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This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled "DEVELOPMENT OF WEED CONTROL BARRIER BENEATH METAL BEAM GUARDRAIL."

16. ABSTRACT

A section of steel-post Metal Beam Guardrail with a weed control barrier was tested in accordance with NCHRP Report 350. The weed control barrier consists of a "leave-out area" of expanded polystyrene foam (EPF) around the base of each post combined with a non-proprietary cementitious material called CRMCrete placed around the EPF and posts. The Metal Beam Guardrail with CRMCrete weed barrier tested was approximately 193 ft (59 m) long and was constructed at the Caltrans Dynamic Test Facility in West Sacramento, California.

Two full-scale crash tests were conducted with a 4410 lbm (2000-kg) pickup truck under Report 350 Test Level 3 (Test 3-31). The first test, which was not successful, was performed on a different test article than that described above. The second test was performed on the test article described above. The results of the second test were within the limits of the Report 350 guidelines.

The CRMCrete/Styrofoam weed barrier tested in this project is recommended for approval on California highways where a weed barrier material is desired under metal beam guardrail.

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DEVELOPMENT OF WEED CONTROL BARRIER BENEATH METAL BEAM GUARDRAIL

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
DIVISION OF RESEARCH AND INNOVATION
OFFICE OF SAFETY INNOVATION AND COOPERATIVE RESEARCH
ROADSIDE SAFETY RESEARCH GROUP

Supervised by..Robert Meline, P.E.

Principal Investigator.. John Jewell, P.E.

Report Prepared by ....David Whitesel, P.E.

Research Performed by...Roadside Safety Research Group

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METRIC (SI) to English System of Measurement

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-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		
kg	lb$_m$	2.205
PRESSURE OR STRESS		
kPa	psi	0.1450
VELOCITY		
km/h	mph	0.6214
m/s	ft/s	3.281
km/h	ft/s	0.9113

ACKNOWLEDGMENTS

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration.

Special appreciation is due to Sal Torres, Caltrans engineer in District 2 who developed the product and provided technical consultation. Additional special appreciation is due to the following staff members of the Division of Research and Innovation and the Roadside Safety Research Group for their help on this project: John Jewell, Mike O'Keeffe, Ali Zalekian, Malinda Gallaher, Vue Her, Christopher Caldwell, and Larry Moore, test preparation, data reduction, vehicle preparation, and video processing; Dave Bengel, Independent Camera Operator; Eric Jacobson and Ed Ung, electronic instrumentation; Martin Zanotti, Mike Said, and Bill Poroshin, machine shop services; and Don Tateishi, Ed Andersen, and Scott Lorenzo, Headquarters Photo Section. This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration.

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1 INTRODUCTION

1.1 Problem

Caltrans currently uses herbicides, mechanical methods, or miscellaneous asphalt concrete (AC) to control weeds beneath metal beam guardrail (MBGR). The use of herbicides is being reduced due to environmental concerns. Worker exposure and cost are also significant issues especially for mechanical weed control. Placement of miscellaneous AC beneath guardrail works well until the AC cracks and the weeds grow through it. A more effective, less costly, but still crashworthy method of weed control beneath guardrail is needed. A non-proprietary cementitious product called CRMCrete that is more durable than miscellaneous AC has been introduced that can be placed under guardrail to physically block weed growth. It is unknown how this material will affect the performance of guardrail posts. There are insufficient crash test data to verify that guardrail subjected to this treatment will comply with National Cooperative Highway Research Program (NCHRP) Report 350[(1)] criteria.

1.2 Objective

The objective of this project was to determine whether a non-proprietary cementitious material can be placed beneath MBGR to prevent weed growth yet still allow the guardrail posts to move as necessary for the system to comply with NCHRP Report 350 Test Level 3 criteria for longitudinal barriers. For research and comparison purposes, a series of dynamic tests were conducted in which a bogie (surrogate test vehicle) was impacted head-on into steel posts at 20 mph (32 km/h). Then, a full-scale crash test with a ¾-ton pick-up truck (2000P) impacting metal beam guardrail was conducted to ensure compliance with NCHRP Report 350, Test Level 3 for longitudinal barriers.

1.3 Background and Significance of Work

Weed growth beneath metal beam guardrail systems is a problem because it is unsightly and the dry weeds can provide enough fuel to become the starting point of a larger brush or wild land fire. Various techniques for controlling weeds have been tried and range from physical barriers, such as weed mats and asphalt concrete, to the use of herbicides to kill weeds. Mechanical weed control is also used in some locations but is labor intensive with worker exposure to traffic

Weed mats are costly and asphalt concrete (AC) does not work well because many types of weeds are able to grow in cracks that inevitably develop in the AC. Because of environmental and worker safety concerns, the Department is reducing the amount of herbicide used along the State highway system.

This project sought to develop a physical barrier to weed growth beneath MBGR by investigating a cementitious material that would be placed under the rail and around the posts.

The material is called CRMCrete and was developed by Sal Torres, Jr. at the Caltrans District 2 Office of Roadside Maintenance. CRMCrete consists of standard 3/8-in (9.5 mm) 6.5 sack (611 lb/ft^3, 9790 kg/m^3) concrete mix, polypropylene fibers, scrap tire crumb rubber, and an optional colorant. Apart from this research project, Mr. Torres conducted compressive strength testing, flexural strength testing, and air content testing on many CRMCrete samples with varying rubber content. His goal was to find a mix design that would be adequate from a durability standpoint and with a low enough compressive strength so as to minimize the CRMCrete's effect on post rotation. Through testing, he determined that a mix design with 4 percent rubber by mass would have a compressive strength of about 1600 psi (11.0 MPa) would be adequate from a durability standpoint. An additional benefit is that scrap tire rubber is recycled and used in this concrete. Dynamic testing would determine whether the weed barrier would inhibit post rotation and the guardrail's ability to dissipate energy and redirect a vehicle.

1.4 Literature Search

A literature search was conducted at the beginning of the project to find research reports or publications related to the objectives of this project. Texas Transportation Institute completed a similar research project in which they tested different types of weed barriers [(2)]. However, the design recommended by TTI utilizes a 5-inch section of normal-strength concrete with a weakened section around each post filled with low-strength grout. This is labor-intensive and expensive since it requires additional formwork and for the contractor to be at the site an additional day to place the grout. It has been used by Caltrans but a more cost-effective solution was desired. Because of the significant differences between the Caltrans design and the TTI recommended design, additional testing was needed. Thin asphalt concrete and Portland cement concrete in various mixtures and configurations have been used to limit weed growth beneath and around roadside hardware by many agencies without evaluation of the affect on the dynamic response of guardrail. The research performed by TTI and this research project improve the understanding of guardrail behavior during impacts.

1.5 Scope

As previously described, a series of dynamic tests were conducted in which a bogie (surrogate test vehicle) was run head-on into various posts at 32 km/h (20 mph) for comparative purposes. Two tests were performed first on two posts without weed control barrier to establish a baseline for post performance. Four bogie tests were then performed on two different configurations of weed control barrier. Finally, a full-scale crash test with a ¾-ton pick-up truck (2000P) impacting metal beam guardrail was performed to validate the bogie test results. The 2000P test was done to ensure the new system did not produce excessive pitch, roll, yaw, deceleration, or occupant compartment deformation of the vehicle. Testing was done in accordance with NCHRP Report 350, Test Level 3, for longitudinal barriers.

The initial designs tested used rubber boots made from recycled rubber around the posts with the CRMCrete poured directly up to the boot edges. Dynamic bogie tests were performed with different boot configurations, including two tests without any boot or CRMCrete. Post rotation characteristics were analyzed to determine which configuration of boot and CRMCrete most closely matched the performance of posts without CRMCrete. For the bogie testing, six steel posts were installed in a strong soil pit at the Caltrans Dynamic Test Facility in West Sacramento. CRM Crete was placed around four of the posts while CRMCrete was left off of two posts (for baseline testing). Data were collected from tests 654-657 and compared to the results of baseline tests (652 and 653). The Bogie test criteria are listed in Table 1-1.

Table 1-1 – Intended Bogie Test Conditions

Test #	Test Article Description	Speed, km/h, (mph)	Nominal Angle ϕ, deg
652	MBGR Steel Post, No weed barrier	32 (20)	90
653	MBGR Steel Post, No weed barrier	32 (20)	90
654	MBGR Steel Post, 8 in (200 mm) Leave-out, 2 in (50 mm) CRMCrete	32 (20)	90
655	MBGR Steel Post, 8 in (200 mm) Leave-out, 2 in (50 mm) CRMCrete	32 (20)	90
656	MBGR Steel Post, 10 in (254 mm) Leave-out, 3.5 in (89 mm) CRMCrete	32 (20)	90
657	MBGR Steel Post, 10 in (254 mm) Leave-out, 3.5 in (89 mm) CRMCrete	32 (20)	90

A full-scale dynamic pickup test was performed on the best configuration. A 200-foot (60.96 m) section of MBGR with steel posts was constructed with SFT end terminals at each end. CRMCrete weed barrier was poured around the posts. Because this first full-scale crash test resulted in a rollover, the CRMCrete weed barrier was re-configured and retested. The leave-out area of this second design utilized a 1.5-inch (38-mm) thick piece of foam around each post (with the top below finished grade) with a thin layer of CRMCrete over the top to hold it down and for uniformity of appearance. For the second full-scale test, a re-test of the first full-scale test, a 193.25-foot (58.9-m) section of MBGR with steel posts was constructed with a SRT end terminal at the upstream end and a SFT at the downstream end. The data were collected from this test and were analyzed to determine if the MBGR with CRMCrete weed barrier met the criteria set forth in NCHRP Report 350. The full-scale test criteria are listed in Table 1-2

Table 1-2 – Full-scale Test Conditions

Test #	MBGR Description	Mass, Kg (lb)	Speed. km/h (mph)	Angle, deg	NCHRP Report 350	
					Test Designation	Vehicle
658	Steel Post, 2 in (51 mm) thick CRMCRETE with 10 in (254 mm) Leave-out behind post and 3 in (76 mm) on the sides	2000 (4410)	100 (62.1)	25	3-11	2000P
659*	Steel Post, 2 in (51 mm) thick CRMCRETE, 8 in (203 mm) Leave-out behind post and 7 in (178 mm) on the sides	2000 (4410)	100 (62.1)	25	3-11	2000P

2 TECHNICAL DISCUSSION

2.1 Test Conditions - Crash Tests

2.1.1 Test Facilities

All of the testing was conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The test area is a large, flat, asphalt concrete surface. The test article was constructed off the edge of pavement on the east side of the facility. There were no obstructions nearby.

2.1.2 Test Vehicles

The test vehicles included a surrogate vehicle (bogie) and GMC/Chevrolet 2500 series pickups. The bogie was used only to compare relative performance of the posts and thus did not conform to NCHRP Report 350. The bogie with ballast weighed 1500 lb (681 kg) and had a 8.5-in (216-mm) outside diameter cylindrical steel tube bumper mounted such that the impact height was 25-in (635 mm). The bogie is shown in Figure 2-1.

* Re-test of Test 658

Figure 2-1 – Lightweight Bogie

The test vehicles for the full-scale tests complied with NCHRP Report 350. For the full-scale test, the vehicles were in good condition, free of major body damage and were not missing any structural parts. The vehicles had standard equipment and front-mounted engines. The 2000P inertial mass for each vehicle was within acceptable limits (see Table 2-1).

Table 2-1 – Test Vehicle Masses

Test No.	Vehicle	Ballast. lb_m (kg)	Test Inertial lb_m (kg)
652-657	Surrogate Vehicle (Bogie)	99 (45)	1500 (681)
658	1988 CHEVY 2500	0 (0)	4387 (1990)
659	1994 CHEVY 2500	0 (0)	4348 (1972)

During tests 652 thru 657, a Ford dually pickup was used to push the bogie up to the impact speed. The push vehicle was equipped with a speed control device to limit acceleration once the impact speed had been reached. The pickup trucks were self-powered and also 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 control. During all tests the test vehicle was released from the guidance rail a short distance before the point of impact. During all full-scale tests, the ignition system was also deactivated a short distance before the point of impact. A detailed description of the test vehicle equipment and guidance system is contained in Appendices 7.1 and 7.2.

2.1.3 Data Acquisition System

The impact of each bogie crash test was recorded with a minimum of three high speed digital movie cameras and one still digital camera. The impact event of test 658 was recorded with 6 high-speed digital video cameras, one normal-speed digital camcorder, and one digital camera in sequence mode. The impact event of test 659 was recorded with 4 high-speed digital video cameras, one normal-speed digital camcorder, and two digital cameras in sequence mode.

The test vehicles and the barrier were photographed before and after impact with a normal-speed digital camcorder and a digital camera.

Two sets of orthogonal accelerometers, one primary set and one as a backup, were mounted at the horizontal center of gravity of the bogie. Two sets of orthogonal accelerometers were similarly mounted in the 2000P vehicle. Rate gyro transducers were also placed at the center of gravity of the 2000P vehicle to measure the roll, pitch, and yaw. The data were used in calculating the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation.

Anthropomorphic dummies were not used in any of the tests.

Two digital data recorders manufactured by GMH Engineering (Data Bricks) were used to record electronic data during all tests. The digital data from test 658 were not analyzed because the test resulted in vehicle rollover. The digital data from test 659 were analyzed with Test Risk Assessment Program (TRAP) Version 2.1 using a desktop computer.

2.2 Test Articles – Design, Construction, and Results of Crash Tests

The test articles evolved during the course of testing. The design, construction, and crash test results of each test article are detailed below.

2.2.1 Test Article Design and Construction – Tests 652-657

A Standard Soil Pit consisting of AASHTO Class 2 Aggregate Base (A.B.) was built off the edge of pavement on one side at the test facility. This was accomplished by excavating a pit approximately 70 ft long x 6 ft wide x 6 ft deep (21.3 m x 1.83 m x 1.83 m) and backfilling the pit with A.B. The A.B. was placed in small lifts and compacted with a roller compactor.

For the bogie testing, all six steel posts were installed in the strong soil pit to eliminate or reduce any variations in soil properties. The posts were installed with 10-ft (3.050m) spacing and approximately 2 ft (0.61 m) off the edge of pavement. The posts were driven to a depth of 36 in (0.91 m), per Caltrans standard installation procedures. Two posts were designated for bogie tests without CRMCrete (base line tests) while the remaining four posts were designated for testing with CRMCrete. CRMCrete bogie tests were then run on the two posts installed in soil only. Material was then excavated around the posts to accommodate a 2-in (51 -mm) thick placement of CRMCrete around two of the posts and a 3.5-in (89-mm) thick placement of CRMCrete around the other two posts. The leave-out* dimensions for the posts in the 2-inch (51 mm) thick CRMCrete were 3 in (76 mm) on the sides measured from the outside edge of the flange, 1 in (25 mm) in front, and 8 in (203 mm) behind the post (see Figure 2-2). The leave-out dimensions for the posts in the 3.5-in (89-mm) thick CRMCrete were 3 in (76 mm) on the sides measured from the outside edge of the flange, 1 in (25 mm) in front, and 10 in (254 mm) behind the post (see Figure 2-3). Typical post installations before the CRMCrete pour are shown in Figure 2-4 (Tests 654 and 655) and Figure 2-5 (Tests 656 and 657). The CRMCrete was leveled and consolidated using a 2x4 screed with a concrete vibrator attached to it (see Figure 2-6). The CRMCrete tested had a 28-day compressive strength of 1660 psi (11.4 Mpa).

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* The leave-out is the weakened area surrounding the post.

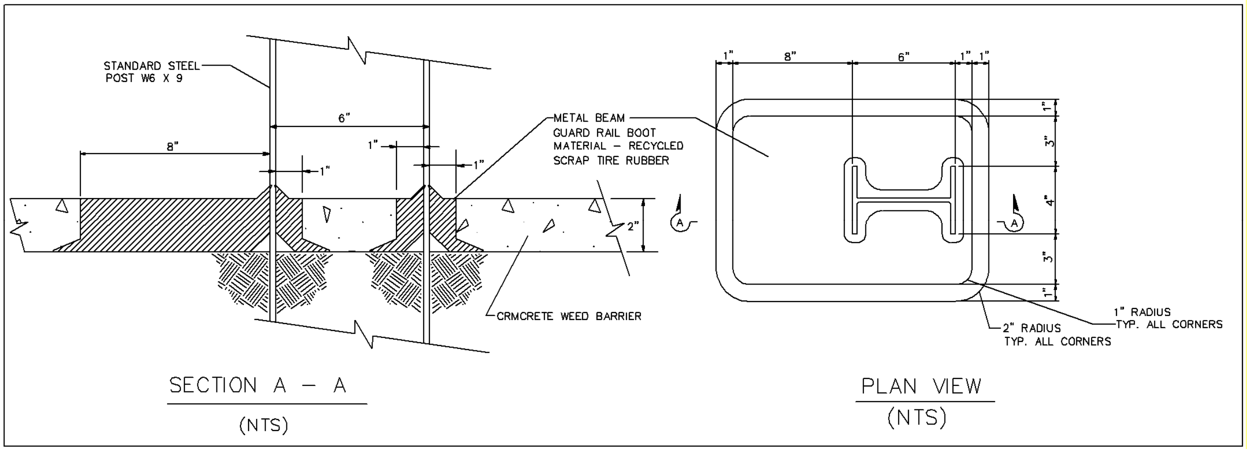


Figure 2-2 – CRMCrete Boot Details for Tests 654 and 655

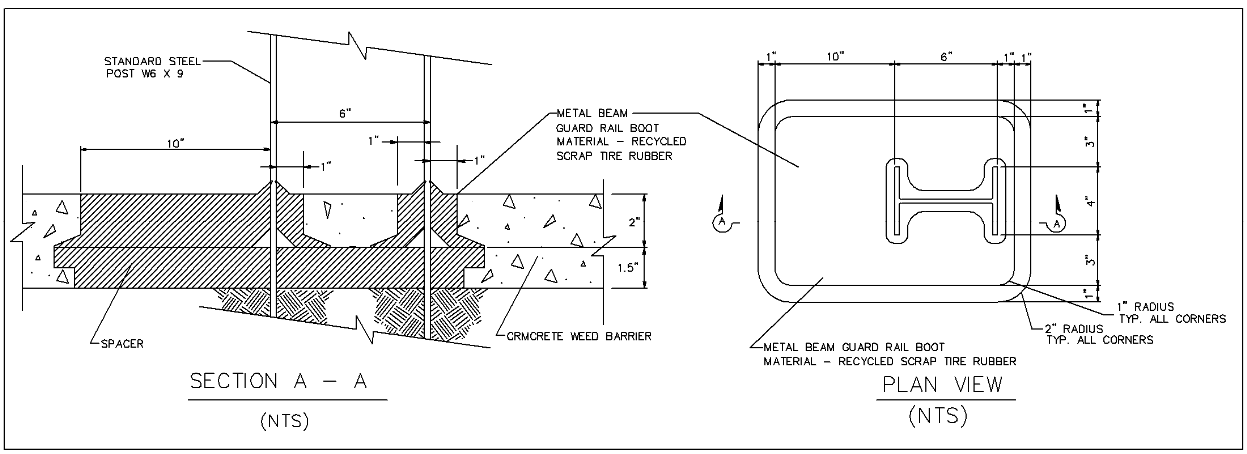


Figure 2-3 – CRMCrete Boot Details for Tests 656 and 657

Figure 2-4 – Boot for 2-inch Thick CRMCrete

Figure 2-5 – Boot with Spacer for 3.5-inch Thick CRMCrete

Figure 2-6 – CRMCrete Placement for Bogie Tests

2.2.2 Impact Description - Tests 652-657

The impact angle was set at 90 ° (head-on) by placement of the guide rail. The impact angle did not deviate significantly (less than two degrees for all tests). The vehicle impact point (center of the steel tube bumper) was also within about 6 in (150 mm) of the post centerline for all tests, with three tests within about an inch of the impact point. The target speed was 20 mph (32.1 km/h). The actual speed was obtained by an average of two different speed traps (for each test) located just upstream from the impact point. The actual speeds varied from 20 to 21.5 mph (32 to 34.6 km/h).

For all tests, the impact description was essentially the same. The front cylindrical bumper of the bogie contacted the post, causing the post to rotate back. The post began to twist in torsion as it bent back. The bogie bumper eventually rode over the top of the post. A large steel plate mounted to the front of the bogie then impacted the post. The bogie continued over the post, in some cases coming to rest on top of the post and in others clearing the post completely.

A typical side impact picture is shown below along with overhead pictures for each test of the bogie bumper impacting the post in Figure 2-7 and Figure 2-8. Video analysis results for

Tests 652, 654, and 656 are provided in Table 2-2. Tests 653, 655, and 657 were not analyzed because the bogie bumper centerline was offset significantly from the post centerline in these tests. Accelerometer data for these tests is shown in Figure 7-10 – Longitudinal Bogie Acceleration vs. Time.

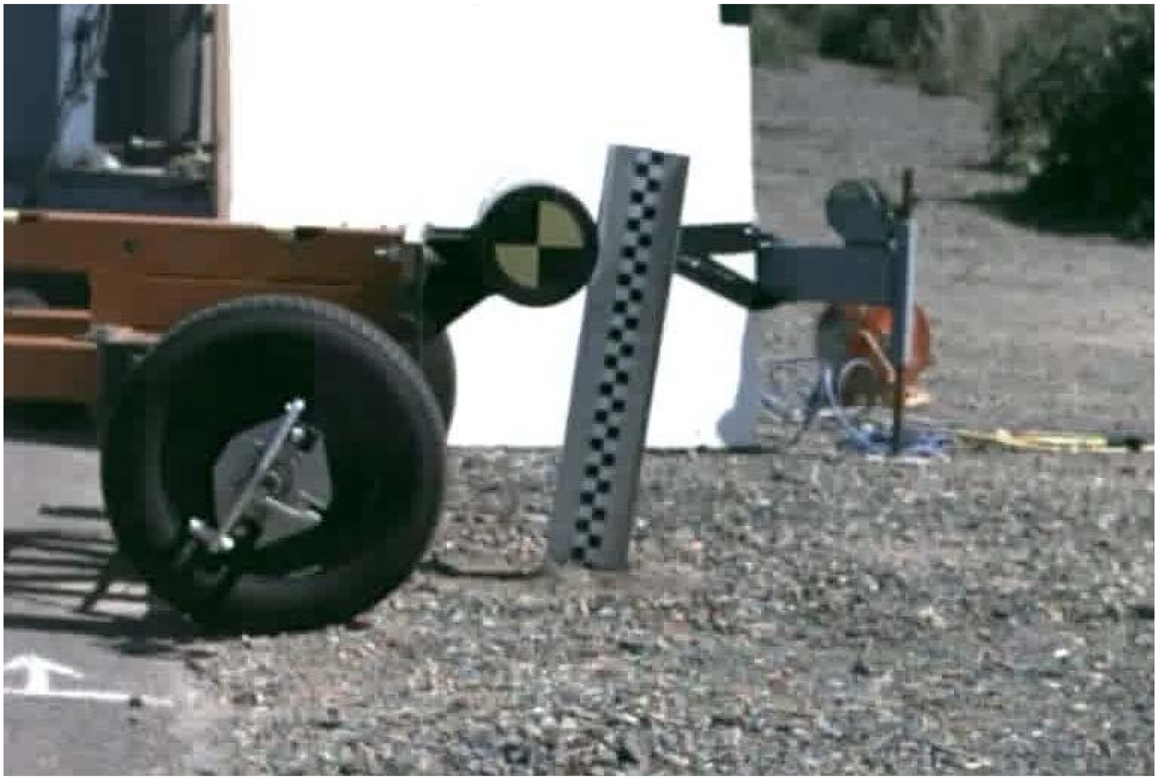


Figure 2-7 – Typical Bogie Impact – Side View

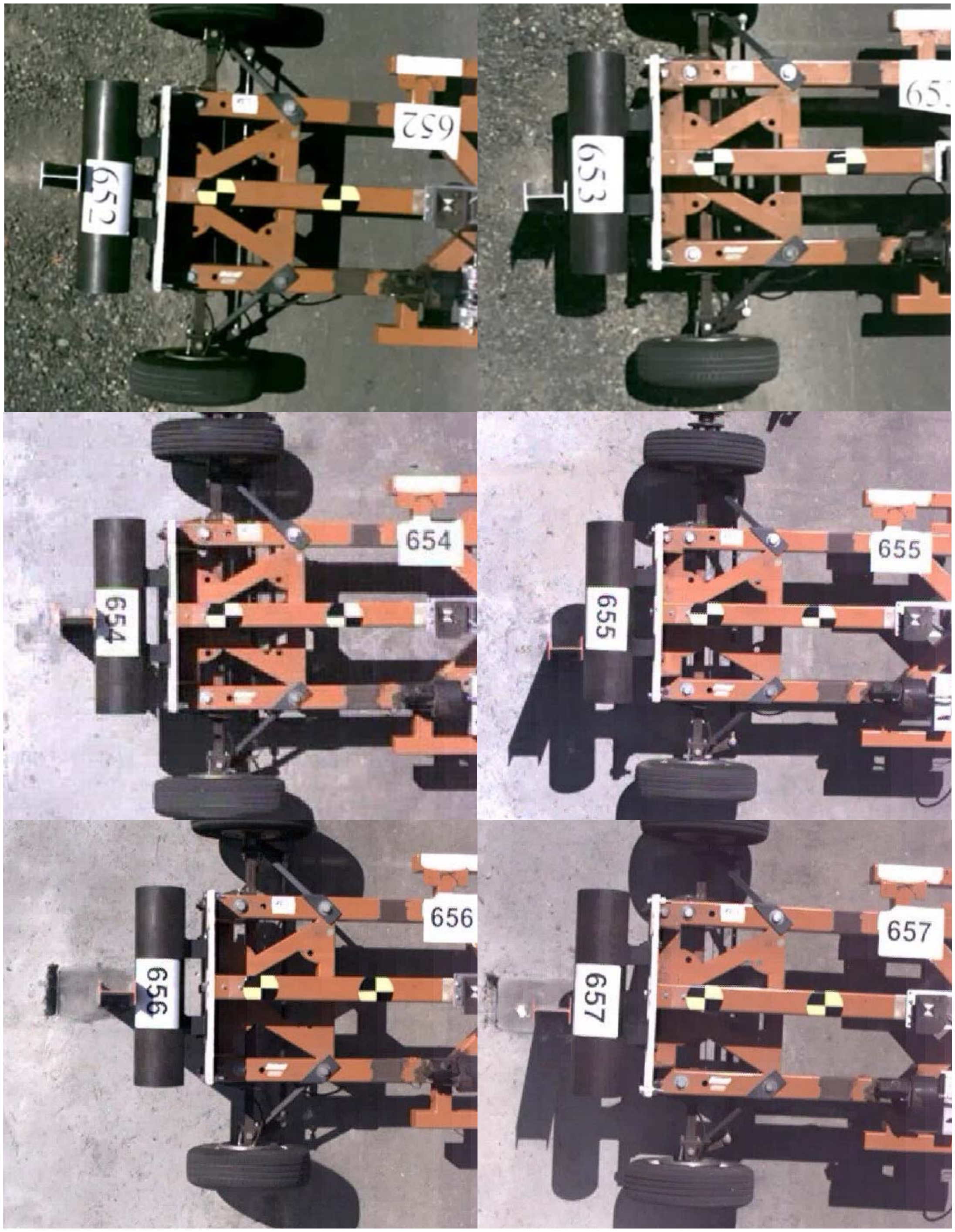


Figure 2-8 – Bogie Tests at Impact

Table 2-2 – Bogie Test Key Events

Test	**652**	**653**	**654**	**655**	**656**	**657**
Speed, mph (km/h)	20.6 (33.1)	19.9 (32.0)	21.4 (34.4)	20.9 (33.6)	21.3 (34.3)	21.5 (34.6)
Time When Post Begins to Bend (sec)	0.024	* 0.024		* 0.022		*
Lateral Deflection When Post Begins to Bend Measured at Top of Post, inches (mm)	9.5 (240)	* 10.7	(270)	* 9.1	(230)	*
Approximate Time when bumper loses contact with post (s)	0.088	* 0.092		* 0.092		*
• Not analyzed due to unacceptable bogie impact point.						

The results of the video analysis and comparison of the accelerometer traces were inconclusive. In the video analysis, for example, there was no distinguished pattern for lateral deflection when the post began to bend. Similarly, it was difficult to ascertain that any differences in the accelerometer traces were due to anything other than normal variability. Therefore, to maximize the chances of obtaining a useable product from a full-scale crash test, the test article for the full-scale crash test was comprised of a 2-in (50-mm) thick section of CRMCrete with post leave-out dimensions of 3 in (76 mm) on the sides, 1 in (25 mm) in front, and 10 in (250 mm) behind.

2.2.3 Test Article Design and Construction – Test 658

After the bogie testing had been completed, the CRMCrete and posts were removed. Next, a 112.25-ft long x 6-ft wide (34.2-m x 1.83-m) section was excavated to allow for a CRMCrete depth of 2 in (51 mm). A 200-ft (60.96-m) section of Metal Beam Guardrail with W6x9 steel posts was then installed at the excavated location. SFT End Treatment Terminal Anchors were installed at each end. The Caltrans 2006 Standard Plan for SFT End Treatment Terminal Anchors A77H1 can be found at:

> http://www.dot.ca.gov/hq/esc/oe/project_plans/highway_plans/stdplans_US-customary-units_06/viewable_pdf/a77h1.pdf

The CRMCrete weed barrier was 5 ft-9 in wide and 100 feet long (1.75 m x 30.5 m). The CRMCrete encompassed the area from seven posts upstream from the intended impact point to ten posts downstream of the intended impact point. A rubber boot with compression relief was placed around each post located in the CRMCrete section. The leave-out dimensions for the posts were 3 in (76 mm) on the sides measured from the outside edge of the flange, 1 in (25 mm) in front, and 10 in (254 mm) behind. A 2-in (51-mm) thick section of CRMCrete weed barrier was place around the posts in the impact area.

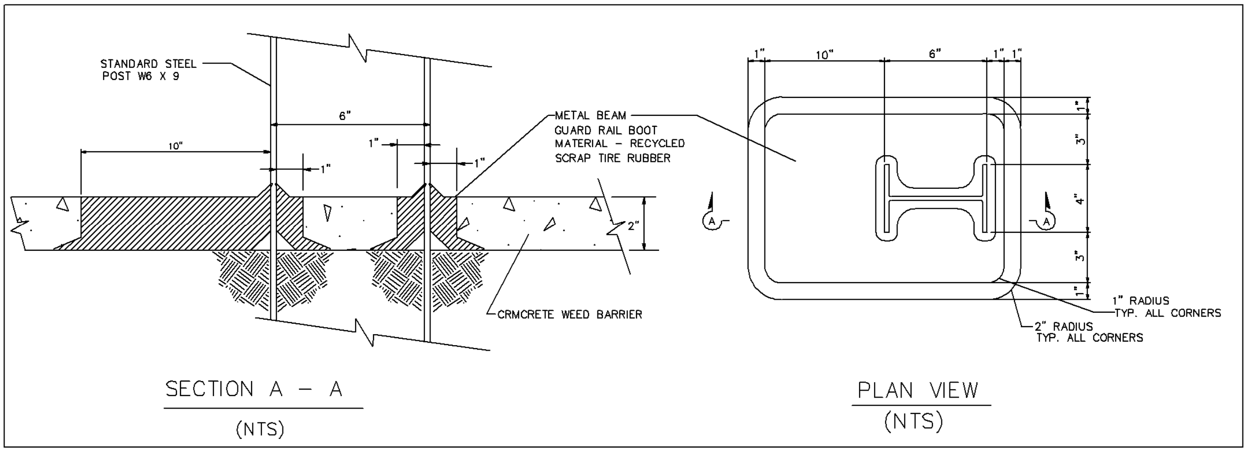


Figure 2-9 – CRMCrete Boot Details for Test 658

The CRMCrete was leveled and compacted using a 2x4 screed with a concrete vibrator attached to it (see Figure 2-11). The CRMCrete tested had a 28-day compressive strength of 1475 psi (10.17 MPa). Figure 2-19 shows the completed guardrail.

After construction was complete and shortly before the test was to be conducted, it was discovered that, although the w-beam element was installed at the proper height, thrie beam posts were installed by mistake. Thrie beam posts are 6 ft-8 in (2.03 m) long whereas w-beam posts are 6 ft-0 in (1.83 m) long. Because of the uncertainty of the effect of the additional embedment length, each post was pulled up 8 in (203 mm) while the w-beam and blockout were moved into holes lower on each post. A band-saw was then used to cut off the excess top portion of each post.

The design guardrail height above finished grade was 27 ¾ ± ½ in (705 ± 13 mm) per the California Department of Transportation Standard Plan A77A2 located at:

http://www.dot.ca.gov/hq/esc/oe/project_plans/highway_plans/stdplans_US-customary-units_06/viewable_pdf/a77a2.pdf

The as-installed guardrail height measured to the asphalt at the midspan between Posts 15-16 and Posts 19-20 (the impact point was near Post 16) ranged from 27 ½ in to 27 ¾ in (699 mm to 705 mm).

Figure 2-10 – Checking CRMCrete Depth for Test 658

Figure 2-11 – Screeding and Compaction of CRMCrete for Test 658

Figure 2-12 – CRMCrete Finishing for Test 658

Figure 2-13 – Test 658 Leave-out Area on Sides of Post

Figure 2-14 – Test 658 Leave-out Area In front of and Behind Post

2.2.4 Impact Description – Test 658

The vehicle impacted the w-beam section approximately 18 in (457 mm) upstream of Post 16, a non-splice post, with a speed of 99.8 km/h and impact angle of 25.8°. Post 16 immediately began to deflect backward, toward the field side of the guard rail. Post 16 reached its maximum deflection 0.048 s after impact. Post 17, which was downstream of Post 16, reached its maximum deflection at 0.094 s after impact. At 0.12 s after impact the left-front tire contacted post 17 and at 0.13 s after impact the front tires were redirected toward the field. At about 0.134 s after impact the w-beam completely ruptured, allowing the vehicle to pass through. When the vehicle left the CRMCrete and entered the unpaved field, it rolled over, coming to rest up-side down.

Figure 2-15 through Figure 2-23 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 658 are shown in Figure 2-24 on page 33.

Figure 2-15 – Test 658 Impact Side of Test Vehicle before Impact

Figure 2-16 – Test 658 Front of Test Vehicle before Impact

Figure 2-17 – Impact Point for Test 658

Figure 2-18 – Test vehicle after Test 658

Figure 2-19 – Test article prior to Test 658

Figure 2-20 – Test 658 Test Article after Impact

Figure 2-21 – Close-up of Impact Point

Figure 2-22 – Downstream SFT after Test 658

Figure 2-23 – Typical Twisted Post after Test 658

Figure 2-24 – Test 658 Data Summary Sheet

t = 0.0 sec | t = 0.10 sec | t = 0.20 sec | t = 0.30 sec

t = 0.40 sec | t = 0.50 sec | t = 0.60 sec | t = 0.70 sec

Test Barrier

Type: Steel Post Metal Beam Guardrail with CRMCrete Weed Barrier (rubber boot leave-outs around each post)

Length: 60.96 m, total length including SFT and SRT End Treatment.

Test Date: September 20, 2006

Test Vehicle:

Model: 1988 Chevrolet 2500

Inertial Mass: 1990 kg

Test Dummy:

Type: None used

Weight/ Position: N/A

Impact/ Exit Conditions:

Impact / Exit Velocity: 99.8 km/h (from speed traps) / Not applicable

Impact / Exit Angle: 25.8° / Not applicable

Impact Severity: 144.9 kJ

Test Data:

Occ. Impact Velocity (Long / Lat): Not applicable

Ridedown Acceleration (Long / Lat): Not applicable

ASI Not applicable

Exterior: VDS[3]/CDC[4] Not analyzed

Interior: OCDI[1] Not analyzed

Max. Roll/Pitch/Yaw Angles: Not analyzed

Barrier Damage: The W-beam ruptured, allowing the vehicle to penetrate beyond the guardrail.

2.2.5 Vehicle Damage - Test 658

The vehicle was extensively damaged from the w-beam rail rupture and subsequent vehicle rollover. No further analysis of vehicle damage was performed.

2.2.6 Barrier Damage - Test 658

The main damage was the rupture of the w-beam rail. Secondly, the upstream SFT deflected toward the impact point, likely because the soil surrounding the metal tube was not adequately compacted. The rail stretched upstream of the impact point and compressed downstream of the impact point, as evidenced by movement of as much as ¼ inch at the lap splices. Every post twisted counterclockwise, possibly also because of the inadequate anchoring of the upstream end treatment. As the rail shifted laterally (in the downstream direction), the wood post at the downstream SFT fractured (see Figure 2-22). Several blockouts also fractured during impact and were thrown from the point of impact toward the field. The blockout nearest the point of impact appeared to fracture upon impact, possibly before the post was able to rotate. Thus the reaction point of the rail would not have been raised, possibly contributing to the system failure. At the rupture point, the bottom of the w-beam element appears to have failed in shear due to contact with the top of the post at that location while the upper portion appears to have failed in tension.

2.2.7 Test Article Design and Construction – Test 659

Because of the results of Test 658, several design changes were made to the test article before re-testing. The test article for Test 658 was removed and replaced with a new test article. A 193.25-foot section (including end treatments) of MBGR with W6x9 steel posts was used. Again, all steel posts were driven into place without pilot holes. A 100-ft long x 4 ft-8 in section of CRMCrete was placed around 16 posts in the vicinity of impact (from the fifth post upstream of the impact point to the eleventh post downstream of the impact point). The first change made was to use an SRT end terminal instead of an SFT at the upstream end for additional anchorage. Wood posts at the SRT were driven into undersized pilot holes. An SFT was again used at the downstream end. A second significant change was to install the entire test article in native soil rather than in the AASHTO Grade A Standard Soil Pit. The native material is not as stiff as the AASHTO Standard Soil. A less stiff soil would be less likely to resist post rotation, thus making any effect the CRMCrete had on post rotation more pronounced. Third, the rubber boots used in Test 658 were replaced with expanded polystyrene foam (EPF) covered by ½ in of CRMCrete flash over. The EPF had a flexural strength of 33 psi and a compressive strength of 13 psi at 10% deformation. Last, the amount of crumb rubber in the mix was reduced from 4% to 3%. This mix design had a higher 28-day strength (1863 psi, 12.84 MPa) and created a more durable section to withstand cracking. The increase in compressive strength had only a minimal effect on the strength of the leave-out area with EPF since the leave-out section consisted of only ½ in (13 mm) of flash over

The design guardrail height above finished grade was 27 ¾ ± ½ in (705 ± 13 mm) per the California Department of Transportation Standard Plan A77A2. However, in the impact area 2 in of soil was excavated and replaced with a 2-in (50-mm) thick section of CRMCrete weed barrier. The CRMCrete section began approximately 35 ft (10.7 m) upstream of the impact point and ended approximately 65 ft (19.8 m) downstream of the impact point. EPF squares were placed around each post in CRMCrete. The EPF was 1.5-in (38-mm) thick with a footprint of 18 in (450 mm) x 16 in (400 mm), creating a leave-out area larger than in Test 658. The leave-out dimensions were 8 in (203 mm) behind each post, 2 in (51 mm) in front, and 7 in (178 mm) on each side. A ½-in (13 mm) flash over of CRMCrete was placed over the EPF to hold it in place (see Figure 2-25 and Figure 7-11). The as-installed guardrail height from two posts upstream of impact to near one post downstream of the exit point ranged from 27 ¾ to 28 ¼ in (705 mm to 718 mm).

Construction photos are shown in Figure 2-26 through Figure 2-30. In this installation, the concrete was consolidated differently than in previous installations. In previous installation the concrete was consolidated using a concrete vibrator was attached to a wooden 2 x 4 screed. In this installation, the concrete was placed and then consolidated by plunging a concrete vibrator into the concrete. This method was slightly more time-consuming but seemed effective in consolidating the concrete and produced similar results in terms of the number of shrinkage cracks that developed.

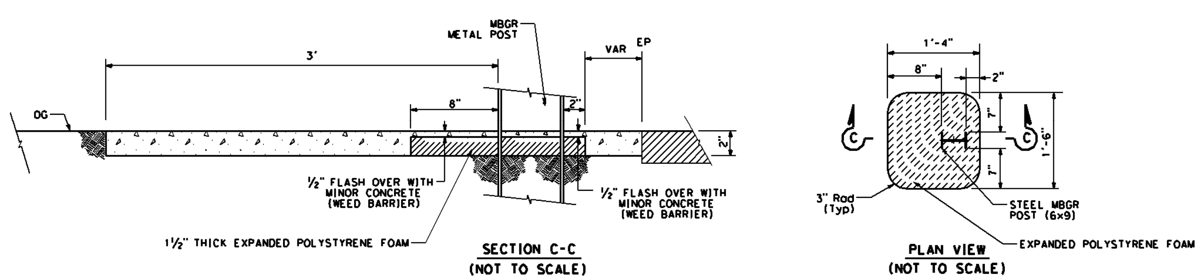


Figure 2-25 – Test 659 Post Leave-out Plan and Cross Section

Figure 2-26 – Test 659 Guardrail Prior to CRMCrete Placement

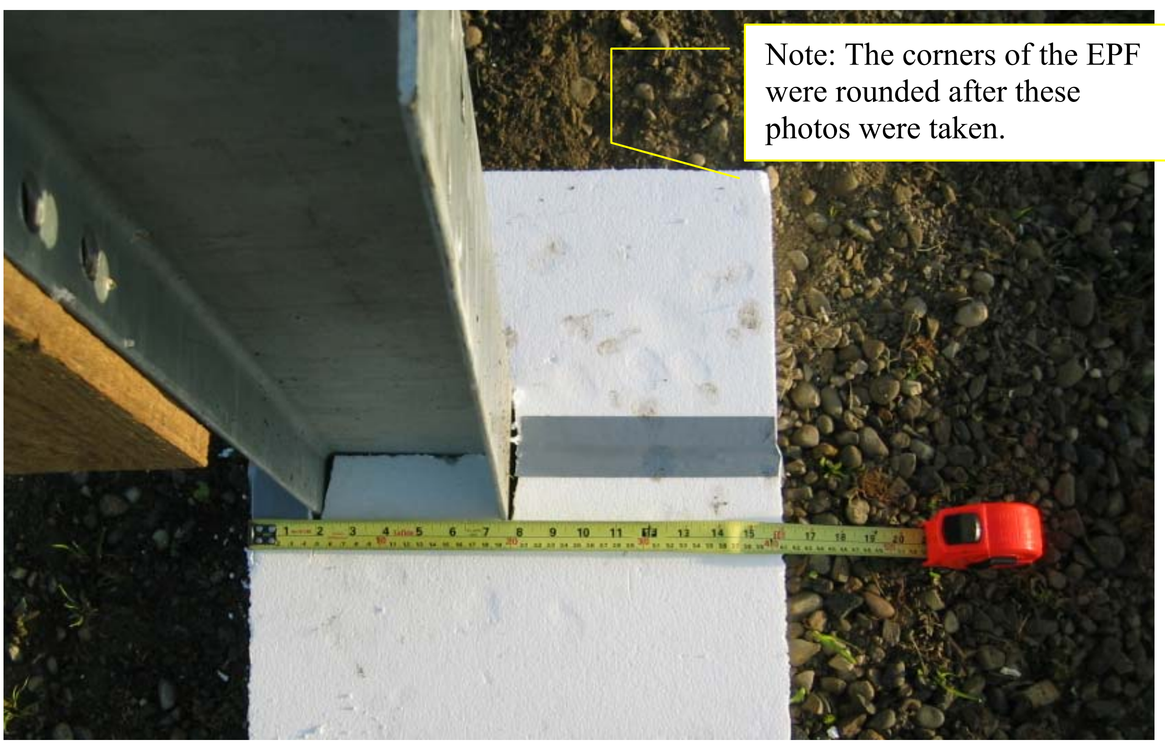


Figure 2-27 – Test 659 Front and Back Leave-out Measurements

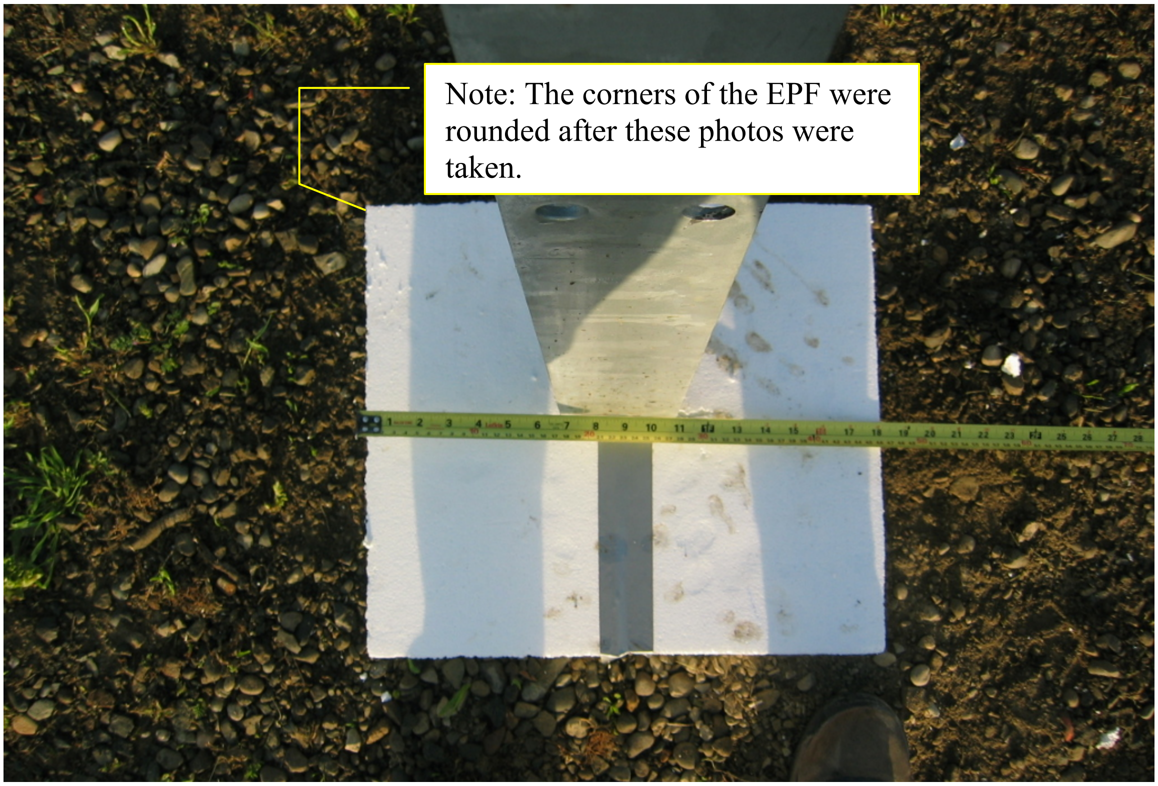


Figure 2-28 – Test 659 Side Leave-out Measurement

Figure 2-29 – Test 659 Placing of the CRMCrete

Figure 2-30 – Test 659 Completed Guardrail and CRMCrete Installation

2.2.8 Impact Description - Test 659

The impact point was intended to be 730 mm upstream of the centerline of Post 19, a non-splice post. The impact angle was set at 25 ° by placement of the guide rail. The vehicle deviated slightly from this angle prior to impact, impacting the W-Beam element with an impact angle of 24.3°. The impact speed of 99.5 km/h was obtained by optical switch data and confirmed (within 0.1 km/h) by an average of two different speed traps located just upstream from the impact point. The test vehicle impacted the barrier approximately 12 in (300 mm) downstream of the intended impact point (17 in, 430 mm upstream of the centerline of Post 19). The impact angle was determined through a combination of video analysis and geometric/trigonometric calculations based on the intended impact angle, intended impact point, and actual impact point.

Post 19 began to rotate away from the travel way soon after impact. The vehicle began to redirect at 0.030 s after impact. At 0.046 s after impact, Post 19 began to rotate away from the travel way. At 0.088 s after impact, Post 20 began to rotate away from the travel way. At about 0.09 s the front left tire contacted Post 20. The blockout detached from Post 20 at about 0.108 s. The front left tire contacted post 21 at about 0.18 s after impact, with the blockout detaching from Post 20 at about 0.206 s after impact. The vehicle was travelling parallel to the guardrail at 0.268 s after impact. The vehicle lost contact with the guardrail at 0.632 s after impact with an exit angle of 14.4°. The exit angle was determined from gouging of the pavement from the front left brake disc housing at the point where the vehicle lost contact with the guardrail. The front left tire of the vehicle became detached from the vehicle during the impact but the time of this event could not be determined. The brakes were applied after the vehicle exited the guardrail but the time of brake application could not be determined because the brake flash did not function correctly. The vehicle came to rest 35.4 m downstream from the point of impact and 6.9 m behind the guardrail face.

See Figure 2-31 through Figure 2-41 for the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 659 are shown on Figure 2-42 on page 45.

Figure 2-31 – Right side of test vehicle for Test 659

Figure 2-32 – Front of test vehicle for Test 659

Figure 2-33 – Test Vehicle and Test Article prior to Test 659

Figure 2-34 – Test Article Impact Point before Test 659

Figure 2-35 – Overview of Test Vehicle after Test 659

Figure 2-36 – Right Side of Test Vehicle after Test 659

Figure 2-37 – Front of Test Vehicle after Test 659

Figure 2-38 – Test Article Overview after Test 659

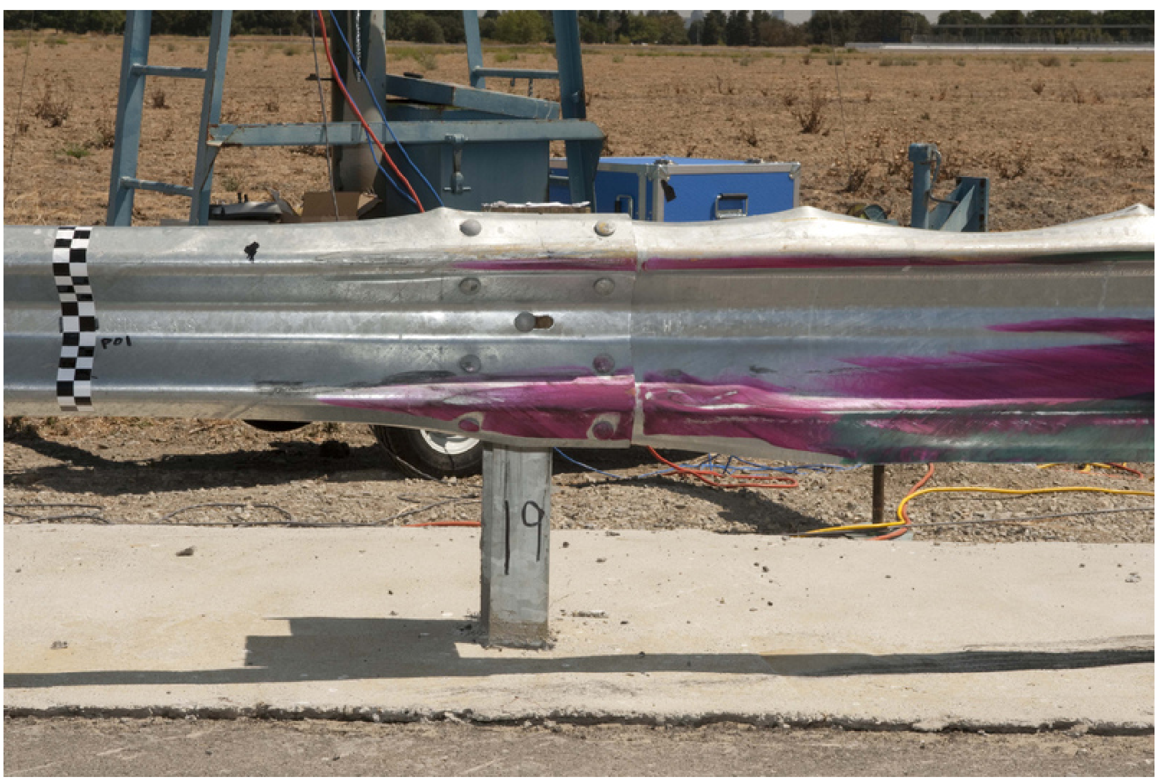
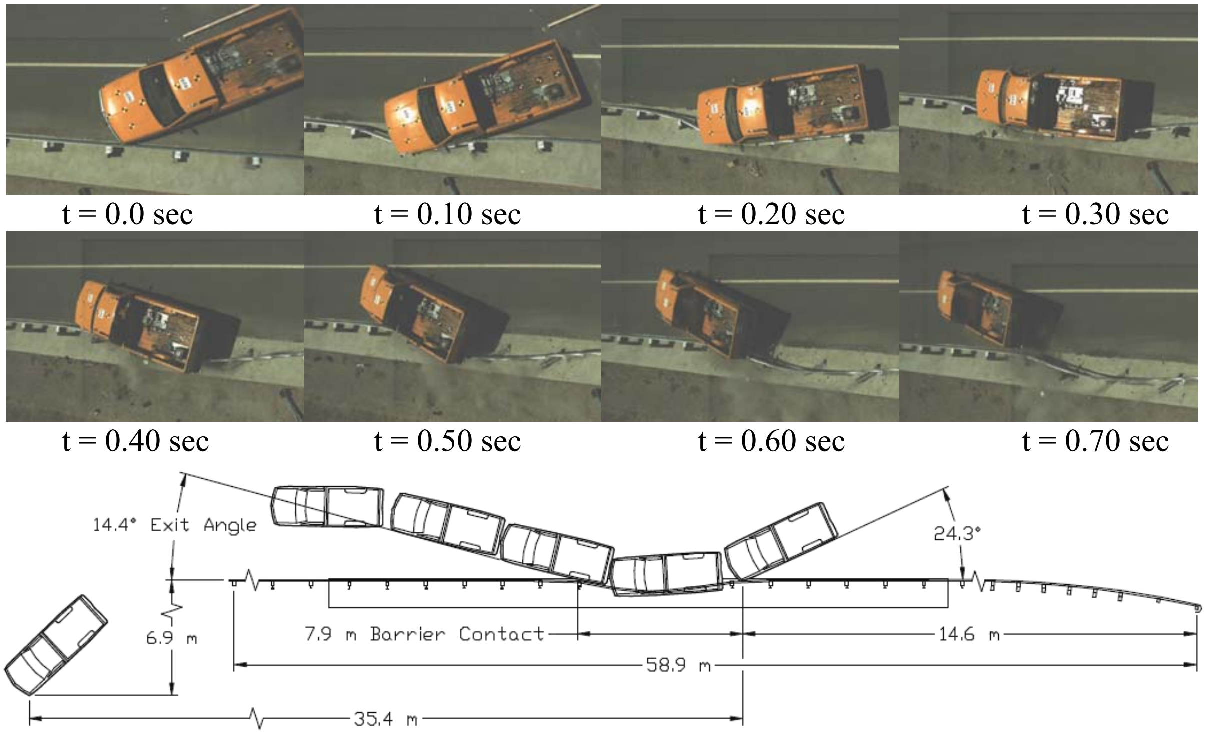


Figure 2-39 – Impact Point after Test 659

Figure 2-40 – Post 21 (Downstream of Impact Point) after Test 659

Figure 2-41 – Close-up of Post 21 after Test 659

Figure 2-42 – Test 659 Data Summary Sheet



Test Barrier

Type: Steel Post Metal Beam Guardrail with Rubberized Concrete Weed Barrier; Posts in native soil; Styrofoam leave-out area 8” behind Posts, 2” in front, and 7” on sides.

Length: 58.9 m , total length including SFT and SRT End Treatments.

Test Date: August 25, 2009

Test Vehicle:

Model: 1994 Chevrolet 2500 2WD Pickup

Inertial Mass: 1972 kg

Test Dummy:

Type: None used

Weight/ Position: N/A

Impact/ Exit Conditions:

Impact / Exit Velocity: 99.5 km/h / N/A

Impact / Exit Angle: 24.3° / 14.4° (from survey of scrapes on pavement)

Impact Severity: 127.6 kJ

Test Data:

Occ. Impact Velocity (Long / Lat): 5.5 m/s / -4.9 m/s

Ridedown Acceleration (Long / Lat): -8.6 g / 9.3 g

ASI 0.73

Exterior: VDS[3]/CDC[4] FL-3, LD-1/10LFEW9

Interior: OCDI[1] LF0001 000

Max. Roll/Pitch/Yaw Angles: -11.3° / -8.8° / 45.8°

Barrier Damage: Permanent deflection at posts 19-23, with the CRMCrete in the leave-out area broken out as expected. Posts 20-22 yielded and were bent over. The W-Beam rail was deflected and deformed but intact. Maximum dynamic deflection was estimated at 40 inches (1016 mm). Maximum permanent deflection of the rail was 1.9 feet (579 mm) at approximately 14.2 feet (4.33 m) downstream of impact.

2.2.9 Vehicle Damage - Test 659

There was mild to moderate damage to the entire left side of the vehicle. The left portion of the front bumper and left front fender were pushed rearward. The left front tire and wheel assembly were detached from the vehicle. There was minor denting of the left door, left side of the bed, and left rear fender. The maximum passenger compartment deformation was one inch, between the motor panel and the rear of the occupant compartment.

2.2.10 Barrier Damage - Test 659

Posts 19-23 were deflected backward toward the field. Posts 20-22 were pushed over and permanently deformed. The blockouts at posts 20 and 21 were detached from the guardrail and damaged during the impact. The w-beam rail between posts 19-23 was permanently deformed. There was damage to the leave-out areas of posts 19-23 but the damage did not extend into the CRMCrete surrounding the leave-out areas. Blockout debris was found on the field-side as far as 172 feet from the point of impact but this is typical for a metal beam guardrail impact.

2.3 Discussion of Test Results - Crash Tests

2.3.1 General - Evaluation Methods (Tests 658 and 659)

NCHRP Report 350 stipulates that crash test performance be 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 3.1 of NCHRP Report 350. Both tests have a NCHRP Report 350 test designation of 3-11. The evaluation criteria are detailed in Chapter 5 of NCHRP Report 350 and are summarized in Table 5.1 of that same report.

2.3.2 Structural Adequacy

For test 658, the structural adequacy of the steel post guardrail with CRMCrete weed barrier was unacceptable since the vehicle penetrated the guardrail and rolled over.

For test 659, the structural adequacy of the CRMCrete weed barrier with EPF was acceptable for use around metal beam guardrail with W6x9 steel posts. The vehicle was contained and smoothly redirected despite the front left tire snagging on a post and detaching from the vehicle. Damage to the w-beam elements and posts was typical for this type of impact. The leave-out areas around the deflected posts were broken out as expected. A detailed assessment summary of structural adequacy is shown in Table 2-2 through Table 2-5.

Table 2-3 – Test 658 Assessment Summary

Test No. 658 (NCHRP Report 350, TL 3-11)
Date Sep tember 20, 2006
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the article is acceptable.	The vehicle penetrated the barrier and rolled over.	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.	Not analyzed.	
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The vehicle penetrated the barrier and rolled over.	fail
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	Not analyzed.	
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 *g*.	Not analyzed.	
M. The exit angle from the test article preferably should be less that 60 percent of the test impact angle, measured at time of vehicle loss of contact with test device."	Not analyzed.	

Table 2-4 – Test 659 Assessment Summary

Test No. 659 (NCHRP Report 350, TL 3-11)
Date A ugust 25, 2009
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the article is acceptable.	The left front tire snagged slightly on a post and became detached from the vehicle. Despite this, the vehicle was contained and smoothly redirected.	Marginal 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.	Two blockouts became detached from the posts and were thrown behind the guardrail. These blockouts did not penetrate the occupant compartment or show the potential for doing so. They remained behind the barrier. Thus, they did not pose a threat to other motorists. The maximum floorboard deformation was 25 mm. (<150mm) There was mild occupant compartment deformation.	pass pass 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. Although the left front tire detached from the vehicle, the vehicle remained stable.	pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle came to rest 35.4 m downstream of impact and 6.9 m behind the traffic face of the rail.	pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 *g*.	Long. Occ. Impact Vel. = 5.5 m/s Long. Occ. Ridedown = -8.6 g	pass
M. The exit angle from the test article preferably should be less that 60 percent of the test impact angle, measured at time of vehicle loss of contact with test device."	Exit angle = 14.4°, 59% of the impact angle.	pass

2.3.3 Occupant Risk

For test 658, the occupant risk was unacceptable due to vehicle rollover.

For test 659, the occupant risk for the CRMCrete Weed Barrier with EPF was acceptable for use around metal beam guardrail with W6x9 steel posts. The test did not indicate the potential for material from the barrier to penetrate the occupant compartment of the vehicles. The calculated occupant ridedown acceleration and occupant impact velocity were within the "preferred" range. Please refer to Table 2-4.

2.3.4 Vehicle Trajectory

For test 658, the post-impact vehicle trajectory was unacceptable due to vehicle rollover.

For test 659, the post-impact vehicle trajectory was acceptable for the CRMCrete Weed Barrier with EPF. The detailed assessment summary of vehicle trajectories may be seen in Table 2-4.

3 CONCLUSION

Based on the testing of the CRMCrete Weed Barrier with EPF used with metal beam guardrail with W6x9 steel posts, the following conclusions can be drawn:

1. It can successfully contain and redirect a 4410-lb (2000-kg) pickup truck impacting at 25° and 62.1 mph (100 km/h). (There was moderate occupant compartment deformation, mainly in the cab floorboard area. This deformation was judged to be insufficient to cause serious injury to vehicle occupants).

2. The CRMCrete weed barrier performed as expected. Damage was limited to the leave-out areas and could be easily repaired.

3. It meets the criteria set in the National Cooperative Highway Research Program's Report 350 "Recommended Procedures for the Safety Performance Evaluation of Highway Features" under Test Level 3 for longitudinal barriers.

The impact conditions for test 659 (including impact angle, speed, and severity) were within Report 350 limits.

In Test 659 all of the NCHRP Report 350 evaluation criteria were within acceptable limits. The exit angle was less that 60% of the impact angle, small enough that the vehicle would not impose undue risks to other motorists. No debris was scattered in such a way that it would create hazards to other motorists. The vehicle was safely contained and redirected by the barrier and remained upright throughout the test.

4 RECOMMENDATION

CRMCrete Weed Barrier with Expanded Polystyrene Foam (EPF) used around metal beam guardrail with W 6x9 steel posts is recommended for use on high-speed highways at Test Level 3 under the following conditions:

- The minimum guardrail height is 27 ¾ in (705 mm) measured from the top of the W-beam element to the weed barrier surface.
- The rubber content of the concrete may be varied. However, the 28-day strength of the CRMCrete should not exceed 1863 psi (12.84 MPa).
- The EPF should have a maximum flexural strength of 33 psi (230 kPa) and a maximum compressive strength of 13 psi (90 kPa) at 10% deformation.
- The depth of the CRMCrete weed barrier should be two inches (50 mm) or less.
- The footprint dimensions of the leave-out areas are, at a minimum, 16 in (400 mm) x 18 in (450 mm), with 8 in (200 mm) behind each post, 2 in (50 mm) in front, and 7 in (180 mm) on each side. Larger leave-out areas may be used as long as all minimum distances from the post are met.
- At the leave-out areas, a maximum ½-in (13 mm) flash over of CRMCrete over the EPF to hold it in place.

5 IMPLEMENTATION

The Office of Landscape Architecture will be responsible for the preparation of standard plans and specifications for the CRMCrete Weed Barrier with EPF, with technical support from Division of Research and Innovation and the Traffic Operations Program.

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. Bligh, Roger, et al., “Dynamic Response of Guardrail Systems Encased in Pavement Mow Strips”, California Texas Transportation Institute, Report No. 0-4162-2, January 2004. http://tti.tamu.edu/documents/0-4162-2.pdf

3. “Vehicle Damage Scale for Traffic Accident Investigators”, Traffic Accident Data Project, National Safety Council, 1968.

4. “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 for Tests 658 and 659 were disconnected from the fuel supply line and drained. For Test 658 and 659, a 12-L safety gas tank was installed in the truck bed and connected to the fuel supply line. The stock fuel tanks had dry ice or gaseous CO_2 added in order to purge fuel vapors.

- One pair of 12-volt wet cell motorcycle storage batteries was mounted in each vehicle. The batteries powered the GMH Engineering Data BRICK transient data recorders. A 12-volt deep cycle gel cell battery operated the Electronic Control Box.

- A 1725-kPa CO_2 system, actuated by a solenoid valve, controlled remote braking after impact and emergency braking if necessary. Part of this system was 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. For Tests 658 and 659, 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 tests 658 and 659, 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 tests 658 and 659, 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 the test by conducting a series of trial runs through a speed trap comprised of two tape switches set a specified distance apart and a digital timer.

- For tests 652-657, the vehicle was pushed up to impact speed with a 1-ton pickup. The speed was limited by the aforementioned speed control device installed in the 1-ton pickup.

- For tests 658 and 659, a microswitch 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.

- Tables 7-1 and Table 7-2 give specific information regarding vehicle dimensions and weights for Test 658 and 659.

Table 7-1 – Test 658 Vehicle Dimensions

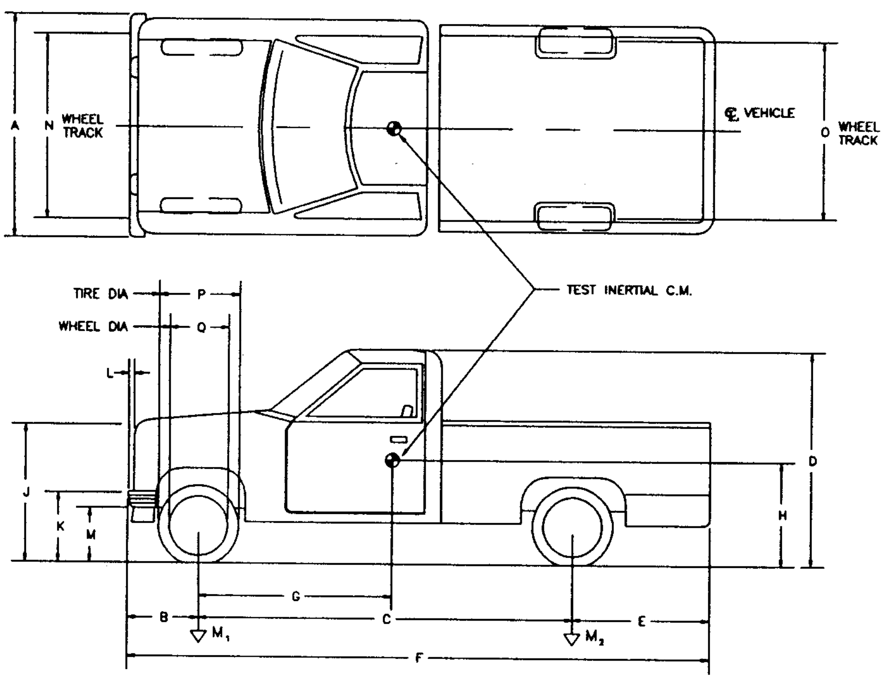
DATE: 8/01/06 **TEST NO:** 658 **VIN NO:** 1GCFC24KOJE173336 **MAKE:** CHEVROLET

MODEL: 2500 Silverado **YEAR:** 1988 **ODOMETER:** 126452 (MI) **TIRE SIZE:** LT 225/75R16

TIRE INFLATION PRESSURE: 50 (PSI)

MASS DISTRIBUTION (kg) **LF** 56 4.0 **RF** 5 557.4 **LR** 40 3.7 **RR** 41 3.2

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: Small 4” dent on side of bed on driver’s side.



ENGINE TYPE: Gas V8

ENGINE CID:

TRANSMISSION TYPE :

X **AUTO**

MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: NA

MASS: NA

SEAT POSITION: NA

GEOMETRY (cm)

A 18 8.5	**D** 17 7.50	**G** 14 1.0	**K** 63. 5	**N** 18 2.0	**Q** 44. 0
B 91. 0	**E** 30. 0	**H**	**L** 10. 0	**O** 15 6.5	
C 33 4.5	**F** 55 5.5	**J** 10 6.5	**M** 42. 0	**P** 73. 0	

MASS - (kg)	**CURB**	**TEST INERTIAL**	**GROSS STATIC**
M1	1121.4	1113.3	1113.3
M2	816.9	877.5	877.5
MT	1937.2	1990.0	1990.0

Table 7-2 – Test 659 Vehicle Dimensions

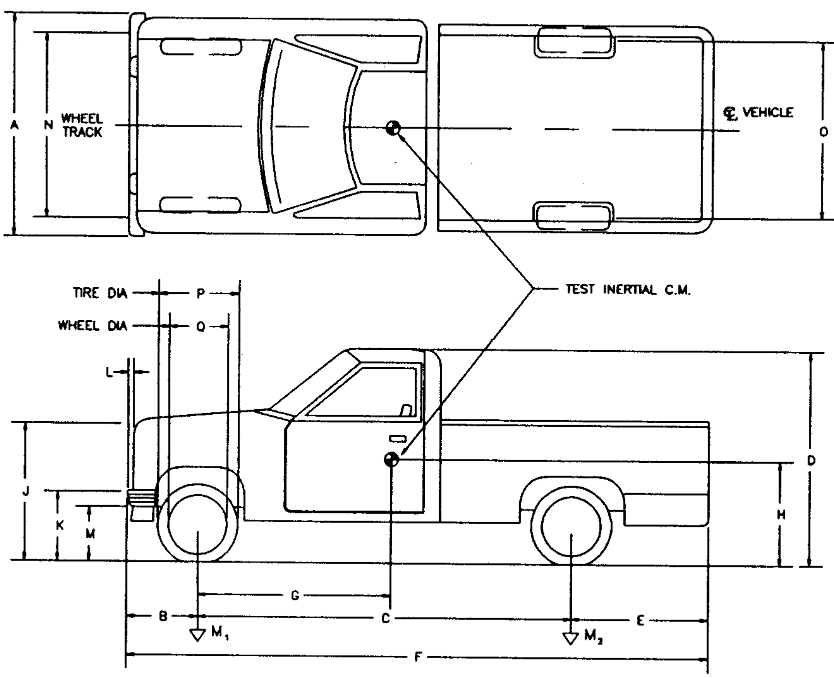
DATE: 5/01/08 **TEST NO:** 659 **VIN NO:** 1GCFC24HIRZ259294 **MAKE:** CHEVROLET

MODEL: 2500 Cheyenne **YEAR:** 1994 **ODOMETER:** 166677 (MI) **TIRE SIZE:** LT 245/75R16

TIRE INFLATION PRESSURE: 55-60 (PSI)

MASS DISTRIBUTION (kg) **LF** 54 3.2 **RF** 54 7.6 **LR** 44 9.2 **RR** 43 1.6

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: No damage.



ENGINE TYPE: Gas V8

ENGINE CID:

TRANSMISSION TYPE :

X **AUTO**

MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: NA

MASS: NA

SEAT POSITION: NA

GEOMETRY (cm)

A 18 6.0	**D** 17 6.0	**G** 15 0.0	**K** 61. 4	**N** 15 8.5	**Q** 44. 4
B 91. 0	**E** 13 1.0	**H**	**L** 8. 5	**O** 16 1.5	
C 33 3.6	**F** 55 5.0	**J** 96. 4	**M** 40. 0	**P** 76. 0	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	1094.7	1090.8	1090.8
M2	819.8	880.1	880.1
MT	1918.5	1972.3	1972.3

7.2 Test Vehicle Guidance System

A rail guidance system directed the vehicle into the barrier. The guidance rail, anchored at 3.8-m intervals along its length, was used to guide a mechanical arm, which was attached to the front right wheel of each of the vehicles. A rope was used to trigger the release mechanism on the guidance arm, thereby releasing the vehicle from the guidance system before impact.

7.3 Photo - Instrumentation

Several high-speed video cameras recorded the impact during the crash tests. The types of cameras and their locations for Test 659 are shown in Table 7-5 and Figure 7-1.

All of these cameras were mounted on tripods except the three that were mounted on a 10.7-m high tower directly over the impact point of the test barrier.

A video camera and a digital still camera were turned on by hand and used for panning during the test. Two additional still cameras were used to photograph the test from the upstream and downstream ends (cameras N2 and N3 in Figure 7-1). The upstream camera (N2) was turned on by hand while the downstream camera (N3) was remotely triggered with a tape switch. A tape switch located on the ground and connected to a computer was used to trigger the high-speed cameras. Both the vehicle and the barrier were photographed before and after impact with a normal-speed beta video camera and a digital still camera.

Table 7-3 – Test 659 Camera Type and Location

Camera Label	Camera Type	Focal Length (mm)	Rate: (fr./sec.)	Coordinate (m) X	Y	Z
V1 (Upstream)	Phantom V10	85	500	39.08	2.53	1.5
V2 (Tower Upstream)	Phantom V10	20	500	0.61	0	10.67
V3 (Tower Downstream)	Phantom V10	20	500	-0.61	0	10.67
V4 (Across)	Phantom V10	24	500	-1.16	17.03	1.5
C (Pan Digital Camera)	Canon XL-1	Varies (zoom lens) 30		2.48	18.50	4.88
N1 (Digital SLR Camera)	Nikon D700 28-70		N/A	5.01	20.25	4.88
N2 (Digital SLR Camera)	Nikon D3	420	N/A	*	*	*
N3 (Digital SLR Camera)	Nikon D700	300	N/A	*	*	*

Note: X, Y, and Z distances are relative to the impact point. (See Figure 7-1)
*Exact Location not documented. General location shown on Figure 7-1

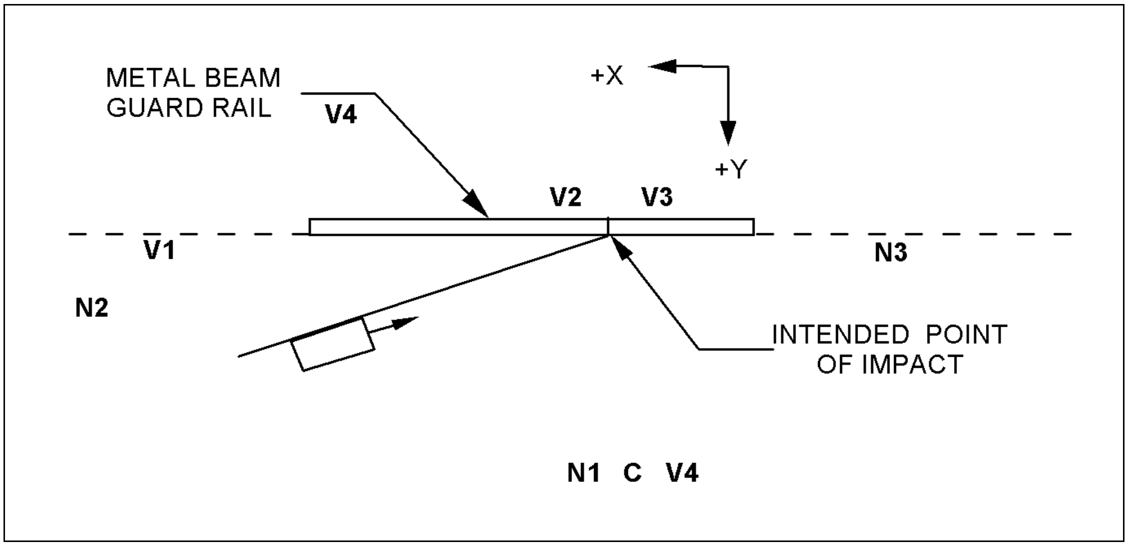


Figure 7-1 – Camera Locations for Test 659

The following are the pretest procedures that were required to enable video data reduction to be performed using video analysis software:

1) Butterfly targets were attached to the top and sides of the test vehicle. The targets were located on the vehicle at intervals of 500 mm (1.64 ft) and 1000 mm (3.28 ft). The targets along the side of the vehicle were located 0.90 m above the pavement. The targets established scale factors and horizontal and vertical alignment.

2) Flashbulbs, mounted on the test vehicle, were electronically triggered to establish a) initial vehicle-to-barrier-contact, and b) 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 reaching full intensity.

3) High-speed digital video cameras were all time-coded through the use of a portable computer and were triggered as the test vehicle passed over a tape switch located on the vehicle path upstream of impact.

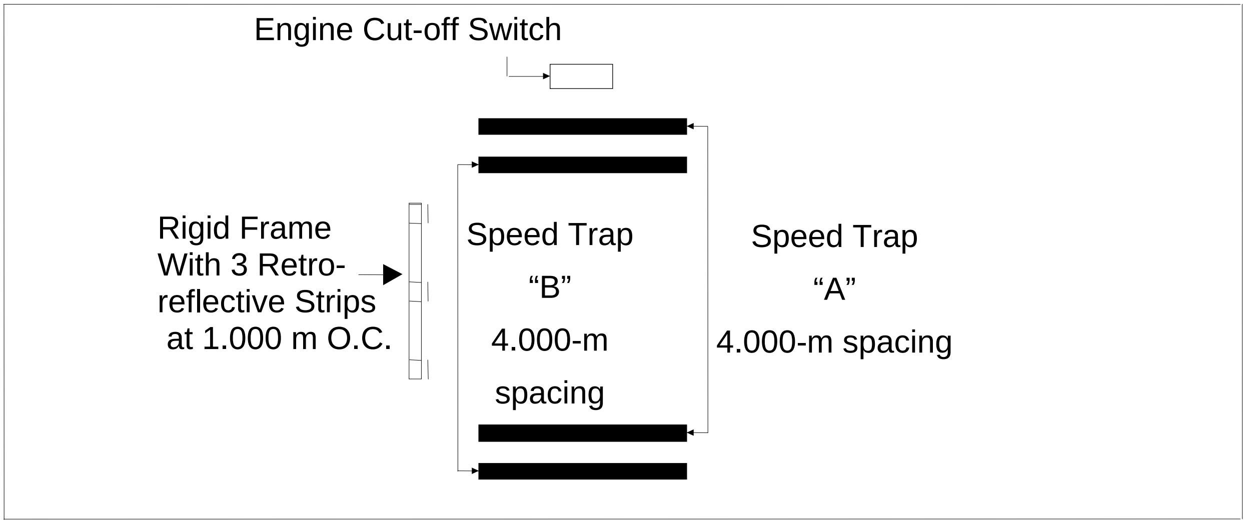


Figure 7-2 – Tape Switch Layout

7.4 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 TDR data were reduced using a desktop personal computer TRAP.

The rate gyro and accelerometer specifications are shown in Table 7-4 – Accelerometer and Rate Gyro Specifications. The vehicle accelerometer and gyro sign convention used throughout this report is the same as that described in NCHRP Report 350 and is shown in Figure 7-3.

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 7-2). The strips were spaced at carefully measured intervals of 1.000 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 4.000 m apart just upstream of the test article specifically to confirm the impact speed of the test vehicle. The layout for all of the pressure-sensitive tape switches is shown in Figure 7-2.

The data curves are shown in Figure 7-4 through Figure 7-19 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 TRAP.

Table 7-4 – Accelerometer and Rate Gyro Specifications

TYPE	LOCATION	RANGE	ORIENTATION	TEST NUMBER
Endevco	VEHICLE C.G.	100 G	Longitudinal (primary)	652, 653, 654, 655, 656, 657, 658, 659
Endevco	VEHICLE C.G.	100 G	Lateral (primary)	652, 653, 654, 655, 656, 657, 658, 659
Endevco	VEHICLE C.G.	100 G	Vertical (primary)	652, 653, 654, 655, 656, 657, 658, 659
Endevco	VEHICLE C.G.	100 G	Longitudinal (secondary)	652, 653, 654, 655, 656, 657, 658, 659
Endevco	VEHICLE C.G.	100 G	Lateral (secondary)	652, 653, 654, 655, 656, 657, 658, 659
Endevco	VEHICLE C.G.	100 G	Vertical (secondary)	652, 653, 654, 655, 656, 657, 658, 659
BEI Systron Donner Inertial	191 mm (7.5-in) behind the C.G. (along the X-axis)	500 deg/sec	Roll	658, 659
BEI Systron Donner Inertial	191 mm (7.5-in) behind the C.G. (along the X-axis)	500 deg/sec	Pitch	658, 659
BEI Systron Donner Inertial	191 mm (7.5-in) behind the C.G. (along the X-axis)	500 deg/sec	Yaw	658, 659

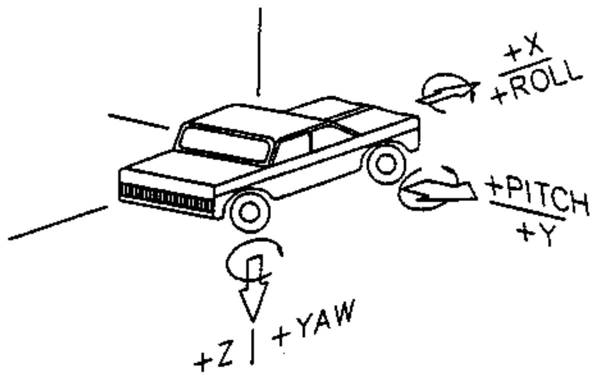


Figure 7-3 – Vehicle Accelerometer Sign Convention

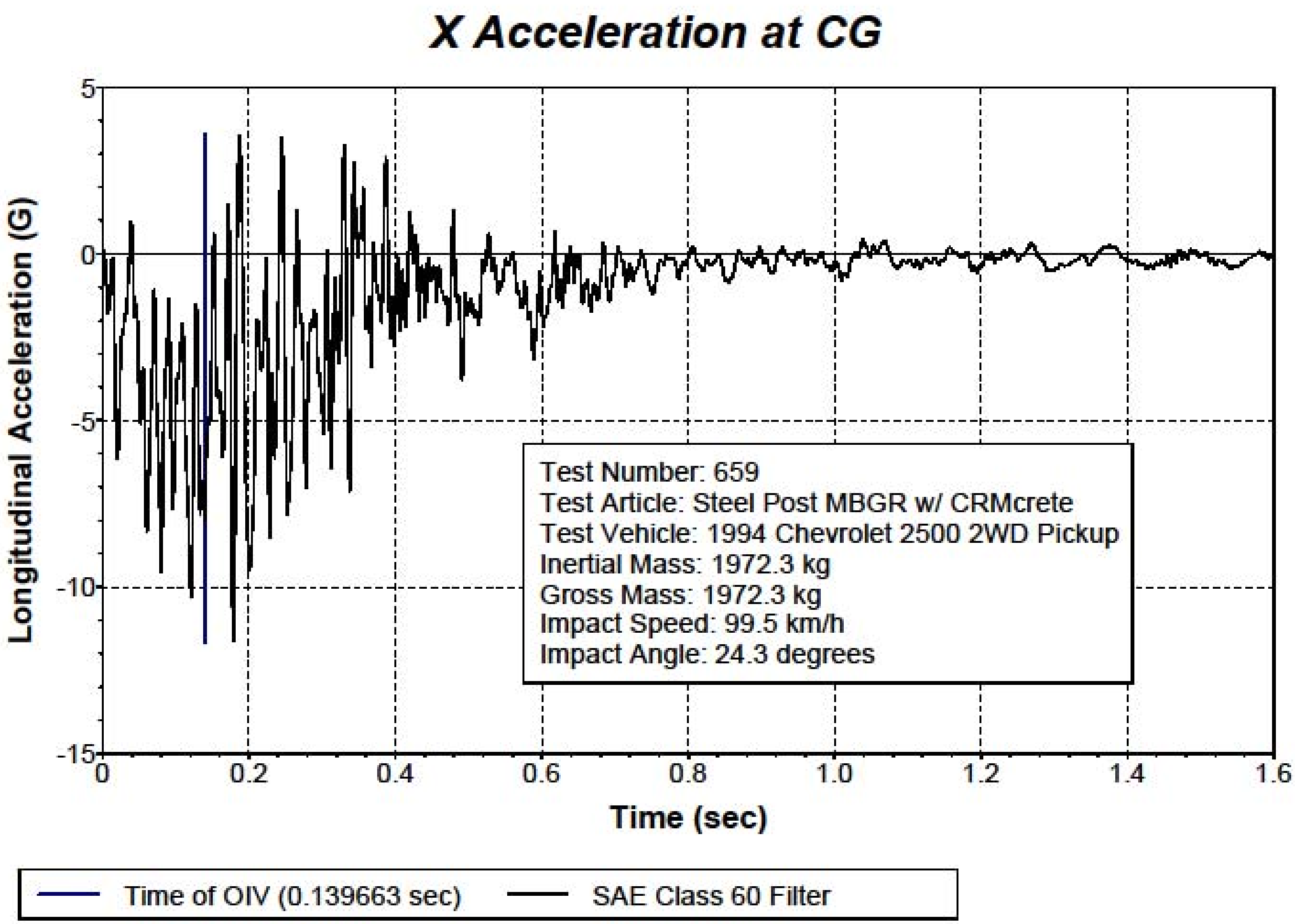


Figure 7-4 – Test 659 Vehicle X (Longitudinal) Acceleration Vs Time

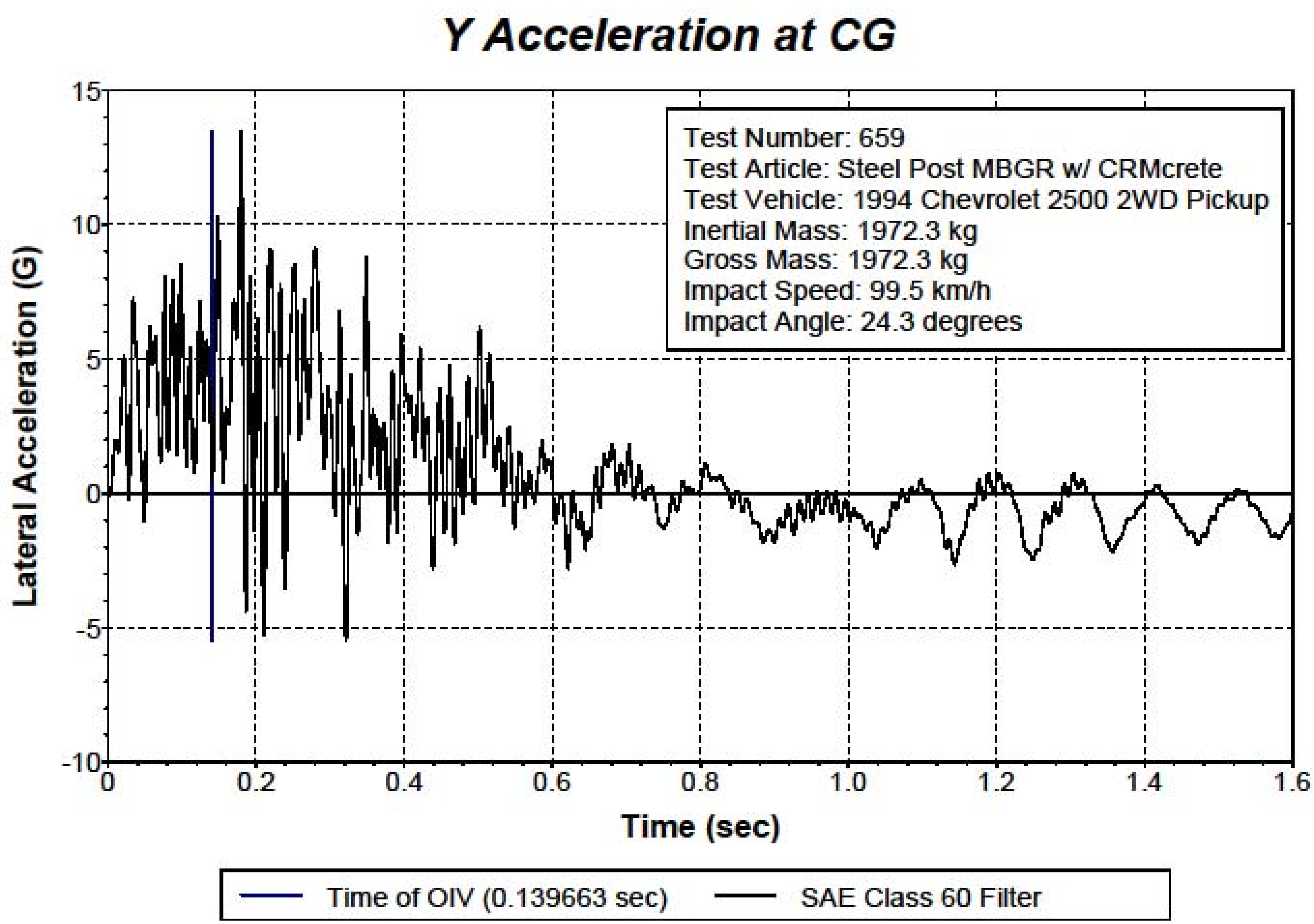


Figure 7-5 – Test 659 Vehicle Y (Lateral) Acceleration Vs Time

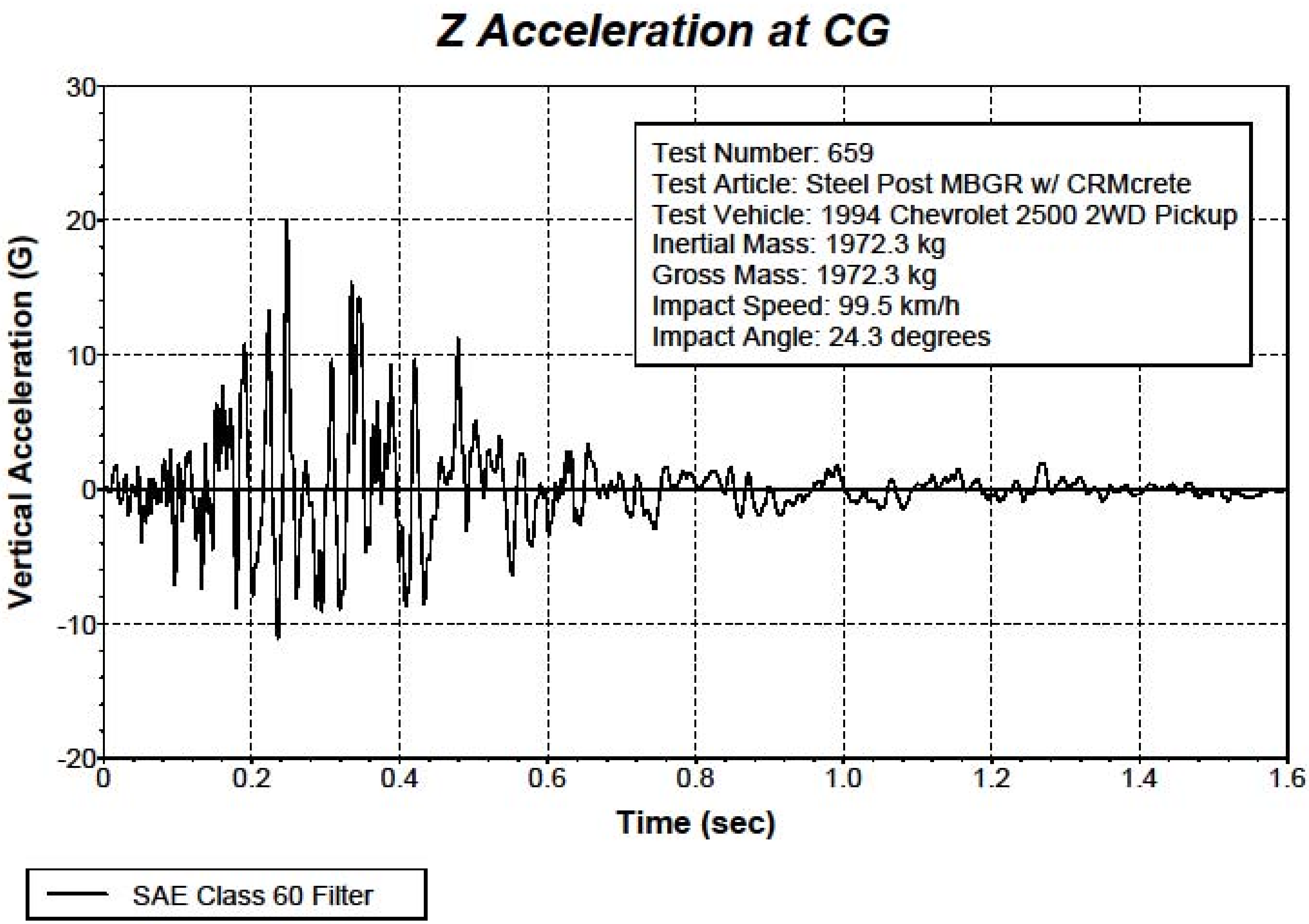


Figure 7-6 – Test 659 Vehicle Z (Vertical) Vs Time

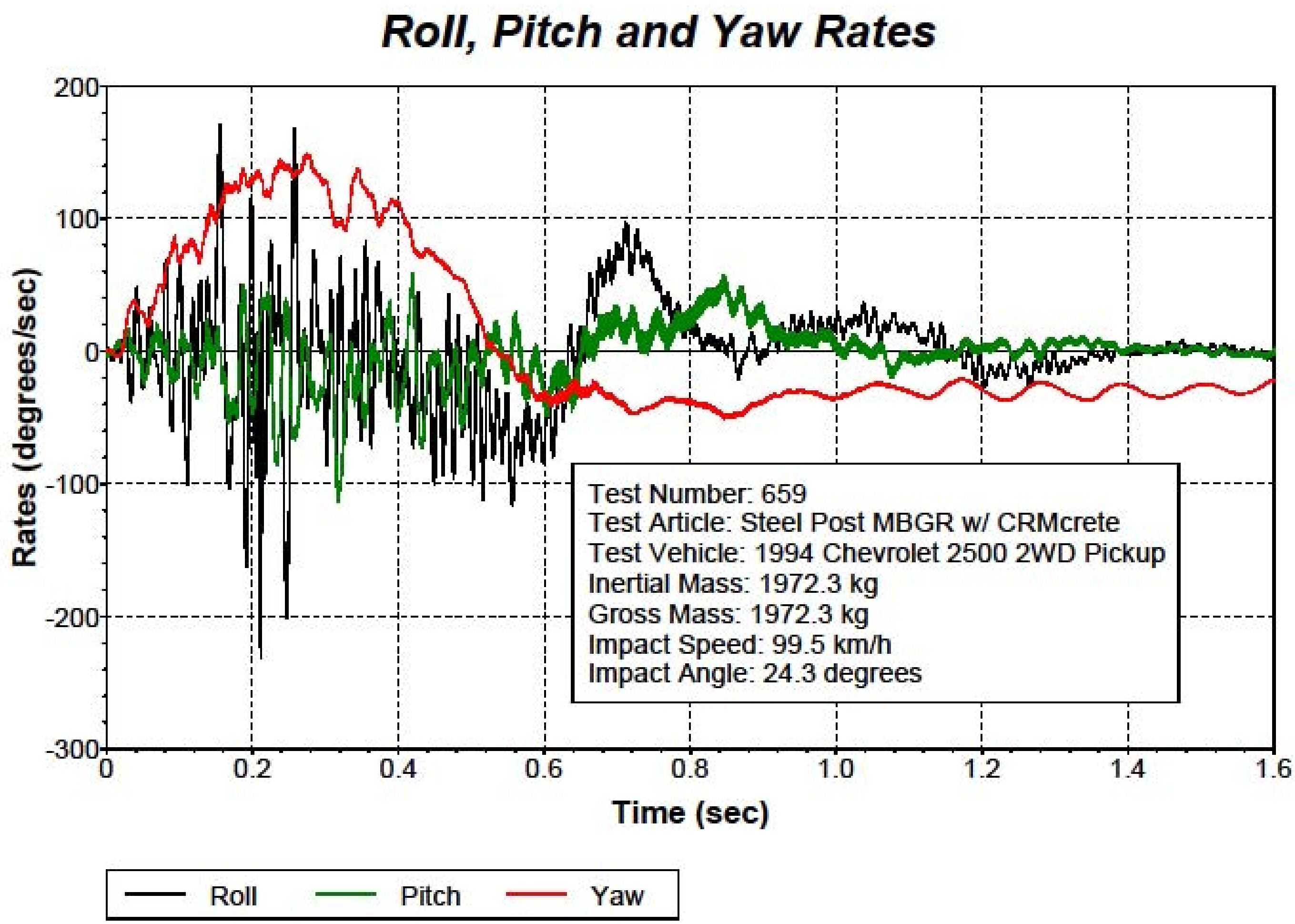


Figure 7-7 – Test 659 Vehicle Roll, Pitch, and Yaw Rate Vs Time

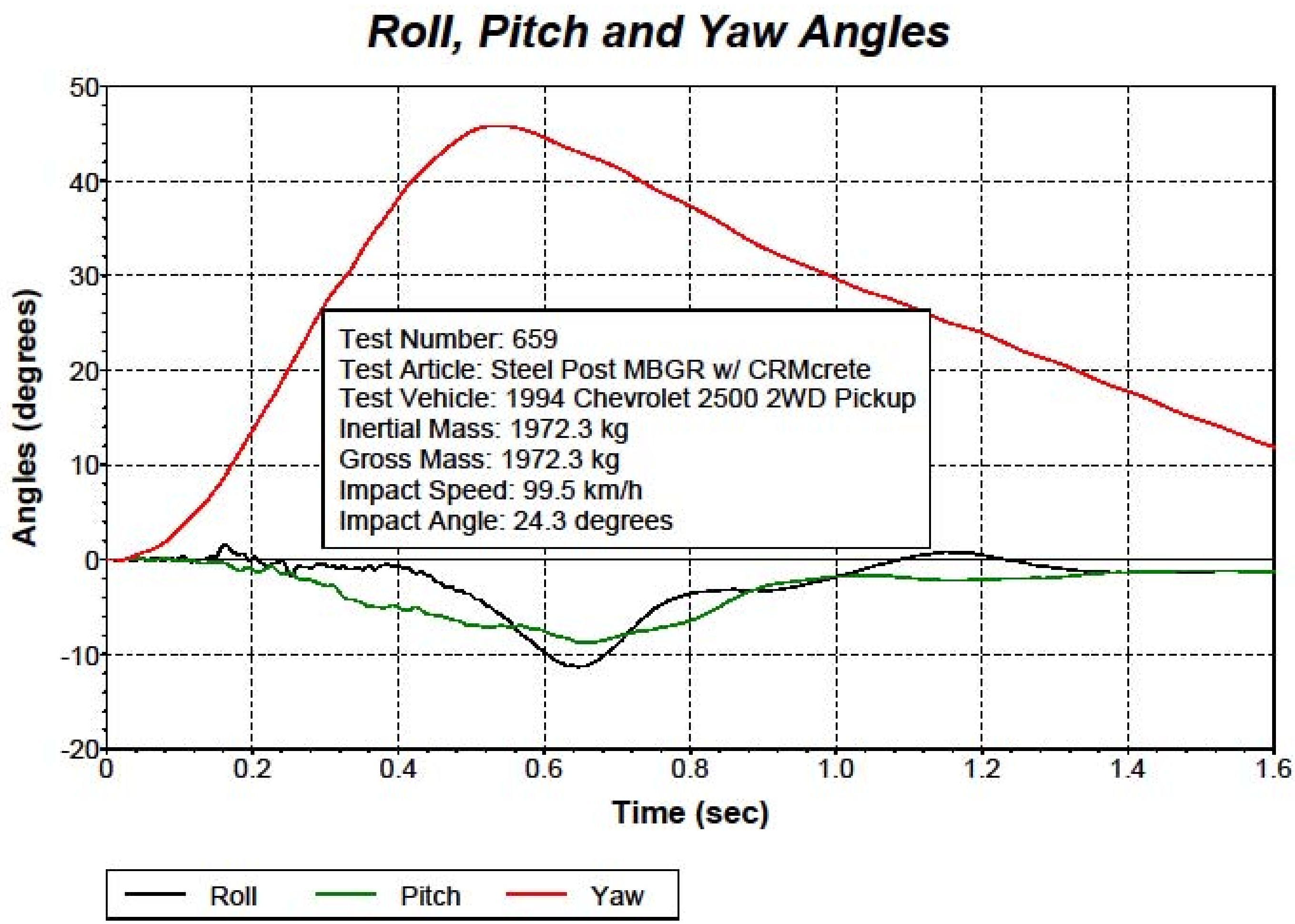


Figure 7-8 – Test 659 Roll, Pitch, and Yaw Angles Vs Time

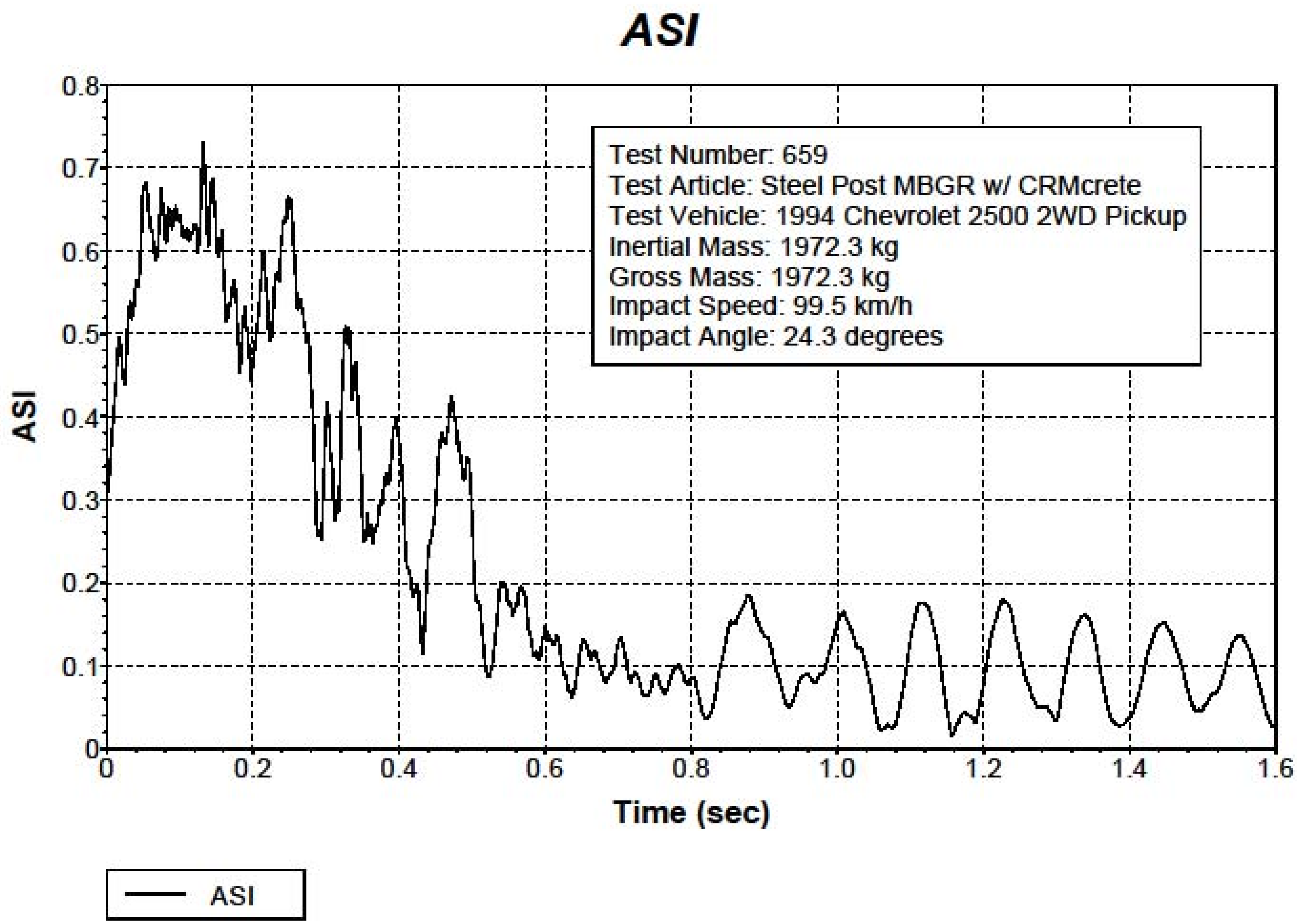


Figure 7-9 – Test 659 Vehicle Acceleration Severity Index (ASI) Vs Time

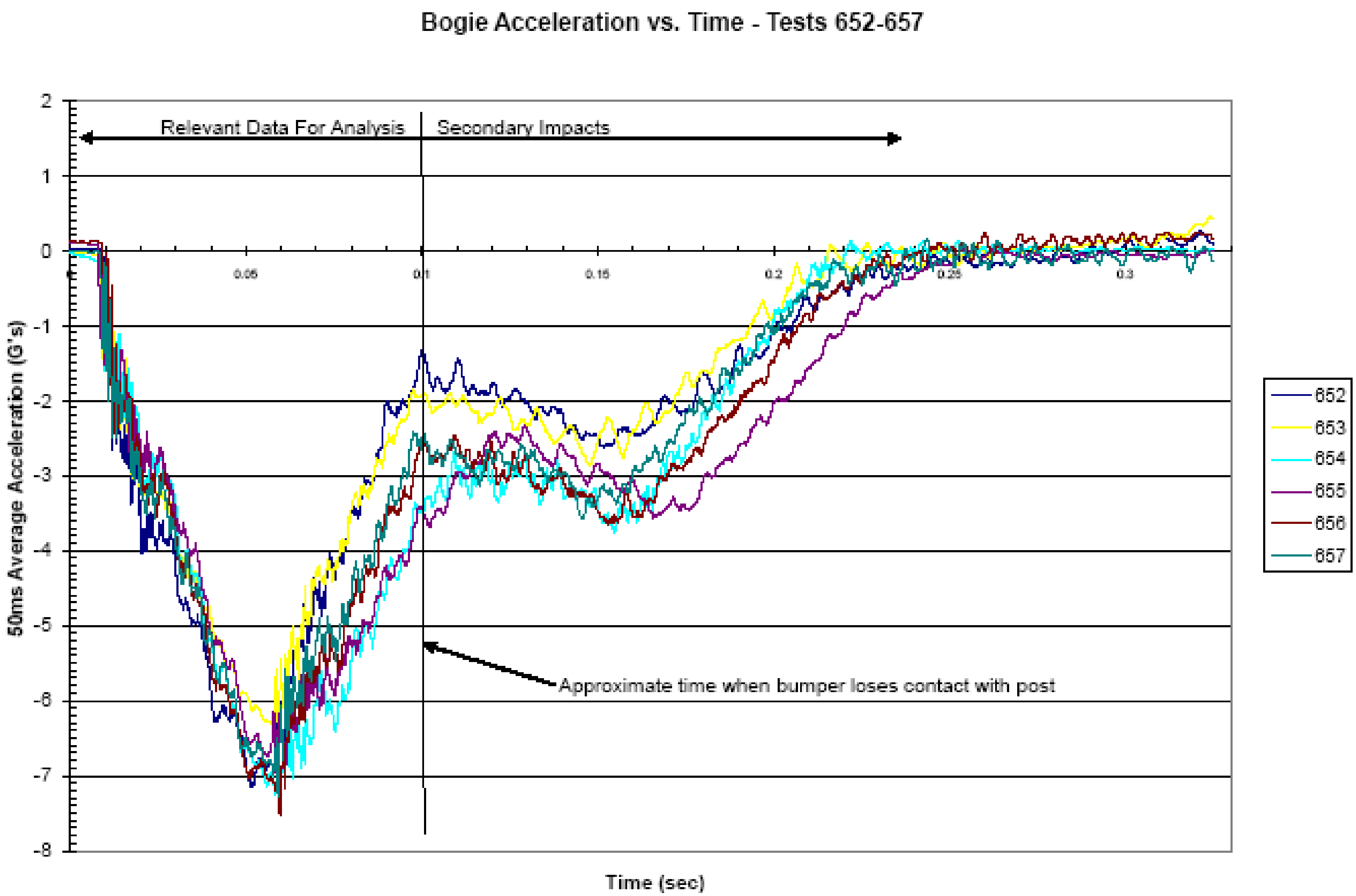


Figure 7-10 – Longitudinal Bogie Acceleration vs. Time

7.5 Detailed Drawings

The following page is the detail drawings of the Weed Control Barrier underneath Metal Beam Guardrail test article for Test 659. Standard Plans are currently under development. Please contact Caltrans, Office of Landscape Architecture for the most current and complete plans.

California Department of Transportation
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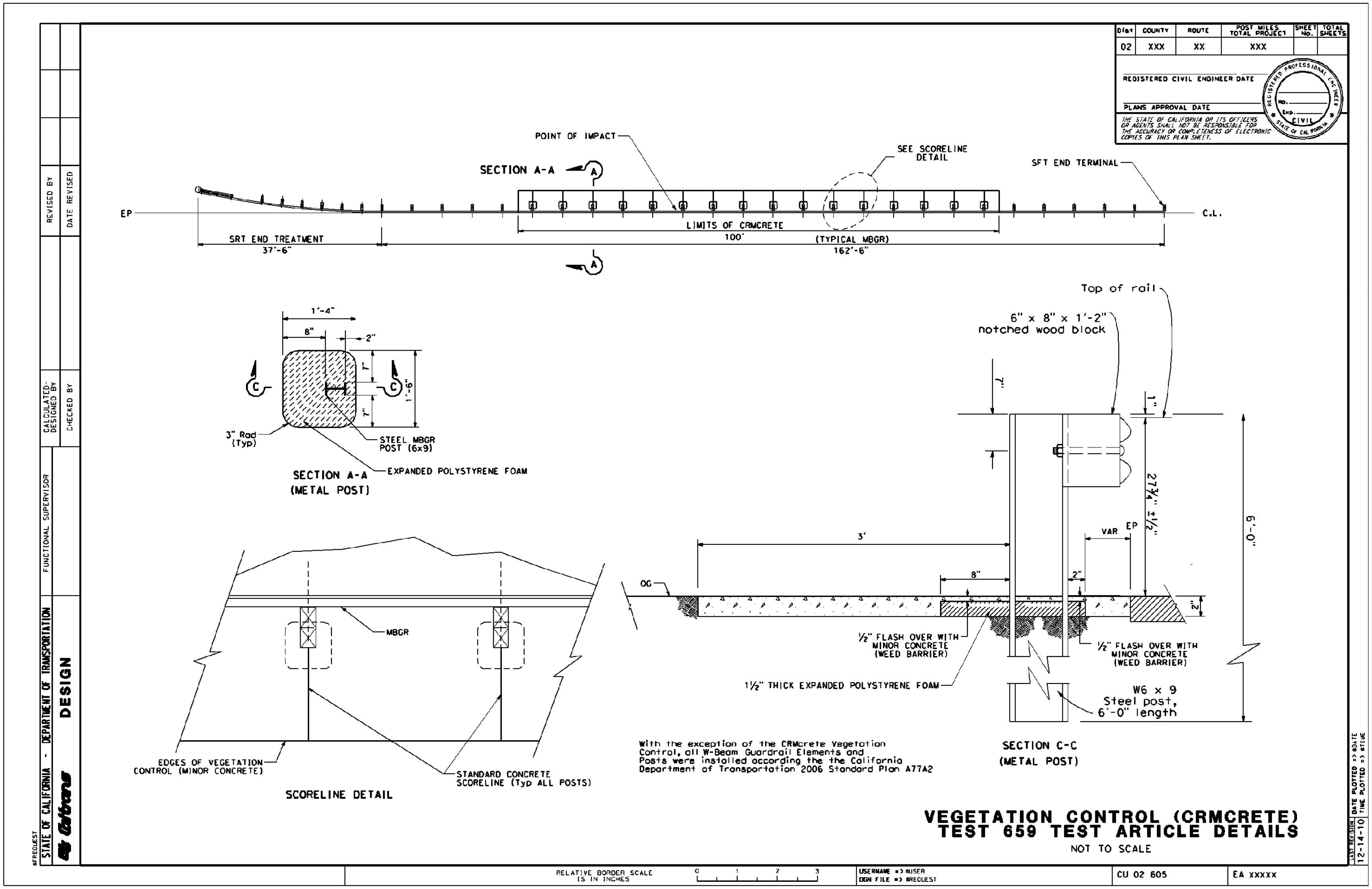

Figure 7-11 – Test 659 Test Article Details