCI employees Kenneth Laine, Martin Schroeder, and Wayne Stadler were very instrumental in the success of this program.