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Michael White P.E., John Jewell P.E., Rich Peter P.E., Malinda Gallaher

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Roadside Safety Research Group
California Department of Transportation
5900 Folsom Blvd.,
Sacramento, CA. 95819

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This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled “CRASH TESTING OF VARIOUS ROADSIDE HARDWARE.”

16. ABSTRACT

Four different test articles were evaluated for crashworthiness. These articles included an electronic controller cabinet, a chain control sign, a warning sign with flashing beacons, and a light standard with a pole top-mounted luminaire (no mast arm). All testing was completed under National Cooperative Highway Research Program Report 350 Test Level 3 guidelines with 820-kg (1807.8 lb) passenger vehicles. Low speed tests at 35 km/h (21.7 mph) were performed first. These were followed by high-speed tests at 100 km/h (62.1 mph) only if the test articles performed satisfactorily during the low-speed tests. The electronic controller cabinet and the pole top-mounted lighting standard failed to perform satisfactorily during the low-speed tests; therefore, the high-speed tests were not conducted. The chain control sign and the warning sign with flashing beacons both performed well during the 35-km/h (21.7 mph) and the 100-km/h (62.1 mph) crash tests. Design standards and policies are being reviewed for the electronic control cabinet and the pole top-mounted luminaire as a result of their substandard performance during low-speed testing.

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CRASH TESTING OF VARIOUS ROADSIDE HARDWARE

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
DIVISION OF RESEARCH AND INNOVATION
OFFICE OF MATERIALS AND INFRASTRUCTURE

Principal Investigator .... Rich Peter, P.E. and John Jewell, P.E.

Report Prepared by .... Michael White, P.E. and Malinda Gallaher

Research Performed by .... Roadside Safety Research Group

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Principal Investigator .... Rich Peter, P.E. and John Jewell, P.E.

Report Prepared by ....Michael White, P.E. and Malinda Gallaher

Research Performed by .... Roadside Safety Research Group

JOSEPH W. HORTON, Office Chief
Office of Safety Innovation and
Cooperative Research

ROBERT MEELINE, Branch Chief
Office of Safety Innovation and
Cooperative Research
Roadside Safety Research Group

JOHN JEWELL, Specialist
Office of Safety Innovation and
Cooperative Research
Roadside Safety Research Group

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SI CONVERSION FACTORS

To Convert From	To	Multiply By
	ACCELERATION	
m/s^2	ft/s^2	3.281
	AREA	
m^2	ft^2	10.764
	ENERGY	
Joule (J)	$ft\text{-}lb_f$	0.7376
	FORCE	
Newton (N)	lb_f	0.2248
	LENGTH	
m	ft	3.281
m	in	39.37
cm	in	0.3937
mm	in	0.03937
	MASS	
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km/h	ft/s	0.9113
	VOLUME	
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ACKNOWLEDGMENTS

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Other persons from Caltrans who made important contributions include: From North Region Construction Technical Services Support Branch: Pete Horvath, Myron Fladland and John Petersen; From Headquarters Photography: Don Tateishi, Ed Andersen, and John Hirtz.

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1. INTRODUCTION

1.1. Problem

Caltrans recently became aware of several types of roadside hardware that had not been crash tested and whose crashworthiness was judged to be uncertain. This hardware includes electronic controller cabinets used for freeway signal and sign control, chain control signs which are designed to be rotated 90° when not in use, warning signs with double flashing beacons, and break-away light standards used in chain-up areas featuring luminaires mounted directly to the top of the standard with no mast arm. The vehicle fleet on the highway today contains many smaller cars, which were not considered in designing some of these hardware devices. There are insufficient crash test data pertaining to similar devices to verify whether this hardware complies with National Cooperative Highway Research Program (NCHRP) Report 350 criteria1.

1.2. Objective

The objective is to determine if the currently used electronic controller cabinets, chain control signs, warning signs with flashing beacons, and pole top-mounted lighting systems will withstand impacts from vehicles with a mass of 820 kg (1808 lbs) at speeds of 35 km/h (22 mph) and 100 km/h (62 mph) at an impact angle of 0° without producing excessive pitch, roll, yaw, deceleration, or deformation of the occupant compartment. Data gathered will be used to make design change recommendations to some or all of these hardware items or to the various mounting systems, if necessary. Testing will be done in accordance with NCHRP Report 350, Test Level 3 (TL-3) for support structures.

1.3. Background and Significance of Work

The cabinets used to house the electronic controllers for freeway on-ramp metering and other signal and signing functions are typically placed near the travel way in the recovery zone. These cabinets have not been tested to the newer, more stringent, crash test criteria contained in NCHRP Report 350.

The signs used to advise motorists of a chain control area are designed to be rotated 90° when not in use. The breakaway feature of this sign works well when the sign is rotated so that the face of the sign is toward on-coming traffic (during chain control operations). The sign assembly has not been tested when the sign is rotated so that the face of the sign is perpendicular to traffic.

On certain sections of State Highways there are signalized intersections with high accident rates. In an effort to make these intersections safer, the Department has placed signs with flashing beacons to warn motorists of upcoming signalized intersections. The intent is to alert the motoring public to either stop or warn about cross traffic ahead. The sign and beacons are mounted on a cut-down Type 15 light standard that does not utilize the arm flange. This light standard is mounted to the Type 30/31 slip base. While this type of slip base works well with the Type 15 light standard, it has not been tested with the advance warning beacon and sign configuration.

Chain control lighting uses a special 12.2-m (40-ft) pole mounted on the Type 30/31 slip base. A luminaire is mounted directly to the top of the pole. This new configuration is currently being used in chain control areas to aid motorists at night with chaining and de-chaining operations.

1.4. Literature Search

All of the test articles to be tested are designs specific to Caltrans. A formal literature search was not conducted because it was already known that these articles had not been tested.

1.5. Scope

Representative controller cabinets, chain control signs, warning signs, and pole top-mounted lighting fixtures were erected at the Caltrans Dynamic Test Facility in West Sacramento. Data were gathered from a series of vehicular crash tests. These data were analyzed to determine whether each piece of hardware meets the criteria set forth in NCHRP Report 350 under the conditions shown in the table below.

Table 1-1. Intended Test Conditions

CALTRANS Test #	Test Article	Vehicle Mass [kg]	Impact Speed [km/h]	Impact Angle [deg]	NCHRP Report 350	
					Test Designation	Vehicle
611	Type 334C Electronic Controller Cabinet	820	35	0	3-60	820C
612[a]	Type 334C Electronic Controller Cabinet	820	100	0	3-61	820C
613	Chain Control Sign	820	35	0	3-60	820C
614	Chain Control Sign	820	100	0	3-61	820C
618	Warning Sign with Flashing Beacons	820	35	0	3-60	820C
616	Warning Sign with Flashing Beacons	820	100	0	3-61	820C
617	Pole-Top Lighting	820	35	0	3-60	820C
615[b]	Pole-Top Lighting	820	100	0	3-61	820C

2. TECHNICAL DISCUSSION

2.1. Test Conditions - Crash Tests

2.1.1. Test Facilities

All of the crash tests were conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The test area is a large, flat, asphalt concrete surface. There were no obstructions nearby for the high-speed tests and only a 2-m (6.5-ft) high earth berm 40-m (130-ft) downstream from the test articles for the low-speed tests.

[a]Due to the failure of Test 611, this test was not conducted.
[b] This test was omitted due to the failure of test 617.

2.1.2. Test Article Designs and Installation

The following subsections describe the four different test articles used in this study. All test articles were fabricated to match (as closely as possible) the weight and dimensions of field-installed hardware. All test articles were erected at the Caltrans Dynamic Test Facility in West Sacramento following procedures similar to those used in the field.

2.1.2.1. Type 334C Controller Cabinet

The 334C Electronic Controller Cabinet is used to house a variety of electronic packages from traffic monitoring systems to informational displays. The cabinet used in this study was configured similarly to those along the highway, which powers and operates the overhead changeable message signs (Figure 2-1). In this configuration, the cabinet had a total mass of 125 kg (276 lb) and a vertical center-of-gravity of 0.980 m (3.2 ft) as measured upward from the bottom edge of the cabinet. The 334C controller cabinets that are configured for on-ramp metering (Figure 2-2) have different components installed in the internal rack, thus it may have a somewhat different mass and vertical center of gravity. However, it is unlikely that these differences would be significant enough to produce substantially different crash test results. For additional technical information, refer to Section 7.2 (located in the Appendix).

Figure 2-1. Type 334C Controller Cabinet Configured for CMS Operation

Figure 2-2. Type 334C Controller Cabinet Configured for Onramp Metering

2.1.2.2. Rotatable Chain Control Sign

The chain control signs used in many mountainous regions of California are designed so the entire signpost can be rotated 90°. This flexibility allows the face of the various sign panels installed on the post to be rotated so they are not facing motorists when chain controls are not in effect. The lower sign panels are also designed to rotate independently from the upper panels to vary the message according to the prevailing road and weather conditions. When the signpost is rotated in the summertime or not-in-use situation, the faces of the sign panels are parallel to the traffic (Figure 2-3). The sign assembly in this position potentially has very different crash test characteristics than when the sign panels are facing the traffic (Figure 2-4). In this study, the sign assembly was tested with the sign panels parallel to traffic, since this configuration was judged to have the most serious potential results. For additional technical information, refer to Section 7.2 (located in the Appendix).

Figure 2-3. Rotatable Chain Control Sign
(Not-In-Use Position)

Figure 2-4. Rotatable Chain Control Sign
(In-Use Position)

2.1.2.3. Warning Sign with Flashing Beacons

The warning sign with flashing beacons is used to alert motorists of upcoming traffic that is either stopped or crossing their path. The sign and beacons are mounted on a cut-down Type 15 light standard without the arm flange on a Type 30/31 slip base. While the Type 30/31 slip base works well with the Type 15 light standard, it has not been tested with the addition of the advance warning beacons and warning sign. For additional technical information, refer to Section 7.2 (located in the Appendix).

Figure 2-5. Warning Sign with Flashing Beacons

2.1.2.4. Pole Top-Mounted Luminaire

The configuration for chain control lighting is a special 12.2-m (40-ft) pole mounted on the Type 30/31 slip base. The pole top-mounted luminaire tested as part of this study utilized a high-pressure sodium-filled lamp and fixture mounted directly on the top of the light pole. It was secured to the top of the pole with an aluminum casting which allows for angular adjustment of the head. Three bolts were threaded through this casting and were tightened down against the outside of the pole top to hold the head in place. For additional technical information, refer to Section 7.2 in the Appendix.

Figure 2-6. Pole Top-Mounted Luminaire (Overall View and Close-Up View of Head).

2.1.3. Concrete

The same concrete mix design was used for the cast-in-drilled-hole footings for the light standard foundations and the footings and pads for the electronic controller cabinet foundations. It was obtained from a local supplier and typically consisted of the following:

Material	Description	Admixture (ml/m^3)	Weight (kg)	Volume (m^3)
Coarse aggregate	Perkins 1 x 4		1,115	0.41
Fine aggregates	Perkins conc. sand		811	0.31
Portland cement	Type I/II		251	0.08
Mineral admix	Class F - flyash		84	0.04
Water	Natural		158	0.16
Type A water reducer	Pozzolith 322N	1,256		
Air content 1.50%				0.01
		TOTAL	2418	1.00

Design slump	101.6 mm
Design unit weight	2413.8 kg/m^3
Design w/c + p ratio	0.47

Sampling cylinders were prepared for later testing of the compressive strength of the concrete. Two cylinders were sent for testing to the concrete testing section at the Caltrans Transportation Laboratory prior to conducting the first crash test of this series. The 28-day average compressive strength was found to be 24.9 MPa (3.61 ksi).

2.1.4. Test Vehicles

The test vehicles complied with NCHRP Report 350 (Table 2-1). For all tests, the vehicles used were Geo Metros in good condition, free of major body damage and not missing any structural parts. All of the vehicles had front-mounted engines and standard equipment.

Table 2-1. Test Vehicle Masses

Test No.	**Vehicle Year (GEO Metros)**	**Ballast** [kg]	**Test Inertial** [kg]
611	1994	10	800
613	1994	33	799
614	1994	19	800
618	1994	0	845
616	1989	0	800
617	1990	34	798

All 820C test vehicles were self-powered and used a speed control device to limit acceleration once the impact speed had been reached. Remote braking was possible at any time during all tests via a radio-link, remote-controlled braking setup. A short distance before the point of impact each vehicle was released from the guidance rail and the ignition system was deactivated. A detailed description of the test vehicle equipment and guidance system is contained in Sections 7.1 and 7.3 (located in the Appendix).

2.1.5. Data Acquisition System

At the time of testing, the Caltrans crash test program was in the midst of a transition from 16-mm movie cameras to high-speed digital video. Some of the testing done in this project was recorded with both high-speed 16-mm movie cameras and high-speed digital video cameras. All tests were also recorded with one normal-speed 16-mm movie camera, one Beta format video camera, and one 35-mm still camera with an auto-winder. The test vehicles and test articles were photographed before and after impact with a normal-speed 16-mm movie camera, a Beta format video camera and a color 35-mm camera. A film report of this project was assembled using edited portions of the film coverage.

Two sets of orthogonal accelerometers were mounted in all vehicles at the center of gravity. One set of rate gyro transducers was placed 191 mm (7.5 in) behind the center of gravity (along the X-axis) to measure the roll, pitch, and yaw rates. The data were used in calculating the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation.

All 820C vehicles had anthropomorphic dummies belted in the front left seat. Two separate digital transient data recorders (TDRs), manufactured by GMH Engineering (Model II), were used to record electronic data during all tests. The digital data were analyzed with custom DADiSP workbooks using a personal computer. All test data are shown in Section 7.5 of the Appendix.

2.2. Test Results - Crash Tests.

2.2.1. Test 611 - 334C Controller Cabinet (35 km/h)

2.2.1.1. Test 611 Impact Description

The intended impact angle of approximately 0° and the impact location on the front center of the vehicle were set by the placement of the guide rail. Film analysis indicated that the actual impact angle was 0°. The impact speed of 35.3 km/h (21.9 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. As the front of the vehicle impacted the 334C controller cabinet, the front of the vehicle began to deform and the cabinet began to shear away from its anchor bolts. The vehicle came to a complete stop on top of the pedestal where the cabinet had been mounted. The cabinet itself was knocked completely free of its foundation and was thrown approximately 3 m (9.8 ft) forward where it came to rest in front of the stopped vehicle. The brakes were applied 0.44 seconds after the initial impact as indicated by the data recorder's event channel.

Figure 2-7 through Figure 2-12 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 611 are shown as Figure 2-13 on the data summary sheet on page 13.

Figure 2-7. Test Vehicle Prior to Test 611

Figure 2-8. Test Vehicle and Article Prior to Test 611

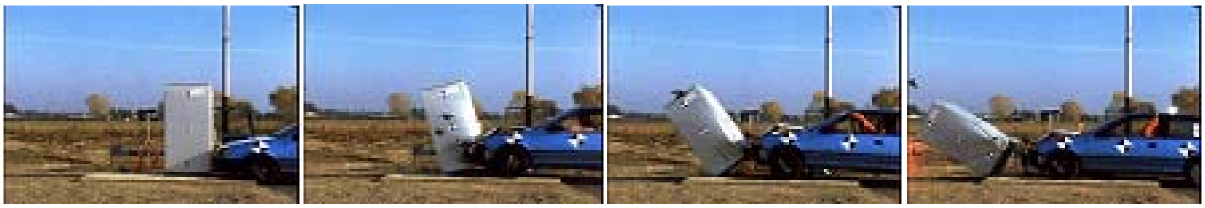
Figure 2-9. Test Vehicle After Test 611

Figure 2-10. Test Article Prior to Test 611

Figure 2-11. Controller Cabinet Test Article After Test 611

Figure 2-12. Controller Cabinet Test Article and Vehicle After Test 611

2.2.1.2. Test 611 Data Summary Sheet



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t = 0.000 sec | t = 0.200 sec | t = 0.400 sec | t = 0.600 sec

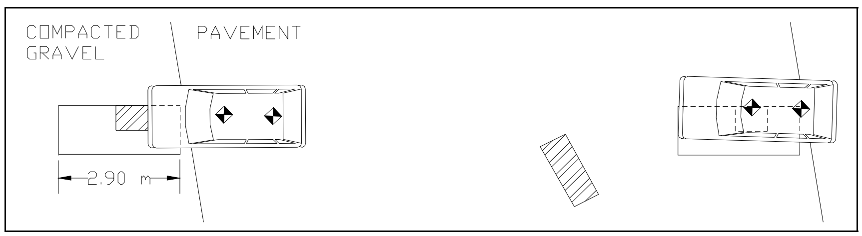


Figure 2-13. Impact Sequence and Diagram for Test 611

General Information	
Testing Agency	California DOT
Test Number	611
Test Date	November 20, 2002
Test Article	
Type	Type 334C Electronic Controller Cabinet
Tested Mass	125 kg (276 lb)
Tested Height	1.7 m (5.5 ft)
Test Vehicle	
Model	1994 Geo Metro, 2-door
Inertial Mass	800 kg (1764 lbs)
Impact Conditions	
Impact Velocity	35.3 km/h (21.9 mph)
Impact Angle	0°
Exit Conditions	
Exit Velocity	7.39 km/h (4.59 mph)
Impact Angle	2.59°

Test Dummy	
Type	Hybrid III
Weight	74.8 kg (165 lbs)
Restraint	Lap and shoulder belt
Position	Front left
Test Data	
Occupant Impact Velocity	
Long.	7.21 m/s (23.6 ft/s)
Lat.	-0.30 m/s (-0.98 ft/s)
Ridedown Acceleration	
Long.	-2.36 g
Lat.	-2.91 g
Vehicle Exterior	
VDS[(2)]	FC-4
CDC[(3)]	12FCEW2
Vehicle Interior	
OCDI[(1)]	FS0000000

Article Damage: The electronic controller cabinet could not be re-used. The concrete foundation and anchor bolt system would require general repair.

2.2.1.3. Test 611 Vehicle Damage

The entire front of the vehicle was moderately damaged in the initial impact with the 334C controller cabinet and would not have been operable afterwards. The hood, bumper, headlamp area, grille, both front fenders, and suspension components were all affected. The radiator was ruptured and pushed back far enough that it made contact with the exhaust manifold of the transverse-mounted engine.

The longitudinal occupant impact velocity was 7.21 m/s (23.6 ft/s), which was above the allowable maximum of 5 m/s (16.4 ft/s) specified in NCHRP Report 350. The longitudinal and lateral occupant ridedown accelerations, –2.36 g and –2.91 g, respectively, were below the allowed maximum of 20 g. Test results are summarized in Table 2-2 on page 50.

2.2.1.4. Test 611 Article Damage

The damage to the test article was extensive and would require complete replacement of the cabinet. It is not known if the electronic components installed in the rack inside the cabinet would have been serviceable after the impact because non-operating units were used to simulate the weight and placement of functioning units. The cast-in-place anchor bolts were bent and damaged enough that their re-use would be questionable. There was significant spalling of the concrete pedestal on the down-stream side as a consequence of the anchor bolts being pushed rearward. The bottom of the cabinet was torn where the anchor bolts pulled through.

2.2.2. Test 612 - 334C Controller Cabinet (100 km/h)

2.2.2.1. Description

Test 612 was not run due to the unsatisfactory performance during the low-speed test of the 334C electronic controller cabinet (Test 611).

2.2.3. Test 613 - Rotatable Chain Control Sign (35 km/h)

2.2.3.1. Test 613 Impact Description

The intended impact angle of approximately 0° and the impact location on the front center of the vehicle were set by the placement of the guide rail. Film analysis indicated that the actual impact angle was 0°. The impact location was 91 mm (3.6 in) to the right of center on the front of test vehicle. The impact speed of 35.4 km/h (22.0 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. As the vehicle impacted the chain control sign, the front of the vehicle began to deform slightly and the slip base commenced to activate. The chain control sign assembly rotated back about a point near its vertical center of mass and the bottom sign made contact with the hood and windshield of the test vehicle. The test article continued to slide up the face of the windshield until it was resting horizontally on the roof of the vehicle. It then slid off the roof on the driver's side, coming to rest on the ground as the vehicle continued on past it. The brakes were applied 1.94 seconds after the initial impact as indicated by the data recorder's event channel. The vehicle came to a stop near an earthen berm approximately 18-m (59.0 ft) downstream from the impact point. Figure 2-14 through Figure 2-19 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 613 are shown as

Figure 2-20 on the data summary sheet on page 18.

Figure 2-14. Test Vehicle Prior to Test 613

Figure 2-15. Test Vehicle and Test Article Prior to Test 613

Figure 2-16. Test Vehicle 613 During the Test

Figure 2-17. Test Vehicle After Test 613

Figure 2-18. Test Article After Test 613

Figure 2-19. Breakaway Base From Test Article After Test 613

2.2.3.2. Test 613 Data Summary Sheet

t = 0.000 sec | t = 0.150 sec | t = 0.300 sec | t = 0.450 sec

t = 0.000 sec | t = 0.150 sec | t = 0.300 sec | t = 0.450 sec

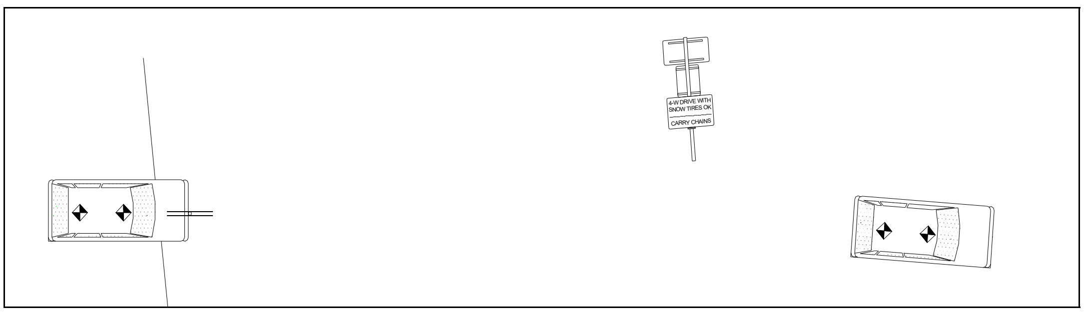


Figure 2-20. Impact Sequence and Diagram for Test 613

General Information	
Testing Agency	California DOT
Test Number	613
Test Date	November 20, 2002
Test Article	
Type	Chain control sign in the "summer" configuration
Height	3.3 m (10.9 ft)
Test Vehicle	
Model	1994 Geo Metro, 2-door
Inertial Mass	799 kg (1761 lbs)
Impact Conditions	
Impact Velocity	35.4 km/h (22.0 mph)
Impact Angle	0°
Exit Conditions	
Exit Velocity	29.9 km/h (18.6 mph)
Impact Angle	0.22°

Test Dummy	
Type	Hybrid III
Weight	74.8 kg (165 lbs)
Restraint	Lap and shoulder belt
Position	Front left
Test Data	
Occupant Impact Velocity	
Long.	1.80 m/s (5.90 ft/s)
Lat.	0.13 m/s (0.43 ft/s)
Ridedown Acceleration	
Long.	-0.67 g
Lat.	-0.56 g
Vehicle Exterior	
VDS[2]	FC-1
CDC[3]	12FCAN1
Vehicle Interior	
OCDI[1]	FS0000000
ASI	0.20

Article Damage: The complete sign assembly could be re-mounted in the damaged condition and would remain usable until repair could be scheduled.

2.2.3.3. Test 613 Vehicle Damage

The entire front of the vehicle was moderately damaged in the initial impact with the chain control sign and was drivable but not legally operable afterwards. The hood, bumper, and grille were all affected. The bottom signs penetrated the windshield approximately 50-75 mm (2.0-3.0 in) (Figure 2-21). The roof's maximum deformation was approximately 50 mm (2.0 in). The windshield penetration and roof deformation were minor enough that there would have been no significant risk of injury to vehicle occupants.

Figure 2-21. Chain Control Sign Penetration into Windshield (Test 613)

The longitudinal occupant impact velocity was 1.80 m/s (5.9 ft/s), which was below the allowable maximum of 5 m/s (16.4 ft/s) specified in NCHRP Report 350. The longitudinal and lateral occupant ridedown accelerations, –0.67 *g* and 0.56 *g*, respectively, were below the allowed maximum of 20 *g*. Test results are summarized in Table 2-3 on page 51.

2.2.3.4. Test 613 Article Damage

Although the sign panels were somewhat deformed, the entire post assembly could be reset on the undisturbed base and remain functional until it is deemed necessary to either replace or repair the panels.

2.2.4. Test 614 - Rotatable Chain Control Sign (100 km/h)

2.2.4.1. Test 614 Impact Description

The intended impact angle and location were set at 0° centered on the front of the vehicle by placement of the guide rail. Film analysis indicated that the actual impact angle was 0° and the impact location was 10 mm (0.39 in) to the right of center. The impact speed of 100.6 km/h (62.5 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. As the vehicle contacted the chain control signpost, the front of the vehicle began to deform slightly and the slip base commenced to activate. The sign assembly rotated back about a point near its vertical center of mass as the vehicle continued its forward progress under the assembly. The vehicle had passed almost completely under the sign assembly when the upper sign struck and shattered the rear window of the vehicle. The brakes were applied 0.58 seconds after the initial impact as indicated by the data recorder's event channel. The vehicle came to rest in an open area approximately 40-m (131.2 ft) downstream from the impact point. Figure 2-22 through Figure 2-29 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 614 are shown as

Figure 2-30 on the data summary sheet on page 25.

Figure 2-22. Test Vehicle Prior to Test 614

Figure 2-23. Test Vehicle During Test 614

Figure 2-24. Test Vehicle During Test 614

Figure 2-25. Test Vehicle After Test 614

Figure 2-26. Rear of Test Vehicle After Test 614

Figure 2-27. Lower Section of Hatchback of Test Vehicle After Test 614

Figure 2-28. Test Article Before Test 614

Figure 2-29. Test Article After Test 614

2.2.4.2. Test 614 Data Summary Sheet

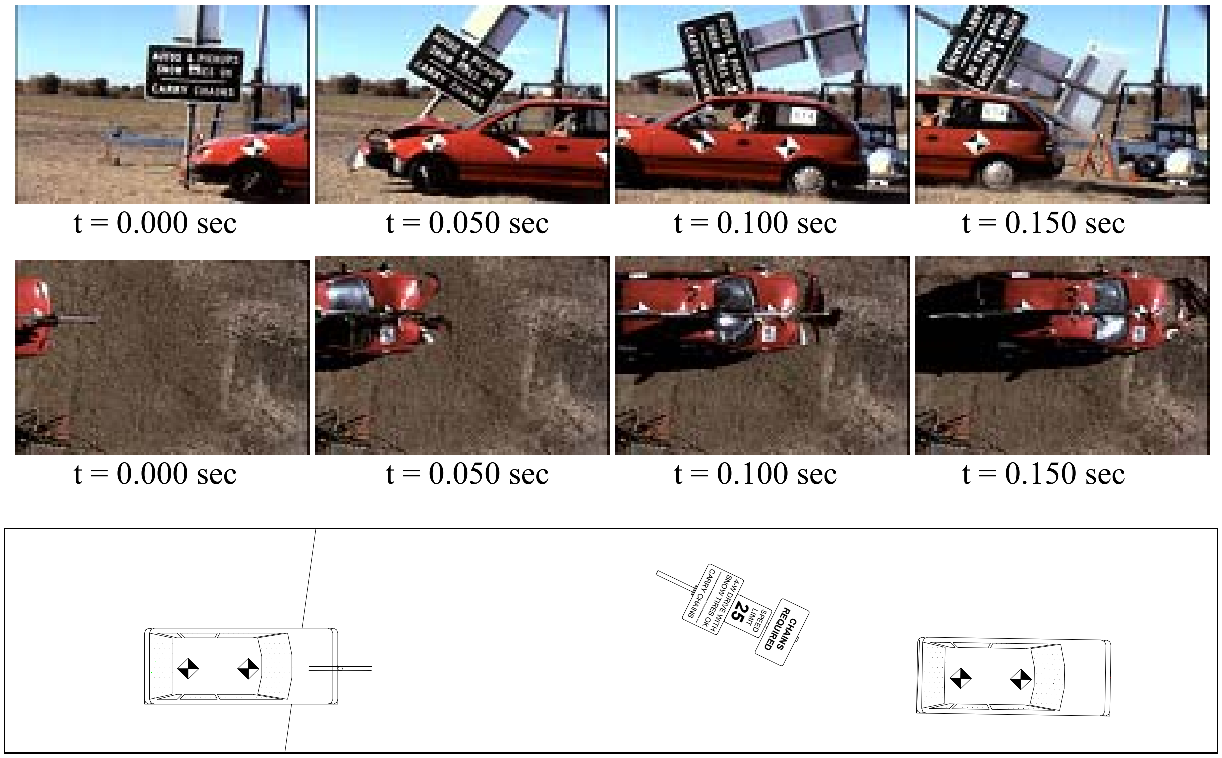


Figure 2-30. Impact Sequence and Diagram for Test 614

General Information	
Testing Agency	California DOT
Test Number	614
Test Date	November 26, 2002
Test Article	
Type	Chain control sign in the "summer" configuration
Height	3.3 m (10.9 ft)
Test Vehicle	
Model	1994 Geo Metro, 2-door
Inertial Mass	800 kg (1764 lbs)
Impact Conditions	
Impact Velocity	100.6 km/h (62.5 mph)
Impact Angle	0°
Exit Conditions	
Exit Velocity	99.4 km/h (61.8 mph)
Impact Angle	0.78°

Test Dummy	
Type	Hybrid III
Weight	74.8 kg (165 kg)
Restraint	Lap and shoulder belt
Position	Front left
Test Data	
Occupant Impact Velocity	
Long.	2.70 m/s (8.86 ft/s)
Lat.	0.57 m/s (1.87 ft/s)
Ridedown Acceleration	
Long.	-2.75 g
Lat.	-5.21 g
Vehicle Exterior	
VDS[2]	FC-4
CDC[3]	12FCAW8
Vehicle Interior	
OCDI[1]	FS0000000
ASI	0.56

Article Damage: All signs were slightly damaged but reusable. The steel post and base were not damaged and could be immediately reused.

2.2.4.3. Test 614 Vehicle Damage

The entire front of the vehicle was slightly damaged in the initial impact with the chain control sign and was drivable, but not legally operable afterwards. The hood, bumper, and grille were all affected. The bottom signs did not penetrated through the windshield, but deformed it inward approximately 50-75 mm (2.0-3.0 in) (Figure 2-31). The roof's maximum deformation was approximately 38 mm (1.5 in) at the front-center. The rear window was penetrated near the bottom-center approximately 20 mm (0.79 in) by the top sign panel (Figure 2-32). The roof deformation and the sign penetration of the windshield and rear window were minor and would have presented no significant risk to vehicle occupants.

Figure 2-31. Chain Control Sign Penetration into Windshield – Test 614

Figure 2-32. Chain Control Sign Penetration into Rear Window – Test 614

The longitudinal occupant impact velocity was 2.70 m/s (8.86 ft/s), which was below the allowable maximum of 5 m/s (16.4 ft/s) specified in NCHRP Report 350. The longitudinal and lateral occupant ridedown accelerations, –2.75 *g* and 5.21 *g*, respectively, were below the allowed maximum of 20 *g*. Test results are summarized in Table 2-4 on page 52.

2.2.4.4. Test 614 Article Damage

Although the sign panels were somewhat deformed, the entire post assembly could be reset on the undisturbed base and remain functional until it is deemed necessary to either replace or repair the panels.

2.2.5. Test 618 - Warning Sign with Beacons (35 km/h)

2.2.5.1. Test 618 Impact Description

The intended impact angle and location was set at 0° centered on the front of the vehicle by placement of the guide rail. Film analysis indicated that the actual impact angle was 0° and the impact location was 126 mm (5.0 in) to the right of center. The impact speed of 38.2 km/h (23.7 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. As the vehicle contacted the sign assembly, the front of the vehicle began to deform and the slip base commenced to function as designed. The sign assembly rotated back about a point near its vertical center of mass and the sign standard made contact along the entire roof of the test vehicle. As the test vehicle continued along its path, the sign assembly continued to rotate until its top impacted the ground behind the vehicle. There was no further contact between the test article and the test vehicle. The data recorder's event channel does not indicate that the brakes were applied within 5.5 seconds of impact (maximum record time). The test article destroyed the brake flash bulb immediately after impact, so the brake time could not be analyzed via film. The vehicle came to rest near an earthen berm approximately 20-m (65.6-ft) downstream from the impact point. Figure 2-33 through Figure 2-39 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 618 are shown as Figure 2-40 on the data summary sheet on page 31.

Figure 2-33. Test Vehicle Prior to Test 618

Figure 2-34. Test Article Prior to Test 618

Figure 2-35. Test Vehicle and Article Prior to Test 618

Figure 2-36. Test Vehicle During Test 618

Figure 2-37. Test Vehicle After Test 618

Figure 2-38. Close-Up View of Type 30/31 Slip-Base Used in Test 618
(Arrow Indicates Direction of Vehicular Impact)

Figure 2-39. Test Article After Test 618

2.2.5.2. Test 618 Data Summary Sheet

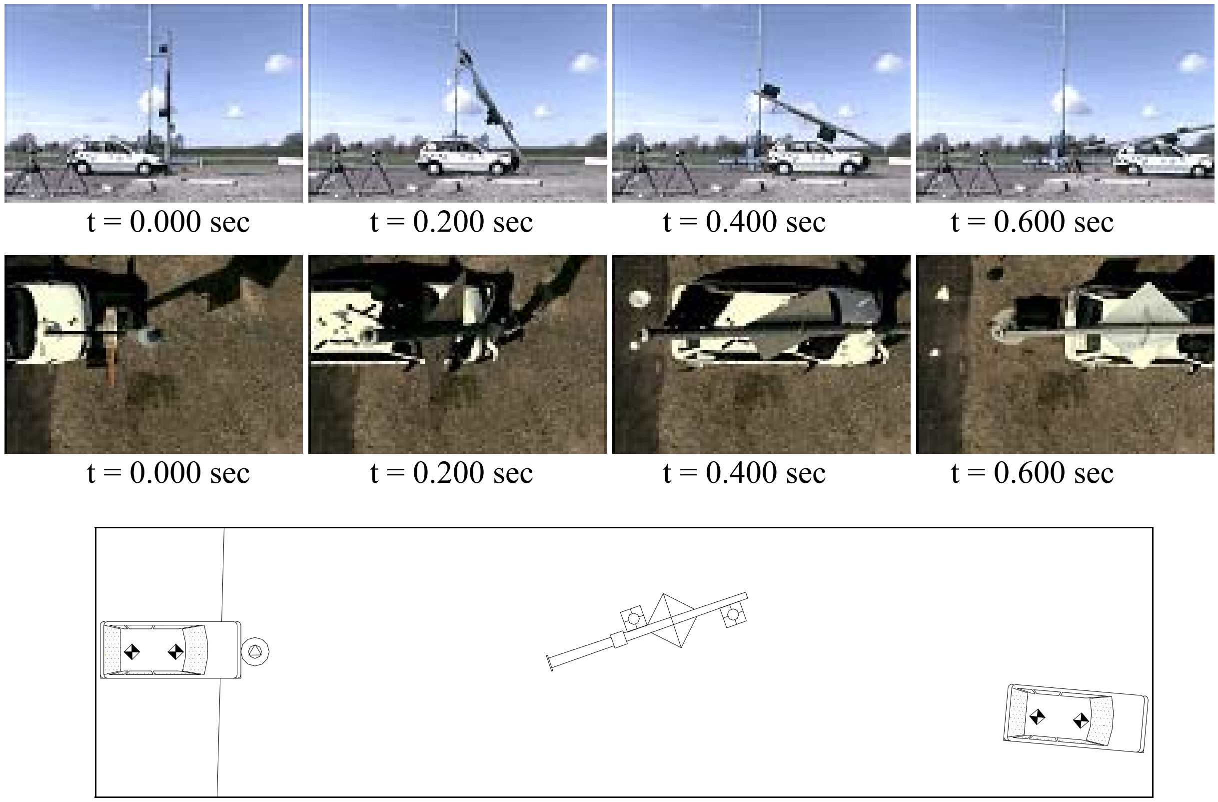


Figure 2-40. Impact Sequence and Diagram for Test 618

General Information	
Testing Agency	California DOT
Test Number	618
Test Date	November 26, 2002
Test Article	
Type	Warning sign (W-41) with flashing beacons
Post	Shorted version of the Type 15-SB
Height	5533 mm (219 in), measured with respect to the slip plane
CG	2521 mm (99.25 in), measured with respect to the slip plane
Test Vehicle	
Model	1994 Geo Metro, 4-door
Inertial Mass	845 kg (1863 lbs)
Impact Conditions	
Impact Velocity	38.2 km/h (23.7 mph)
Impact Angle	0°

Exit Conditions	
Exit Velocity	29.9 km/h (18.6 mph)
Impact Angle	2.49°
Test Dummy	
Type	Hybrid III
Weight	74.8 kg (165 lbs)
Restraint	Lap and shoulder belt
Position	Front left
Test Data	
Occupant Impact Velocity	
Long.	2.38 m/s (7.81 ft/s)
Lat.	0.48 m/s (1.57 ft/s)
Ridedown Acceleration	
Long.	-1.09 g
Lat.	2.04 g
Vehicle Exterior	
VDS[2]	FC-3
CDC[3]	12FCAW8
Vehicle Interior	
OCDI[1]	FS0000000
ASI	0.36

Article Damage: The assembly could be field-repaired by placing new components on the undamaged pole and re-erecting it on site.

2.2.5.3. Test 618 Vehicle Damage

The entire front of the vehicle was moderately damaged in the initial impact with the test article. The vehicle was drivable, but not legally operable after the impact. The hood, bumper, and grille were all affected. The front windshield was damaged along the roofline but was not penetrated. The greatest roof deformation was centered at the top of the windshield and was found to be approximately 90 mm (3.5 in). The extent of the deformation inside the passenger compartment is evident by comparing Figure 2-41 with Figure 2-42. Because of the location of this deformation, there would have been no significant risk to vehicle occupants.

The longitudinal occupant impact velocity was 2.38 m/s (7.80 ft/s), which was below the allowable maximum of 5 m/s (16.4 ft/s) specified in NCHRP Report 350. The longitudinal and lateral occupant ridedown accelerations, –1.09 *g* and 2.04 *g*, respectively, were below the allowed maximum of 20 *g*. Test results are summarized in Table 2-5 on page 53.

Figure 2-41. Interior and Roof of Test Vehicle Prior to Test 618

Figure 2-42. Vehicle Roof After Test 618

2.2.5.4. Test 618 Article Damage

The sign panels were somewhat deformed, the flashing beacons were damaged beyond repair, and the light fixture had broken away from the pole. The entire post assembly could be repaired in the field and reset on the undisturbed base or removed to a shop location for repair.

2.2.6. Test 616 - Warning Sign with Beacons (100 km/h)

2.2.6.1. Test 616 Impact Description

The intended impact angle and location was set at 0° centered on the front of the vehicle by placement of the guide rail. Film analysis indicated that the actual impact angle was 0° and the impact location was 109 mm (4.3 in) to the right of center. The impact speed of 102.7 km/h (63.8 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. As the vehicle contacted the sign standard, the front of the vehicle began to deform and the slip base commenced to function as designed. The sign assembly rotated back about a point near its vertical center of mass and completely cleared the rest of the vehicle. While the test vehicle continued along its path, the sign assembly struck the ground and came to rest behind the vehicle. No further contact took place between the test article and the test vehicle. The brakes were applied 1.19 seconds after the initial impact as indicated by data recorder's event channel. The vehicle came to rest in an open area approximately 140-m (456.3-ft) downstream from the impact point. Figure 2-43 through Figure 2-51 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 616 are shown as Figure 2-52 on the data summary sheet on page 38.

Figure 2-43. Test Vehicle for Test 616

Figure 2-44. Test Vehicle and Article Prior to Test 616

Figure 2-45. Test Article Prior to Test 616

Figure 2-46. Test Vehicle During Test 616

Figure 2-47. Test Vehicle During Test 616

Figure 2-48. Test Vehicle During Test 616

Figure 2-49. Test Vehicle During Test 616

Figure 2-50. Test Vehicle After Test 616

Figure 2-51. Test Article After Test 616

2.2.6.2. Test 616 Data Summary Sheet

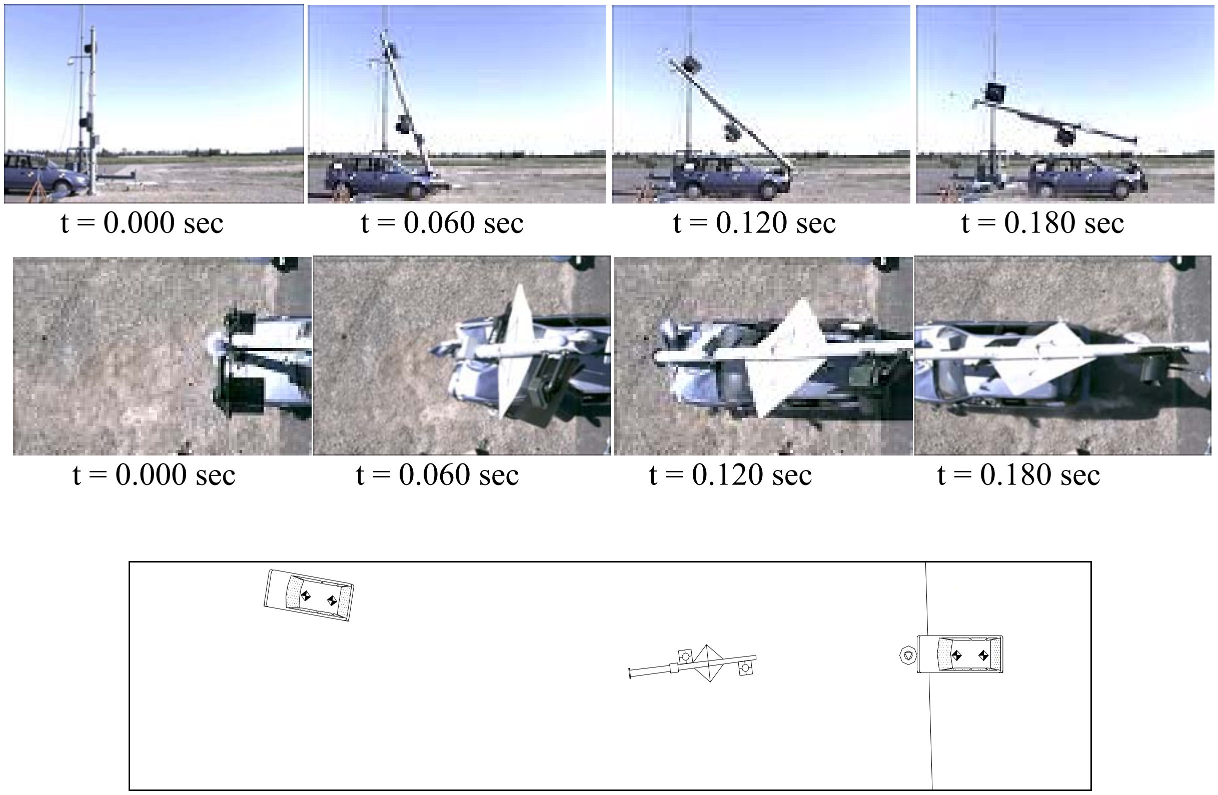


Figure 2-52. Impact Sequence and Diagram for Test 616

General Information	
Testing Agency	California DOT
Test Number	616
Test Date	March 5, 2003
Test Article	
Type	Warning sign (W-41) with flashing beacons
Post	Shorted version of the Type 15-SB
Height	5533 mm (219 in), measured with respect to the slip plane
CG	2521 mm (99.25 in), measured with respect to the slip plane
Test Vehicle	
Model	1989 Geo Metro, 4-door
Inertial Mass	800 kg (1764 lbs)
Impact Conditions	
Impact Velocity	102.7 km/h (63.8 mph)
Impact Angle	0°

Exit Conditions	
Exit Velocity	89.5 km/h (55.6 mph)
Impact Angle	0.97°
Test Dummy	
Type	Hybrid III
Weight	74.8 kg (165 lbs)
Restraint	Lap and shoulder belt
Position	Front left
Test Data	
Occupant Impact Velocity	
Long.	3.47 m/s (11.4 ft/s)
Lat.	-0.27 m/s (0.88 ft/s)
Ridedown Acceleration	
Long.	-3.08 g
Lat.	4.40 g
Vehicle Exterior	
VDS[2]	FC-4
CDC[3]	12FCAW9
Vehicle Interior	
OCDI[1]	FS0000000
ASI	0.85

Article Damage: The assembly could be field-repaired by placing new components on the undamaged pole and re-erecting it on site.

2.2.6.3. Test 616 Vehicle Damage

The entire front of the vehicle was significantly damaged in the initial impact with the warning sign with flashing beacons and was inoperable afterwards. The hood, bumper, headlamp area, grille, both front fenders, and suspension components were all affected. The test article did not penetrate through the windshield or roof. The radiator was ruptured and pushed back far enough that it made contact with the exhaust manifold of the transverse-mounted engine.

The longitudinal occupant impact velocity was 3.47 m/s (11.4 ft/s), which was below the allowable maximum of 5 m/s (16.4 ft/s) specified in NCHRP Report 350. The longitudinal and lateral occupant ridedown accelerations, –3.08 *g* and 4.40 *g*, respectively, were below the allowed 20 *g* maximum. Test results are summarized in Table 2-6 on page 54.

2.2.6.4. Test 616 Article Damage

The sign panels were somewhat deformed, the flashing beacons were damaged beyond repair, and the light fixture had broken away from the pole. The entire post assembly could be repaired in the field and reset on the undisturbed base or removed to a shop location for repair.

2.2.7. Test 617 - Pole Top-Mounted Luminaire (35 km/h)

2.2.7.1. Test 617 Impact Description

The intended impact angle and location was set at 0° centered on the front of the vehicle by placement of the guide rail. Film analysis indicated that the actual impact angle was 0° and the impact location was 132 mm (5.2 in) to the right of center. The impact speed of 38.4 km/h (23.9 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. As the vehicle contacted the sign assembly, the front of the vehicle began to deform and the slip base commenced to function as designed. The light standard rotated back about a point near its vertical center of mass and the standard made contact along the entire roof of the test vehicle. The vehicle continued along its path as the test article rotated until the pole top impacted the ground behind the vehicle. This impact caused the pole to flex to the point that the standard base lost contact with the roof of the vehicle. As the flexure introduced into the light standard suddenly relaxed, the heavy steel plate that makes up the base made sharp contact with the roof of the vehicle just above the front windshield. This secondary impact caused significant damage to the passenger compartment and caused unacceptable levels of roof deformation. The brakes were applied 3.89 seconds after the initial impact as indicated by data recorder's event channel. The vehicle came to rest near an earthen berm approximately 20-m (65.6-ft) downstream from the impact point.

Figure 2-53 through Figure 2-65 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 617 are shown as Figure 2-63 on the data summary sheet on page 46.

Figure 2-53. Test Vehicle for Test 617

Figure 2-54. Test Article Prior to Test 617

Figure 2-55. Test Vehicle and Article Prior to Test 617

Figure 2-56. Test Vehicle During Test 617

Figure 2-57. Test Vehicle During Test 617

Figure 2-58. Test Vehicle During Test 617

Figure 2-59. Test Vehicle During Test 617

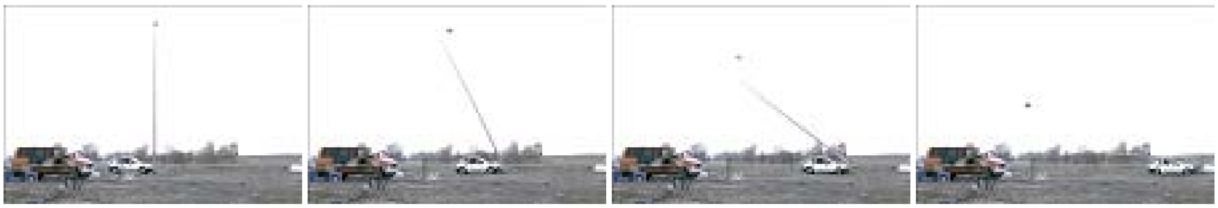
Figure 2-60. Test Vehicle During Test 617

Figure 2-61. Test Vehicle During Test 617

Figure 2-62. Test Vehicle After Test 617

2.2.7.2. Test 617 Data Summary Sheet

t = 0.000 sec | t = 0.100 sec | t = 0.200 sec | t = 0.300 sec



t = 0.000 sec | t = 0.200 sec | t = 0.400 sec | t = 0.600 sec

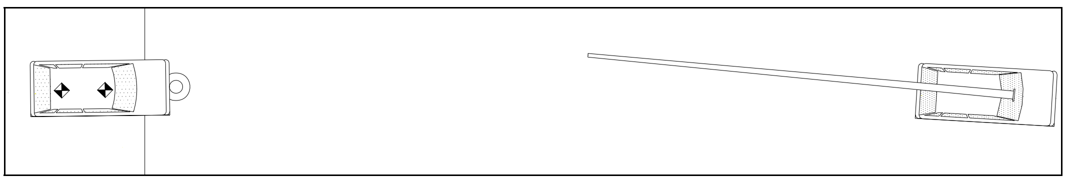


Figure 2-63. Impact Sequence and Diagram for Test 617

General Information	
Testing Agency	California DOT
Test Number	617
Test Date	December 11, 2002
Test Article	
Type	Pole Top-Mounted Lighting
Height	12.2 m (40 ft)
CG	4.46 m (14.63 ft), measured with respect to the slip plane
Test Vehicle	
Model	1990 Geo Metro, 2-door
Inertial Mass	798 kg (1759 lbs)
Impact Conditions	
Impact Velocity	38.5 km/h (23.9 mph)
Impact Angle	0°
Exit Conditions	
Exit Velocity	23.9 km/h (14.8 mph)
Impact Angle	0.91°

Test Dummy	
Type Hybrid III	
Weight	74.8 kg (165 lbs)
Restraint	Lap and shoulder belt
Position	Front left
Test Data	
Occupant Impact Velocity	
Long.	2.47 m/s (8.10 ft/s)
Lat.	0.51 m/s (1.67 ft/s)
Ridedown Acceleration	
Long.	-1.32 g
Lat.	-0.79 g
Vehicle Exterior	
VDS[2]	FC-4
CDC[3]	12FCAW8
Vehicle Interior	
OCDI[1]	FS0100000
ASI	0.35

Article Damage: The assembly could be field-repaired by placing new components on the undamaged pole and re-erecting it on site.

2.2.7.3. Test 617 Vehicle Damage

The entire front of the vehicle was moderately damaged in the initial impact with the light standard and the vehicle was inoperable afterwards. The roof, hood, bumper, headlamp area, grille, both front fenders, and suspension components were all affected. The entire length and width of the roof was deformed by the secondary impact and presented risk to occupants. The roof's maximum deformation was approximately 64 mm (2.5 in) and was centered at the top of the windshield. The radiator was ruptured and pushed back far enough that it made contact with the exhaust manifold of the transverse-mounted engine.

The longitudinal occupant impact velocity was 2.47 m/s (8.10 ft/s), which was below the allowable maximum of 5 m/s (16.4 ft/s) specified in NCHRP Report 350. The longitudinal and lateral occupant ridedown accelerations, –1.32 *g* and –0.79 *g*, respectively, were below the allowed maximum of 20 *g*. Test results are summarized in Table 2-7 on page 55.

Figure 2-64. Damage to the Front Roof

Figure 2-65. Damage to Rear Roof

2.2.7.4. Test 617 Article Damage

The light standard was not damaged and could be reused. The pole-top mounted luminaire was completely destroyed. It could be field-replaced and the entire assembly could be reset on the undisturbed base.

2.2.8. Test 615

2.2.8.1. Description

Test 615 was not run due to the unsatisfactory performance during the low-speed test of the pole top-mounted luminaire test article (Test 617).

2.3. Discussion of Test Results - Crash Tests

2.3.1. General - Evaluation Methods (Tests 611 through 618)

NCHRP Report 350 stipulates that crash test performance is assessed according to three evaluation factors: 1) Structural Adequacy, 2) Occupant Risk, and 3) Vehicle Trajectory. These evaluation factors are further defined by evaluation criteria and are shown for each test designation in Table 5.1 of NCHRP Report 350. The NCHRP Report 350 test designation of all low-speed tests is 3-60 (820C vehicle) and the high-speed designation is 3-61 (820C vehicle).

2.3.2. Structural Adequacy

The structural adequacy for the chain control sign and the warning sign with flashing beacon was acceptable in both the low-speed and the high-speed crash tests. The pole-top luminaire test article did break away as intended. The electronic controller cabinet did not break away in a controlled manner, though it did ultimately yield through unpredictable tearing and shearing of the sheet aluminum around the base of the cabinet. A detailed assessment summary of structural adequacy is shown in Table 2-2 through Table 2-7.

2.3.3. Occupant Risk

The chain control sign and the warning sign with flashing beacon did not show potential for detached elements, fragments, or other debris that would pose a risk to occupants or others.

The occupant risk for the electronic controller cabinet was unacceptable due to excessive occupant impact velocity and occupant ridedown accelerations. The pole-top luminaire test articles posed unacceptable occupant risk due to excessive passenger compartment roof deformation.

Please refer to Table 2-2 through Table 2-7 for a detailed assessment summary of occupant risk.

2.3.4. Vehicle Trajectory

The post-impact vehicle trajectory was acceptable for all tests in that the vehicle did not intrude into adjacent traffic lanes. All test vehicles with the exception of Test 611 did have a trajectory that carried them beyond the test article, which is acceptable with NCHRP Report 350 criteria outlined in Table 5.1. The detailed assessment summary of vehicle trajectories may be seen in Table 2-2 through Table 2-7. Vehicle trajectories and speeds are summarized in Table 2-8.

Table 2-2. Test 611 Assessment Summary

Test No. 611 – Type 334C Electronic control cabinet with 820C
Date November 20, 2002
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The Test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The article broke away in an unpredictable manner with tearing and yielding of the cabinet base.	Fail
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was moderate occupant compartment deformation.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The observed levels of roll, pitch, and yaw were deemed acceptable.	Pass
G. Occupant impact velocities should satisfy the following limits: Preferred Maximum Longitudinal 3 m/s 5 m/s	Long. Occ. Impact Vel. = 7.21m/s	Fail
H. Occupant ridedown accelerations should satisfy the following limits (G's): Preferred Maximum Longitudinal and Lateral 15 20	Long. Occ. Ridedown = -2.36 g Lateral Occ. Ridedown = -2.91 g	Pass Pass
J. (Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, Title 49 of Code of Federal Regulation, Chapter V (10-1-88 Edition). See Section 5.3 for limitations of Hybrid III dummy.		
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle maintained a relatively straight course after impact.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle trajectory did continue behind the test article.	Pass

Table 2-3. Test 613 Assessment Summary

Test No. 613 – Rotatable chain control sign with 820C
Date November 20, 2002
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The Test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The article activated by breaking away.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was minor occupant compartment deformation and penetration of the windshield and rear window by a sign corner. This deformation and penetration would have presented no significant risk of injury to vehicle occupants.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The observed levels of roll, pitch, and yaw were deemed acceptable.	Pass
H. Occupant impact velocities should satisfy the following limits: Preferred / Maximum Longitudinal 3 m/s / 5 m/s	Long. Occ. Impact Vel. = 1.80 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following limits (G's): Preferred / Maximum Longitudinal and Lateral 15 / 20	Long. Occ. Ridedown = -0.67 g Lateral Occ. Ridedown = 0.56 g	Pass Pass
J. (Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, Title 49 of Code of Federal Regulation, Chapter V (10-1-88 Edition). See Section 5.3 for limitations of Hybrid III dummy.		
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle maintained a relatively straight course after impact.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle trajectory did continue behind the test article.	Pass

Table 2-4. Test 614 Assessment Summary

Test No. 614 – Rotatable chain control sign with 820C
Date November 26, 2002
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The Test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The article activated by breaking away.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was minor occupant compartment deformation and penetration of the windshield by a sign corner. This deformation and penetration would have presented no significant risk of injury to vehicle occupants.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The observed levels of roll, pitch, and yaw were deemed acceptable.	Pass
H. Occupant impact velocities should satisfy the following limits: Preferred / Maximum Longitudinal 3 m/s / 5 m/s	Long. Occ. Impact Vel. = 2.70 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following limits (G's): Preferred / Maximum Longitudinal and Lateral 15 / 20	Long. Occ. Ridedown = -2.75 g Lateral Occ. Ridedown = -5.21 g	Pass Pass
J. (Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, Title 49 of Code of Federal Regulation, Chapter V (10-1-88 Edition). See Section 5.3 for limitations of Hybrid III dummy.		
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle maintained a relatively straight course after impact.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle trajectory did continue behind the test article.	Pass

Table 2-5. Test 618 Assessment Summary

Test No. 618 – Warning sign with flashing beacons (35 km/h)
Date February 26, 2003
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The Test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The article activated by breaking away.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was moderate occupant compartment deformation.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The observed levels of roll, pitch, and yaw were deemed acceptable.	Pass
H. Occupant impact velocities should satisfy the following limits: Preferred / Maximum Longitudinal 3 m/s / 5 m/s	Long. Occ. Impact Vel. = 2.38 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following limits (G's): Preferred / Maximum Longitudinal and Lateral 15 / 20	Long. Occ. Ridedown = -1.09 g Lateral Occ. Ridedown = 2.04 g	Pass Pass
J. (Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, Title 49 of Code of Federal Regulation, Chapter V (10-1-88 Edition). See Section 5.3 for limitations of Hybrid III dummy.		
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle maintained a relatively straight course after impact.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle trajectory did continue behind the test article.	Pass

Table 2-6. Test 616 Assessment Summary

Test No. 616 – Warning sign with flashing beacons (100 km/h)
Date March 5, 2003
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The Test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The article activated by breaking away.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was moderate occupant compartment deformation.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The observed levels of roll, pitch, and yaw were deemed acceptable.	Pass
H. Occupant impact velocities should satisfy the following limits: Preferred / Maximum Longitudinal 3 m/s / 5 m/s	Long. Occ. Impact Vel. = 3.47 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following limits (G's): Preferred / Maximum Longitudinal and Lateral 15 / 20	Long. Occ. Ridedown = -3.08 g Lateral Occ. Ridedown = 4.40 g	Pass Pass
J. (Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, Title 49 of Code of Federal Regulation, Chapter V (10-1-88 Edition). See Section 5.3 for limitations of Hybrid III dummy.		
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle maintained a relatively straight course after impact.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle trajectory did continue behind the test article.	Pass

Table 2-7. Test 617 Assessment Summary

Test No. 617 – Pole-top luminaire
Date December 11, 2002
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. The Test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The article activated by breaking away.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was unacceptable occupant compartment deformation.	Fail
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The observed levels of roll, pitch, and yaw were deemed acceptable.	Pass
H. Occupant impact velocities should satisfy the following limits: Preferred / Maximum Longitudinal 3 m/s / 5 m/s	Long. Occ. Impact Vel. = 2.47 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following limits (G's): Preferred / Maximum Longitudinal and Lateral 15 / 20	Long. Occ. Ridedown = -1.32 g Lateral Occ. Ridedown = -0.79 g	Pass Pass
J. (Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, Title 49 of Code of Federal Regulation, Chapter V (10-1-88 Edition). See Section 5.3 for limitations of Hybrid III dummy.		
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle maintained a relatively straight course after impact.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle trajectory did continue behind the test article.	Pass

Table 2-8. Vehicle Trajectories and Speeds

Test Number	**Impact Angle** [deg]	**Impact Speed, V_i** [km/h]	**Exit Speed, V_e** [km/h]	**Speed Change $V_i - V_e$** [km/h]
611	0.0	35.3	7.39	27.91
613	0.0	35.4	29.88	5.52
614	0.0	100.6	99.44	1.16
618	0.0	38.2	29.90	8.3
616	0.0	102.7	89.52	13.18
617	0.0	38.5	23.87	14.63

3. CONCLUSION

Based on the testing of the various roadside hardware devices discussed in this report, the following conclusions can be drawn:

1. The standard 334C electronic control cabinet typically used for applications such as changeable message signs, ramp metering, and vehicle speed acquisition should be considered a fixed object and properly protected as such.
2. The pole top-mounted luminaire as tested in this study should be considered a fixed object and properly protected as such.
3. The rotatable chain control sign proved acceptable based on the current vehicular crash test criteria and may continue to be used on the state's highways.
4. The warning sign with flashing beacon assembly proved acceptable based on the current vehicular crash test criteria and may continue to be used on the state's highways.

4. RECOMMENDATION

Based on the testing discussed in this report, the electronic controller cabinet and the pole top-mounted luminaire assembly should be considered fixed objects. Further placement of these devices in the recovery zone should be avoided and steps should be taken to protect, relocate or remove existing placements as time and resources permit.

The chain control sign and the warning sign with flashing beacons proved acceptable and no corrective action is needed regarding these two devices.

5. IMPLEMENTATION

The Caltrans Division of Traffic Operations will be responsible for creating and distributing a policy memo dictating the appropriate placement of any future installations of either the electronic controller cabinet or the pole-top mounted luminaire. This memo will also address procedures for protecting, relocating or removing existing devices.

6. REFERENCES

1. "Recommended Procedures for the Safety Performance Evaluation of Highway Features", Transportation Research Board, National Cooperative Highway Research Program Report 350, 1993.

2. "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project, National Safety Council, 1968.

3. "Collision Deformation Classification" - SAE J224 Mar80, SAE Recommended Practices, 1980.

7. APPENDICES

7.1. Test Vehicle Equipment

The test vehicles were modified as follows for the crash tests:

- The gas tanks on the test vehicles were disconnected from the fuel supply line and drained. A 12-liter safety gas tank was installed in the rear cargo area and connected to the fuel supply line. The stock fuel tanks had dry ice or gaseous CO_2 added to purge fuel vapors.
- One 12-volt, deep-cycle, gel cell motorcycle storage battery was mounted in the vehicle. The battery operated the solenoid-valve braking/accelerator system, rate gyros, and the electronic control box. A second 12-volt, deep-cycle, gel cell battery powered the transient data recorder.
- A 4800-kPa (700-psi) CO_2 system, actuated by a solenoid valve, controlled remote braking after impact and emergency braking if necessary. This system included a pneumatic ram that was attached to the brake pedal. The operating pressure for the ram was adjusted through a pressure regulator during a series of trial runs prior to the actual test. Adjustments were made to assure the shortest stopping distance without locking up the wheels. When activated, the brakes could be applied in less than 100 milliseconds.
- The remote brakes were controlled via a radio link transmitter at a console trailer. When the brakes were applied by remote control from the console trailer, the ignition was automatically rendered inoperable by removing power to the coil.
- For all self-propelled vehicle tests an accelerator switch was located on the rear of the vehicle. The switch opened an electric solenoid, which in turn released compressed CO_2 from a reservoir into a pneumatic ram that had been attached to the accelerator pedal. The CO_2 pressure for the accelerator ram was regulated to the same pressure of the remote braking system with a valve to adjust CO_2 flow rate.
- For all self-propelled vehicle tests a speed control device, connected in-line with the primary winding of the coil, was used to regulate the speed of the test vehicle based on the signal from a speed sensor output from the vehicle transmission. This device was calibrated prior to all tests by conducting a series of trial runs through a speed trap comprising two tape switches set a specified distance apart and a digital timer.
- For all self-propelled vehicle tests a micro switch was mounted below the front bumper and connected to the ignition system. A trip plate on the ground near the impact point triggered the switch when the car passed over it. The switch would open the ignition circuit and shut off the vehicle's engine prior to impact.

Table 7-1 through Table 7-6 gives specific information regarding vehicle dimensions and weights for Tests 611 through 618.

Table 7-1. Test 611 – Electronic Control Cabinet – 35 km/h - Blue

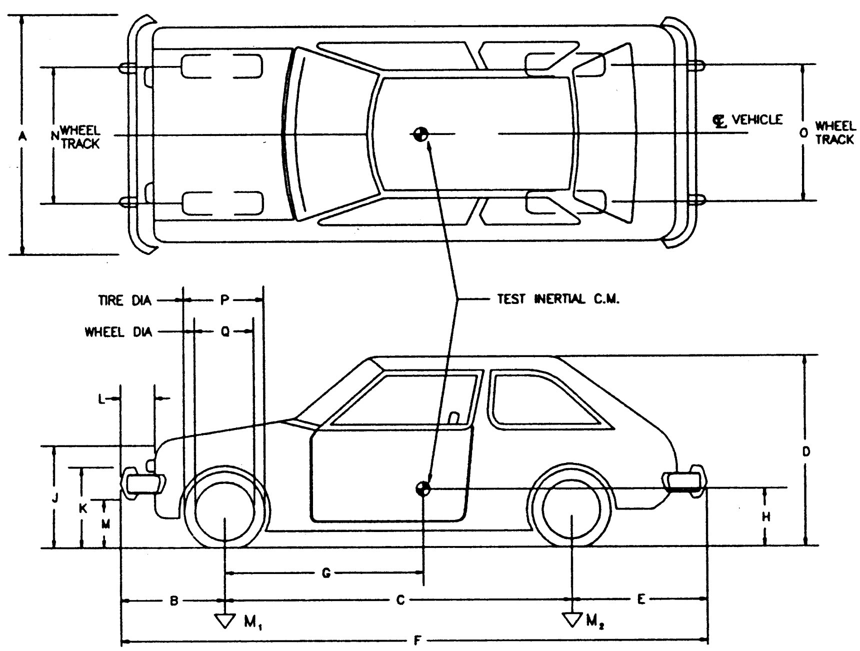
DATE: 20 NOV 2002 **TEST NO:** 611 **VIN NO:** 2C1MR2466R6738274 **MAKE:** Geo

MODEL: Metro **YEAR:** 1994 **ODOMETER:** 137,509 miles **TIRE SIZE:** 155R12

TIRE INFLATION PRESSURE: **LF** 32 **RF** 32 **LR** 32 **RR** 32

MASS DISTRIBUTION (kg) **LF** ____ **RF** ____ **LR** ____ **RR** ____

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: Side-swipe along driver's door – documented with pictures. Front bumper was pushed rearward 19mm from a previous minor impact.



ENGINE TYPE: 3 cylinder

ENGINE: 1000 cc

TRANSMISSION TYPE :

_AUTO

X _MANUAL

OPTIONAL EQUIPMENT:

Air conditioning

DUMMY DATA:

TYPE: HYBRID III 50th %

MASS: 75 kg

SEAT POSITION: LEFT FRONT

GEOMETRY (mm)

A	1510	D	1330	G	901	K	520	N	1360	Q	330
B	750	E	685	H	not measured	L	115	O	1335		
C	2275	F	3710	J	680	M	390	P	540		

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	460.8	483.0	483.0
M2	291.6	317.0	317.0
MT	752.4	800.0	800.0

Table 7-2. Test 613 – Chain Control Sign – 35 km/h - Grey

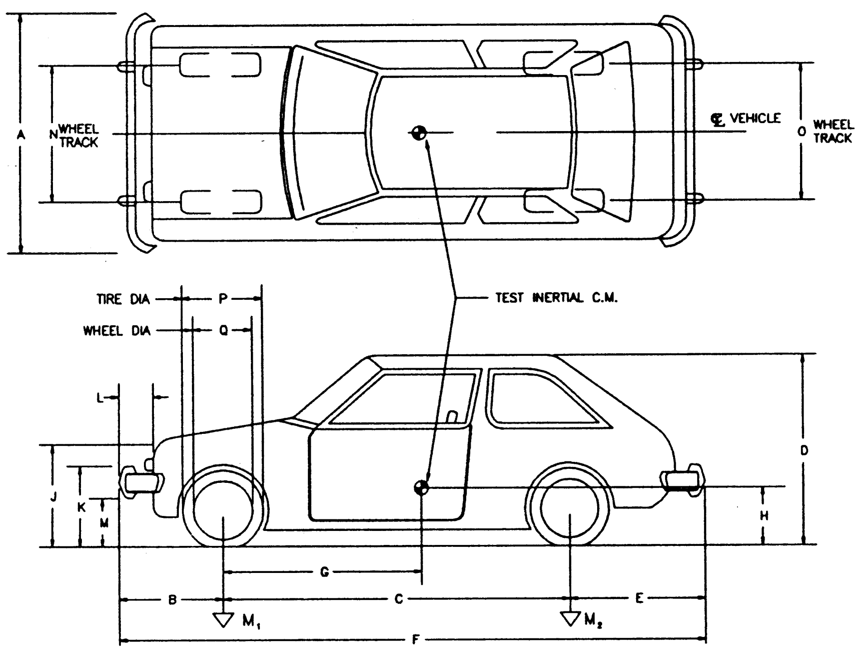
DATE: 19 NOV 2002 **TEST NO:** 613 **VIN NO:** 2C1MR2468R6747557 **MAKE:** Geo

MODEL: Metro **YEAR:** 1994 **ODOMETER:** 144,557 mph **TIRE SIZE:** 155R12

TIRE INFLATION PRESSURE: **LF** 32 **RF** 32 **LR** 32 **RR** 32

MASS DISTRIBUTION (kg) **LF** 221.5 **RF** 217.2 **LR** 146.5 **RR** 139.7

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: small dent on hood – front and centered



ENGINE TYPE: 3 cylinder

ENGINE: 1000 cc

TRANSMISSION TYPE :

__AUTO

X

__MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: HYBRID III 50th %

MASS: 75 kg

SEAT POSITION: LEFT FRONT

GEOMETRY (mm)

A 1520	**D** 1330	**G** 945	**K** 510	**N** 1360	**Q** 330
B 760	**E** 690	**H** not measured	**L** 110	**O** 1310	
C 2260	**F** 3710	**J** 670	**M** 380	**P** 540	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	438.7	465.0	465.0
M2	286.2	334.0	334.0
MT	724.9	799.0	799.0

Table 7-3. Test 614 – Chain Control Sign – 100 km/h - Red

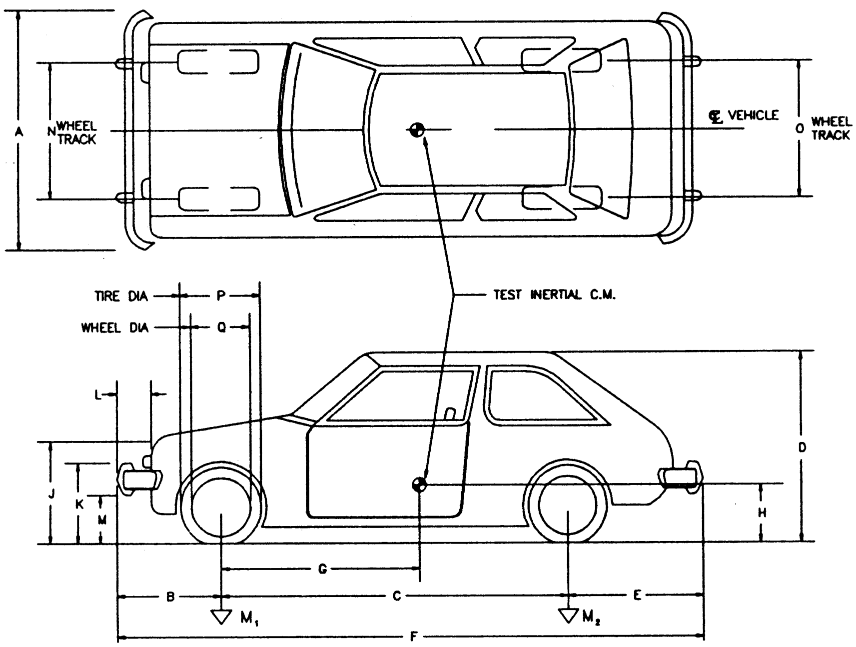
DATE: 25 NOV 2002 **TEST NO:** 614 **VIN NO:** 2C1MR2462R6724890 **MAKE:** Geo

MODEL: Metro **YEAR:** 1994 **ODOMETER:** 96,514 mph **TIRE SIZE:** 155R12

TIRE INFLATION PRESSURE: **LF** 32 **RF** 32 **LR** 32 **RR** 32

MASS DISTRIBUTION (kg) **LF** 242.0 **RF** 240.0 **LR** 160.0 **RR** 158.0

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: ______



ENGINE TYPE: 3 cylinder

ENGINE: 1000 cc

TRANSMISSION TYPE :

__AUTO

_X_MANUAL

OPTIONAL EQUIPMENT:

Air conditioning

__

__

DUMMY DATA:

TYPE: HYBRID III 50th %

MASS: 75 kg

SEAT POSITION: LEFT FRONT

GEOMETRY (mm)

A 1490	**D** 1350	**G** 902	**K** 500	**N** 1360	**Q** 335
B 770	**E** 700	**H** not measured	**L** 100	**O** 1340	
C 2270	**F** 3740	**J** 640	**M** 375	**P** 545	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	460.7	482.0	482.0
M2	302.2	318.0	318.0
MT	762.9	800.0	800.0

Table 7-4. Test 618 – Warning Sign with Flashing Beacons – 35 km/h - White

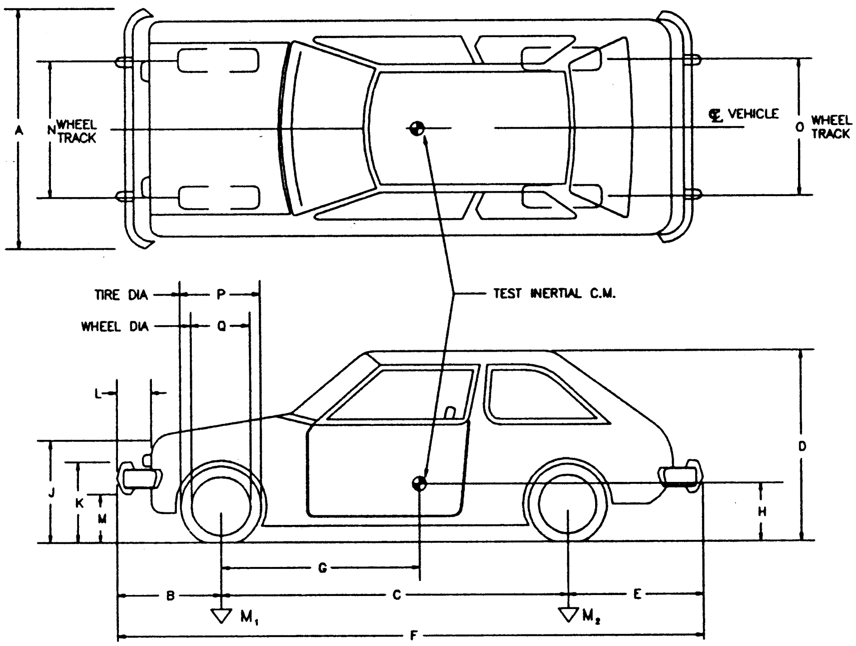
DATE: 10 DEC 2002 **TEST NO:** 618 **VIN NO:** 2C1MR6463R6740247 **MAKE:** Geo

MODEL: Metro **YEAR:** 1994 **ODOMETER:** 105,323 mph **TIRE SIZE:** 155R12

TIRE INFLATION PRESSURE: **LF** 32 **RF** 32 **LR** 32 **RR** 32

MASS DISTRIBUTION (kg) **LF** 264.0 **RF** 250.0 **LR** 171.0 **RR** 160.0

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 cylinder

ENGINE: 1000 cc

TRANSMISSION TYPE :

X **AUTO**

__ **MANUAL**

OPTIONAL EQUIPMENT:

Air Conditioning

DUMMY DATA:

TYPE: HYBRID III 50th %

MASS: 75 kg

SEAT POSITION: LEFT FRONT

GEOMETRY (mm)

A 1480	D 1360	G 928	K 520	N 1335	Q 330
B 700	E 670	H not measured	L 100	O 1330	
C 2370	F 3740	J 670	M 390	P 540	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	502.0	514.0	514.0
M2	307.0	331.0	331.0
MT	809.0	845.0	845.0

Table 7-5. Test 616 – Warning Sign with Flashing Beacons – 100 km/h - Blue

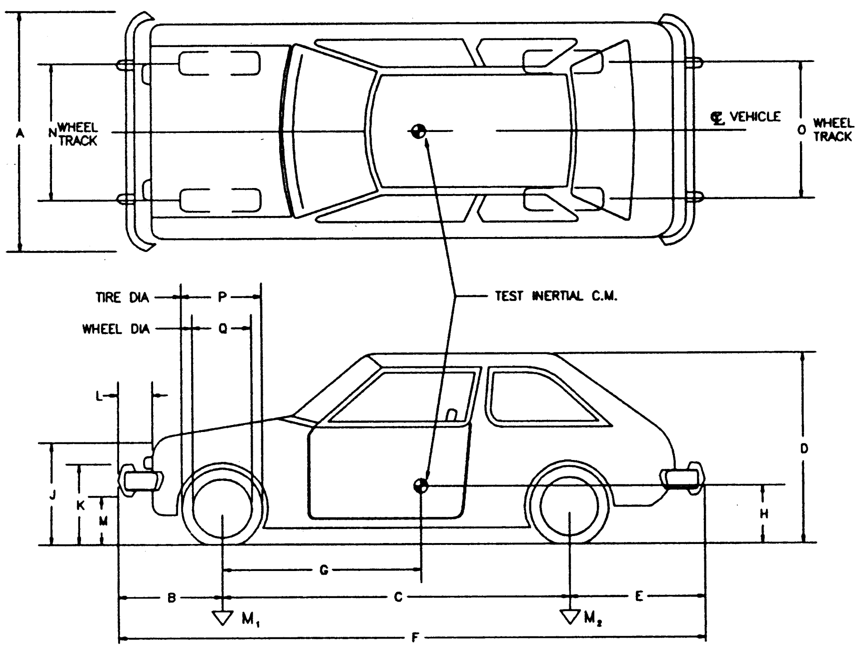
DATE: 27 FEB 2003 **TEST NO:** 616 **VIN NO:** 1G1MR6169KK745293 **MAKE:** Geo

MODEL: Metro **YEAR:** 1989 **ODOMETER:** 64,607 mph **TIRE SIZE:** 155R12

TIRE INFLATION PRESSURE: **LF** 32 **RF** 32 **LR** 32 **RR** 32

MASS DISTRIBUTION (kg) **LF** 244.0 **RF** 229.0 **LR** 163.0 **RR** 164.0

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: small dent in driver's door, 50 mm long, 1.5 mm deep. Passenger door window molding was missing which resulted in a loose window condition – irrelevant to testing.



ENGINE TYPE: 3 cylinder

ENGINE: 1000 cc

TRANSMISSION TYPE :

___AUTO

_X_MANUAL

OPTIONAL EQUIPMENT:

Air conditioning

___

___

DUMMY DATA:

TYPE: HYBRID III 50th %

MASS: 75 kg

SEAT POSITION: LEFT FRONT

GEOMETRY (mm)

A 1510	D 1375	G 969	K 520	N 1330	Q 340
B 710	E 620	H not measured	L 90	O 1320	
C 2370	F 3700	J 700	M 390	P 535	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	455.0	473.0	473.0
M2	302.0	327.0	327.0
MT	757.0	800.0	800.0

Table 7-6. Test 617 – Pole Top-Mounted Lighting – 35 km/h – White

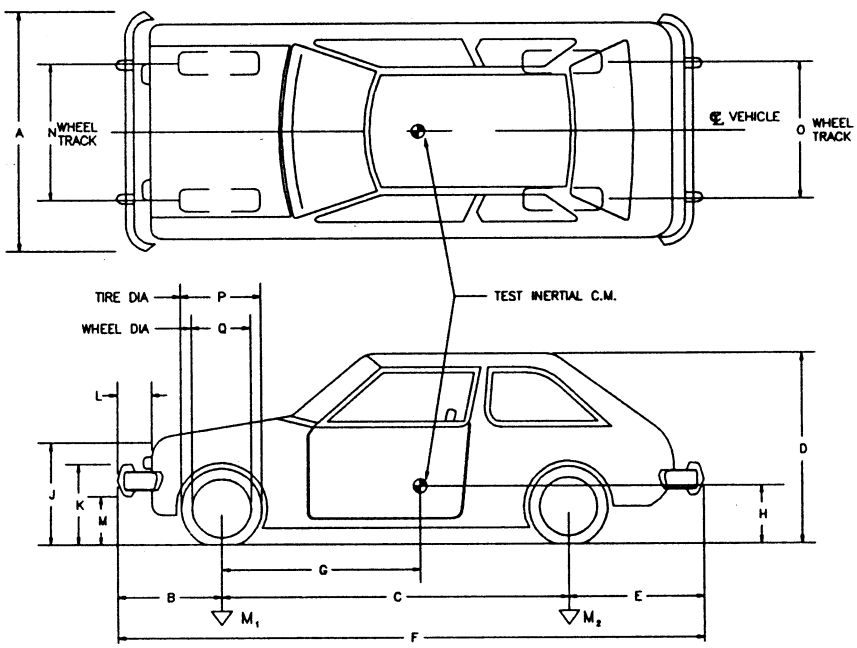
DATE: 4 DEC 2002 **TEST NO:** 617 **VIN NO:** 2C1MR2465L6008170 **MAKE:** Geo

MODEL: Metro **YEAR:** 1990 **ODOMETER:** 31,956 mph **TIRE SIZE:** 155R12

TIRE INFLATION PRESSURE: **LF** 32 **RF** 32 **LR** 32 **RR** 32

MASS DISTRIBUTION (kg) **LF** 235.0 **RF** 227.0 **LR** 168.0 **RR** 168.0

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 cylinder

ENGINE: 1000 cc

TRANSMISSION TYPE :

___ **AUTO**

X **MANUAL**

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: HYBRID III 50th %

MASS: 75 kg

SEAT POSITION: LEFT FRONT

GEOMETRY (mm)

A	1560	**D**	1320	**G**	960	**K**	550	**N**	1340	**Q**	330
B	720	**E**	640	**H**	not measured	**L**	80	**O**	1340		
C	2280	**F**	3640	**J**	660	**M**	390	**P**	550		

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	433.1	462.0	462.0
M2	296.7	336.0	336.0
MT	729.8	798.0	798.0

7.2. Test Article Specifications and Drawings

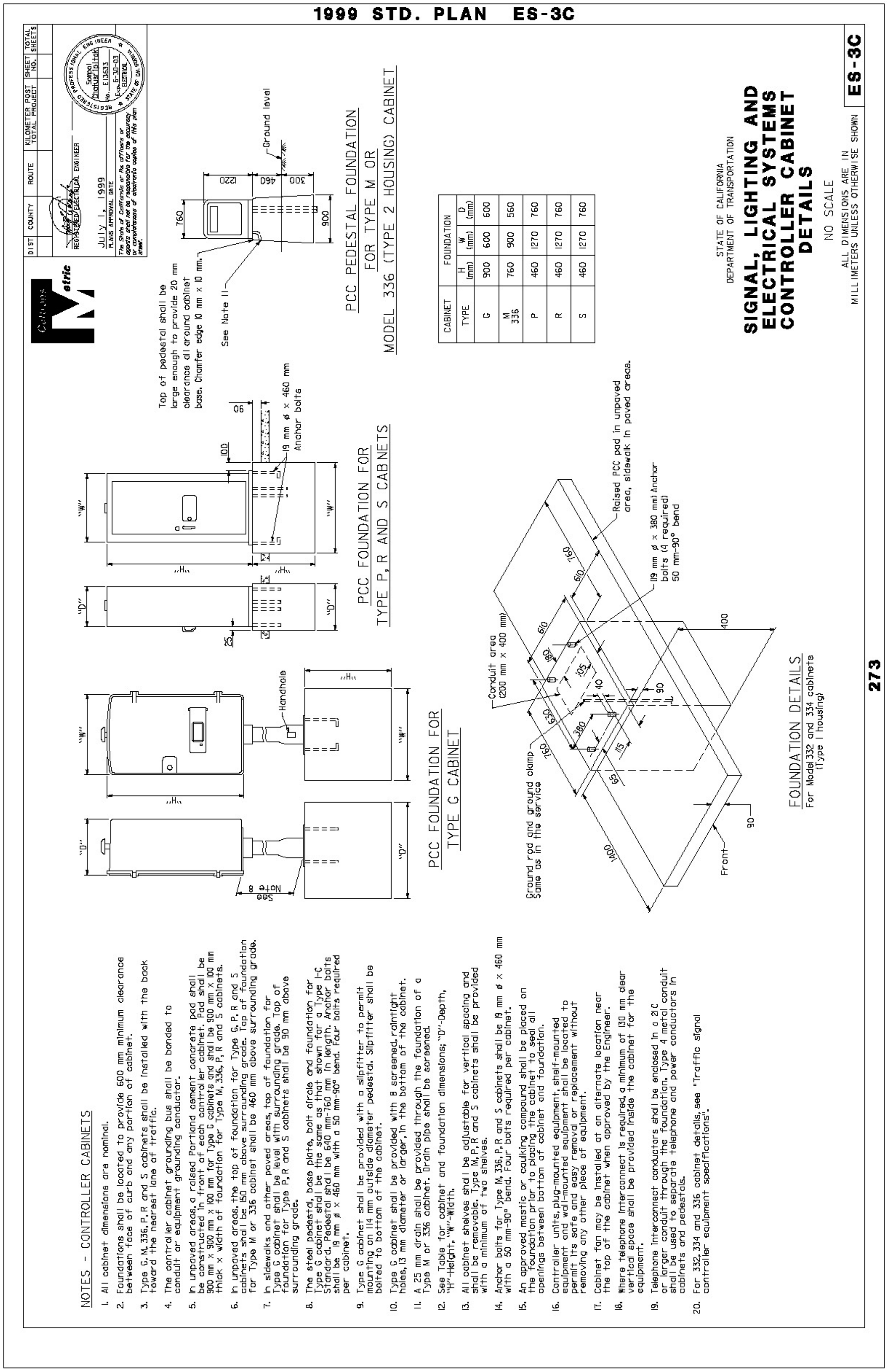
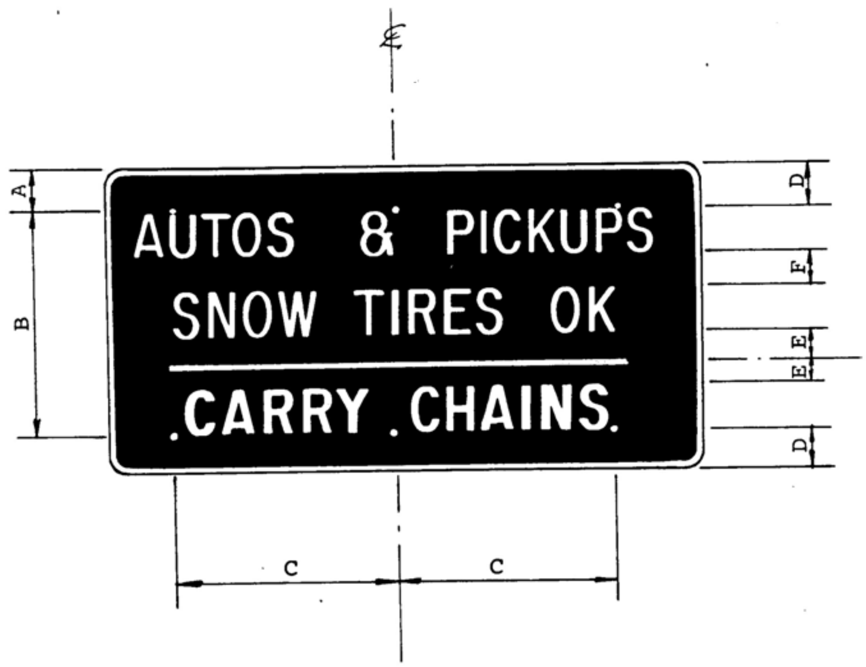


Figure 7-1. 334C Cabinet Foundation [1999 Standard Plan 3S-EC]

CODE R79



ALL DIMENSIONS ARE IN INCHES

R79 SUFFIX	SIZE	BORDER WIDTH	MARGIN WIDTH	LETTER SIZE. SERIES & STROKE WIDTH LINE 1	LINE 2	LINE 3	LINE 4	LINE 5	COR. RAD.
-1	48x30	½	--	4C-.64	4C-.64	1/2 BAR	4D-.72		1½

R79 SUFFIX	SIZE	DIMENSIONS A	B	C	D	E	F	G	H	I	J	K	L
-1	48x30	3	24	16	4-1/4	3-1/4	3						

Black BACKGROUND WITH White BORDER & SYMBOL Reflective message & border

3/8" Dia Holes

APPROVED [signature] TRAFFIC ENGINEER 8/23/72 DATE 10/1/72 REVISION

HT-69 REV. 12/30 69

Figure 7-2. Caltrans MUTCD – California Code R79

STATE OF CALIFORNIA - DEPARTMENT OF TRANSPORTATION

MUTCD NUMBER NONE

CODE R80-1

SIGN	DIMENSIONS (INCHES)												
	A	B	C	D	E	F	G	H	J	K	L	M	N
STANDARD	48	30	3	24	16	4 1/4	3 1/4	3	1/2	4C	1/2	4D	1 1/2

COLOR
BORDER, LEGEND & SYMBOL - WHITE (REFL. MESSAGE & BORDER)
BACKGROUND - BLACK

- THE POLICY FOR INTENDED USAGE OF THIS SIGN IS SHOWN ON THE REVERSE SIDE -

CHIEF, DIVISION OF TRAFFIC ENGINEERING — 12/5/95 DATE — REVISION — REVISION

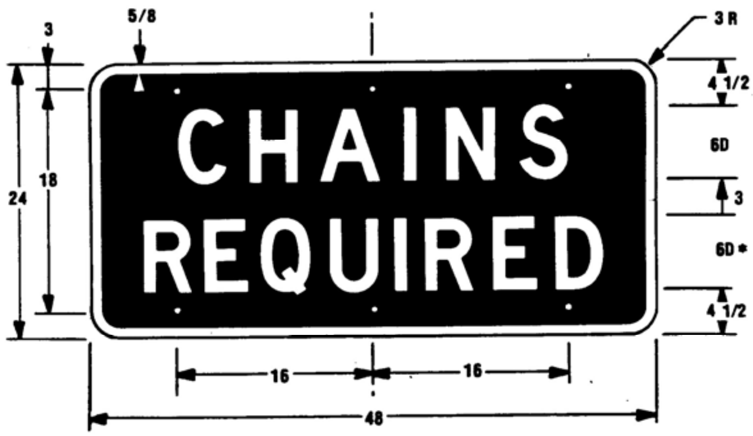
DMO - 69 (REV. 05/87)

Figure 7-3. Caltrans MUTCD – California Code R80-1

STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION

MUTCD NUMBER NONE

CODE R76



*CONDENSE SPACING 17%.

COLORS
BORDER & LEGEND - WHITE (REFL)
BACKGROUND - BLACK

DIMENSIONS IN INCHES

THE POLICY FOR INTENDED USAGE OF THIS SIGN IS SHOWN ON REVERSE SIDE.

CHIEF, DIVISION OF TRAFFIC ENGINEERING	11/10/86 DATE	REVISION	REVISION

DMO T 69 (REV 12-80)

Figure 7-4. Caltrans MUTCD – California Code R76

R2-1
SPEED LIMIT (ENGLISH)

*Optically space numerals about centerline

	A	B	C	D	E	F	G	H	J	K	L
	300	400	10	15	75	50 E	25	100 E	116.5	90.5	40
C	450	600	10	15	75	75 E	50	200 E	176	137	40
	600	750	10	15	100	100 E	50	250 E	234.5	183	50
	900	1200	15	25	175	150 E	100	350 E	351.5	274.5	60
	1200	1500	20	30	200	200 E	150	400 E	466.5	364	70

COLORS: LEGEND — BLACK
BACKGROUND — WHITE (RETROREFLECTIVE)

1-10

Figure 7-5. FHWA MUTCD R2-1

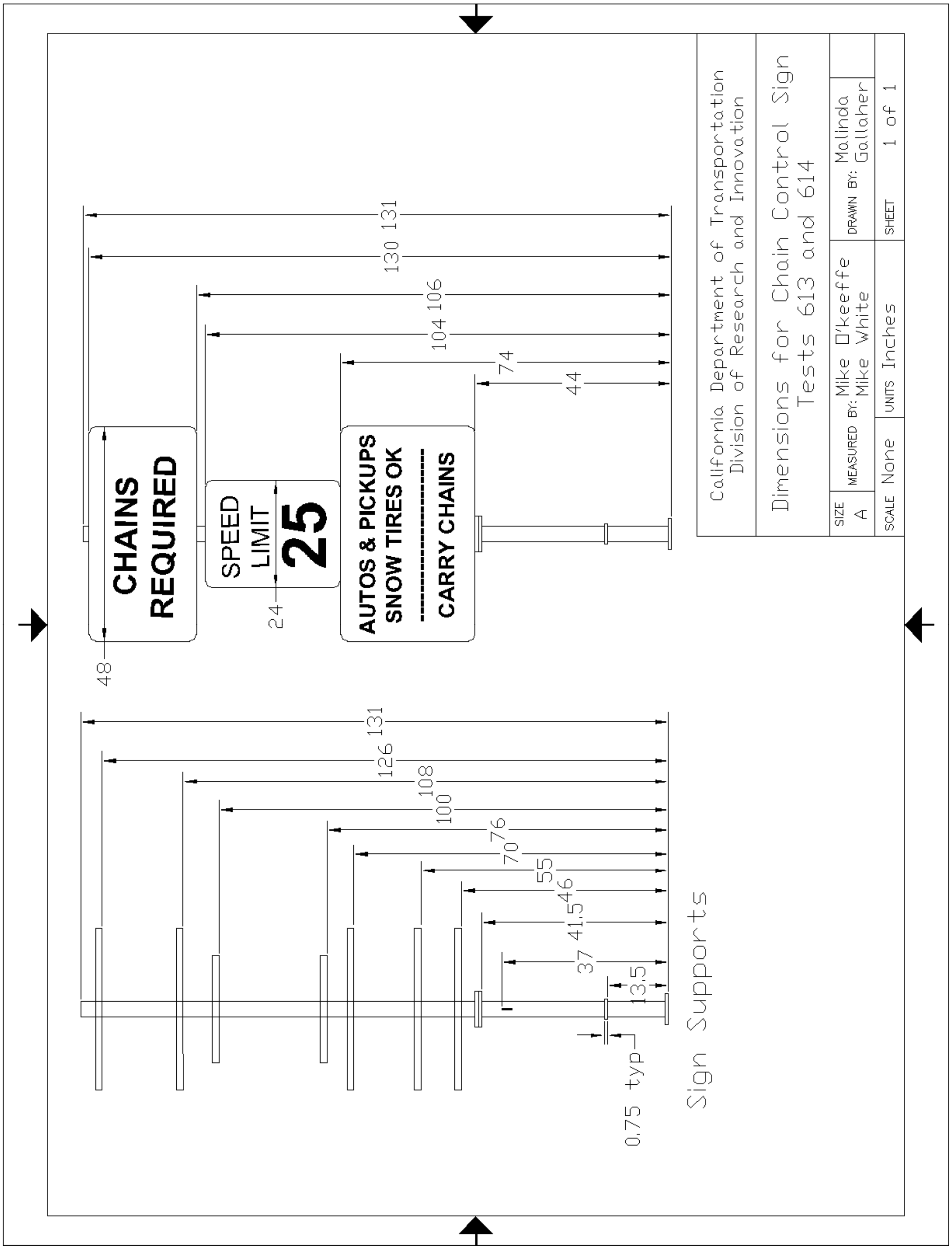


Figure 7-6. Chain Control Sign Overall Dimensions

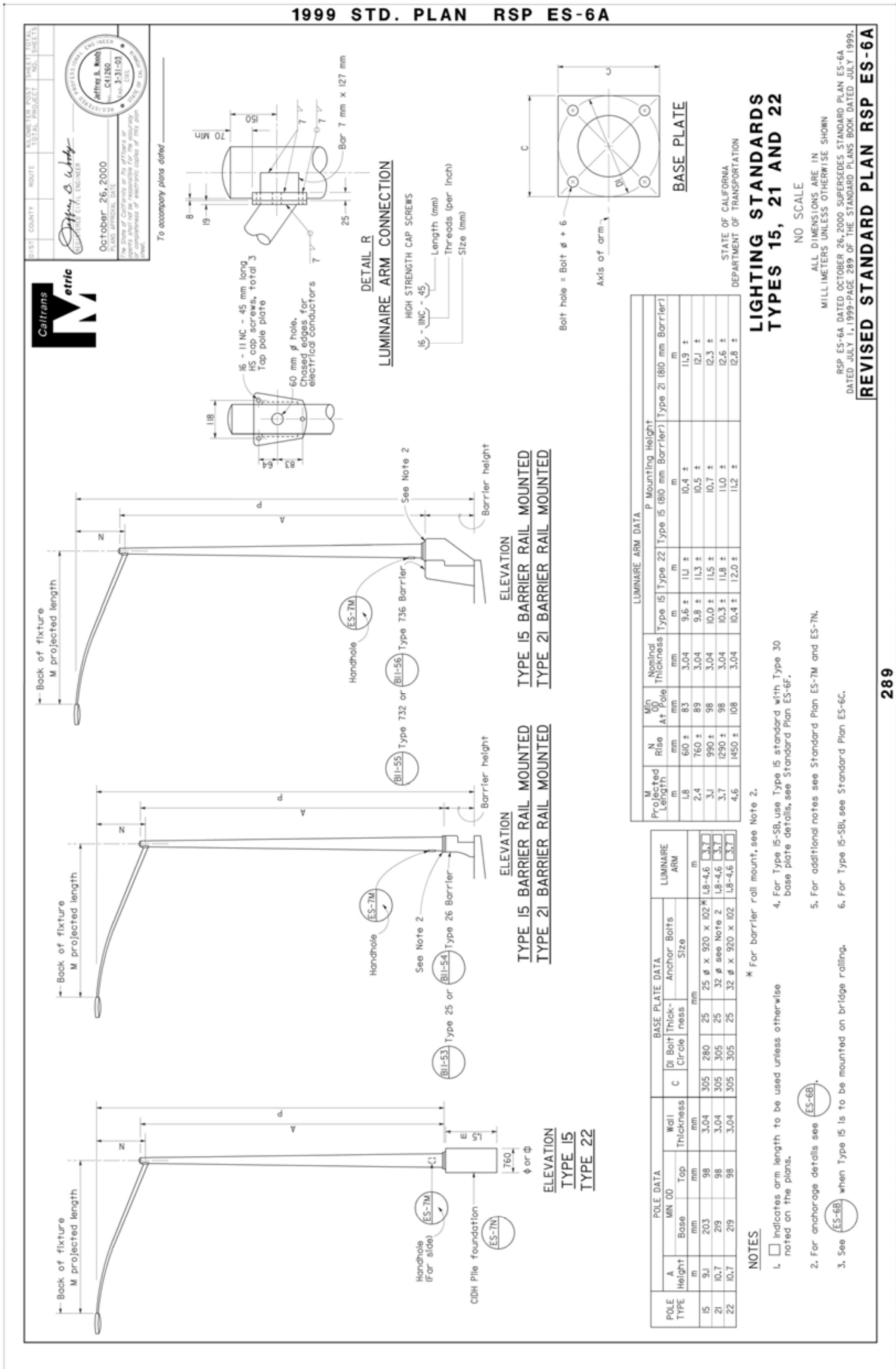


Figure 7-7. Type 15 Light Standard (1999 Revised Standard Plans ES-6U)
(Used for Tests 616 and 618)

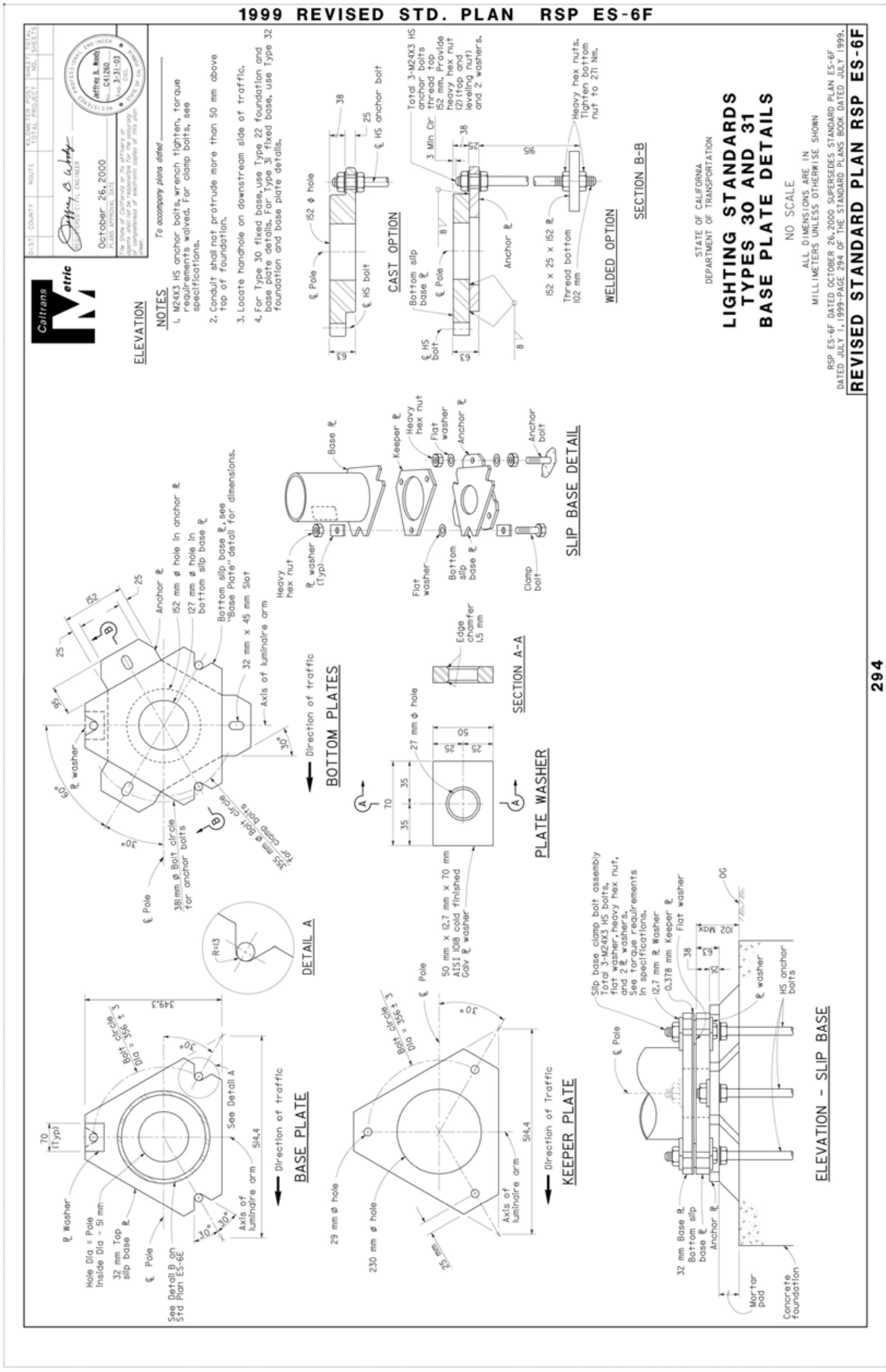


Figure 7-8. Type 30/31 Base Plate (1999 Revised Standard Plans ES-6F)
(Used for Tests 616, 617 and 618)

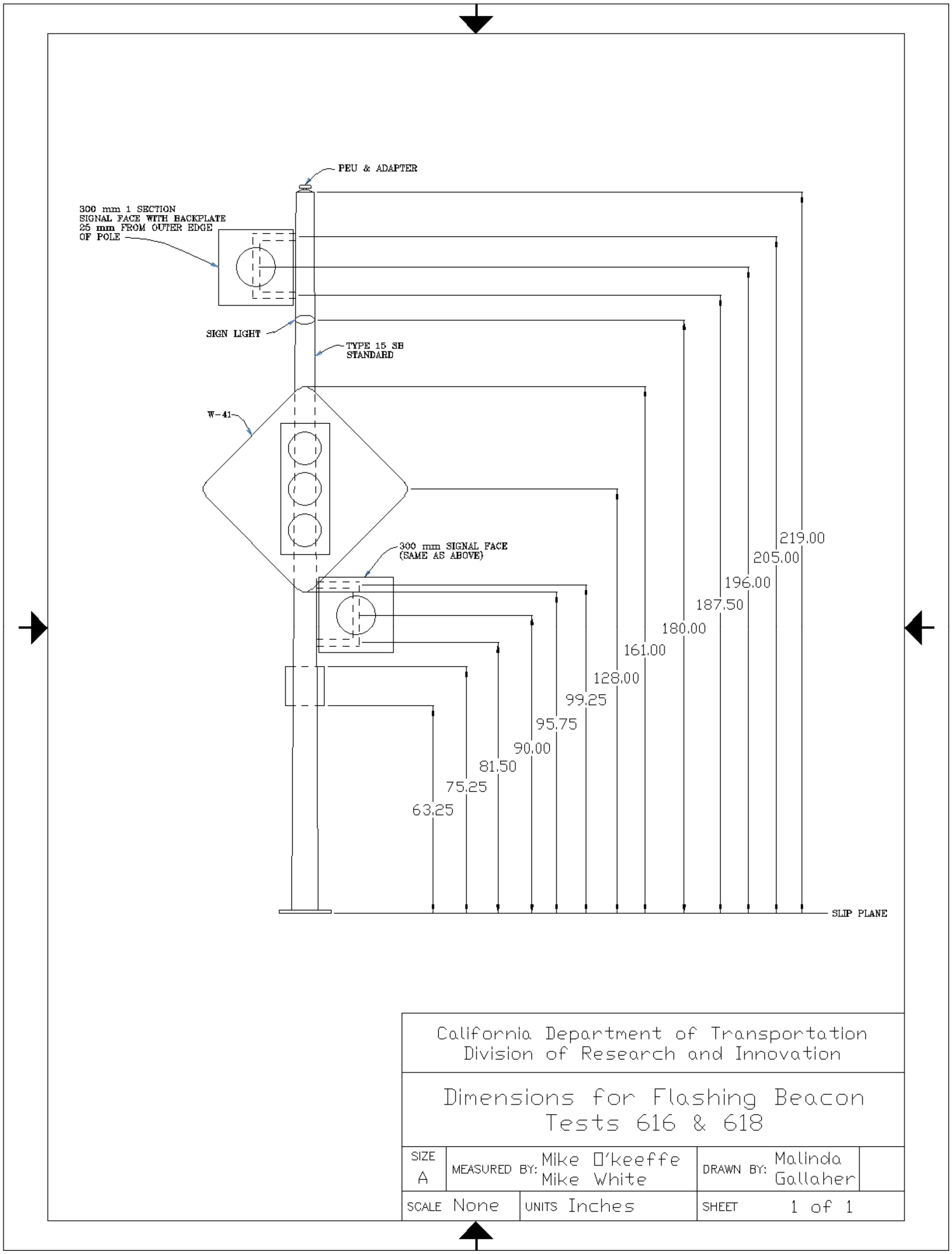


Figure 7-9. Flashing Beacon Overall Dimensions

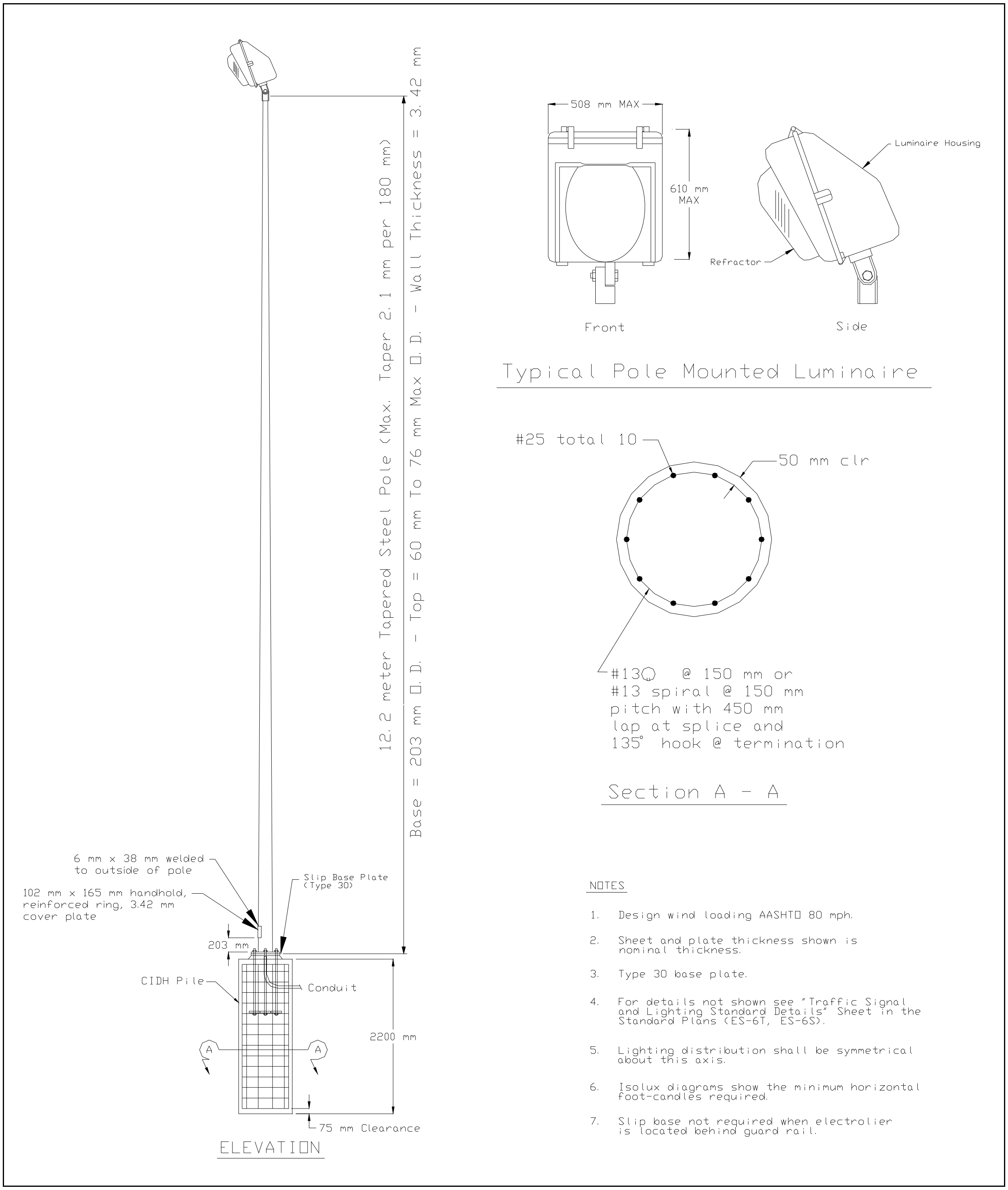


Figure 7-10. Pole Top-Mounted Lighting Diagram

7.3. Test Vehicle Guidance System

A rail guidance system directed all vehicles into the test articles. The guidance rail, anchored at 3.8-m (12.5 ft) intervals along its length, was used to guide a mechanical arm that was attached to the front right wheel of each of the vehicles. A 10-mm nylon rope was used to trigger the release mechanism on the guidance arm, thereby releasing the vehicle from the guidance system before impact.

7.4. Photo - Instrumentation

Several high-speed movie cameras recorded the impact during the crash tests. The types of cameras and their locations are shown in Table 7-7 and Figure 7-11. All of these cameras were mounted on tripods except the three that were mounted on a 10.7-m (35-ft) high tower directly over the impact location. A video camera and a 16-mm film camera were turned on by hand and used to obtain pan shots during the test. Switches on a console trailer near the impact area remotely triggered all other cameras. The test vehicle and test article were photographed before and after impact with a normal-speed movie camera, a beta video camera and a color still camera. A film report of this project has been assembled using edited portions of the crash testing coverage.

Table 7-7. Typical Camera Type and Locations

Typical Coordinates, m						
Camera Label	Film Size (mm)	Camera Type	Rate: (fr./sec.)	X*	Y*	Z*
L1	16	LOCAM 1	400	10.0	-1.4	-2.0
L2	16	LOCAM 2	400	0.0	0.0	-9.1
L3	16	LOCAM 3	400	-35.8	0.2	-1.2
L4	16	LOCAM 4	400	0.45	0.0	-9.1
L5	16	LOCAM 5	400	95.6	0.33	-2.1
L6	16	LOCAM 6	400	-0.45	0.0	-9.1
L8	16	LOCAM 8	400	3.1	21.5	-1.2
V	1.27	SONY BETACAM	30	1.8	22.0	-1.2
H	35	HULCHER	40	95.7	0.71	-2.1

Note: Camera location measurements were approximated and are typical for all crash tests involved in this report.
*X, Y and Z distances are relative to the impact point.

The Caltrans Roadside Safety Research Group is in the process of switching from high-speed film cameras to high-speed digital video cameras. This changeover is accompanied by a switch from the analog motion analyzer mentioned above to a computer-based motion analysis software program called Visual Fusion. Both camera systems were set up for each test and images were recorded from both systems. All motion analysis detailed in this report is from the older high-speed film system while staff become familiar with the new system.

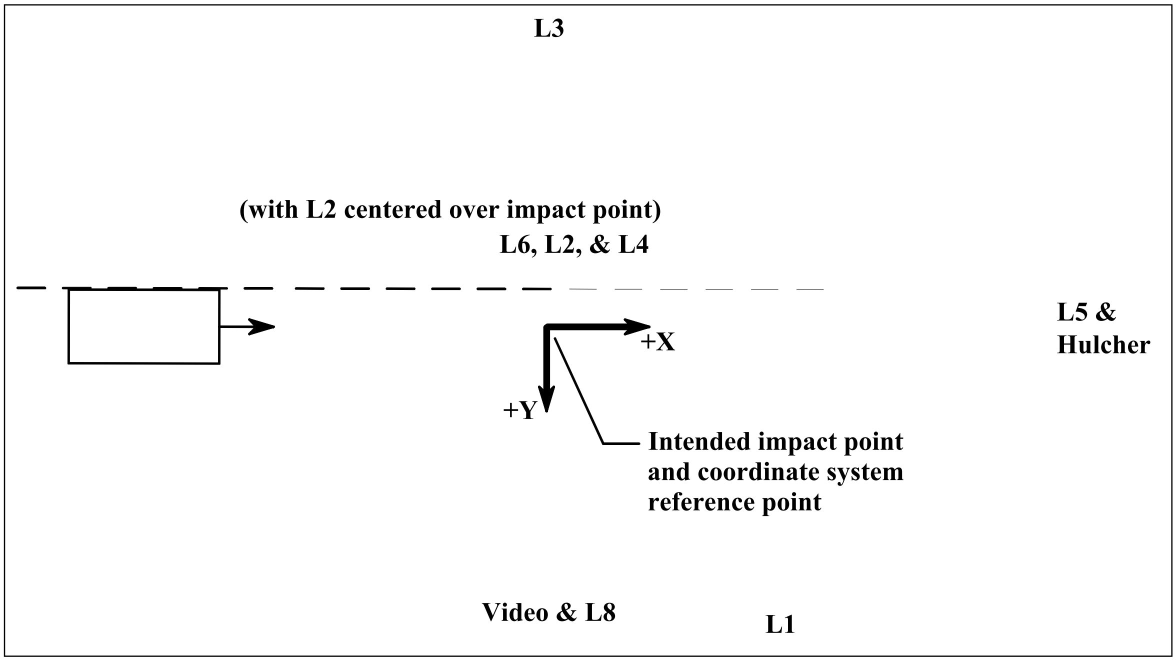


Figure 7-11. Camera Locations

The following are the pretest procedures that were required to enable film data reduction to be performed using a Visual Instrumentation Corporation Model 1214A film motion analyzer:

1) Butterfly targets were attached to the top and sides of each test vehicle. The targets were located on the vehicle at intervals of 0.5 and 1.0 meters. The targets established scale factors and horizontal and vertical alignment. The test articles were targeted.

2) Flashbulbs, mounted on the test vehicle, were electronically triggered to establish 1) initial vehicle-to-article contact, and 2) the time of the application of the vehicle brakes. The impact flashbulbs begin to glow immediately upon activation, but have a delay of several milliseconds before lighting up to full intensity.

3) Five tape switches, placed at 4 m intervals, were attached to the ground near the article and were perpendicular to the path of the test vehicle. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of the cameras. The flashbulbs were used to correlate the cameras with the impact events and to calculate the impact speed independent of the electronic speed trap. The tape switch layout is shown in Figure 7-12.

4) High-speed cameras had timing light generators, which exposed red timing pips on the film at a rate of 100 per second. (Note: The original film was lost for these tests, but digital copies remained. The digital copies do not contain the pips needed for the film rate analysis.)

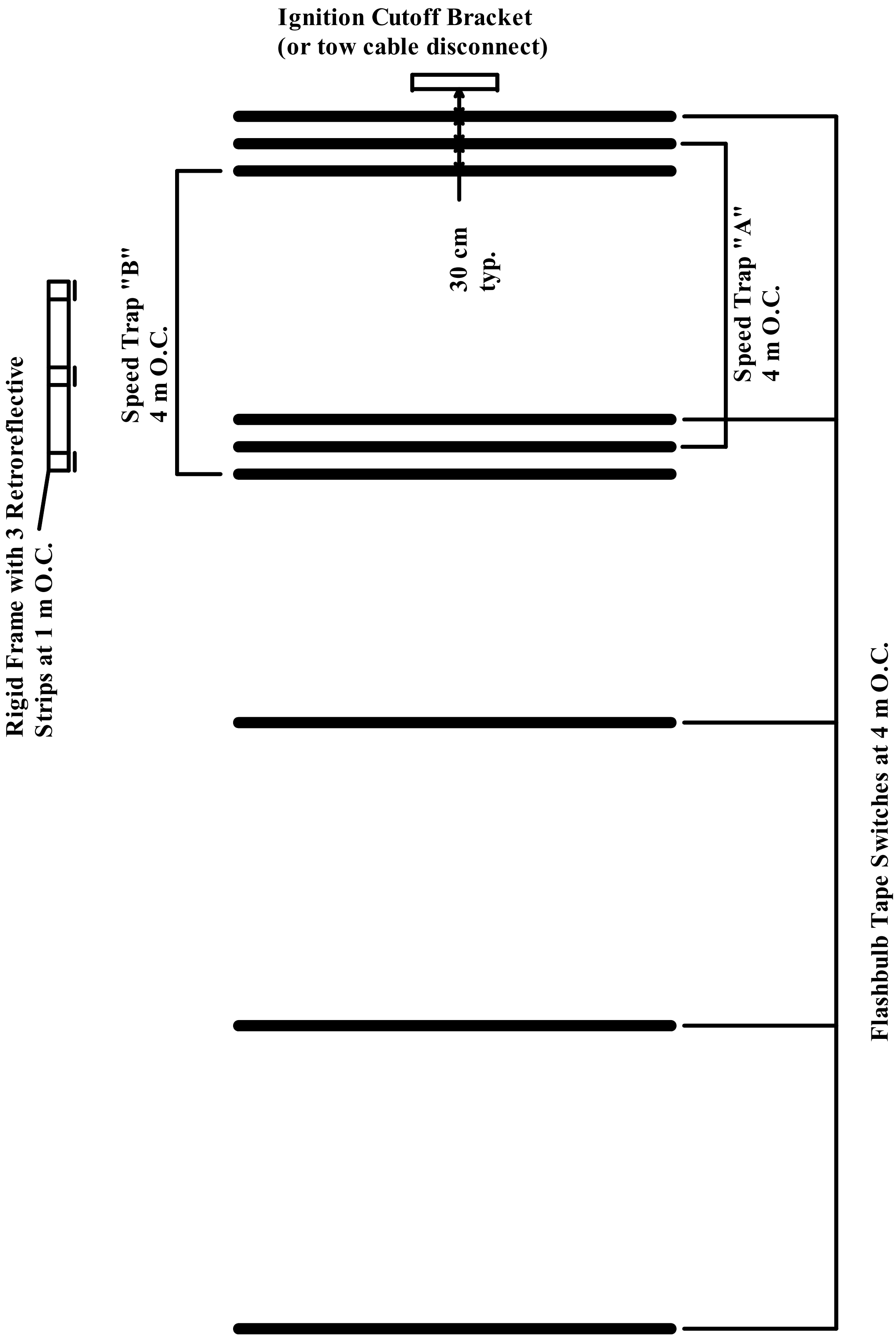


Figure 7-12. Event Switch Layout

7.5. Electronic Instrumentation and Data

Transducer data were recorded on two separate GMH Engineering, Data Brick, Model II, digital transient data recorders (TDRs) that were mounted in the vehicle for all tests. The transducers mounted on the vehicle include two sets of accelerometers and one set of rate gyros at the center of gravity. The 820C vehicles also had one set of accelerometers 600 mm (23.6”) behind the center of gravity. The TDR data were reduced using a desktop personal computer running DADiSP 4.1.

Accelerometer specifications are shown in Table 7-8. The vehicle accelerometer sign convention used throughout this report is the same as that described in NCHRP Report 350 and is shown in Figure 7-13.

A rigid stand with three retro-reflective 90° polarizing tape strips was placed on the ground near the test article and alongside the path of the test vehicle (Figure 7-12). The strips were spaced at carefully measured intervals of 1 m. The test vehicle had an onboard optical sensor that produced sequential impulses or "event blips" that were recorded concurrently with the accelerometer signals on the TDR, serving as "event markers". The impact velocity of the vehicle could be determined from these sensor impulses and timing cycles and the known distance between the tape strips. A pressure-sensitive tape switch on the front bumper of the vehicle closed at the instant of impact and triggered two events: 1) an “event marker” was added to the recorded data, and 2) a flashbulb mounted on the top of the vehicle was activated. Two other pressure-sensitive tape switches, connected to a speed trap, were placed 4 m apart just upstream of the test article specifically to establish the impact speed of the test vehicle. The layout for all of the pressure-sensitive tape switches is shown in Figure 7-12.

The data curves are shown in Figure 7-14 through Figure 7-43 and include the accelerometer and rate gyro records from the test vehicles. They also show the velocity and displacement curves for the longitudinal and lateral components. These plots were needed to calculate the occupant impact velocity defined in NCHRP Report 350. All data were analyzed using software written by DADiSP and modified by Caltrans.

Table 7-8. Accelerometer and Gyro Specifications

TYPE	LOCATION	RANGE	ORIENTATION	TEST NUMBER
STATHAM	VEHICLE C.G.	100 G	LONGITUDINAL	ALL
STATHAM	VEHICLE C.G.	100 G	LATERAL	ALL
STATHAM	VEHICLE C.G.	50 G	VERTICAL	ALL
HUMPHREY	VEHICLE C.G.	180 DEG/SEC	ROLL	ALL
HUMPHREY	VEHICLE C.G.	90 DEG/SEC	PITCH	ALL
HUMPHREY	VEHICLE C.G.	180 DEG/SEC	YAW	ALL
ENDEVCO	VEHICLE C.G.	200 G	LONGITUDINAL	ALL
ENDEVCO	VEHICLE C.G.	200 G	LATERAL	ALL
ENDEVCO	VEHICLE C.G.	200 G	VERTICAL	ALL

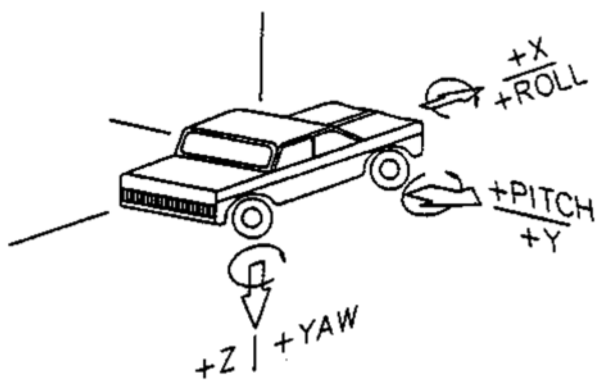


Figure 7-13. Vehicle Accelerometer Sign Convention

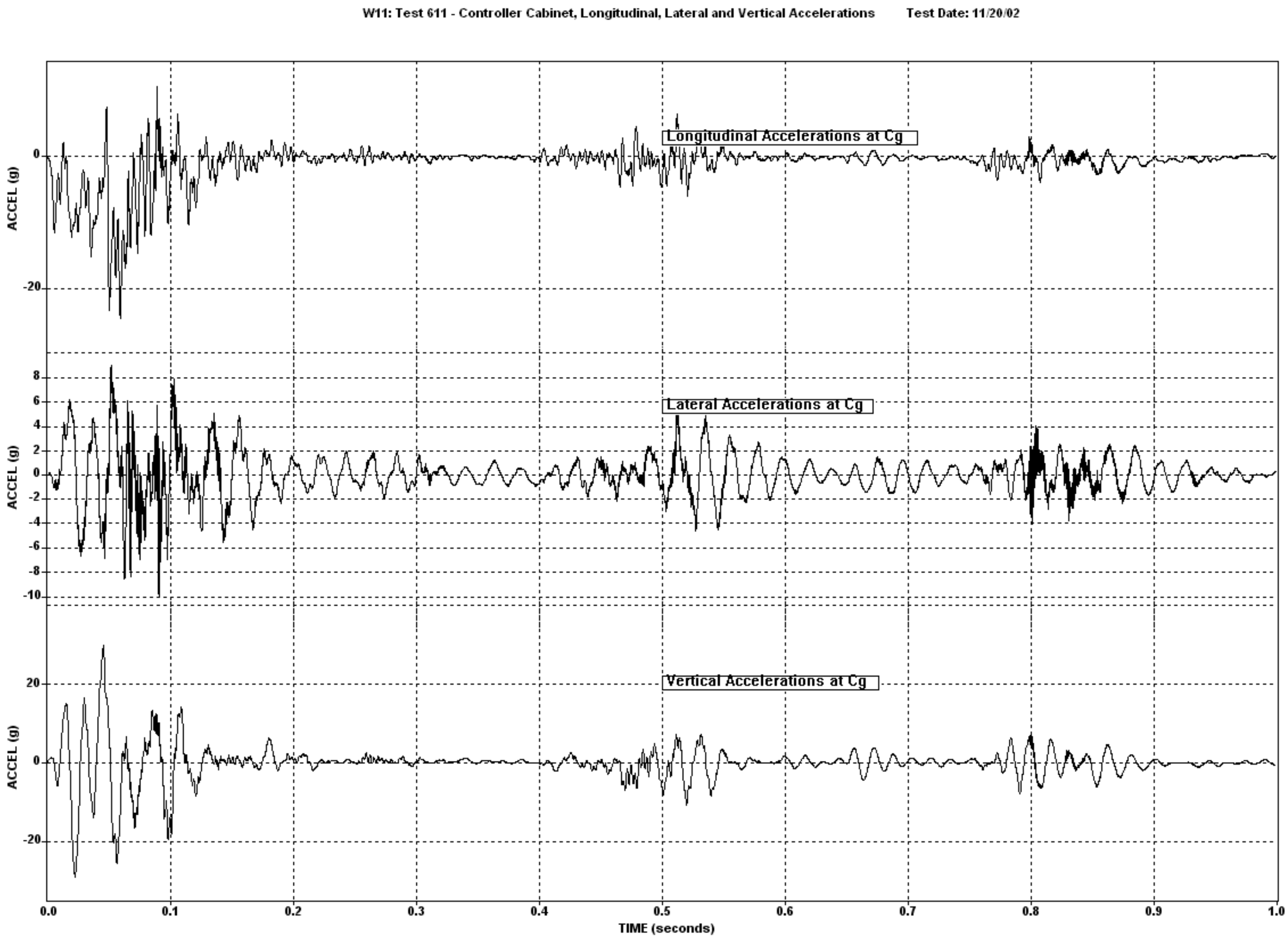


Figure 7-14. Test 611 Vehicle Accelerations Vs Time

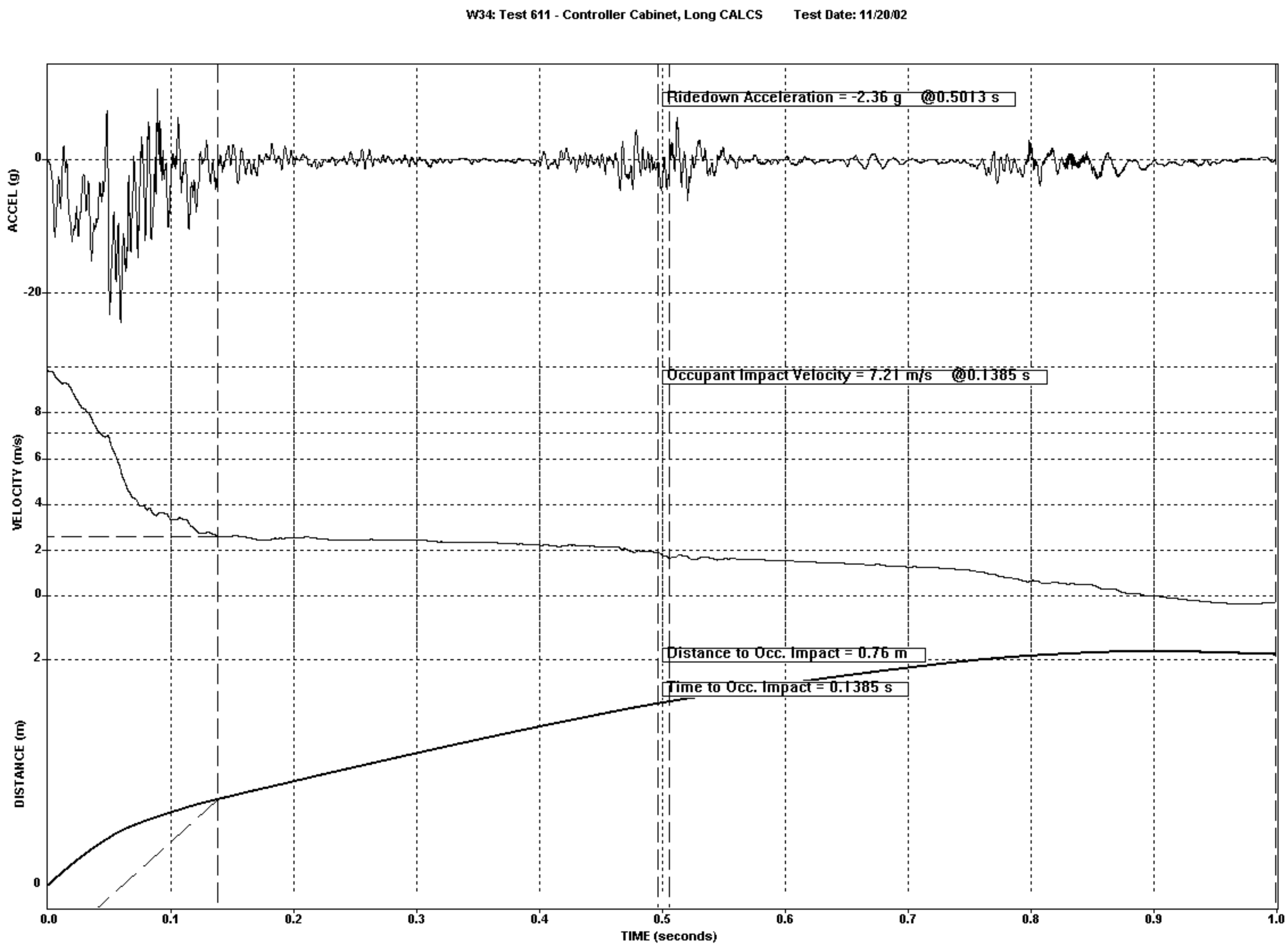


Figure 7-15. Test 611 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time

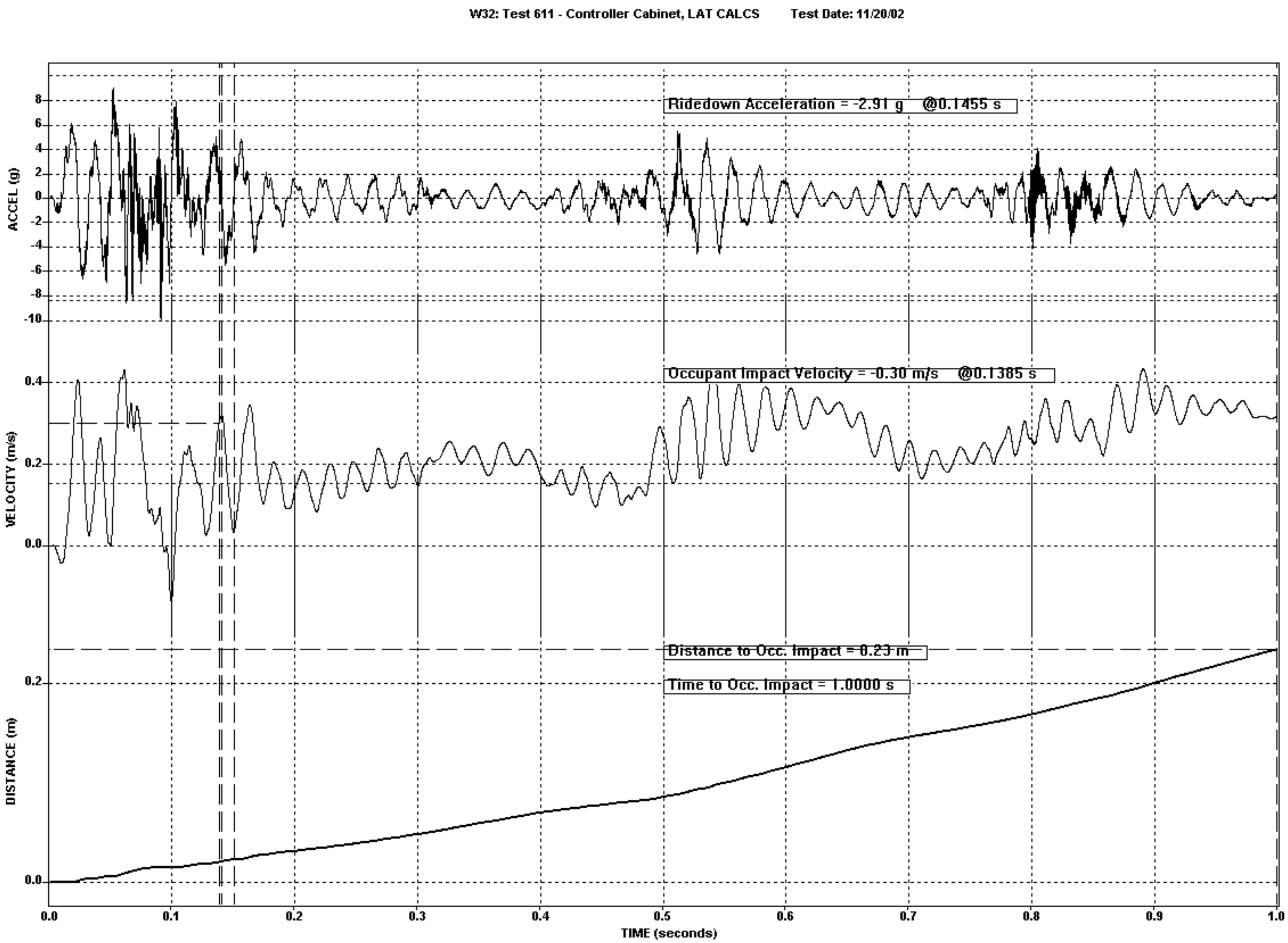


Figure 7-16. Test 611 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time

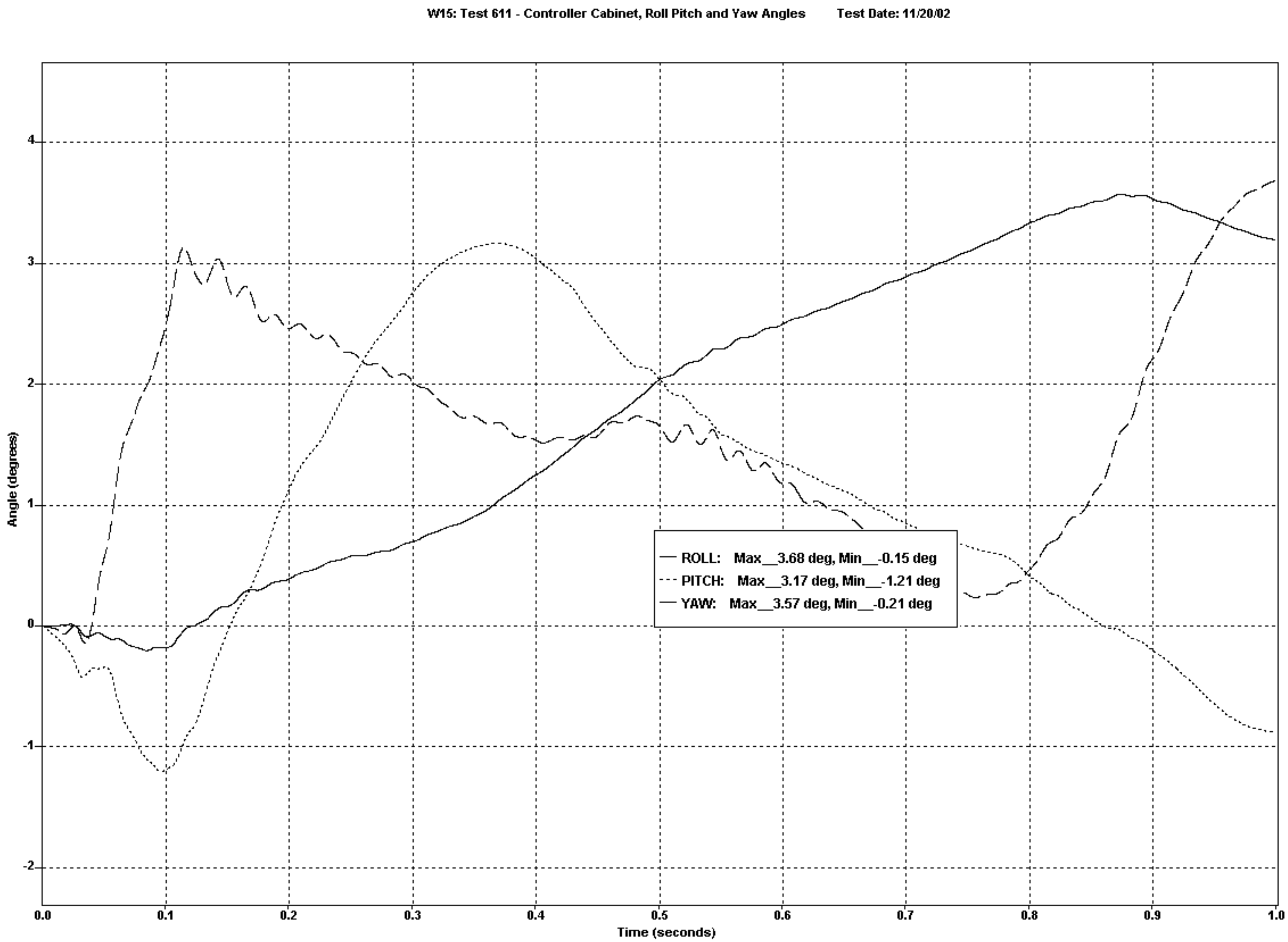


Figure 7-17. Test 611 Vehicle Roll, Pitch, and Yaw Vs Time

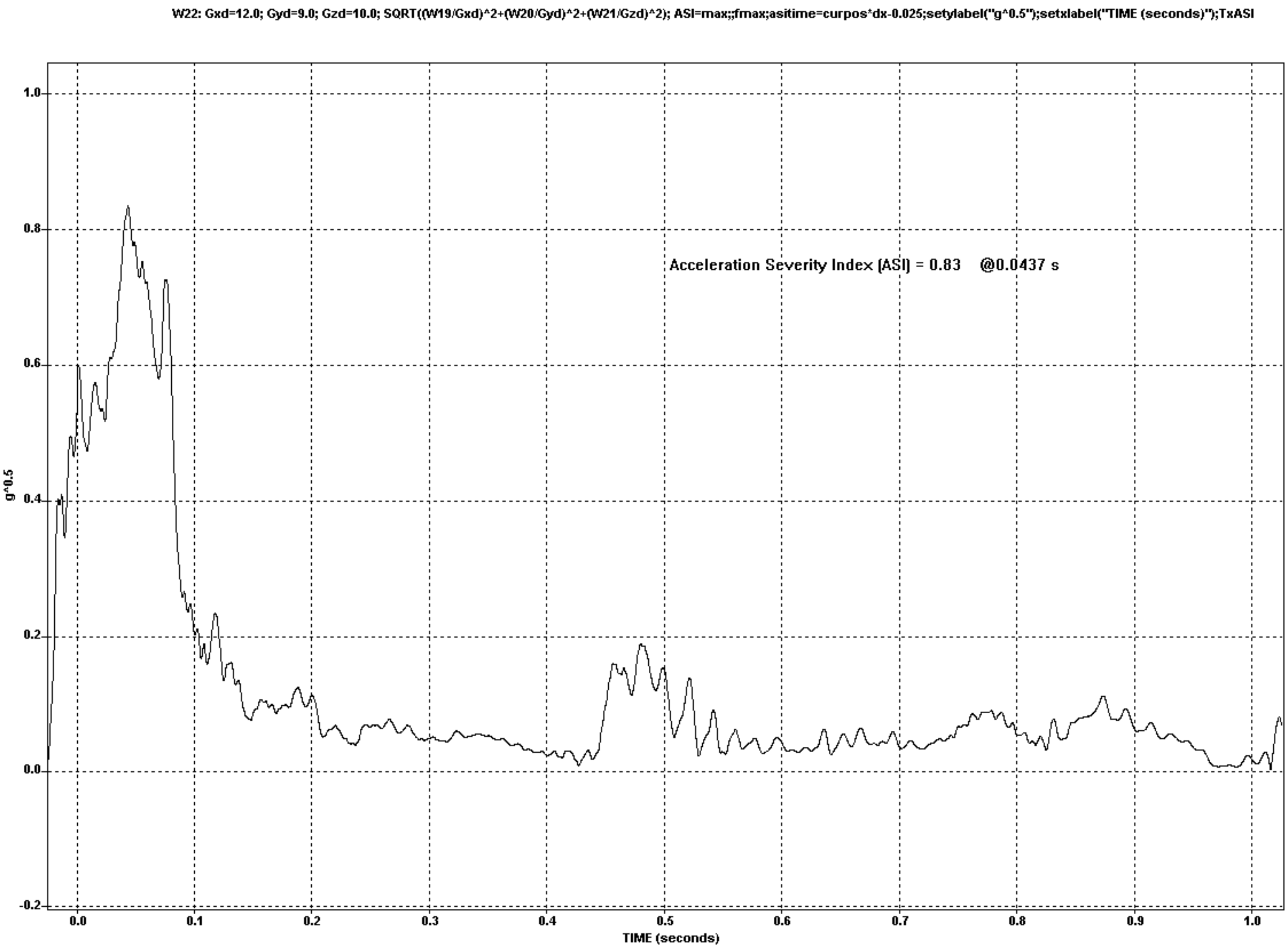


Figure 7-18. Test 611 Acceleration Severity Index Vs Time

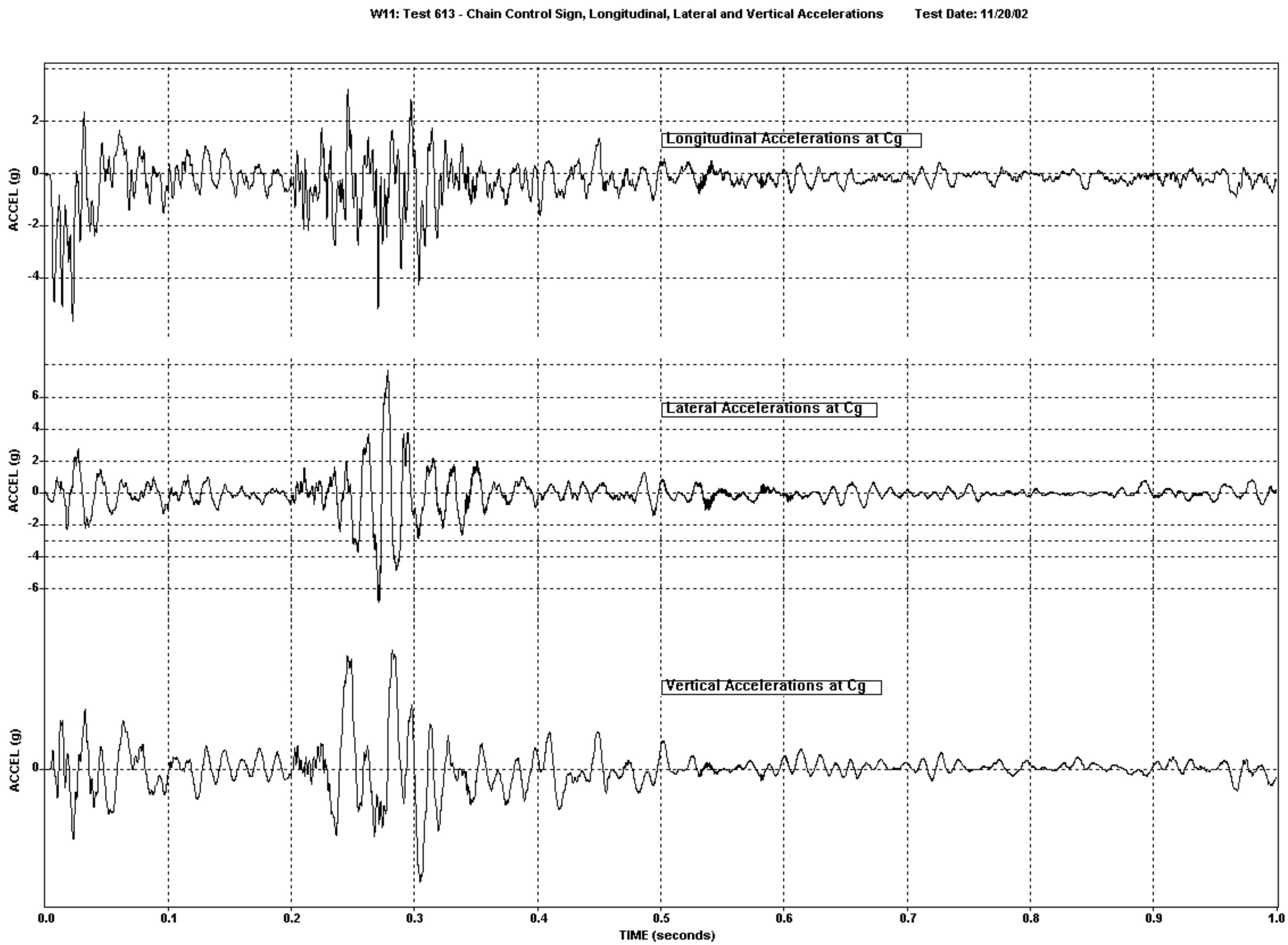


Figure 7-19. Test 613 Vehicle Accelerations Vs Time

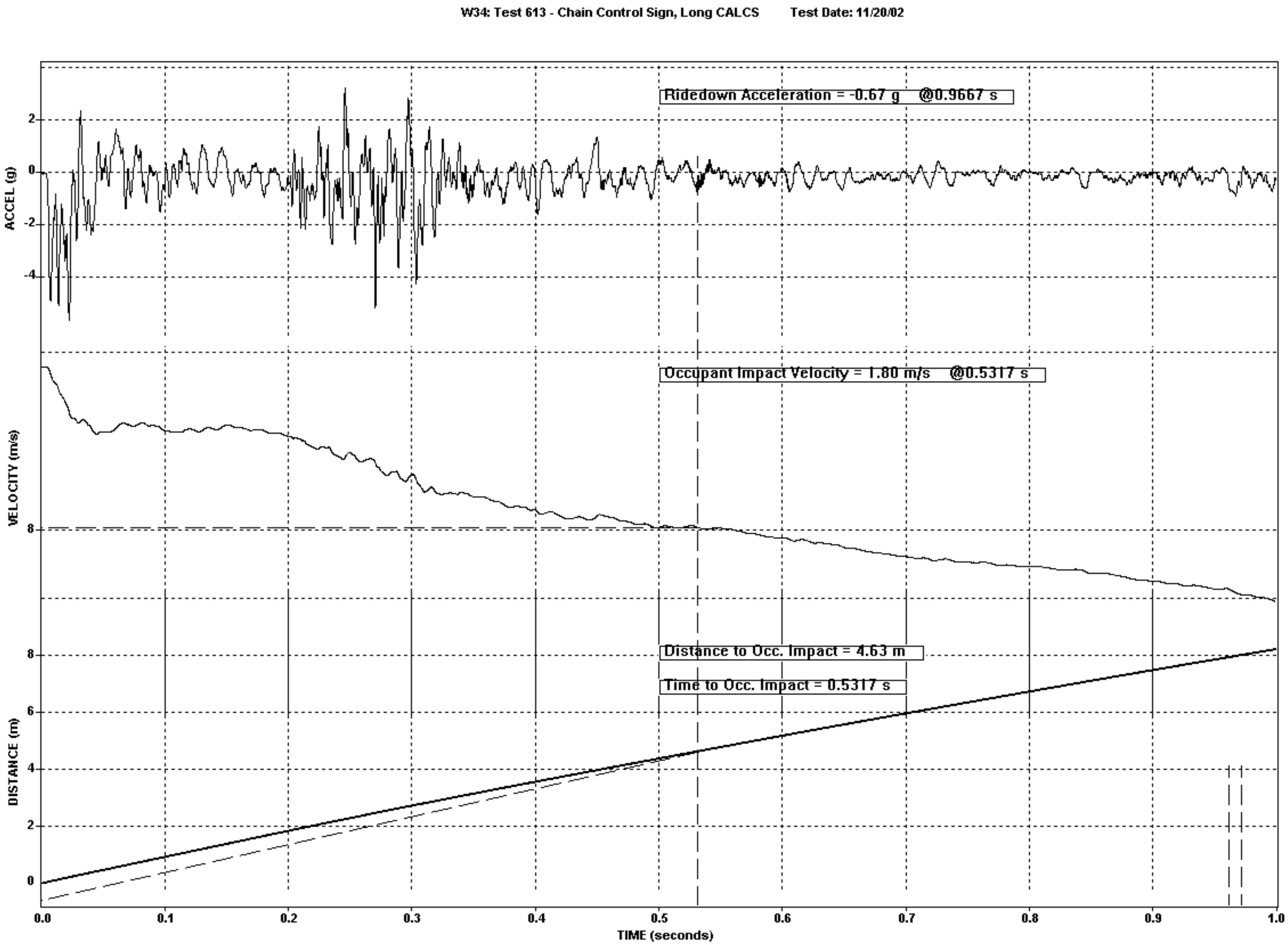


Figure 7-20. Test 613 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time

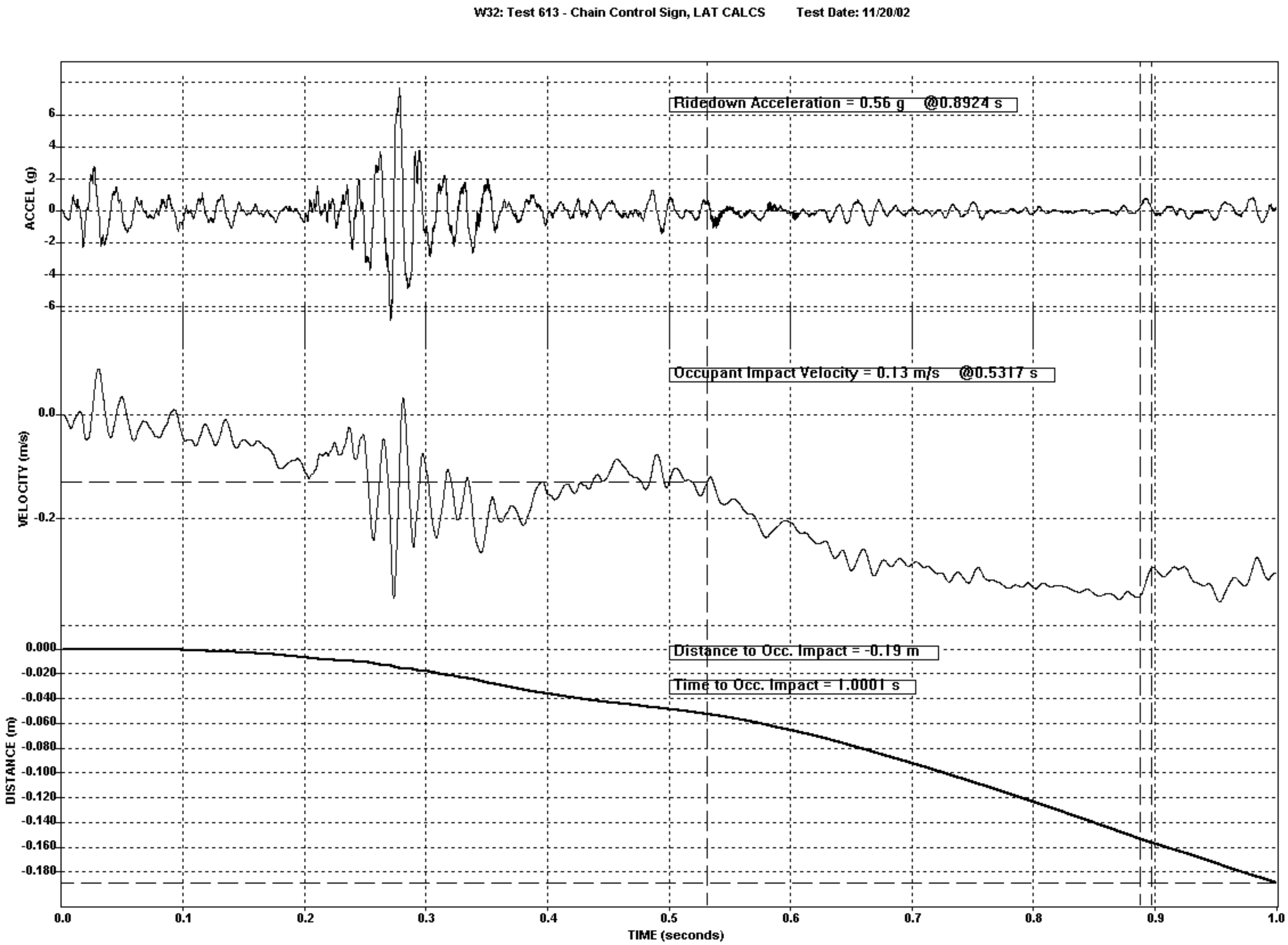


Figure 7-21. Test 613 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time

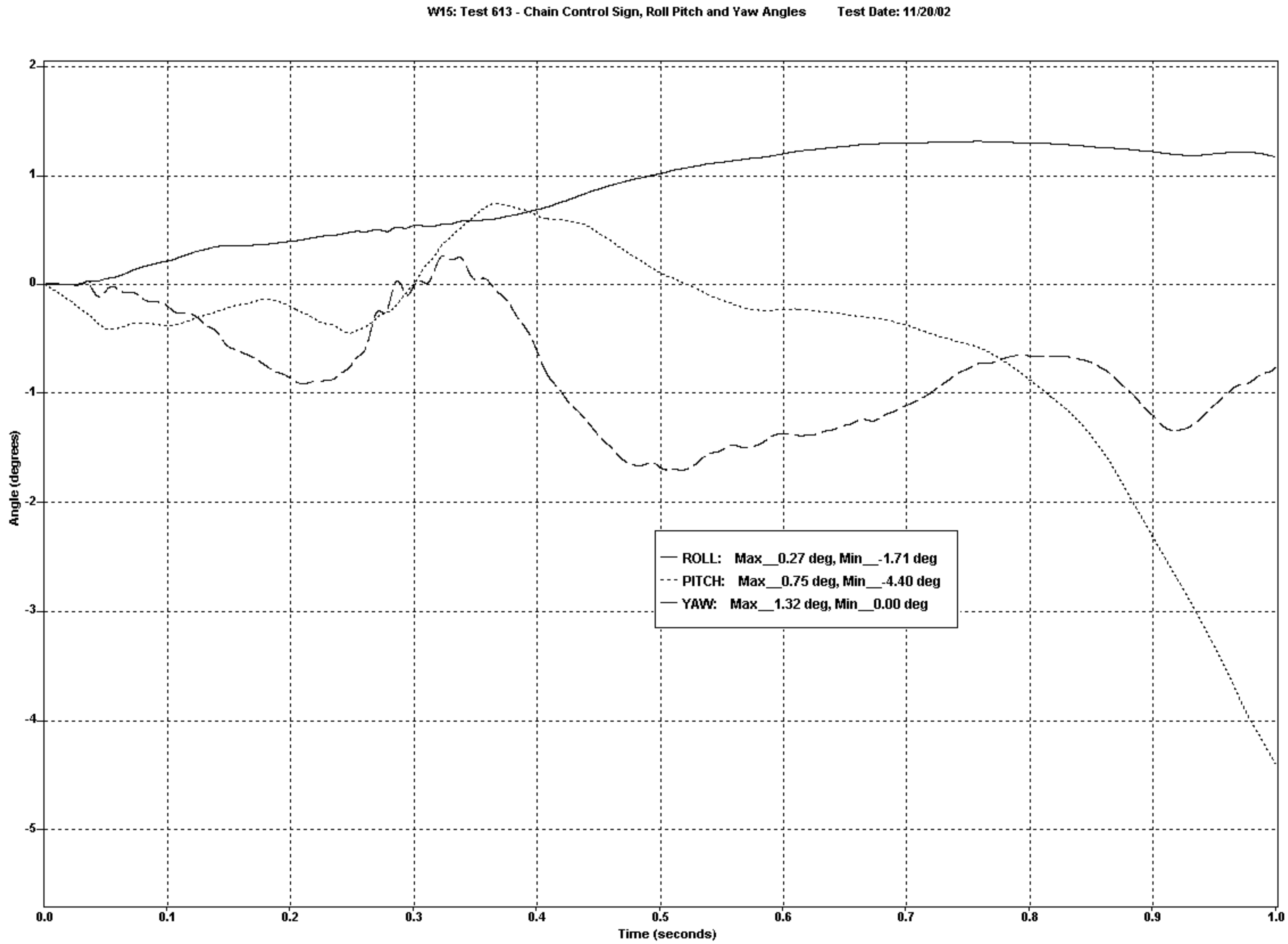


Figure 7-22. Test 613 Vehicle Roll, Pitch, and Yaw Vs Time

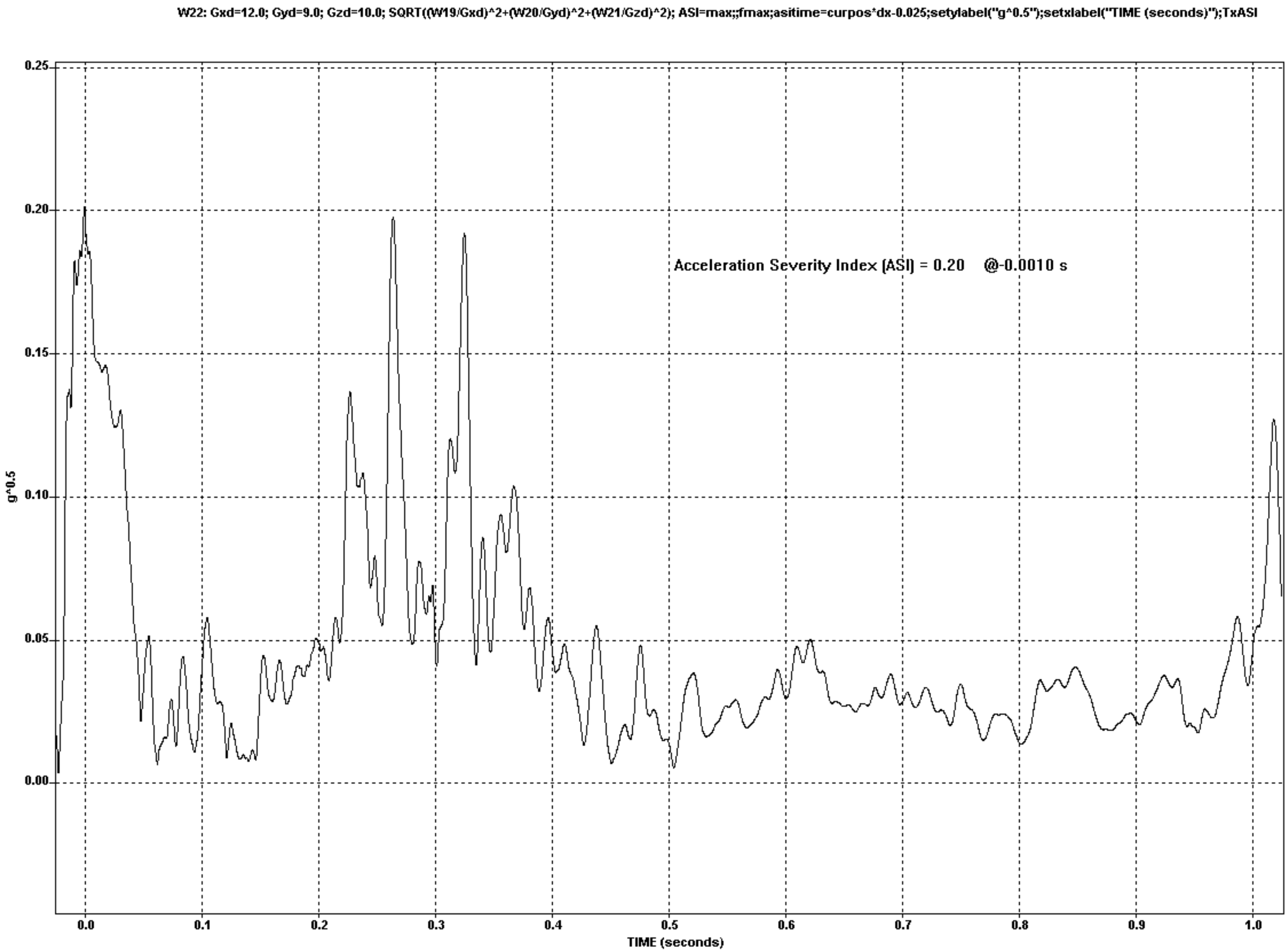


Figure 7-23. Test 613 Acceleration Severity Index Vs Time

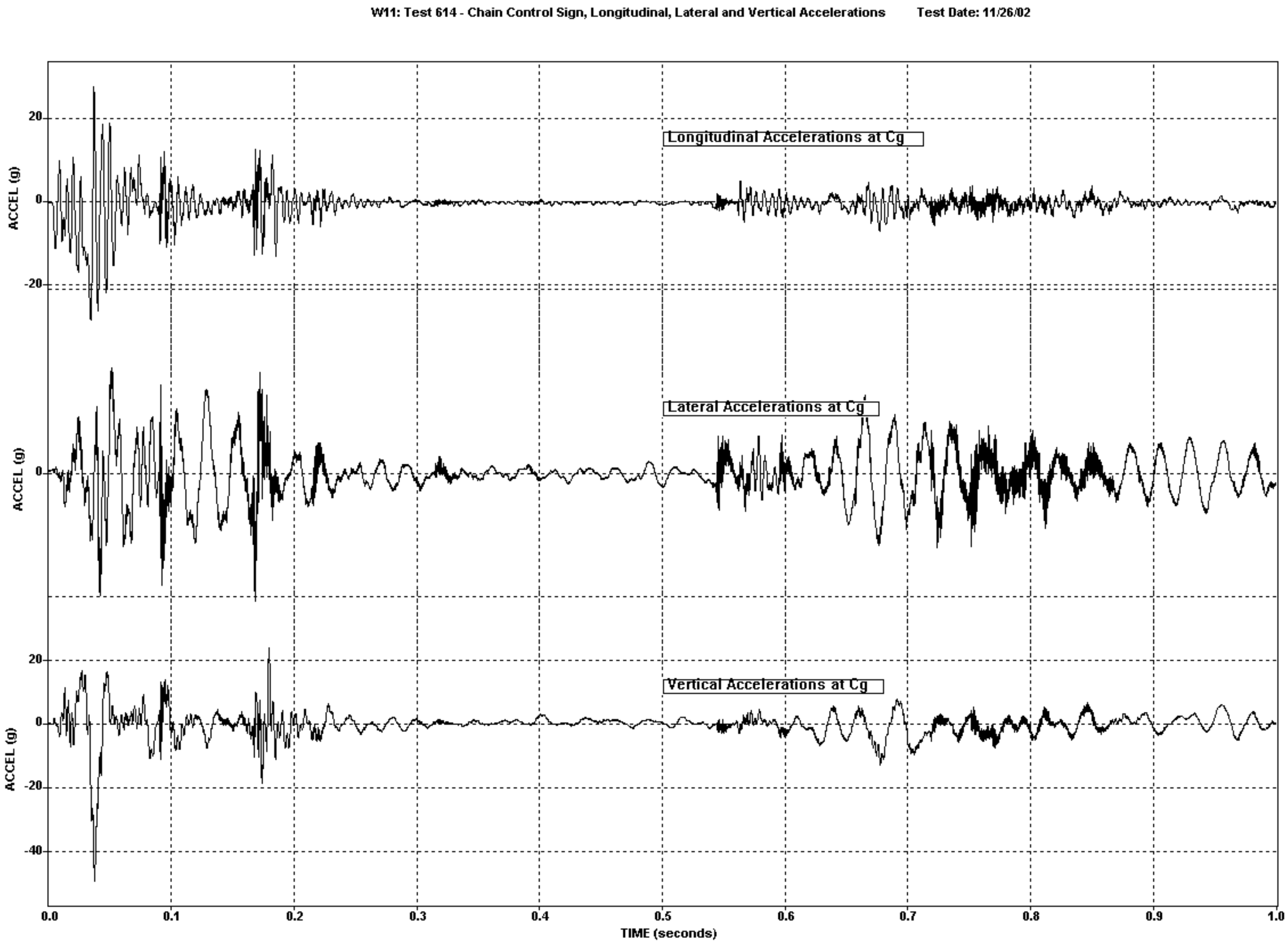


Figure 7-24. Test 614 Vehicle Accelerations Vs Time

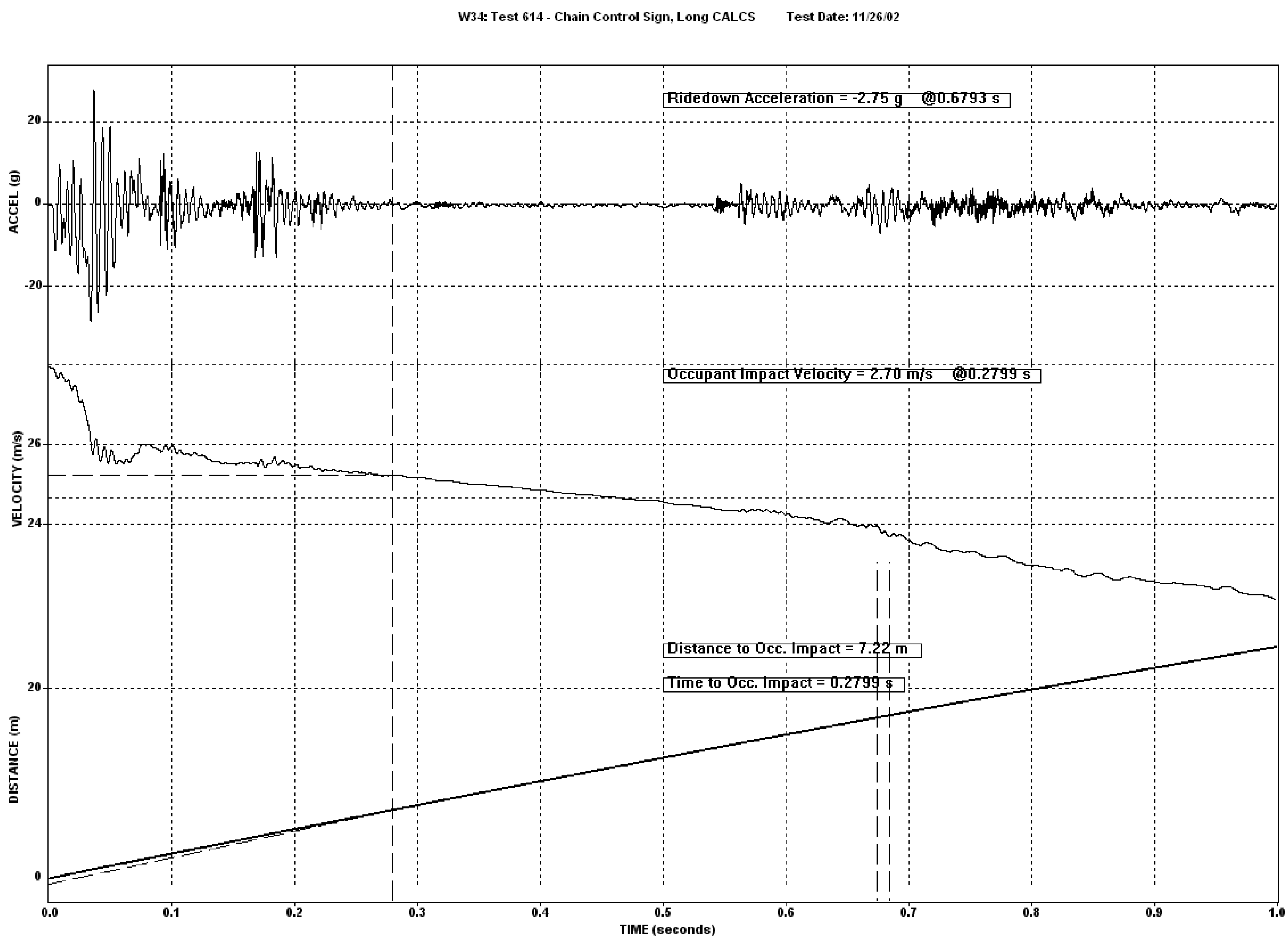


Figure 7-25. Test 614 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time

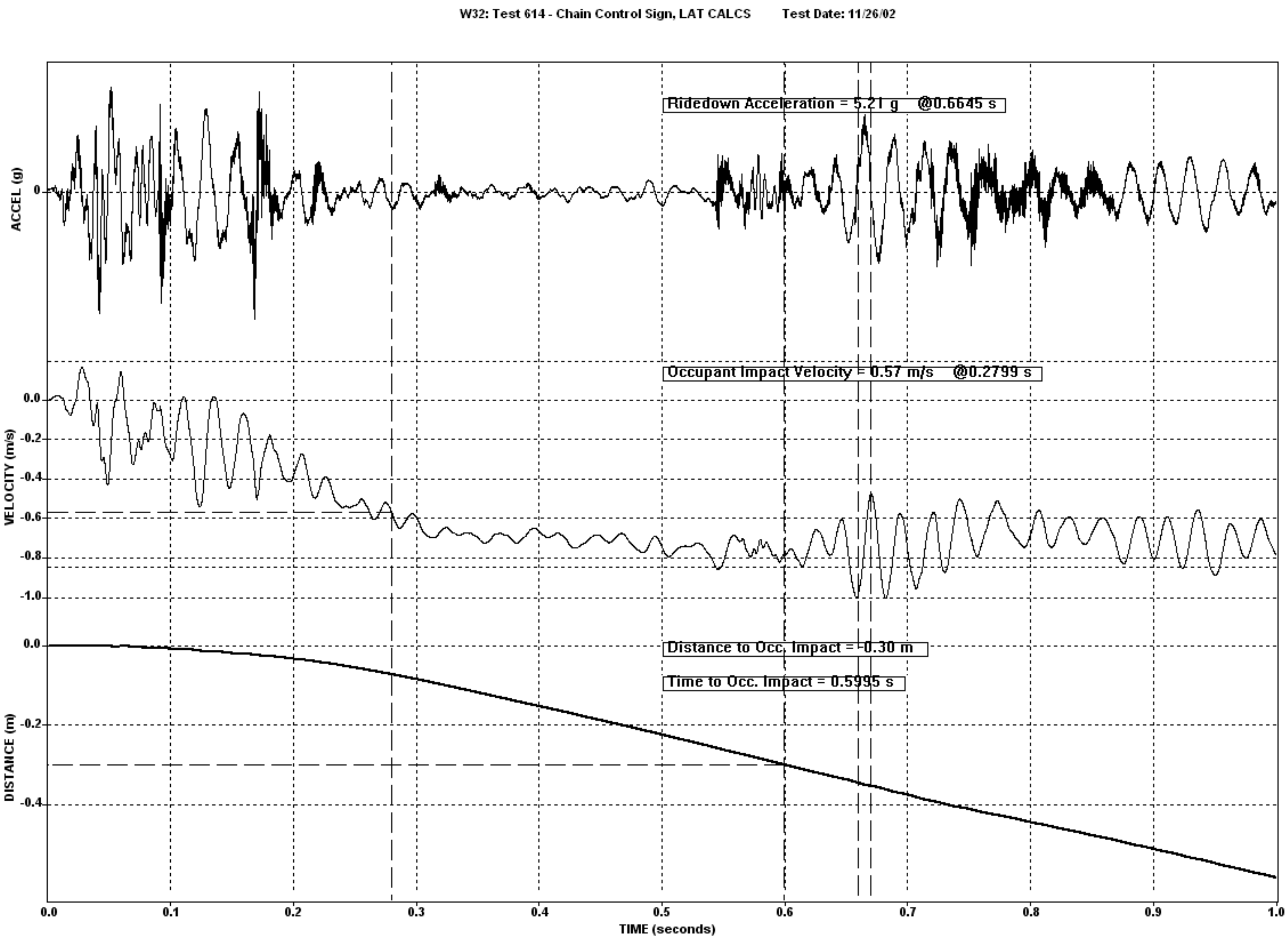


Figure 7-26. Test 614 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time

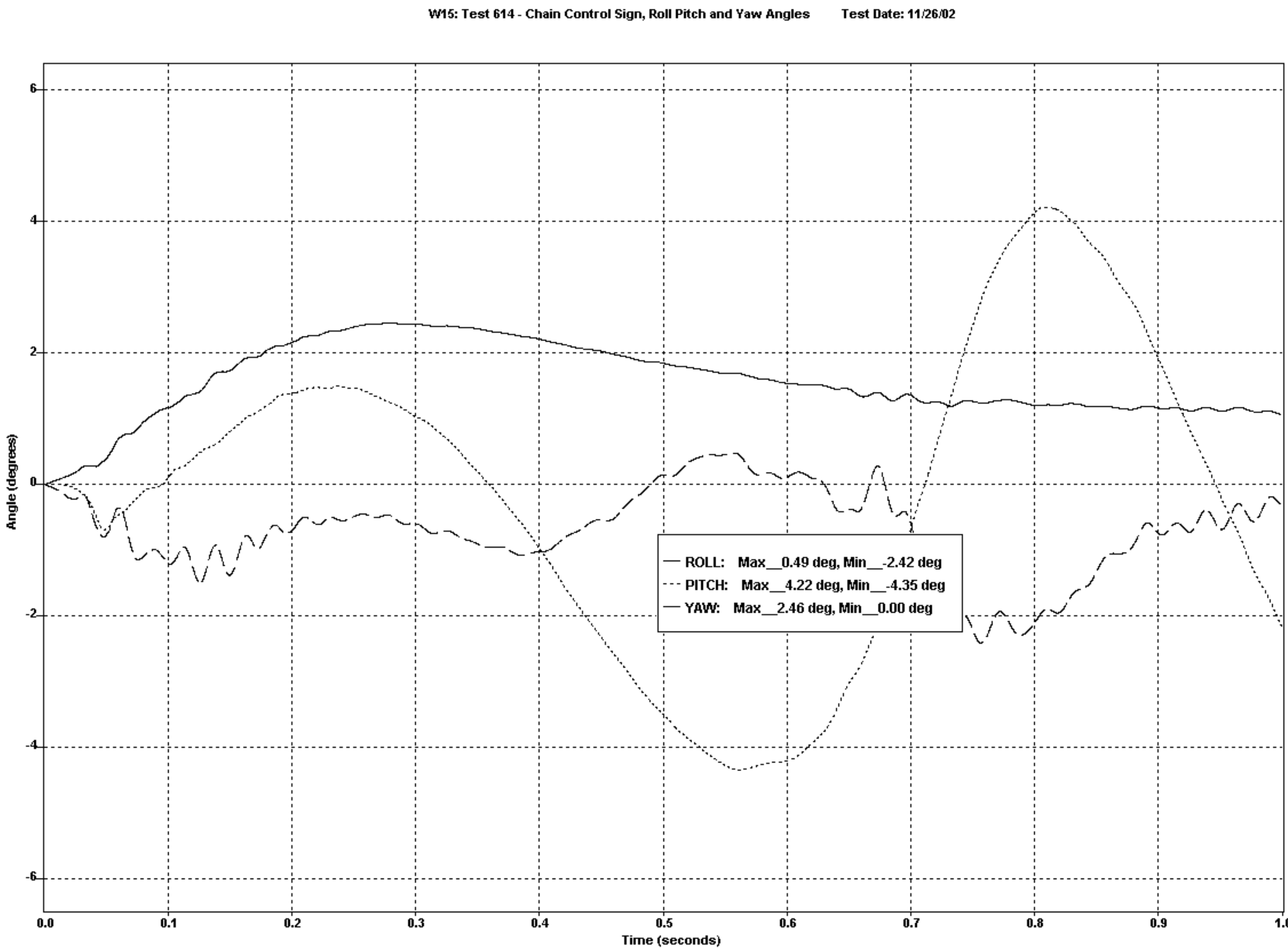


Figure 7-27. Test 614 Vehicle Roll, Pitch, and Yaw Vs Time

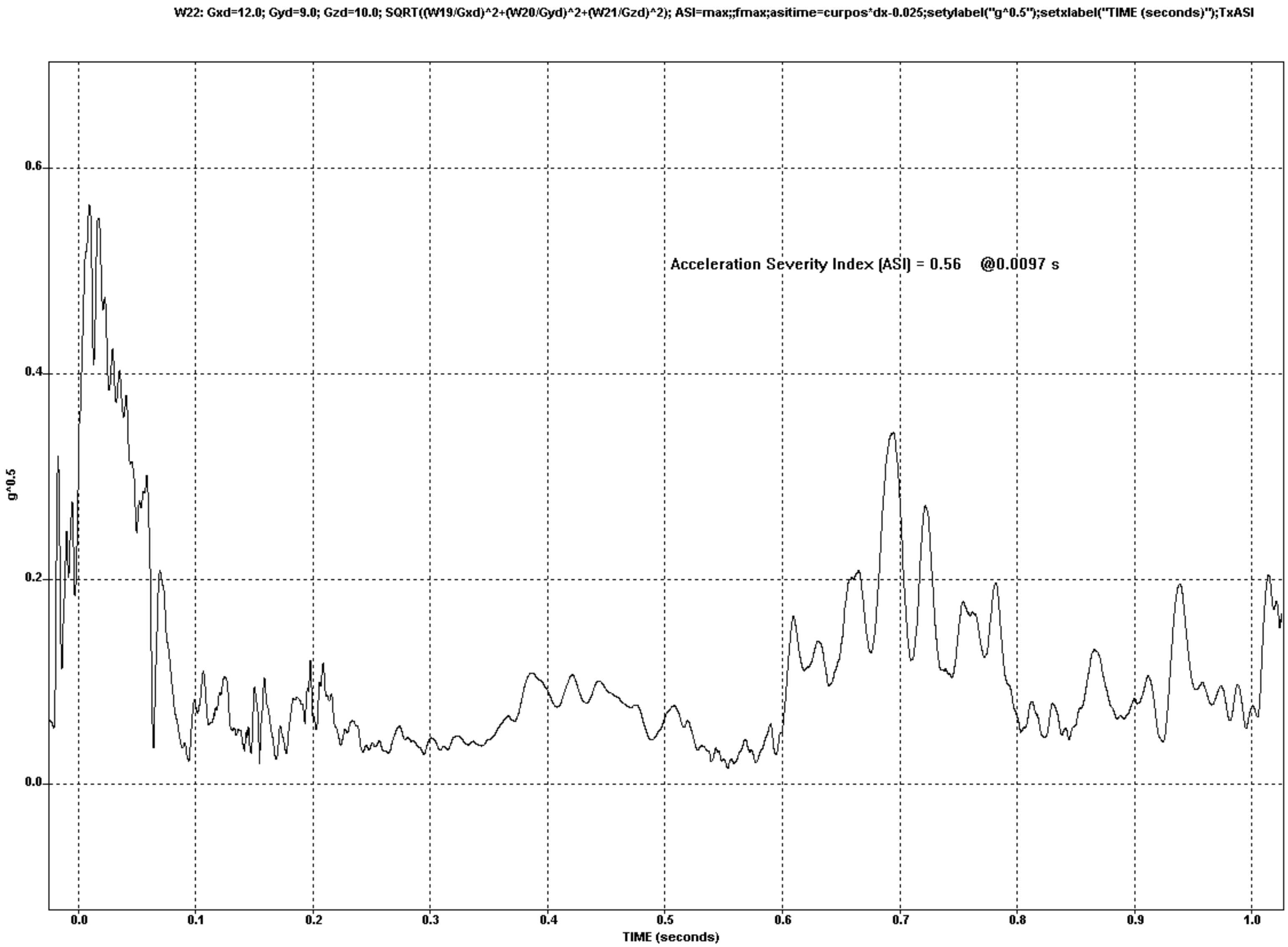


Figure 7-28. Test 614 Acceleration Severity Index Vs Time

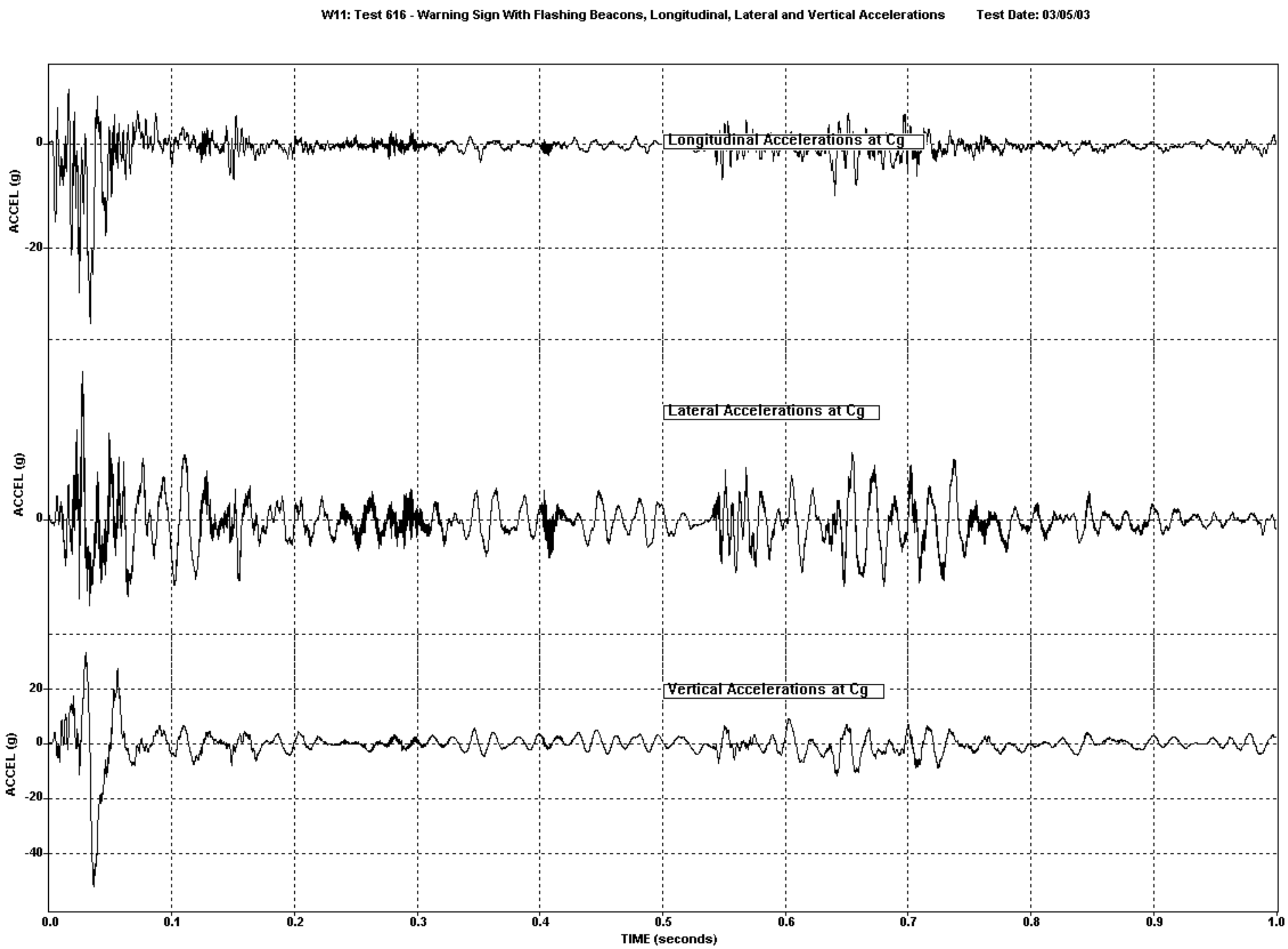


Figure 7-29. Test 616 Vehicle Accelerations Vs Time

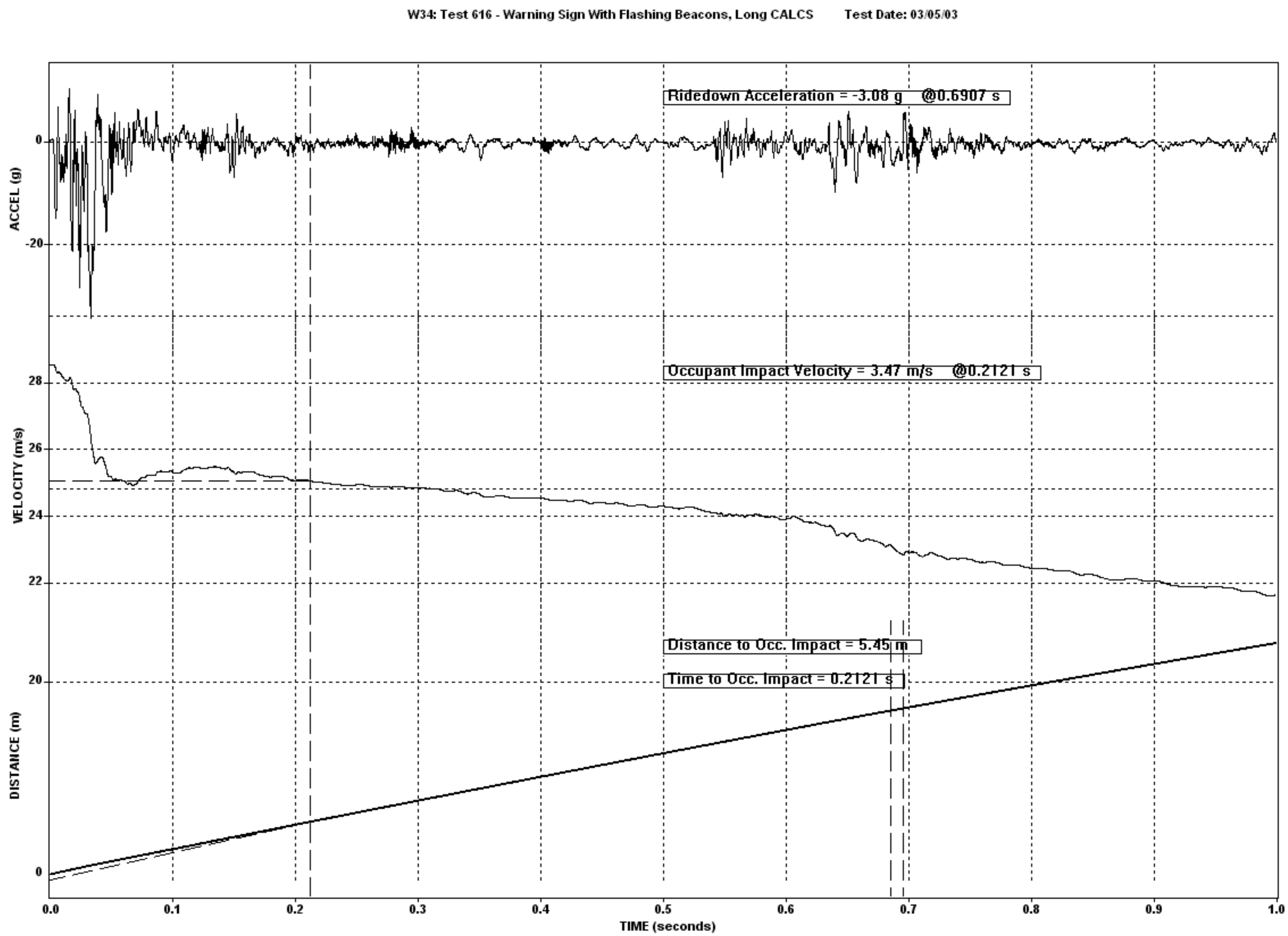


Figure 7-30. Test 616 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time

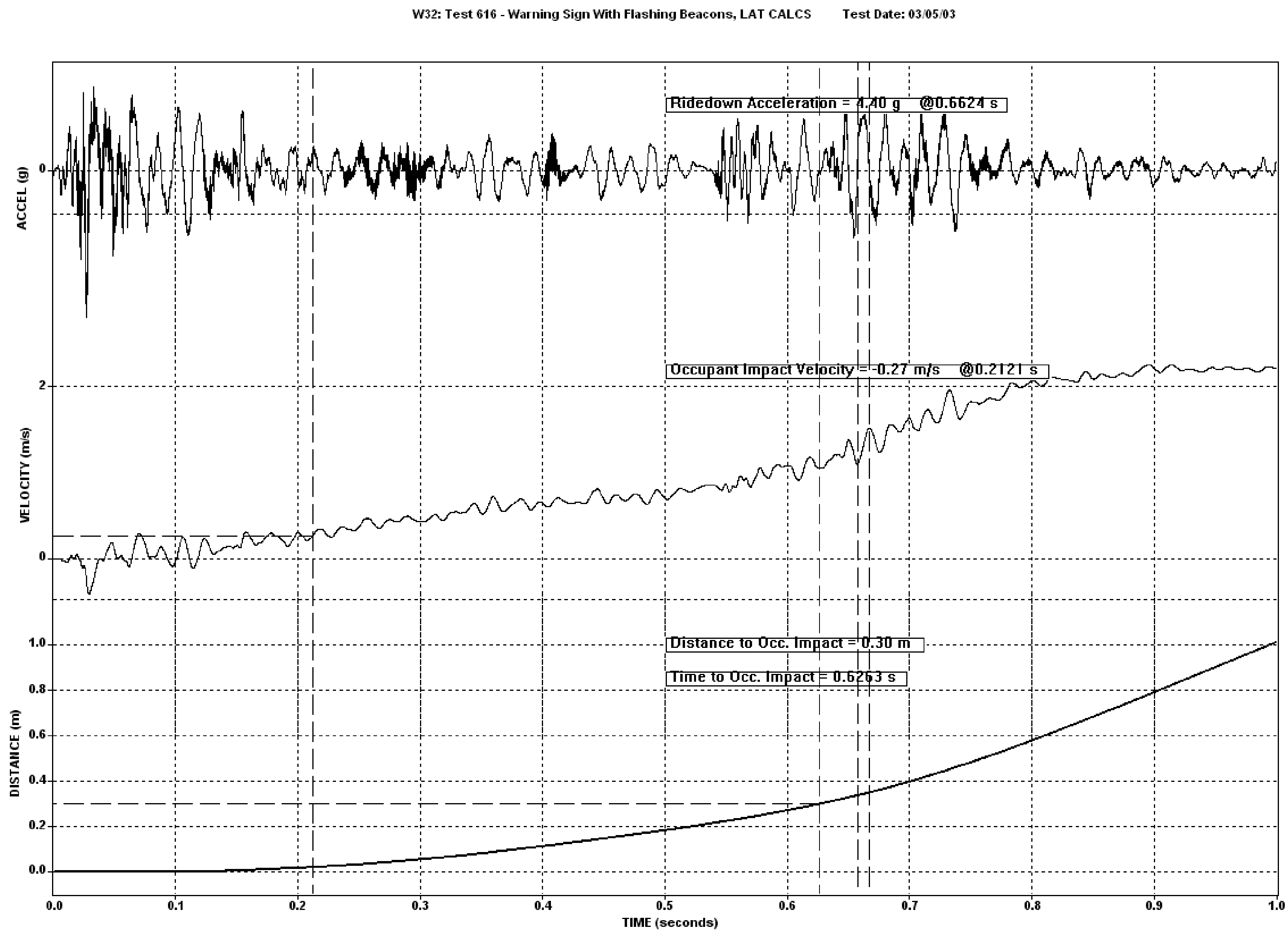


Figure 7-31. Test 616 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time

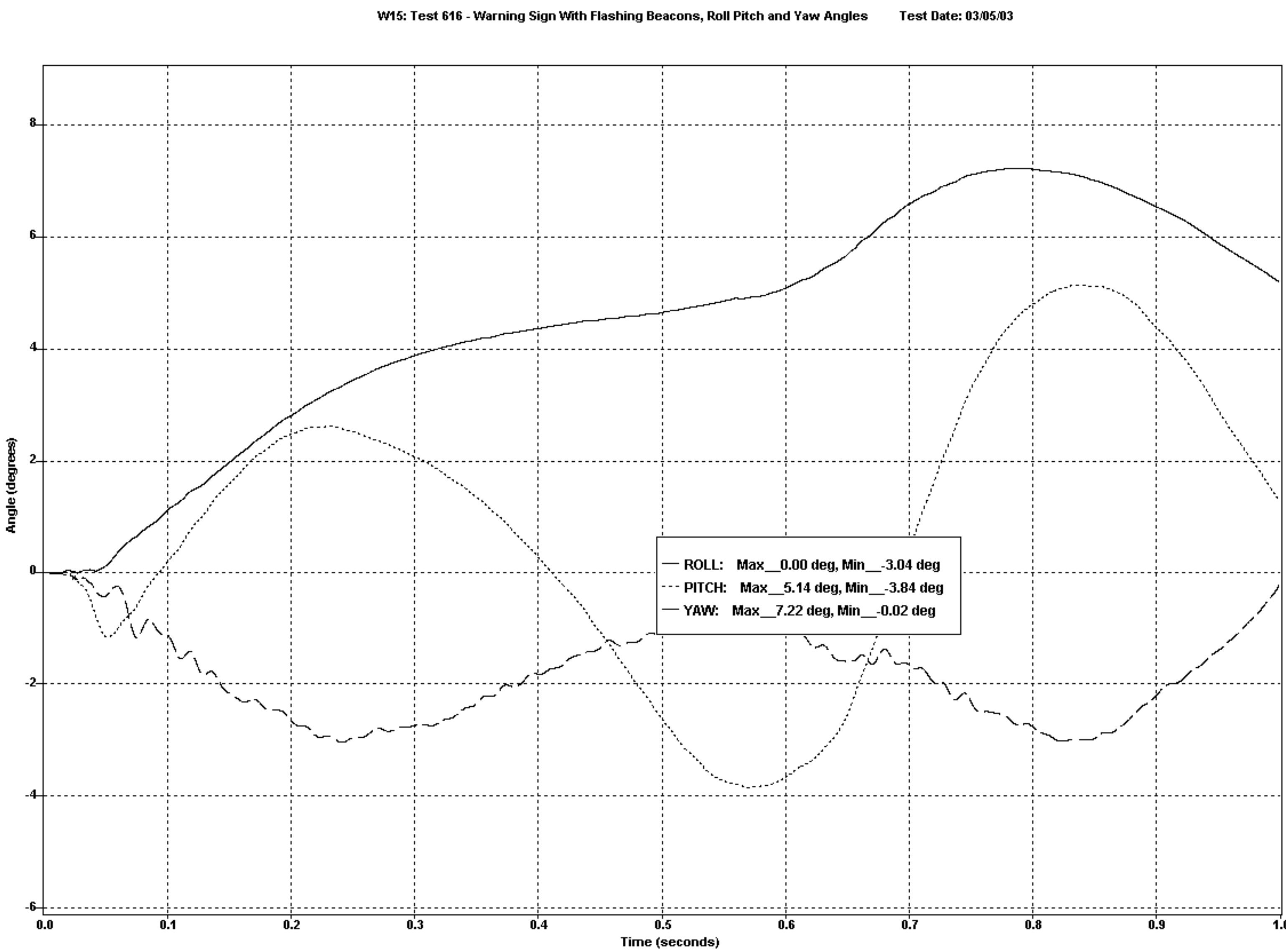


Figure 7-32. Test 616 Vehicle Roll, Pitch, and Yaw Vs Time

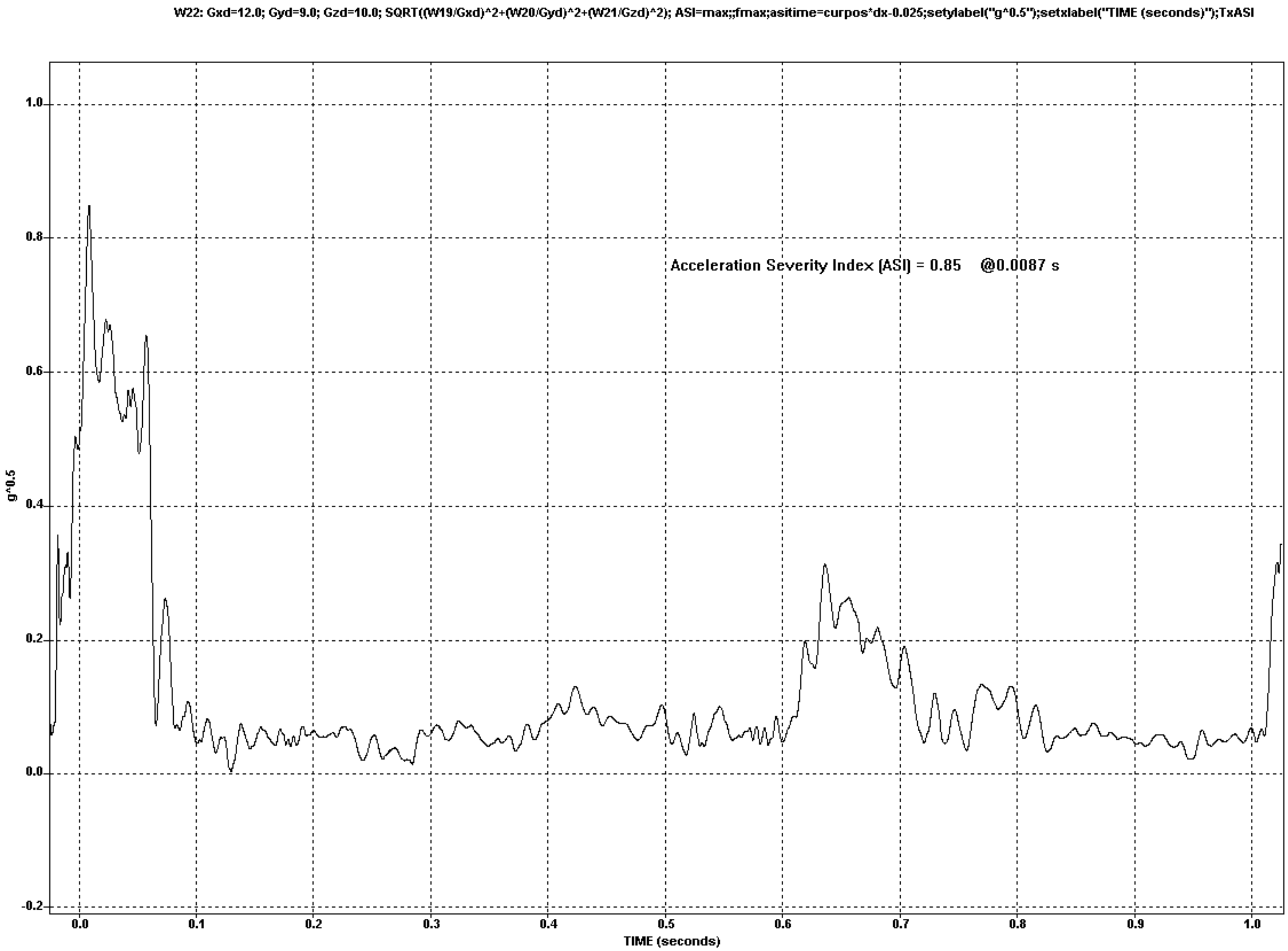


Figure 7-33. Test 616 Acceleration Severity Index Vs Time

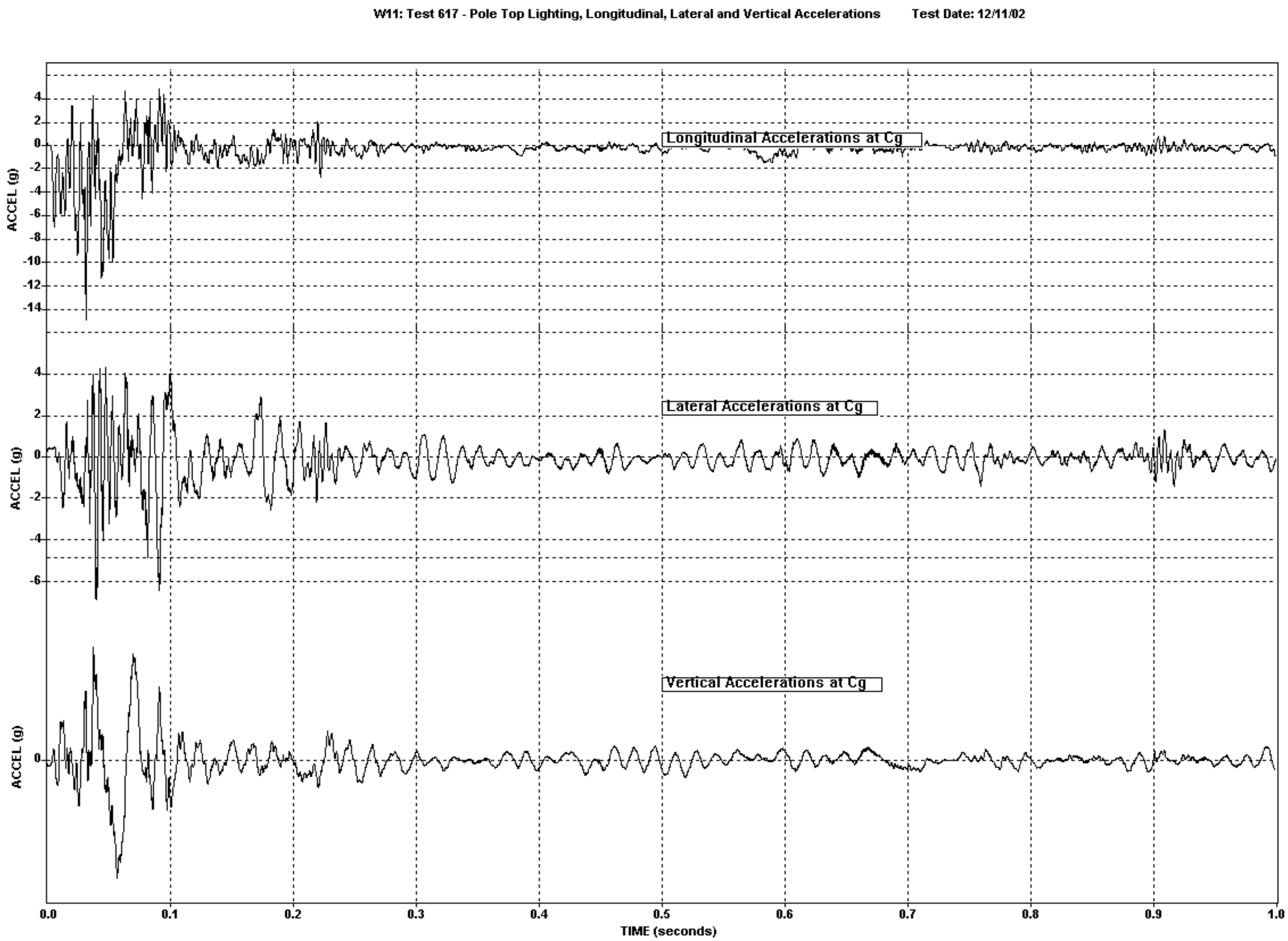


Figure 7-34. Test 617 Vehicle Accelerations Vs Time

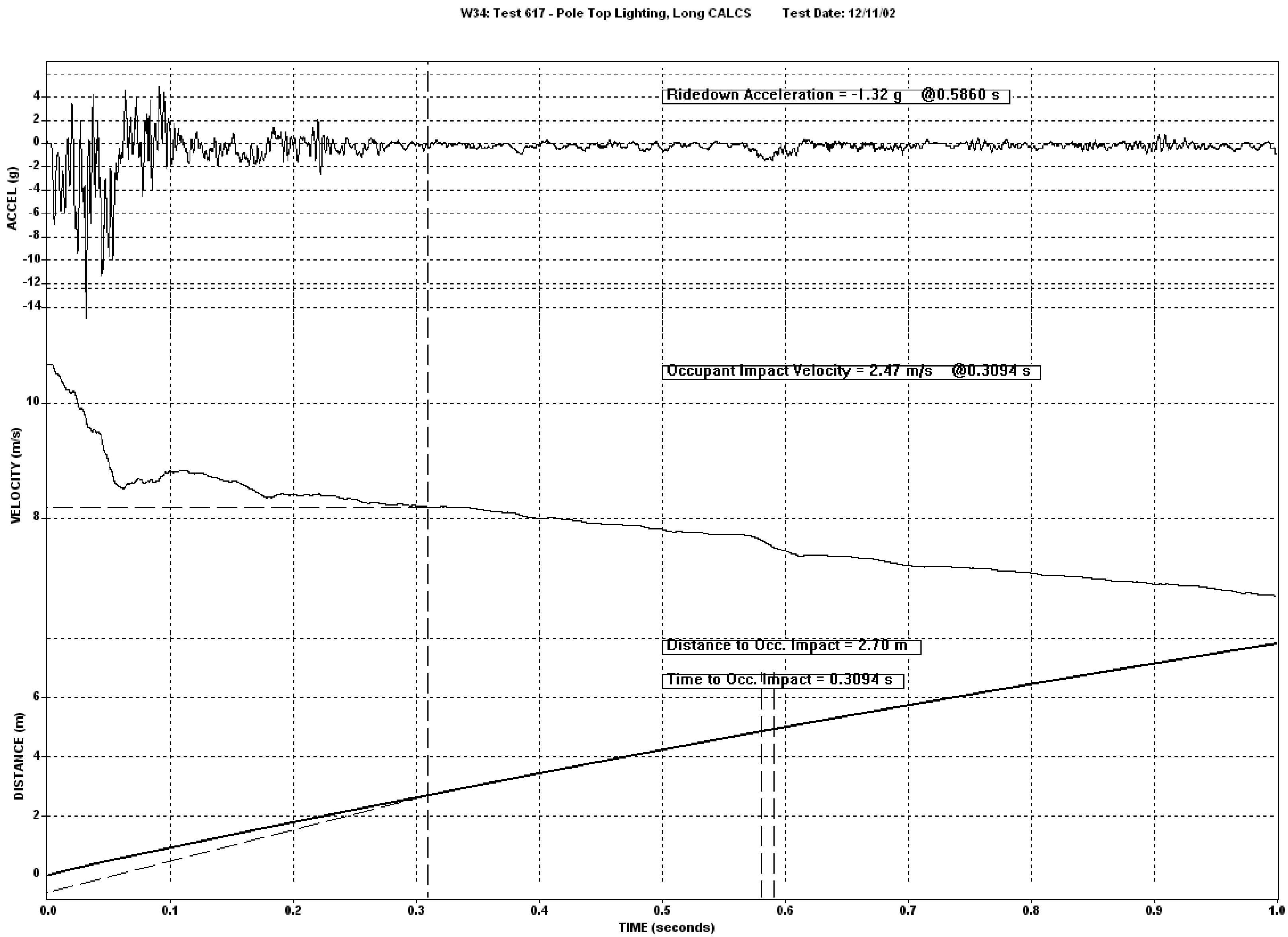


Figure 7-35. Test 617 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time

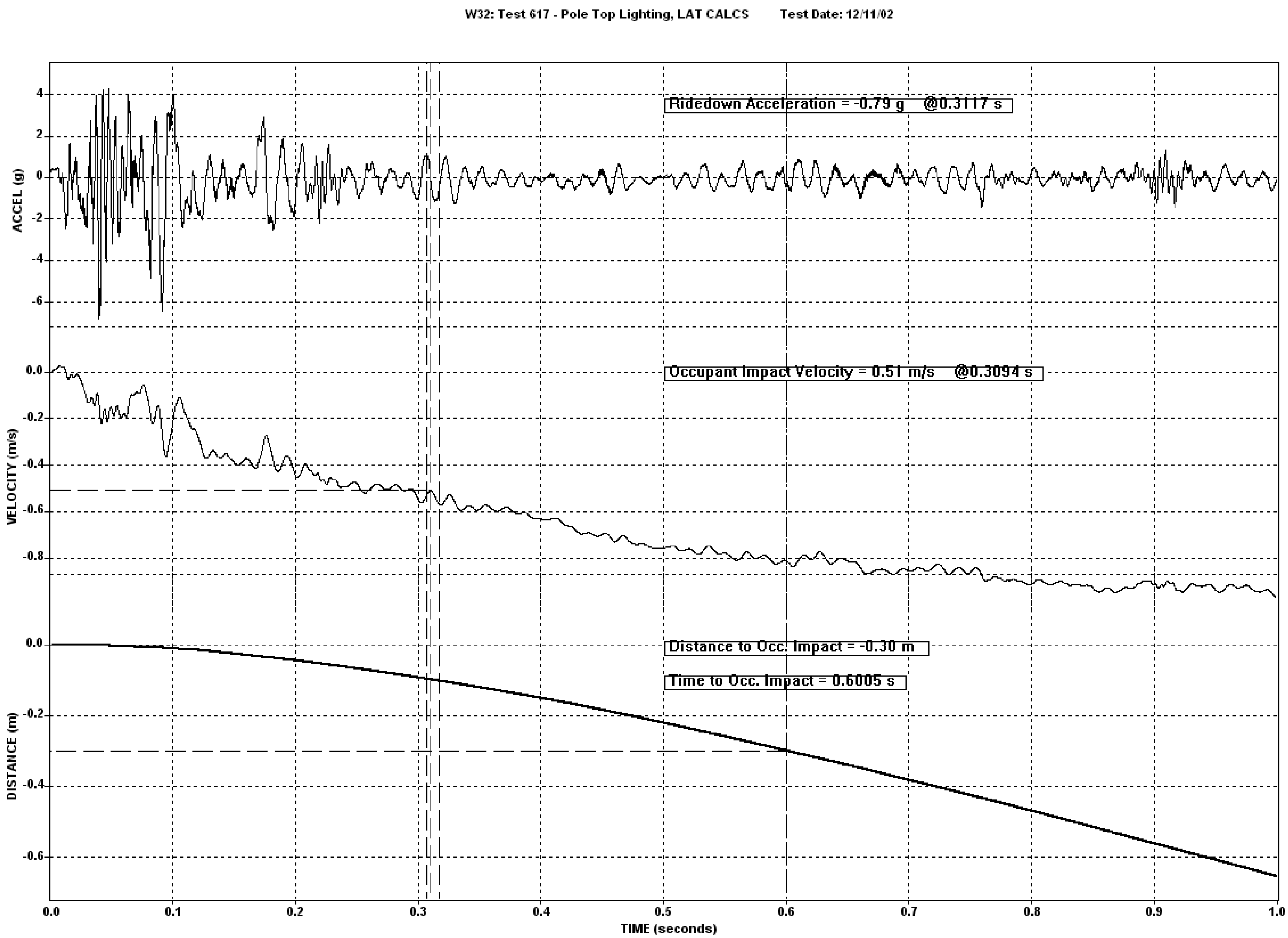


Figure 7-36. Test 617 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time

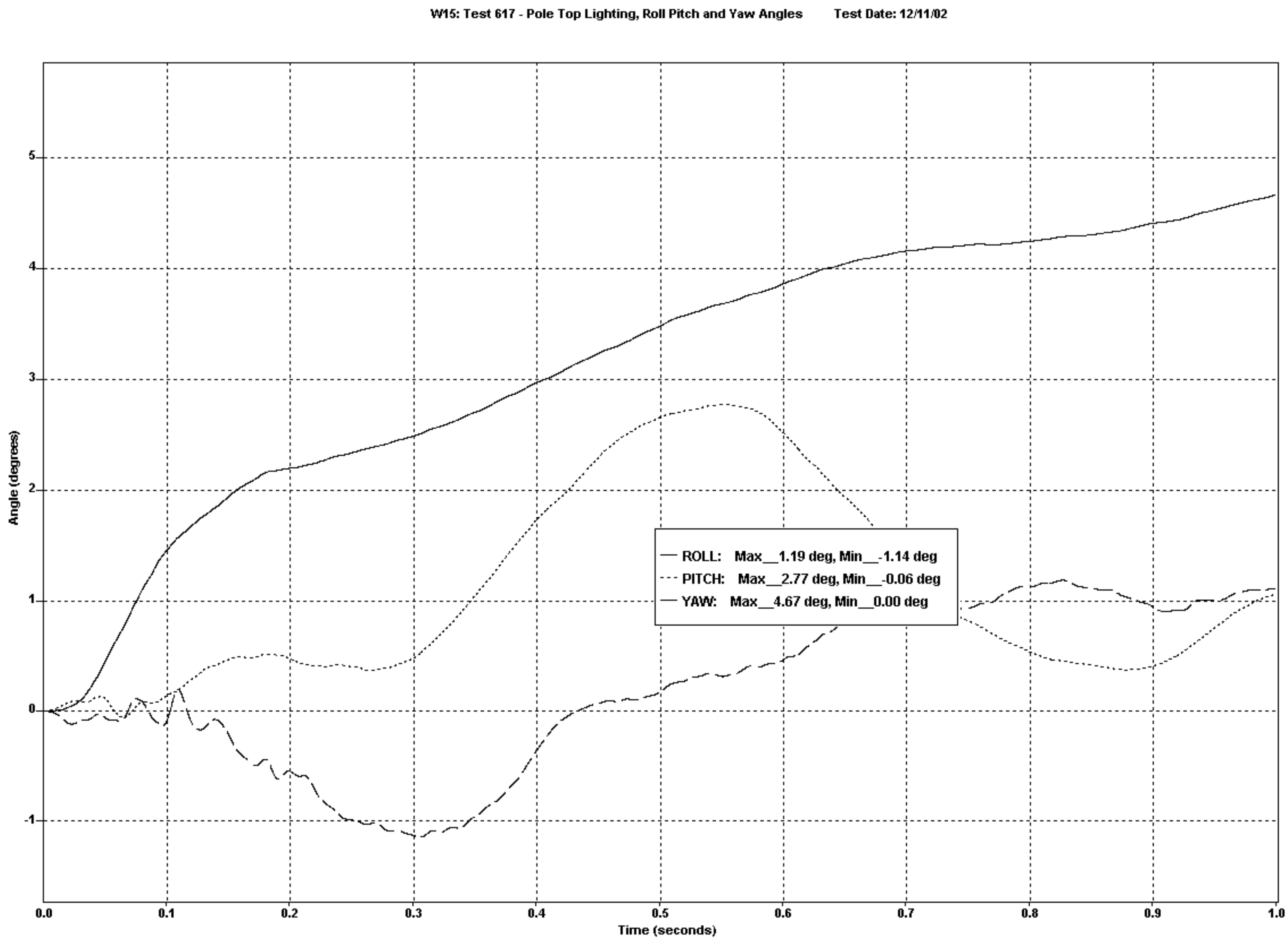


Figure 7-37. Test 617 Vehicle Roll, Pitch, and Yaw Vs Time

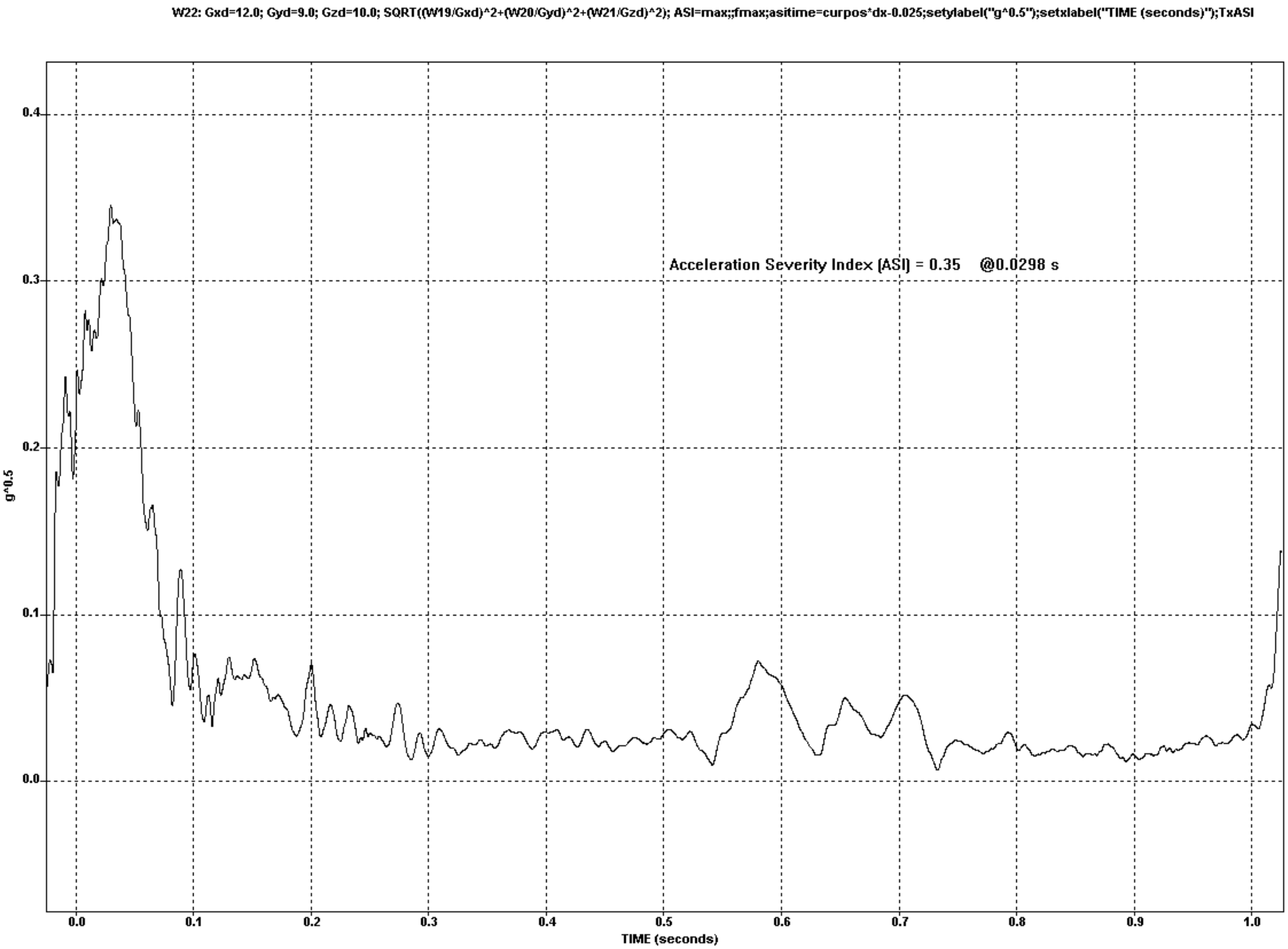


Figure 7-38. Test 617 Acceleration Severity Index Vs Time

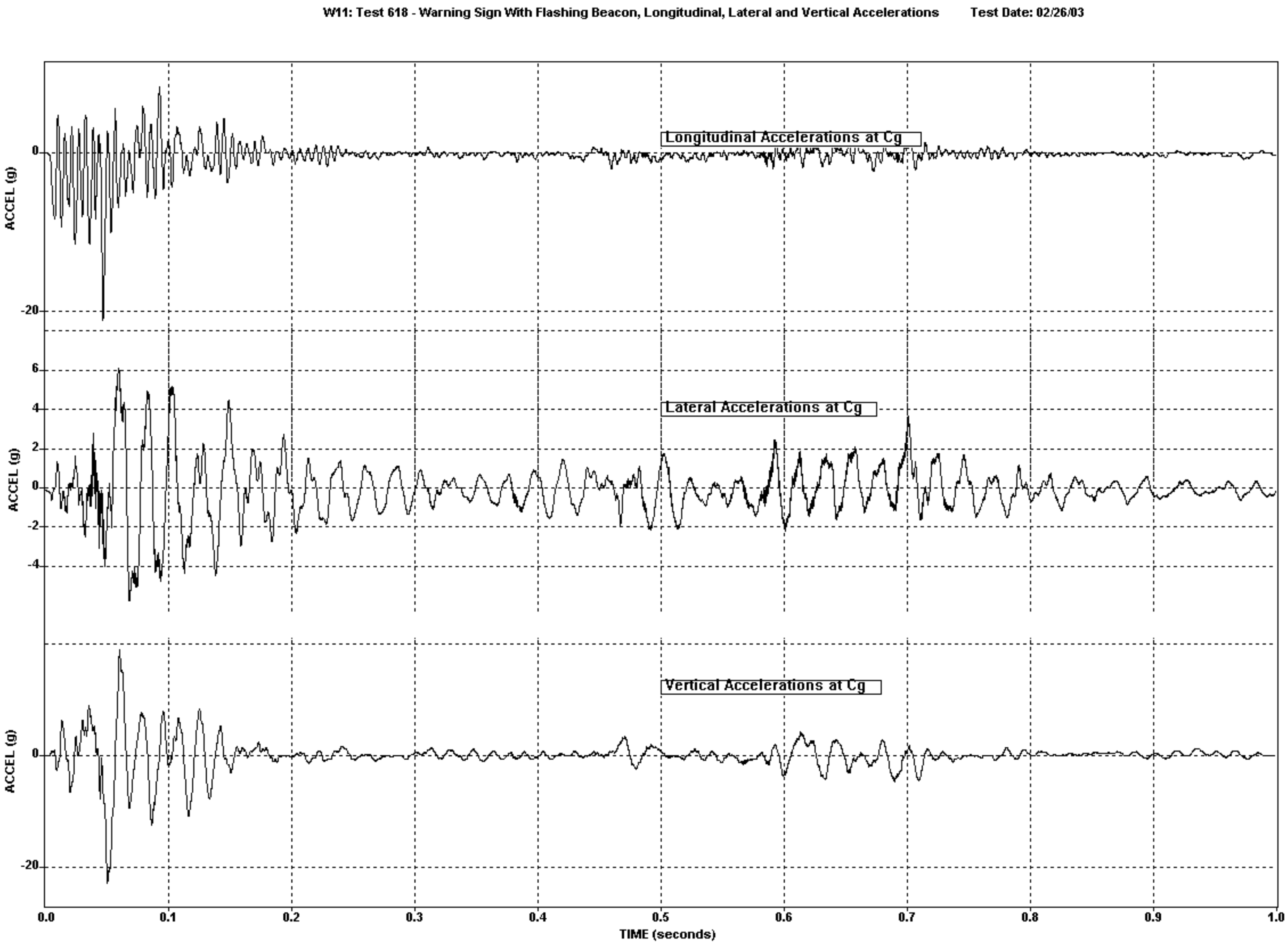


Figure 7-39. Test 618 Vehicle Accelerations Vs Time

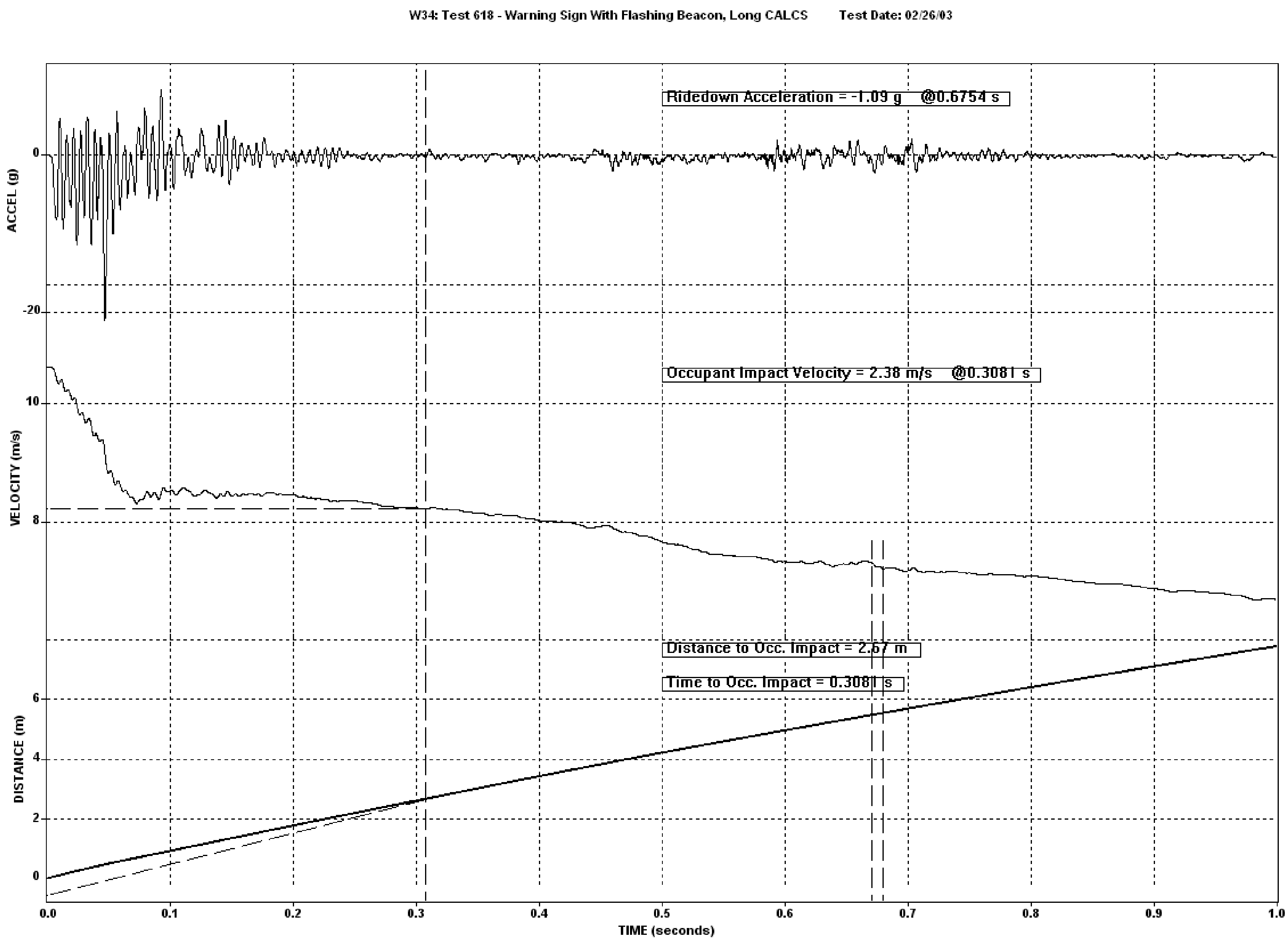


Figure 7-40. Test 618 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time

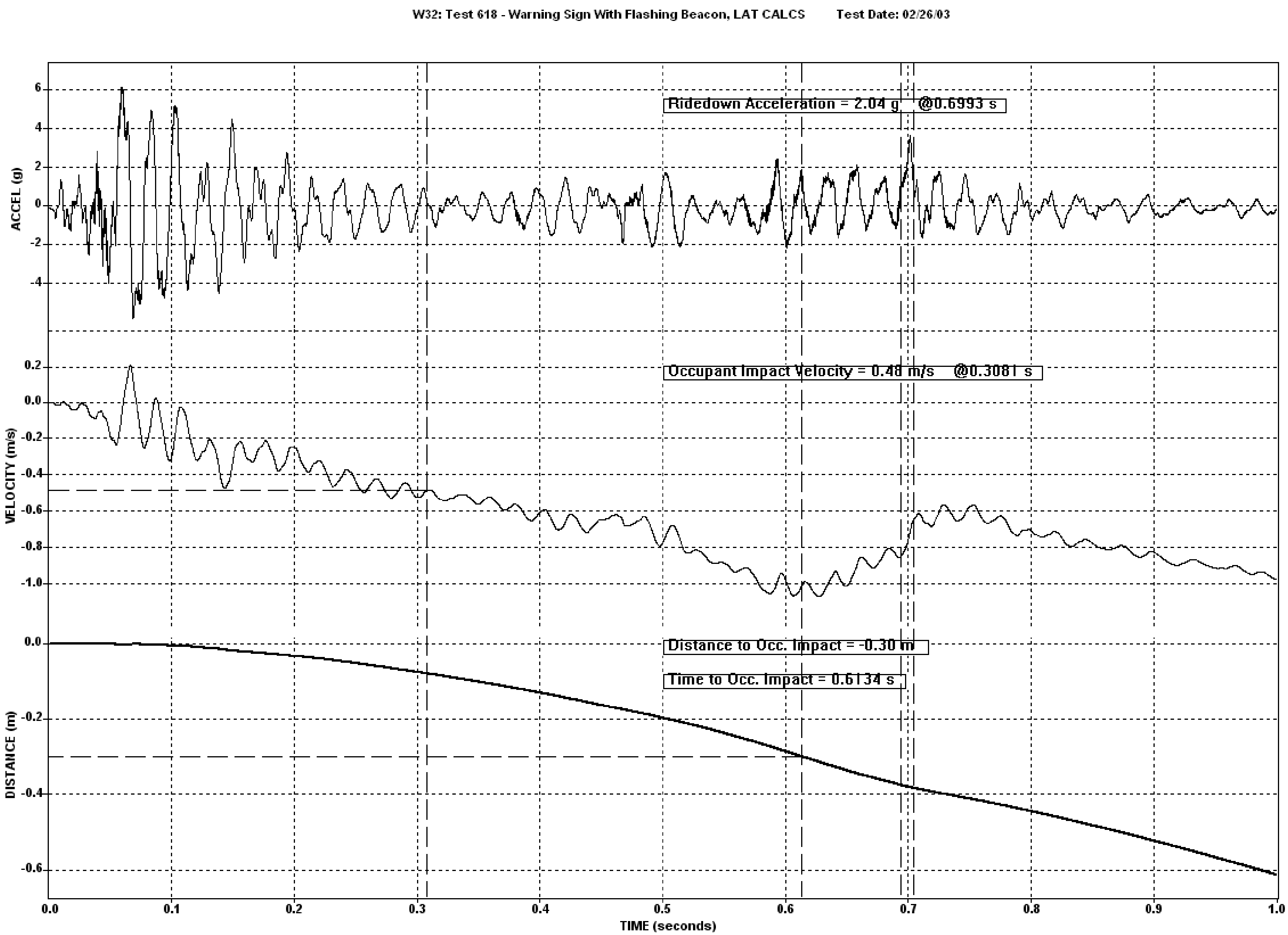


Figure 7-41. Test 618 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time

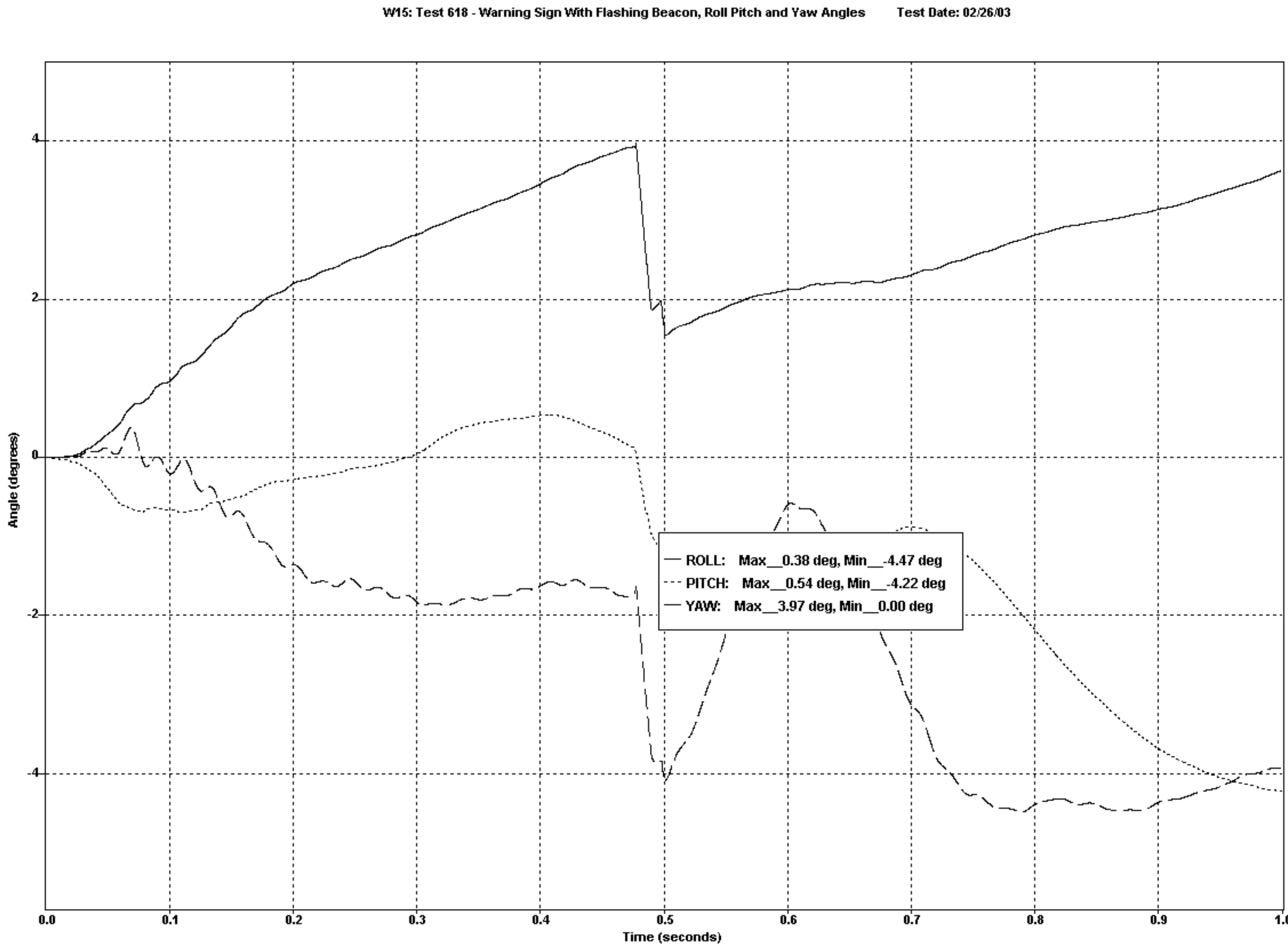


Figure 7-42. Test 618 Vehicle Roll, Pitch, and Yaw Vs Time

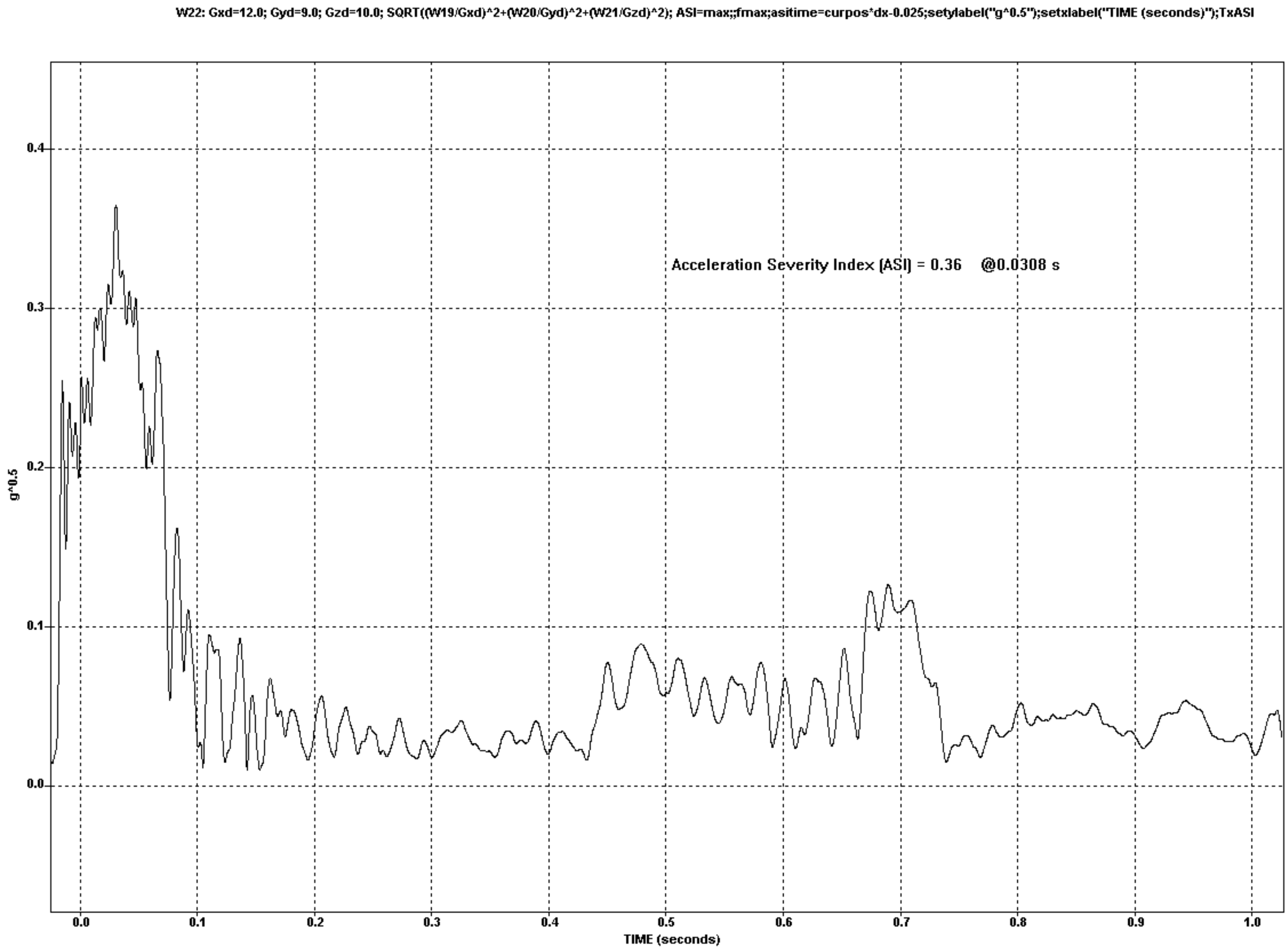


Figure 7-43. Test 618 Acceleration Severity Index Vs Time