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7. AUTHOR(S) VUE HER, CHRISTOPHER CALDWELL, JOHN JEWELL, ROBERT MELINE		8. PERFORMING ORGANIZATION REPORT NO. FHWA/ CA17-2557
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15. SUPPLEMENTARY NOTES

This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled "COMPLIANCE CRASH TESTING OF A SIDE MOUNTED BRIDGE RAIL".

16. ABSTRACT

The California ST-70SM Side Mounted Bridge Rail was developed and tested in accordance with the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware 2009* (MASH 2009). The barrier is 42 inches (1.07 m) in height and consists of four rails with posts every ten feet. It is mounted to the side of a bridge deck by five 1-1/4 inch (32 mm) high strength anchor rods. On each rod, there are two disc springs stacked together, totaling 10 per post. For testing, the end posts were rigidly mounted to the bridge deck and did not have disc springs. The disc springs reduce the effective stiffness of the post, allowing the rails to distribute more of the load to adjacent posts and lessening damage to the bridge deck. The barrier tested was 76 feet (23.2 m) in length and mounted to a bridge deck, which was anchored to a 4.5' x 10' x 76' (1.4 m x 3.0 m x 23.2 m) anchor block. The barrier was constructed at the Caltrans Dynamic Test Facility in West Sacramento, California.

Three full-scale crash tests were conducted under MASH 2009 Test Level 4 for longitudinal barriers. All three tests met MASH 2009's evaluation criteria for Test Level 4 longitudinal barriers. The results of all three test were within the limits of MASH 2009 guidelines.

The California ST-70SM Side Mounted Bridge Rail tested in the project is recommended for approval on California highways in areas designated as Test Level 4.

17. KEY WORDS Barriers, Crash Test, Median Barrier, Vehicle Impact Test, Bridge Rail, See-Through, Side Mounted		18. DISTRIBUTION STATEMENT No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161	
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UNCERTAINTY OF MEASUREMENT STATEMENT

The Caltrans Roadside Safety Research Group (RSRG) has determined the uncertainty of measurements in the testing of roadside safety hardware as well as in standard full-scale crash testing of roadside safety features. The results contained in this report are only for the tested article(s) and not any other articles based on the same design and/or thereof. Information regarding the uncertainty of measurements for critical parameters is available upon request made to the California Department of Transportation (Caltrans) Roadside Safety Research Group.

COMPLIANCE CRASH TESTING OF THE CA ST-70SM

SIDE MOUNTED BRIDGE RAIL

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION
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.. Vue Her, M.S., P.E.

Research Performed by ....Roadside Safety Research Group

Testing Cert # 3046.01

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION
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COMPLIANCE CRASH TESTING OF THE CA ST-70SM SIDE MOUNTED BRIDGE RAIL

Supervised by..Robert Meline, P.E.

Principal Investigator..John Jewell, P.E.

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SI CONVERSION FACTORS

Metric (SI) to English System of Measurement

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	
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

ACKNOWLEDGEMENTS

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1. Introduction

1.1. Problem

The California Department of Transportation (Caltrans) is constantly faced with Right-of-Way issues and other limitations that make it impossible to mount standard bridge rails to the top of bridge decks. The Caltrans Division of Engineering Services (DES) and the Highway Safety Features New Products Committee (HSFNPC), a committee comprised of representatives from several Divisions within Caltrans, recognizes that crash testing of a side mounted bridge rail that meets American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware* (MASH) 2009[1] Test Level 4 rated guidelines is a high priority.

1.2. Objective

The objective of this research project is to design and test a side mounted bridge rail that will meet the evaluation criteria of MASH 2009 Test level 4 (TL-4) for longitudinal barriers. TL-4 consists of three crash tests as follows:

1. A 2,420 lbs. (1,100 kg) small car impacting the test article at 62 mph (100 km/h) and an angle of 25° (MASH 2009 Test No. 4-10).
2. A 5,000 lbs. (2,270 kg) pickup truck impacting the test article at 62 mph (100 km/h) and an angle of 25° (MASH 2009 Test No. 4-11).
3. A 22,000 lbs. (10,000 kg) single-unit truck impacting the test article at 56 mph (90 km/h) and an angle of 15° (MASH 2009 Test No. 4-12).

1.3. Background

Caltrans has several side mounted bridge rails in their inventory but none of the barriers had been crash tested under either the current MASH 2009 guidelines or previous NCHRP Report 350 guidelines. (See "Side Mounted Bridge Rail" Preliminary Investigation[2]).

1.4. Literature Search

Several locations[2] were searched for crash test information on side mounted bridge rails. No similar products were found that had been tested to MASH 2009 TL-4. There are two products that were tested to the previously accepted guidelines, the National Cooperative Highway Research Program (NCHRP) Report 350 at TL-4 and also accepted by FHWA[3, 4]. They were designed and tested by the University of Nebraska-Lincoln, Midwest Roadside Safety Facility. Although these products were tested to NCHRP Report 350 guidelines, they were only designed for use on transverse, glue-laminated timber bridge decks. These products were found acceptable by FHWA under NCHRP Report 350 TL-4 guidelines but have not been tested under MASH 2009.

1.5. Scope

Three full-scale crash tests were performed and evaluated in accordance with MASH 2009 TL-4 guidelines. The primary purpose of the testing was to determine if the barrier would successfully contain and safely redirect the test vehicles while meeting vehicle occupant safety guidelines. A secondary purpose of the testing was to determine the level of maintenance required after a major impact.

2. Technical Discussion

2.1. Barrier Design

The design criteria for the CA ST-70SM Side Mounted Bridge Rail are as follows:

1. Must meet MASH 2009 Test Level 4
2. Minimize damage to bridge deck

2.2. Test Conditions

2.2.1.Test Facilities

Crash testing was conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The test area is a large, flat, asphalt concrete surface. At the time of testing, there were no obstructions nearby.

2.2.2.Construction

The California ST-70SM Side Mounted Bridge Rail was constructed at the Caltrans Dynamic Test Facility. The barrier was constructed in two stages; Stage 1 was the placement of the anchor block foundation then the bridge deck overhang, Stage 2 was the installation of the bridge rail. The anchor block consisted of a 10’-0” x 4’-6” x 76’-0” (3.0 m x 1.4 m x 23.2 m) reinforced concrete block and is designed to support the bridge deck overhang and act as a resistance mass to help reduce motion during testing. See Section 10 for detail drawings.

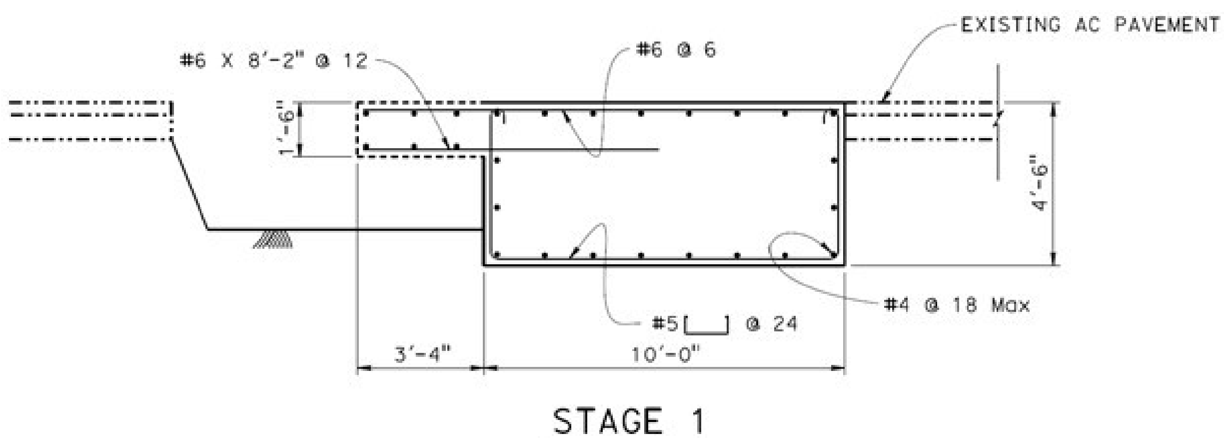

Figure 2-1. Stage 1 Construction of Anchor Block and Bridge Deck Overhang

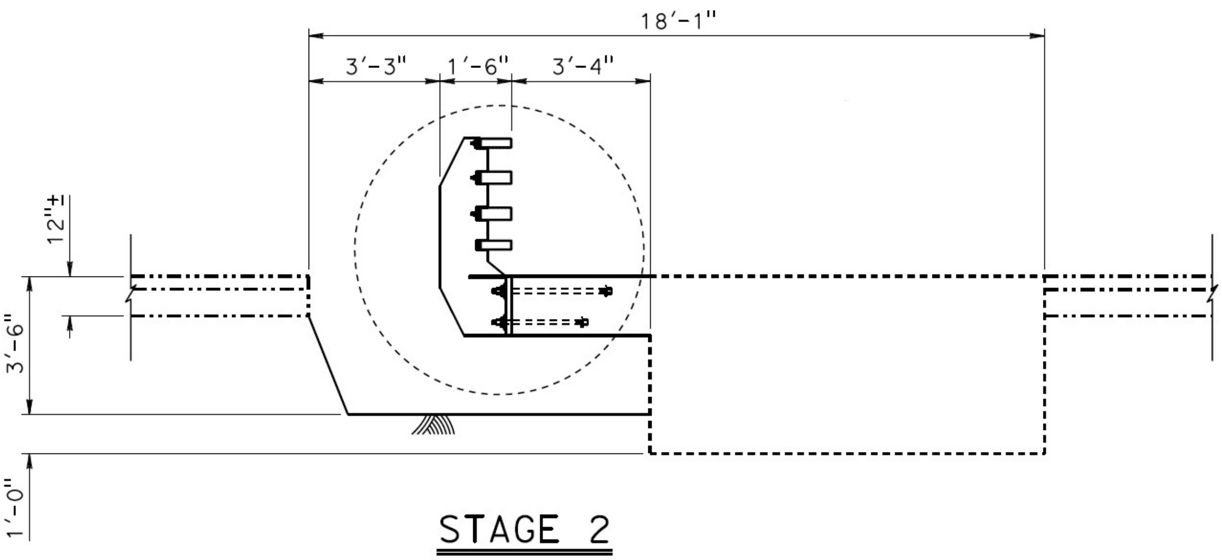

Figure 2-2. Stage 2 Installation of Bridge Rail

Figure 2-3. Forming the Anchor Block

Figure 2-4. Anchor Block Rebar

There were eight bridge rail posts. The two outer posts were mounted directly to the deck without any springs. The six inner posts had double stacked disc springs installed on each anchor bolt (5 pairs of disc springs per rail post). The disc springs on the bridge rail were designed to reduce the effective stiffness of the post, allowing the rails to distribute more of the load to adjacent posts. This should decrease damage to posts, anchor bolts, and bridge deck. Also, under high enough loads, the disc springs are designed to undergo plastic deformation prior to yielding of the anchor bolts, providing some additional overload protection for the anchor bolts and deck overhang. The deck overhang is designed to yield prior to deck rebar yielding. See Table 8-25 in Appendix 8.5 for disc spring information. See Figure 2-5 for a typical rail post.

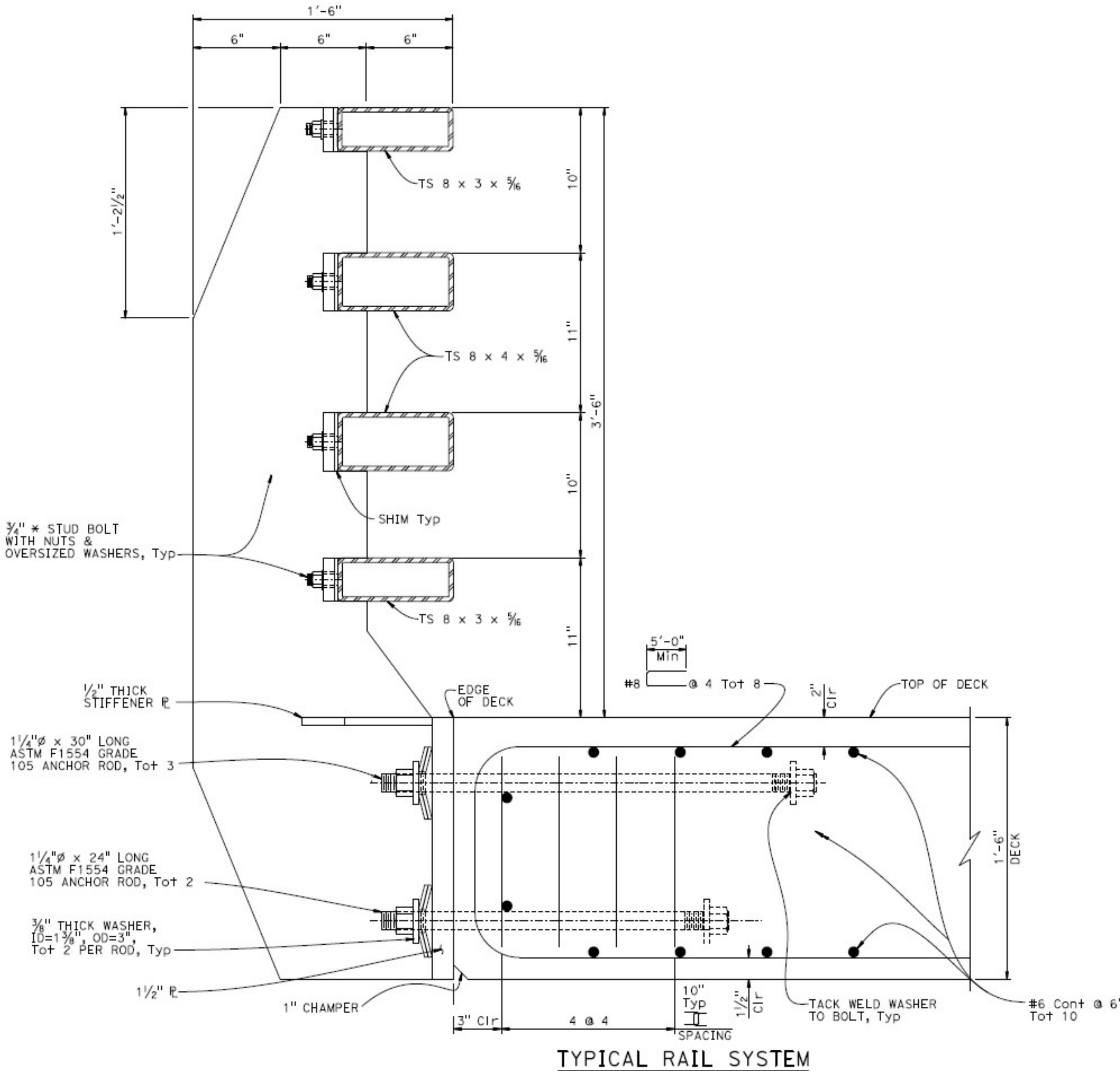

Figure 2-5. CA ST-70SM Side Mounted Bridge Rail Typical

Bridge rail posts 3, 4, and 5 had strain gages installed on their anchor rods prior to installation and concrete deck pour. See *FHWA/ CA17-2557 Supplement* report for strain gage and string pot results. (*Strain gage and string pot measurements are not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab*)

Figure 2-6. Strain Gages Installed on Anchor Rods for Posts 3, 4, and 5

Figure 2-7. Anchor Block and Bridge Deck Rebar

Figure 2-8. Rebar Configuration at Rail Post Location

Figure 2-9. Pouring Anchor Block Concrete

Figure 2-10. Surface Finishing on Anchor Block

Figure 2-11. Anchor Rod Installation

Figure 2-12. Anchor Rod Placement in Deck Overhang

The deck overhang was poured separate from the anchor block to make removal of the deck easier for future research projects.

Figure 2-13. Concrete Deck Overhang Pour

Figure 2-14. Concrete Deck Overhang Finish

Figure 2-15. Installation of CA ST-70SM Side Mounted Bridge Rail Posts

Figure 2-16. Installation of CA ST-70SM Side Mounted Bridge Rails

The completed test article was 76 feet (23.2 m) long with a bridge rail nominal height of 42 inches (1.07 m). Rails were placed in cutouts in the posts and held in place with ¾" stud bolts. For the stud bolts welded on the railing it was determined that "bolt stud welds" were needed instead of the originally specified "full penetration butt weld". During construction the shims shown in the construction plans could not be installed on the lower three rails once the rails were installed. The Caltrans Translab Machine Shop modified the shims for the test barrier installation. Also, the railing washers were undersized and could slip into the post slots, no longer supporting the nut. The 6 inner posts were held in place with 5 anchor bolts per post. Two stacked disc springs were installed on each anchor bolt, on the outside of the barrier post. The discs were retained with a flat washer and nut torqued to provide 10,000 lbs. (4536 kg) of preload. For this research project, thread locking compound was not used to secure the nuts of the test article. The discs allow the barrier to have some controlled deflection, reducing the peak load on the rail and providing some energy dampening during impact. The reduced peak load provides a lower maximum stress on the top anchor bolts and a slightly lower peak deceleration of the impacting vehicle. Barrier (test article) construction was completed December 2014. See Appendix 8.4 for bridge rail anchor bolt/nut torque information.

2.2.3. Test Vehicles

The test vehicles complied with MASH 2009 tests 4-10, 4-11, and 4-12 requirements. The vehicles were a 2007 Dodge Ram 1500 ST, a 2008 Kia Rio, and a 2005 Freightliner M2. The MASH 2009 2270P, 1100C, and 10000S tests for the CA ST-70SM Side Mounted Bridge Rail were assigned test identification numbers 110MASH3P15-01, 110MASH4C15-02, and 110MASH4S16-03, respectively. All vehicles were in good condition and free of any major body damage. The vehicles were not missing any structural parts nor were they modified in any way other than described in this report. All the standard equipment for each vehicle was present. The inertial mass of the pickup truck, small car, and van truck were 5,030 lbs. (2,282 kg), 2,465 lbs. (1,118 kg), and 21,887 lbs. (9,928 kg), respectively. The vehicles were within the recommended limits of MASH 2009 vehicle mass requirements.

2.2.3.1. Test Vehicle 2270P: 2007 Dodge Ram 1500ST (Test 110MASH3P15-01)

To achieve the desired impact speed, the pickup truck was self-powered. A speed control device was installed in the Dodge Ram which limited the acceleration of the vehicle once the target impact speed was achieved. The steering was accomplished by means of a guidance rail anchored to the ground and a guide arm connecting the vehicle wheel hub to the guidance rail. Remote braking was possible at any time during the test via radio control. The vehicle was released from the guidance rail a short distance before impact. The pickup truck ignition was turned off via an engine kill switch that activated just before impact. Photos of the test vehicle are shown in Figure 2-17 to Figure 2-19. See Appendix 8.1 for more information on test 110MASH3P15-01 vehicle instrumentation.

Figure 2-17. 110MASH3P15-01 Dodge Ram 1500 (Side)

Figure 2-18. 110MASH3P15-01 Dodge Ram 1500 (Front Right)

Figure 2-19. 110MASH3P15-01 Dodge Ram 1500 (Relative to Barrier)

2.2.3.2. Test Vehicle 1100C 2008 Kia Rio (Test 110MASH4C15-02)

To achieve the desired impact speed for the small car, the vehicle was towed. A speed control device was installed in the tow vehicle, which limited the acceleration of the vehicle once the target impact speed was reached. The steering was accomplished by means of a guidance rail anchored to the ground and a guide arm connecting the vehicle wheel hub to the guidance rail. Remote braking was possible at any time during the test via radio control. The vehicle was released from the guidance rail a short distance before impact. Photos of the test vehicle are shown in Figure 2-20 to Figure 2-22. See Appendix 8.2 for more information on test 110MASH4C15-02 vehicle instrumentation.

Figure 2-20. 110MASH4C15-02 Kia Rio (Side)

Figure 2-21. 110MASH4C15-02 Kia Rio (Front Right)

Figure 2-22. 110MASH4C15-02 Kia Rio (Relative to Barrier)

2.2.3.3. Test Vehicle 10000S: 2005 Freightliner M2 (Test 110MASH4S16-03)

To achieve the desired impact speed within the allowable physical distance, the van truck was self-powered and pushed with a 2001 Ford F350 regular cab dually. The Ford F350 assisted in the acceleration of the van truck for the first 900 ft. (274 m). The vehicle's target speed was accomplished by reprogramming the electronic control module and setting the speed governor in the vehicle to MASH 2009's recommended impact speed of 56 mph (90 km/h) for Test 4-12. The steering was accomplished by means of a guidance rail anchored to the ground and a guide arm connecting the vehicle wheel hub to the guidance rail. Remote braking was possible at any time during the test via radio control. The vehicle was released from the guidance rail a short distance before impact. The van truck ignition was turned off via an engine kill switch that activated just before impact. Photos of the test vehicle are shown in Figure

2-23 to Figure 2-25. See Appendix 8.3 for more information on test 110MASH4S16-03 vehicle instrumentation.

Figure 2-23. 110MASH4S16-03 Freightliner M2 (Side)

Figure 2-24. 110MASH4S16-03 Freightliner M2 (Front Right)

Figure 2-25. 110MASH4S16-03 Freightliner M2 (Relative to Barrier)

2.2.4.Data Acquisition System

The tests were visually documented through the use of still cameras, video cameras, and high-definition high-speed digital video cameras. The impact phase of the crash test was recorded with five high-definition high-speed digital video cameras, a normal-speed DVC format video camera, several small action style cameras and digital SLR cameras. The test vehicle and barrier were photographed before and after impact with the DVC format camera and a digital SLR camera.

DataBrick III Transient data recorders (TDR), manufactured by GMH Engineering, were used to record accelerations and rotational rate changes during the test. The digital data was downloaded to a laptop computer and analyzed with Texas Transportation Institute's Test Risk Assessment Program (TRAP). A DADiSP workbook was used to create the necessary TRAP input files.

Figure 2-26. Dodge Ram 1500 Vehicle Instrumentation

Figure 2-27. Kia Rio Vehicle Instrumentation

Figure 2-28. Freightliner M2 Vehicle Instrumentation

Two sets of orthogonal accelerometers were mounted at the center of gravity for vehicles of tests 110MASH3P15-01 and 110MASH4C16-02 (as per MASH 2009 specifications). Rate gyro transducers (angular rate sensors) were also placed at the center of gravity of the test vehicles to measure roll, pitch, and yaw rates. The data was analyzed in TRAP to determine the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation.

Additional instrumentation was installed on the barrier around the proximity of the impact location to record displacements of the bridge rail. Strain gages were also installed on the anchor rods of posts 3, 4, and 5. Information on the measurements for all three tests can be found in the supplement report (*FHWA/ CA17-2557 Supplement*). *(Strain gage and string pot measurements are not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab)*

3. Crash Test Matrix and Results

The first test on the CA ST-70SM Side Mounted Bridge Rail is MASH 2009 Test 4-11. It consists of a 5000 lbs. (2270 kg) 2007 Dodge Ram 1500 pickup truck with target impact conditions of 62 mph (100 km/h) at an angle of 25°. The second test is MASH 2009 Test 4-10. It consists of a 2420 lbs. (1100 kg) 2008 Kia Rio with target impact conditions of 62 mph (100 km/h) at an angle of 25°. The final test is MASH 2009 Test 4-12 and consists of a 22,000 lbs. (10,000 kg) single-unit van body truck with target impact conditions of 56 mph (90 km/h) at an angle of 15°. The test numbers for the three tests are 110MASH3P15-01, 110MASH4C15-02, and 110MASH4S16-03, respectively. The following table shows the test matrix for the CA ST-70SM Side Mounted Bridge Rail.

Table 3-1. CA ST-70SM Side Mount Bridge Rail Test Matrix

RSRG Test Number	MASH 2009 Test Number	Impact Speed	Impact Angle
110MASH3P15-01	4-11	62 mph (100 km/h)	25°
110MASH4C15-02	4-10	62 mph (100 km/h)	25°
110MASH4S16-03	4-12	56 mph (90 km/h)	15°

3.1. Test 110MASH3P15-01 Impact Description and Results

The 2270P vehicle impacted the barrier at 61.5 mph (98.9kph) and at an angle of 25.0 degrees. The impact point was 66 inches (1.7 m) upstream from the center of post 4. It was estimated that this point of impact would provide the greatest load on post 4 based on the location of the vehicle frame and observations from previous similar testing and computer simulations. The impact severity was 113.6 kip-ft (154 kJ). The barrier contained and redirected the 2270P vehicle in a controlled manner and the vehicle exited the barrier within the MASH exit box criteria. There was no indication of any pocketing of the vehicle or snagging of the vehicle on the bridge rail. The Occupant Risk factors, Occupant Impact Velocities (OIV) and Occupant Ridedown Accelerations (ORA) were within the MASH criteria limits. The OIV_x = 13.45 ft/s (4.1 m/s) is below the preferred limit of 30 ft/s (9.1 m/s). The OIV_y = 26.9 ft/s (8.2 m/s) is close to the preferred limit but is well below the maximum of 40 ft/s (12.2 m/s). The ORA_x = -2.6 G is below the preferred limit of 15.0 G and the ORA_y = -16.9 G is below the maximum of 20.49 G.

3.1.1. Test 110MASH3P15-01 Barrier Damage

The point of impact was 66 inches (1.7 m) upstream from the center of post 4. There was minimal damage to the barrier. The vehicle bumper first made contact at the impact point upstream of rail post 4 (see Figure 3-2). The red contact marks on the bridge rail were from the front right tire. The green contact marks on the bridge rail were from the rear right tire. Based on video analysis and markings on the barrier, the vehicle stayed in contact with the bridge rail for 14 feet (4.3 m). The vehicle did not snag or pocket. The three upper disc spring sets on post 4 went into plastic deformation during impact, thus requiring replacement for future testing. String potentiometers (pots) were mounted on posts 3, 4, and 5 to measure deflection. Both dynamic and static displacements were measured from the rear middle of the top rail. See Table 3-2 for maximum dynamic and static displacements. Strain gages were installed on the all anchor rods for posts 3, 4, and 5 to indicate stress levels during testing. See *FHWA/ CA17-2557 Supplement* report for strain gage and string pot results. (*Strain gage and string pot measurements are not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab*)

Figure 3-1. Point of Impact 66 inches (1.7 m) Upstream of Post 4

Table 3-2. Maximum Dynamic and Static Displacements (110MASH3P15-01)*

	Post 3	Post 4	Post 5
Maximum Dynamic Displacement	0.92 in (23.4 mm)	1.62 in (41.0 mm)	0.38 in (9.6 mm)
Static Displacement	0.05 in (1.3 mm)	0.18 in (4.6 mm)	0.03 in (0.7 mm)

** Not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab*

Figure 3-2. Vehicle Impact Tire Marks (Red – Front Right Tire, Green – Rear Right Tire)

Figure 3-3. Upstream Impact View

Figure 3-4. Downstream Impact View

Figure 3-5. CA ST-70SM Side Mounted Bridge Rail after 2270P Vehicle Impact

Figure 3-6. Disc Spring Installed

Figure 3-7. Posts 3, 4, and 5 String Pot Setup

Figure 3-8. String Pot Installed on Upper Post

3.1.2. Test 110MASH3P15-01 Vehicle Damage

The front right corner of the test vehicle sustained most of the damage from the impact with the side mounted bridge rail. The bumper, headlight, hood, doors, and front and rear fenders were severely damaged. The right front tire ruptured upon impact with the bridge rail. Both airbags deployed in the vehicle. The right front and rear doors were wedged in and still attached but could not be opened. The impact with the bridge rail left indentations along the pickup truck's side relative to where it was in contact with the rails during impact. The windshield cracked but did not separate or enter the occupant compartment. The maximum amount of passenger compartment deformation was 1.2 inches (31 mm), which occurred at the roof of the vehicle. The maximum amount of deformation for the floorboard and dashboard were 0.7 inches (18 mm) and 0.7 inches (18 mm), respectively. These values are below the maximum MASH 2009 limits. See Appendix 8.1.6 for complete interior deformation measurements for test 110MASH3P15-01.

Figure 3-9. 110MASH3P15-01 Dodge Ram 1500 Damage (Side)

Figure 3-10. 110MASH3P15-01 Dodge Ram 1500 Damage (Rear)

Figure 3-11. 110MASH3P15-01 Dodge Ram 1500 Damage (Front)

Figure 3-12. 110MASH3P15-01 Dodge Ram 1500 Airbags Deploy

Figure 3-13. 110MASH3P15-01 Dodge Ram 1500 Damage (Truck Bed)

The vehicle sustained damage from a secondary impact with a construction barrier (k-rail) that was set about 270 feet (82 m) downstream of the target impact point to protect a high-speed video camera. The vehicle remote braking system was applied several vehicle lengths after leaving the bridge rail but the brake did not stop the vehicle before it hit the K-Rail. The impact with the K-Rail occurred on the front left (drivers side) of the vehicle causing the bumper to fold under with the vehicle coming to rest on the K-Rail. Even though the left side of the vehicle was damaged during the secondary impact, it did not cause difficulty analyzing the damage from the primary impact with the bridge rail. The interior deformations were still within acceptable limits.

Figure 3-14. Trajectory Towards K-Rail

Figure 3-15. Secondary Impact on K-Rail

Figure 3-16. Vehicle Resting Location

3.1.3. Test 110MASH3P15-01 Summary Sheet


0.000 sec


0.070 sec


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0.210 sec


0.280 sec


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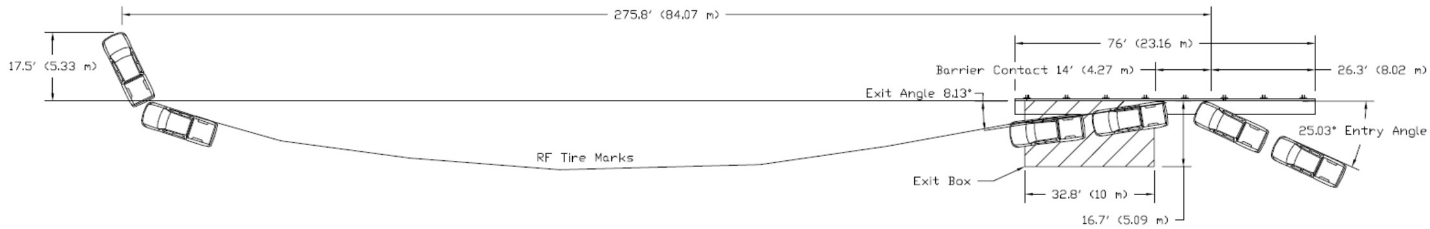


Test Agency: California, Department of Transportation
Test Number: 110MASH3P15-01
Date: 8/26/2015
Test Article: CA ST-70SM Side Mounted Bridge Rail
Total Length: 76 ft (23.2 m)
Key Elements – Barrier
- Description: Side Mounted Bridge Rail
- Length: 120 in (3048 mm) O.C. Posts
- Base Width: 18 in (457 mm)
- Height: 42 in (1067 mm)

Test Vehicle
- Type/Designation: 2270P
- Make and Model: 2007 Dodge Ram 1500 Quad Cab Pickup
- Curb: 4867 lb (2208 kg)
- Test Inertial: 5030 lb (2282 kg)
- Gross Static: 5038 lb (2285 kg)

Impact Conditions
- Speed: 61.5 mph (98.9 kph)
- Angle: 25.0 deg
- Location/Orientation: 66 in (1.7 m) upstream of post 4
- Impact Severity: 113.6 kip-ft (154.0 kJ)

Exit Conditions
- Speed: 53.0 mph (85.3 kph)
- Angle: 8.1 deg

Post-impact Trajectory
- Vehicle Stability: Satisfactory
- Stopping Distance: 276 ft (84.1 m) downstream 17.5 ft (5.3 m) laterally behind

Vehicle Snagging: None
Vehicle Pocketing: None
Occupant Impact Velocity
- Longitudinal: 13.45 ft/s (4.1 m/s)
- Lateral: 26.90 ft/s (8.2 m/s)

Occupant Ridedown Deceleration (10 msec avg.)
- Longitudinal: -2.6 G
- Lateral: -16.9 G

THIV: 30.5 ft/s (9.3 m/s)
PHD: 16.9 G
Test Article Damage: Minor (3 spring sets to be replaced Post 4)
Test Article Deflections*
- Permanent Set: 0.2 in (5 mm)
- Dynamic: 1.6 in (41 mm)
- Working Width: 20.25 in (514 mm)

Vehicle Damage: Moderate
- VDS: 01-FR-3, 03-RP-3
- CDC: 01-RFEK3, 03-RDEK1
- Maximum Deformation: 1.2 in (31 mm) roof deformation

**String potentiometer measurements are not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab*

3.2. Test 110MASH4C15-02 Impact Description and Results

The 1100C vehicle impacted the barrier at 64.7 mph (104.1kph) and at an angle of 25.0 degrees. The impact point was 66 inches (1.7 m) upstream from the center of post 4. An impact at this location would help indicate possible vehicle wheel snagging on post 4. The impact speed of 64.7 mph (104.1 kph) is 0.7 mph (0.1 kph) above MASH 2009 maximum desired value. Although the speed was over the maximum desired value, it was consider acceptable because the impact severity and ride down decelerations were within acceptable limits. The impact severity was calculated to be 61.6 kip-ft (83.5 kJ). The barrier contained and redirected the 1100C vehicle in a controlled manner and the vehicle exited the barrier within the MASH exit box criteria. There was no indication of any pocketing of the vehicle or snagging of the vehicle on the bridge rail. The Occupant Risk factors, OIV and ORA were within the MASH criteria limits. The OIV_x = 17.4 ft/s (5.3 m/s) is below the preferred limit of 30 ft/s (9.1 m/s). The OIV_y = 36.4 ft/s (11.1 m/s) is below the maximum of 40 ft/s (12.2 m/s). The ORA_x = 3.9 G is below the preferred limit of 15.0 G and the ORA_y = -13.4 G is also below the preferred limit.

3.2.1. Test 110MASH4C15-02 Barrier Damage

The point of impact was 66 inches (1.7 m) upstream from the center of post 4. There was no damage to the barrier. The vehicle bumper first made contact at the impact point upstream of rail post 4 (see Figure 3-18). The red contact marks on the bridge rail were from the front right tire. The green contact marks on the bridge rail were from the rear right tire. The vehicle stayed in contact with the bridge rail for 10.6 feet (3.2 m). The vehicle did not snag or pocket. There were no permanent deflections on the disc springs. String pots were mounted on posts 3, 4, and 5 to measure deflection. Both dynamic and static displacements were measured from the rear middle of the top rail. See Table 3-3 for maximum dynamic and static displacements. Strain gages were installed on the all anchor rods for posts 3, 4, and 5. See *FHWA/ CA17-2557 Supplement* for strain gage and string pot results. (*Strain gage and string pot measurements are not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab*)

Figure 3-17. Target Point of Impact 66 inches (1.7 m) Upstream of Post 4

Table 3-3. Maximum Dynamic and Static Displacements (110MASH4C15-02)*

	Post 3	Post 4	Post 5
Maximum Dynamic Displacement	NA (Damaged)	0.93 in (23.5 mm)	0.11 in (2.7 mm)
Static Displacement	0.01 in (0.3 mm)	0.03 in (0.8 mm)	0.00 in (0.1 mm)

** Not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab*

Figure 3-18. Vehicle Impact Tire Marks (Red – Front Right Tire, Green – Rear Right Tire)

Figure 3-19. Upstream Impact View

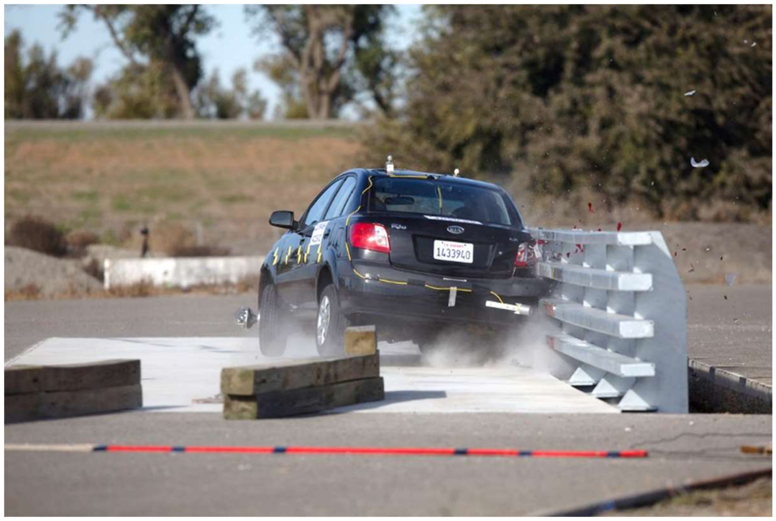


Figure 3-20. Downstream Impact View

Figure 3-21. CA ST-70SM Side Mounted Bridge Rail after 1100C Vehicle

Figure 3-22. Disc Spring Installation

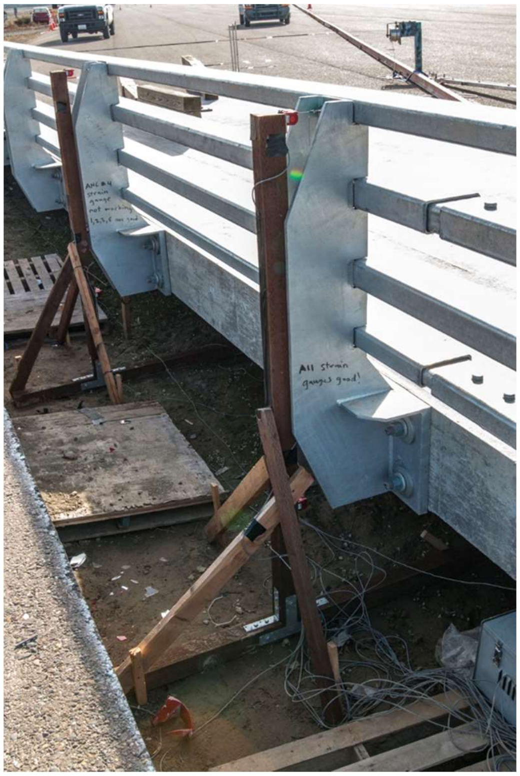


Figure 3-23. Posts 3 and 4 String Pot Mount Supports

Figure 3-24. String Pot Installed on Base of Post

3.2.2. Test 110MASH4C15-02 Vehicle Damage

The front right corner and passenger side of the test vehicle sustained most of the damage from the impact with the side mounted bridge rail. The whole passenger side of the vehicle made contact with the side mounted bridge rail. The passenger headlight was completely torn off the vehicle. The bumper, hood, doors, and front and rear fenders were severely damaged. The airbags did not deploy because the vehicle was towed and the vehicle's battery had been removed. The right front and rear doors were damaged and could not be opened. The impact with the bridge rail left depressions along the vehicle's side relative to where it contacted the rails during impact. The windshield cracked but did not separate or enter the occupant compartment. The maximum amount of passenger compartment deformation was 2.0 inches (52 mm), which occurred at the floorboard. The maximum amount of deformation for the roof and dashboard are 0.4 inches (10 mm) and 0.3 inches (8 mm), respectively. These values are below the maximum MASH 2009 limits. See Appendix 8.2.6 for complete interior deformation measurements for test 110MASH4C15-02.

Figure 3-25. 110MASH4C15-02 Kia Rio Damage (Side)

Figure 3-26. 110MASH4CP15-02 Kia Rio Damage (Rear)

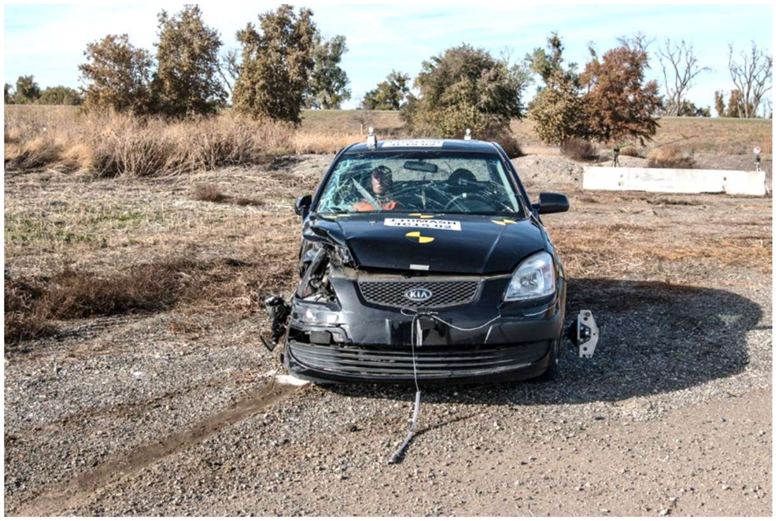


Figure 3-27. 110MASH4C15-02 Kia Rio Damage (Front)

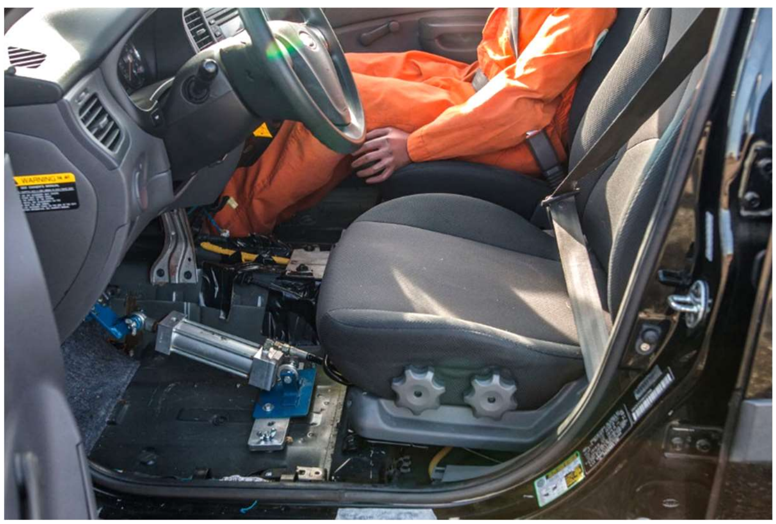


Figure 3-28. 110MASH4C15-02 Kia Rio Interior Post Test

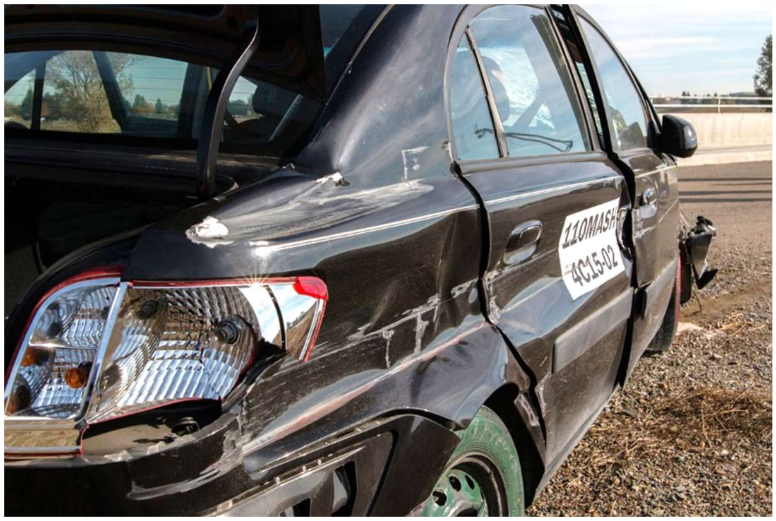


Figure 3-29. 110MASH4C15-02 Kia Rio Side Damage

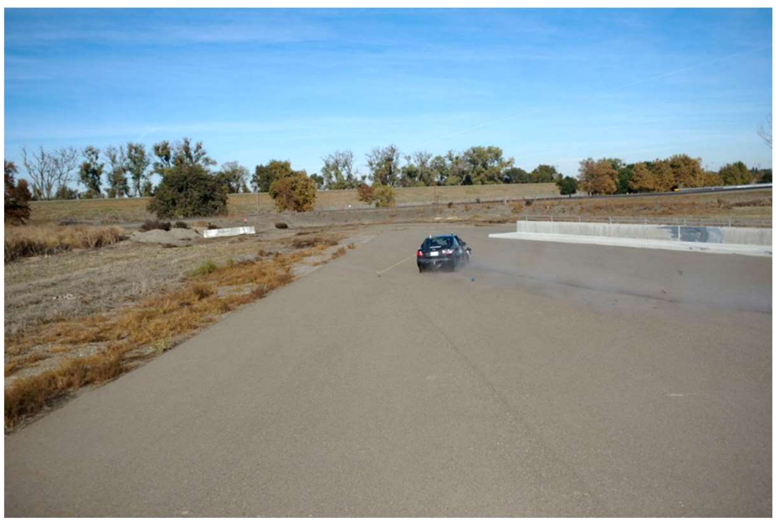


Figure 3-30. Trajectory After Impact

Figure 3-31. Vehicle in Yaw

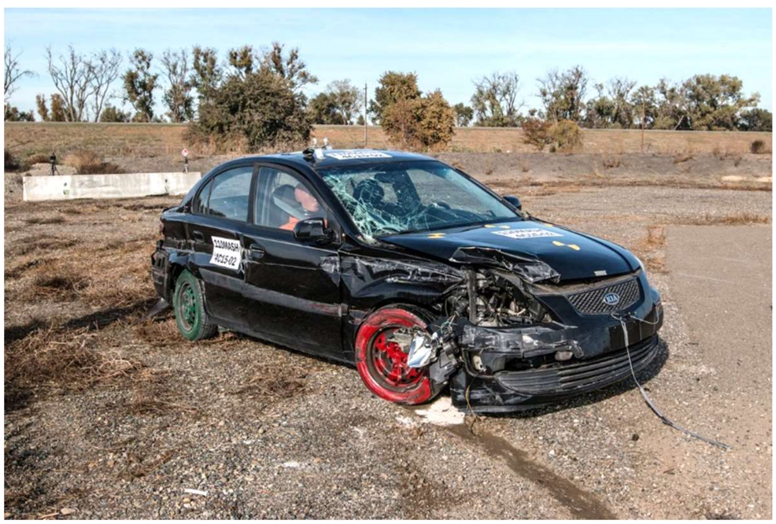
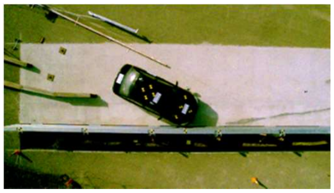
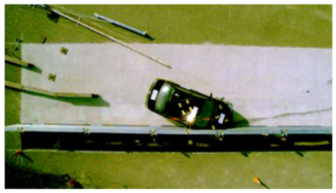
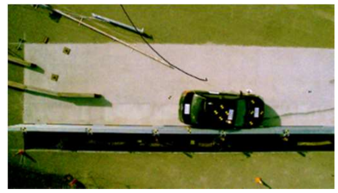


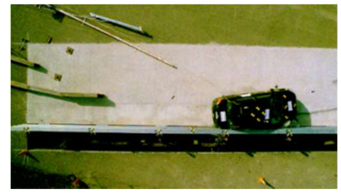
Figure 3-32. Vehicle Resting Location

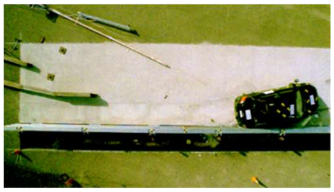
3.2.1.Test 110MASH4C15-02 Summary Sheet


0.000 sec


0.060 sec


0.120 sec

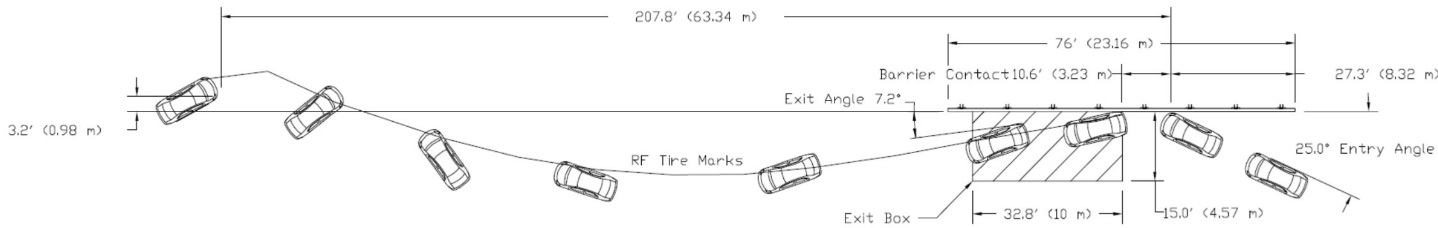

0.180 sec


0.240 sec


0.300 sec


0.360 sec


0.420 sec



Test Agency.......California, Department of Transportation
Test Number.......110MASH4C15-02
Date.......11/18/2015
Test Article.......CA ST-70SM Side Mounted Bridge Rail
Total Length.......76 ft (23.2 m)
Key Elements – Barrier
- Description.......Side Mounted Bridge Rail
- Length.......120 in (3048 mm) O.C. Posts
- Base Width.......18 in (457 mm)
- Height.......42 in (1067 mm)

Test Vehicle
- Type/Designation.......1100C
- Make and Model.......2008 Kia Rio
- Curb.......2435 lb (1104 kg)
- Test Inertial.......2465 lb (1118 kg)
- Gross Static.......2642 lb (1199 kg)

Impact Conditions
- Speed.......64.7 mph (104.1 kph)
- Angle.......25.0 deg
- Location/Orientation.......66 in (1676 mm) upstream of post 4
- Impact Severity.......61.6 kip-ft (83.5 kJ)

Exit Conditions
- Speed.......59.2 mph (95.3 kph)
- Angle.......7.2 deg

Post-impact Trajectory
- Vehicle Stability.......Satisfactory
- Stopping Distance.......208 ft (63.3m) downstream 3.2 ft (1 m) laterally behind

Vehicle Snagging.......None
Vehicle Pocketing.......None
Occupant Impact Velocity
- Longitudinal.......17.4 ft/s (5.3 m/s)
- Lateral.......36.4 ft/s (11.1 m/s)

Occupant Ridedown Deceleration (10 msec avg.)
- Longitudinal.......3.9 G
- Lateral.......-13.4 G

THIV.......40.4 ft/s (12.3 m/s)
PHD.......13.4 G
Test Article Damage.......NONE
Test Article Deflections*
- Permanent Set.......0.03 in (0.8 mm)
- Dynamic.......0.93 in (23.5 mm)
- Working Width.......19 in (483 mm)

Vehicle Damage.......Moderate
- VDS.......01-FR-3, 03-RP-2
- CDC.......01-RFEK2, 03-RDEK1

Maximum Deformation.......2.1 in (52 mm) floorboard deformation

**String potentiometer measurements are not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab*

3.3. Test 110MASH4S16-03 Impact Description and Results

The target point of impact for test 110MASH4S16-03 was determined from Table 2-7 of MASH 2009, which was 60 inches (1.5 m) upstream from the center of post 3. This point would apply maximum loading to post 3. The vehicle impacted the barrier at 56.3 mph (90.6 kph) at an angle of 15.8°. The impact severity was 171.9 kip-ft (233.1 kJ).

Figure 3-33. Point of Impact 60 inches (1.5 m) Upstream of Post 3

3.3.1. Test 110MASH4S16-03 Barrier Damage

The single-unit truck first made contact with the barrier at the impact point, 60 inches (1.5 m) upstream of post 3. The green marks on the barrier were from the front right tire. The red marks were from the rear right tire. The rear of the vehicle made contact with the barrier upstream of post 2. The vehicle stayed in contact with the bridge rail for 65.6 feet (20 m). This measurement was from where the rear of the vehicle made contact with the rail and all along the entire length of the rail downstream. The vehicle did not snag or pocket.

Most of the damage to the barrier was on the rails. The studs from the front right tire gouged the two inner rails and left longitudinal dents between posts 2 and 4. The nuts for the three upper disc springs from posts 2 and 3 were loose after contact, which meant that those upper disc spring sets went into plastic deformation. A piece of concrete spalled right below post 3.

Figure 3-34. 110MASH4S16-03 Post 3 Concrete Spalling

Figure 3-35. 110MASH4S16-03 Approximate Size of Spalled Concrete from Post 3

String pots were mounted on posts 3, 4, and 5 to measure deflection. Both dynamic and static displacements were measured from the rear middle of the top rail. See Table 3-4. for maximum dynamic and static displacements. Strain gages were installed on all the anchor rods for posts 3, 4, and 5. Neither string pots nor strain gages were installed on post 2 as the target impact location was originally planned for farther downstream. The target impact point was ultimately moved to upstream of post 3 to address the concern over inadequate barrier length for vehicle interaction after impact. Also, originally loading on post 2 was not expected to be as high as post 3. However, since the upper disc springs on post 2 went into plastic deformation the loading on post 2 was high. See *FHWA/ CA17-2557 Supplement* for strain gage and string pot results. (*Strain gage and string pot measurements are not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab*)

Table 3-4. Maximum Dynamic and Static Displacements (110MASH4S16-03)*

	Post 3	Post 4	Post 5
Maximum Dynamic Displacement	Estimated at ~2.4 in (61 mm)	0.71 in (17.9 mm)	NA (channel malfunction) Estimated at less than 0.1 in
Static Displacement	0.58 in (14.7 mm)	0.02 in (0.6 mm)	NA (channel malfunction) Estimated at less than 0.1 in

** Not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab*

Figure 3-36. 110MASH4S16-03 Green (Front Tire) / Red (Rear Tire)

Figure 3-37. 110MASH4S16-03 Upstream Impact View

Figure 3-38. 110MASH4S16-03 Side Impact View

Figure 3-39. 110MASH4S16-03 Traveling Downstream

Figure 3-40. 110MASH4S16-03 Impact with Fence

3.3.2. Test 110MASH4S16-03 Vehicle Damage

The front right fender and right side of test vehicle sustained most of the damage from the impact with the side mounted bridge rail. Still camera images and high-speed videos showed the test vehicle's hood release broke and the hood partially opened. The front right wheel detached and folded under the vehicle. The front axle was also broken during impact. It disconnected from the vehicle with the exception of the hydraulic steering lines, which dragged the axle underneath the front of the vehicle. The front right headlight broke and right side of the bumper folded into the engine compartment. The right fuel tank was also damaged from contact with the barrier. The right passenger door was damaged but it was able to be opened.

The 10000S test vehicle sustained damage from a secondary impact with a fence that was installed downstream of the vehicles presumed exit path. The fence was placed there to help slow the test vehicle down. Even though the fence caused some damage during the secondary impact, it did not cause difficulty analyzing the damage from the primary impact with the bridge rail.

Figure 3-41. 110MASH4S16-03 Upstream View

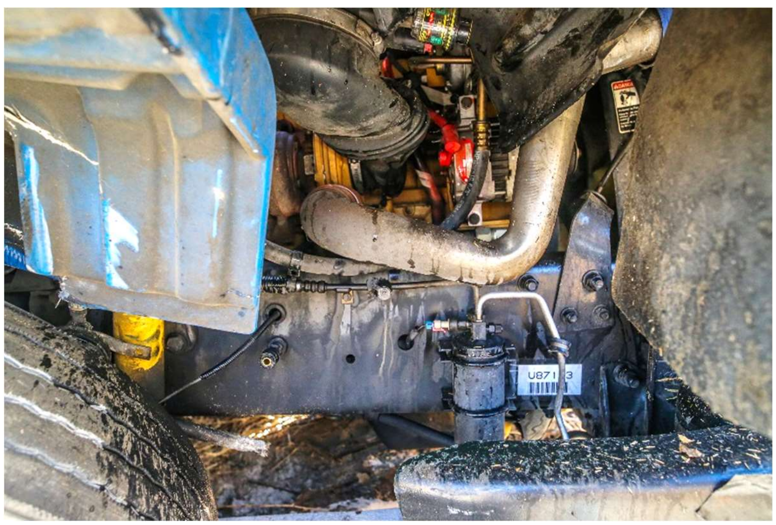


Figure 3-42. 110MASH4S16-03 Leaking Fluids from Engine Bay

The vehicle remote braking system was applied several vehicle lengths after leaving the bridge rail but the brake did not stop the vehicle before the vehicle hit the fence. The fence used four 3/8" (10 mm) steel cables stacked at approximately one foot (0.3 m) apart horizontally. The impact with the fence caused some damage to the front end of the test vehicle. The fence rode over the vehicle's hood and into the windshield. Although the windshield was still intact, the cable broke the windshield and bent the A-pillars. The fence was connected to the four steel cables, which were connected to two Caltrans Type 60k portable concrete barriers (one on each side). The fence did help slow the vehicle down. The vehicle came to rest on a berm at the north end of the test facility.

Figure 3-43. 110MASH4S16-03 Front Right Tire

Figure 3-44. 110MASH4S16-03 Front Right Fender

Figure 3-45. 110MASH4S16-03 Fuel Tank and Right A-Pillar Damage

Figure 3-46. 110MASH4S16-03 Fence into Windshield

Figure 3-47. 110MASH4S16-03 Front End with Fence Removed

Figure 3-48. 110MASH4S16-03 Windshield Damage

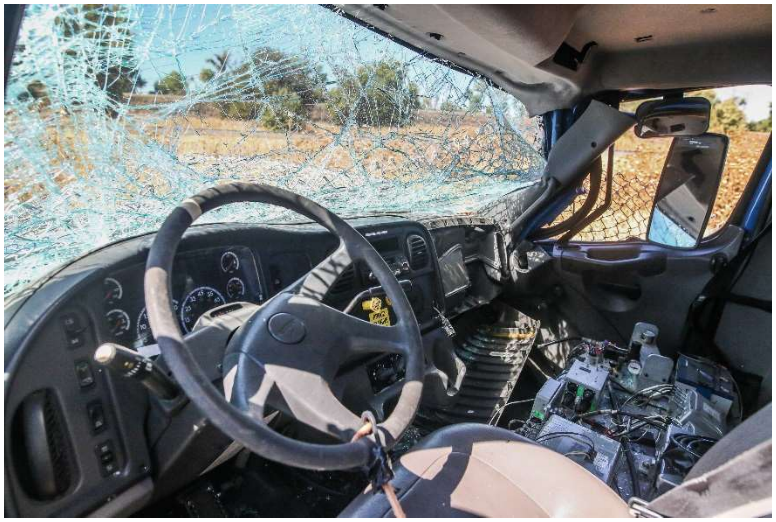


Figure 3-49. 110MASH4S16-03 Cab View Damage

Figure 3-50. 110MASH4S16-03 Rear View

The box did not disconnect from the frame. The ballasts did shift a few inches toward the impact side but did not disconnect. The box also had a permanent lean towards the impact side after impact.

Figure 3-51. 110MASH4S16-03 Permanent Box Leaning to Impact Side

Figure 3-52. 110MASH4S16-03 Vehicle Resting Location on Berm

Figure 3-53. 110MASH4S16-03 Ballasts Shifted to Passenger Side

Figure 3-54. 110MASH4S16-03 Alternate View of Ballast After Impact

3.3.3. Test 110MASH4S16-03 Summary Sheet

0.000 sec (Overhead 1)

0.070 sec (Overhead 1)

0.140 sec (Overhead 2)

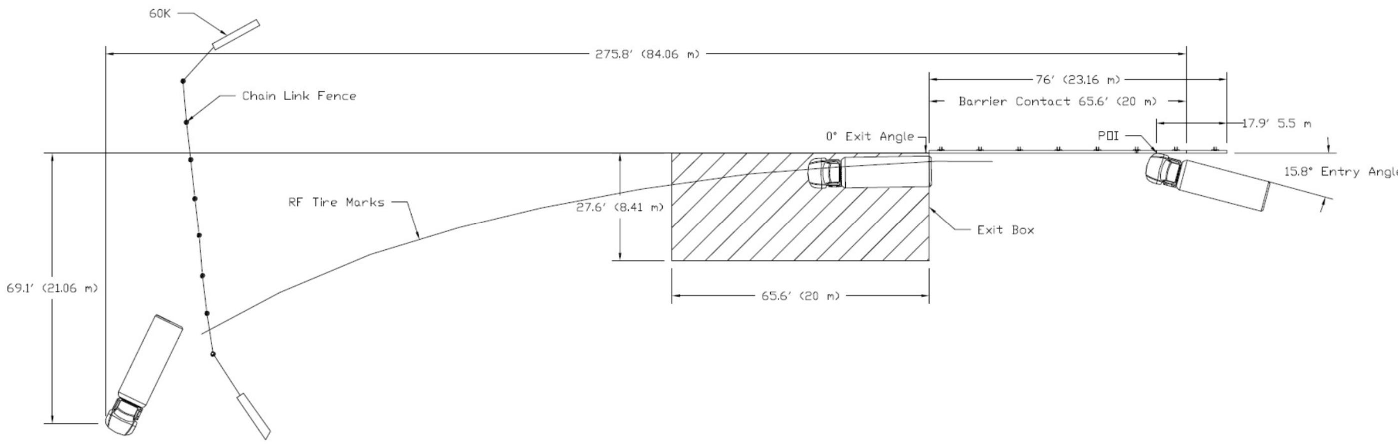
0.210 sec (Overhead 2)

0.280 sec (Overhead 2)

0.350 sec (Overhead 2)

0.490 sec (Overhead 2)

1.158 sec (Overhead 2)



Test Agency: California, Department of Transportation
Test Number: 110MASH4S16-03
Date: 8/31/2016
Test Article: CA ST-70SM Side Mounted Bridge Rail
Total Length: 76 ft (23.2 m)
Key Elements – Barrier
- Description: Side Mounted Bridge Rail
- Length: 120 in (3048 mm) O.C. Posts
- Base Width: 18 in (457.2 mm)
- Height: 42 in (1066.8 mm)

Test Vehicle
- Type/Designation: 10000s
- Make and Model: 2005 Freightliner M2
- Curb: 14,786 lb (6707 kg)
- Test Inertial: 21,887 lb (9928 kg)
- Gross Static: 21,887 lb (9928 kg)

Impact Conditions
- Speed: 56.3 mph (90.6 kph)
- Angle: 15.8 deg
- Location/Orientation: 60 in (1.5 m) upstream of post 3
- Impact Severity: 171.9 kip-ft (233.1 kJ)

Exit Conditions
- Speed: 53.4 mph (85.9 kph)
- Angle: 0.00 deg

Post-impact Trajectory
- Vehicle Stability: Satisfactory
- Stopping Distance: 275.8 ft (84.1 m) downstream 69.1 ft (21.1 m) laterally in front

Vehicle Snagging: None
Vehicle Pocketing: None
Occupant Impact Velocity
- Longitudinal: N/A
- Lateral: N/A

Occupant Ridedown Deceleration (10 msec avg.)
- Longitudinal: N/A
- Lateral: N/A

THIV: N/A
PHD: N/A
Test Article Damage: Moderate (6 spring sets damage at Posts 2 & 3)
Test Article Deflections*
- Permanent Set: 0.6 in (15 mm)
- Dynamic: 2.4 in (61 mm)
- Working Width: 23 in (584 mm)

Vehicle Damage: Moderate
- VDS: 01-FR-4, 03-RP-03
- CDC: 01-RFEK5, 03-RDEK1
- Maximum Deformation: N/A

**String potentiometer measurements are not within the scope of ISO 17025 A2LA Accreditation of the RSRG Lab*

4. Discussion of Test Results

4.1. General Evaluation Methods

MASH 2009 recommends that crash test performance be assessed according to three evaluation factors: (1) structural adequacy, (2) occupant risk, and (3) post-impact vehicular response.

The structural adequacy and occupant risk associated with the side mounted bridge rail were evaluated using evaluation criteria found in Tables 2.2 and 5.1 of MASH 2009. The post-impact vehicular response was evaluated using section 5.4 of MASH 2009.

4.2. Structural Adequacy

The structural adequacy of the side mounted bridge rail was acceptable for all three tests. The three upper disc spring sets from posts 2, 3 and 4 of the bridge rail went into plastic deformation during the 2270P and 10000S impacts and required replacement. Other than replacing the top disc springs sets on the posts, the CA ST-70SM Side Mounted Bridge Rail was functional. The anchor rods were tested after the bridge rail was demolished. The anchor rods all passed tensile testing with the rods breaking within or above the tensile strength specifications of 125 to 150 ksi. See Appendix 9 for Post-Impact Anchor Rod Testing.

Refer to Table 4-1, 4-2 and Table 4-3 for the assessment summaries of the safety evaluation criteria for the CA ST-70SM Side Mounted Bridge Rail.

4.3. Occupant Risk

The occupant risk values for the 2270P and 1100C vehicles were acceptable according to MASH criteria. The OIV and ORA values are not included in the testing of the 10000S vehicle. The occupant compartment was not significantly compromised in any of the three tests. The yaw, pitch, and roll of the vehicles were within acceptable limits for all three tests.

Refer to Table 4-1, 4-2 and Table 4-3 for the assessment summaries of the safety evaluation criteria for the CA ST-70SM Side Mounted Bridge Rail.

4.4. Vehicle Trajectory

The vehicle trajectories were acceptable for all three tests. The exit trajectories were within the required exit box. The yaw, pitch, and roll of the vehicles were below the maximums allowed in the MASH guidelines.

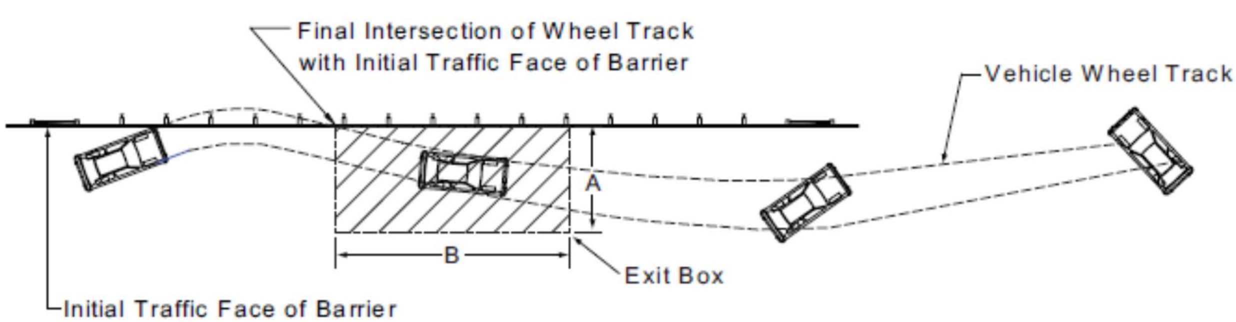


Figure 4-1. Exit Box for Longitudinal Barriers

Refer to Table 4-1, 4-2 and Table 4-3 for the assessment summaries of the safety evaluation criteria for the CA ST-70SM Side Mounted Bridge Rail.

Table 4-1. 110MASH3P15-01 Assessment Summary

<table>
<tr><th>Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td>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 test article is acceptable.</td><td>The vehicle was contained and redirected smoothly.</td><td>PASS</td></tr>
<tr><td>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 personnel in a work zone.

Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E (MASH 2009).</td><td>The bridge rail did not detach any elements, fragments, and/or other debris</td><td>PASS</td></tr>
<tr><td>Occupant Risk
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>The vehicle remained upright during and after the collision.</td><td>PASS</td></tr>
<tr><td>Occupant Risk
H. Occupant Impact Velocities (OIV) (see Appendix A, Section A5.3 (MASH 2009) for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
</table></td><td>Longitudinal OIV_x =
13.45 ft/s (4.1 m/s)

Lateral OIV_y =
26.9 ft/s (8.2 m/s)</td><td>PASS</td></tr>
<tr><td>Occupant Risk
I. The occupant ridedown acceleration (see Appendix A, Section A5.3 (MASH 2009) for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (G)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 G</td><td>20.49 G</td></tr>
</table></td><td>Longitudinal ORA_x =
-2.6 G

Lateral ORA_y =
-16.9 G</td><td>PASS</td></tr>
<tr><td>Vehicle Trajectory
It is preferable that the vehicle be smoothly redirected, and this is typically indicated when the vehicle leaves the barrier within the "exit box". The concept of the exit box is defined by the initial traffic face of the barrier and a line parallel to the initial traffic face of the barrier, at a distance A plus the width of the vehicle plus 16 percent of the length of the vehicle, starting at the final intersection (break) of the wheel track with the initial traffic face of the barrier for a distance of B. All wheel tracks of the vehicle should not cross the parallel line within the distance B.</td><td>A = 16.7 ft (5.1 m)
B = 32.8 ft (10 m)</td><td>PASS</td></tr>
</table>

Table 4-2. 110MASH4C15-02 Assessment Summary

<table>
<tr><th>Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td>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 test article is acceptable.</td><td>The vehicle was contained and redirected smoothly.</td><td>PASS</td></tr>
<tr><td>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 personnel in a work zone.

Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E (MASH 2009).</td><td>The bridge rail did not detach any elements, fragments, and/or other debris</td><td>PASS</td></tr>
<tr><td>Occupant Risk
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>The vehicle remained upright during and after the collision.</td><td>PASS</td></tr>
<tr><td>Occupant Risk
H. Occupant Impact Velocities (OIV) (see Appendix A, Section A5.3 (MASH 2009) for calculation procedure) should satisfy the following limits:
<table><tr><th colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr></table></td><td>Longitudinal OIV_x = 17.4 ft/s (5.3 m/s)

Lateral OIV_y = 36.4 ft/s (11.1 m/s)</td><td>PASS</td></tr>
<tr><td>Occupant Risk
I. The occupant ridedown acceleration (see Appendix A, Section A5.3 (MASH 2009) for calculation procedure) should satisfy the following limits:
<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits (G)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 G</td><td>20.49 G</td></tr></table></td><td>Longitudinal ORA_x = 3.9 G

Lateral ORA_y = -13.4 G</td><td>PASS</td></tr>
<tr><td>Vehicle Trajectory
It is preferable that the vehicle be smoothly redirected, and this is typically indicated when the vehicle leaves the barrier within the "exit box". The concept of the exit box is defined by the initial traffic face of the barrier and a line parallel to the initial traffic face of the barrier, at a distance A plus the width of the vehicle plus 16 percent of the length of the vehicle, starting at the final intersection (break) of the wheel track with the initial traffic face of the barrier for a distance of B. All wheel tracks of the vehicle should not cross the parallel line within the distance B.</td><td>A = 15.0 ft (4.6 m)
B = 32.8 ft (10 m)</td><td>PASS</td></tr>
</table>

Table 4-3. 110MASH4S16-03 Assessment Summary

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 test article is acceptable.	The vehicle was contained and redirected smoothly.	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 personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E (MASH 2009).	The bridge rail did not detach any elements, fragments, and/or other debris	PASS
Occupant Risk G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The vehicle remained upright during and after the collision.	PASS
Vehicle Trajectory It is preferable that the vehicle be smoothly redirected, and this is typically indicated when the vehicle leaves the barrier within the "exit box". The concept of the exit box is defined by the initial traffic face of the barrier and a line parallel to the initial traffic face of the barrier, at a distance A plus the width of the vehicle plus 16 percent of the length of the vehicle, starting at the final intersection (break) of the wheel track with the initial traffic face of the barrier for a distance of B. All wheel tracks of the vehicle should not cross the parallel line within the distance B.	A = 27.6 ft (8.4 m) B = 65.6 ft (20 m)	PASS

5. Conclusion

Based on the physical crash testing involved in this project, the following conclusions can be drawn:

1. The California ST-70SM Side Mounted Bridge Rail can successfully contain and redirect a MASH 2009 2270P pickup truck impacting at 62 mph (100 km/h) and 25°.
2. The California ST-70SM Side Mounted Bridge Rail can successfully contain and redirect a MASH 2009 1100C small car impacting at 62 mph (100 km/h) and 25°.
3. The California ST-70SM Side Mounted Bridge Rail can successfully contain and redirect a MASH 2009 10000S single-unit van body truck impacting at 56 mph (90 km/h) and 15°.
4. Impact damage to the California ST-70SM Side Mounted Bridge Rail would require inspection of the disc springs and replacement, if necessary. Other than the disc spring replacements, rail damage was primarily cosmetic.
5. The California ST-70SM Side Mounted Bridge Rail meets the criteria set in the American Association of State Highway and Transportation Officials' *Manual for Assessing Safety Hardware* 2009 as a Test Level 4 longitudinal barrier.

6. Recommendations

During the assembly of the CA ST-70SM Side Mounted Bridge Rail to the deck, the contractor ran into tolerance problems. The following are recommendations from Caltrans' Division of Structure Policy and Innovation and the Division of Research, Innovation and System Information:

1. The vertical opening in the post for the tube railing must be 0.16 inches (4 mm) larger than the height of the steel tube railing ASTM A500 railing has a mill tolerance of +0.12 inches (+3 mm), thus there can be issues with the rails fitting into the posts.
2. Size the slotted holes to 1-1/4" x 1-9/16" to accommodate the diameter of the stud bolt weld. This will reduce interference between the stud weld and slotted hole reducing the need for shims.
3. The diameter of the railing washers should be increased to provide better support for the nut. The updated plans in this report specify "oversized washers".
4. Redesign shims so that they can be installed after rails are mounted onto the posts. One concept considered was a shim that could slide in from the side instead of from the top. Also, the size of the shim opening needs to be large enough to clear stud weld. Note that shims are needed only if there is a gap between the rail and post opening after installation and may not be needed. Future project details may not include shims.

7. Implementation

Caltrans' Division of Structure Policy and Innovation will be responsible for the preparation of Standard Plans (if required) and specifications for the California ST-70SM Side Mounted Bridge Rail, with technical support from the Division of Research, Innovation and System Information.

8. Appendix

8.1. Test 110MASH3P15-01 Vehicle Setup

8.1.1. Test Vehicle Equipment

The vehicle used for this test is a 2007 Dodge Ram 1500 ST. The gas tank was disconnected from the fuel supply line and drained. A 12L safety gas tank was installed in the truck bed and connected to the fuel supply line. The stock fuel tank had gaseous CO_2 added in order to purge the gas vapors and eliminate oxygen.

Figure 8-1. Ballast Added to Increase CG Height

One pair of 12-volt wet cell batteries was mounted in the pickup truck. The batteries powered the GMH DataBrick III transient data recorders. A 12-volt deep-cycle gel cell battery powers the Electronic Control Box.

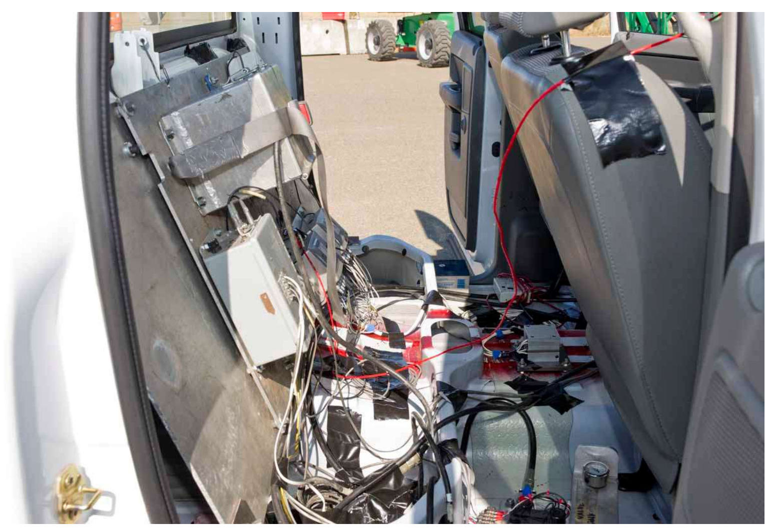


Figure 8-2. Instrumentation Board Mounting Location

A 4800 kPA CO_2 system, actuated by a solenoid valve, controlled remote braking after the impact and emergency braking if necessary. Part of this system included a pneumatic ram, which 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 ensure the shortest stopping distance without locking up the wheels. When activated, the brakes could be applied in less than 100 milliseconds.

Figure 8-3. Brake Receiver

An accelerator switch was located on the rear fender of the vehicle. The switch opens an electronic solenoid that releases compressed CO_2 from a reservoir into a pneumatic ram, which was attached to the accelerator pedal. The CO_2 pressure for the accelerator ram was regulated to the same pressure as the remote braking system with a valve to adjust CO_2 flow rate.

Figure 8-4. Brake and Gas Pedal Actuators

A speed control device was connected in-line with the ignition module signal to the coil. It was used to regulate the speed of the test vehicle based on the signal from the vehicle transmission speed sensor. This device was tuned prior to the test by conducting a series of trial runs through a speed trap comprised of two tape switches (set at a specific distance apart) and a digital timer. A microswitch was mounted below the front bumper and connected to the ignition system. A trip plate on the ground near the impact point triggers the switch when the truck passed over it removing power to the engine coil.

Figure 8-5. Speed Control Box Mounted to Dashboard

8.1.2. Test Vehicle Guidance System

A rail guidance system directed the vehicle into the barrier. The guidance rail, anchored at 12.5 ft (3.8 m) intervals along its length was use to guide a mechanical arm, which was attached to the front left wheel of each of the vehicles. A plate and lever were used to trigger the release pin on the guidance arm, thereby releasing the vehicle from the guidance system before impact.

Figure 8-6. Rail Guidance Hub

Figure 8-7. Rail Guidance System with 2270P Attached

8.1.3. Photo - Instrumentation

Several high-speed video cameras recorded the impact during the test. The high-speed video frame rates were set to 500 frames per second. The types of cameras and their locations are shown in Figure 8-8 and Table 8-1. The origin of the coordinates is at the intended point of impact.

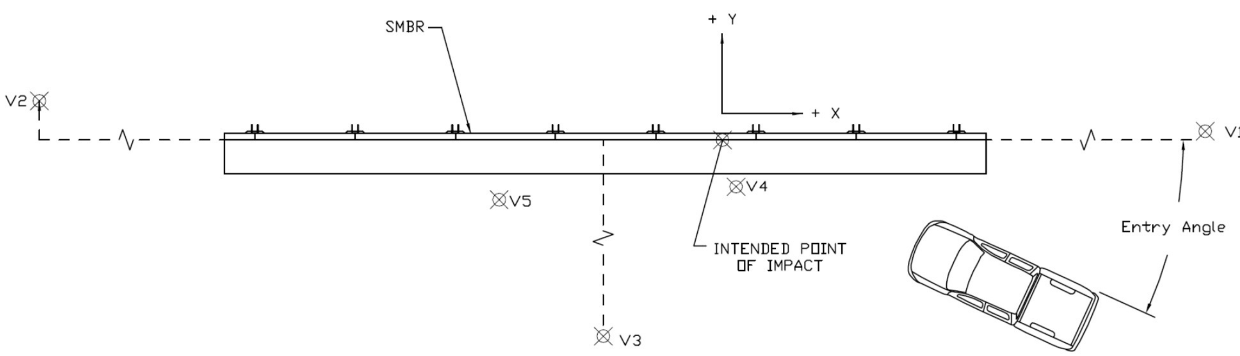


Figure 8-8. High-Speed Video Camera Locations

Table 8-1. 110MASH3P15-01 Camera Types and Location Coordinates

Camera Location	Camera Make/Model	Camera Serial No.	Lens	Lens Serial No.	Coordinates		
					x	y	z
V4	Vision Resesarch Miro 110	13235	14 mm	210927	1.4 ft (0.41 m)	-4.7 ft (-1.43 m)	29.9 ft (9.12 m)
V5	Vision Resesarch Miro 110	13234	14 mm	217706	-22.3 ft (-6.80 m)	6.0 ft (1.83 m)	30.6 ft (9.34 m)
V3	Olympus iSpeed 3	1400012	35 mm	173792	-11.9 ft (-3.26 m)	-71.3 ft (-21.74 m)	3.9 ft (1.18 m)
V1	Olympus iSpeed 3	1400022	35 mm	259936	96.0 ft (29.26 m)	0.9 ft (0.27 m)	2.9 ft (0.87 m)
V2	Olympus iSpeed 3	1400014	85 mm	420398	-279.8 ft (-85.27 m)	3.9 ft (1.19 m)	4.0 ft (1.22 m)

The following are the pretest procedures that were required to enable video data reduction to be performed using the Research's video analysis software (Phantom Camera Control):

1. Butterfly targets were attached to the top and sides of the test vehicle. The targets were located on the vehicle at intervals of 19.7 inches (500 mm) and 39.4 inches (1000 mm). The targets established scale factors.
2. Flashbulbs, mounted on the test vehicle, were electronically triggered to establish initial vehicle-to-barrier contact and the time of the application of the vehicle brakes.
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.

8.1.4. Electronic Instrumentation and Data

Transducer data were recorded on two separate GMH Engineering, DataBrick, Model III, digital transient data recorders (TDRs) that were mounted on the test vehicle. These transducers included two sets of accelerometers and two sets of angular rate sensors at the center of gravity. The TDR data were reduced using a desktop personal computer running DADiSP 2002 version 6.0 NI NK B14 (pre-processing) and TRAP version 2.3.10 (post-processing). Accelerometer and angular rate sensor specifications are shown in Table 8-2.

Table 8-2. Accelerometer and Angular Rate Sensor Specifications

Type	Manufacturer	Model	Serial #	Location	Range	Orientation
Accelerometer	Measurement Specialties	64CM32	MS13366	CG	±200g	Primary Longitudinal
Accelerometer	Measurement Specialties	64CM32	MS13328	GC	±200g	Primary Lateral
Accelerometer	Measurement Specialties	64CM32	MS13358	CG	±200g	Primary Vertical
Accelerometer	Measurement Specialties	64CM32	MS13364	CG	±200g	Secondary Longitudinal
Accelerometer	Measurement Specialties	64CM32	MS13361	CG	±200g	Secondary Lateral
Accelerometer	Measurement Specialties	64CM32	MS13329	CG	±200g	Secondary Vertical
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS4018	CG	±1500°/s	Primary Roll
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS4217	CG	±1500°/s	Primary Pitch
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS3348	CG	±1500°/s	Primary Yaw
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS3355	CG	±1500°/s	Secondary Roll
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS3336	CG	±1500°/s	Secondary Pitch
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS4019	CG	±1500°/s	Secondary Yaw

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. The strips were spaced at carefully measured intervals of 39.4 inches (1000 mm). The test vehicle had an onboard optical sensor that produced sequential impulses or “event blips” as the vehicle passed the reflective tape strips. The event blips 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, the data record time, 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. One set of pressure activated tape switches, connected to a speed trap, were placed 13.1 ft (4 m) apart just upstream of the test article specifically to establish the impact speed of the test vehicle. The layout of the pressure sensitive tape switches and reflective tape is shown in Figure 8-9.

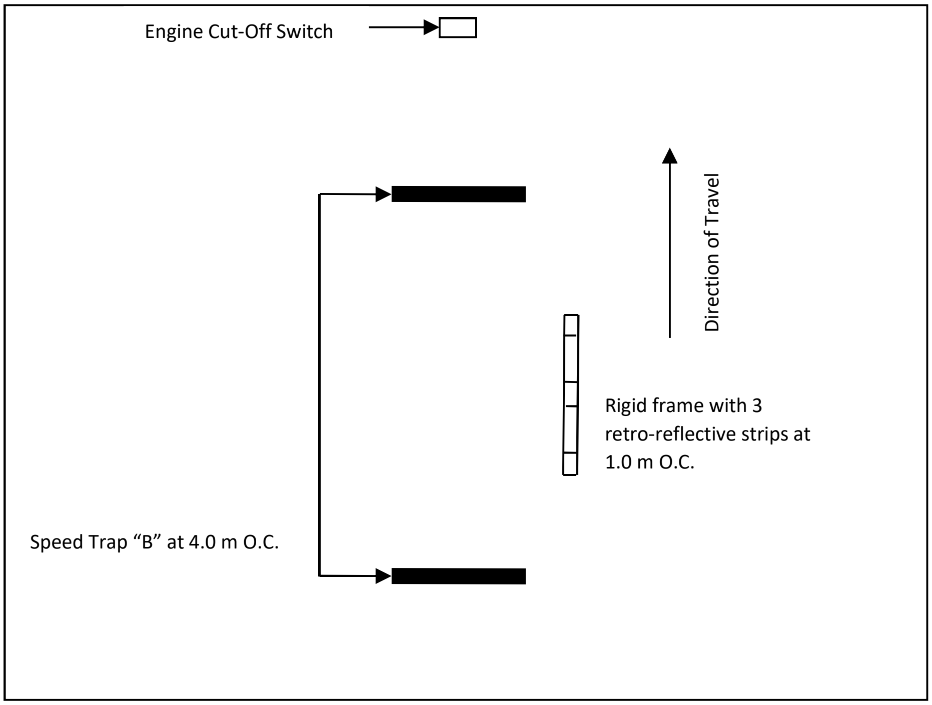


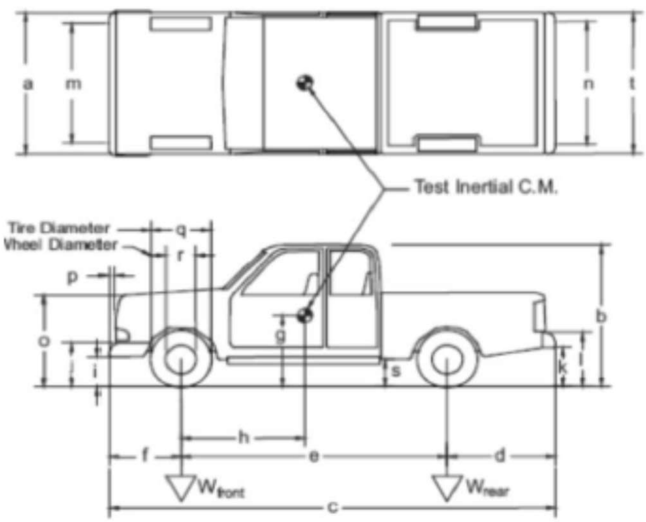
Figure 8-9. Speed Trap Tape Layout

8.1.5. Vehicle Measurements

Table 8-3. Exterior Vehicle Measurements

Date:	8/24/2015	Test Number:	110MASH3P15-01	Model:	Dodge Ram
Make:	1500	VIN:	1D7HA18N47S105053		
Tire Size:	P245/70R17	Year:	2007	Odometer:	183719
Tire Inflation Pressure:	35psi	Tape Measure Used:	Tape 1		

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm (inches)

a	1971	(77.6)	b	1913	(75.3)
c	5780	(227.6)	d	1210	(47.6)
e	3572	(140.6)	f	996	(39.2)
g	711.8	(28)	h	1482	(58.3)
i	385	(15.2)	j	680	(26.8)
k	526	(20.7)	l	745	(29.3)
m	1732	(68.2)	n	1715	(67.5)
o	1125	(44.3)	p	125	(4.9)
q	755	(29.7)	r	467	(18.4)
s	387	(15.2)	t	1920	(75.6)

Wheel Center Height Front:	361	(14.2)
Wheel Center Height Rear:	363	(14.3)
Wheel Well Clearance (F)	143	(5.6)
Wheel Well Clearance (R)	220	(8.7)
Frame Height (F):	455	(17.9)
Frame Height (R):	643	(25.3)
Engine Type:	V8	
Engine Size:	4.7L	

Transmission Type:

Automatic or Manual:	Automatic
FWD or RWD or 4WD:	RWD

Mass Distribution - kg (lbs)

Left Front:	665.5	(1467.2)	Scale:	red	Right Front:	626.25	(1380.6)	Scale:	blue
Left Rear:	453.15	(999)	Scale:	yellow	Right Rear:	462.35	(1019.3)	Scale:	green

Weights

kg (lbs)	Curb		Test Inertial		Gross Static	
W_{front}	1291.75	(2847.8)	1297.5	(2860.4)	1298.9	(2863.5)
W_{rear}	915.5	(2018.3)	984.1	(2169.5)	986.25	(2174.3)
W_{total}	2207.5	(4866.6)	2281.6	(5030)	2285.15	(5037.8)

GVWR Ratings - kg (lbs)

Front:	1679	(3701.5)
Back:	1770	(3902.1)
Total:	3040	(6701.9)

Dummy Data

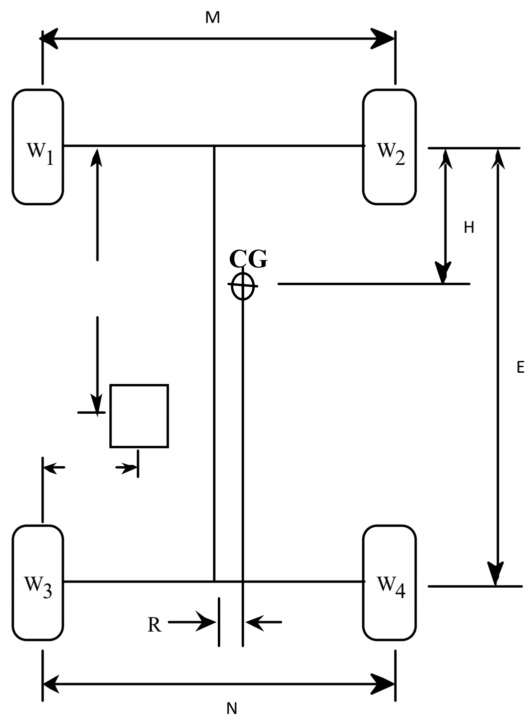
Type:	N/A
Mass:	N/A
Seat Position:	N/A

Note any damage prior to test: A number of quarter sized small dents are on the front bumper.
The tire were changed to replace aluminum rims. Copied from test 430MASH3P13-04-L.

Table 8-4. CG Calculation: Curb Weight

CG Calculation Worksheet #1: Curb Weight

Make:	1500	Test Number:	110MASH3P15-01
Model:	Dodge Ram	Date:	8/24/2015
Year:	2007	Temperature:	N/A
VIN:	1D7HA18N47S105053		
Fuel in Tank:	10 gal		
Fuel Removed:	none		
Staff:	Ali Z.		
	Chris C.		
	Vue H		



W1 = Left Front (LF) = 665.5 kg
Scale Used: red

W2 = Right Front (RF) = 626.25 kg
Scale Used: blue

W3 = Left Rear (LR) = 453.15 kg
Scale Used: yellow

W4 = Right Rear (RR) = 462.35 kg
Scale Used: green

Total Weight:
Wtotal (measured) = 2207.5 kg

Wtotal (calculated) = 2207.25 kg

Distance between front wheels:
M = 1732 mm

Distance between rear wheels:
N = 1715 mm

Distance from front to rear wheels:
E = 3572 mm

Distance from front wheels back to CG:
H = 1482 mm

Distance from vehicle centerline to CG:
R = -12 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

If R is negative the CG is left of center, if R is positive the CG is right of center

Curb Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Copied from test 430MASH3P13-04-L. No spare Tire.

Table 8-5. CG Calculation: Test Inertial Weight

CG Calculation Worksheet #2: Test Inertial Weight

Make:	1500	Test Number:	110MASH3P15-01
Model:	Dodge Ram	Date:	8/24/2015
Year:	2007	Temperature:	N/A
VIN:	1D7HA18N47S105053		
Fuel in Tank:	0 gal		
Fuel Removed:	10 gal		
Staff:	Ali Z.		
	Chris C.		
	Vue H		

W1 = Left Front (LF) = 652.65 kg
Scale Used: red

W2 = Right Front (RF) = 644.85 kg
Scale Used: blue

W3 = Left Rear (LR) = 486.3 kg
Scale Used: yellow

W4 = Right Rear (RR) = 497.8 kg
Scale Used: green

Total Weight:
Wtotal (measured) = 2281.3 kg

Wtotal (calculated) = 2281.60 kg

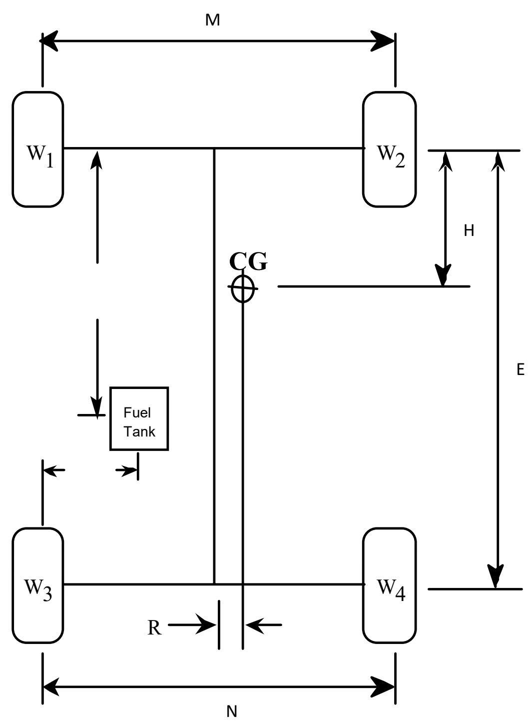
Distance between front wheels:
M = 1732 mm

Distance between rear wheels:
N = 1715 mm

Distance from front to rear wheels:
E = 3572 mm

Distance from front wheels back to CG:
H = 1541 mm

Distance from vehicle centerline to CG:
R = 1 mm



$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

If R is negative the CG is left of center, if R is positive the CG is right of center

Test Inertial Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Copied from test 430MASH3P13-04-L. With all equipment and ballast.

Table 8-6. CG Calculation: Gross Static Weight

CG Calculation Worksheet #3: Gross Static Weight

Make:	1500	Test Number:	110MASH3P15-01
Model:	Dodge Ram	Date:	8/24/2015
Year:	2007	Temperature:	N/A
VIN:	1D7HA18N47S105053		
Fuel in Tank:	none		
Fuel Removed:	none		
Staff:	Ali Z.		
	Chris C.		
	Vue H		

W1 = Left Front (LF) = 660.6 kg
Scale Used: red

W2 = Right Front (RF) = 638.3 kg
Scale Used: blue

W3 = Left Rear (LR) = 491.3 kg
Scale Used: yellow

W4 = Right Rear (RR) = 494.95 kg
Scale Used: green

Total Weight:
Wtotal (measured) = 2285.3 kg

Wtotal (calculated) = 2285.15 kg

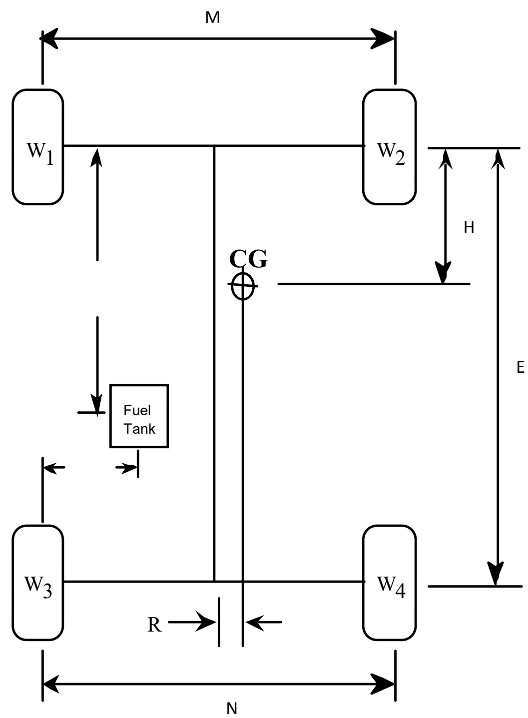
Distance between front wheels:
M = 1732 mm

Distance between rear wheels:
N = 1715 mm

Distance from front to rear wheels:
E = 3572 mm

Distance from front wheels back to CG:
H = 1542 mm

Distance from vehicle centerline to CG:
R = -7 mm



$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

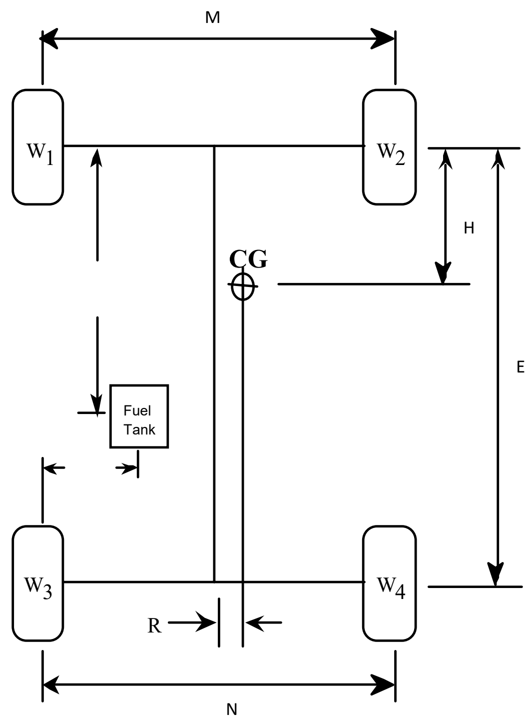
If R is negative the CG is left of center, if R is positive the CG is right of center

Gross Static Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Copied from test 430MASH3P13-04-L. Final vehicle weight with all equipment and ballast. No spare tire.

Table 8-7. CG Calculation: Vertical CG Weight

CG Calculation Worksheet #4: Vertical CG Weight

Make:	1500	Test Number:	110MASH3P15-01
Model:	Dodge Ram	Date:	8/27/2015
Year:	2007	Temperature:	N/A
VIN:	1D7HA18N47S105053		
Fuel in Tank:	none		
Fuel Removed:	none		
Staff:	Ali Z.		
	Chris C.		
	Vue H		



W1 = Left Front (LF) = 655.3 kg
Scale Used: red

W2 = Right Front (RF) = 640 kg
Scale Used: blue

W3 = Left Rear (LR) = 494.35 kg
Scale Used: yellow

W4 = Right Rear (RR) = 499.25 kg
Scale Used: green

Total Weight:
Wtotal (measured) = 2288.35 kg

Wtotal (calculated) = 2288.90 kg

Distance between front wheels:
M = 1732 mm

Distance between rear wheels:
N = 1715 mm

Distance from front to rear wheels:
E = 3572 mm

Distance from front wheels back to CG:
H = 1551 mm

Distance from vehicle centerline to CG:
R = -4 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

If R is negative the CG is left of center, if R is positive the CG is right of center

Gross Static Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Copied from test 430MASH3P13-04-L. Vehicle has equipment installed for vertical CG measurement.

Table 8-8. Vehicle CG Measurements

Vehicle Center of Gravity Measurements

Project Title: Compliance Crash Testing of Side Mounted Bridge Rail

Vehicle Test Number:	110MASH3P15-01	Model:	Ram 1500
Make:	Dodge	Year:	2007
VIN:	1D7HA18N47S105053		

Vehicle Weights (Test Inertail):

Left Front Tire:	660.6 kg	Right Front Tire:	638.3 kg	Front Axle:	1298.9 kg
Left Rear Tire:	491.3 kg	Right Rear tire:	495.0 kg	Rear Axle:	986.3 kg
Ballast and Location:	55.55 kg added to front of the truck bed			Total:	2285.2 kg

Vehicle Wheel Base Measurements:

Vehicle length from center of front tires to center of back tires:	3572.0	mm
Vehicle width from center of left front tire to center of right front tire:	1732.0	mm
Vehicle width from center of left rear tire to center of right rear tire:	1715.0	mm

Center of Gravity:

X:	1541.6	mm	Center of front tire to CG.
Y:	-7.1	mm	The CG will be left if negative and right if positive of vehicle's center line.
Z:	711.8	mm	CG location above ground level

8.1.6. Vehicle Interior Deformation Measurements

Table 8-9. Pretest and Post-test Interior Floorboard Deformation Measurements

Vehicle Type	2270P	Test Number	110MASH3P15-01
Make	Dodge	Model	Ram
Year	2007	Color	White
VIN #	1D7HA18N47S105053		

Floorboard Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
F20	1650 (65)	800 (31.5)	324 (12.8)	1652 (65)	788 (31)	332 (13.1)	2 (0.1)	-12 (-0.5)	8 (0.3)
F21	1650 (65)	673 (26.5)	320 (12.6)	1649 (64.9)	658 (25.9)	324 (12.8)	-1 (0)	-15 (-0.6)	4 (0.2)
F22	1650 (65)	546 (21.5)	321 (12.6)	1643 (64.7)	533 (21)	318 (12.5)	-7 (-0.3)	-13 (-0.5)	-3 (-0.1)
F23	1650 (65)	419 (16.5)	321 (12.6)	1639 (64.5)	404 (15.9)	310 (12.2)	-11 (-0.4)	-15 (-0.6)	-11 (-0.4)
F24	1777 (70)	800 (31.5)	326 (12.8)	1772 (69.8)	785 (30.9)	334 (13.1)	-5 (-0.2)	-15 (-0.6)	8 (0.3)
F25	1777 (70)	673 (26.5)	323 (12.7)	1776 (69.9)	657 (25.9)	327 (12.9)	-1 (0)	-16 (-0.6)	4 (0.2)
F26	1777 (70)	546 (21.5)	323 (12.7)	1776 (69.9)	530 (20.9)	320 (12.6)	-1 (0)	-16 (-0.6)	-3 (-0.1)
F27	1777 (70)	419 (16.5)	321 (12.6)	1771 (69.7)	401 (15.8)	311 (12.2)	-6 (-0.2)	-18 (-0.7)	-10 (-0.4)
F28	1904 (75)	800 (31.5)	328 (12.9)	1900 (74.8)	786 (30.9)	334 (13.1)	-4 (-0.2)	-14 (-0.6)	6 (0.2)
F29	1904 (75)	673 (26.5)	325 (12.8)	1903 (74.9)	658 (25.9)	327 (12.9)	-1 (0)	-15 (-0.6)	2 (0.1)
F30	1904 (75)	546 (21.5)	325 (12.8)	1898 (74.7)	533 (21)	320 (12.6)	-6 (-0.2)	-13 (-0.5)	-5 (-0.2)
F31	2020 (79.5)	800 (31.5)	280 (11)	2017 (79.4)	786 (30.9)	281 (11.1)	-3 (-0.1)	-14 (-0.6)	1 (0)
F32	2027 (79.8)	673 (26.5)	275 (10.8)	2024 (79.7)	661 (26)	275 (10.8)	-3 (-0.1)	-12 (-0.5)	0 (0)
F33	2027 (79.8)	560 (22)	275 (10.8)	2022 (79.6)	549 (21.6)	267 (10.5)	-5 (-0.2)	-11 (-0.4)	-8 (-0.3)
F34	2147 (84.5)	637 (25.1)	215 (8.5)	2147 (84.5)	622 (24.5)	215 (8.5)	0 (0)	-15 (-0.6)	0 (0)

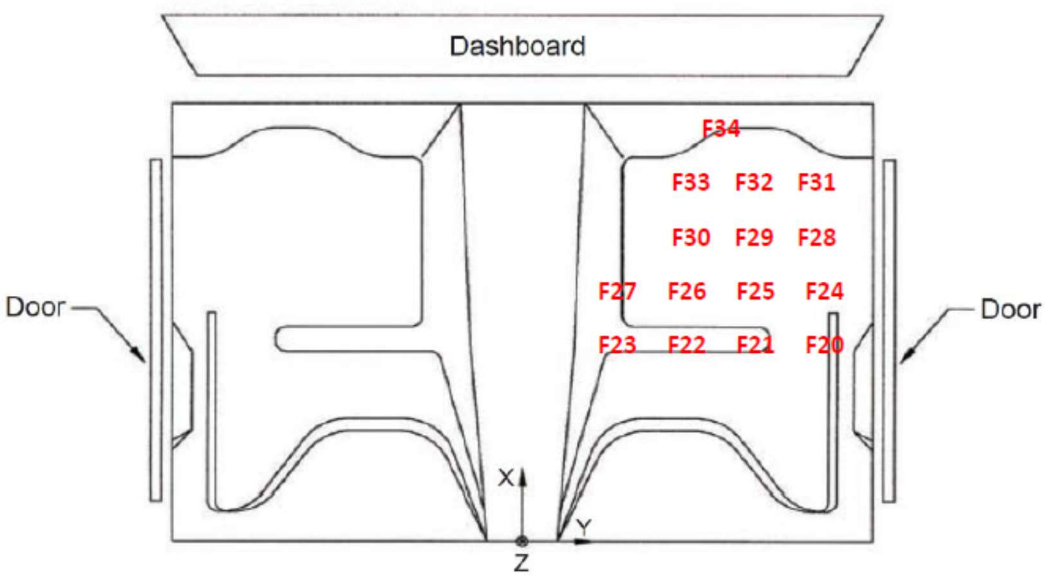


Table 8-10. Pretest and Post-test Interior Dashboard and Roof Deformation Measurements

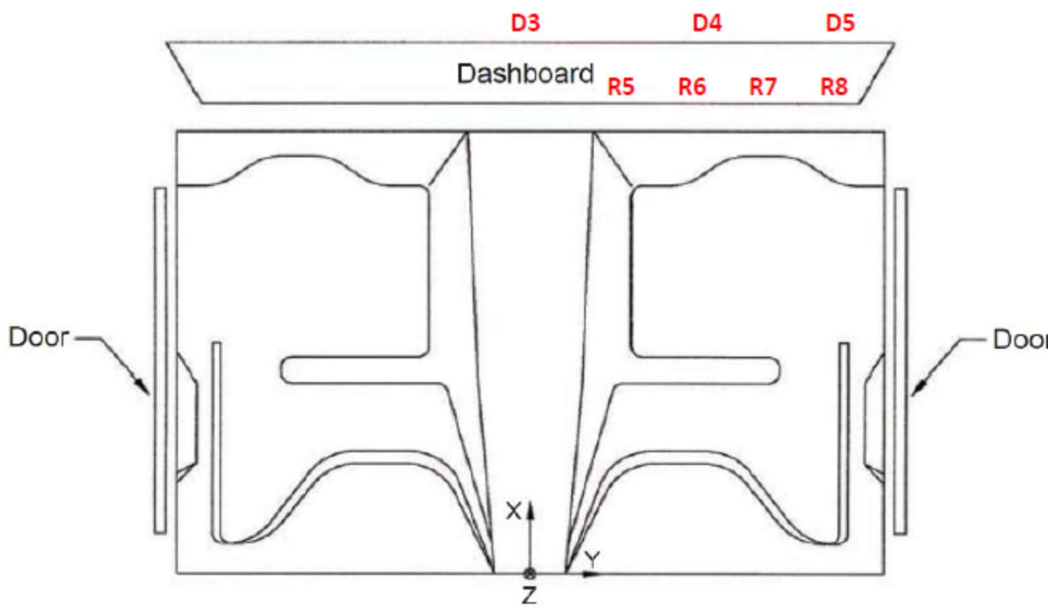
Vehicle Type	2270P	Test Number	110MASH3P15-01
Make	Dodge	Model	Ram
Year	2007	Color	White
VIN #	1D7HA18N47S105053		

Dashboard Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
D3	1765 (69.5)	100 (3.9)	-537 (-21.1)	1758 (69.2)	90 (3.5)	-549 (-21.6)	-7 (-0.3)	-10 (-0.4)	-12 (-0.5)
D4	1790 (70.5)	546 (21.5)	-465 (-18.3)	1777 (70)	537 (21.1)	-471 (-18.5)	-13 (-0.5)	-9 (-0.4)	-6 (-0.2)
D5	1798 (70.8)	800 (31.5)	-442 (-17.4)	1780 (70.1)	792 (31.2)	-452 (-17.8)	-18 (-0.7)	-8 (-0.3)	-10 (-0.4)

Roof Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
R5	1450 (57.1)	419 (16.5)	-919 (-36.2)	1434 (56.5)	423 (16.7)	-931 (-36.7)	-16 (-0.6)	4 (0.2)	-12 (-0.5)
R6	1450 (57.1)	546 (21.5)	-900 (-35.4)	1434 (56.5)	551 (21.7)	-920 (-36.2)	-16 (-0.6)	5 (0.2)	-20 (-0.8)
R7	1450 (57.1)	673 (26.5)	-890 (-35)	1419 (55.9)	681 (26.8)	-916 (-36.1)	-31 (-1.2)	8 (0.3)	-26 (-1)
R8	1450 (57.1)	800 (31.5)	-810 (-31.9)	1432 (56.4)	810 (31.9)	-831 (-32.7)	-18 (-0.7)	10 (0.4)	-21 (-0.8)



8.1.7. Data Plots

The data plots are shown in Figure 8-10 through Figure 8-15 include the accelerometer and angular rate sensor records from the test vehicle in test 110MASH3P15-01. They also show the velocity and displacement curves for the longitudinal and lateral components. These plots are required to calculate the occupant impact velocity (OIV) defined in MASH 2009. All data were analyzed using TRAP.

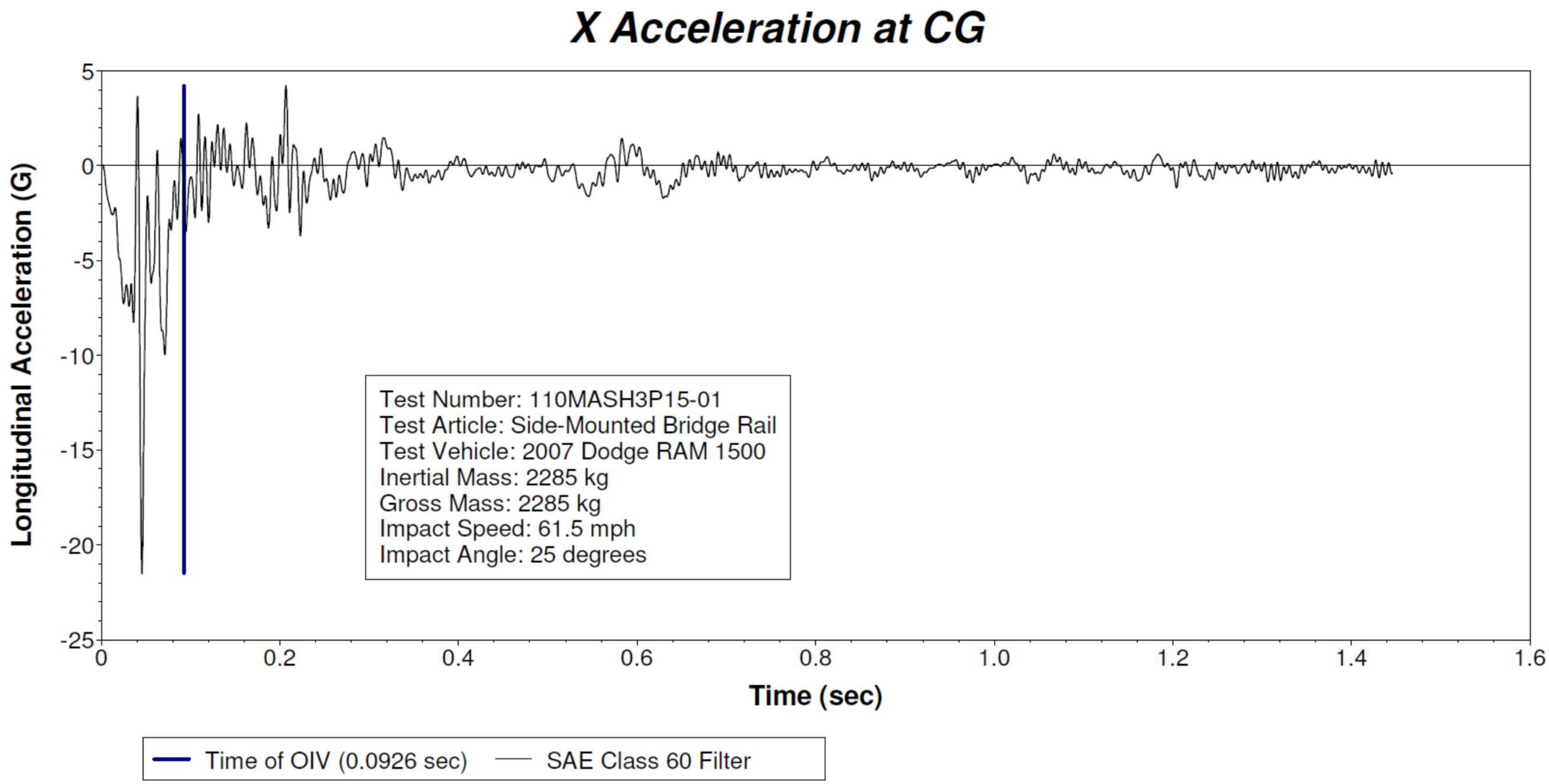


Figure 8-10. 110MASH3P15-01 X (Longitudinal) Acceleration at CG vs Time

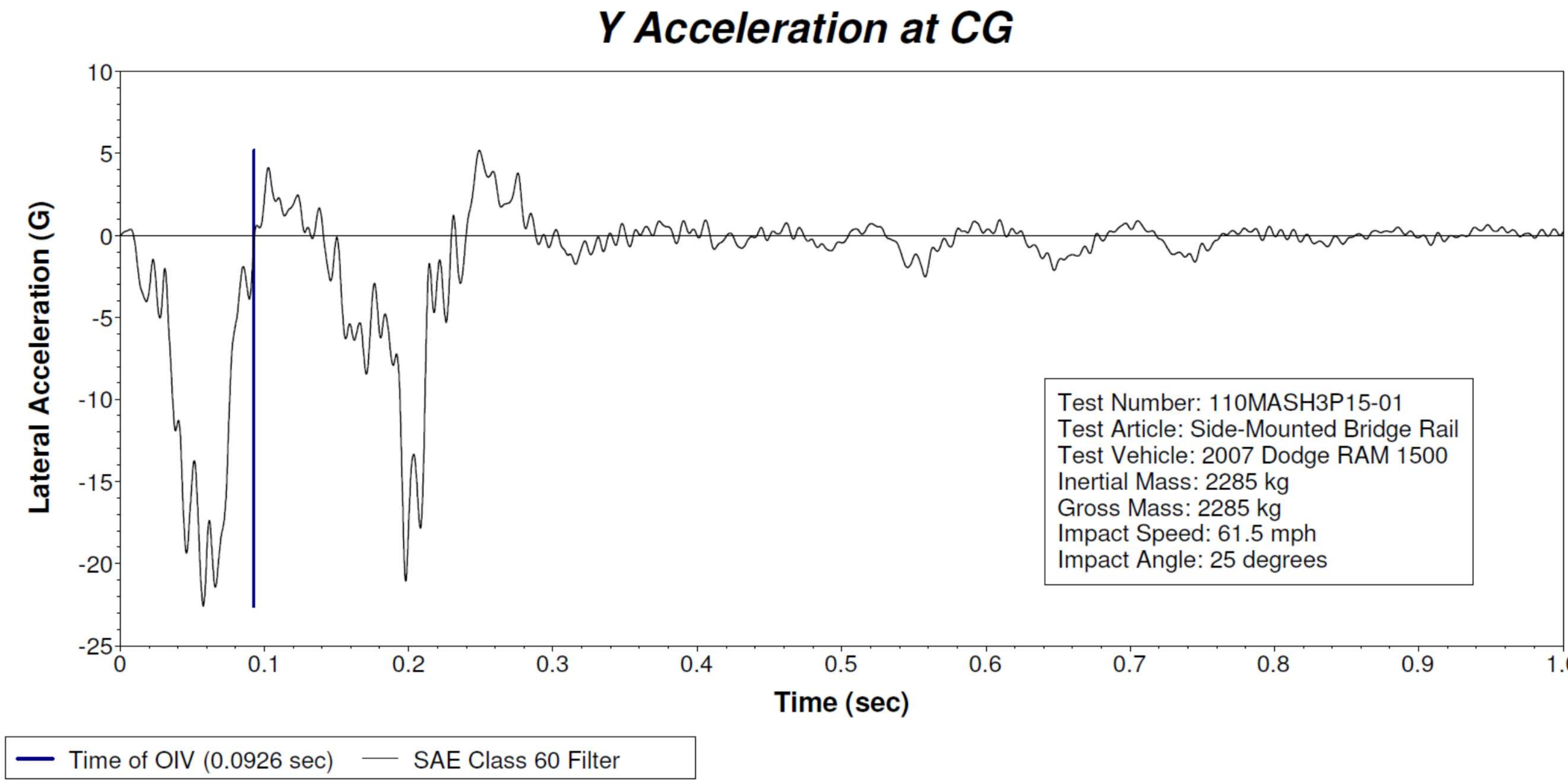


Figure 8-11. 110MASH3P15-01 Y (Lateral) Acceleration at CG vs Time

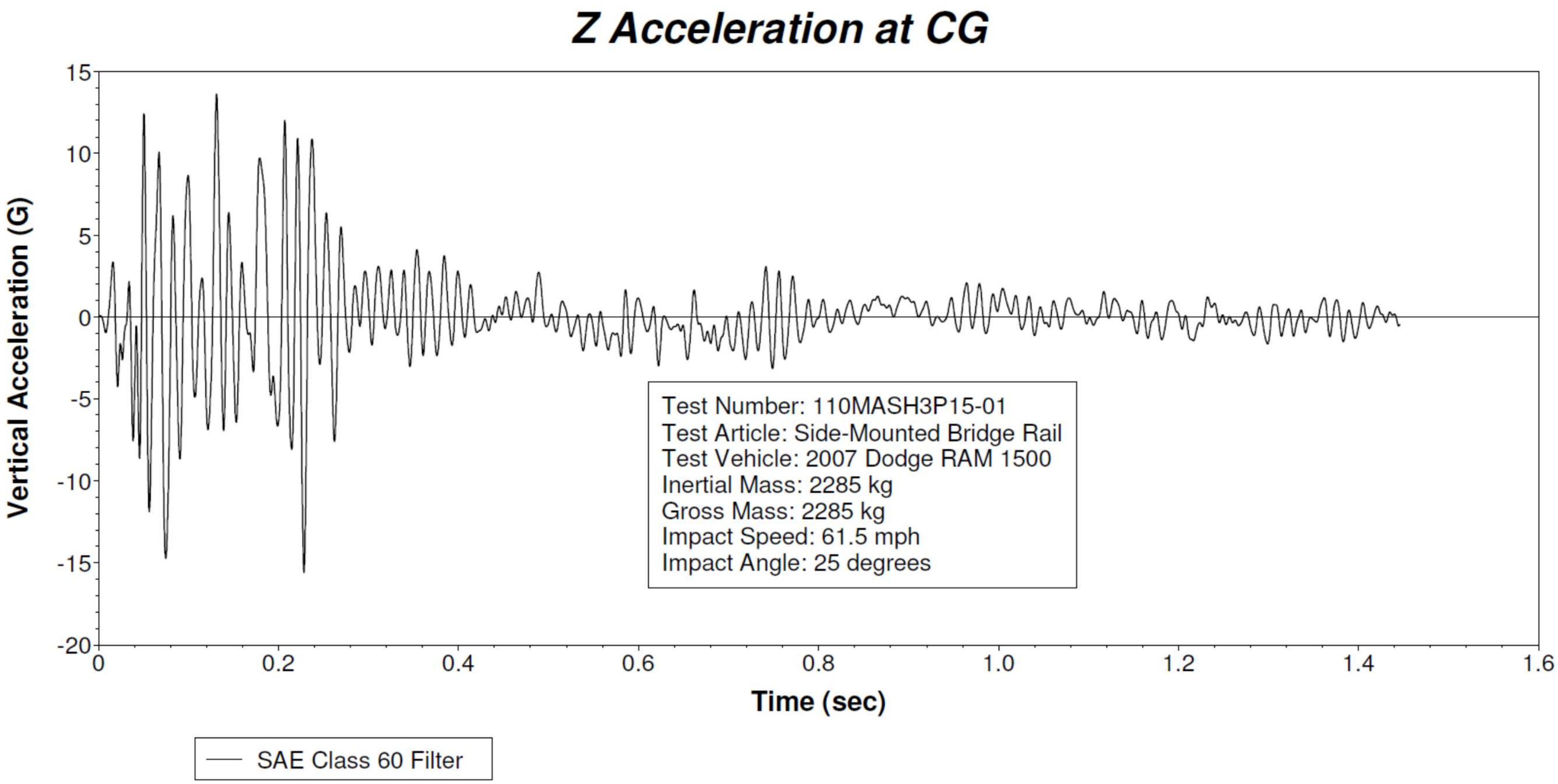


Figure 8-12. 110MASH3P15-01 Z (Vertical) Acceleration at CG vs Time

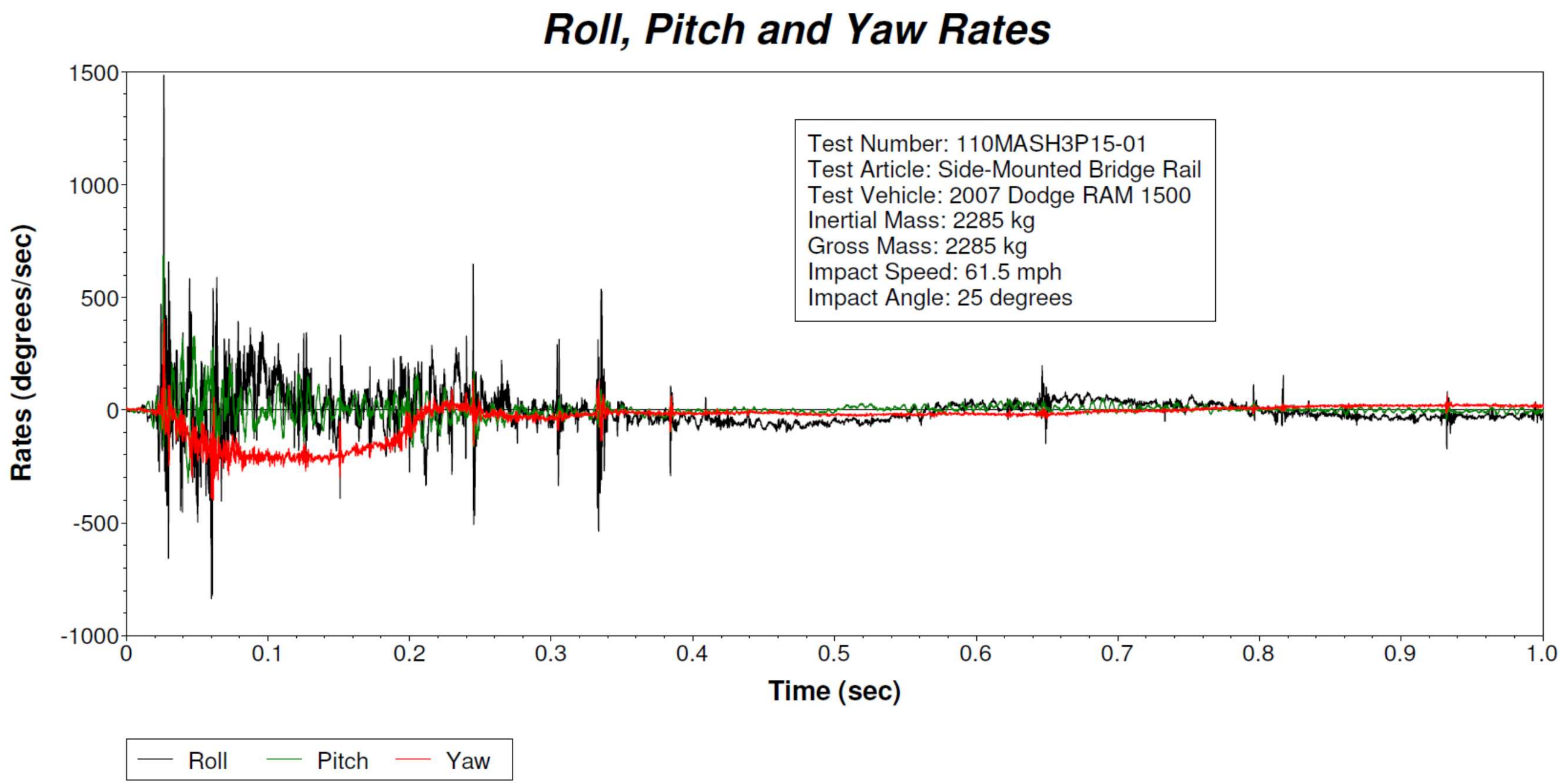


Figure 8-13. 110MASH3P15-01 Roll, Pitch, and Yaw Rates vs Time

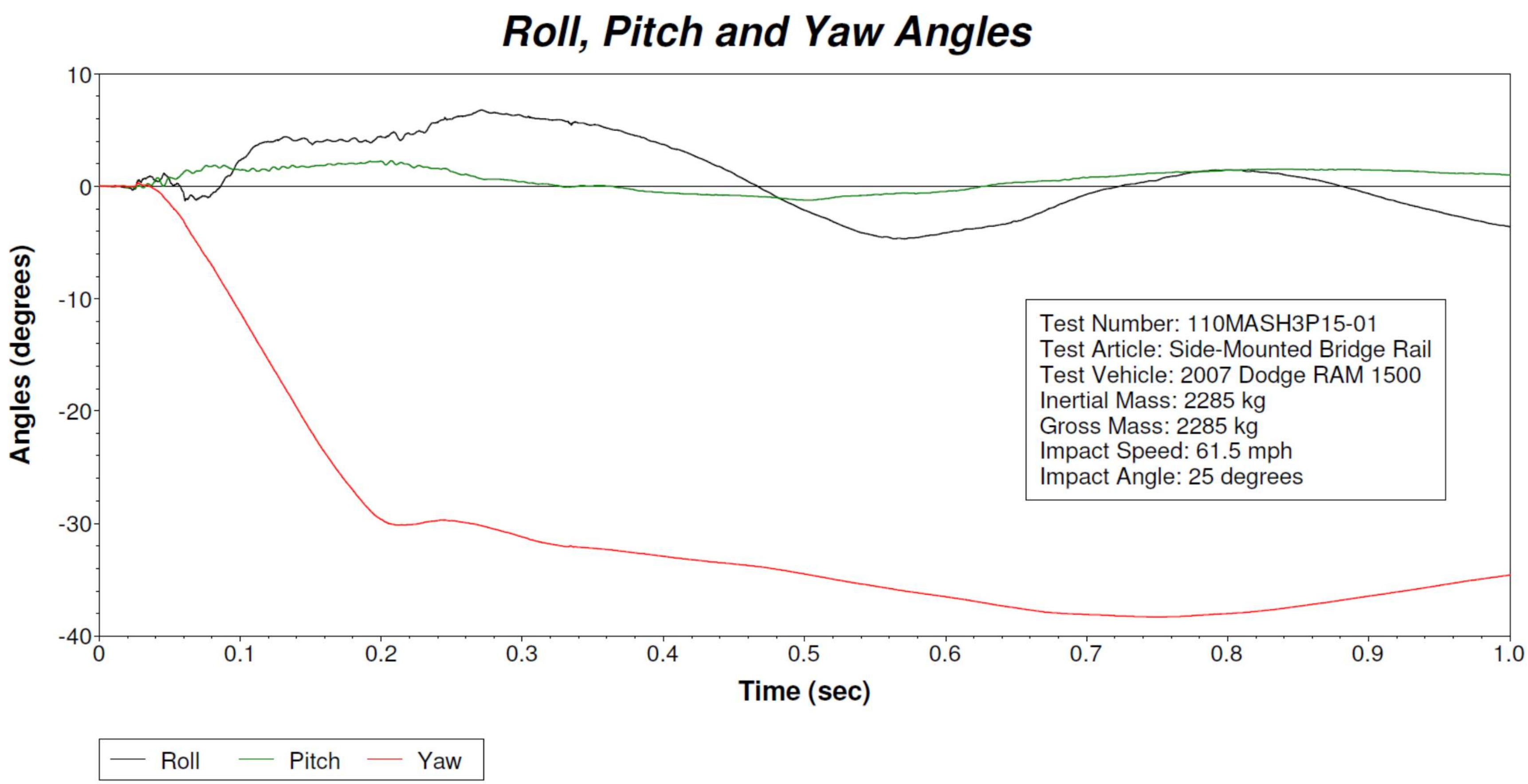


Figure 8-14. 110MASH3P15-01 Roll, Pitch, and Yaw Angles vs Time

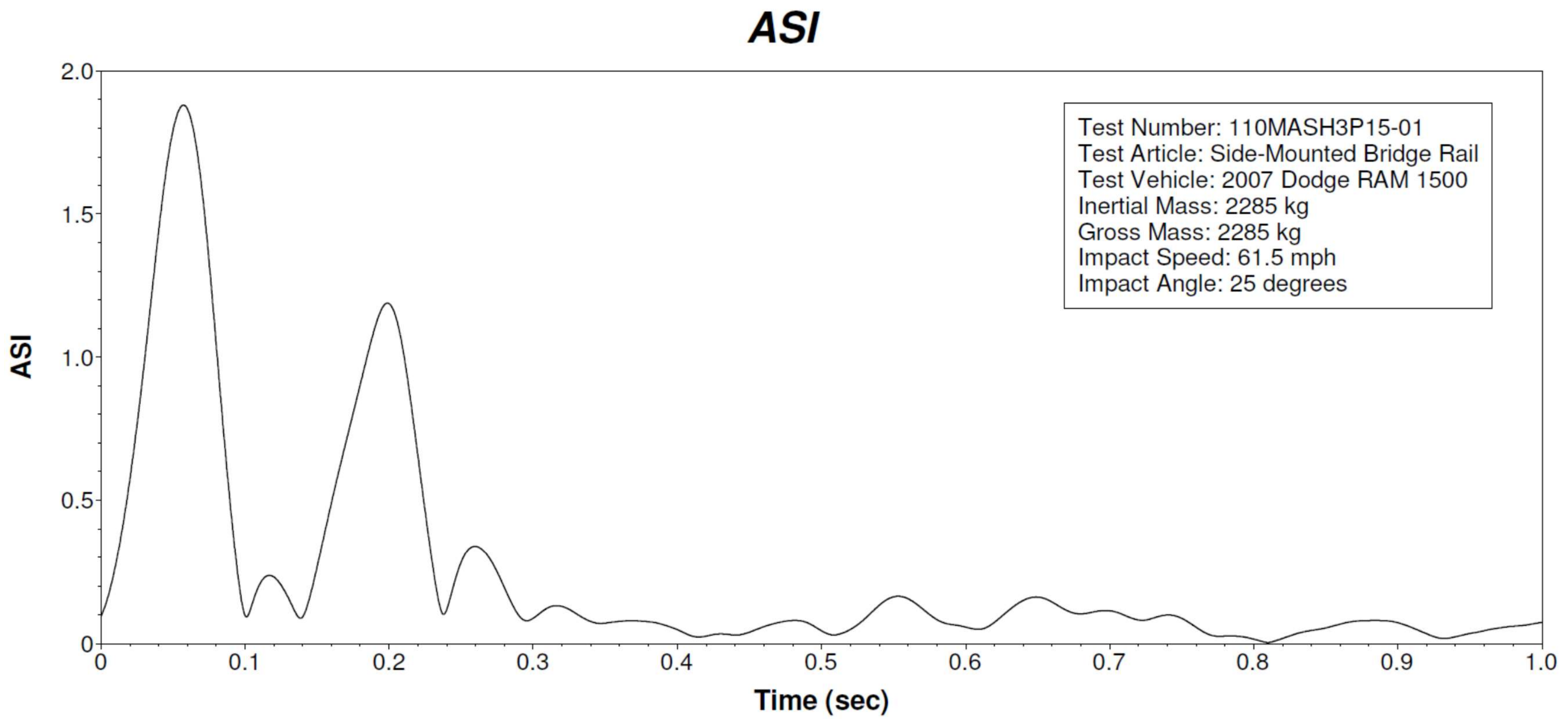


Figure 8-15. 110MASH3P15-01 Vehicle Acceleration Severity Index (ASI) vs Time

8.2. Test 110MASH4C15-02 Vehicle Setup

8.2.1. Test Vehicle Equipment

The vehicle used for this test was a 2008 Kia Rio. Since the vehicle was towed and not self-powered, the fuel in the gas tank was pumped out and gaseous CO_2 added in order to purge the fuel vapors and eliminate oxygen. One pair of 12-volt wet cell batteries were mounted in the vehicle. The batteries powered the GMH DataBrick transient data recorders. A 12-volt deep-cycle gel cell battery powers the Electronic Control Box.

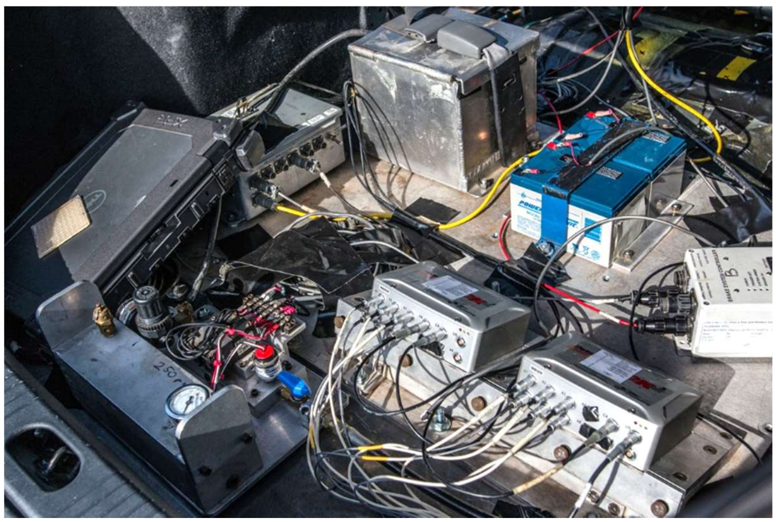


Figure 8-16. Instrumentation Board Mounting Location

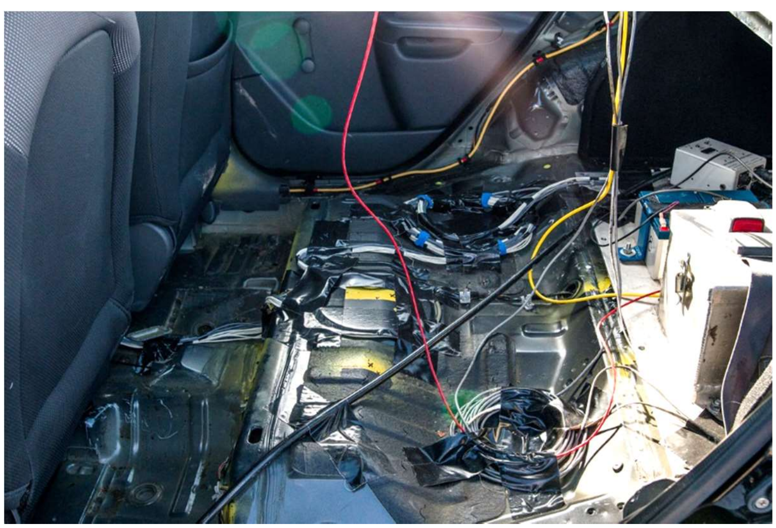


Figure 8-17. Backseat Removed

A 4800 kPA CO_2 system, actuated by a solenoid valve, controlled remote braking after the impact and emergency braking if necessary. Part of this system was a pneumatic ram which 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 ensure the shortest stopping distance without locking up the wheels. When activated, the brakes could be applied in less than 100 milliseconds.

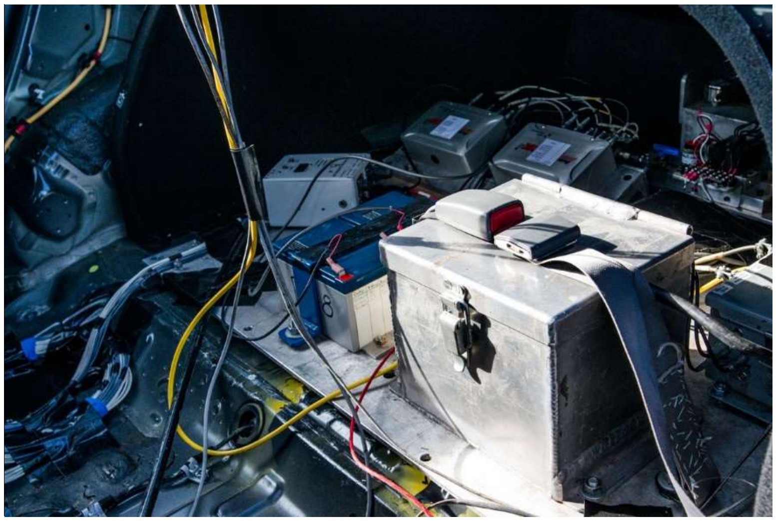


Figure 8-18. Rear of Instrumentation Panel

Figure 8-19. Brake Pedal Actuator

A speed control device was connected in-line with the ignition module signal to the coil on the tow vehicle. It was use to regulate the speed based on the signal from the vehicle transmission speed sensor. 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 at a specific distance apart) and a digital timer.

8.2.2. Test Vehicle Guidance System

A rail guidance system directed the vehicle into the barrier. The guidance rail, anchored at 12.5 ft (3.8 m) intervals along its length was use to guide a mechanical arm, which was attached to the front left wheel of the vehicle. A plate and lever were used to trigger the release pin on the guidance arm, thereby releasing the vehicle from the guidance system before impact.

Figure 8-20. Rail Guidance Hub

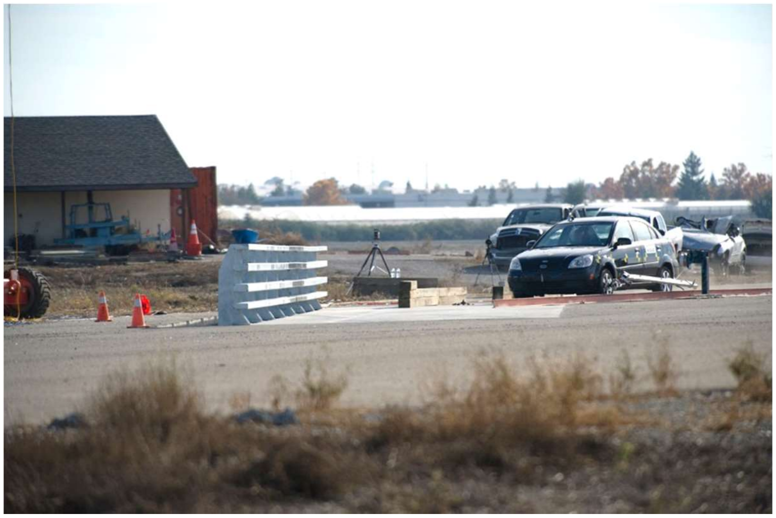


Figure 8-21. Rail Guidance System

8.2.3. Photo - Instrumentation

Several high-speed video cameras recorded the impact during the test. The high-speed video frame rates were set to 500 frames per second. The types of cameras and their locations are shown in Figure 8-22 and Table 8-11. The origin of the coordinates is at the intended point of impact.

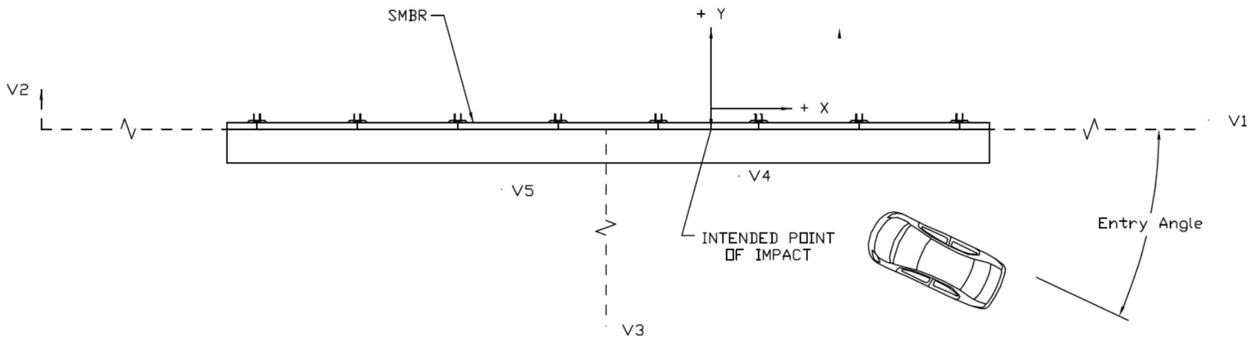


Figure 8-22. High-Speed Video Camera Locations

Table 8-11. 110MASH3P15-01 Camera Types and Location Coordinates

Camera Location	Camera Make/Model	Camera Serial No.	Lens	Lens Serial No.	Coordinates		
					x	y	z
V4	Vision Resesarch Miro 110	13235	14 mm	210927	3.1 ft (0.94 m)	-4.6 ft (-1.41 m)	29.9 ft (9.12 m)
V5	Vision Resesarch Miro 110	13234	14 mm	217706	-21.4 ft (-6.5 m)	-6.1 ft (-1.85 m)	29.9 ft (9.12 m)
V3	Olympus iSpeed 3	1400012	35 mm	173792	-4.2 ft (-1.27 m)	-69.9 ft (-21.29 m)	3.9 ft (1.17 m)
V1	Olympus iSpeed 3	1400022	35 mm	259936	111.0 ft (33.83 m)	0.6 ft (0.15 m)	2.9 ft (0.87 m)
V2	Olympus iSpeed 3	1400014	85 mm	420398	-303.8 ft (-92.58 m)	0.3 ft (0.08 m)	5.1 ft (1.56 m)

The following are the pretest procedures that were required to enable video data reduction to be performed using the Research's video analysis software (Phantom Camera Control):

1. Butterfly targets were attached to the top and sides of the test vehicle. The targets were located on the vehicle at intervals of 19.7 inches (500 mm) and 39.4 inches (1000 mm). The targets established scale factors.
2. Flashbulbs, mounted on the test vehicle, were electronically triggered to establish initial vehicle-to-barrier contact and the time of the application of the vehicle brakes.
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.

8.2.4. Electronic Instrumentation and Data

Transducer data were recorded on two separate GMH Engineering, Data Brick, Model III, digital transient data recorders (TDRs) that were mounted on the test vehicle. These transducers included two sets of accelerometers and two sets of angular rate sensors at the center of gravity. The TDR data were reduced using a desktop personal computer running DADiSP 2002 version 6.0 NI NK B14 (pre-processing) and TRAP version 2.3.10 (post-processing). Accelerometer and angular rate sensor specifications are shown in Table 8-12.

Table 8-12. Accelerometer and Angular Rate Sensor Specifications

Type	Manufacturer	Model	Serial #	Location	Range	Orientation
Accelerometer	Measurement Specialties	64CM32	MS13366	CG	±200	Primary Longitudinal
Accelerometer	Measurement Specialties	64CM32	MS13328	GC	±200	Primary Lateral
Accelerometer	Measurement Specialties	64CM32	MS13358	CG	±200	Primary Vertical
Accelerometer	Measurement Specialties	64CM32	MS13364	CG	±200	Secondary Longitudinal
Accelerometer	Measurement Specialties	64CM32	MS13361	CG	±200	Secondary Lateral
Accelerometer	Measurement Specialties	64CM32	MS13329	CG	±200	Secondary Vertical
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS4018	CG	±1500	Primary Roll
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS4217	CG	±1500	Primary Pitch
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS3348	CG	±1500	Primary Yaw
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS3355	CG	±1500	Secondary Roll
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS3336	CG	±1500	Secondary Pitch
Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS4019	CG	±1500	Secondary Yaw

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. The strips were spaced at carefully measured intervals of 39.4 inches (1000 mm). The test vehicle had an onboard optical sensor that produced sequential impulses or “event blips” as the vehicle passed the reflective tape strips. The event blips 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, the data record time, 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. One set of pressure activated tape switches, connected to a speed trap, were placed 13.1 ft (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 and reflective tape is shown in Figure 8-23.

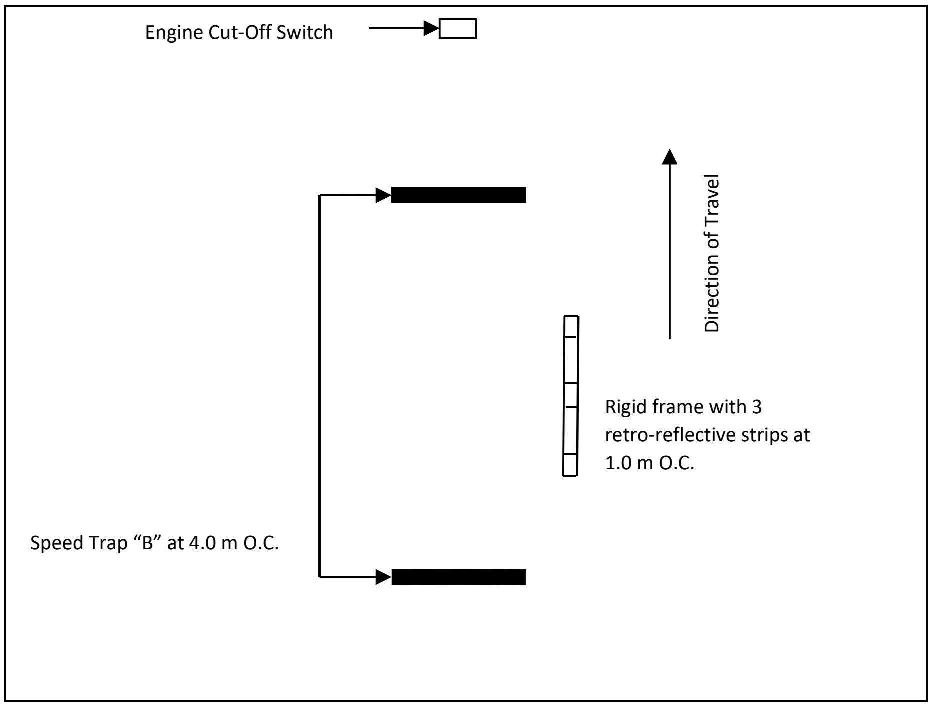


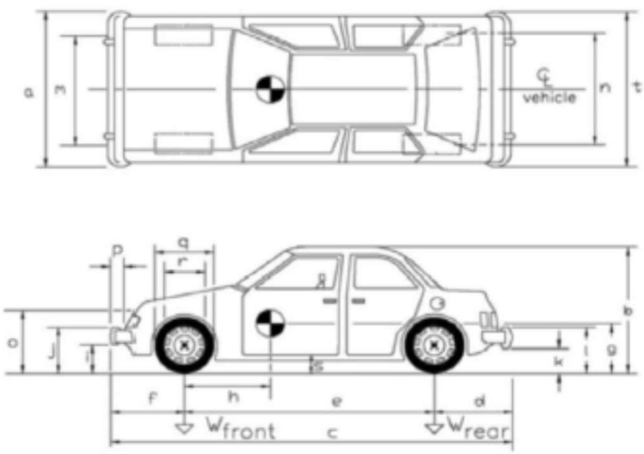
Figure 8-23. Speed Trap Tape Layout

8.2.5. Vehicle Measurements

Table 8-13. Exterior Vehicle Measurements

Date:	Oct. 6, 2015	Test Number:	110MASH4C15-02	Model:	Rio
Make:	Kia	VIN:	KNADE123386322346		
Tire Size:	P185/65R14	Year:	2008	Odometer:	116422
Tire Inflation Pressure:	32 psi	Tape Measure Used:	Tape #1		

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm (inches)

a	1671	(65.8)	b	1436	(56.5)
c	4246	(167.2)	d	922	(36.3)
e	2497	(98.3)	f	826	(32.5)
g	n/a	n/a	h	972.09	(38.3)
i	179	(7)	j	685	(27)
k	281	(11.1)	l	615	(24.2)
m	1470	(57.9)	n	1443	(56.8)
o	693	(27.3)	p	109	(4.3)
q	575	(22.6)	r	388	(15.3)
s	297	(11.7)	t	1680	(66.1)

Wheel Center Height Front:	268	(10.6)
Wheel Center Height Rear:	282	(11.1)
Wheel Well Clearance (F)	123	(4.8)
Wheel Well Clearance (R)	144	(5.7)
Frame Height (F):	165	(6.5)
Frame Height (R):	175	(6.9)
Engine Type:	4 cylinder	
Engine Size:	1.6 L	
Transmission Type:		
Automatic or Manual:	manual	
FWD or RWD or 4WD:	FWD	

Mass Distribution

Left Front:	33%	Scale:	red	Right Front:	30%	Scale:	green
Left Rear:	19%	Scale:	yellow	Right Rear:	19%	Scale:	blue

Weights

kg (lbs)	Curb		Test Inertial		Gross Static	
W_{front}	693.9	(1529.8)	682.7	(1505.1)	723.3	(1594.6)
W_{rear}	410.5	(904.9)	435.2	(959.4)	475.2	(1047.6)
W_{total}	1104.4	(2434.6)	1117.9	(2464.5)	1198.5	(2642.2)

GVWR Ratings

Front:	867 kg	1918 lbs
Back:	850 kg	1874 lbs
Total:	1650 kg	3638 lbs

Dummy Data

Type:	50th hybrid III Test Dummy
Mass:	171 lbs (78 kg)
Seat Position:	Passenger side

Note any damage prior to test: No damage.

Table 8-14. CG Calculation: Curb Weight

CG Calculation Worksheet #1: Curb Weight

Make:	Kia	Test Number:	110MASH4C15-02
Model:	Rio	Date:	Oct. 6, 2015
Year:	2008	Temperature:	73°F
VIN:	KNADE123386322346		
Fuel in Tank:	25% tank		
Fuel Removed:	none		
Staff:	Jean V.		
	Chris C.		
	Ali Z.		
	David W.		

W1 = Left Front (LF) = 363.2 kg
Scale Used: red

W2 = Right Front (RF) = 330.7 kg
Scale Used: green

W3 = Left Rear (LR) = 198.45 kg
Scale Used: yellow

W4 = Right Rear (RR) = 212 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 1104.45 kg

Wtotal (calculated) = 1104.35 kg

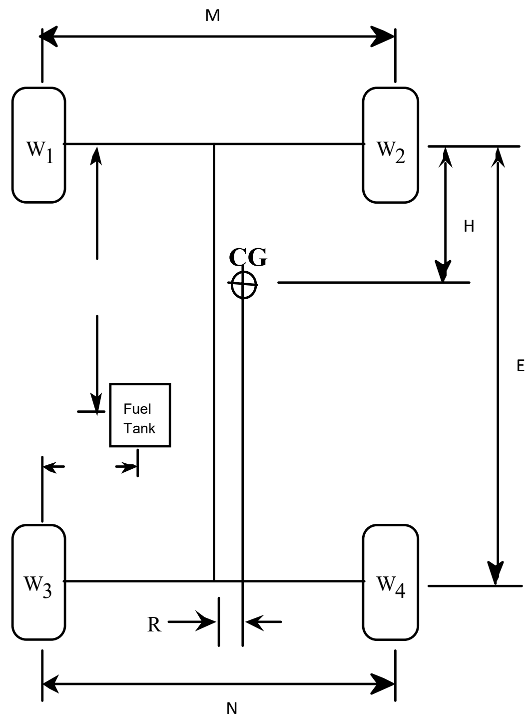
Distance between front wheels:
M = 1470 mm

Distance between rear wheels:
N = 1443 mm

Distance from front to rear wheels:
E = 2497 mm

Distance from front wheels back to CG:
H = 928.05 mm

Distance from vehicle centerline to CG:
R = -12.78 mm



$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

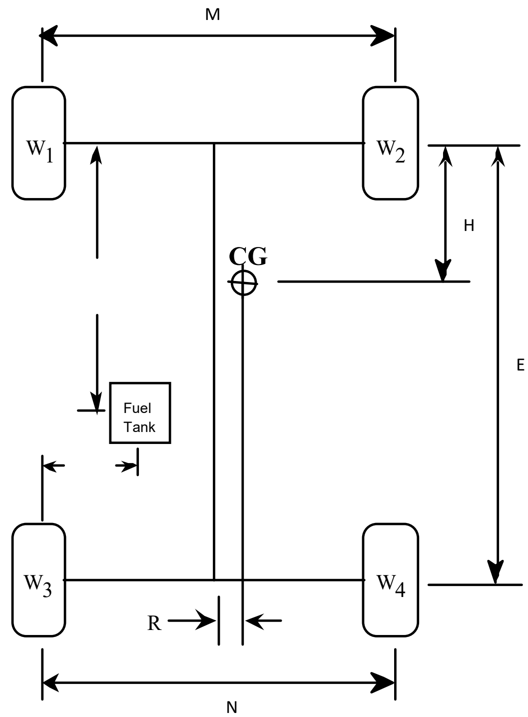
If R is negative the CG is left of center, if R is positive the CG is right of center

Curb Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
As received: spare tire included

Table 8-15. CG Calculation: Test Inertial Weight

CG Calculation Worksheet #2: Test Inertial Weight

Make:	Kia	Test Number:	110MASH4C15-02
Model:	Rio	Date:	Oct. 22, 2015
Year:	2008	Temperature:	73°F
VIN:	KNADE123386322346		
Fuel in Tank:	25%		
Fuel Removed:	No fuel removed		
Staff:	Jean V.		
	Chris C.		
	David W.		
	Vue H.		



W1 = Left Front (LF) = 360.6 kg
Scale Used: red

W2 = Right Front (RF) = 322.1 kg
Scale Used: green

W3 = Left Rear (LR) = 212.95 kg
Scale Used: yellow

W4 = Right Rear (RR) = 222.25 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 1118.25 kg

Wtotal (calculated) = 1117.9 kg

Distance between front wheels:
M = 1470 mm

Distance between rear wheels:
N = 1443 mm

Distance from front to rear wheels:
E = 2497 mm

Distance from front wheels back to CG:
H = 972.09 mm

Distance from vehicle centerline to CG:
R = -19.31 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

If R is negative the CG is left of center, if R is positive the CG is right of center

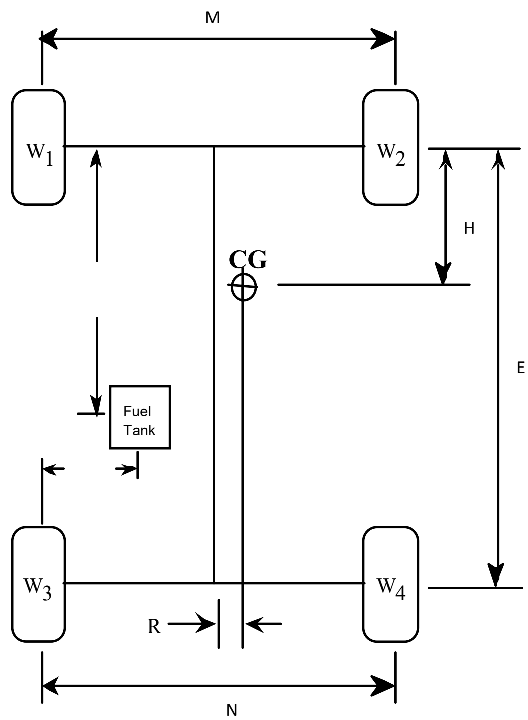
Test Inertial Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)

Note: *Spare tire, rear seats, carpet, trunk carpet, and rear plastic panel removed. Fuel tank was ¼ full, guide hub installed on front left wheel, and all instrumentation installed in vehicle.*

Table 8-16. CG Calculation: Gross Static Weight

CG Calculation Worksheet #3: Gross Static Weight

Make:	Kia	Test Number:	110MASH4C15-02
Model:	Rio	Date:	Oct. 22, 2015
Year:	2008	Temperature:	73°F
VIN:	KNADE123386322346		
Fuel in Tank:	25%		
Fuel Removed:	No fuel removed		
Staff:	Jean V.		
	Chris C.		
	David W.		
	Vue H.		



W1 = Left Front (LF) = 371.1 kg
Scale Used: red

W2 = Right Front (RF) = 352.2 kg
Scale Used: green

W3 = Left Rear (LR) = 224.9 kg
Scale Used: yellow

W4 = Right Rear (RR) = 250.3 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 1198.5 kg

Wtotal (calculated) = 1198.5 kg

Distance between front wheels:
M = 1470 mm

Distance between rear wheels:
N = 1443 mm

Distance from front to rear wheels:
E = 2497 mm

Distance from front wheels back to CG:
H = 990.05 mm

Distance from vehicle centerline to CG:
R = 3.70 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

If R is negative the CG is left of center, if R is positive the CG is right of center

Gross Static Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Dummy added.

8.2.6. Vehicle Interior Deformation Measurements

Table 8-17. Pretest and Post-test Interior Floorboard Deformation Measurements

Vehicle Type	1100C	Test Number	110MASH4C15-02
Make	Kia	Model	Rio
Year	2008	Color	Black
VIN #	KNADE123386322346		

Floorboard Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
F1	850 (33.5)	400 (15.7)	-181 (-7.1)	852 (33.5)	400 (15.7)	-183 (-7.2)	2 (0.1)	0 (0)	-2 (-0.1)
F2	850 (33.5)	550 (21.7)	-183 (-7.2)	838 (33)	547 (21.5)	-194 (-7.6)	-12 (-0.5)	-3 (-0.1)	-11 (-0.4)
F3	850 (33.5)	700 (27.6)	-184 (-7.2)	840 (33.1)	695 (27.4)	-192 (-7.6)	-10 (-0.4)	-5 (-0.2)	-8 (-0.3)
F4	850 (33.5)	800 (31.5)	-183 (-7.2)	846 (33.3)	792 (31.2)	-190 (-7.5)	-4 (-0.2)	-8 (-0.3)	-7 (-0.3)
F5	1000 (39.4)	400 (15.7)	-204 (-8)	1000 (39.4)	409 (16.1)	-191 (-7.5)	0 (0)	9 (0.4)	13 (0.5)
F6	1000 (39.4)	550 (21.7)	-184 (-7.2)	988 (38.9)	539 (21.2)	-190 (-7.5)	-12 (-0.5)	-11 (-0.4)	-6 (-0.2)
F7	1000 (39.4)	700 (27.6)	-192 (-7.6)	993 (39.1)	688 (27.1)	-196 (-7.7)	-7 (-0.3)	-12 (-0.5)	-4 (-0.2)
F8	1000 (39.4)	800 (31.5)	-197 (-7.8)	996 (39.2)	791 (31.1)	-199 (-7.8)	-4 (-0.2)	-9 (-0.4)	-2 (-0.1)
F9	1150 (45.3)	400 (15.7)	-196 (-7.7)	1138 (44.8)	402 (15.8)	-144 (-5.7)	-12 (-0.5)	2 (0.1)	52 (2)
F10	1150 (45.3)	550 (21.7)	-184 (-7.2)	1139 (44.8)	534 (21)	-186 (-7.3)	-11 (-0.4)	-16 (-0.6)	-2 (-0.1)
F11	1150 (45.3)	700 (27.6)	-191 (-7.5)	1145 (45.1)	691 (27.2)	-196 (-7.7)	-5 (-0.2)	-9 (-0.4)	-5 (-0.2)
F12	1150 (45.3)	800 (31.5)	-191 (-7.5)	1150 (45.3)	786 (30.9)	-190 (-7.5)	0 (0)	-14 (-0.6)	1 (0)
F13	1300 (51.2)	550 (21.7)	-179 (-7)	1290 (50.8)	516 (20.3)	-175 (-6.9)	-10 (-0.4)	-34 (-1.3)	4 (0.2)
F14	1300 (51.2)	700 (27.6)	-181 (-7.1)	1295 (51)	678 (26.7)	-179 (-7)	-5 (-0.2)	-22 (-0.9)	2 (0.1)
F15	1300 (51.2)	800 (31.5)	-180 (-7.1)	1300 (51.2)	780 (30.7)	-178 (-7)	0 (0)	-20 (-0.8)	2 (0.1)
F16	1450 (57.1)	550 (21.7)	-105 (-4.1)	1430 (56.3)	523 (20.6)	-90 (-3.5)	-20 (-0.8)	-27 (-1.1)	15 (0.6)
F17	1450 (57.1)	700 (27.6)	-85 (-3.3)	1415 (55.7)	675 (26.6)	-72 (-2.8)	-35 (-1.4)	-25 (-1)	13 (0.5)

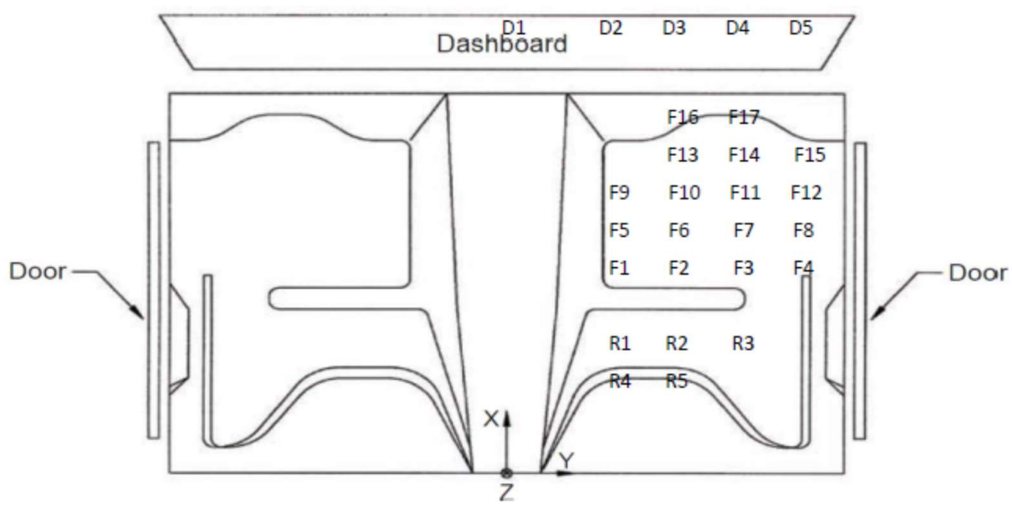


Table 8-18. Pretest and Post-test Interior Dashboard and Roof Deformation Measurements

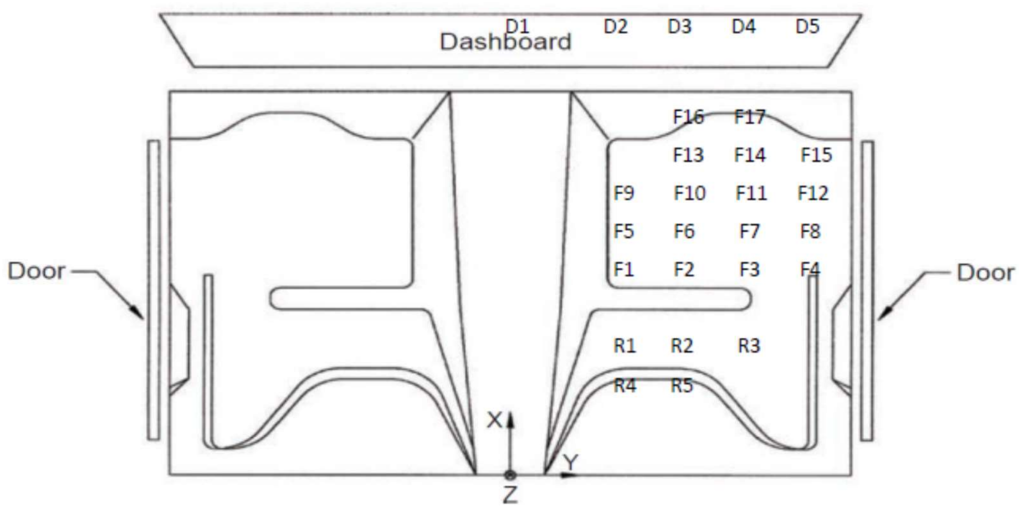
Vehicle Type	1100C	Test Number	110MASH4C15-02
Make	Kia	Model	Rio
Year	2008	Color	Black
VIN #	KNADE123386322346		

Dashboard Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
D1	1076 (42.4)	200 (7.9)	532 (20.9)	1084 (42.7)	196 (7.7)	534 (21)	8 (0.3)	-4 (-0.2)	2 (0.1)
D2	1047 (41.2)	400 (15.7)	532 (20.9)	1052 (41.4)	395 (15.6)	530 (20.9)	5 (0.2)	-5 (-0.2)	-2 (-0.1)
D3	1115 (43.9)	550 (21.7)	532 (20.9)	1118 (44)	546 (21.5)	533 (21)	3 (0.1)	-4 (-0.2)	1 (0)
D4	1118 (44)	700 (27.6)	519 (20.4)	1118 (44)	695 (27.4)	526 (20.7)	0 (0)	-5 (-0.2)	7 (0.3)
D5	1106 (43.5)	800 (31.5)	515 (20.3)	1105 (43.5)	797 (31.4)	523 (20.6)	-1 (0)	-3 (-0.1)	8 (0.3)

Roof Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
R1	730 (28.7)	400 (15.7)	921 (36.3)	738 (29.1)	400 (15.7)	925 (36.4)	8 (0.3)	0 (0)	4 (0.2)
R2	730 (28.7)	550 (21.7)	911 (35.9)	739 (29.1)	551 (21.7)	912 (35.9)	9 (0.4)	1 (0)	1 (0)
R3	730 (28.7)	700 (27.6)	891 (35.1)	740 (29.1)	703 (27.7)	895 (35.2)	10 (0.4)	3 (0.1)	4 (0.2)
R4	467 (18.4)	550 (21.7)	979 (38.5)	470 (18.5)	553 (21.8)	979 (38.5)	3 (0.1)	3 (0.1)	0 (0)
R5	475 (18.7)	700 (27.6)	900 (35.4)	481 (18.9)	710 (28)	901 (35.5)	6 (0.2)	10 (0.4)	1 (0)



8.2.7.Data Plots

The data plots are shown in Figure 8-24 through Figure 8-29 include the accelerometer and angular rate sensor records from the test vehicle in test 110MASH4C15-02. They also show the velocity and displacement curves for the longitudinal and lateral components. These plots are required to calculate the occupant impact velocity (OIV) defined in MASH 2009. All data were analyzed using TRAP.

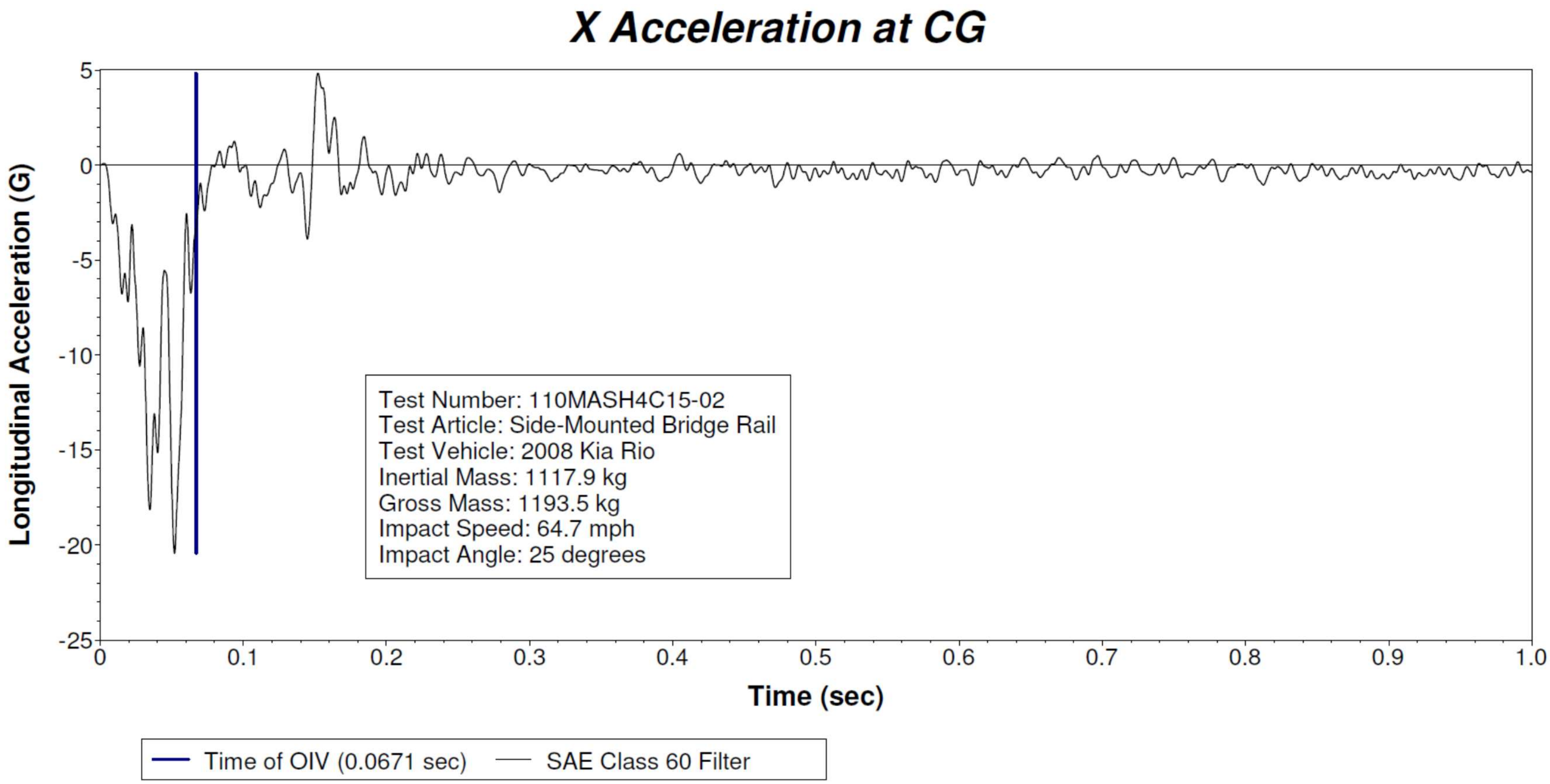


Figure 8-24. 110MASH4C15-02 X (Longitudinal) Acceleration at CG vs Time

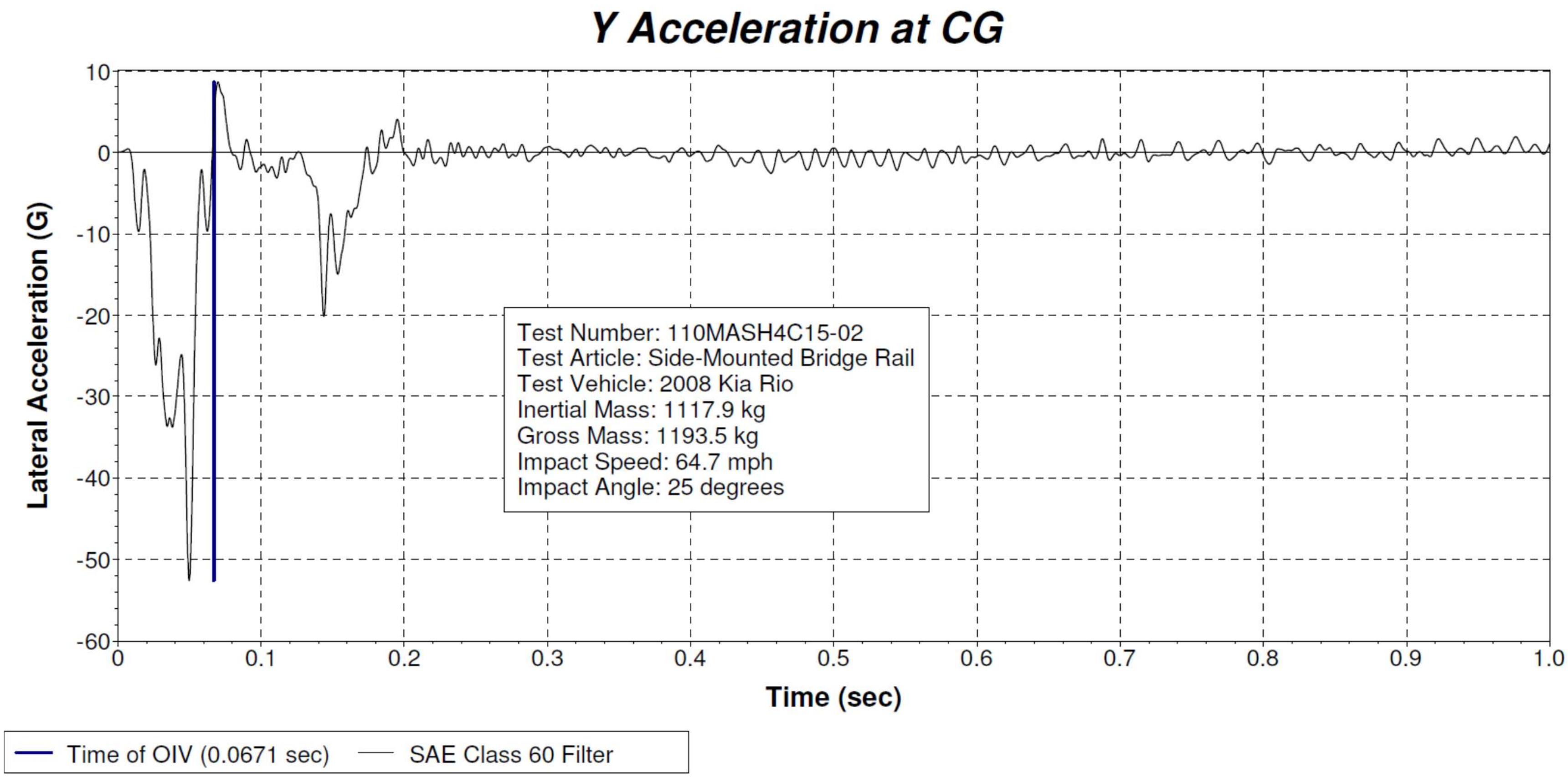


Figure 8-25. 110MASH4C15-02 Y (Lateral) Acceleration at CG vs Time

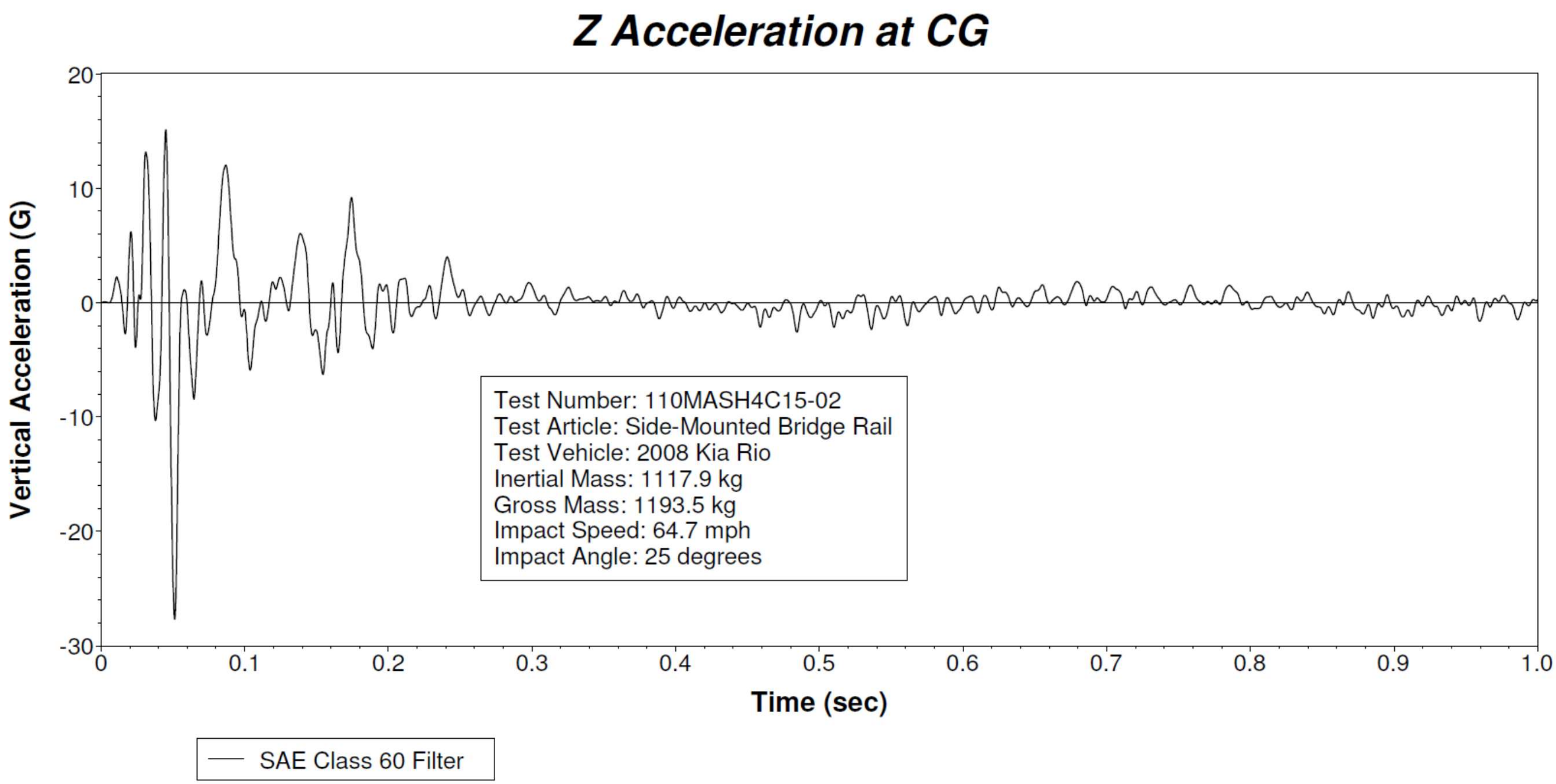


Figure 8-26. 110MASH4C15-02 Z (Vertical) Acceleration at CG vs Time

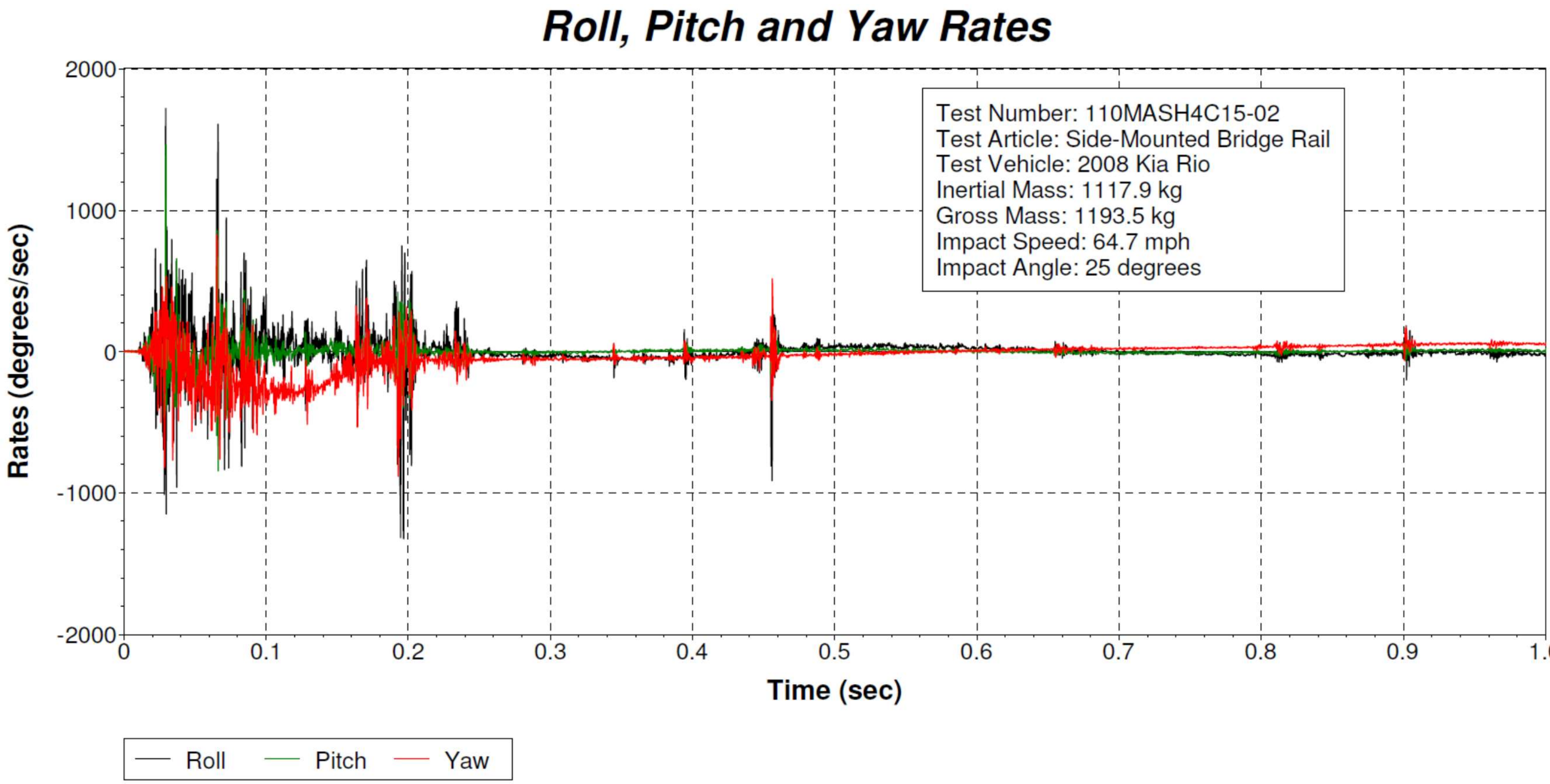


Figure 8-27. 110MASH4C15-02 Roll, Pitch, and Yaw Rates vs Time

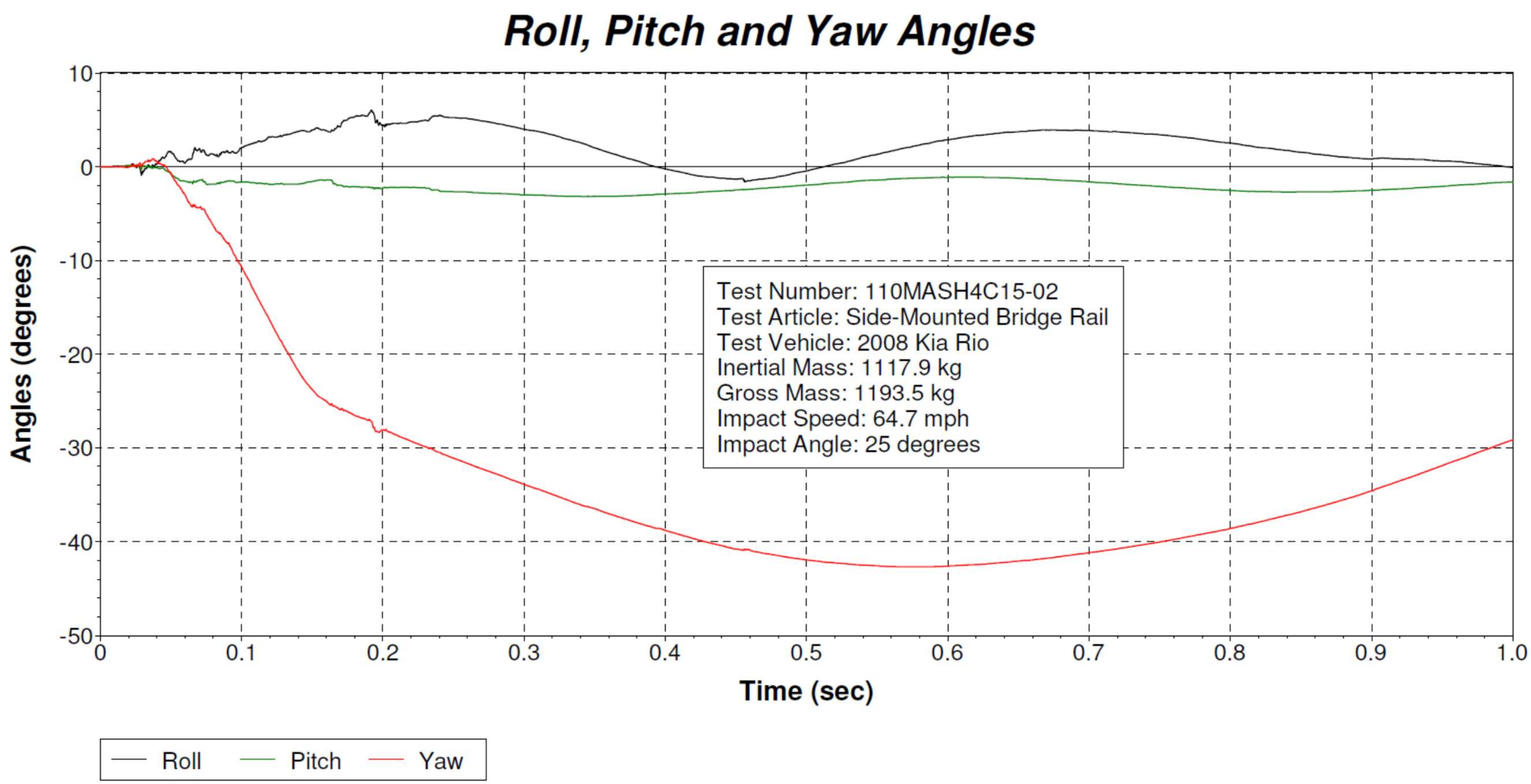


Figure 8-28. 110MASH4C15-02 Roll, Pitch, and Yaw Angles vs Time

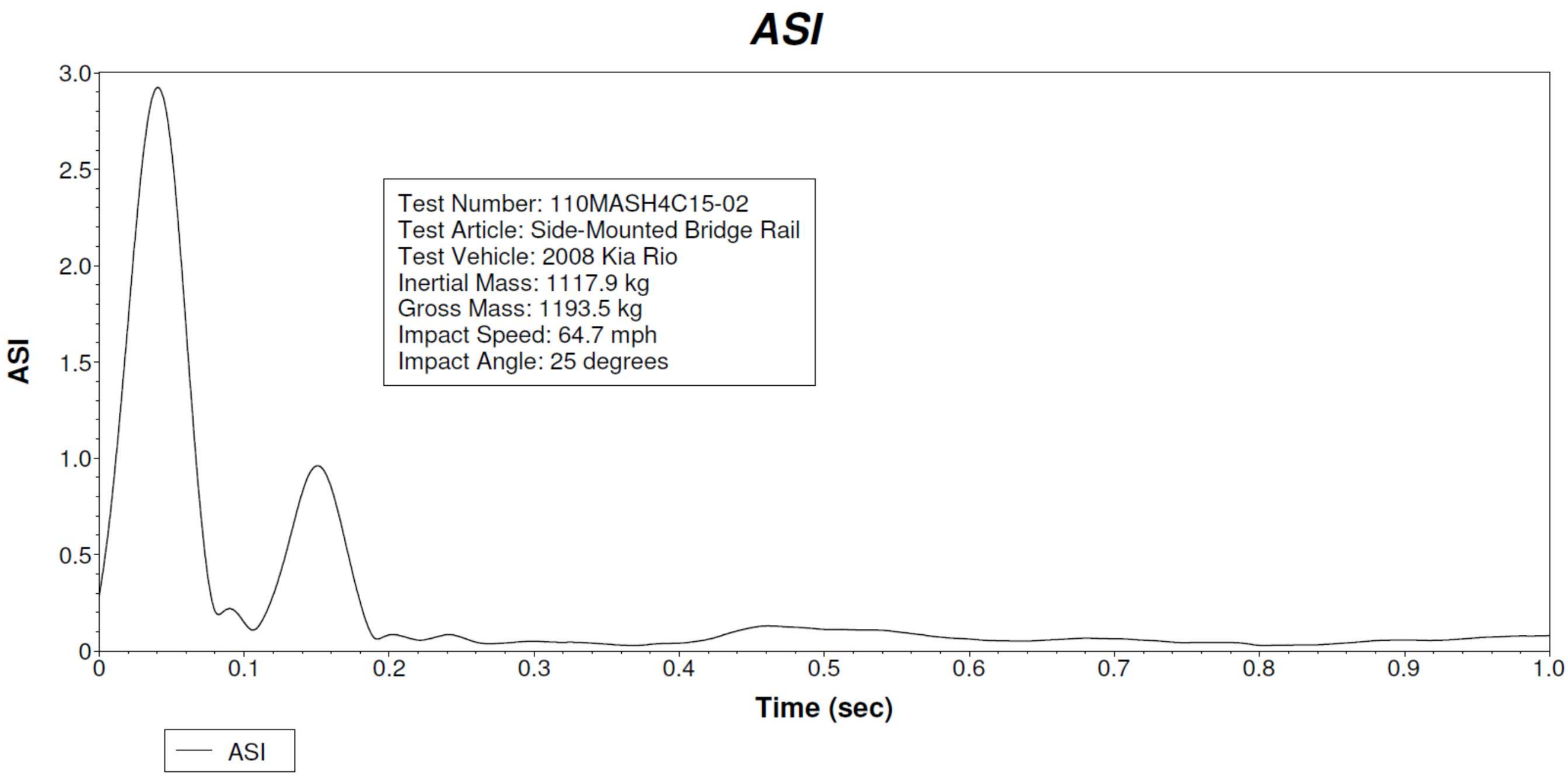


Figure 8-29. 110MASH4C15-02 Vehicle Acceleration Severity Index (ASI) vs Time

8.3. Test 110MASH4S16-03 Vehicle Setup

8.3.1. Test Vehicle Equipment

The vehicle used for this test is a 2005 Freightliner M2. The vehicle had two diesel fuel tanks, one on each side. The impact (passenger) side fuel tank was disconnected, drained, and purged with CO_2 gas to eliminate fuel vapors and oxygen. Fuel in the driver's side tank remained and was used to supply fuel to the engine during the test. In addition to being self-powered, the vehicle was also pushed with a 2001 Ford F350 Super Duty truck because the allowable runway length was not sufficient for the self-powered vehicle to reach the desired test speed.

Figure 8-30. 110MASH4S16-03 F350 Push Vehicle and the 10000S Test Vehicle

One pair of a 12-volt wet cell batteries were mounted in the vehicle on the instrumentation board. The batteries powered the GMH DataBrick transient data recorders. A 12-volt deep-cycle gel cell battery powered the Electronic Control Box. A 4800 kPA CO_2 system, actuated by a solenoid valve, controlled remote braking after the impact and emergency braking if necessary. Part of this system was a pneumatic ram which was attached to the brake pedal. The operating pressure for the ram was adjusted through a pressure regulator during a series of trail runs prior to the actual test. Adjustments were made to ensure the shortest stopping distance without locking up the wheels. When activated, the brakes could be applied in less than 100 milliseconds.

An accelerator switch was located on the rear left of the vehicles cargo box. The switch opens an electronic solenoid that releases compressed CO_2 from a reservoir into a pneumatic ram, which was attached to the accelerator pedal. The CO_2 pressure for the accelerator ram was regulated to the same pressure as the remote braking system with a valve to adjust CO_2 flow rate. Speed control was accomplished by *Holt of California* in West Sacramento, California; Caterpillar engine service center. The service center reprogramed the speed governor to not exceed the target speed of 56 mph.

Three 5 feet by 5 feet by 2 inch (1.5 m by 1.5 m by 51 mm) steel plates were used as ballast. Each plate weighed approximately 2000 lbs (907 kg). They were mounted uniformly across the length and width of the cargo bed using 8 threaded rods through the bed to c-channel brackets under the bed. The ballast center of gravity height was at 64 inches (1626 mm).

Figure 8-31. 110MASH4S16-03 Vehicle Ballast

Figure 8-32. 110MASH4S16-03 Vehicle Ballast Mounted in with C-Channels Sections

Figure 8-33. 110MASH4S16-03 Vehicle Ballast CG Height (Red Laser at 64 inches)

The rear of the van body had a lift gate which was welded to the frame, thus shear plates were only mounted toward the front of the cargo box. Two shear plates, one on each side of the frame were mounted 48 inches (1219 mm) from the front of the cargo box to the middle of the plates. The shear plates are 20” x 4” x 3/8” (508 mm x 102 mm x 10 mm) HRLC steel plates, cut at 45° angles on each end and were mounted with 4-5/8” (117 mm) grade 8 bolts. All reinforcements were installed in accordance with the guidelines in *Ford’s 2005 Body Builder Layout Book*.

Figure 8-34. 110MASH4S16-03 Shear Plates

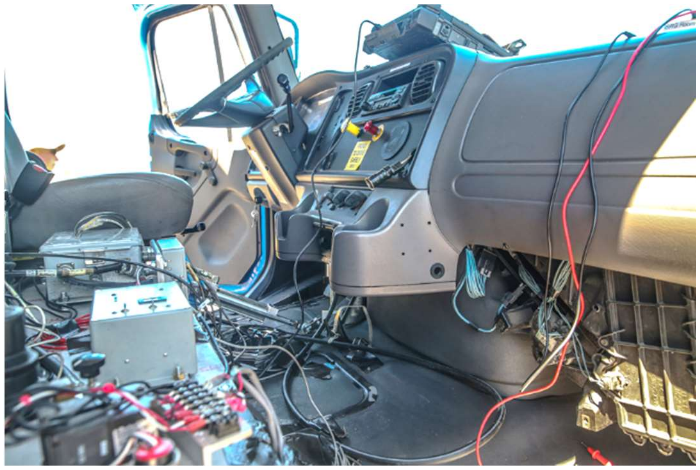


Figure 8-35. 110MASH4S16-03 Instrumentation

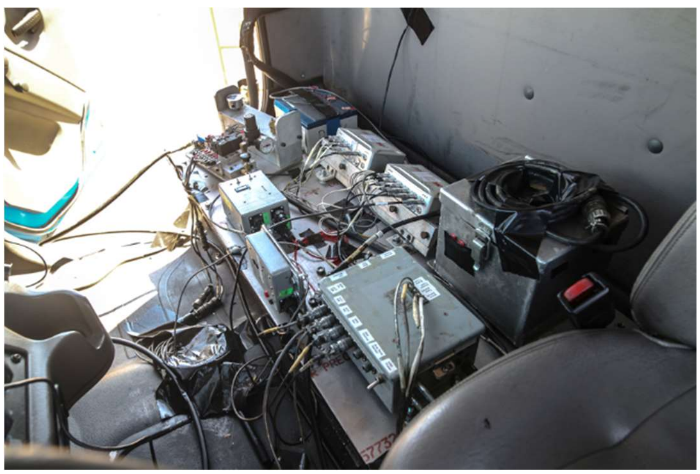


Figure 8-36. 110MASH4S16-03 Instrumentation Mounted on Passenger Seat Mount

Figure 8-37. 110 MASH4S16-01 Brake and Gas Pedal Actuators

8.3.2. Test Vehicle Guidance System

The same rail guidance system as previous tests was used to direct the vehicle into the barrier. The guidance rail, anchored at 12.5 ft (3.8 m) intervals along its length was used to guide a mechanical arm, which was attached to the front left wheel of the vehicle. A plate and lever were used to trigger the release pin on the guidance arm, thereby releasing the vehicle from the guidance system before impact.

Figure 8-38. 110MASH4S16-03 Rail Guidance Hub

Figure 8-39. 110MASH4S16-03 Rail Guidance System with 10000S Disengaged

8.3.3. Photo – Instrumentation

Several high-speed video cameras recorded the impact during the test. The high-speed video frame rates were set to 500 frames per second. The types of cameras and their locations are shown in Figure 8-40 and Table 8-19. 110MASH4S16-03 Camera Types and Location Coordinates. The origin of the coordinates is at the intended point of impact.

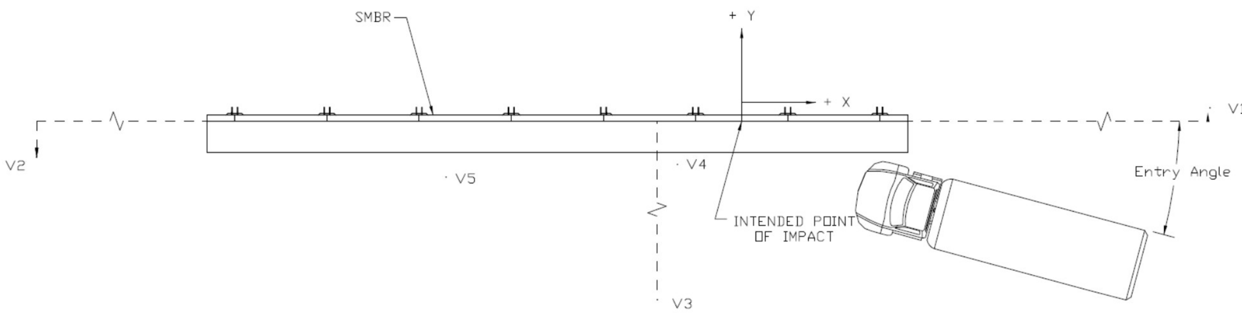


Figure 8-40. High-Speed Video Camera Locations

Table 8-19. 110MASH4S16-03 Camera Types and Location Coordinates

Camera Location	Camera Make/Model	Camera Serial No.	Lens	Lens Serial No.	Coordinates		
					x	y	z
V4	Vision Resesarch Miro 110	13235	14 mm	210927	11.2 ft (3.4 m)	-7.4 ft (2.3 m)	30.7 ft (9.4 m)
V5	Vision Resesarch Miro 110	13234	14 mm	217706	-31.6 ft (-9.6 m)	-6.7 ft (-2.0 m)	40.7 ft (12.4 m)
V3	Olympus iSpeed 3	1400012	20 mm	217706	-9.2 ft (-2.8 m)	-90.6 ft (-27.6 m)	N/A
V1	Olympus iSpeed 3	1400022	35mm	259936	97.0 ft (29.6 m)	1.3 ft (0.4 m)	N/A
V2	Olympus iSpeed 3	1400014	28-200 @ 200 mm	402495	-345.8 ft (-105.4 m)	-5.5 ft (-1.7 m)	N/A

The following are the pretest procedures that were required to enable video data reduction to be performed using the Vision Research's video analysis software (Phantom Camera Control):

1. Butterfly targets were attached to the top and sides of the test vehicle. The targets were located on the vehicle at intervals of 19.7 inches (500 mm) and 39.4 inches (1000 mm). The targets established scale factors.
2. Flashbulbs, mounted on the test vehicle, were electronically triggered to establish initial vehicle-to-barrier contact and the time of the application of the vehicle brakes.

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.

8.3.4. Electronic Instrumentation and Data

Transducer data were recorded on two separate GMH Engineering, Data Brick, Model III, digital transient data recorders (TDRs) that were mounted on the test vehicle. These transducers included two sets of accelerometers and two sets of angular rate sensors. One set of sensors was located in the cab of the vehicle 104.6 inches (2658 mm) in front and 0.9 inches (24 mm) to the right of the vehicle's center of gravity (CG). The other set of sensors was in the cargo bed of the vehicle located 64.3 inches (1634 mm) in front and 0.9 inches (24 mm) to the right of the vehicle's CG. The TDR data were reduced using a desktop personal computer running DADiSP 2002 version 6.0 NI NK B14 (pre-processing) and TRAP version 2.3.10 (post-processing). Accelerometer and angular rate sensor specifications are shown in Table 8-21.

The following table indicates where on the single-unit truck the sensors were mounted:

Table 8-20. 110MASH4S16-03 Sensor Locations

Sensor Mount Location from CG	X	Y	Z
Truck Cab	2658 mm (104.6 inches) In Front of CG	24 mm (0.9 inches) Right of CG	N/A
Cargo Box	1634 mm (64.3 inches) In Front of CG	24 mm (0.9 inches) Right of CG	N/A

Table 8-21. Accelerometer and Angular Rate Sensor Specifications

Location	Type	Manufacturer	Model	Serial #	Range	Orientation
Truck Cab	Accelerometer	Measurement Specialties	64CM32	MS13366	±200g	Longitudinal
	Accelerometer	Measurement Specialties	64CM32	MS13328	±200g	Lateral
	Accelerometer	Measurement Specialties	64CM32	MS13358	±200g	Vertical
	Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS4018	±1500°/s	Roll
	Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS4217	±1500°/s	Pitch
	Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS3348	±1500°/s	Yaw
Cargo Box	Accelerometer	Measurement Specialties	64CM32	MS13364	±200g	Longitudinal
	Accelerometer	Measurement Specialties	64CM32	MS13361	±200g	Lateral
	Accelerometer	Measurement Specialties	64CM32	MS13329	±200g	Vertical
	Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS3355	±1500°/s	Roll
	Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS3336	±1500°/s	Pitch
	Angular Rate Sensors	Data Acquisition Systems	ARS-1500(1000HZ)	ARS4019	±1500°/s	Yaw

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. The strips were spaced at carefully measured intervals of 39.4 inches (1000 mm). The test vehicle had an onboard optical sensor that produced sequential impulses or "event blips" as the vehicle passed the reflective tape strips. The event blips 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, the data record time, 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. One set of pressure activated tape switches, connected to a speed trap, were placed 13.1 ft (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 and reflective tape is shown in Figure 8-41.

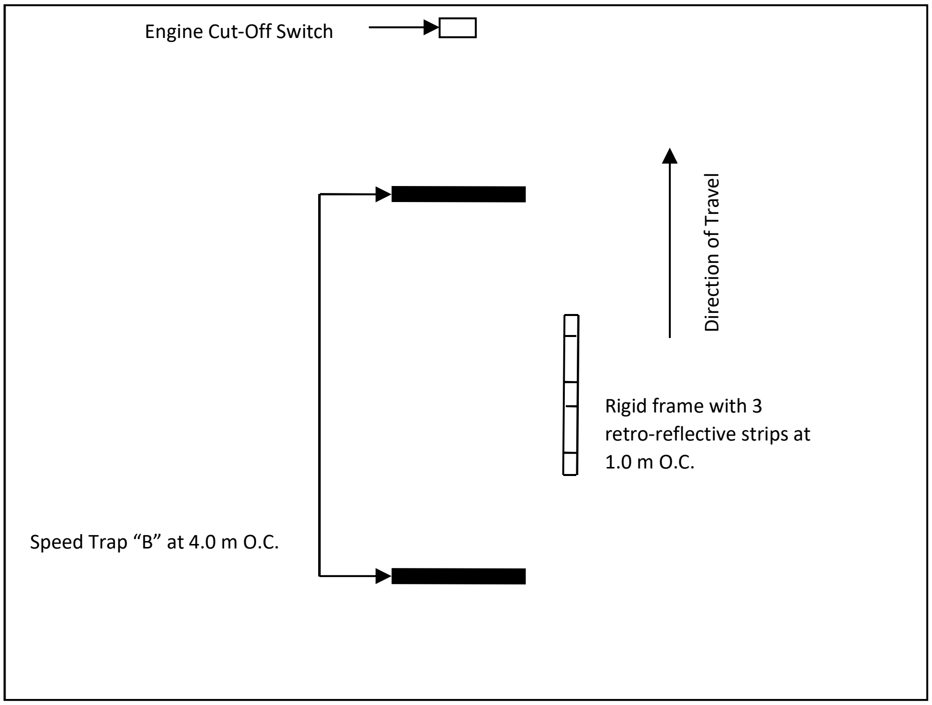
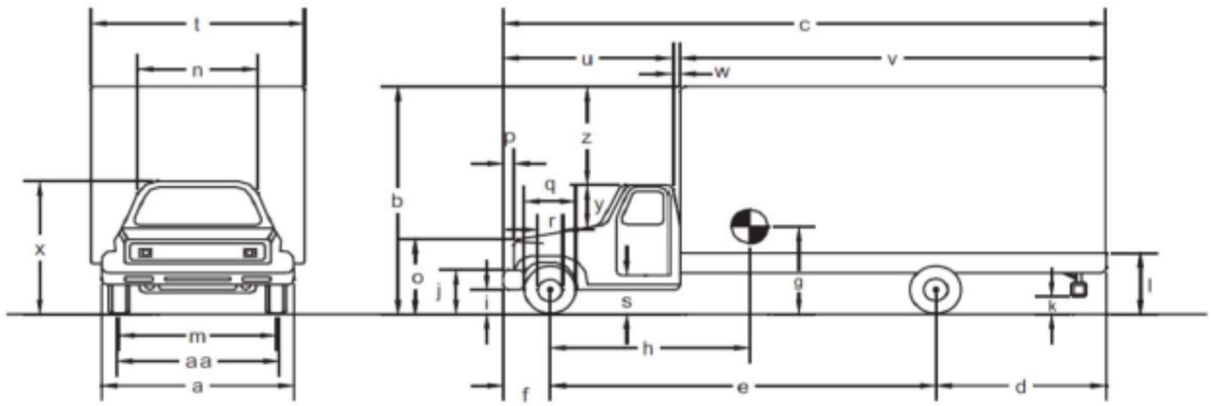


Figure 8-41. Speed Trap Tape Layout

8.3.5. 2005 Freightliner M2 Vehicle Measurements

Table 8-22. Exterior Vehicle Measurement

Date:	6/29/2016	Test Number:	110MASH4S16-03	Model:	Freightliner
Tire Size Front:	11R22.5	Odometer:	196523	Make:	Business Class M2
Tire Size Rear:	11R22.5	VIN:	1FVACWDC35HU87193	Year:	2004
Tire Inflation Pressure:		Tape Measure Used:	#1 & #4	CLE:	DRISI 1502



Vehicle Geometry - mm (inches) Tape Measure Used: #1 & #4

a)	2333	(91.9)	j)	755	(29.7)	s)	870	(34.3)
b)	3818	(150.3)	k)	529	(20.8)	t)	2436	(95.9)
c)	9972	(392.6)	l)	1284	(50.6)	u)	2698	(106.2)
d)	2961	(116.6)	m)	2070	(81.5)	v)	6960	(274)
e)	5966	(234.9)	n)	1800	(70.9)	w)	65	(2.6)
f)	1044	(41.1)	o)	1335	(52.6)	x)	2483	(97.8)
g)		(0)	p)	14	(0.6)	y)	850	(33.5)
h)	3436	(135.3)	q)	1025	(40.4)	z)	1318	(51.9)
i)	390	(15.4)	r)	590	(23.2)	aa)	1844	(72.6)

Weights - kg (lbs)

	Curb		Test Inertial		Gross Static	
$W_{front\ axel}$	2844	(6269.8)	3239	(7140.7)	3239	(7140.7)
$W_{rear\ axel}$	3863	(8516.3)	6689	(14746.5)	6689	(14746.5)
W_{TOTAL}	6707	(14786.2)	9928	(21887.1)	9928	(21887.1)

Wheel Center Height Front:	500	(19.7)
Wheel Center Height Rear:	525	(20.7)
Wheel Well Clearance (FR):	170	(6.7)
Wheel Well Clearance (RR):	170	(6.7)
Engine Type:	C7, Diesel	
Engine Size:	L6, 7.2L	

Ballast: 3142.5 (6927.9) Scale: blue

Transmission Type:
Automatic
RWD

Mass Distribution

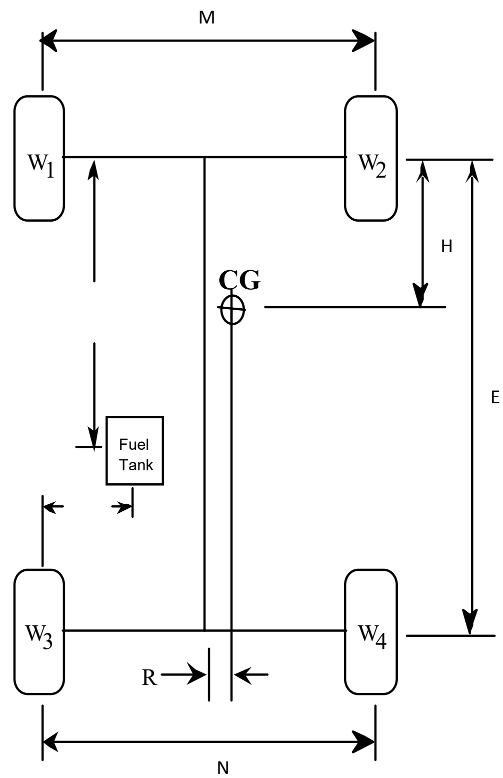
Left Front	1618	(3567)	Scale:	green	Right Front	1621	(3573.6)	Scale:	red
Left Rear	3474	(7658.7)	Scale:	blue	Right Rear	3215	(7087.7)	Scale:	yellow

Note any damage prior to test: Roll-up door has minor damage on low left side. Cargo box has damage on top passenger side corner. Dent on top back or cargo bed.

Table 8-23. 2005 Freightliner M2 CG Calculation: Curb Weight

CG Calculation Worksheet #1: Curb Weight

Make:	Freightliner	Test Number:	110MASH4S16-03
Model:	Business Class M@	Date:	6/29/2016
Year:	2004	Temperature:	85 °F
VIN:	1FVACWDC35HU87193		
Fuel in Tank:	1/4 tank		
Fuel Removed:	none		
Staff:	C Caldwell		
	J Williams		



W1 = Left Front (LF) = 1352 kg
Scale Used: red

W2 = Right Front (RF) = 1492 kg
Scale Used: blue

W3 = Left Rear (LR) = 1962 kg
Scale Used: yellow

W4 = Right Rear (RR) = 1901 kg
Scale Used: green

Total Weight:
Wtotal (measured) = 6707 kg

Wtotal (calculated) = 6707 kg

Distance between front wheels:
M = 2070 mm

Distance between rear wheels:
N = 1844 mm

Distance from front to rear wheels:
E = 5966 mm

Distance from front wheels back to CG:
H = 3436 mm

Distance from vehicle centerline to CG:
R = 13 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

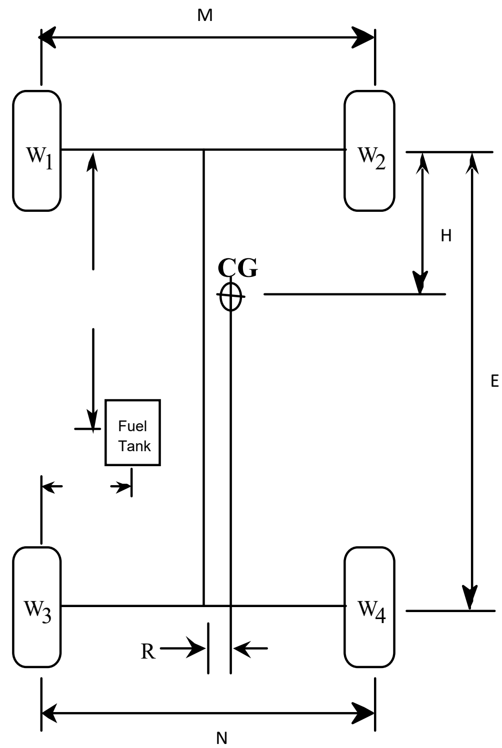
If R is negative the CG is left of center, if R is positive the CG is right of center

Gross Static Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
As purchased, no additions. Used new 40,000 Capacity Roadrunner Scales.

Table 8-24. 2005 Freightliner M2 CG Calculation: Test Inertial Weight (same as Gross Static Weight)

CG Calculation Worksheet #2: Test Inertial Weight

Make:	Freightliner	Test Number:	110MASH4S16-03
Model:	Business Class M2	Date:	8/26/2016
Year:	2004	Temperature:	
VIN:	1FVACWDC35HU87193		
Fuel in Tank:	1/8th of a tank		
Fuel Removed:	none		
Staff:	John W.		
	Chris C.		



W1 = Left Front (LF) = 1618 kg
Scale Used: green

W2 = Right Front (RF) = 1621 kg
Scale Used: red

W3 = Left Rear (LR) = 3474 kg
Scale Used: blue

W4 = Right Rear (RR) = 3215 kg
Scale Used: yellow

Total Weight:
Wtotal (measured) = 9929 kg

Wtotal (calculated) = 9928 kg

Distance between front wheels:
M = 2070 mm

Distance between rear wheels:
N = 1844 mm

Distance from front to rear wheels:
E = 5966 mm

Distance from front wheels back to CG:
H = 4019.6 mm

Distance from vehicle centerline to CG:
R = -23.7 mm

$$W_{Total} = W_1 + W_2 + W_3 + W_4$$

$$H = \frac{(W_3 + W_4)E}{W_{Total}}$$

$$R = \frac{(W_2 - W_1)M + (W_4 - W_3)N}{2W_{Total}}$$

If R is negative the CG is left of center, if R is positive the CG is right of center

Test Inertial Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
All equipment installed and ballast installed.

8.4. Anchor Bolt/Nut Torque Tension Testing

The Division of Engineering Services requested that a 10-kip pre load be established on each anchor bolt that connects the side-mounted post to the deck. It was decided that a *click adjustable* torque wrench would be used to set the torque on each of the anchor bolts. A Skidmore-Wilhelm[1] bolt tension machine (Model: ML, SN: 9682) was utilized to establish the requisite torque associated with a 10-kip load.

Testing was performed with the Skidmore-Wilhelm bolt tension machine clamped to a steel table. An anchor bolt, two disk springs, and two nuts were sampled from side-mount bridge rail hardware and placed in the tension machine as shown in the pictures below. Other than the blue coating, no additional lubrication was used during the torqueing. The adjustment dial on the torque wrench was increased until the applied torque corresponded with a 10,000 lb reading on the Skidmore Wilhelm gage. The corresponding torque required to reach the 10,000 lb load was 158 ft-lbs. Both the procedure and the results were repeated using a second nut.

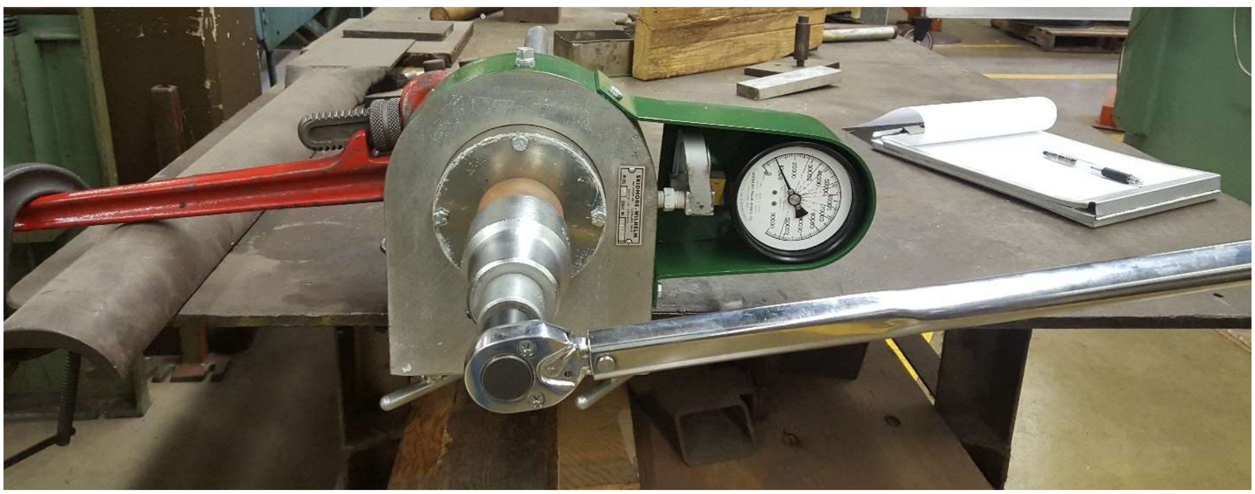


Figure 8-42. Skidmore-Wilhelm Bolt Tension Machine

[1]The Skidmore-Wilhelm bolt tension machine was verified in the Caltrans Structural Materials Lab using a Calibrated Instron 67kip Universal Tensile/Compression test machine.

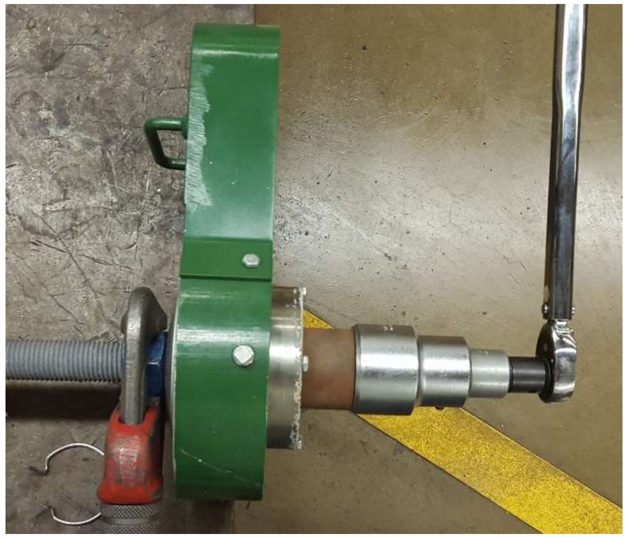


Figure 8-43. Top View

Figure 8-44. Disc Spring View

The Skidmore-Wilhelm bolt tension machine was verified in the Caltrans Structural Materials Lab using a Calibrated Instron 67kip Universal Tensile/Compression test machine. Compression in the Instron machine was brought to three levels (5k, 10k, 15k) and reading was verified in the tension machine dial.

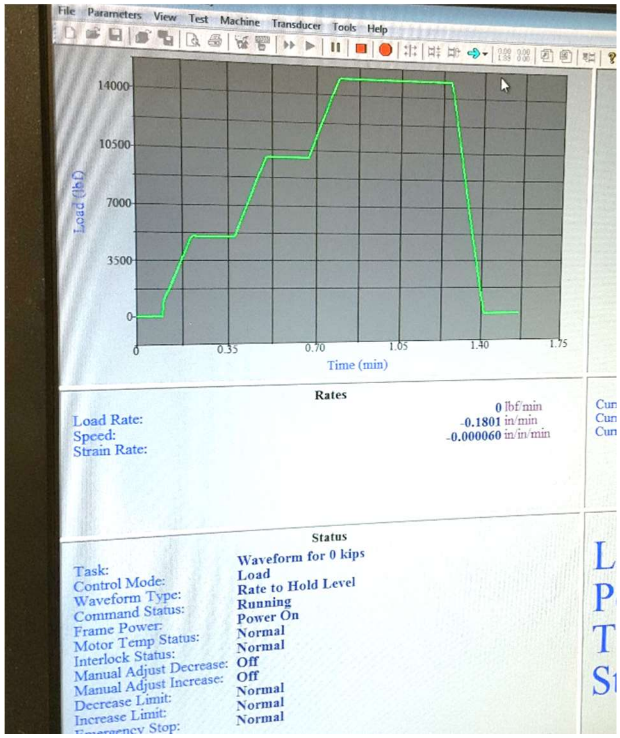


Figure 8-45. Verification of Skidmore-Wilhelm Bolt Tension Machine

Figure 8-46. Skidmore-Wilhelm Verification

8.5. Disc Springs

Table 8-25. Disc Spring Design Information

ROLEX SPRING
ENGINEERING DESIGN ANALYSIS

Conical Disc Spring Design
Predicted Load and Stress by Deflection
Engineering Load Design Analysis

Customer Name	CALIFORNIA DOT		
Cust. Part No.	BRIDGE RAIL SPRING		
Contact Name	DAVID WHITESEL		
Customer Phone	Ext.		
Customer Fax			
Supplier Part No.			
Prepared by	Ext.		
Material Type	6150 Spring Steel		
Load Type	Pounds		
Parts in Series	1	in Parallel	1
Total # of parts	1	Appl. Type	Dynamic
	INCH		MM
Outside Dia.	4.984		126.6
Inside Dia.	1.507		38.3
Thickness	0.2490		6.32
Overall Height	0.6250		15.88
Bearing Flat OD	0.000		0.00
Bearing Flat ID	0.000		0.00
Radius	0.042		1.07
Pc. weight lbs.	1.2535	Newtons	5.562
OD @ Flat	4.980		124.43
ID @ Flat	1.510		36.12

^ Theoretical Calculations ^

Date 14-Jan-15

Deflection in inches	Height in inches	Load in pounds	Stresses S1 Comp. psi		S2 Tension psi		S3 Tension psi	
0.0000	**0.6250**	**0.0**	**0**		**0**		**0**	
0.0191	0.6059	6880.1	141,615		13,185		54,140	
0.0382	0.5868	13034.2	279,262		22,400		106,500	
0.0573	0.5677	18500.6	412,938		27,646		157,079	
0.0765	0.5485	23317.4	542,646		28,923		205,877	Y
0.0956	**0.5294**	**27523.0**	**668,385**		**26,231**		**252,895**	M
0.1147	0.5103	31155.4	790,154		19,569		298,132	M
0.1338	0.4912	34252.9	907,954		8,939		341,588	M
0.1529	0.4721	36853.8	1,021,785	C	5,661		383,263	M
0.1720	0.4530	38996.1	1,131,646	C	24,231		423,158	M
0.1911	**0.4339**	**40718.2**	**1,237,538**	C	**46,769**		**461,272**	M
0.2102	0.4148	42058.2	1,339,461	C	73,277		497,605	M
0.2294	0.3956	43054.3	1,437,415	C	103,754		532,158	M
0.2485	0.3765	43744.8	1,531,400	C	138,200		564,930	M
0.2676	0.3574	44167.8	1,621,415	C	176,615		595,921	M
0.2867	**0.3383**	**44361.6**	**1,707,461**	C	**219,000**	Y	**625,132**	M
0.3058	0.3192	44364.4	1,789,538	C	265,354	M	652,561	M
0.3249	0.3001	44214.3	1,867,646	C	315,677	M	678,210	M
0.3440	0.2810	43949.6	1,941,784	C	369,969	M	702,079	M
0.3632	0.2618	43608.4	2,011,954	C	428,230	M	724,167	M
0.3823	**0.2427**	**43229.1**	**2,078,154**	C	**490,461**	M	**744,474**	M

Max stress yield is identified "M", Design Max with "Y" Compression yield with "C".

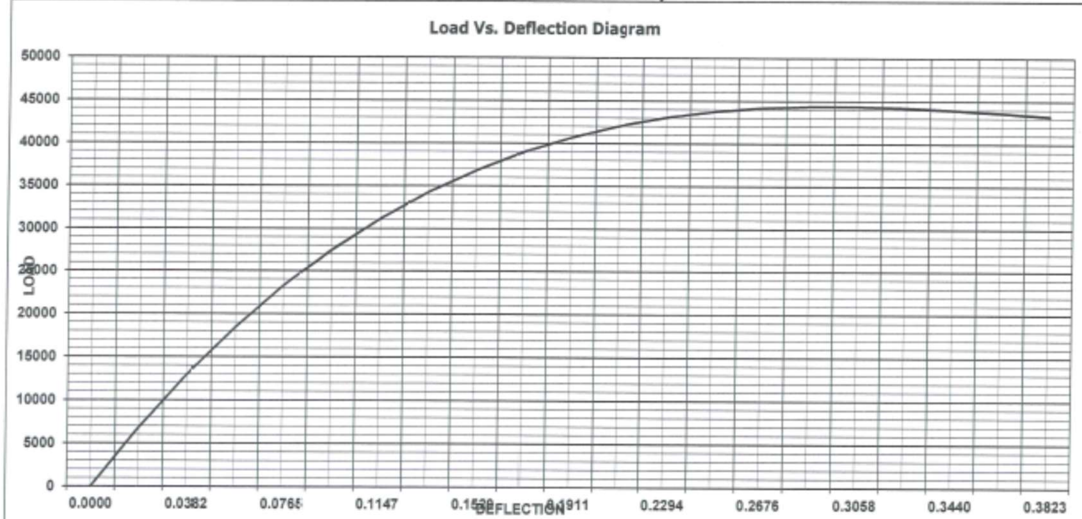
Spring Rate	113,086 lbs / inch	Poisson	0.30	Yields Maximum	230000 (M)	h	0.376
		E Modulus	29,700,000	Design Margin	200000 (Y)	h/t	1.510

Using	Target	Load	S1 Comp.	S2 Tension	S3 Tension
Deflection					

© Quality Issues 11/01 b.j.p. 10/1/07 p.d.

Load is in Pounds < > Deflection is in Inches

* * * * * * * * * * * * * * * * Internal Use Only * * * * * * * * * * * * * * * *



Engineering Load Design Analysis

8.6. Finite Element Modeling

8.6.1. Objective

The purpose of this document is to record the RSRG Lab's experience with finite element modeling and analysis. Finite element (FE) analysis was performed using Livermore Software Technology Corporation's (LSTC) LS-Dyna, which is a commercial finite element program commonly used for crashworthiness analysis. The purpose of the modeling was to build finite element models that would represent their real world counterparts.

8.6.2. Barrier Models

A number of models were developed to represent different elements of the Side Mounted Bridge Rail research project. All the models were processed with LS-Dyna. All of the models were designed to simulate American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware (MASH)* required testing of longitudinal barriers to Test Level 4. The CA ST-70SM Side Mount Bridge Rail is 42 inches (1.07 m) high and consists of four steel beams. The top and bottom rails are 8 inch (203 mm) by 3 inch (76 mm) steel tubes and the middle two rails are 8 inch (203 mm) by 4 inch (102 mm) steel tubes. Each post is mounted to the side of a bridge deck with five anchor bolts. On each of the anchor bolts are two disc springs that reduce the effective stiffness of the post, allowing the rails to distribute more of the load to adjacent posts and lessening damage to the bridge deck during an impact. An oversight was made in the model regarding the application of a 10,000 lb_f (44,500 N) preload to all of the anchor bolts. This preload was applied to the actual test article by torqueing all the bolts to 158 ft-lbs (214 N-m). The barrier models did not have this preload applied to the bolts.

8.6.2.1. Disc Springs

In order to understand the affects that the two disc springs per bolt have on the bridge rail system, four spring models where built. All models had the springs between two plates. The bottom plate was constrained so that there was no translation or rotation in any direction. The top plate was allowed to move in the z-direction only, to apply a load to the springs. Two of the models consisted of a single spring and two of the models consisted of two springs stacked on top of each other, see Figure 8-47 and Figure 8-48. The single spring models had a load that started at zero and was ramped up 5,000 lbs/sec (2,270 kg/sec) until a maximum load of 50,000 lbf (222,400 N) was reached. The stacked springs models had a load that started at zero and was ramped up 10,000 lbs/sec (4,540 kg/sec) until a maximum load of 100,000 lbf (444,800 N) was reached. All of the material properties of the spring model where based on the properties on AISI 6150 spring steel. AISI 6150 spring steel has a yield strength around 105 ksi (720 MPa). One single spring model and one stacked spring model have material definitions that include the 105 ksi (720 MPa) yield strength. The other single spring model and stacked spring model have material definition that match the yield strength that was given in the Rolex Spring's Conical Disc Spring Design Analysis. The yield strength provided by Rolex Spring was 200 ksi (1,380 MPa).

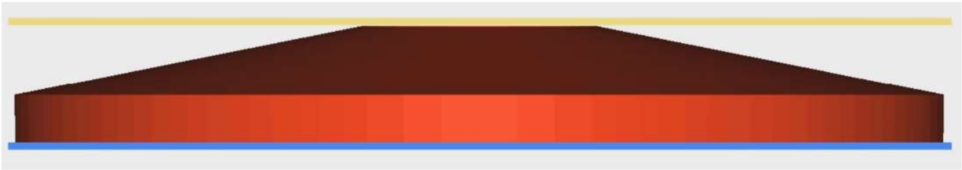


Figure 8-47. Single Disc Spring Model

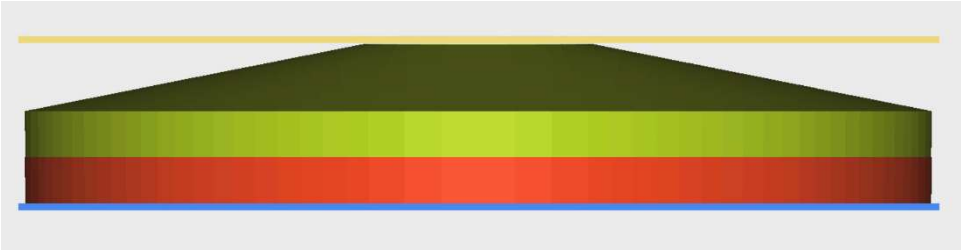


Figure 8-48. Double Disc Spring Model

8.6.2.2. SMBR Shell Model with Springs

Only the anchor bolts, anchor bolt washers, and disc springs were solid elements in the CA ST-70SM Shell Model with Springs.

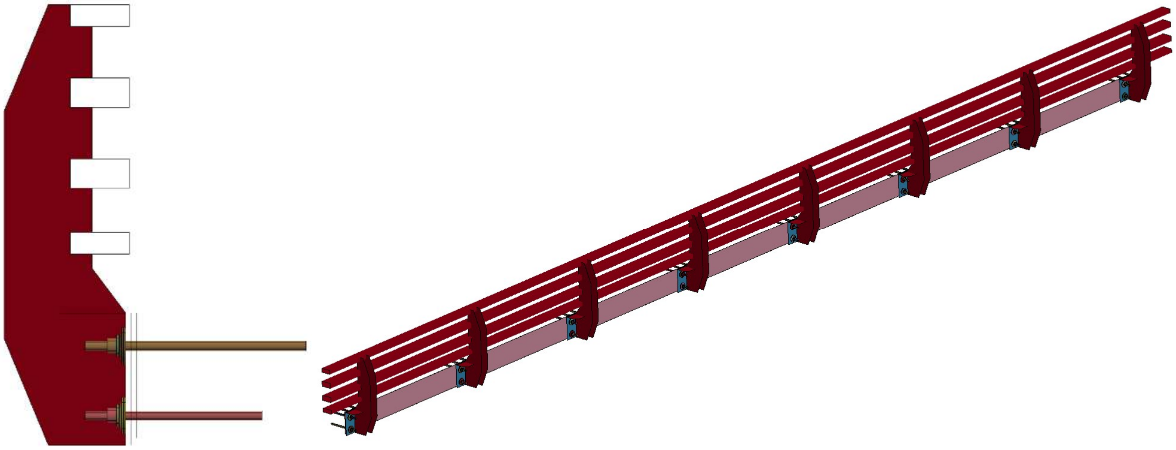


Figure 8-49. SMBR Shell Model With Springs

8.6.2.3. SMBR Solid Model with Springs

All elements in the CA ST-70SM Solid Model with Springs simulation are solid elements.

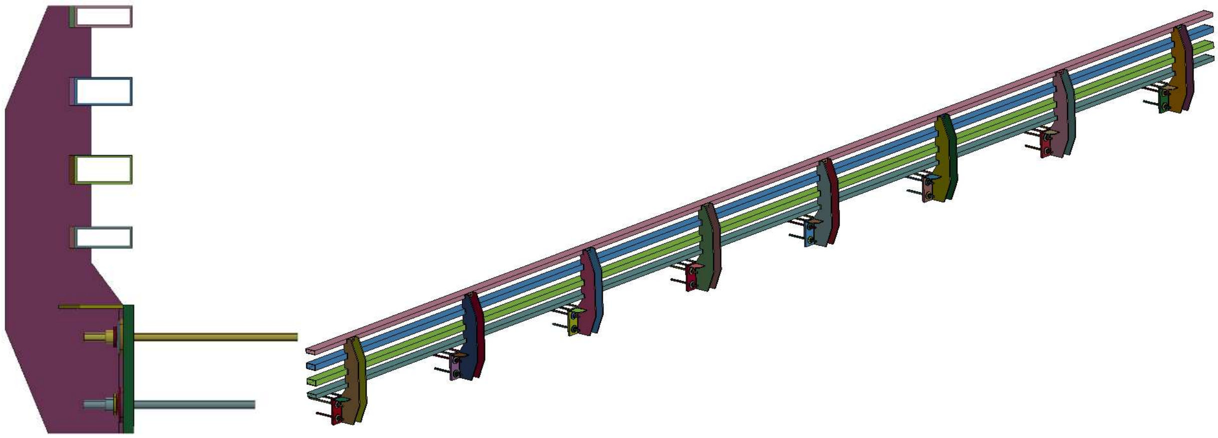


Figure 8-50. SMBR Solid Model With Springs

8.6.2.4. CA ST-70SM Solid Model without Springs

The CA ST-70SM Solid Model without Springs is the same as the CA ST-70SM Solid Model with Springs model except that the disc springs have been removed. There was a possibility that the CA ST-70SM Side Mount Bridge Rail system would be tested without the disc springs on the anchor bolts. It was ultimately decided that this testing was not needed. Although testing was not conducted on the CA ST-70SM without springs, simulations of this testing were performed and the results are included in the summaries below.

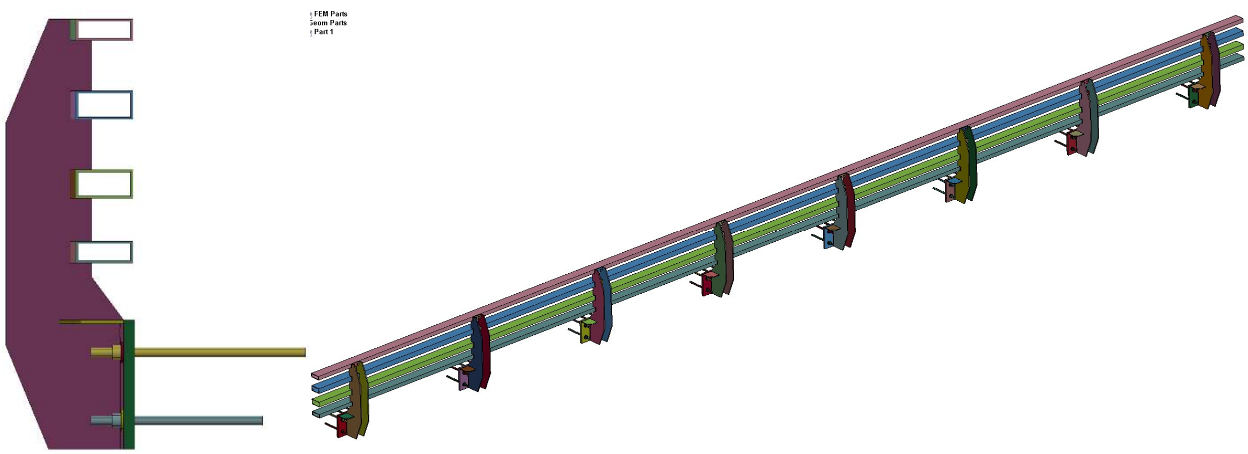


Figure 8-51. SMBR Solid Model Without Springs

8.6.3. Vehicle Models

All vehicle models were provide by the National Crash Analysis Center's (NCAC) Finite Element Model Archive webpage, http://www.ncac.gwu.edu/vml/models.html. This section will list which models were used and how they were modified.

8.6.3.1. 2270P Truck

The truck model used for any MASH 2270P truck test simulations was the 2270-kg 2007 Chevy Silverado version 2 that was posted February 27, 2009. The only change to the vehicle model was to increase the velocity of the vehicle model to match the required speed for a MASH Test Level 4 longitudinal barrier test. For this test the 2270P truck will impact the barrier at a speed of 62.2 mph (100 km/h) at an angle of 25 degrees.

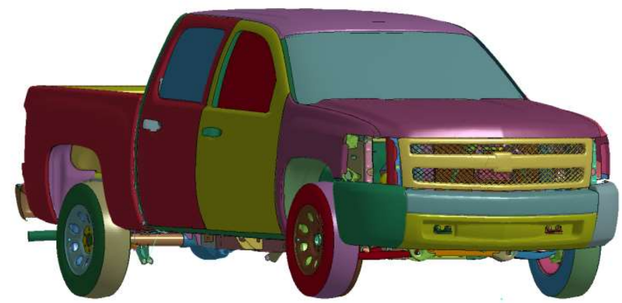


Figure 8-52. 2270P Truck

8.6.3.2. 1100C Car

The car model used for any MASH 1100C car test simulations was the 1100-kg 2010 Toyota Yaris that was posted November 17, 2014. The only change to the vehicle model was to increase the velocity of the vehicle model to match the required speed for a MASH Test Level 4 test. For this test the 1100C car will impact the barrier at a speed of 62.2 mph (100 km/h) at an angle of 25 degrees.

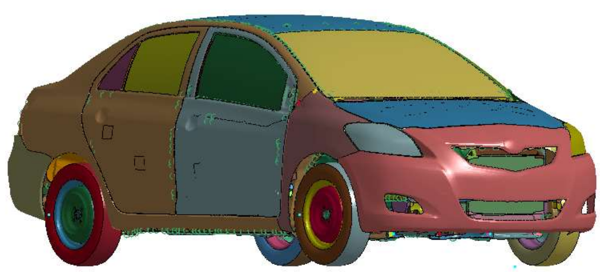


Figure 8-53. 1100C Car

8.6.3.3. 10000S Single-Unit Van Truck

The single-unit van truck model used for any MASH 10000S single-unit van truck test simulations was the Ford Single Unit Truck that was posted November 3, 2008. This model is of a 1996 Ford 18,000 lbs (8,150 kg) van body truck which was designed to meet the properties of the NCHRP Report 350 8000S single-unit van truck. The NCAC website did not have a MASH 10000S model when this report was written. Therefore, the Ford Single Unit Truck was modified in the following ways. The shape of the ballast in the bed of the truck was changed so that the ballast's center of gravity was 63 inches (1,600 mm) above the ground. The density of the ballast was increased so that the total mass of the truck was 22,050 lbs (10,000 kg). The wheelbase and overall length of the truck were not changed. Therefore, the wheelbase is short 29.5 inches (750 mm) and the overall length is short 51.2 inches (1,300 mm) of the properties given in MASH for a 10000S truck. The velocity of vehicle model was increased to match the required speed for a

MASH Test Level 4 test. For this test the 10000S truck will impact the barrier at a speed of 56 mph (90 km/h) at an angle of 15 degrees.

Figure 8-54. 10000S Single-Unit Van Truck

8.6.4.Comparing Modeling Data to Real World Data

8.6.4.1. Disc Springs

On February 11, 2015 a test of the disc springs for the CA ST-70SM Side Mounted Bridge Rail project was conducted. The purpose of the testing was to compare the displacement versus load curves for a single disc spring and for a stack of two disc springs with the displacement versus load curve provided by the manufacturer, Rolex Spring. Since these results were available the results of the simulations were included in the overall analysis of the disc springs.

Figure 8-55. Spring Testing Setup

Figure 8-57 shows the load versus displacement curves for the single disc springs tests, simulations, and the data provided by Rolex Spring. Test 1 and Test 2 are the results of testing two springs independently.

Each spring was placed in a materials testing machine that applied a load and measured the deflection. The machine applied the load in 2,000 lbf (8,900 N) increments until it reached 30,000 lbf (133,500 N). After 30,000 lbf (133500 N) the applied load was increased to 5,000 lbf (22,200 N) increments. Both tested springs have similar curves, deflected about 0.16 inches (4 mm) before flattening, and had a maximum load between 28,000 lbf (124,600 N) and 30,000 lbf (133,500 N). Test 1 and Test 2 springs had about 67% of the maximum load provided by the Rolex Spring design data. Both of the simulation models had similar curves to the Rolex Spring design data but reached their maximums at lower loads. For the single spring simulation where the spring material had the yield strength defined as 105 ksi (720 MPa) the spring reached its maximum load around 29,000 lbf (129,000 N) and deflection of about 0.10 inches (3 mm) before flattening. The 105 ksi (720 MPa) single spring simulation had about 67% the maximum load of the Rolex Spring design data. The single spring simulation with the yield strength of 200 ksi (1,380 MPa) reached its maximum load around 35,000 lbf (155,700 N) and deflection of about 0.15 inches (4 mm) before flattening. The 200 ksi (1,380 MPa) single spring simulation had about 78% the maximum load of the Rolex Spring design data.

Figure 8-56. Springs for Test 1 and Test 2

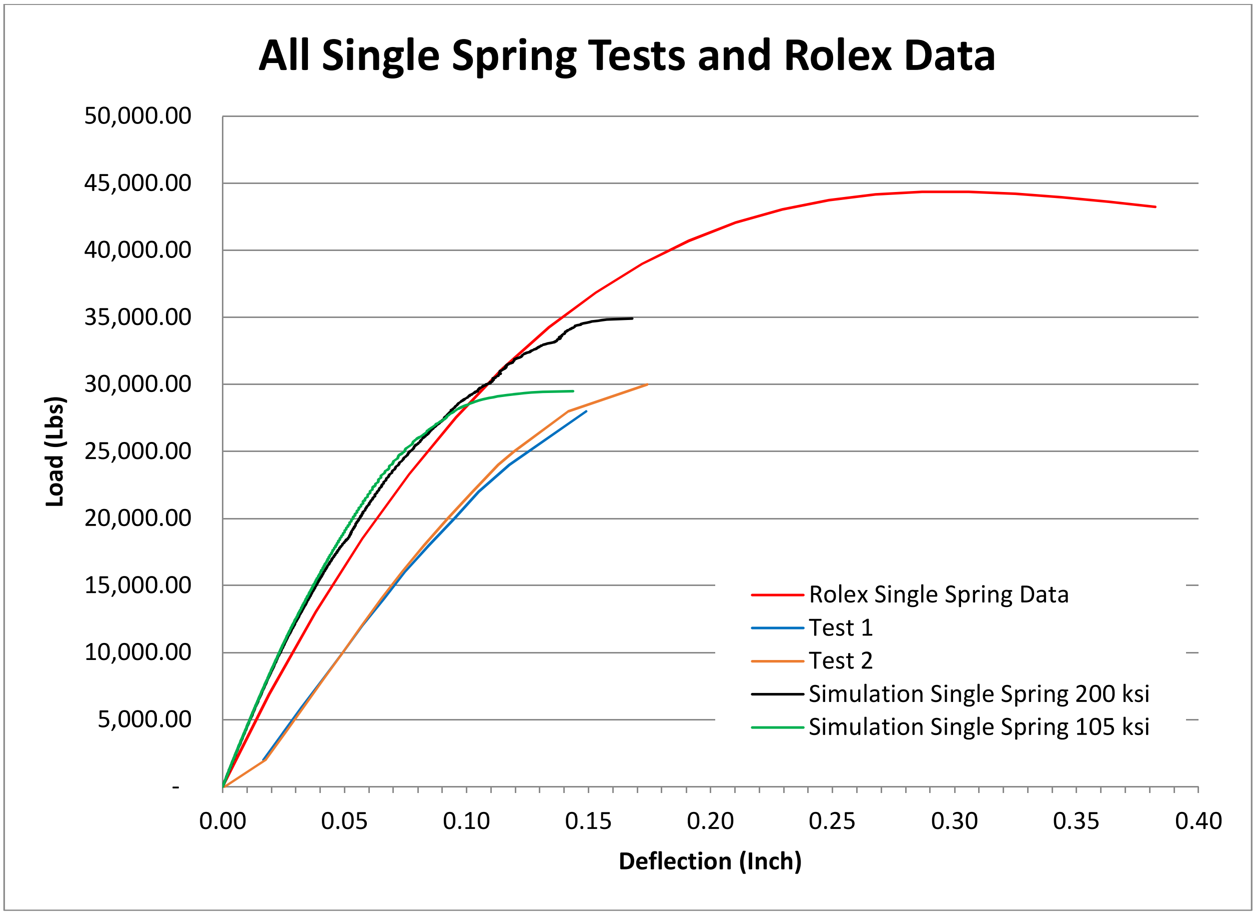


Figure 8-57. Graph of All Single Disc Spring Tests and Models

Figure 8-59 shows the load versus displacement curves for the double disc springs test, simulations, and modified Rolex Spring design data. The Rolex Spring design data was modified by doubling the load over the same deflection to represent two disc springs stacked on top of each other. Test 3 is the result of testing two springs stacked on top of each other. The two springs were placed in a materials testing machine that applied a load and measured the deflection. The machine applied the load in 2,000 lbf (8,900 N) increments until it reached 30,000 lbf (133,500 N). After 30,000 lbf (133,500 N) the applied load was increased to 5,000 lbf (22,200 N) increments. Test 3 deflected about 0.23 inches (6 mm) before flattening, and had a maximum load around 60,000 lbf (267,000 N). Test 3 had about 69% of the maximum load provided by the modified Rolex Spring design data. The double spring simulation with the yield strength of 105 ksi (720 MPa) reached its maximum load around 42,000 lbf (187,000 N) and deflection of about 0.13 inches (3 mm) before flattening. The 105 ksi (720 MPa) single spring simulation had about 48% the maximum load of the modified Rolex Spring design data. The double spring simulation with the yield strength of 200 ksi (1,380 MPa) reached its maximum load around 52,000 lbf (231,300 N) and deflection of about 0.17 inches (4 mm) before flattening. The 200 ksi (1,380 MPa) single spring simulation had about 60% the maximum load of the modified Rolex Spring design data.

Figure 8-58. Spring for Test 3

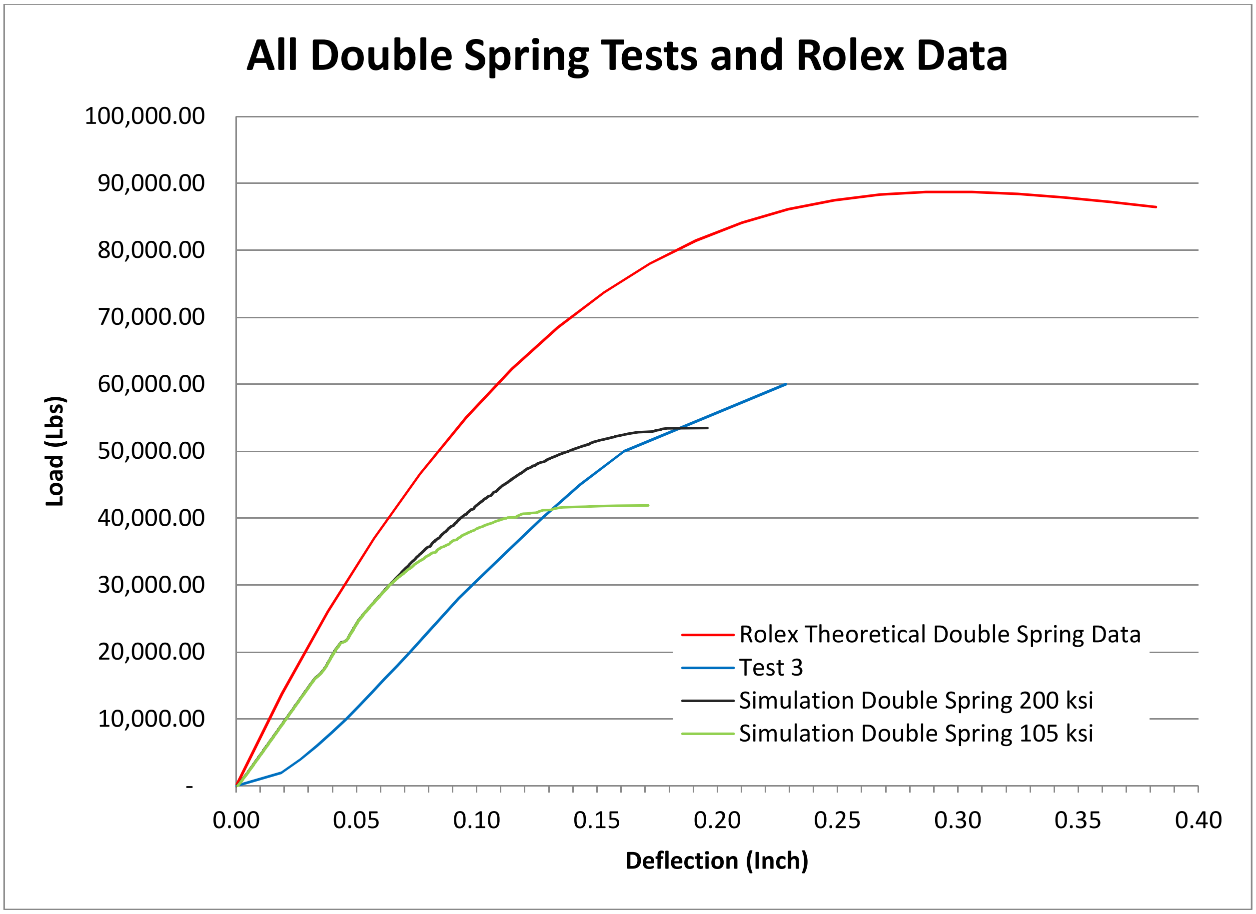


Figure 8-59. Graph of All Double Disc Spring Tests and Models

8.6.4.2. 2270P Truck

This section compares the FE modeling to the full scale crash testing of the CA ST-70SM Side Mounted Bridge Rail and a 2270P truck. Section 8.6.4.2.1 compares the movement of the test article between the FE models and the full scale test. Section 8.6.4.2.2 compares the analyzed data from the FE models and the full scale test. Section 8.6.4.2.3 is a visual comparison of the FE modeling and the full scale test. Table 8-26 shows the differences between the vehicle used in testing and the vehicle model used in the finite element modeling.

Table 8-26. Center of Gravity for 2270P Truck Test Vehicle and LS-Dyna Finite Element Model

	Vehicle Type	X*	Y**	Z	Mass	Wheel Base
Test 110MASH3P15-01	2007 Dodge Ram 1500	60.7 inches (1541 mm)	0.0 inches (1 mm)	28.0 inches (712 mm)	5028 lbs (2281 kg)	140.6 inches (3572 mm)
2270P Vehicle Models	2007 Chevrolet Silverado	65.7 inches (1670 mm)	-0.4 inches (-11 mm)	28.6 inches (726 mm)	5004 lbs (2270 kg)	144.1 inches (3660 mm)

* Behind centerline of front tire
** Negative means CG is on the driver side of the vehicle's centerline

8.6.4.2.1. Test Article Movement

When comparing the full scale test to the two FE models of the Bridge Rail with springs, only the solid model of the barrier has similar test article movement. Movement in the full scale test article was measured by string potentiometers. The top rail had a dynamic deflection of 1.62 inches (41 mm) and a static displacement of 0.18 inches (5 mm). The top of the test article in the Shell Model with Springs simulation had a dynamic deflection of 0.5 inches (13 mm) and a static deflection of 0.04 inches (1 mm). The barrier in the shell model's reaction was very stiff, even stiffer than the test article in the Solid Model without Springs Truck model.

The top of the test article in the Solid Model with Springs simulation had a dynamic displacement of 2.3 inches (59 mm) and the static displacement was not measured because the test article was still moving when the simulation was stopped.

Although the CA ST-70SM SMBR system without the disc springs was not tested, the results of the FE model without the springs is included in Table 8-27. The top of the barrier in the Solid Model without Springs Truck simulation had a dynamic displacement of 0.63 inches (16 mm) and a static displacement of 0.08 inches (2 mm). These results appear reasonable since the system is more rigid without the disc springs on the anchor bolts.

Table 8-27. Test Article Movement Comparison Full Scale and FE Model Results for 2270P with Disc Springs

Maximum Test Article Movement	Test 110MASH3P15-01	Shell Model with Springs Truck	Solid Model with Springs Truck	Solid Model without Springs Truck
Top Rail Dynamic Deflection	1.62 inches (41 mm)	0.5 inches (12 mm)	2.3 inches (59 mm)	0.63 inches (16 mm)
Top Rail Static Displacement	0.18 inches (5 mm)	0.04 inches (1 mm)	Barrier Still Moving When Simulation was Stopped	0.16 inches (4 mm)

8.6.4.2.2. TRAP Data Comparison

The accelerometer and angular rate sensor data gathered during the full scale test and the FE modeling were processed with Test Risk Assessment Program (TRAP) and an SAE class 180 filter. See Table 8-28 for all of the TRAP results including the results of the Solid Model without Springs Truck simulation.

When Test 110MASH3P15-01 is compared to the results of the Shell Model with Springs Truck simulation the majority of the test data differs from the simulation. The TRAP results for the simulation tend to be higher than the test results. While the crash test was within the MASH evaluation criteria the simulation would have been considered a failure due to the Lateral Ridedown Acceleration being 25.7 G which is higher than the maximum of 20.49 G allowed in MASH.

When comparing the results of Test 110MASH3P15-01 to the Solid Model with Springs Truck simulation the majority of the test data differs slightly from the simulation data. The simulation TRAP results still tend to be higher than the test results but of the data is within the evaluation criteria provided by MASH.

Although the CA ST-70SM Side Mounted Bridge Rail system was not tested without the disc springs on the anchor bolts, the CA ST-70SM SMBR simulation Solid Model without Springs Truck can still be compared to Test 110MASH3P15-01. Most of the results are similar but the longitudinal and lateral accelerations were much higher in the simulation. The Lateral Ridedown Acceleration was 21.7 G which is higher than the maximum allowed in MASH and would be considered a failure. However the simulation results are high compared to testing.

Table 8-28. TRAP Results Data Comparison for Full Scale and FE Models for 2270P Truck (Absolute Values)

Data Results	MASH Criteria	Test 110MASH3P15-01	Shell Model with Springs Truck	Solid Model with Springs Truck	Solid Model without Springs Truck
Longitudinal Occupant Impact Velocity	Preferred = 9.1 m/s Max = 12.2 m/s	4.1 m/s	2.6m/s	3.5 m/s	3.5 m/s
Longitudinal Ridedown Acceleration 10 msec Average	Preferred = 15.0 G Max = 20.49 G	2.6 G	9.3 G	4.5 G	10 G
Lateral Occupant Impact Velocity	Preferred = 9.1 m/s Max = 12.2 m/s	8.2 m/s	8.9 m/s	8.6 m/s	6.3 m/s
Lateral Ridedown Acceleration 10 msec Average	Preferred = 15.0 G Max = 20.49 G	16.9 G	25.7 G	19.7 G	21.7 G
PHD	n/a	16.9 G	25.9 G	19.8 G	21.7 G
ASI	n/a	1.88	2.05	1.9	1.89
Max Roll	<75 Degrees	6.8 degrees	19.7 degrees	20.5 degrees	17.1 degrees
Max Pitch	<75 Degrees	2.3 degrees	4.9 degrees	4.4 degrees	5.7 degrees
Max Yaw	n/a	38.3 degrees	38.7 degrees	35.0 degrees	42.7 degrees

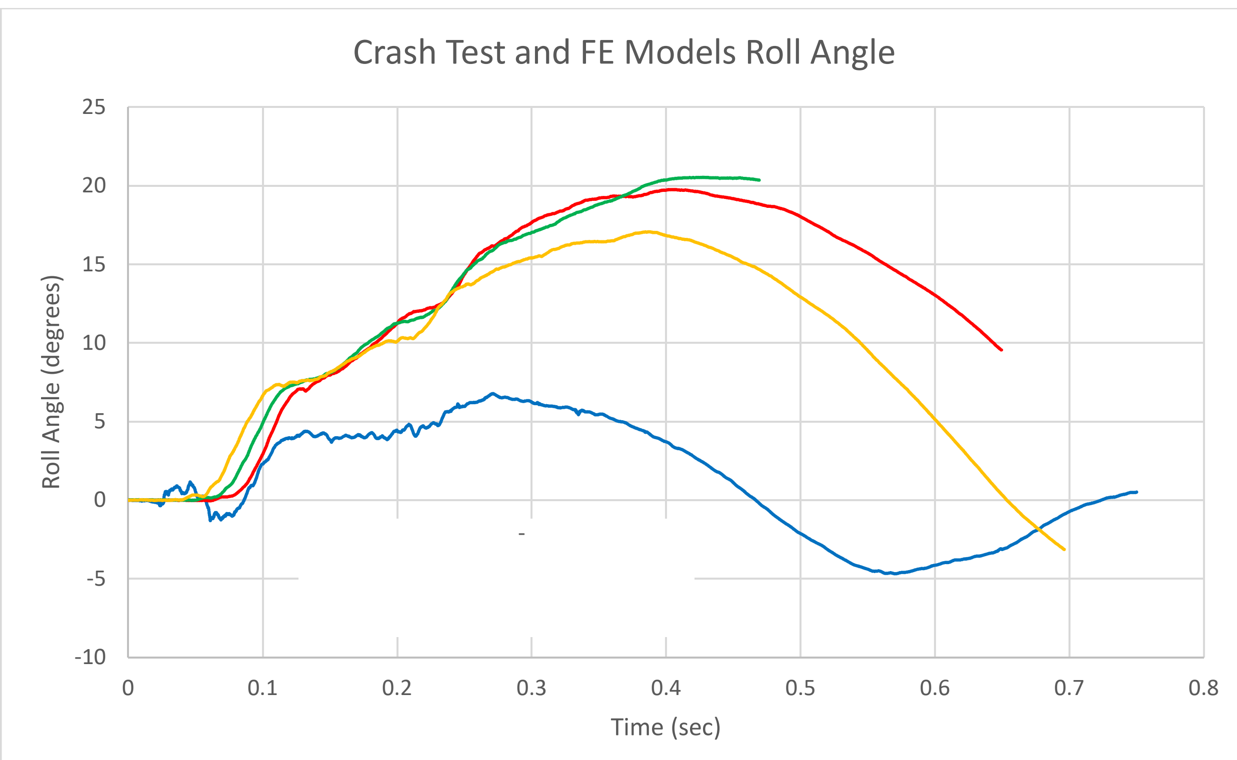


Figure 8-60. Graph of Roll Angles for Full Scale and FE Model TRAP Results for 2270P Truck

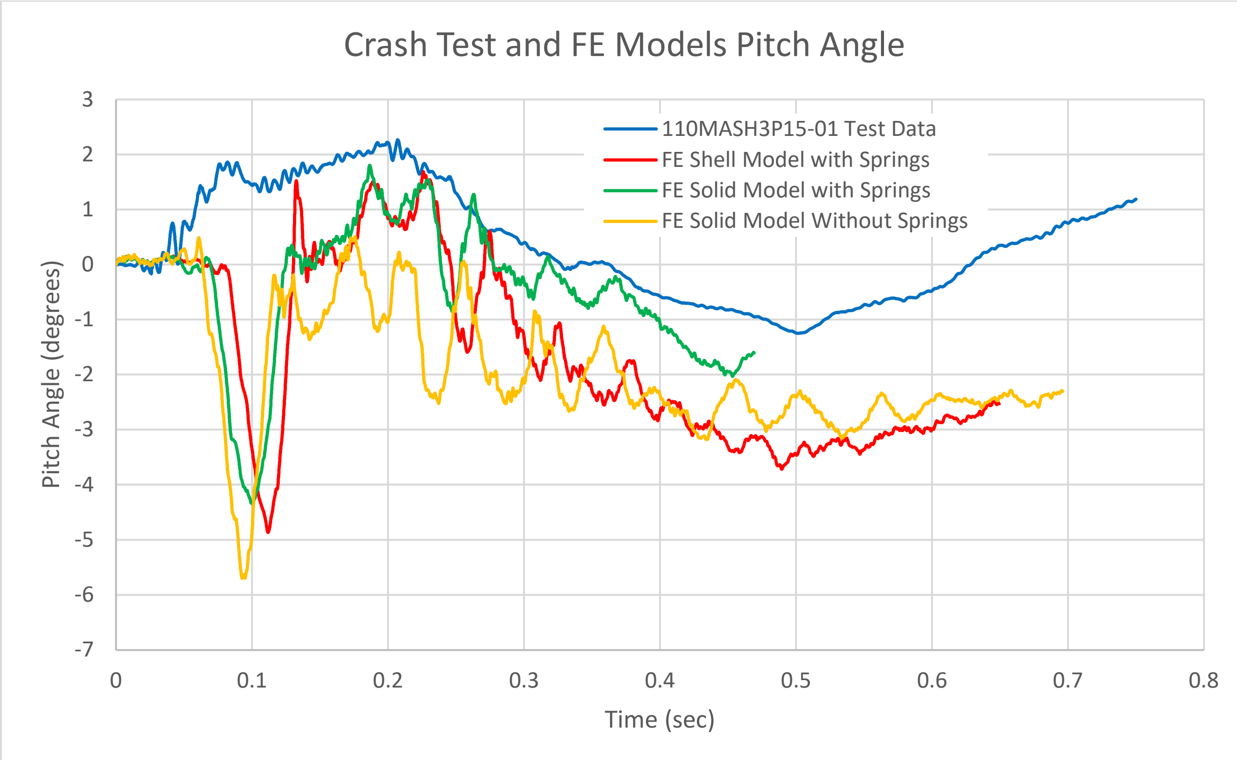


Figure 8-61. Graph of Pitch Angles for Full Scale and FE Model TRAP Results for 2270P Truck

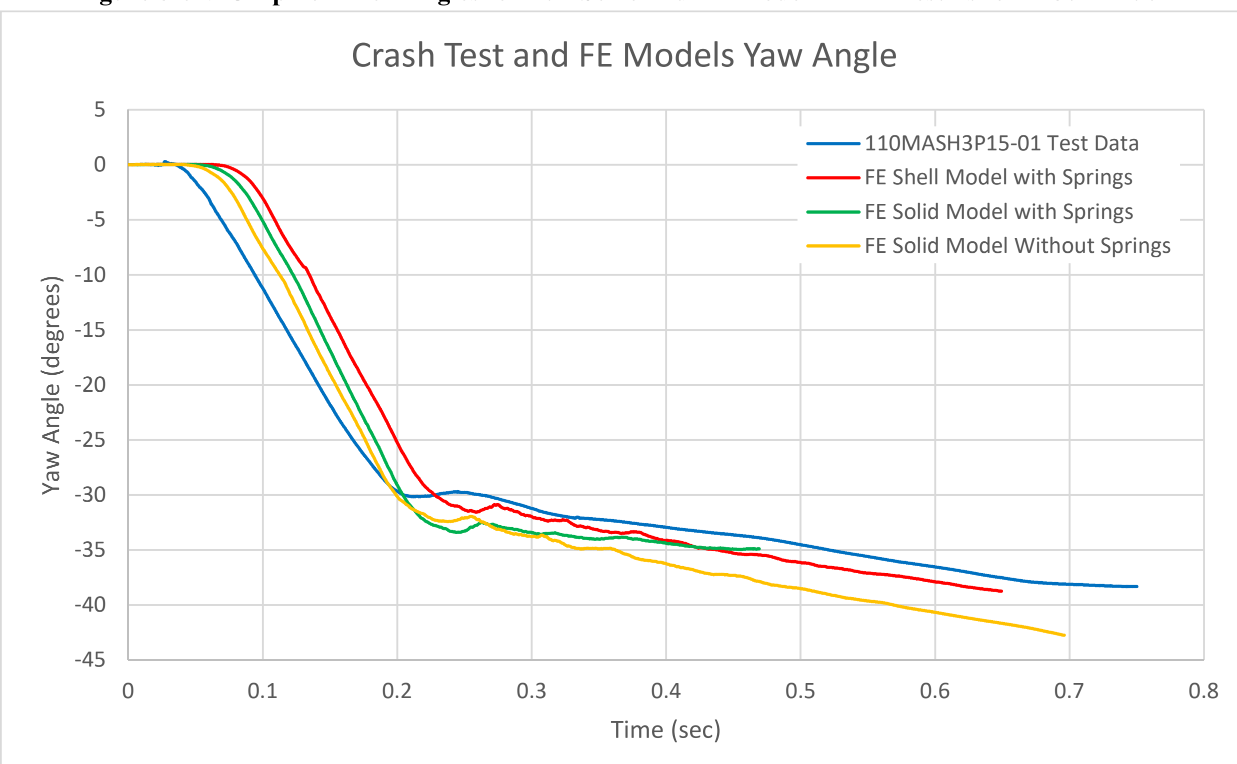


Figure 8-62. Graph of Yaw Angles for Full Scale and FE Model TRAP Results for 2270P Truck

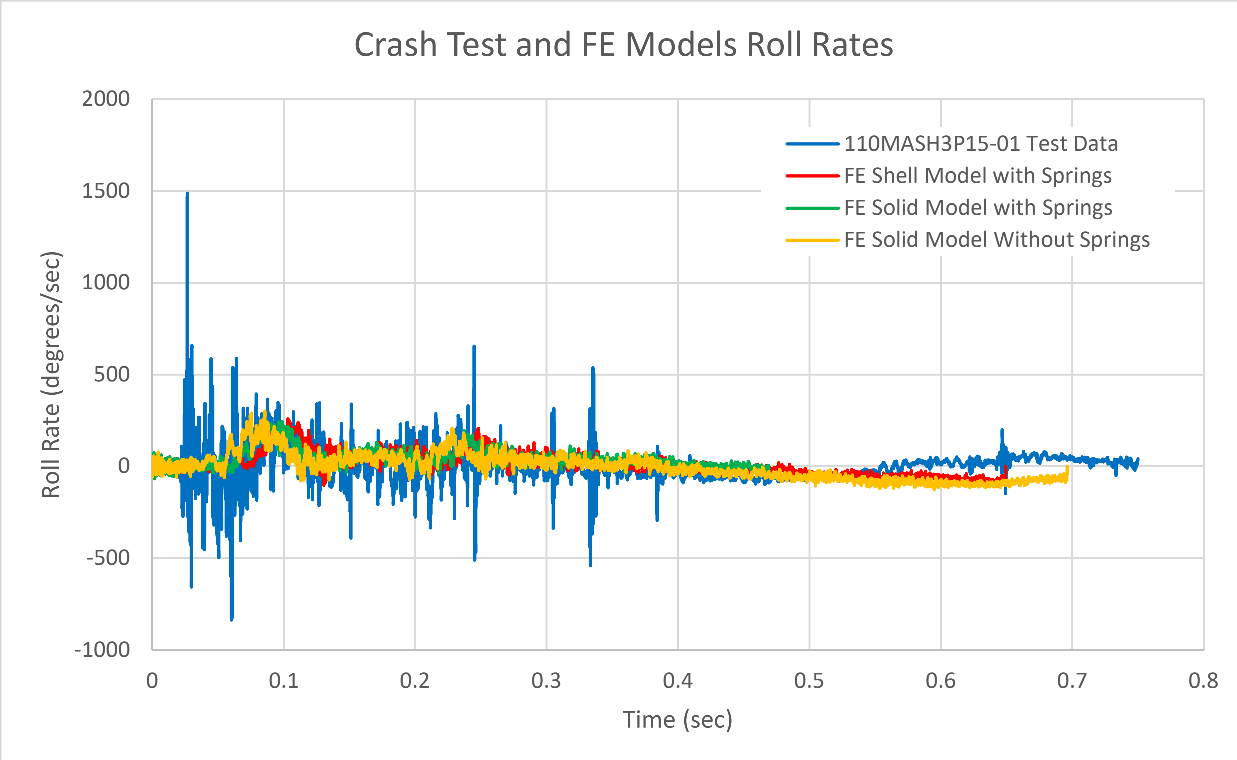


Figure 8-63. Graph of Roll Rates for Full Scale and FE Model TRAP Results for 2270P Truck

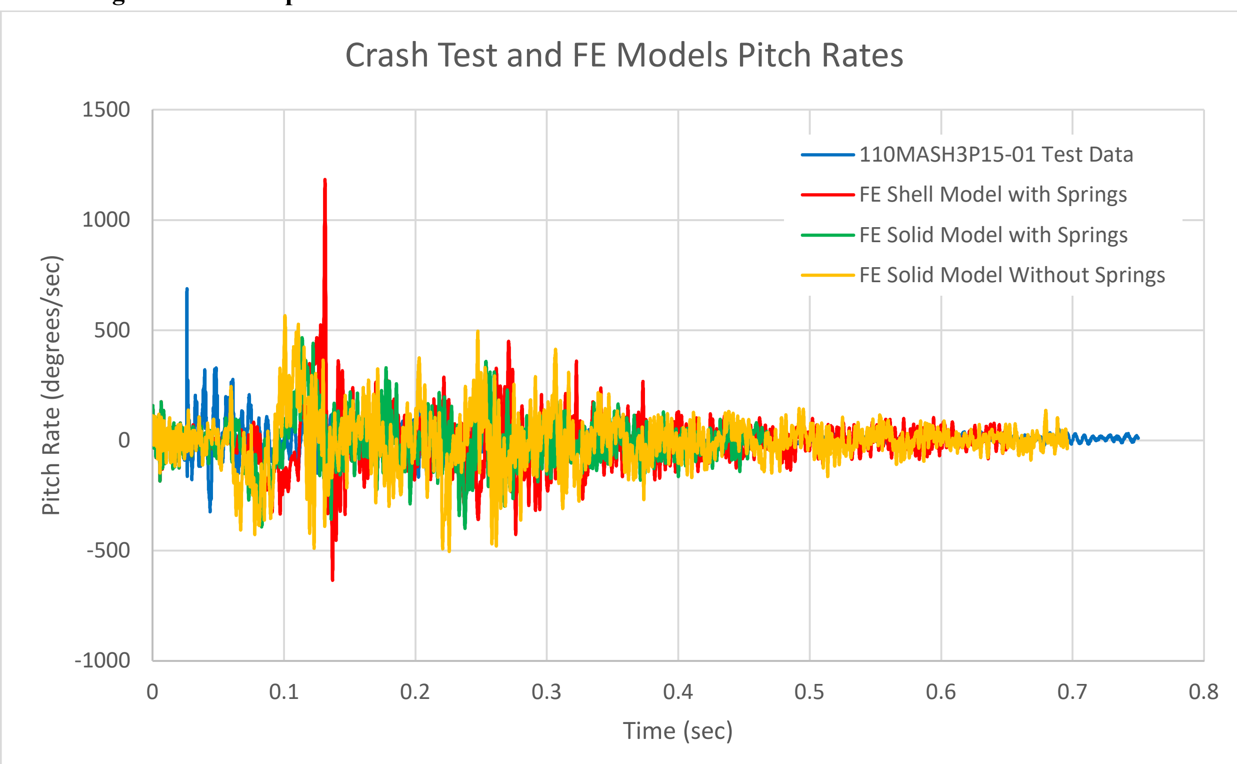


Figure 8-64. Graph of Pitch Rates for Full Scale and FE Model TRAP Results for 2270P Truck

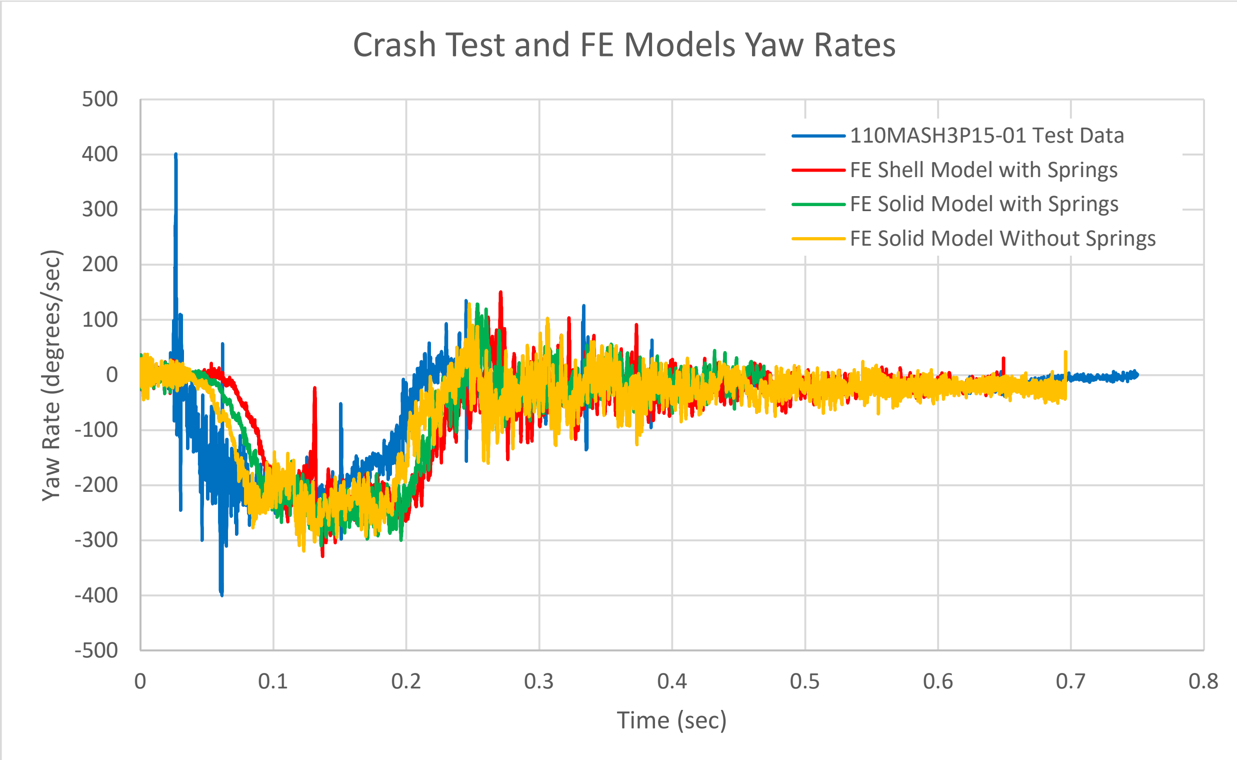


Figure 8-65. Graph of Yaw Rates for Full Scale and FE Model TRAP Results for 2270P Truck

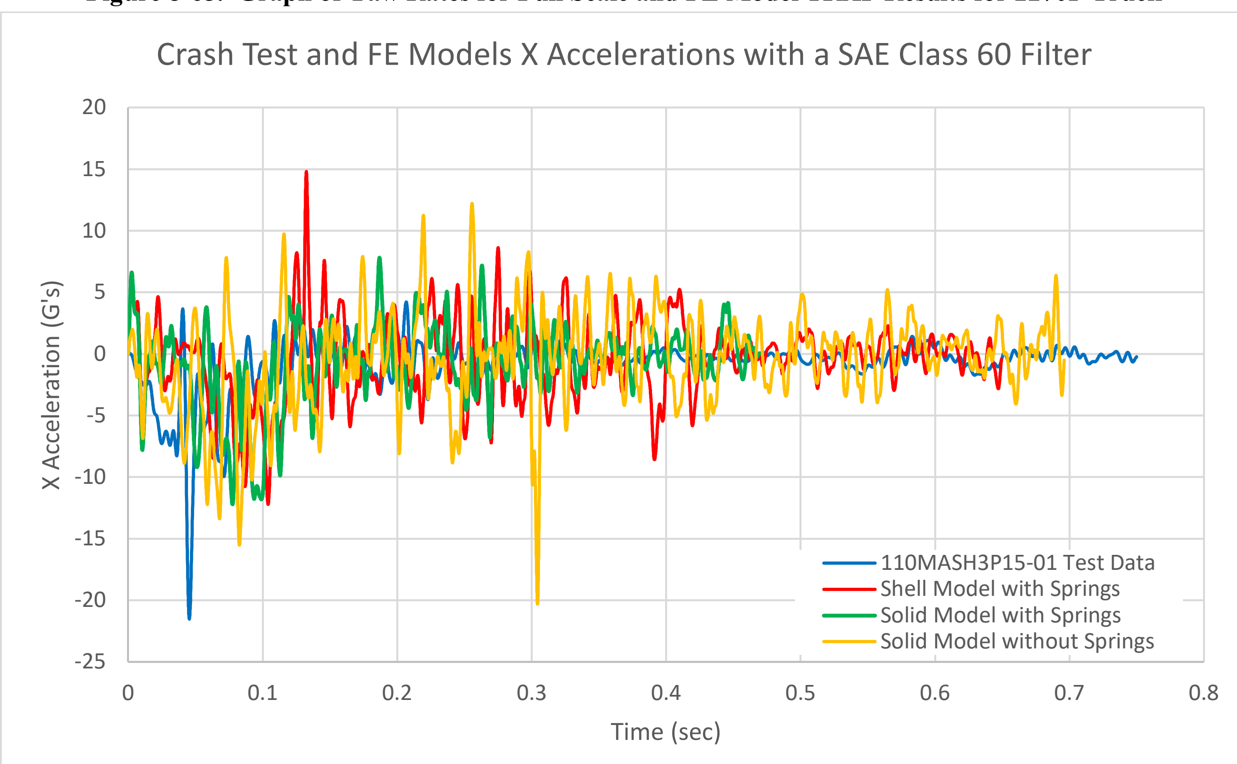


Figure 8-66. Graph of Longitudinal Accelerations for Full Scale and FE Model TRAP Results for 2270P Truck

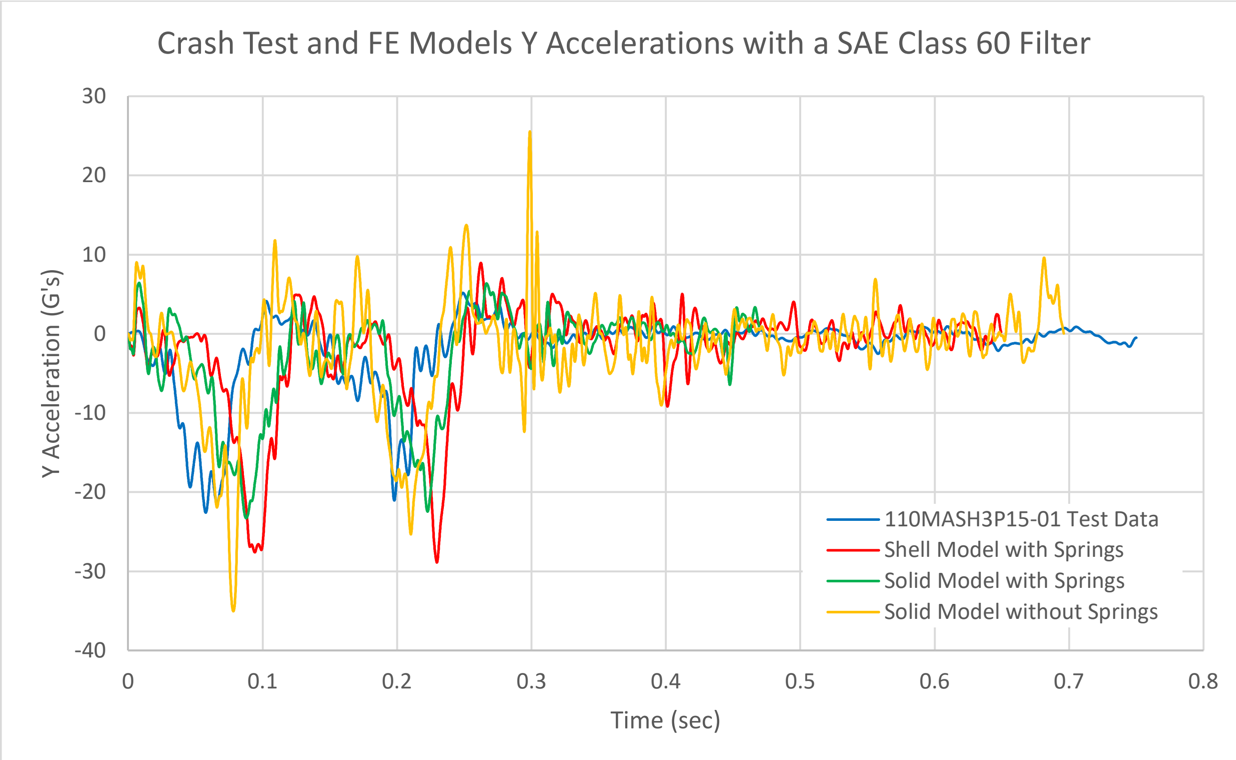


Figure 8-67. Graph of Lateral Accelerations for Full Scale and FE Model TRAP Results for 2270P Truck

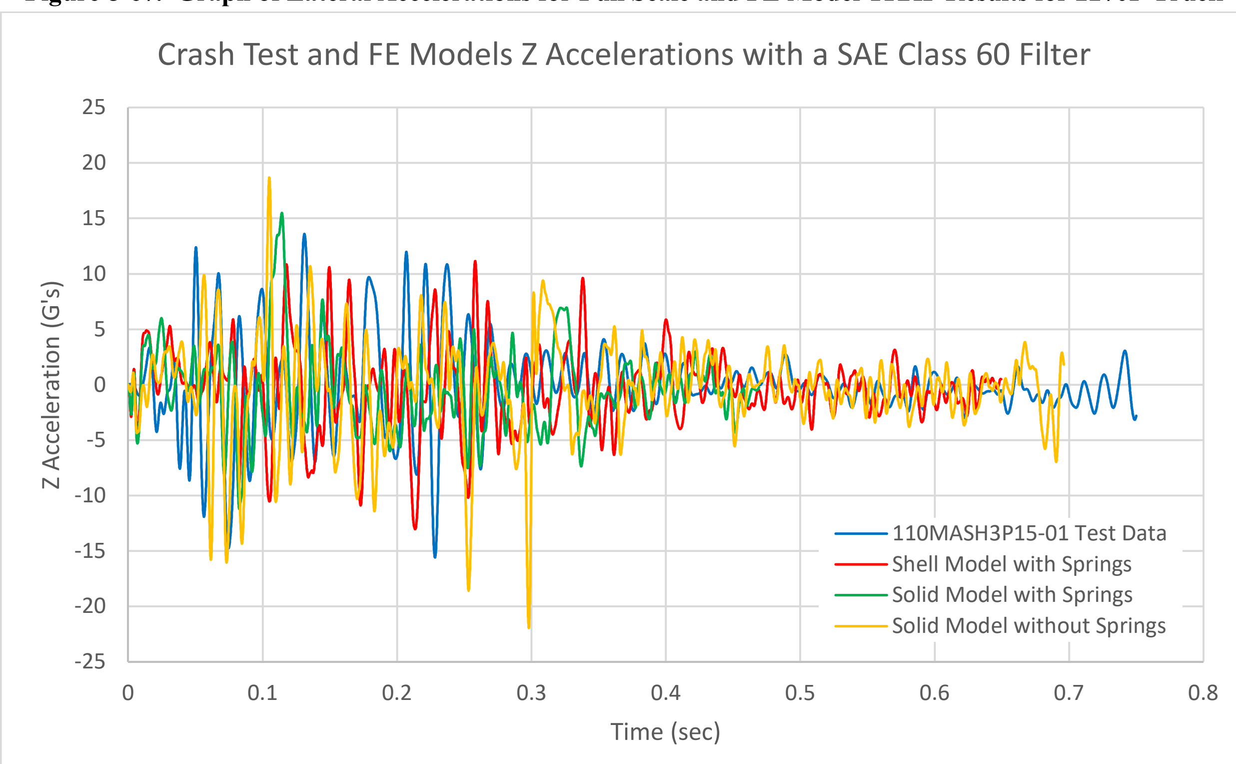


Figure 8-68. Graph of Vertical Accelerations for Full Scale and FE Model TRAP Results for 2270P Truck

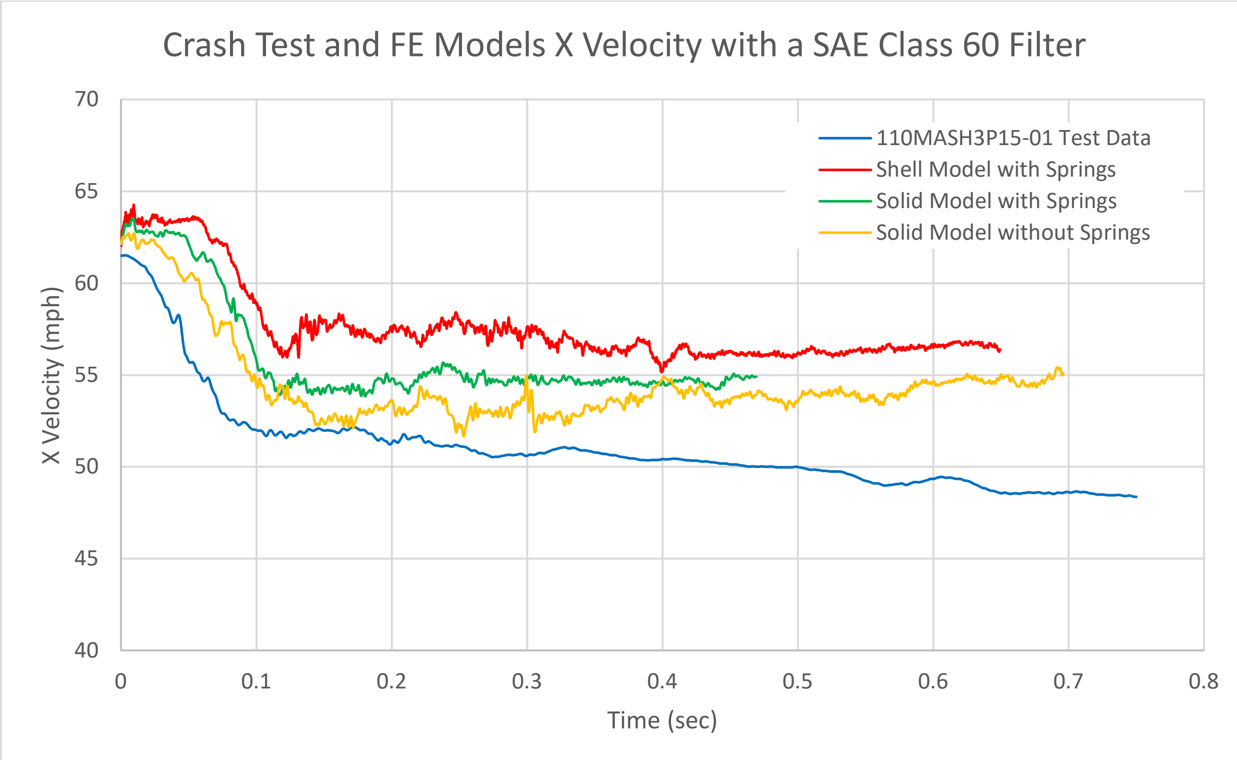


Figure 8-69. Graph of Longitudinal Velocities for Full Scale and FE Model TRAP Results for 2270P Truck

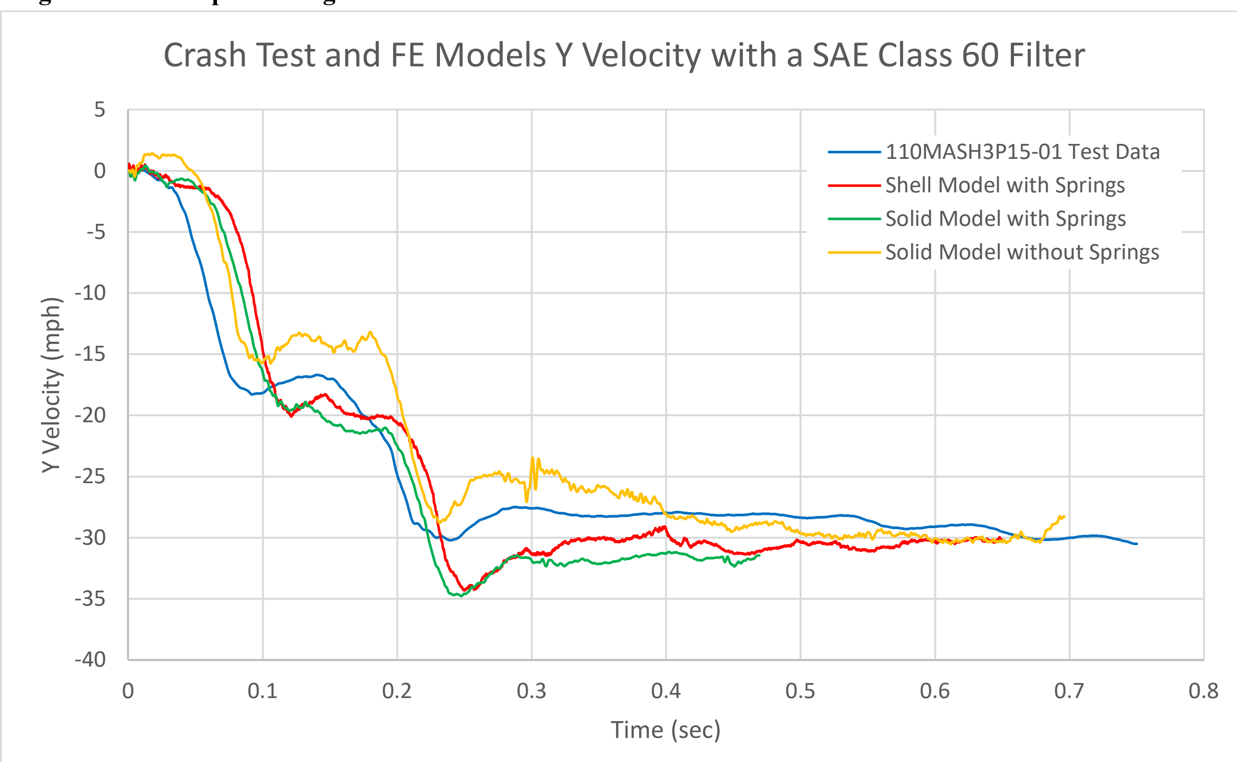


Figure 8-70. Graph of Lateral Velocities for Full Scale and FE Model TRAP Results for 2270P Truck

8.6.4.2.3. Visual Comparison

Figure 8-71 shows a comparison of the full scale test and the FE model simulations for the 2270P truck. The images of the full scale test were flipped for the purposes of a visual comparison, impact was on the passenger side. In all the simulations and the actual test the vehicle and barrier appear to interact similarly. All of the vehicles remain upright and have similar exit trajectories.

110MASH3P15-01 Full Scale Test (Images are Flipped)	SMBR Shell Model with Springs Truck	SMBR Solid Model with Springs Truck	SMBR Solid Model without Springs Truck

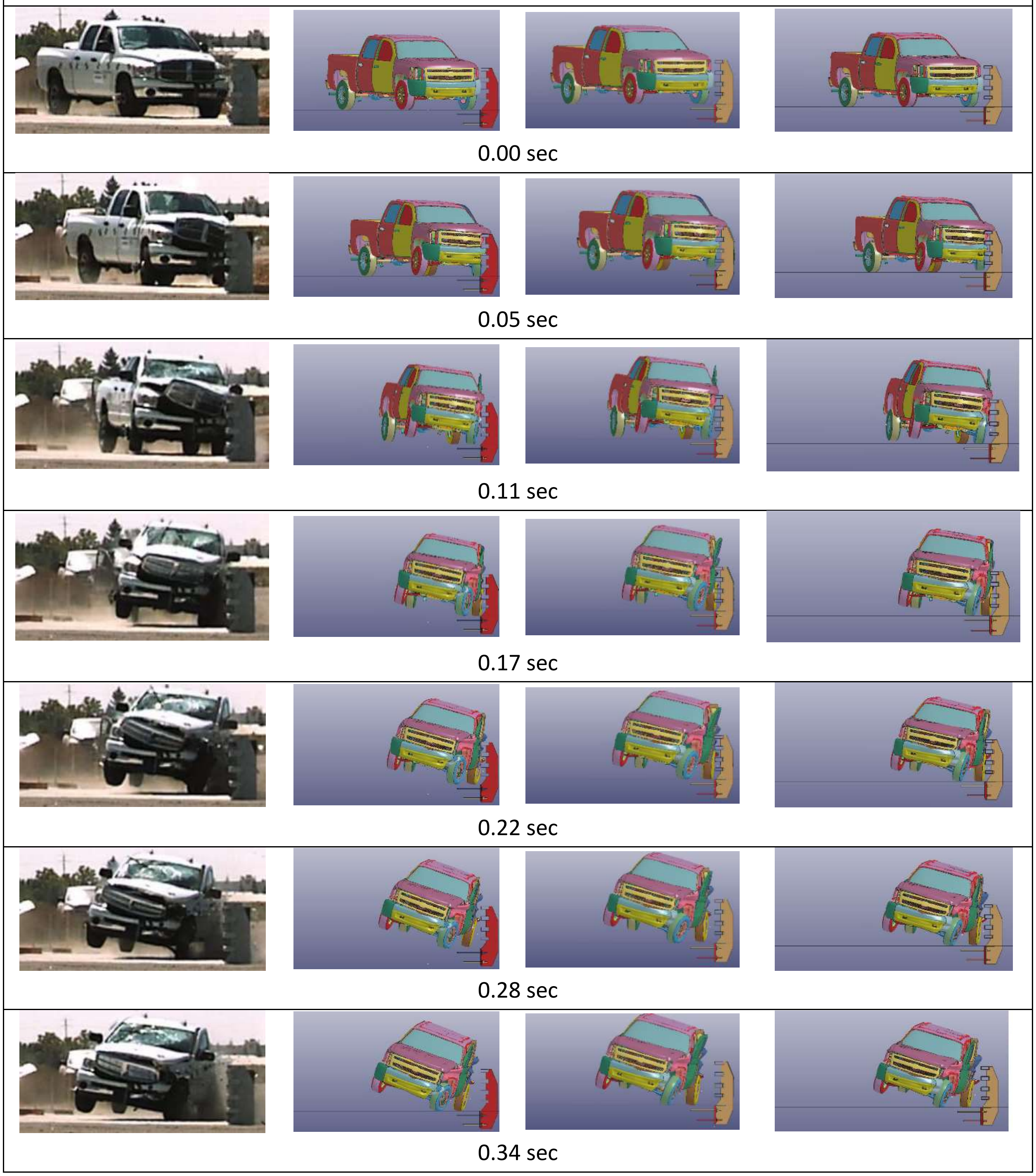


Figure 8-71. Visual Comparison of Actual Crash Test and Simulations for 2270P Truck

8.6.4.3. 1100C Car

This section compares the FE modeling to the full scale crash testing of the CA ST-70SM Side Mounted Bridge Rail and an 1100C car. Section 8.6.4.3.1 compares the movement of the test article between the FE models and the full scale test. Section 8.6.4.3.2 compares the analyzed data from the FE models and the full scale test. Section 8.6.4.3.3 is a visual comparison of the FE modeling and the full scale test. Table 8-29 shows the differences between the vehicle used in testing and the vehicle model used in the finite element modeling.

It was deemed unnecessary to continue to run simulations with the CA ST-70SM SMBR Shell Model with springs. The primary reason for this was the stiffness of the test article.

Table 8-29. Center of Gravity for 1100C Car Test Vehicle and LS-Dyna Finite Element Model

	Vehicle Type	X*	Y**	Z	Mass	Wheel Base
110MASH4C15-02	2008 Kia Rio	972 mm (38.3 inches)	-19 mm (0.8 Inches)	N/A	1118 kg (2465 lbs)	2497 mm (98.3 inches)
1100C Vehicle Models	2010 Toyota Yaris	1035 mm (40.7 inches)	-4 mm (0.2 Inches)	N/A	1100 kg (2425 lbs)	2538 mm (99.9 inches)

* Behind centerline of front tire
** Negative means CG is on the driver side of the centerline

8.6.4.3.1. Test Article Movement

Both the full scale test and the FE model of the CA ST-70SM SMBR with springs have similar test article movement. Movement in the full scale test article was measured by string potentiometers. The top rail had a dynamic deflection of 0.93 inches (24 mm) and a static displacement of 0.03 inches (1 mm). The top of the test article in the Solid Model with Springs simulation had a dynamic deflection of 1.33 inches (34 mm) and a static deflection of 0.10 inches (2.5 mm) See Table 8-30 for a tabulated comparison.

Although the CA ST-70SM SMBR system without the disc springs was not tested, the results of the FE model without the springs is included in Table 8-30. The top of the barrier in the Solid Model without Springs 1100C Car simulation had a dynamic displacement of 0.33 inches (8 mm) and a static displacement of 0.09 inches (2 mm). These results appear reasonable since the system is more rigid without the disc springs on the anchor bolts.

Table 8-30. Test Article Movement Comparison Full Scale and FE Model Results for 1100C

Maximum Test Article Movement	Test 110MASH4C15-02	Solid Model with Springs 1100C Car	Solid Model without Springs 1100C Car
Top Rail Dynamic Deflection	0.93 inches (24 mm)	1.33 inches (34 mm)	0.33 inches (8 mm)
Top Rail Static Displacement	0.03 inches (1 mm)	0.10 inches (3 mm)	0.09 inches (2 mm)

8.6.4.3.2. TRAP Data Comparison

The accelerometer and angular rate sensor data gathered during the full scale test and the FE modeling were processed with Test Risk Assessment Program (TRAP) and an SAE class 180 filter. When the data from the full scale test is compared to the FE models the majority of the results are similar. Only the

Lateral Ridedown Acceleration and the PHD were different; about 1.5 times higher than the full scale test. The Lateral Ridedown Acceleration in the simulation exceeds the maximum allowed by MASH, therefore the simulation resulted in a failure. See Table 8-31 for all of the TRAP results.

Included in Table 8-31 are the results of the Solid Model without Springs 1100C Car simulation. The majority of the results are similar to the full scale test except for the Lateral Ridedown Acceleration. The simulation would fail due to the Lateral Ridedown Acceleration of 23.4 G exceeding the MASH criteria of 20.49 G.

Table 8-31. TRAP Data Comparison for Full Scale and FE Model TRAP Results for 1100C (Absolute Values)

Data Results	MASH Criteria	Test 110MASH4C15-02	Solid Model with Springs 1100C Car	Solid Model without Springs 1100C Car
Longitudinal Occupant Impact Velocity	Preferred = 9.1 m/s Max = 12.2 m/s	5.3 m/s	4.6 m/s	4.7 m/s
Longitudinal Ridedown Acceleration 10 msec Average	Preferred = 15.0 G Max = 20.49 G	3.9 G	3.6 G	5.9 G
Lateral Occupant Impact Velocity	Preferred = 9.1 m/s Max = 12.2 m/s	11.1 m/s	9.7 m/s	8.7 m/s
Lateral Ridedown Acceleration 10 msec Average	Preferred = 15.0 G Max = 20.49 G	13.4 G	21.0 G	23.4 G
PHD	n/a	13.4 G	21.1 G	23.5 G
ASI	n/a	2.92	2.46	2.27
Max Roll	<75 Degrees	6.0 degrees	5.7 degrees	6.5 degrees
Max Pitch	<75 Degrees	3.2 degrees	2.3 degrees	2.7 degrees
Max Yaw	n/a	42.7 degrees	40.9 degrees	45.3 degrees

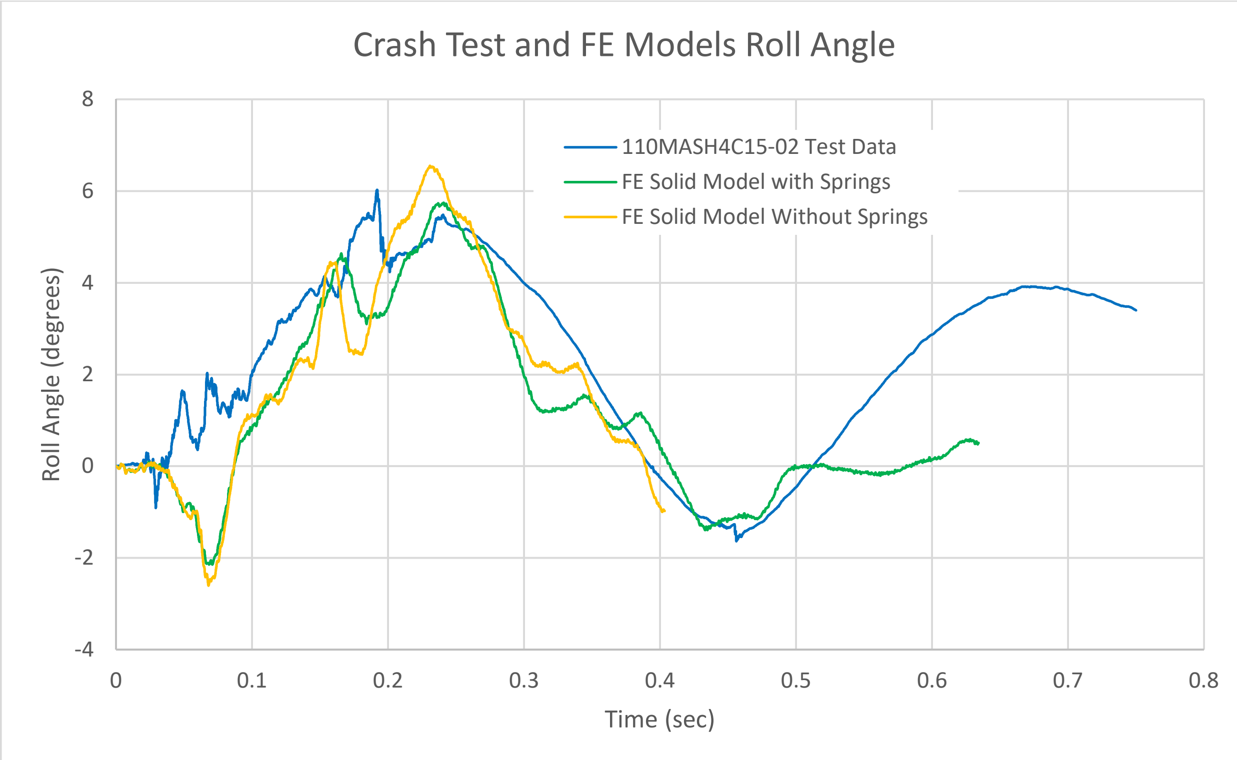


Figure 8-72. Graph of Roll Angles for Full Scale and FE Model TRAP Results for 1100C Car

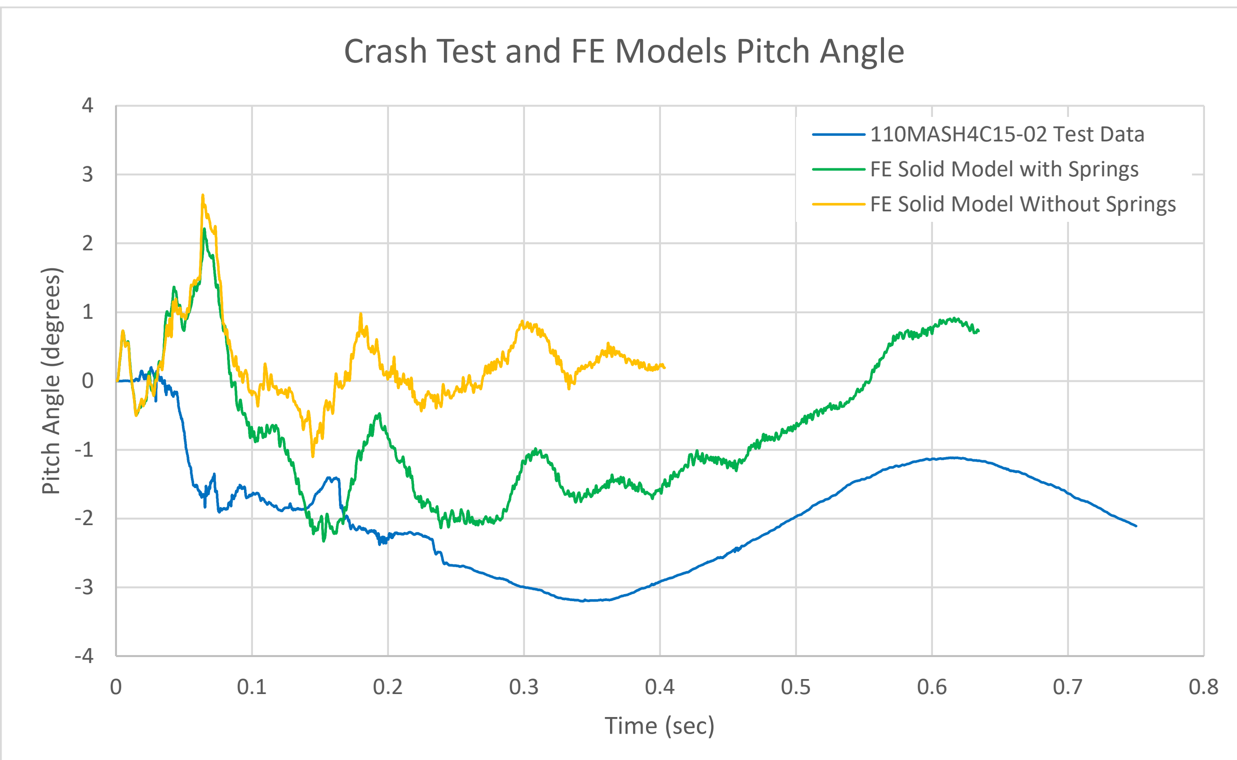


Figure 8-73. Graph of Pitch Angles for Full Scale and FE Model TRAP Results for 1100C Car

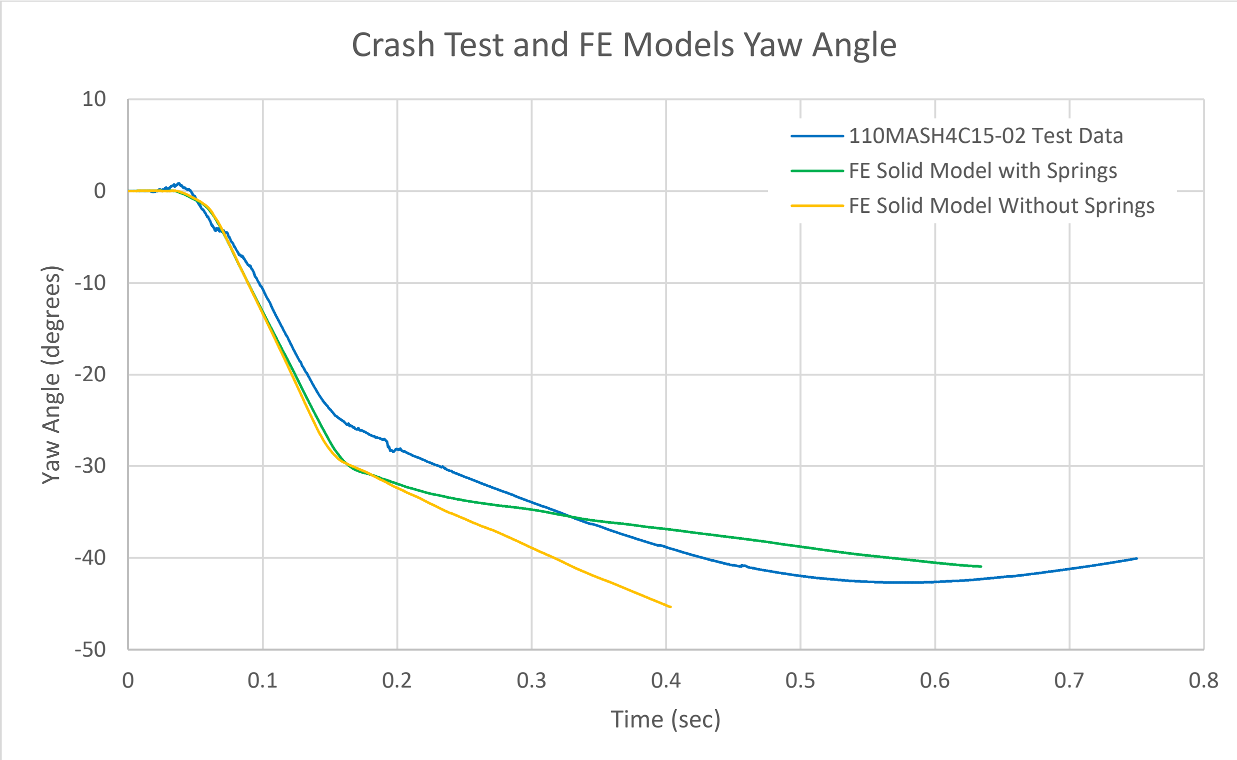


Figure 8-74. Graph of Yaw Angles for Full Scale and FE Model TRAP Results for 1100C Car

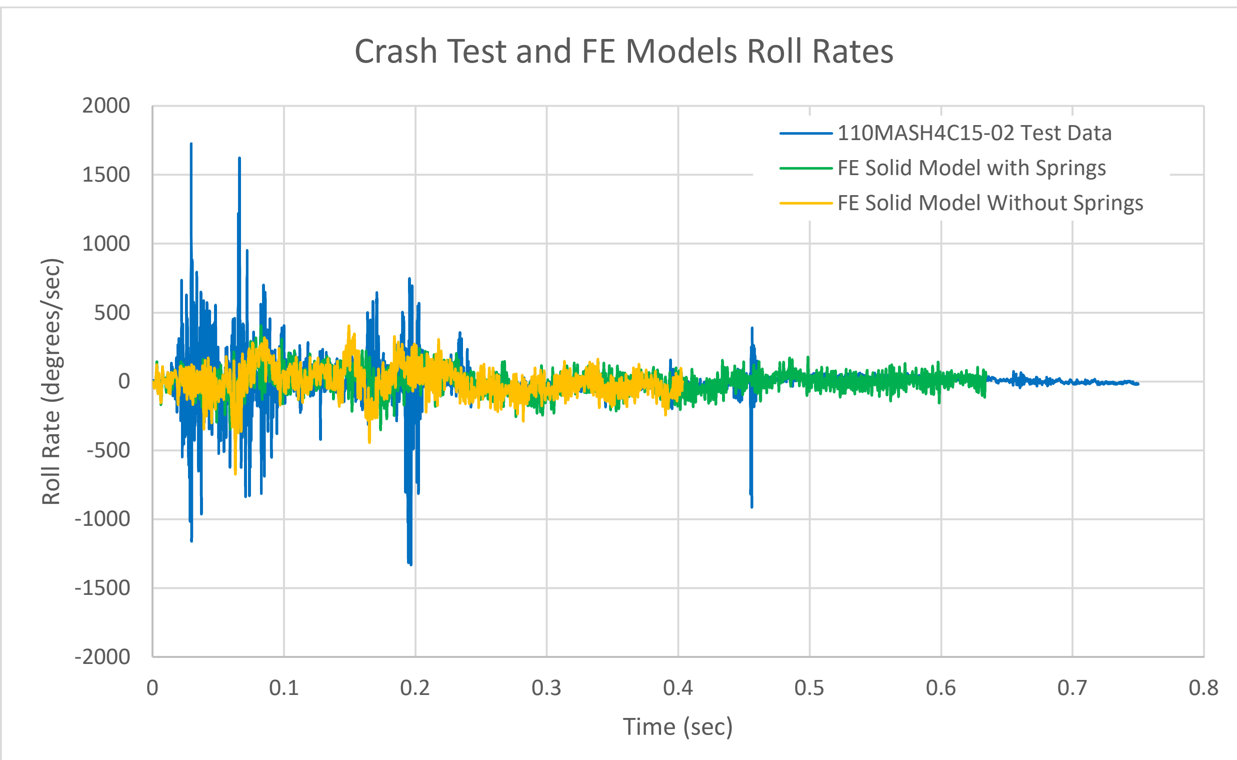


Figure 8-75. Graph of Roll Rates for Full Scale and FE Model TRAP Results for 1100C Car

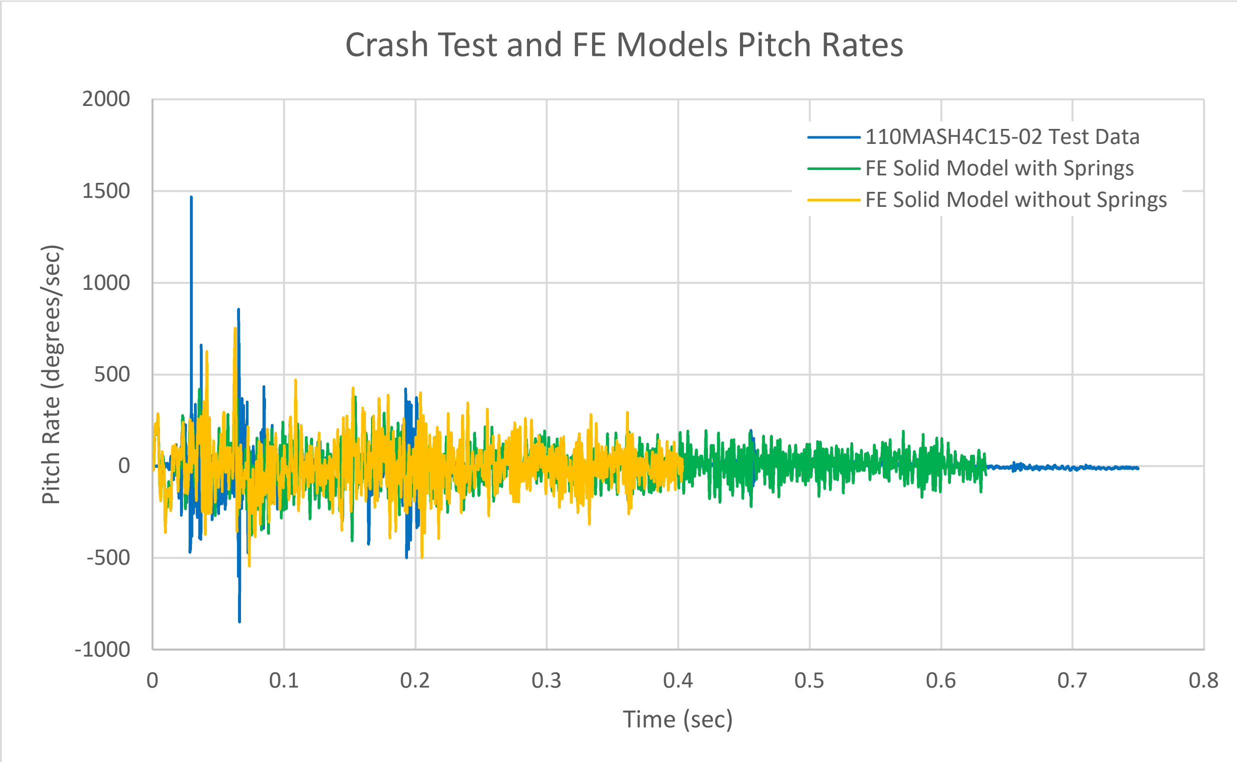


Figure 8-76. Graph of Pitch Rates for Full Scale and FE Model TRAP Results for 1100C Car

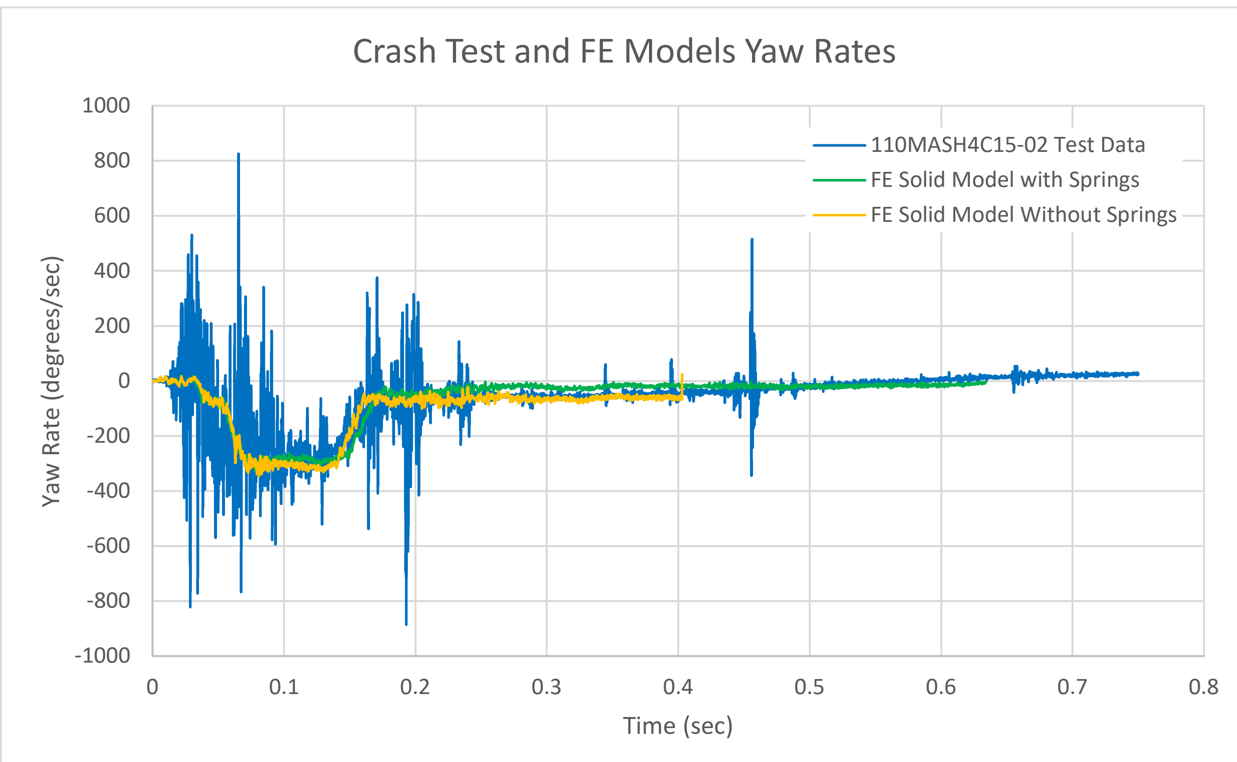


Figure 8-77. Graph of Yaw Rates for Full Scale and FE Model TRAP Results for 1100C Car

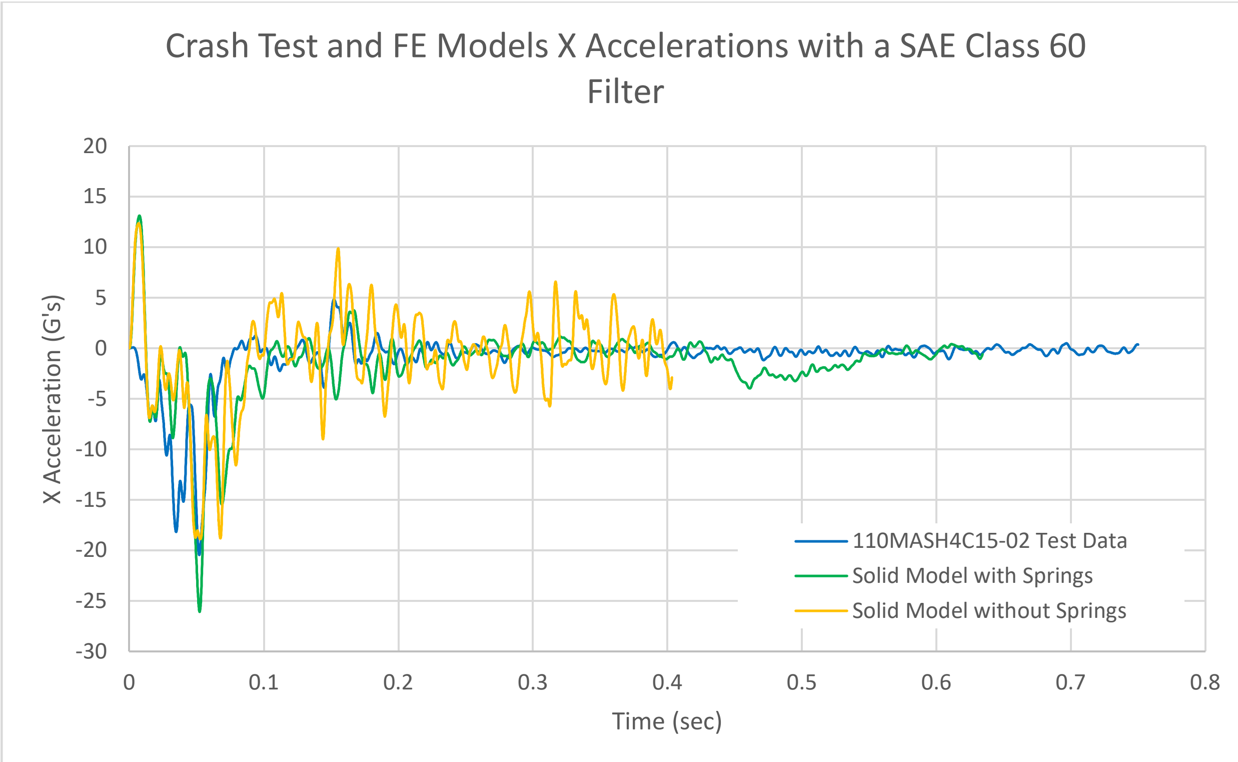


Figure 8-78. Graph of Longitudinal Accelerations for Full Scale and FE Model TRAP Results for 1100C Car

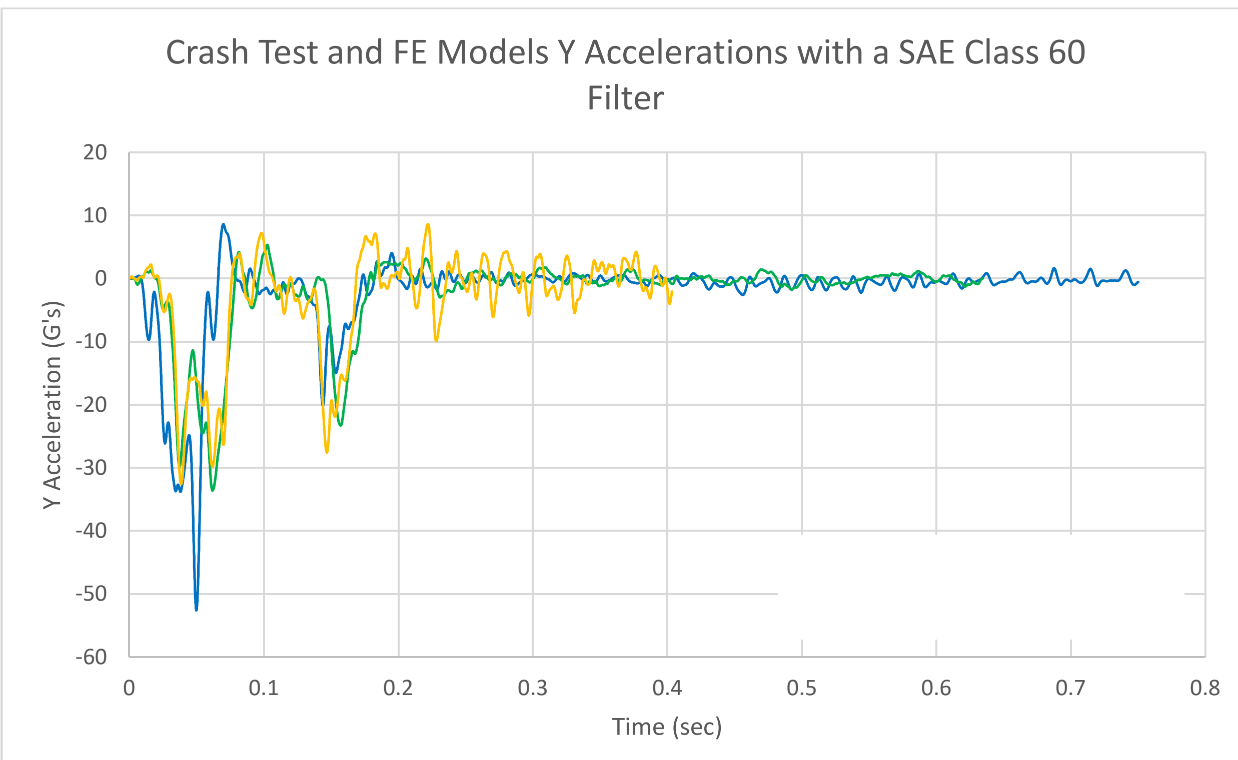


Figure 8-79. Graph of Lateral Accelerations for Full Scale and FE Model TRAP Results for 1100C Car

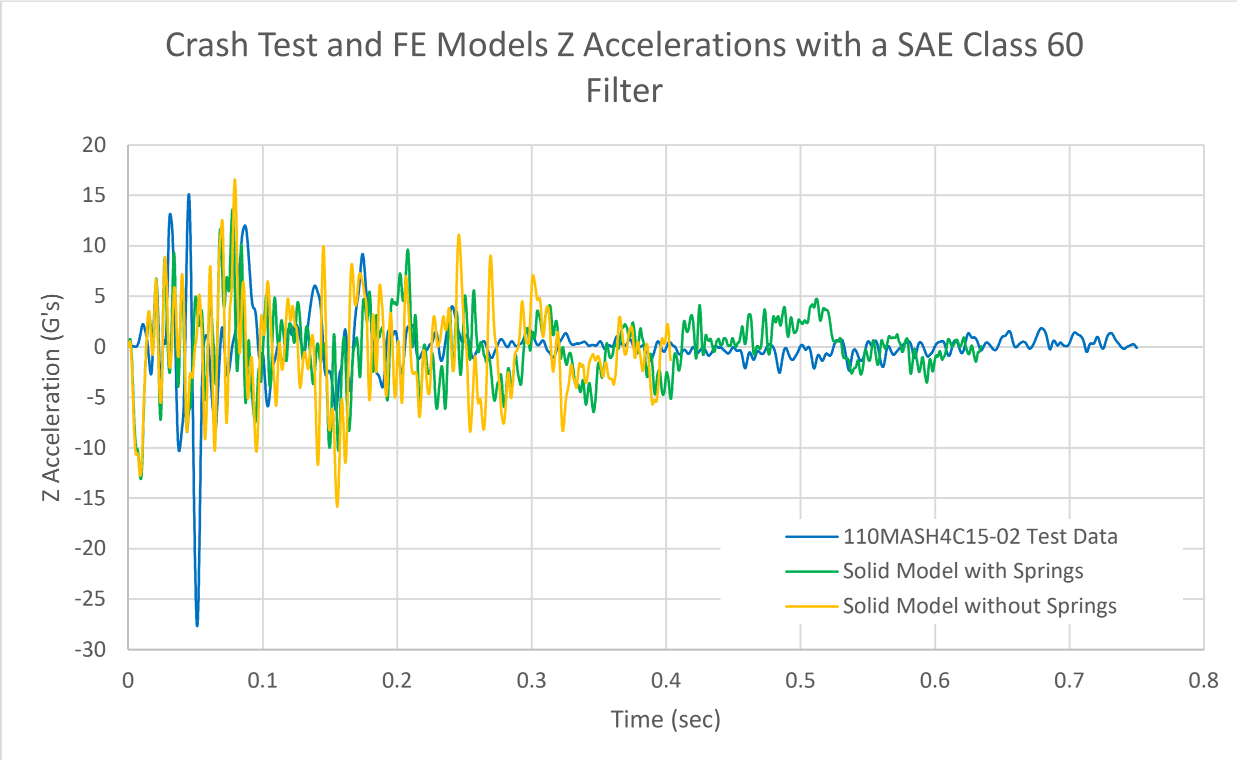


Figure 8-80. Graph of Vertical Accelerations for Full Scale and FE Model TRAP Results for 1100C Car

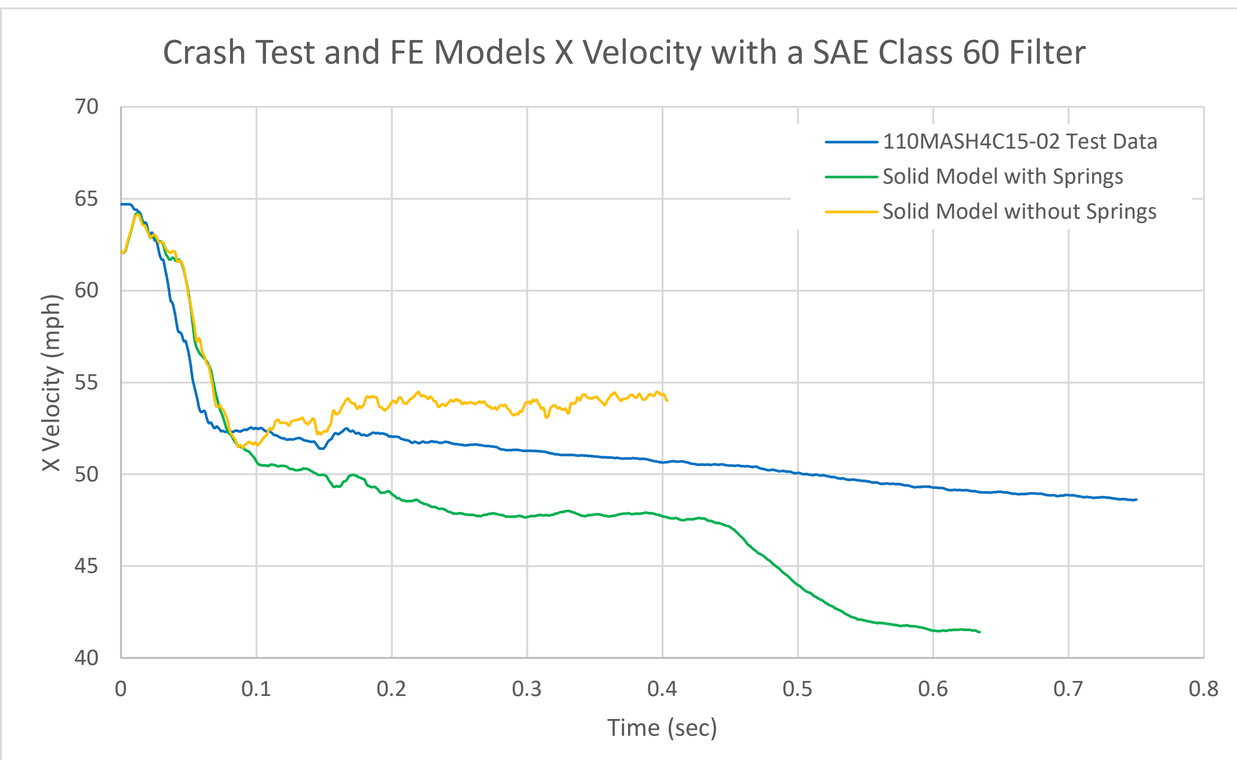


Figure 8-81. Graph of Longitudinal Velocity for Full Scale and FE Model TRAP Results for 1100C Car

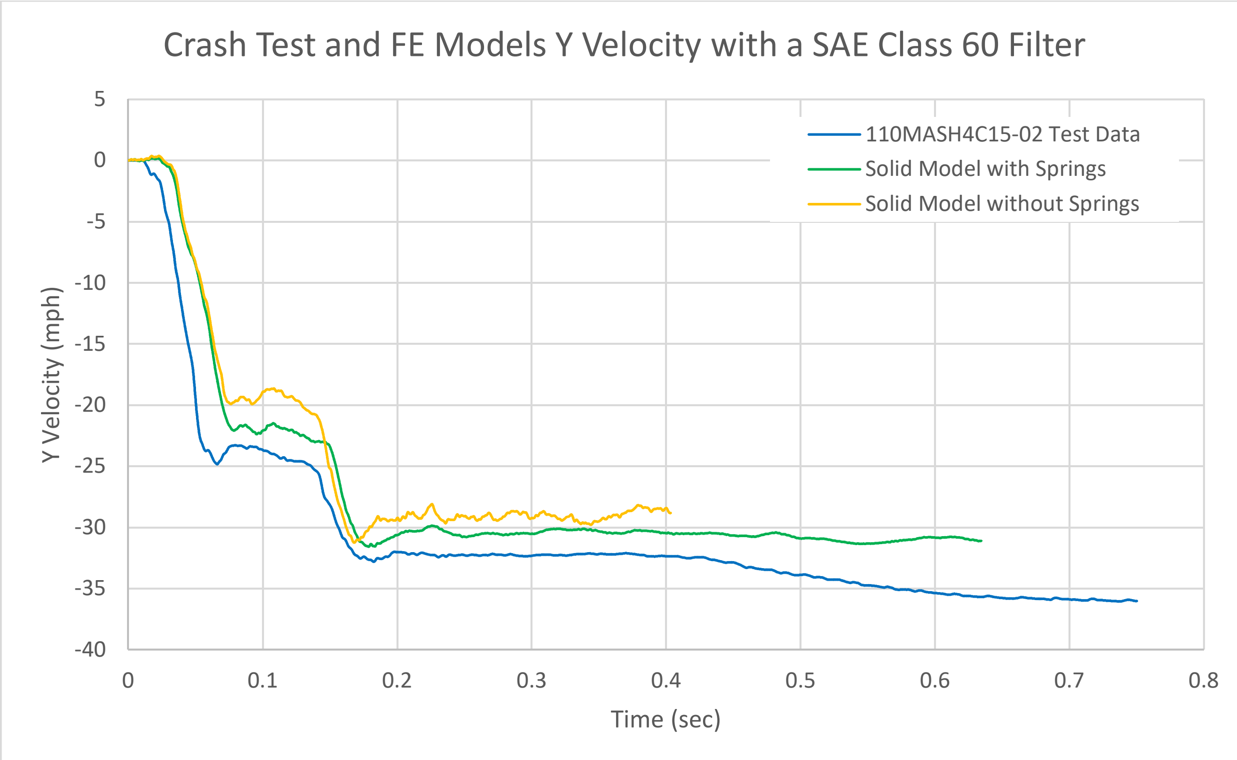


Figure 8-82. Graph of Lateral Velocity for Full Scale and FE Model TRAP Results for 1100C Car

8.6.4.3.3. Visual Comparison

Figure 8-83 shows a comparison of the full scale test and the FE model simulation for the 1100C car. The images of the full scale test were flipped for the purposes of a visual comparison, impact was on the passenger side. In the simulations and the actual test the vehicle and barrier appear to interact similarly. The vehicles remain upright and have similar exit trajectories.

Figure 8-83. Visual Comparison of Actual Crash Test and Simulations for 1100C Small Car

8.6.4.4. 10000S Single-Unit Van Truck

This section compares the FE modeling to the full scale crash testing of the CA ST-70SM Side Mounted Bridge Rail and a 10000S Single-Unit Van Truck. Section 8.6.4.4.1 compares the movement of the test article between the FE models and the full scale test. Section 8.6.4.4.2 is a visual comparison of the FE modeling and the full scale test.

Table 8-32. Center of Gravity for 10000S Single Unit Truck Test Vehicle and LS-Dyna Finite Element Model

	Vehicle Type	X*	Y**	Z	Mass	Wheel Base
110MASH4S16-03	2005 Freightliner M2	4019 mm (158.2 inches)	-24 mm (0.9 Inches)	N/A	9929 kg (21890 lbs)	5966 mm (234.9 inches)
10000S Vehicle Model	1996 Ford F800	3206 mm (126.2 inches)	-9 mm (0.4 Inches)	N/A	10000 kg (22046 lbs)	5300 mm (208.7 inches)

* Behind centerline of front tire
** Negative means CG is on the driver side of the centerline

8.6.4.4.1. Test Article Movement

Both the full scale test and the FE model of the CA ST-70SM SMBR with springs have similar test article movement. Movement in the full scale test article was measured by string potentiometers. The top rail had a dynamic deflection of 2.4 inches (61 mm) and a static displacement of 0.6 inches (15 mm). The top of the test article in the Solid Model with Springs simulation had a dynamic deflection of 2.6 inches (66 mm). The vehicle was still in contact with the barrier when the simulation was stopped so the static displacement was not measured. See Table 8-33 for a tabulated comparison.

Although the CA ST-70SM SMBR system without the disc springs was not tested, the results of the FE model without the springs is included in Table 8-33. The top of the barrier in the Solid Model without Springs 10000S Truck simulation had a dynamic displacement of 1.1 inches (28 mm). The vehicle was still in contact with the barrier when the simulation was stopped so the static displacement was not measured. These results appear reasonable since the system is more rigid without the disc springs on the anchor bolts.

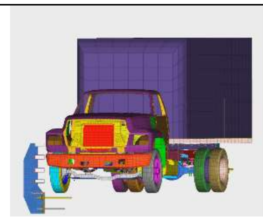
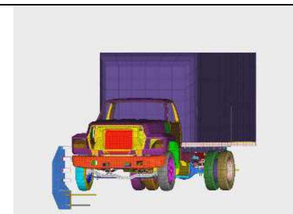
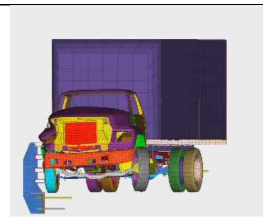
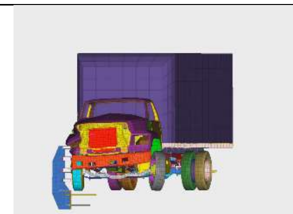
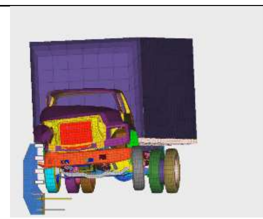
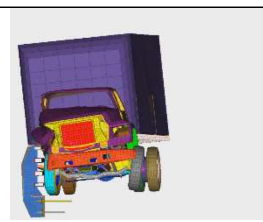
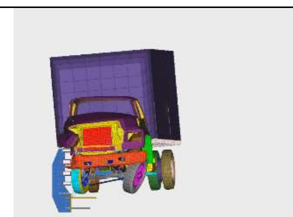
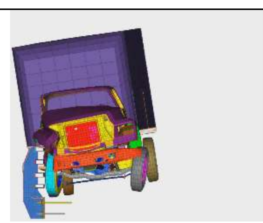
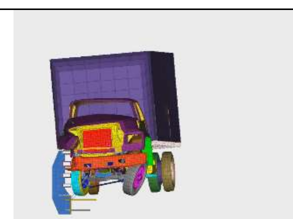
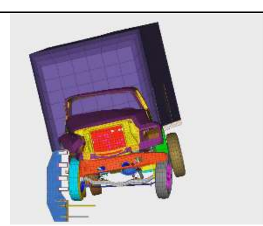
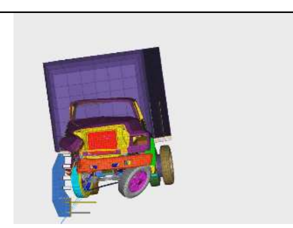
Table 8-33. Test Article Movement Comparison Full Scale and FE Model Results for 10000S

Maximum Test Article Movement	Test 110MASH4S16-03	Solid Model with Springs 10000S Single Unit Truck	Solid Model without Springs 10000S Single Unit Truck
Top Rail Dynamic Deflection	2.4 inches (61 mm)	2.6 inches (66 mm)	1.1 inches (28 mm)
Top Rail Static Displacement	0.6 inches (15 mm)	Vehicle still in contact with the barrier when the simulation was stopped.	Vehicle still in contact with the barrier when the simulation was stopped.

8.6.4.4.2. Visual Comparison

Figure 8-84 shows a comparison of the full scale test and the FE model simulation that included springs for the 10000S Van Body Truck. In the simulation and the actual test the vehicle and barrier appear to interact similarly. The vehicles remain upright and have similar exit trajectories.

The simulations, which were completed prior to the actual crash test, showed an issue with the front end of the vehicle. In the simulation, the axle separated from the vehicle resulting in erratic behavior. However, the actual crash test confirmed what the simulation depicted; the axle did break away from the front of the vehicle. Therefore the simulation was more accurate than initially thought. The erratic behavior might be due to the tires being the only elements of the front axle assembly that was defined to have contact with the ground. The rest of the elements would just pass through the ground which might have caused some of the erratic behavior.

Full Scale Test	Solid Model with Springs Single Unit Truck	Solid Model without Springs Single Unit Truck
	 0.00 sec	
	 0.08 sec	
	 0.17 sec	
	 0.25 sec	
	 0.34 sec	
	 0.42 sec	

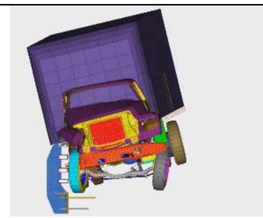
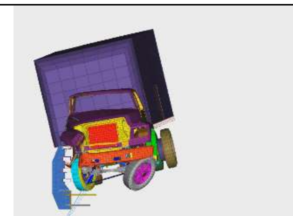
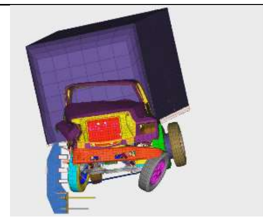
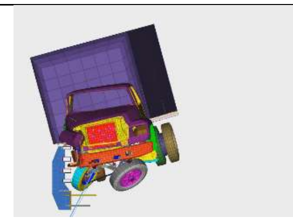
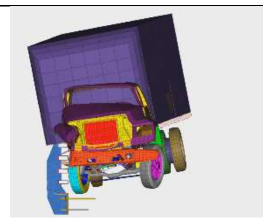
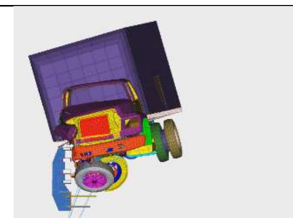
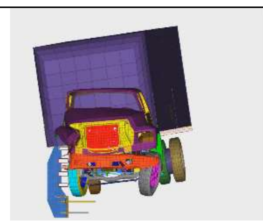
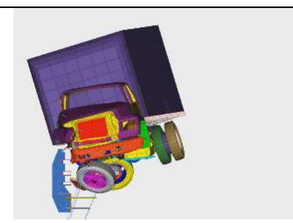
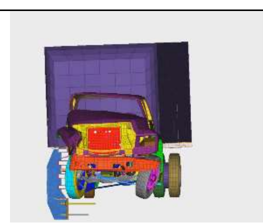
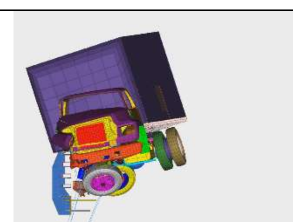
Full Scale Test Continued	Solid Model with Springs Single Unit Truck Continued	Solid Model without Springs Single Unit Truck Continued
	 0.50 sec	
	 0.59 sec	
	 0.67 sec	
	 0.76 sec	
	 0.84 sec	

Figure 8-84. Visual Comparison of Actual Crash Test and Simulations for 10000S Single Unit Truck

8.6.5. Conclusions

8.6.5.1. Test Article Movement

- Solid models had similar movement compared to the actual test.
- Movement in the solid models without spring seemed reasonable even though the actual system was not tested without springs.

8.6.5.2. TRAP Data Comparison

- The truck and car simulation velocities were similar to the related crash test.
- The truck model accelerations were higher compared to the actual test in the shell model of the test barrier.
- The truck model accelerations were similar compared to the actual test in the solid model of the test barrier.
- The truck models had higher roll values, 3x actual.
- The car model's longitudinal accelerations were similar to the actual test and the lateral accelerations were higher than the actual test, predicting a failure pre MASH 2009 criteria.
- All other angles were similar to actual test in the truck and car simulations.

8.6.5.3. Visual Comparison

- All of the models had similar interactions with the test article.

8.6.5.4. Overall

- The CA ST-70SM Side Mounted Bridge Rail solid model with springs appeared to act in a way that represented its real world counterpart.
- The truck model interacted in a similar way as the actual test with slightly higher accelerations.
- The car model interacted in a similar way as the actual test with the exception of the Lateral Ridedown Acceleration.
- The van body truck model interacted in a similar way as the actual test.
- Any future simulations of the CA ST-70SM Side Mounted Bridge Rail should use the CA ST-70SM SMBR Solid Model with Springs.

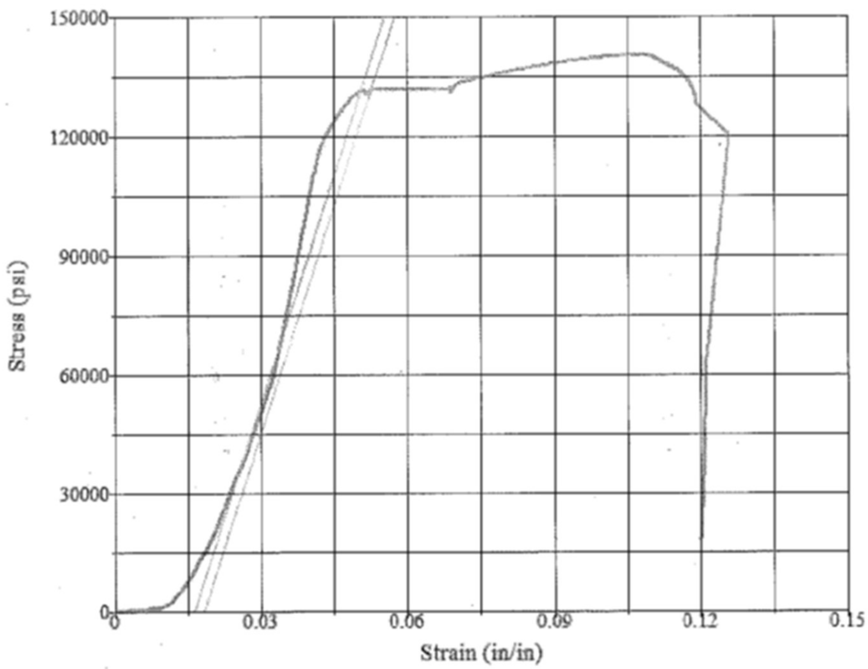
9. Post-Impact Anchor Rod Testing

During the demolition of the CA ST-70SM barrier, the upper anchor rods from posts 2, 3, and 4 were carefully removed to be tensile tested. All of these rods had strain gages installed. Table 9-1 includes the specimen gage length and tensile strength of the rods. All of the anchor rods tested were within the expected range of 125-150 ksi with the exception of rod 2 from post 2 and rod 1 from post 4, which exceeded the range. The anchor rods from posts 3 and 4 fractured at the strain gage location (milled flat for gage installation).

Table 9-1. CA ST-70SM Anchor Rod Tensile Test Data

CA ST-70SM Anchor Rod Tensile Test Data			
Post 2	**Date of Test**	**Specimen Gage Length (in)**	**Tensile Strength (psi)**
Rod 1	10/12/2017	24.0	140,257
Rod 2	10/12/2017	24.0	170,025
Rod 3	9/29/2017	26.0	140,637
Post 3			
Rod 1	10/12/2017	24.0	138,492
Rod 2	10/12/2017	24.0	137,519
Rod 3	10/12/2017	24.0	136,330
Post 4			
Rod 1	10/12/2017	24.0	174,372
Rod 2	10/12/2017	24.0	136,210
Rod 3	10/12/2017	24.0	138,687

PC59W7DHQ442668532 9:05:34 AM 10/12/2017



Test Summary

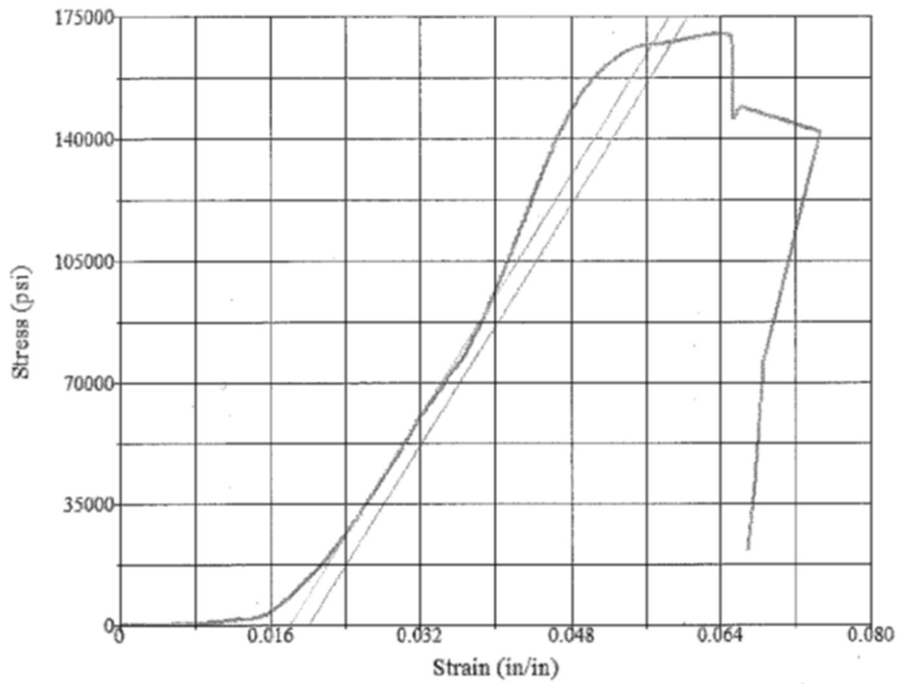
Counter:	8532
Elapsed Time:	00:05:44
Sample:	1A
Size:	Post 2 Rod 1
Comments:	P2 R1
Procedure Name:	DIME TM3 A449 Fastener Tensile Procedure
Start Date:	10/12/2017
Start Time:	8:57:27 AM
End Date:	10/12/2017
End Time:	9:03:11 AM
Workstation:	PC59W7DHQ44266
Tested By:	bewing
DIME Sample ID:	2018-10-12-1
Operator:	Fred
Temperature:	72 °F
Is Test Valid Y/N:	Y
UTM:	400KIP
Heat Number:	

Test Results

Specimen Gage Length:	24.0000 in
Area:	0.9690 in²
Peak Load:	135909 lbf
Peak Stress:	140257 psi
Correlation Coefficient:	0.9907
Tangent Modulus:	3842192 psi
Load at Offset:	127395 lbf
Stress at Offset:	131471 psi
Tensile Strength:	140257 psi
Peak Load in kN:	604.5534 kN

Figure 9-1. Post 2, Anchor Rod 1 Tensile Test Data

PC59W7DHQ442668533 9:19:11 AM 10/12/2017



Test Summary

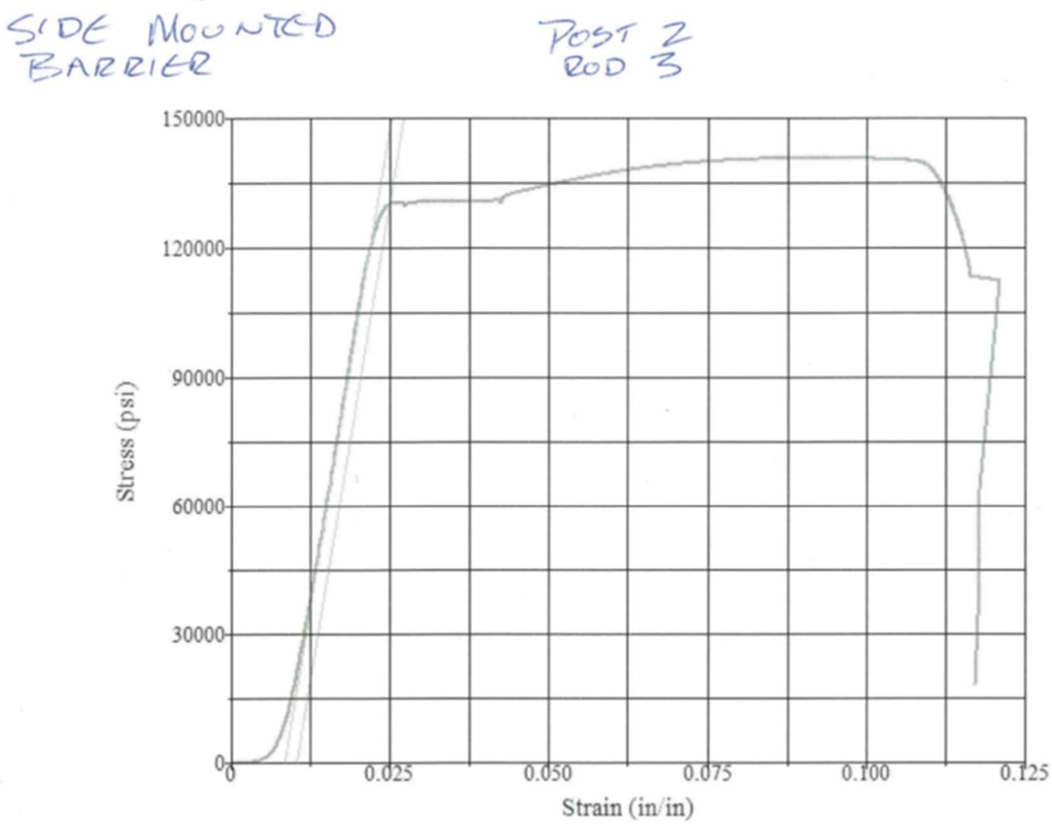
Counter:	8533
Elapsed Time:	00:03:11
Sample:	1B
Size:	Post 2 Rod 2
Comments:	P 2 R 1
Procedure Name:	DIME TM3 A449 Fastener Tensile Procedure
Start Date:	10/12/2017
Start Time:	9:09:53 AM
End Date:	10/12/2017
End Time:	9:13:04 AM
Workstation:	PC59W7DHQ44266
Tested By:	bewing
DIME Sample ID:	2018-10-12-2
Operator:	Fred
Temperature:	72 °F
Is Test Valid Y/N:	Y
UTM:	400KIP
Heat Number:	

Test Results

Specimen Gage Length:	24.0000 in
Area:	0.9690 in²
Peak Load:	164754 lbf
Peak Stress:	170025 psi
Correlation Coefficient:	0.9969
Tangent Modulus:	4310975 psi
Load at Offset:	162366 lbf
Stress at Offset:	167561 psi
Tensile Strength:	170025 psi
Peak Load in kN:	732.8624 kN

Figure 9-2. Post 2, Anchor Rod 2 Tensile Test Data

PC59W7DHQ442668504 9:05:44 AM 9/29/2017

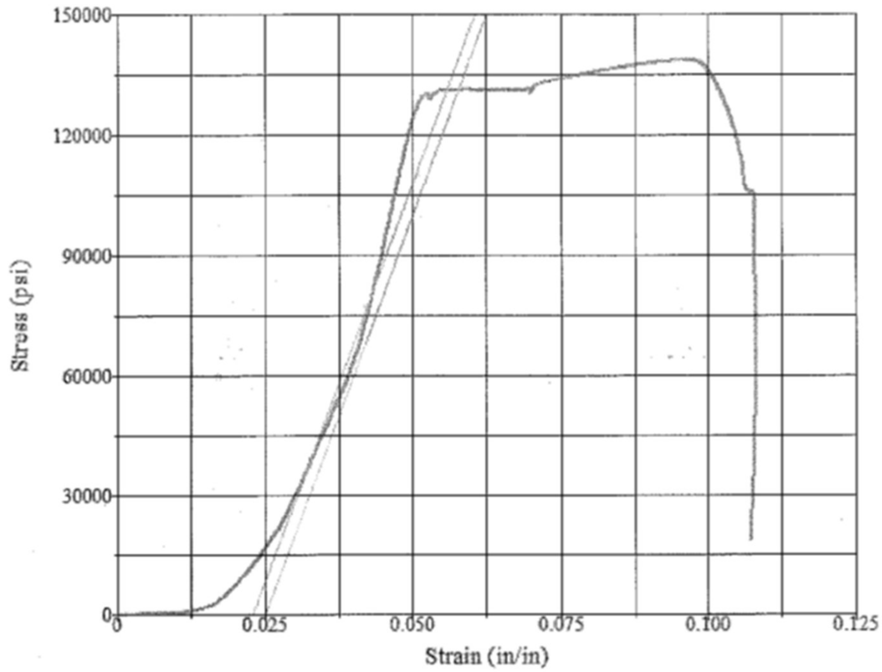


Test Summary	
Counter:	8504
Elapsed Time:	00:06:04
Sample:	1A
Mfg. Lot:	
SM Number:	Crash Test
SIC Number:	N/A
Contract No.:	
Size:	F1554 Althread Rod Grade 105
Comments:	F1554
Procedure Name:	A449
Start Date:	9/29/2017
Start Time:	8:57:02 AM
End Date:	9/29/2017
End Time:	9:03:06 AM
Workstation:	PC59W7DHQ44266
Tested By:	FSaylor

Test Results	
Specimen Gage Length:	26.0000 in
Area:	0.9690 in²
Peak Load:	136277 lbf
Peak Stress:	140637 psi
Correlation Coefficient:	0.9997
Tangent Modulus:	8955508 psi
Load at Offset:	125980 lbf
Stress at Offset:	130010 psi
Tensile Strength:	140637 psi

Figure 9-3. Post 2, Anchor Rod 3 Tensile Test Data

PC59W7DHQ442668534 9:32:05 AM 10/12/2017



Test Summary

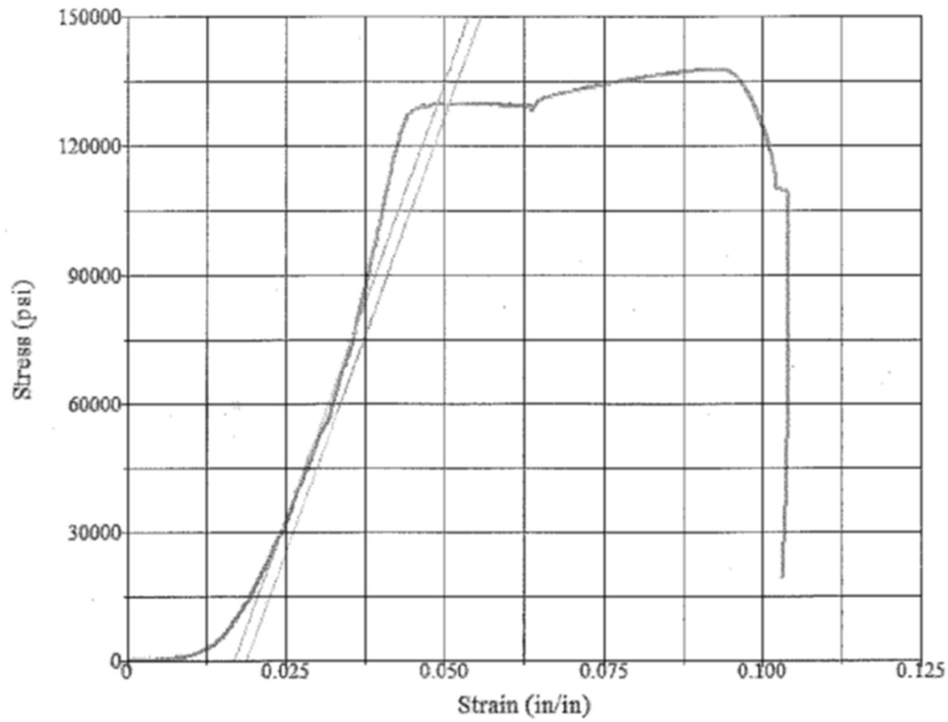
Counter:	8534
Elapsed Time:	00:05:07
Sample:	2A
Size:	Post 3 Rod 1
Comments:	P2 R1
Procedure Name:	DIME TM3 A449 Fastener Tensile Procedure
Start Date:	10/12/2017
Start Time:	9:25:00 AM
End Date:	10/12/2017
End Time:	9:30:07 AM
Workstation:	PC59W7DHQ44266
Tested By:	bewing
DIME Sample ID:	2018-10-12-3
Operator:	Fred
Temperature:	72 °F
Is Test Valid Y/N:	Y
UTM:	400KIP
Heat Number:	

Test Results

Specimen Gage Length:	24.0000 in
Area:	0.9690 in²
Peak Load:	134199 lbf
Peak Stress:	138492 psi
Correlation Coefficient:	0.9891
Tangent Modulus:	3988622 psi
Load at Offset:	127059 lbf
Stress at Offset:	131124 psi
Tensile Strength:	138492 psi
Peak Load in kN:	596.9470 kN

Figure 9-4. Post 3, Anchor Rod 1 Tensile Test Data

PC59W7DHQ442668535 10:11:57 AM 10/12/2017



Test Summary

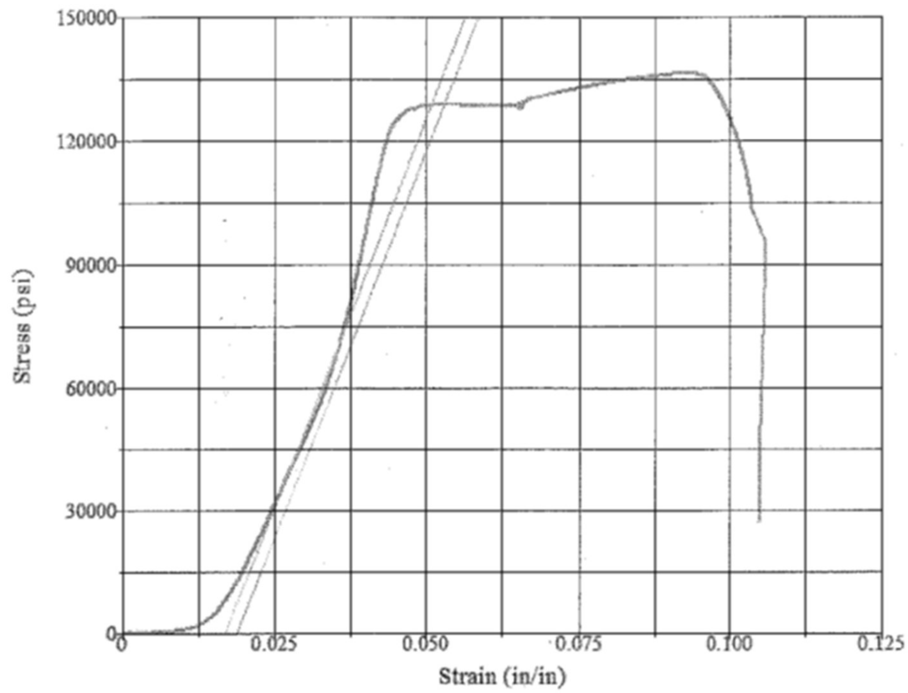
Counter:	8535
Elapsed Time:	00:04:55
Sample:	2B
Size:	Post 3 Rod 2
Comments:	P3 R1
Procedure Name:	DIME TM3 A449 Fastener Tensile Procedure
Start Date:	10/12/2017
Start Time:	10:06:22 AM
End Date:	10/12/2017
End Time:	10:11:17 AM
Workstation:	PC59W7DHQ44266
Tested By:	bewing
DIME Sample ID:	2018-10-12-4
Operator:	Fred
Temperature:	72 °F
Is Test Valid Y/N:	Y
UTM:	400KIP
Heat Number:	

Test Results

Specimen Gage Length:	24.0000 in
Area:	0.9690 in²
Peak Load:	133256 lbf
Peak Stress:	137519 psi
Correlation Coefficient:	0.9927
Tangent Modulus:	4070650 psi
Load at Offset:	125339 lbf
Stress at Offset:	129349 psi
Tensile Strength:	137519 psi
Peak Load in kN:	592.7523 kN

Figure 9-5. Post 3, Anchor Rod 2 Tensile Test Data

PC59W7DHQ442668536 10:25:11 AM 10/12/2017



Test Summary

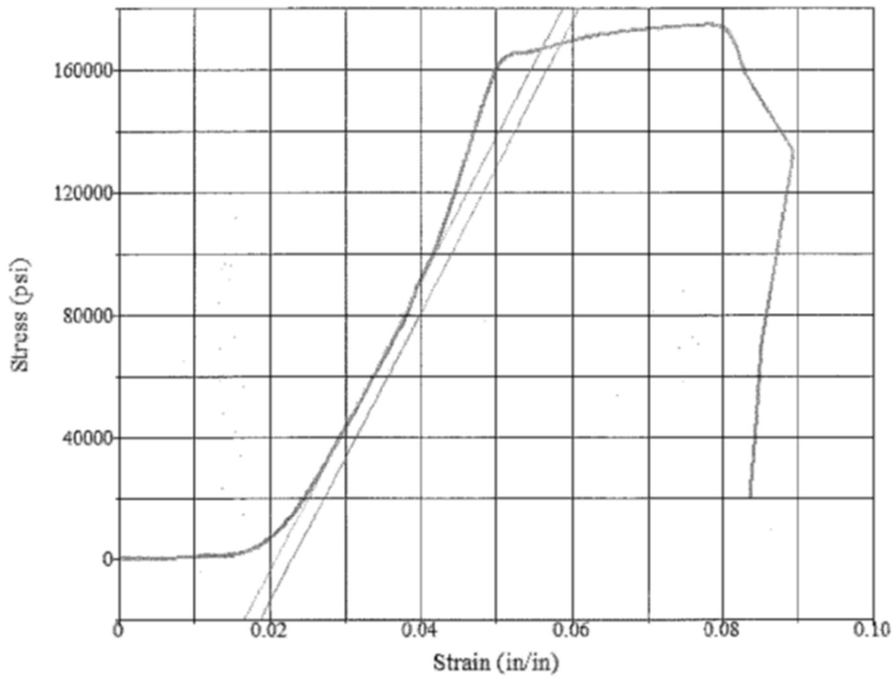
Counter:	8536
Elapsed Time:	00:04:59
Sample:	2C
Size:	Post 3 Rod 3
Comments:	P3 R3
Procedure Name:	DIME TM3 A449 Fastener Tensile Procedure
Start Date:	10/12/2017
Start Time:	10:17:09 AM
End Date:	10/12/2017
End Time:	10:22:08 AM
Workstation:	PC59W7DHQ44266
Tested By:	bewing
DIME Sample ID:	2018-10-12-5
Operator:	Fred
Temperature:	72 °F
Is Test Valid Y/N:	Y
UTM:	400KIP
Heat Number:	

Test Results

Specimen Gage Length:	24.0000 in
Area:	0.9690 in²
Peak Load:	132104 lbf
Peak Stress:	136330 psi
Correlation Coefficient:	0.9928
Tangent Modulus:	3775588 psi
Load at Offset:	124786 lbf
Stress at Offset:	128778 psi
Tensile Strength:	136330 psi
Peak Load in kN:	587.6279 kN

Figure 9-6. Post 3, Anchor Rod 3 Tensile Test Data

PC59W7DHQ442668537 10:34:20 AM 10/12/2017

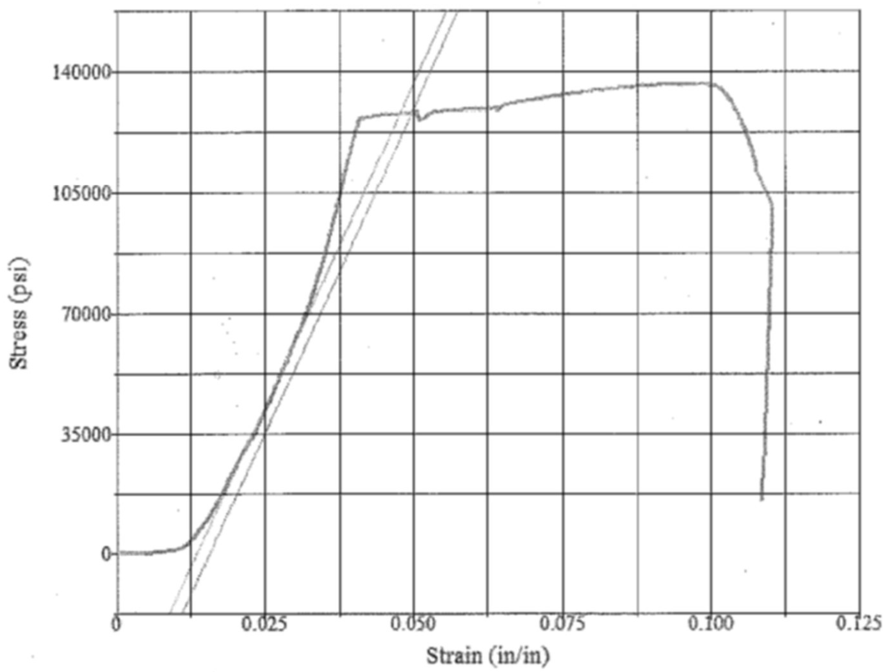


Test Summary	
Counter:	8537
Elapsed Time:	00:03:59
Sample:	2C
Size:	Post 4 Rod 1
Comments:	P4 R1
Procedure Name:	DIME TM3 A449 Fastener Tensile Procedure
Start Date:	10/12/2017
Start Time:	10:27:35 AM
End Date:	10/12/2017
End Time:	10:31:34 AM
Workstation:	PC59W7DHQ44266
Tested By:	bewing
DIME Sample ID:	2018-10-12-6
Operator:	Fred
Temperature:	72 °F
Is Test Valid Y/N:	Y
UTM:	400KIP
Heat Number:	

Test Results	
Specimen Gage Length:	24.0000 in
Area:	0.9690 in²
Peak Load:	168966 lbf
Peak Stress:	174372 psi
Correlation Coefficient:	0.9986
Tangent Modulus:	4744210 psi
Load at Offset:	162939 lbf
Stress at Offset:	168152 psi
Tensile Strength:	174372 psi
Peak Load in kN:	751.5983 kN

Figure 9-7. Post 4, Anchor Rod 1 Tensile Test Data

PC59W7DHQ442668538 10:44:45 AM 10/12/2017



Test Summary

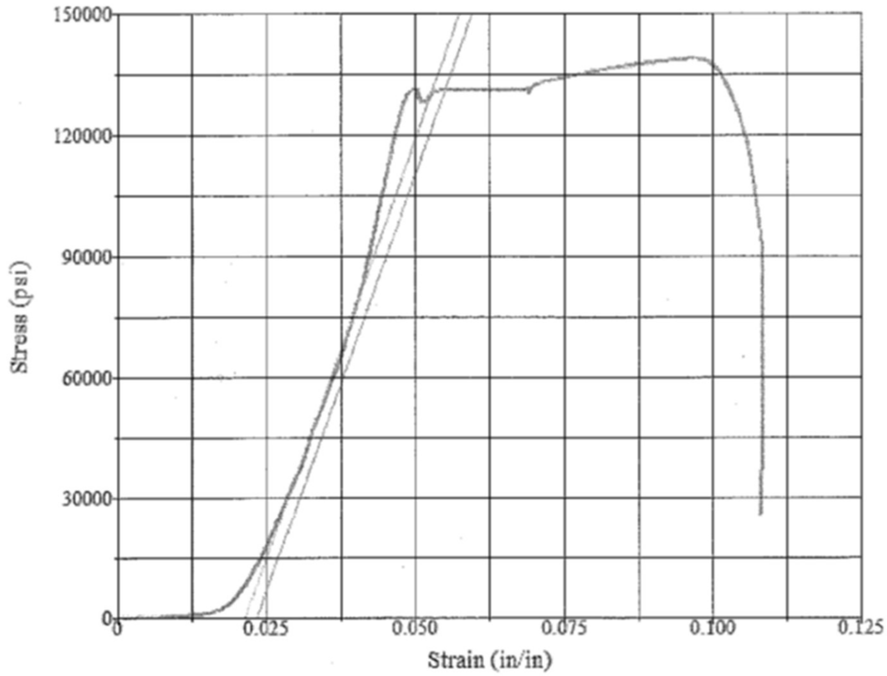
Counter:	8538
Elapsed Time:	00:05:11
Sample:	4A
Size:	Post 4 Rod 2
Comments:	P4 R2
Procedure Name:	DIME TM3 A449 Fastener Tensile Procedure
Start Date:	10/12/2017
Start Time:	10:37:44 AM
End Date:	10/12/2017
End Time:	10:42:55 AM
Workstation:	PC59W7DHQ44266
Tested By:	bewing
DIME Sample ID:	2018-10-12-7
Operator:	Fred
Temperature:	72 °F
Is Test Valid Y/N:	Y
UTM:	400KIP
Heat Number:	

Test Results

Specimen Gage Length:	24.0000 in
Area:	0.9690 in²
Peak Load:	131987 lbf
Peak Stress:	136210 psi
Correlation Coefficient:	0.9978
Tangent Modulus:	3775517 psi
Load at Offset:	124025 lbf
Stress at Offset:	127993 psi
Tensile Strength:	136210 psi
Peak Load in kN:	587.1075 kN

Figure 9-8. Post 4, Anchor Rod 2 Tensile Test Data

PC59W7DHQ442668539 10:55:09 AM 10/12/2017



Test Summary

Counter:	8539
Elapsed Time:	00:05:08
Sample:	4C
Size:	Post 4 Rod 3
Comments:	P4 R3
Procedure Name:	DIME TM3 A449 Fastener Tensile Procedure
Start Date:	10/12/2017
Start Time:	10:48:35 AM
End Date:	10/12/2017
End Time:	10:53:43 AM
Workstation:	PC59W7DHQ44266
Tested By:	bewing
DIME Sample ID:	2018-10-12-8
Operator:	Fred
Temperature:	72 °F
Is Test Valid Y/N:	Y
UTM:	400KIP
Heat Number:	

Test Results

Specimen Gage Length:	24.0000 in
Area:	0.9690 in^2
Peak Load:	134388 lbf
Peak Stress:	138687 psi
Correlation Coefficient:	0.9967
Tangent Modulus:	4154752 psi
Load at Offset:	126883 lbf
Stress at Offset:	130942 psi
Tensile Strength:	138687 psi
Peak Load in kN:	597.7877 kN

Figure 9-9. Post 4, Anchor Rod 3 Tensile Test Data

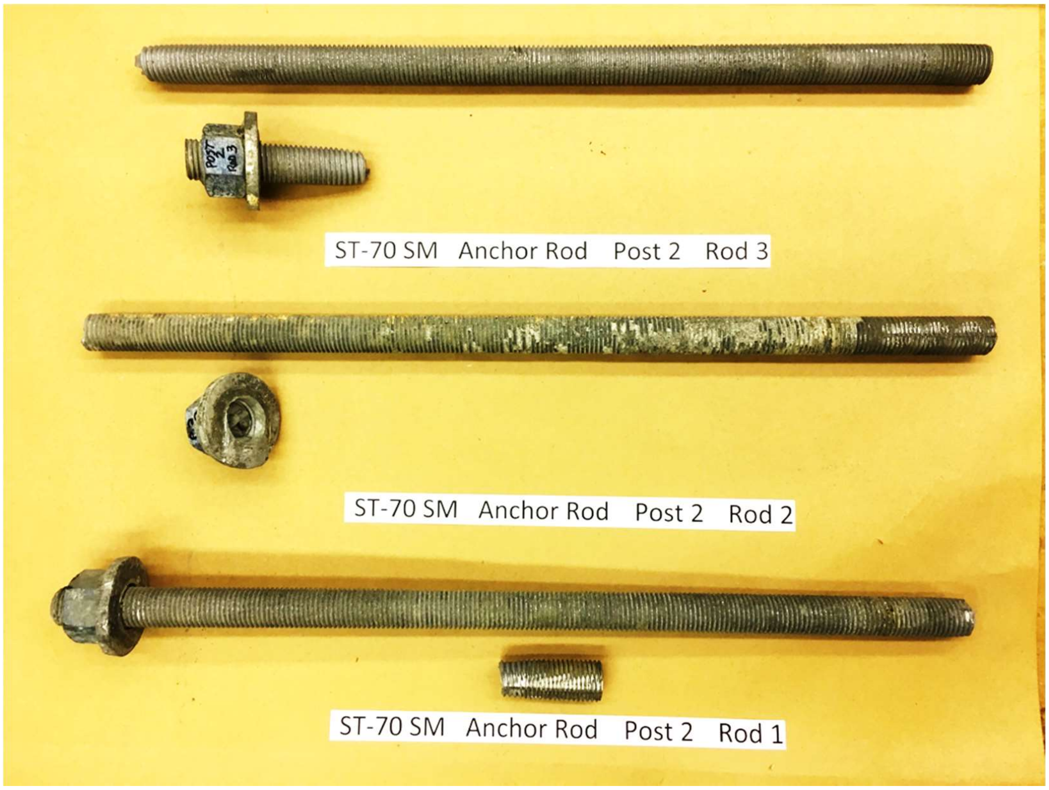


Figure 9-10. Post 2, Anchor Rods 1, 2, & 3

Figure 9-11. Post 3, Anchor Rods 1, 2, & 3

Figure 9-12. Post 4, Anchor Rods 1, 2, & 3

10. Detail Drawings and Materials Data

The following details in Figure 10-1 to Figure 10-4 are for the tested barrier only.

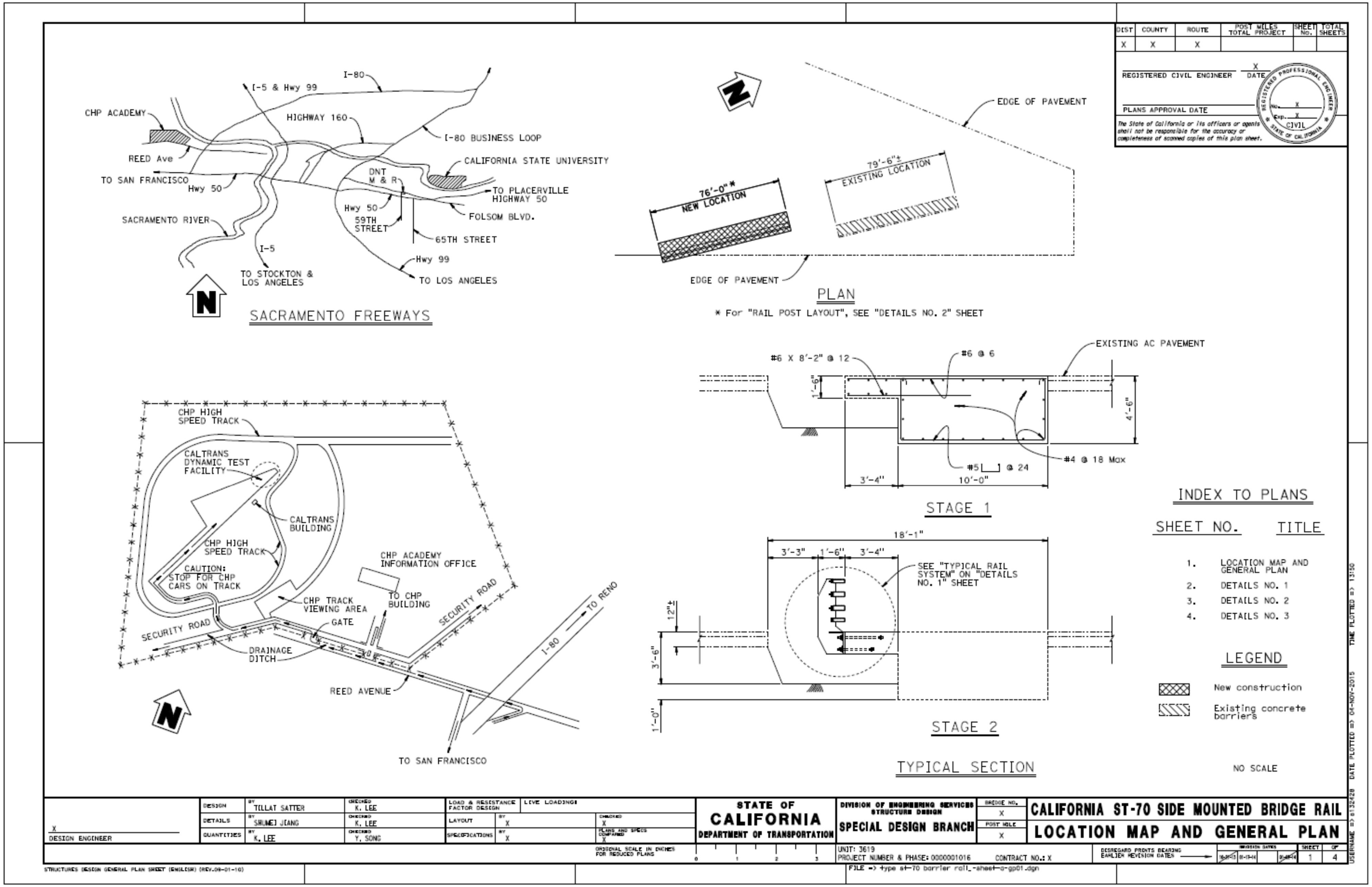


Figure 10-1. CA ST-70SM Side Mounted Bridge Rail (Title Page)

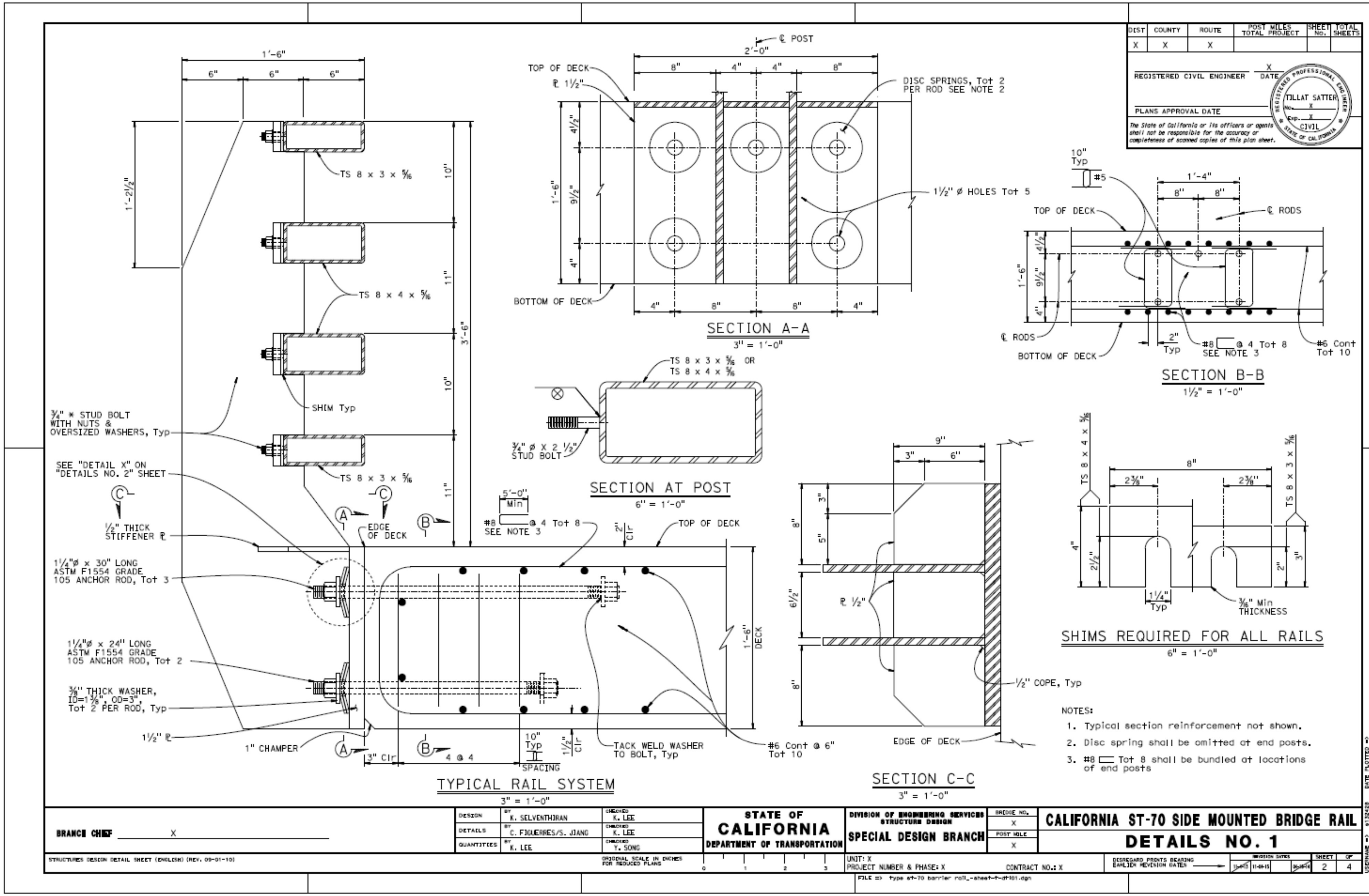


Figure 10-2. CA ST-70SM Side Mounted Bridge Rail (Details Page 1)

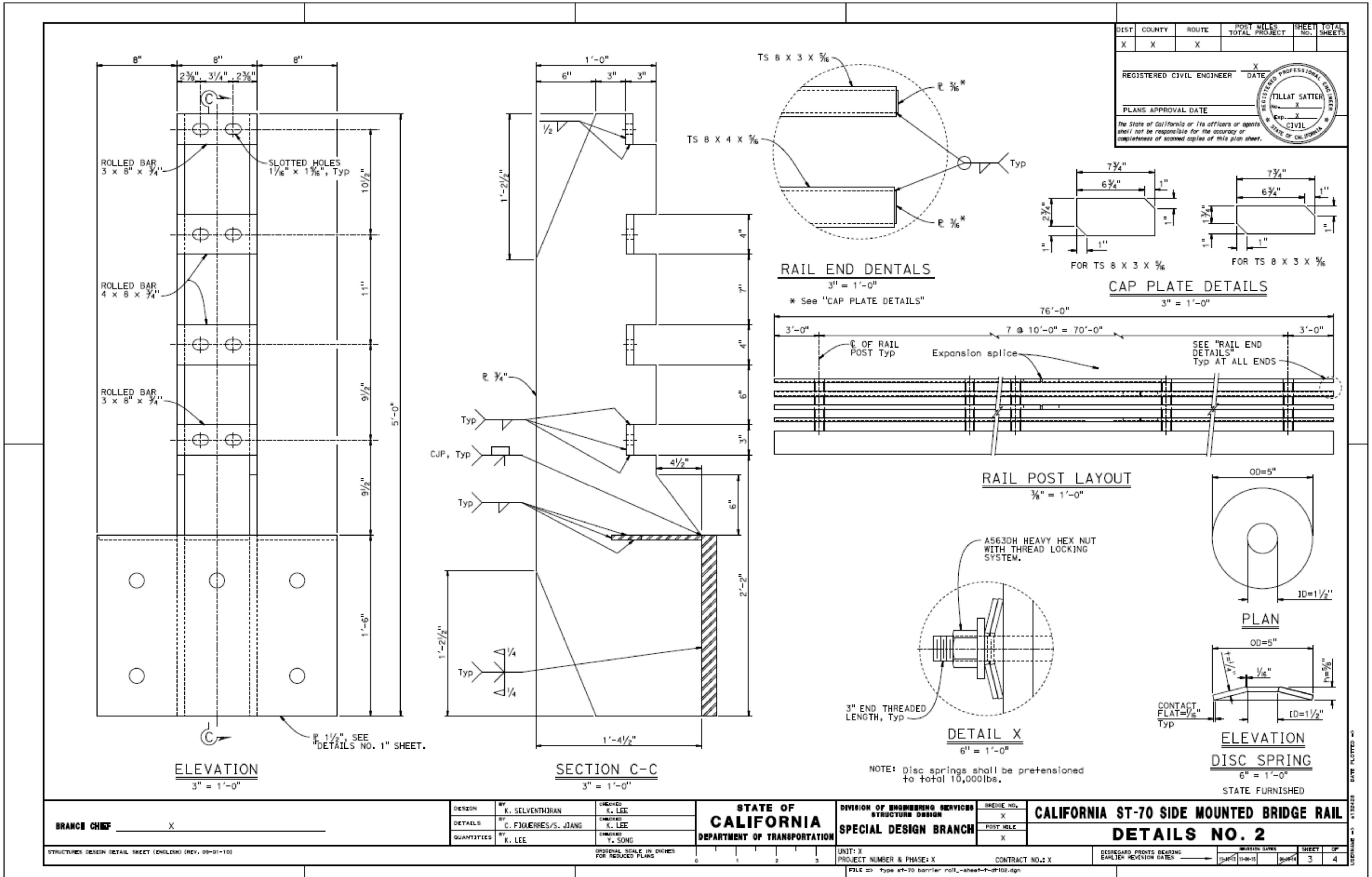


Figure 10-3. CA ST-70SM Side Mounted Bridge Rail (Details Page 2)

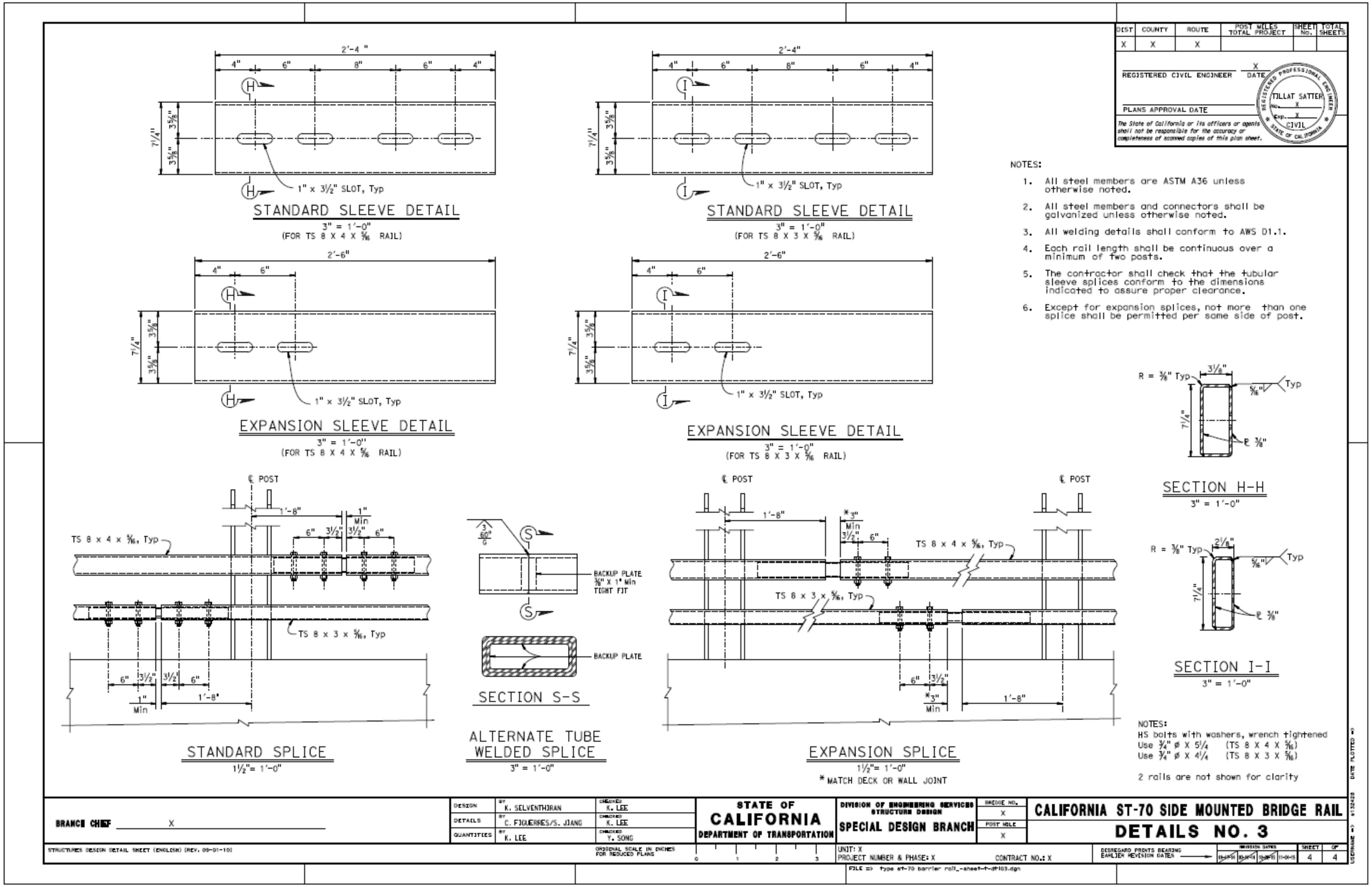


Figure 10-4. CA ST-70SM Side Mounted Bridge Rail (Details Page 3)

State of California
Department of Transportation

Structural Materials Testing Laboratory
5900 Folsom Boulevard, Sacramento, CA 95819

TEST REPORT

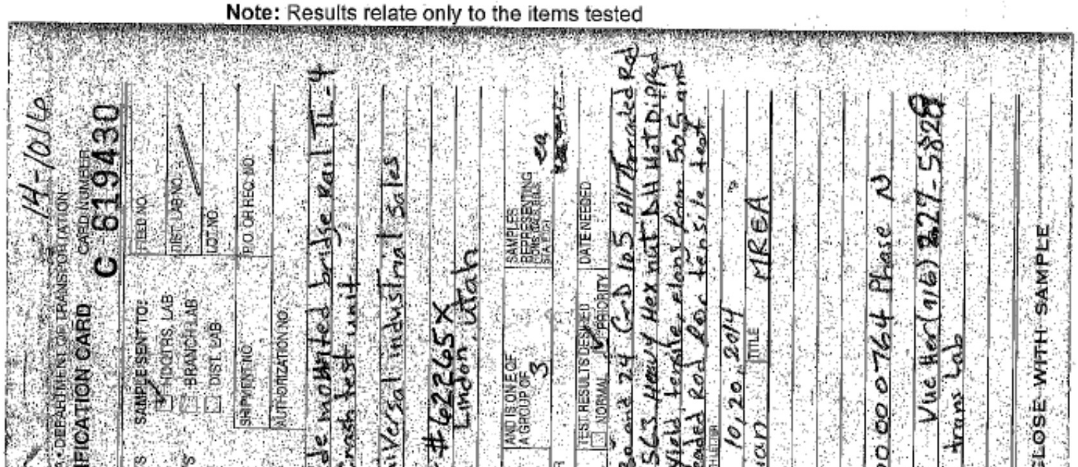
ACCREDITED
TESTING CERT # 2364.01

Remarks ref: ASTM F1554, A563, A153/F2329, TM03. Bolt Heat #62265X; Nut Lot #17075-M50465. Bridge Rail Components for Crash Test Unit.

Sample No: SM-14-1016
Date Sampled: 10/20/14 **Date Rec'd:** 10/20/14 **Date Reported:** 10/27/14
Lot No: N/A **TL-101 / SIC No:** C619430
Contract/Permit No: Stock
Material: 1.25" F1554 Grade 105 HDG Threaded Rods w/ HDG Nuts.
Manufacturer: Universal Industrial / Unytite
Sampler: Ali Zalekian

Results: SAMPLES SUBMITTED COMPLY WITH MATERIAL SPECIFICATIONS.

Note: Results relate only to the items tested


STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION
SAMPLE IDENTIFICATION CARD
CARD NUMBER C 619430
10-20 14-1016
Sample of: Side mounted bridge Rail TL-4
For use in: Crash test unit
Sample from: Universal industrial Sales
Location of source: Heat #62265X Lindon, Utah
Remarks: 1 1/4 x 30 and 24 C-D 105 All Threaded Rod and ASTM A563 Heavy Hex nut D.H Hot Dipped. Please test for Yield, tensile, elong. from 50% and test all Threaded Rod for tensile test
Date sampled: 10, 20, 2014
By: Ali Zalekian Title: MREA
Cont. No.: 0000000764 Phase N
Res. Engr. or Supt.: Vue Her (916) 227-5828
Address: trans Lab
ENCLOSE WITH SAMPLE

Print

.500 SAMPLES

Caltrans

Department of Transportation
Structural Materials Testing Laboratory
UTM: BALDWIN 60 Kip

SM Number = 14-1016

Temperature 70°

Sample	Heat Number	Diameter	Area	Stress at Offset	Tensile Strength	Elongation in 4 x d	Tested By
		(in)	(in^2)	(psi)	(psi)	(%)	
5XA	62265X	0.501	0.1971	135780	142460	19.2	bewing
5XB	62265X	0.502	0.1979	135239	143320	18.8	bewing
				OK	OK	OK	

Monday, October 27, 2014 Page 1 of 1 1:26 PM

STRUCTURAL MATERIALS TESTING LABORATORY
FORM TM-3 (REV. 07/11)

APPROVED FOR USE BY SMTL QUALITY MANAGER

FASTENER ASSEMBLY WORKSHEET

SM Number	14-1016	Lot Number	N/A	Date Received	10/20/14
Contract Number	0000000764-N	TL-0101 Number	C619430	Date Tested	10/23/14
Lab Technician	FRED	Test Temperature	72°	Page 1 of 1	

BOLTS: F1554 Grade 105 HDG

Sample No.	1A	1B	1C				
Heat / Mfg. Lot No.	62265X	→					
Product Markings	PAB AB105	→					
Size	1 1/4"	→					
Pitch Diameter	—	—	—				
Bolt Length	24"	→					
Ring Gage Go/No-Go	OK/GO	→		✓			
Zinc Coating Thick.	5.08	5.15	4.98	✓			
Hardness: Rc / Rb	~~Full~~	—	—				
Spacing	~~Full~~	—	.500				
5.00 ~~Wedge~~ Axial Tensile	135831			✓			

NUTS: A563 HDG

Sample No.	1A	1B	1C	1D	1E		
Mfg. Lot No.	7075-M50465	→					
Product Markings	DH	→					
Size	1 1/4"	→					
Plug Gage Go/No-Go	OK/GO	→				✓	
Zinc Coating Thick.	4.75	4.13	4.96	4.60	4.42	✓	
Hardness: Rc / Rb	Pulled with Rod	—	—	—	—		
Spacing		—	—	—	—		
Nut Proof Load		148258	148721	—	—	✓	

WASHER: Tubing

Sample ~~No.~~	~~F2~~	—	~~E2~~				
Mfg. Lot No.	—	—	—				
Product Markings	—	—	—				
Zinc Coating Thick.							
Hardness: Rc / Rb	—	—	—				
Spacing	—	—	—				

F1554 Grade 105 Rod & Nut proof

State of California
Department of Transportation
Structural Materials Testing Laboratory
UTM: SATEC 400

SM Number = 14-1016

Temperature___________

Sample	Size	Area	Peak Load	Tensile Strength	Stress at Offset	Load at Offset	Comments
		(in^2)	(lbf)	(psi)	(psi)	(lbf)	
1A	F1554 Grade 105 1-1/4" x 24" Allthread Rod	0.969 OK	135831 OK	140177 OK	130270 OK	126231 OK	F1554 Grade 105
1B	1¼"		148258				Nut Proof Load
1C	1¼"		148721 OK				Nut Proof Load

Tuesday, October 28, 2014 Page 1 of 1 10:59 AM

State of California
Department of Transportation

Structural Materials Testing Laboratory
5900 Folsom Boulevard, Sacramento, CA 95819

TEST REPORT

ACCREDITED
TESTING CERT # 2364.01

Remarks ref: ASTM A500, A123, TM06. 8"x 4"x .313" Tube F2 Heat #???; 8"x 3"x .313" Tube E2 Heat #???.

Sample No: SM-14-1017
Date Sampled: 10/20/14 **Date Rec'd:** 10/20/14 **Date Reported:** 10/29/14
Lot No: N/A **TL-101 / SIC No:** C619431
Contract/Permit No: Stock
Material: 8"x 4"x .313" & 8"x 3"x .313" A500 HDG Steel Rectangle Tubing For Bridge Rail.
Manufacturer: Universal Industrial / Atlas Tube
Sampler: Ali Zalekian

Results: SAMPLES SUBMITTED COMPLY WITH MATERIAL SPECIFICATIONS.

Note: Results relate only to the items tested

10-20 SM-14-1017
STATE OF CALIFORNIA - DEPARTMENT OF TRANSPORTATION
SAMPLE IDENTIFICATION CARD
TL-0101 (REV. 10/92)
CARD NUMBER C 619431
PRELIMINARY TESTS / PROCESS TESTS / ✓ ACCEPTANCE TESTS / INDEPENDENT ASSURANCE TESTS: DIST. LAB / TRANS. LAB / SPECIAL TESTS
SAMPLE SENT TO: ✓ HDQTRS. LAB / BRANCH LAB / DIST. LAB
FIELD NO. / DIST. CAB NO. / OT NO. / P.O. OR REQ. NO. / SHIPMENT NO. / AUTHORIZATION NO.
SAMPLE OF: side mounted bridge rail TL-4
FOR USE IN: Crash test unit
SAMPLE FROM: Universal industrial sales
8"x 4"x 5/16 - F2
DEPTH: 8"x 3"x 5/16 - E2
LOCATION OF SOURCE: Atlas ABC Carl, chicago
THIS SAMPLE IS/SHIPPED IN / NO. CONTAINERS — AND IS ONE OF X GROUP OF 2 — SAMPLES REPRESENTING: ea
OWNER OR MANUFACTURER
TOTAL QUANTITY AVAILABLE — TEST RESULTS DESIRED: NORMAL / PRIORITY — DATE NEEDED
REMARKS: 8.0x4.0x5/16 ASTM A500-13 Grade B&C
Please test for yield, tensile, elong, and Galv Thickness from steel tube
DATE SAMPLED: 10/21/2014
BY: Ali Zalekian TITLE: MREA
DIST., CO., RTE., PM:
LIMITS:
CONT. NO.: 00 00000 764 Phase 10
FED. NO.:
RES. ENGR. OR SUPT.: Vue Her (916) 227-5828
ADDRESS: trans Lab
CONTRACTOR:
ENCLOSE WITH SAMPLE

Lab Manager Quality Manager

Print

Flat Specimens

Caltrans

Department of Transportation
Structural Materials Testing Laboratory
UTM: BALDWIN 60 Kip

SM Number = 14-1017

Temperature 72

Grade B= 23% min
Grade C= 21% min

Sample	Heat Number	Width (in)	Thickness (in)	Area (in^2)	Stress at Offset (psi)	Tensile Strength (psi)	Total Elongation (%)
F2A-T	F2	0.5	0.294	0.147	66868	76905 OK	22.7 Grade B - Low
F2B-T	F2	0.5	0.294	0.147	66125 OK	76857	22.3 Grade C - Pass
F2A-L	F2	0.501	0.295	0.1478	69015 OK	79242 OK	25 OK
F2B-L	F2	0.501	0.296	0.1483	69612	78847	24.4
E2A-T	E2	0.501	0.287	0.1438	57724	71975	26.1
E2B-T	E2	0.501	0.287	0.1438	57943 OK	72072 OK	22.9 OK
E2A-L	E2	0.498	0.292	0.1454	56927	74312	26.5 OK
E2B-L	E2	0.498	0.295	0.1469	61596 OK	75623 OK	28.2

Tuesday, October 28, 2014 Page 1 of 1 2:43 PM

STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION

TRANSPORTATION LABORATORY
REPORT OF TESTS

TL-619 (REV. 5/95)

ADA Notice
For individuals with sensory disabilities, this document is available in alternate formats. For information call (916) 654-6410 or TDD (916) 654-3880 or write Records and Forms Management, 1120 N Street, MS-89, Sacramento, CA 95814.

S.M. NO. 14-1017
DATE RECEIVED 10/20
T 101 NO. C619431
CONT., W.O., OR P.O. NO. Stock
LOT NO.
F.A.P. NO.

TEST NAME
DISTRICT
COUNTY
ROUTE
POST MILES
CONTRACTOR
SAMPLED BY
DATE SAMPLED
SUPPLY SOURCE
AGENCY
MANUFACTURER
MATERIAL TESTED FOR

SAMPLE		HEAT NO.	SIZE	AREA		YIELD		ULTIMATE		ELONG.	RED AREA	COLD BEND	CHEMICAL ANALYSIS					A OR E
NO.	TYPE			BEFORE	AFTER	ACTUAL	PSI	ACTUAL	PSI	%	%		C	MN	P	S	SI	
F2A-T		F2	T .294 / W .500	2.0005	2.4555		66868		76905	22.7								
F2B-T		F2	T .294 / W .500	2.0005	2.4465		66125		76857	22.3								
F2A-L		F2	T .295 / W .501	2.0000	2.5000		69015		79242	25.0								
F2B-L		F2	T .296 / W .501	2.0000	24.885		69612		78847	24.4								
E2A-T		E2	.287 / .501	2.0000	2.5225		57724		71975	26.1								
E2B-T		E2	.287 / .501	2.0000	2.4585		57943		72072	22.9								
E2A-L		E2	.292 / .498	2.0000	2.5300		56927		74312	26.5								
E2B-L		E2	.295 / .498	2.0000	2.5645		61596		75623	28.2								

SPECIFICATIONS

REMARKS

DATE TESTED 10/28/14
TESTED BY
APPROVED BY

STRUCTURAL MATERIALS TESTING LABORATORY
FORM TM-3 (REV. 07/11)

APPROVED FOR USE BY SMTL QUALITY MANAGER
[signature]

FASTENER ASSEMBLY WORKSHEET

SM Number	14-1017	Lot Number	N/A	Date Received	10/20/14
Contract Number	00000000764-N	TL-0101 Number	C619431	Date Tested	10/23/14
Lab Technician	FRED	Test Temperature	72	Page ____ of ____	

BOLTS: Tubing

Sample No.	F2		E2				
Heat / Mfg. Lot No.							
Product Markings							
Size							
Pitch Diameter							
Bolt Length							
Ring Gage Go/No-Go							
Zinc Coating Thick.	3.83		.489				
Hardness: Rc / Rb							
Spacing							
Wedge Tensile							

NUTS:

Sample No.							
Mfg. Lot No.							
Product Markings							
Size							
Plug Gage Go/No-Go							
Zinc Coating Thick.							
Hardness: Rc / Rb							
Spacing							
Nut Proof Load							

WASHER:

Sample No.							
Mfg. Lot No.							
Product Markings							
Zinc Coating Thick.							
Hardness: Rc / Rb							
Spacing							

Camblin Steel
SERVICE, INC. SINCE 1954

Thm

CONTRACTOR'S LICENSE NO. 218839

4175 CINCINNATI AVENUE
ROCKLIN, CA 95765
(916) 644-1300
FAX (916) 408-6999

MILL CERTIFICATE OF COMPLIANCE

SUBJECT PROJECT: Type SE-70 Rail JOB # 14-233

In accordance with the Specifications and requirements for the above referenced subject project, we do hereby certify to the best of our knowledge, that any and all reinforcing steel shipped corresponds to the Mill Certifications that accompany this load.

ITEM(S) SHIPPED: Fndn Slab RELEASE: 1

AUTHORIZED REPRESENTATIVE: [signature] DATE: 10/30/14

SIZE	MILL	HEAT NO.	GRADE	WEIGHT
4	CMC	~~4039110~~	~~60~~ A706	2525
		4039162		
5	CMC	4039339	A706	1835
6	CMC	4038499	A706	4203
8	CMC	4039761	A706	1909

WE CERTIFY THAT ALL MANUFACTURING PROCESSES FOR THE MATERIALS OCCURRED IN THE UNITED STATES.

TOTAL WEIGHT 10,472

CMC STEEL ARIZONA
11444 E. GERMANN RD.
MESA AZ 85212-9700

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Jacob Selzer – CMC Steel AZ
Quality Assurance Manager

HEAT NO.:4039162 SECTION: REBAR 13MM (#4) 60'0" A706 GRADE: A706-14 Grade 420 (60) ROLL DATE: 08/30/2014 MELT DATE: 08/30/2014	SOLD TO	Camblin Steel Service Inc 4175 Cincinnati Ave Rocklin CA US 95765-1402 9166441300 9169251502	SHIP TO	Camblin Steel Service Inc 4175 Cincinnati Ave Rocklin CA US 95765-1402 9166441300 9169251502	Delivery#: 81328359 BOL#: 70483657 CUST PO#: Mark CUST P/N: DLVRY LBS / HEAT: 30855.000 LB DLVRY PCS / HEAT: 770 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.25%	Elongation test 1	16%		
Mn	1.18%	Elongation Gage Lgth test 1	8IN		
P	0.012%	Bend Test Diameter	1.500IN		
S	0.029%	Bend Test 1	Passed		
Si	0.19%	Rebar Deformation Avg. Heigh	0.026IN		
Cu	0.32%	Rebar Deformation Max. Gap	0.120IN		
Cr	0.11%				
Ni	0.12%				
Mo	0.022%				
V	0.000%				
Cb	0.000%				
Sn	0.011%				
Al	0.001%				
N	0.0141%				
Carbon Eq A706	0.47%				
Yield Strength test 1	73.9ksi				
Yield Strength test 1 (metri	510MPa				
Tensile Strength test 1	100.6ksi				
Tensile Strength 1 (metric)	694MPa				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

09/05/2014 00:05:01
Page 1 OF 1

CMC STEEL ARIZONA
11444 E. GERMANN RD.
MESA AZ 85212-9700

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Jacob Selzer – CMC Steel AZ
Quality Assurance Manager

HEAT NO.:4039339 SECTION: REBAR 16MM (#5) 60'0" A706 GRADE: A706-14 Grade 420 (60) ROLL DATE: 09/08/2014 MELT DATE: 09/08/2014	S O L D T O	Camblin Steel Service Inc 4175 Cincinnati Ave Rocklin CA US 95765-1402 9166441300 9169251502	S H I P T O	Camblin Steel Service Inc 4175 Cincinnati Ave Rocklin CA US 95765-1402 9166441300 9169251502	Delivery#: 81328400 BOL#: 70484633 CUST PO#: Mark CUST P/N: DLVRY LBS / HEAT: 49056.000 LB DLVRY PCS / HEAT: 784 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.26%	Elongation test 1	15%		
Mn	1.18%	Elongation Gage Lgth test 1	8IN		
P	0.010%	Bend Test Diameter	1.875IN		
S	0.027%	Bend Test 1	Passed		
Si	0.19%	Rebar Deformation Avg. Spaci	0.410IN		
Cu	0.26%	Rebar Deformation Avg. Heigh	0.038IN		
Cr	0.09%	Rebar Deformation Max. Gap	0.124IN		
Ni	0.08%				
Mo	0.016%				
V	0.001%				
Cb	0.000%				
Sn	0.010%				
Al	0.001%				
N	0.0110%				
Carbon Eq A706	0.47%				
Yield Strength test 1	72.6ksi				
Yield Strength test 1 (metri	501MPa				
Tensile Strength test 1	93.2ksi				
Tensile Strength 1 (metric)	643MPa				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

09/09/2014 11:47:09
Page 1 OF 1

CMC WEST DISTRIBUTION
11444 E. GERMANN RD.
MESA AZ 85212-9700

CERTIFIED MILL TEST REPORT
For additional copies call:

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

HEAT NO.:4038499 SECTION: REBAR 19MM (#6) 60'0" A706 GRADE: A706-14 Grade 420 (60) ROLL DATE: 08/04/2014 MELT DATE:	S O L D T O	Camblin Steel Service Inc 4175 Cincinnati Ave Rocklin CA US 95765-1402 9166441300 9169251502	S H I P T O	CPU Modesto Taxable 300 Codoni Rd Modesto CA US 95357-0506 2098396500	Delivery#: 81323494 BOL#: 1070080 CUST PO#: Mark 08272014 CUST P/N: DLVRY LBS / HEAT: 36768.000 LB DLVRY PCS / HEAT: 408 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.27%	Elongation test 1	14%		
Mn	1.21%	Elongation Gage Lgth test 1	8IN		
P	0.013%	Bend Test Diameter	3.000IN		
S	0.025%	Bend Test 1	Passed		
Si	0.21%	Rebar Deformation Avg. Spaci	0.486IN		
Cu	0.28%	Rebar Deformation Avg. Heigh	0.058IN		
Cr	0.15%	Rebar Deformation Max. Gap	0.100IN		
Ni	0.12%				
Mo	0.031%				
V	0.003%				
Cb	0.000%				
Sn	0.012%				
Al	0.001%				
N	0.0114%				
Carbon Eq A706	0.49%				
Yield Strength test 1	72.6ksi				
Yield Strength test 1 (metri	501MPa				
Tensile Strength test 1	97.7ksi				
Tensile Strength 1 (metric)	674MPa				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

08/27/2014 12:56:13
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CMC STEEL ARIZONA
11444 E. GERMANN RD.
MESA AZ 85212-9700

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Jacob Selzer – CMC Steel AZ
Quality Assurance Manager

	SOLD TO	SHIP TO	
HEAT NO.:4039761 SECTION: REBAR 25MM (#8) 60'0" A706 GRADE: A706-14 Grade 420 (60) ROLL DATE: 09/22/2014 MELT DATE: 09/22/2014	Camblin Steel Service Inc 4175 Cincinnati Ave Rocklin CA US 95765-1402 9166441300 9169251502	Camblin Steel Service Inc 4175 Cincinnati Ave Rocklin CA US 95765-1402 9166441300 9169251502	Delivery#: 81341412 BOL#: 70488090 CUST PO#: Mark 9-18-14 CUST P/N: DLVRY LBS / HEAT: 42616.000 LB DLVRY PCS / HEAT: 266 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.25%	Elongation test 1	14%		
Mn	1.18%	Elongation Gage Lgth test 1	8IN		
P	0.009%	Bend Test Diameter	4.000IN		
S	0.025%	Bend Test 1	Passed		
Si	0.20%	Rebar Deformation Avg. Spaci	0.664IN		
Cu	0.39%	Rebar Deformation Avg. Heigh	0.068IN		
Cr	0.13%	Rebar Deformation Max. Gap	0.152IN		
Ni	0.14%				
Mo	0.032%				
V	0.002%				
Cb	0.000%				
Sn	0.012%				
Al	0.001%				
N	0.0145%				
Carbon Eq A706	0.47%				
Yield Strength test 1	73.9ksi				
Yield Strength test 1 (metri	510MPa				
Tensile Strength test 1	95.2ksi				
Tensile Strength 1 (metric)	657MPa				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

09/22/2014 08:47:21
Page 1 OF 1

Camblin Steel Services
4175 Cincinnatti Ave
Rocklin, CA 95765-
Phone: (916)644-1300 FAX: (916)408-6999

JOB NUMBER	RELEASE NUMBER	REQ. DELIVERY DATE	PAGE
14233	1		1 of 1

JOB NAME	CC
TYPE ST-70 RAIL	HRT

CUSTOMER	BY
C.G. GREEN CONST.	RH

MATERIAL TYPE	REFERENCE	DRAWING ID	DESCRIPTION
Rebar, Grade A706, Black	RED	R-1	Rail Foundation Slab

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
1	64	8	11-02	8A10	17	1909		5-00	1-022	5-00								H10
	64.					1909.												
2	20	6	10-04	6A5	25	310		0-06	3-101	0-06	3-101	1-08		3-101		0-01		P16
3	153	6	12-10			2948												0
4	77	6	8-02			945												0
	250.					4203.												
5	39	5	18-10	5A4	S9	766	0-07	4-01	9-06	4-01			0-07					L05
6	384	5	2-08	5A9	17	1069		0-10	1-002	0-10								H06
	423.					1835.												
7	20	4	4-06	4A8	25	60		0-06	0-11	0-06	0-11	1-08		0-11		0-01		P09
8	90	4	30-00			1804												0
9	45	4	22-00			661												0
	155.					2525.												

Miscellaneous Items

DOC2.5	1 1/2 x 2 x 2 1/2" COMBINATION DOBIES	20 Pcs	0 Lbs	
DOP3	3X3X3" PLAIN DOBIES	80 Pcs	0 Lbs	
DOW3	3X3X3" WIRED DOBIES	80 Pcs	0 Lbs	

Total Weight: 10,472 Lbs

Longest Length: 30-00

WEIGHT SUMMARY

	TOTAL			STRAIGHT			LIGHT BENDING			HEAVY BENDING		
SIZE	ITEMS	PIECES	LBS	ITEMS	PIECES	LBS	ITEMS	PIECES	LBS	ITEMS	PIECES	LBS
Rebar, Grade A706, Black												
4	3	155	2525	2	135	2465	1	20	60	0	0	0
5	2	423	1835	0	0	0	1	39	766	1	384	1069
6	3	250	4203	2	230	3893	1	20	310	0	0	0
8	1	64	1909	0	0	0	0	0	0	1	64	1909
	9	892	10472	4	365	6358	3	79	1136	2	448	2978

MISCELLANEOUS PRODUCT SUMMARY

DOC2.5	1 1/2 x 2 x 2 1/2" COMBINATION DOBIES	20 Pcs	0 Lbs
DOP3	3X3X3" PLAIN DOBIES	80 Pcs	0 Lbs
DOW3	3X3X3" WIRED DOBIES	80 Pcs	0 Lbs
Sub-Total			0 Lbs

Total Weight: 10,472 Lbs

Longest Length: 30-00

 CUSTOMER COPY Tuesday, October 28, 2014 2:53 PM

Camblin Steel Services, Inc. — Sacramento, CA

Item Bundle Check List

Session: 001312 Run: 131347 Fab Shop: Sacramento, CA Shift: Shift 1 Fab Date: 10/28/2014 Caption:

HRT Job Name: TYPE ST-70 RAIL Customer: C.G. GREEN CONST. Job: 14233 Release: 1 Description: Rail Foundation Slab Ship Date: **RED**

Tag	Load	Color / Shape	Quantity	Size	Length	Mark	Shape	Lbs	Grade	Coating	BC	Page / Item	CL / Tag
Bent													
1	______		32	8	11-02	8A10	17	954	A706	Blk	H	1 / 1	1 / 1
2	______		32	8	11-02	8A10	17	954	A706	Blk	H	1 / 1	1 / 2
3	______		20	6	10-04	6A5	25	310	A706	Blk	P	1 / 2	2 / 4
7	______		39	5	18-10	5A4	S9	766	A706	Blk	L	1 / 5	3 / 1
8	______		192	5	2-08	5A9	17	535	A706	Blk	H	1 / 6	3 / 2
9	______		192	5	2-08	5A9	17	535	A706	Blk	H	1 / 6	3 / 3
10	______		20	4	4-06	4A8	25	60	A706	Blk	P	1 / 7	4 / 3
Straight													
4	______		135	6	12-10			2,602	A706	Blk	0	1 / 3	2 / 1
5	______		18	6	12-10			347	A706	Blk	0	1 / 3	2 / 2
6	______		77	6	8-02			945	A706	Blk	0	1 / 4	2 / 3
11	______		90	4	30-00			1,804	A706	Blk	0	1 / 8	4 / 1
12	______		45	4	22-00			661	A706	Blk	0	1 / 9	4 / 2

v13.01.4021 Tuesday, October 28, 2014 2:54:21 PM Page 1 of 2

11. References

1. *Manual for Assessing Safety Hardware 2009 (MASH 09).* American Association of State Highway and Transportation Officials. Washington, DC. 2009.
2. Her, Vue, "Compliance Crash Testing of Side Mounted Bridge Rail." *Preliminary Investigation* March 6, 2013. Web. 4/10/2018. <http://www.dot.ca.gov/research/researchreports/preliminary_investigations/docs/side_mounted_tl4_preliminary_investigation_final_combined.pdf>
3. Rosson, Barry T., Faller, Ronald K., and Ritter, Michael A. *Performance Level 2 and Test Lever 4 Bridge Railings for Timber Decks.* Transportation Research Record 1500. Pgs. 102-111
4. Ronald K. Faller, Michael A. Ritter, Barry T. Rosson, Michael D. Fowler, and Sheila R. Duwadi. *Two Test Level 4 Bridge Railing and Transition Systems for Transverse Timber Deck Bridges.* Transportation Research Record 1696. Pgs. 334-351

12. Document Revision History

Date	Description
x/x/2018	Initial publication