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COMPLIANCE CRASH TESTING OF THE TYPE 732SW BRIDGE RAIL

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This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled “COMPLIANCE CRASH TESTING OF THE TYPE 732SW BRIDGE RAIL.”

16. ABSTRACT

The Type 732SW bridge rail is an updated version of the Type 26 bridge rail and was tested for compliance to the Manual for Assessing Safety Hardware (MASH 09) as a part of this research project.

The 732SW is a taller, stronger version of the Type 26 with a sidewalk. It is comprised of a sidewalk, vertical concrete wall, and steel handrail for pedestrians. The barrier tested was about 24 m (79 ft) long and was constructed at the Caltrans Dynamic Test Facility in West Sacramento, California.

Three crash tests were conducted under MASH 09: Test 3-11 (the 2270P pickup at TL-3), Test 3-10 (the 1100C small car at TL-3), and Test 2-10 (the 1100C small car at TL-2) because Test 3-10 resulted in a ridedown acceleration that was outside of the MASH 09 limits. The results of Tests 3-11 and 2-10 were within the limits of the MASH 09 guidelines.

The Type 732SW bridge rail is recommended for approval on California highways requiring TL-2 bridge rails with pedestrian traffic. Since it is symmetric, the Type 732SW is also recommended in locations where a reverse hit is possible.

17. KEY WORDS
Barriers, Crash Test, Bridge Rail, Concrete, Steel, Vehicle Impact Test, Pedestrian, Sidewalk, Vertical, Type 732SW

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OFFICE OF SAFETY INNOVATION AND COOPERATIVE RESEARCH
ROADSIDE SAFETY RESEARCH GROUP

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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 by the California Department of Transportation, Roadside Safety Research Group.

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-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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C.E. Green, Inc., of Orangevale, CA, constructed the test article.

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1. Introduction

1.1. Problem

The Type 26 bridge rail is an existing design that had been built on numerous bridges throughout the state, providing adequate service since it first became a California Department of Transportation (Caltrans) Standard Plan in 1973. It had never been crash tested, however. A project to test the crashworthiness of the Type 26 under NCHRP Report 350 was initiated in the early 2000s but the project was modified to test a higher priority bridge rail (the Type ST-20). When the project was restarted, new crash testing guidelines (Manual for Assessing Safety Hardware (MASH 09)) had been developed and the Federal Highway Administration (FHWA) had established dates by which new products must be tested to the new standards. Because barrier construction and crash testing could not be completed by FHWA's deadline for NCHRP Report 350 testing, a taller, stronger version of the Type 26 with a sidewalk had to be developed and crash tested according the MASH 09 guidelines. This new version was named the Type 732SW.

1.2. Objective

The objective of this project was to crash test the Type 732SW (a modified barrier based on the Type 26 bridge rail) that was designed to meet the MASH 09 Test Level 3 criteria for longitudinal barriers. It was originally intended that two tests would need to be successful in order to comply with MASH 09 Test Level 3: Test 3-11, a 2270-kg (5000-lb) pickup truck impacting the barrier at 100 km/h (62 mph) with an impact angle of 25° and Test 3-10, an 1100-kg (2425-lb) sedan impacting the barrier at 100 km/h (62 mph) and 25°. However, as will be explained later, Test 3-10 did not meet all MASH 09 criteria. Because the bridge rail will only be used under TL-2 conditions, FHWA concurred that a passing 3-11 test and a passing 2-10 test with an 1100-kg (2425-lb) sedan impacting the barrier at 70 km/h (43 mph) with an impact angle of 25° would be sufficient to qualify the barrier as TL-2.

1.3. Background

The Type 26 bridge rail has been a Caltrans standard plan since June 1973. The rail is essentially a vertical, reinforced concrete wall on a sidewalk, outfitted with a pedestrian steel tubular handrail or chain link fence on top (See Figure 1-1). The top of the concrete portion of the rail is 685 mm (27 in) above the sidewalk surface, which in turn is about 225 mm (9 in) off the deck. The Type 26 is primarily built by Caltrans on routes requiring pedestrian walkways and having posted speeds of 70 km/h (45 mph) or less.

The FHWA mandated that all crash testing after January 1, 2011 be conducted according to MASH 09. Caltrans followed suit with the adoption of MASH. Caltrans' Office of Design and Technical Services was able to determine that the Type 26 would likely not meet MASH criteria so they decided to design an updated bridge rail. It was therefore modified to be taller and stronger in an effort to meet the more stringent MASH criteria. The new design was called the Type 732SW.

With FHWA's input, the 732SW bridge rail would need to be tested only to MASH TL-2 for use on highways with posted speed limits of 45 mph or less. For an added factor of safety against vehicle penetration, Caltrans opted to perform TL-3 testing. Successful crash testing would provide Caltrans with a MASH-compliant TL-2 bridge rail with a sidewalk that will likely be used often throughout California.

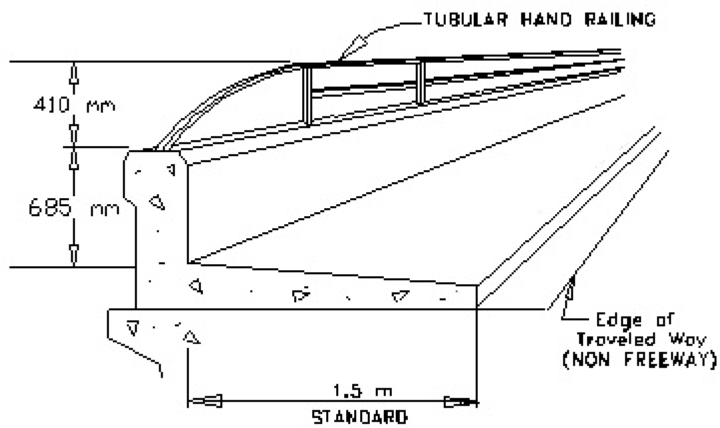


Figure 1-1 - Type 26 Bridge Rail

1.4. Literature Search

A literature search was conducted using the Federal Highway Administration Website, the National Transportation Library, databases within Caltrans, TRIS RIP, and the internet. No similar products were found that had been tested to MASH Test Level 2 (TL-2). The literature search and related communication were summarized in a Preliminary Investigation report titled “Compliance Crash Testing of the Caltrans Type 26 Bridge Rail” dated 11/18/2011.

There are, however, two vertical solid-wall concrete bridge rail designs used outside of California that are approved by the FHWA. One is the 32-inch Vertical Concrete Parapet and the other is its larger sister, the 42-inch Vertical Concrete Parapet. Both were crash tested by the Texas Transportation Institute in 1987, with the 32-inch meeting PL-2 and the 42-inch meeting PL-3 performance levels. The FHWA has granted both designs equivalent NCHRP Report 350 ratings of TL-4 and TL-5 respectively. However, neither one has a sidewalk.

1.5. Scope

A representative section of the Type 732SW bridge rail was constructed at the Caltrans Dynamic Test Facility in West Sacramento. Data were collected from two vehicular crash tests under the intended conditions shown in Table 1-1. These data were analyzed to determine if the Type 732SW met the criteria set forth in MASH 09.

Table 1-1 – Intended Test Conditions

CALTRANS Test #	**Mass kg (lb)**	**Speed km/h (mph)**	**Angle (deg)**	**MASH 09**	
				Test Designation	**Vehicle**
130MASH3P13-01	2270 (5000)	100 (62)	25	3-11	2270P
130MASH3C13-02	1100 (2420)	100 (62)	25	3-10	1100C
*110MASH2C14-01	1100 (2420)	70 (44)	25	2-10	1100C

*This test was conducted with FHWA's concurrence to qualify the bridge rail as TL-2 after test 130MASH3C13-02 failed to meet all MASH 09 criteria for TL-3 longitudinal barriers.

2. Technical Discussion

2.1. Test Conditions

2.1.1. Test Facilities

Each of the crash tests was conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The test area is a large, flat, asphalt concrete surface. There were no obstructions nearby except for a 2 m-high earth berm 40 m downstream from the bridge rail. An existing concrete anchor block (0.9 m (3 ft) deep by 1.1 m (3.6 ft) wide by 24.23 m (80 ft) long) at the north end of the test area was used as a simulated bridge deck for the construction of the Type 732SW bridge rail.

2.1.2. Construction

The Type 732SW bridge rail was designed by the California Department of Transportation's Division of Engineering Services to be a MASH-compliant version of the Type 26. The bridge rail was designed for use on roadways with pedestrians and speed limits of 70 km/h or less. New ADA regulations require at least a 6-foot (1.83 m) sidewalk so the test barrier was constructed with a sidewalk wide enough for the vehicle to have all four tires atop it before impact with the parapet, resulting in a worst-case test. The width chosen was 8 feet, 2 inches (2.5 m).

The bridge rail has a vertical concrete face atop an eight-inch (0.20 m) high concrete curb with a steel handrail on top of the vertical concrete parapet. The height of the parapet is 41 inches above the bridge deck and 32 inches (0.79 m) above the sidewalk where the two come together. For drainage, there is a 1-inch (2.5 cm) drop in sidewalk height from the parapet to the edge of sidewalk adjacent to the road. The handrail is comprised of a 3x2x3/16 tube steel top rail, a 2x2x3/16 tube steel lower rail, and 2x2x3/16 tube steel posts spaced at 9 feet-1.5 inches (2.78 m). The posts are set in mortar in square holes cast into the parapet. The parapet has dimensions shown in the typical section (Figure 2-1). The traffic-side edge of the handrail post is offset 5 inches from the traffic-face of the parapet. A typical section is shown in Figure 2-1 – Type 732SW Test Article Typical Section. See Figure 9-1 and Figure 9-2 for detail drawings.

C.E. Green, Inc. was awarded the contract for construction of the Type 732SW test section. A 80-ft (24.23-m) long test section was constructed at the Caltrans Dynamic Test Facility. One expansion joint was placed in the barrier and sidewalk 48 ft (14.63 m) from the downstream end. An expansion joint was also placed in the steel handrail 7.5 inches (0.19 m) downstream of the concrete expansion joint.

First, the existing concrete bridge overhang was demolished, leaving the transverse #16 (metric) rebar in place for the new overhang. Where the rebar was not salvageable, new #16 (metric) rebar was lap spliced with the existing rebar or drilled and bonded into the anchor block with epoxy. All rebar had a yield-strength of 60 ksi (414 MPa). Additional #5 rebar was shaped and then tied to the existing/new rebar (with the upper portion left exposed after the overhang pour) to anchor the (future) concrete parapet curb to the new overhang. See Figure 2-2.

The new overhang, concrete parapet, and sidewalk were constructed in three separate concrete pours. After the overhang pour was completed (Figure 2-3), the rebar for the parapet was tied to the exposed rebar and additional rebar was left exposed for anchoring the sidewalk to the parapet (Figure 2-4). The parapet was then poured, leaving the sidewalk rebar exposed and blocked out holes in the parapet top for handrail attachment. The rebar for anchoring the sidewalk to the anchor block were then placed and the sidewalk was poured (Figure 2-5). During construction it was discovered that the anchor block was about 8.5 feet (2.6 m) wide rather than 10 feet (3 m) wide. The solution was to anchor the sidewalk to the anchor block closer to the barrier face. See Figure 2-4 for a picture of how the rebar configuration was altered. Concrete from all three pours had a minimum 28-day compressive strength of 4,000 psi (24.8 MPa)[1].

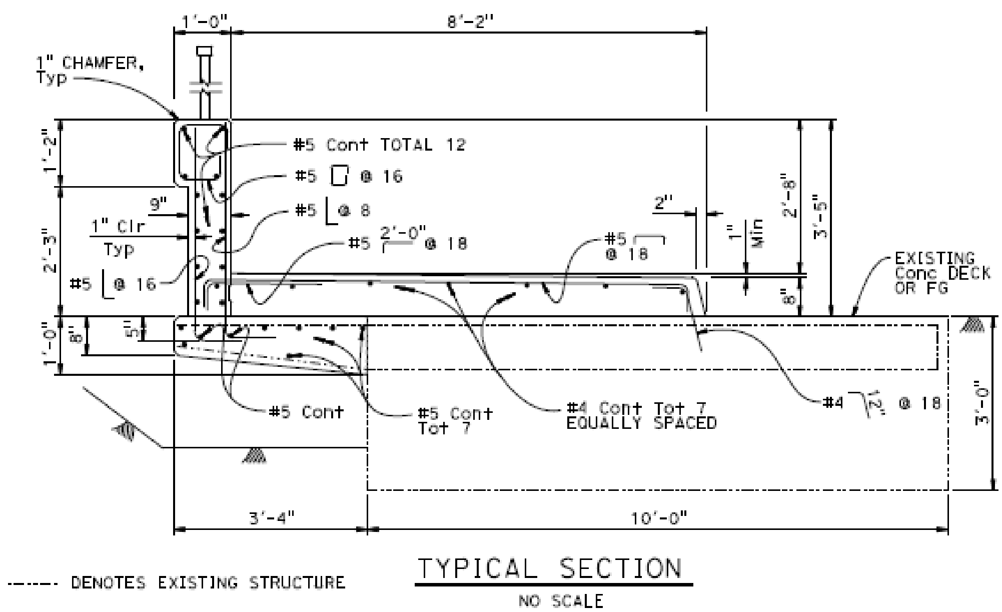


Figure 2-1 – Type 732SW Test Article Typical Section

[1] The concrete compressive strength testing does not fall within the scope of our Lab's A2LA Scope of Accreditation.

Figure 2-2 – New rebar spliced with existing rebar for new bridge deck

Figure 2-3 – New bridge deck in place for Type 732SW bridge rail

Figure 2-4 – Type 732SW formwork in place for the concrete parapet and rebar in place for the sidewalk

Figure 2-5 – Type 732SW after sidewalk pour

Figure 2-6 – Type 732SW with the steel handrail in place

2.1.3. Test Vehicles

The test vehicles complied with the MASH 09. For all tests, the vehicles were in good condition, free of major body damage and were not missing any structural parts. All of the vehicles had standard equipment and front-mounted engines. The vehicle inertial masses for all tests were within acceptable limits (Table 2-1). The CG height for the 2270P vehicle was 28.09 inches, greater than 28 inches as required by MASH 09.

Table 2-1 – Test Vehicle Masses

Test No.	Vehicle	Ballast, kg (lb)	Test Inertial, kg (lb)
130MASH3P13-01	2006 Dodge RAM 1500 Crew Cab	58 (128)	2296 (5062)
130MASH3C13-02	2006 Kia Rio	0	1112 (2452)
*110MASH2C14-01	2006 Kia Rio	0	1122 (2474)

The Dodge RAM 1500 was self-powered. A speed control device was used to limit acceleration once the impact speed had been reached. The Kia Rio in the TL-3 test was towed to the impact speed using a 2:1-mechanical advantage pulley system, with a speed control device installed in the tow vehicle. The Kia Rio in the TL-2 test was towed to the impact speed using a 1:1 pulley system, with a speed control device installed in the tow vehicle. Remote braking was possible at any time during all tests via a wireless remote control. A short distance before the point of impact, the vehicle for test 130MASH3P13-01 was released from the guidance rail and the ignition system was deactivated. In 130MASH3P13-02 and 110MASH2C14-01, the vehicle was released first from the tow cable and second from the guidance rail a short distance from the point of impact. A detailed description of the test vehicle equipment and guidance system is contained in Appendices 8.1 and 8.2.

2.1.4. Data Acquisition System

The impact event of each crash test was recorded with 5 high-speed digital video cameras, one normal-speed digital camcorder, and one digital camera in sequence mode. The test vehicles and the barrier were photographed before and after impact with a normal-speed digital camcorder and a digital camera. Two sets of three orthogonal accelerometers were mounted at the center of gravity in the 2270P and 1100C vehicles to measure acceleration in all three directions. Two sets of three angular rate sensors were also placed at the center of gravity of the 2270P and 1100C vehicles to measure the rates of roll, pitch, and yaw. The data were used in calculating the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation.

A 50th percentile, Hybrid III, anthropomorphic dummy was used in the 1100C tests.

A high-performance data acquisition system manufactured by GMH Engineering (Data Brick 2) was used to record electronic data during Tests 130MASH3P13-01 and 130MASH3C13-02, and 110MASH2C14-01. DaDisp was used to process the digital data into files compatible with Test Risk Assessment Program (TRAP). TRAP was then used to analyze the data.

Transducer data were recorded on two separate GMH Engineering Data Brick 2 digital transient data recorders (TDRs) that were mounted in the test vehicle. The transducers mounted in the vehicle included one set of accelerometers and angular rate sensors at the center of gravity (CG) and one set of accelerometers and angular rate sensors 3.1 in (78.7 mm) behind the CG along the X-axis. The TDR data were reduced using a desktop personal computer running DaDisp 2002 version 6.0 NI NK B18 (pre-processing) and Test Risk Assessment Program (TRAP) version 2.3.2 (post-processing). Accelerometer and angular rate sensors specifications are shown in Table 8-10 – Accelerometer and Angular Rate Sensor Specifications. The coordinate sign convention used throughout this report is the same as described in MASH and is shown in Figure 8-4 – Vehicle Accelerometer Sign Convention.

3. Crash Test Results

3.1. Test 130MASH3P13-01 Impact Description and Results

The impact angle was set at 25° by placement of the guide rail. The vehicle impact angle at the barrier sidewalk was measured to be 24.8°. The impact speed of 62.7 mph (100.9 km/h) was obtained by optical switch data and confirmed by an average of two different speed traps located just upstream from the impact point. The vehicle impacted the sidewalk approximately 4.9 ft (1.5 m) from the upstream end and the vertical face of the concrete wall approximately 22.2 ft (6.8 m) from the upstream end of the barrier. The impact point was chosen to try to maximize the potential for hood snag on a handrail post. The top right corner of the vehicle hood rode over the top of the concrete barrier and caused the handrail to deflect approximately 2 inches (50 mm). There was no permanent deflection of the handrail. The front-right tire contacted the sidewalk edge at t = 0 seconds (impact). The left front tire impacted the sidewalk edge about 0.11 seconds after impact. The bumper contacted the vertical barrier face approximately 0.18 seconds after impact. The right front of the vehicle continued to deform moderately as the vehicle began to yaw slightly left (negative) until the back right side of the vehicle contacted the barrier 0.37 seconds after the initial impact. The vehicle was parallel to the barrier face approximately 0.38 seconds after initial impact. The rear of the vehicle lost contact with the barrier face 0.54 seconds after impact. The vehicle lost contact with the sidewalk about 0.90 seconds after impact. Through video analysis the exit speed and angle when the vehicle exited the vertical face[1] were determined to be 51 mph (82.0 km/h) and 9°, respectively.

The vehicle stayed in contact with the barrier face for about 16 ft (4.9 m). The vehicle came to rest 199 ft (60.6 m) downstream from the initial contact point with the barrier face and 7.5 ft (2.3 m) from the barrier face on the traffic side. The remote brakes did not function as evidenced by the event channel trace.

Figure 3-1 through Figure 3-10 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 130MASH3P13-01 are shown on Figure 3-11.

[1] Impact angle and speed were determined at impact with the sidewalk because the sidewalk is considered part of the barrier. The exit speed and angle would also ideally have been determined when the vehicle left the sidewalk. However, that was indeterminable because the vehicle had left the view of the overhead cameras when it left the sidewalk.

3.1.1. Barrier Damage

There was only minimal permanent damage to the barrier during Test 130MASH3P13-01. There was only very minor scraping of the concrete barrier face and scraping of the steel handrail. There was no structural damage to warrant immediate repair. There was no permanent deflection in the concrete curb or steel rail. As the vehicle impacted the barrier, the dynamic deflection in the steel rail was 1 inch (25 mm), as measured from the overhead camera.

Figure 3-1 – Test article prior to Test 130MASH3P13-01

Figure 3-2 – Type 732SW Barrier after Test 130MASH3P13-01

Figure 3-3 – Close-up of 732SW Barrier after Test 130MASH3P13-01

3.1.2. Vehicle Damage

The right front tire ruptured upon impact with the sidewalk. The right front corner of the vehicle was severely damaged in the impact with the barrier face. The right front fender, hood, bumper, headlamp area, grille, and suspension components were all affected. The passenger side doorframe was deformed outward but the doors remained latched. The left front and right rear tires were also ruptured. The top of the vertical concrete wall caused denting along the entire length of the passenger side as the vehicle continued to contact the barrier after the initial impact. The right front tire was pushed rearward and slightly into the passenger side foot well area. The maximum amount of passenger compartment deformation was 54 mm (2.1 in), which occurred in the floorboard and is below maximum MASH 09 limits. All other occupant compartment deformations were below MASH 09 limits for that area of the vehicle. The passenger side of the windshield cracked but did not separate or enter the occupant compartment.

Figure 3-4 – Test vehicle for Test 130MASH3P13-01

Figure 3-5 – Impact Condition for Test 130MASH3P13-01

Figure 3-6 – Test vehicle after Test 130MASH3P13-01

Figure 3-7 – Right front corner of test vehicle after Test 130MASH3P13-01

Figure 3-8 – Floorboard deformation of test vehicle after Test 130MASH3P13-01

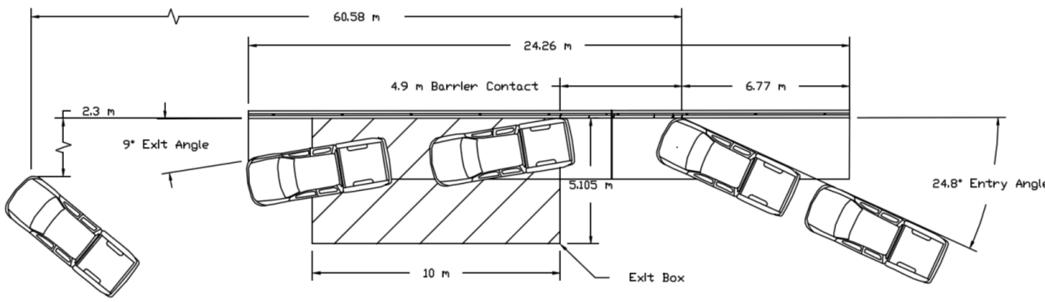
Figure 3-9 – Vehicle windshield before Test 130MASH3P13-01

Figure 3-10 – Vehicle windshield after Test 130MASH3P13-01

Figure 3-11 – Test 130MASH3P13-01 Data Summary Sheet

t = 0.0 sec　t = 0.1 sec　t = 0.2 sec　t = 0.3 sec　t = 0.4 sec

t = 0.5 sec　t = 0.6 sec　t = 0.7 sec　t = 0.8 sec　t = 0.9 sec



Test Barrier

Type: Type 732 SW bridge rail

Length: 80 ft (24.23 m). Handrail posts spaced at 9.125 ft (2.78 m).

Test Date: May 14, 2013

Test Vehicle:

Model: 2006 Dodge RAM 1500 Crew Cab

Inertial Mass: 5062 lb (2296 kg) with ballast

Test Dummy:

Type: None used

Weight/ Position: N/A

Impact/ Exit Conditions:

Impact[1] / Exit Velocity[2]: 62.7 mph (100.9 km/h) / 51 mph (82.0 km/h)

Impact / Exit Angle: 24.8° / 9°

Impact Severity: 117,000 ft-lb (158.6 kJ)

Test Data:

Occ. Impact Velocity (Long / Lat): 17.71 ft/s (5.4 m/s) / 27.9 ft/s (8.5 m/s)

Ridedown Acceleration (Long / Lat): 9.2 g / -8.1 g

ASI 2.06

Exterior: VDS(6)/CDC(7) FR-5, RD-4/01RFEK9, 01RDEK9

Interior: Occupant Compartment Deformation(3) : Maximum 2.1" (54 mm) at floor pan

Max. Roll/Pitch/Yaw Angles: 27.9° /4.9° /-20.6°

Barrier Damage:

Handrail dynamic deflection of 1 inch (25 mm). Minor scraping of steel handrail, superficial concrete scraping, and no permanent lateral deflection of handrail.

---

1 Impact angle and speed were determined when the vehicle impacted the sidewalk.

2 Exit speed and angle were determined when the vehicle exited the vertical face.

3.2. Test 130MASH3C13-02 Impact Description and Results

The impact angle was set at 25° by placement of the guide rail. The vehicle was measured to impact the barrier sidewalk at 25.3°. The impact speed of 59.8 mph (96.3 km/h) was obtained by optical switch data and confirmed by two different speed traps located just upstream from the impact point. The vehicle impacted the sidewalk approximately 6.9 ft (2.1 m) from the upstream end and the vertical face of the concrete wall approximately 26.2 ft (8 m) from the upstream end of the barrier. The front-right tire contacted the sidewalk edge at t = 0 seconds (impact). The right rear tire impacted the sidewalk edge about 0.10 seconds after impact. The bumper contacted the vertical barrier face approximately 0.24 seconds after impact. The right front of the vehicle continued to deform moderately as the vehicle began to yaw slightly left (negative) until the back right side of the vehicle contacted the barrier 0.38 seconds after the initial impact. The vehicle hood snagged slightly on post 4 around 0.29 s, which caused the hood to pop up after the vehicle left all of the overhead camera views. The vehicle was parallel to the barrier face approximately 0.38 seconds after initial impact. The rear of the vehicle lost contact with the barrier face 0.62 seconds after impact. The vehicle stayed in contact with the barrier face for about 8.3 ft (2.5 m). The vehicle lost contact with the sidewalk after the vehicle left the view of both of the overhead cameras. Through video analysis the exit speed and angle were determined to be 51 mph (82.0 km/h) and 9°, respectively[1].

The brakes were applied after the vehicle left the sidewalk. The vehicle came to rest 145 ft (44.1 m) downstream from the initial contact point with the barrier face and 34.5 ft (10.5 m) from the barrier face on the traffic side.

See Figure 3-12 through Figure 3-20 for the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 130MASH3C13-02 are shown on Figure 3-21 on the Data Summary Sheet.

3.2.1. Barrier Damage

There was essentially no permanent damage to the barrier during 130MASH3C13-02. The barrier scraped paint off the vehicle along the length of contact. There was a negligible amount of scraping and gouging of the concrete face. Although the vehicle hood snagged slightly on the barrier post, there was no damage to the post. There would be no need for repair by maintenance crews.

[1] Impact angle and speed were determined at impact with the sidewalk because the sidewalk is considered part of the barrier. The exit speed and angle would also ideally have been determined when the vehicle left the sidewalk. However, that was indeterminable because the vehicle had left the view of the overhead cameras when it left the sidewalk.

Figure 3-12 – Type 732SW test article prior to 130MASH3C13-02

Figure 3-13 – Type 732SW bridge rail face after 130MASH3C13-02

Figure 3-14 – Barrier face scraping after 130MASH3C13-02

3.2.2. Vehicle Damage

The front right wheel absorbed most of the impact with the barrier curb and face. The rim was bent during impact with the curb causing the tire to deflate. The wheel well of the test vehicle sustained most of the damage. Additional damage also occurred to the side of the vehicle as it scraped the barrier when redirected. Since the front right wheel took most of the impact, there was no distinguishable damage to the floorboard (see Figure 3-20). The right front corner of the vehicle was moderately damaged. The right front bumper and right fender were pushed rearward. The entire right side of the vehicle was moderately damaged. All four tires deflated during the impact. The maximum passenger compartment deformation was 1.7 inches at the floor pan near the center of the vehicle.

Figure 3-15 – Right side of test vehicle for 130MASH3C13-02

Figure 3-16 – Front of test vehicle for 130MASH3C13-02

Figure 3-17 – Pre-doc Impact Photo of 130MASH3C13-02

Figure 3-18 – Front right corner of test vehicle after 130MASH3C13-02

Figure 3-19 – Right side of test vehicle after 130MASH3C13-02

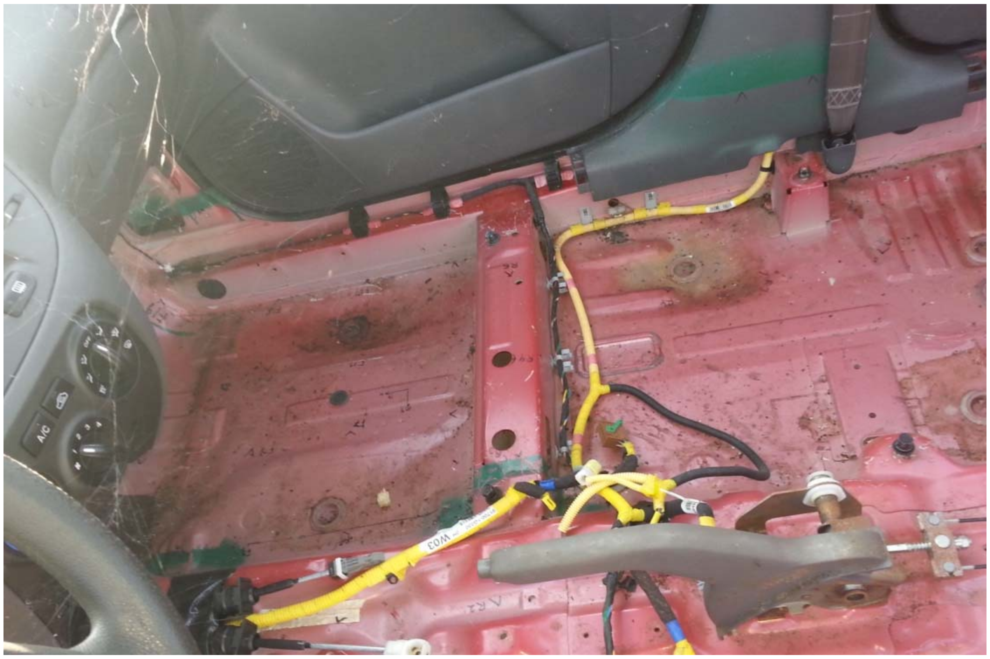
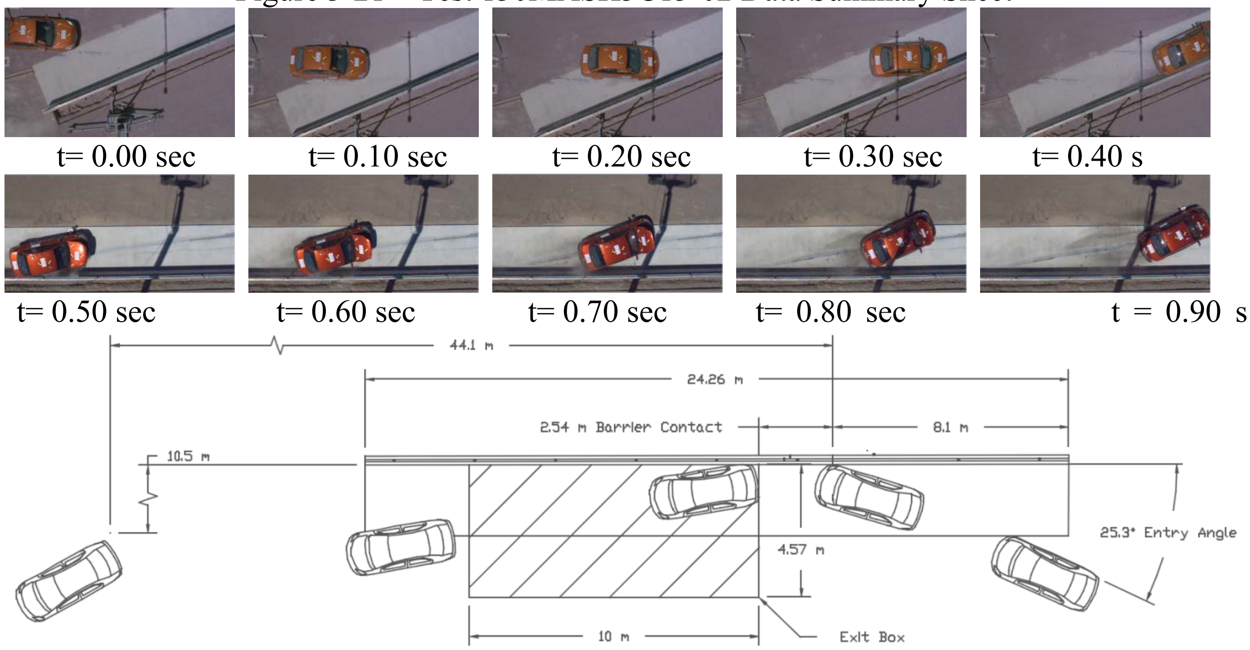


Figure 3-20 – Interior Floor Board of test vehicle after 130MASH3C13-02

Figure 3-21 – Test 130MASH3C13-02 Data Summary Sheet



Test Barrier

Type: Type 732SW bridge rail

Length: 80 ft (24.23 m). Handrail posts spaced at 9.125 ft (2.78 m).

Test Date: August 7, 2013

Test Vehicle:

Model: 2006 Kia Rio

Inertial Mass: 2452 lb (1112 kg)

Gross static Mass: 2612 lb (1185 kg)

Test Dummy:

Type: Hybrid III 50th %

Weight / Position: 165 lb (75 kg) / Front Passenger

Impact/ Exit Conditions:

Impact[1] / Exit Velocity[2]: 59.8 mph (96.3 km/h) / 49.3 mph (79.4 km/h)

Impact / Exit Angle: 25.3° / 13.3°

Impact Severity: 53,600 ft-lb (72.7 kJ)

Test Data:

Occ. Impact Velocity (Long / Lat): 11.8 ft/s (3.6 m/s) / 20.0 ft/s (6.1 m/s)

Ridedown Acceleration (Long / Lat): -9.5 g / -23.8 g[3]

ASI 2.13

Exterior: VDS(6)/CDC(7) FR-3, BR-3/01RFEK8, 01RBEK5

Interior: Occupant Compartment Deformation(3) : Max. 1.7 in (44 mm) at floor pan near enter

Max. Roll/Pitch/Yaw Angles: -16.2° / -10.2° / --51.0°

Barrier Damage:

No deflection in steel handrail, minor superficial concrete spalling.

[1] Impact angle and speed were determined when the vehicle impacted the sidewalk.
[2] Exit speed and angle were determined when the vehicle exited the vertical face.
[3] The data was also analyzed with impact at the vertical face of the concrete wall for reference (see Figure 3-22). The TRAP results are shown below and discussed in the Conclusions.

Figure 3-22 – TRAP Summary Sheet for Test 3-10 Analyzed with Impact at Vertical Face

```
Test Summary Report (Using SAE Class 180 Filter on Acceleration Data and Angular Velocity/Displa

General Information
   Test Agency:   California Department of Transportation
   Test Number:   130MASH3C13-02
   Test Date:     8/7/2013
   Test Article:  Type 732SW Bridge Rail

Test Vehicle
   Description:           2006 Kia Rio
   Test Inertial Mass:    1112 kg
   Gross Static Mass:     1185 kg

Impact Conditions
   Speed:   96.3   km/h
   Angle:   25.3   degrees

Occupant Risk Factors
   Impact Velocity (m/s)      at 0.0792 seconds on right side of interior
      x-direction     4.2
      y-direction     8.0

   THIV (km/hr):      32.5     at 0.0772  seconds on right side of interior
   THIV (m/s):        9.0

   Ridedown Accelerations (g's)
      x-direction     -1.7     (0.0792 -  0.0892 seconds)
      y-direction     -10.6    (0.1642 -  0.1742 seconds)

   PHD (g's):         10.7     (0.1641 -  0.1741 seconds)

   ASI:               1.90     (0.0154 -  0.0654 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
   x-direction        -7.2     (0.0161 -  0.0661 seconds)
   y-direction        -16.2    (0.0152 -  0.0652 seconds)
   z-direction        -2.6     (0.0292 -  0.0792 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
   Roll            -18.7    (0.3138 seconds)
   Pitch              -13.9    (0.3669 seconds)
   Yaw             -35.1    (0.3669 seconds)
```

3.3. Test 110MASH2C14-01 Impact Description and Results

The impact point was 25.6 ft (7.8 m) downstream of the upstream end of the barrier face. The impact point was selected to maximize any potential snag at the expansion joint and hood snag on one of the handrail posts. The impact angle was set at 25° by placement of the guide rail. The vehicle deviated slightly from this angle prior to impact, achieving a 24.3° impact angle. The impact speed of 44.1 mph (71.0 km/h), just above the intended speed of 44 mph (70 km/h), was obtained by optical switch data and confirmed by two different speed traps located just upstream from the impact point. The vehicle impacted the sidewalk approximately 6.9 ft (2.1 m) from the upstream end and the vertical face of the concrete wall approximately 27.2 ft (8.3 m) from the upstream end of the barrier. The front-right tire contacted the sidewalk edge at t = 0 seconds (impact). The right rear tire impacted the sidewalk edge about 0.13 seconds after impact. The bumper contacted the vertical barrier face approximately 0.33 seconds after impact. The right front of the vehicle continued to deform moderately as the vehicle began to yaw slightly left (negative) until the back right side of the vehicle contacted the barrier 0.52 seconds after the initial impact. The vehicle became parallel to the barrier face approximately 0.50 seconds after initial impact. The rear of the vehicle lost contact with the barrier face 0.64 seconds after impact. The vehicle stayed in contact with the barrier face for about 14.3 ft (4.35 m). The vehicle lost contact with the sidewalk after the vehicle left the view of either overhead camera. Through video analysis the exit speed and angle were determined to be 35.2 mph (56.6 km/h) and 10.6°, respectively[1].

The remote brakes did not function as evidenced by the event channel trace. The vehicle came to rest was 155 ft (47.3 m) downstream from the initial contact point with the barrier face and 28 ft (8.5 m) from the barrier face on the traffic side.

See Figure 3-23 through Figure 3-31 for the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 110MASH2C14-01 are shown on Figure 3-32 on the Data Summary Sheet (page 32).

3.3.1. Barrier Damage

There was essentially no permanent damage to the barrier during 110MASH2C14-01. The only damage was a negligible amount of scraping and gouging of the concrete face. Damage to the barrier was considered cosmetic and would not have required field repairs.

Figure 3-23 – Type 732SW test article prior to Test 110MASH2C14-01

[1] Impact angle and speed were determined at impact with the sidewalk because the sidewalk is considered part of the barrier. The exit speed and angle would also ideally have been determined when the vehicle left the sidewalk. However, that was indeterminable because the vehicle had left the view of the overhead cameras when it left the sidewalk.

Figure 3-24 – Type 732SW bridge rail face after Test 110MASH2C14-01

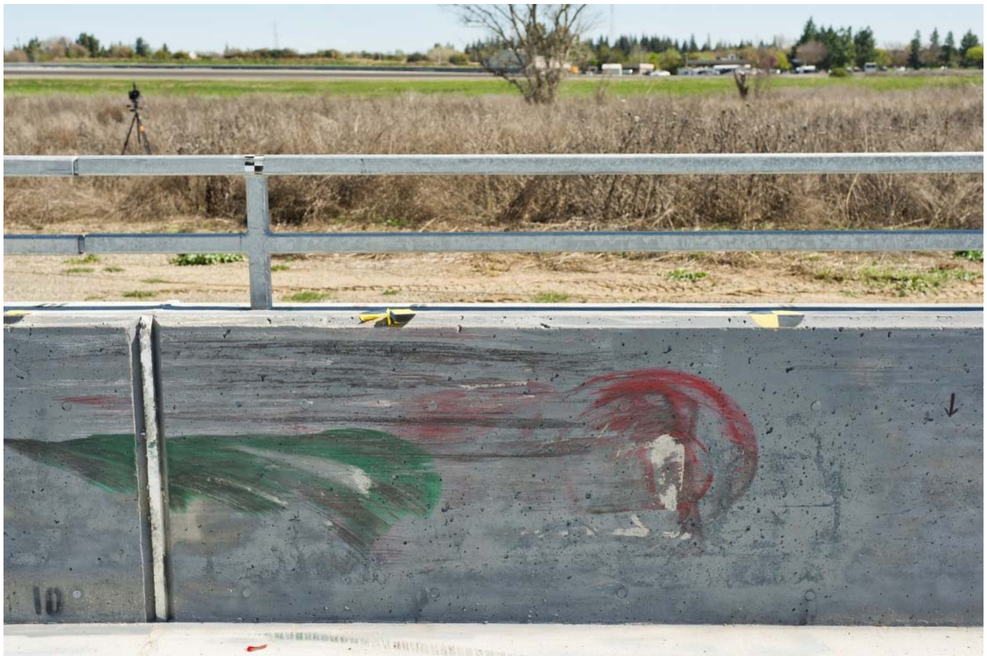


Figure 3-25 – 732SW Barrier face scraping after Test 110MASH2C14-01

3.3.2. Vehicle Damage

The front right wheel absorbed most of the impact. The rim was bent during impact causing the tire to deflate. The wheel well of the test vehicle sustained most of the damage. Additional damage also occurred to the side of the vehicle as it scraped the barrier when redirected. Since the front right wheel took most of the impact, there was no distinguishable damage to the floorboard (see Figure 3-31). The right front corner of the vehicle was moderately damaged. The right front bumper and right fender were pushed rearward. The right side of the vehicle at the front and rear was moderately damaged. The two front tires deflated during the impact. The maximum passenger compartment deformation was 0.6 inches at the floor pan near the passenger door.

Figure 3-26 – Right side of test vehicle for Test 110MASH2C14-01

Figure 3-27 – Front of test vehicle for Test 110MASH2C14-01

Figure 3-28 – Test vehicle prior to impact for Test 110MASH2C14-01

Figure 3-29 – Front right corner of test vehicle after Test 110MASH2C14-01

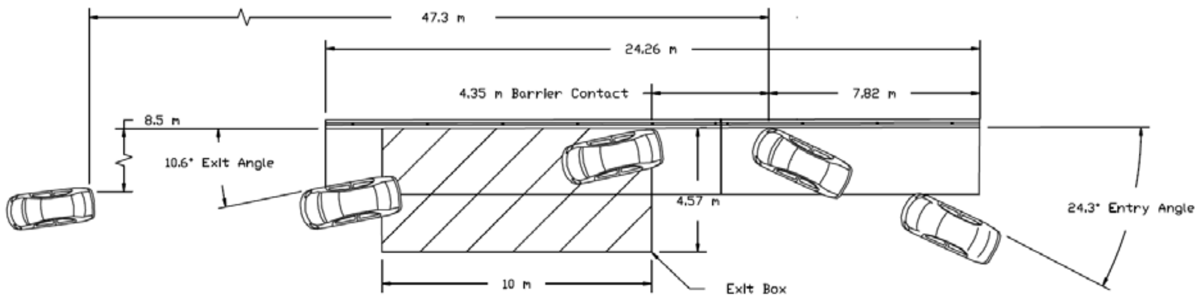
Figure 3-30 – Right side of test vehicle after Test 110MASH2C14-01

Figure 3-31 – Floor Board of test vehicle after Test 110MASH2C14-01

Figure 3-32 – Test 110MASH2C14-01 Data Summary Sheet

t= 0.00 sec t= 0.15 sec t= 0.30 sec t= 0.45 sec t= 0.60 s

t= 0.75 sec t= 0.90 sec t= 1.05 sec t= 1.20 sec t = 1.35 s



Test Barrier

Type: Type 732SW bridge rail

Length: 80 ft (24.23 m). Handrail posts spaced at 9.125 ft (2.78 m).

Test Date: March 12, 2014

Test Vehicle:

Model: 2006 Kia Rio

Inertial Mass: 2474 lb (1122 kg)

Gross static Mass: 2646 lb (1200 kg)

Test Dummy:

Type: Hybrid III 50^{th} %

Weight / Position: 165 kg (75 kg) / Front Passenger

Impact/ Exit Conditions:

Impact[1] / Exit Velocity[2]: 44.1 mph (71.0 km/h) / 35.2 mph (56.6 km/h)

Impact / Exit Angle: 24.3° / 10.6°

Impact Severity: 26,300 ft-lb (35.6 kJ)

Test Data:

Occ. Impact Velocity (Long / Lat): 11.2 ft/s (3.4 m/s) / 19.4 ft/s (5.9 m/s)

Ridedown Acceleration (Long / Lat)[3]: -3.9 g / -8.3 g

ASI 1.54

Exterior: VDS[(6)]/CDC[(7)] FR-2, BR-3/01RFEK9, 01RBEK5

Interior: Occupant Compartment Deformation[(3)] : Max. 0.6 in (15 mm) at floor pan near door

Max. Roll/Pitch/Yaw Angles: 17.0° / -12.0° / -33.9°

Barrier Damage:

No deflection in steel handrail, minor superficial concrete spalling.

[1] Impact angle and speed were determined when the vehicle impacted the sidewalk.

[2] Exit speed and angle were determined when the vehicle exited the vertical face.

[3] There were some issues with lateral channel data acquisition. See Appendix 10 for details.

4. Discussion of Test Results

4.1. General Evaluation Methods (Test 130MASH3P13-01, 130MASH3C13-02, and 110MASH2C14-01)

MASH 09 recommends that crash test performance be assessed according to three evaluation factors: 1) Structural Adequacy, 2) Occupant Risk, and 3) Vehicle Trajectory.

The structural adequacy, occupant risk, and vehicle trajectory associated with the Type 732SW bridge rail testing were evaluated using the evaluation criteria found in Tables 3.1 and 5.1 of MASH 09.

The 732SW bridge rail was originally planned to be tested to MASH TL-3. The pickup test (Test 3-11) was performed successfully but there was an issue with ridedown acceleration in the small car test (Test 3-10). See Section 4.3 below. Because the 732SW will only be used under TL-2 speeds and with FHWA's concurrence, a second small car test was conducted at TL-2 (test 2-10).

4.2. Structural Adequacy

The structural adequacy of the Type 732SW bridge rail is acceptable. There were minor amounts of scraping and spalling on the vertical face, which would not have rendered the barrier ineffective. The barrier also would not have required immediate repair.

Refer to Table 4-1, Table 4-2 , and Table 4-3for the assessment summary of the structural adequacy for the Type 732SW bridge rail.

4.3. Occupant Risk

The occupant risk for tests 130MASH3P13-01 and 110MASH2C14-01 were acceptable. The floorboard deformation for Test 130MASH3P13-01 was 2.1 inches and 0.6 inches for Test 110MASH2C14-01 (less than 9 inches allowed by MASH). The remainder of the occupant compartment areas for both tests was not compromised. The longitudinal occupant velocities and ridedown accelerations were each well below the maximums allowed.

As provided in Table 4-2, all of the Occupant Risk Values were within the guidelines of MASH 09 except for the Lateral Ridedown Acceleration, measured at -24.0 g, higher than the maximum of 20.49 g. The higher value was a result of having the flail space model start time at the initial contact of the curb instead of the barrier face. Due to this early impact with the curb, part of the flail space was taken up between the impact with the curb and impact with the barrier face. This left less space available during the most severe portion of the impact and resulted in higher

Ridedown Acceleration values[1]. This was discussed with FHWA and retesting at TL-2 was recommended. For reference, Figure 3-22, includes TRAP results when setting the initial time to be zero, when impacting the barrier face, instead of the curb. The results indicate a lower Ridedown Acceleration.

Refer to Table 4-1, Table 4-2, and Table 4-3for the assessment summary of the occupant risk for the Type 732SW bridge rail.

4.4. Vehicle Trajectory

The vehicle trajectories were acceptable. The exit trajectories were within the required exit box. The yaw, pitch, and roll of the vehicle were below the maximums allowed.

Refer to Table 4-1, Table 4-2, and Table 4-3 for the assessment summary of the vehicle trajectory for the Type 732SW bridge rail.

[1] This explanation is an opinion and interpretation. The opinions/interpretations identified/expressed in this report are outside the scope of this organization's A2LA Accreditation.

Table 4-1 – Test 130MASH3P13-01 Assessment Summary

Test No. 130MASH3P13-01
Date May 14, 2014
Test Agency California Department of Transportation

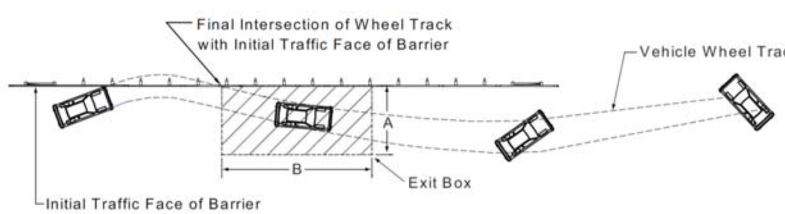
Structural Adequacy	A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.			The vehicle was smoothly redirected.	Pass
Occupant Risk	D.	Detached element, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, 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.			There was no penetration or potential for penetration into the occupant compartment.	Pass
	F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.			The vehicle remained upright. The maximum roll and pitch angles were 27.9 degrees and 4.9 degrees, respectively.	Pass
	H.	Occupant impact velocities (OIV) (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:				
		Occupant Impact Velocity Limits, ft/s (m/s)				
		Component	Preferred	Maximum	Actual	
		Longitudinal and Lateral	30 ft/s (9.1 m/s)	40 ft/s (12.2 m/s)	Longitudinal 17.71 ft/s (5.4 m/s) Lateral 27.9 ft/s (8.5 m/s)	Pass

<table>
<tr><td rowspan="4"></td><td rowspan="4">I.</td><td colspan="4">The occupant ridedown acceleration (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:</td><td></td></tr>
<tr><td colspan="4">Occupant Ridedown Acceleration Limits (G)</td><td></td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td><td>Actual</td><td></td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 G</td><td>20.49 G</td><td>Longitudinal 9.2 g
Lateral -8.1 g</td><td>Pass</td></tr>
<tr><td>Vehicular Trajectory</td><td></td><td colspan="4">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.

<u>For Test 130MASH3P13-03: A = 16.8ft (4.57m) and B = 32.8ft (10.0m)</u>

Distance for Exit Box Criterion

<table>
<tr><th>Vehicle Type</th><th>A ft (m)</th><th>B ft (m)</th></tr>
<tr><td>Car/Pickup</td><td>7.2 + V_W + 0.16V_L
(2.2 + V_W + 0.16V_L)</td><td>32.8
(10.0)</td></tr>
<tr><td>Other Vehicles</td><td>14.4 + V_W + 0.16V_L
(4.4 + V_W + 0.16V_L)</td><td>65.6
(20.0)</td></tr>
</table>
V_W = Vehicle Width
V_L = Vehicle Length



</td><td>Pass (see Figure 3-11 for vehicle trajectory drawing)</td></tr>
</table>

Table 4-2 – Test 130MASH3C13-02 Assessment Summary

Test No.	130MASH3C13-02
Date	August 7, 2013
Test Agency	California Department of Transportation

Structural Adequacy	A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.			The vehicle was smoothly redirected.	Pass
Occupant Risk	D.	Detached element, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, 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.			There was no penetration or potential for penetration into the occupant compartment.	Pass
	F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.			The vehicle remained upright. The maximum roll and pitch angles were -16.2 degrees and -10.2 degrees, respectively	Pass
	H.	Occupant impact velocities (OIV) (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:				
		Occupant Impact Velocity Limits, ft/s (m/s)				
		Component	Preferred	Maximum	Actual	
		Longitudinal and Lateral	30 ft/s (9.1 m/s)	40 ft/s (12.2 m/s)	Longitudinal 11.8 ft/s (3.6 m/s) Lateral 20.0 ft/s (6.1 m/s)	Pass
	I.	The occupant ridedown acceleration (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:				
		Occupant Ridedown Acceleration Limits (G)				
		Component	Preferred	Maximum	Actual	

<table>
<tr><td></td><td></td><td>Longitudinal and Lateral</td><td>15.0 G</td><td>20.49 G</td><td>Longitudinal -9.5 g

Lateral -23.8 g</td><td>Fail</td></tr>
<tr><td>Vehicular Trajectory</td><td></td><td colspan="4">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

For Test 130MASH3C13-02: A = 15.0ft (4.57m) and B = 32.8ft (10.0m)

Distance for Exit Box Criterion
<table><tr><td>Vehicle Type</td><td>A
ft (m)</td><td>B
ft (m)</td></tr><tr><td>Car/Pickup</td><td>7.2 + V_W + 0.16V_L
(2.2 + V_W + 0.16V_L)</td><td>32.8
(10.0)</td></tr><tr><td>Other Vehicles</td><td>14.4 + V_W + 0.16V_L
(4.4 + V_W + 0.16V_L)</td><td>65.6
(20.0)</td></tr></table>V_W = Vehicle Width
V_L = Vehicle Length

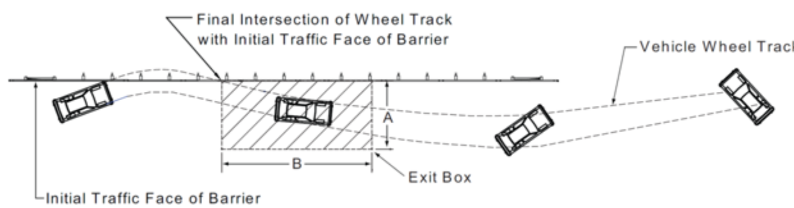

</td><td>Pass (see Figure 3-21 for vehicle trajectory drawing)</td></tr>
</table>

Table 4-3 – Test 110MASH2C14-01 Assessment Summary

Test No.	110MASH2C14-01
Date	March 11, 2014
Test Agency	California Department of Transportation

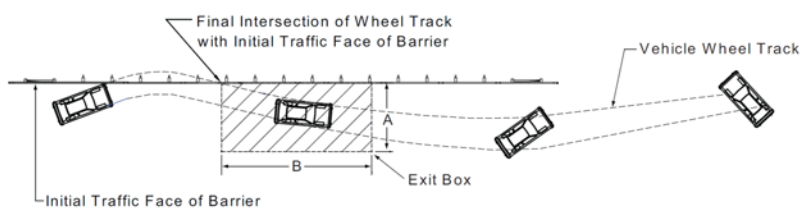
4. DISCUSSION OF TEST RESULTS (CONTINUED)

Structural Adequacy	A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.			The vehicle was smoothly redirected.	Pass
Occupant Risk	D.	Detached element, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, 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.			There was no penetration or potential for penetration into the occupant compartment.	Pass
	F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.			The vehicle remained upright. The maximum roll and pitch angles were 17.0 degrees and -12.0 degrees, respectively	Pass
	H.	Occupant impact velocities (OIV) (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:				
		Occupant Impact Velocity Limits, ft/s (m/s)				
		Component	Preferred	Maximum	Actual	
		Longitudinal and Lateral	30 ft/s (9.1 m/s)	40 ft/s (12.2 m/s)	Longitudinal 11.2 ft/s (3.4 m/s) Lateral 19.4 ft/s (5.9 m/s)	Pass

4. DISCUSSION OF TEST RESULTS (CONTINUED)

<table>
<tr><td rowspan="4"></td><td rowspan="4">I.</td><td colspan="4">The occupant ridedown acceleration (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:</td><td></td></tr>
<tr><td colspan="4">Occupant Ridedown Acceleration Limits (G)</td><td></td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td><td>Actual</td><td></td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 G</td><td>20.49 G</td><td>Longitudinal -3.9 g
Lateral -8.3 g</td><td>Pass</td></tr>
<tr><td>Vehicular Trajectory</td><td></td><td colspan="4">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

<u>For Test 110MASH2C14-01: A = 15.0ft (4.57m) and B = 32.8ft (10.0m)</u>

Distance for Exit Box Criterion
<table>
<tr><th>Vehicle Type</th><th>A
ft (m)</th><th>B
ft (m)</th></tr>
<tr><td>Car/Pickup</td><td>$7.2 + V_W + 0.16V_L$
$(2.2 + V_W + 0.16V_L)$</td><td>32.8
(10.0)</td></tr>
<tr><td>Other Vehicles</td><td>$14.4 + V_W + 0.16V_L$
$(4.4 + V_W + 0.16V_L)$</td><td>65.6
(20.0)</td></tr>
</table>
V_W = Vehicle Width
V_L = Vehicle Length


</td><td>Pass (see Figure 3-32 for vehicle trajectory drawing)</td></tr>
</table>

Table 4-4 – Vehicle Trajectories and Speeds

Test Number	**Impact Angle (deg)**	**60% of Impact Angle (deg)**	**Exit Angle (deg)**	**Impact Speed, V_i (mph) km/h**	**Exit Speed, Ve (mph) km/h**	**Speed Change, $V_i - V_e$ (mph) km/h**
130MASH3P13-01	24.8°	14.88°	9°	62.7 (100.9)	51.0 (82.0)	11.7 (18.9)
130MASH3C13-02	25.3°	15.18°	13.25°	59.8 (96.3)	49.3 (79.4)	10.5 (16.9)
110MASH2C14-01	24.3	14.58°	10.61°	44.1 (71.0)	35.2 (56.6)	8.9 (14.4)

5. Conclusions

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

1. The Type 732SW Bridge Rail can successfully redirect a 5000-lb (2270-kg) pickup truck impacting at 62 mph (100 km/h) and 25°.
2. The Type 732SW Bridge Rail can successfully redirect a 2420-lb (1100-kg) small car impacting at 44 mph (70 km/h) and 25°.
3. Damage to the Type 732SW Bridge Rail was cosmetic and would not have required immediate repair, if any.
4. The Type 732SW Bridge Rail meets the criteria set in the American Association of State Highway and Transportation Officials' Manual for Assessing Safety Hardware 2009 (MASH 09) "Recommended Procedures for the Safety Performance Evaluation of Highway Safety Features" as a Test Level 2 longitudinal barrier.
5. The Type 732SW Bridge Rail was successfully tested with a 96-inch wide sidewalk, which meant the Test 3-11 pickup had three tires on top of the sidewalk at impact and the fourth nearly on top. Because the vehicle was stable and exhibited relatively little roll during Test 3-31, a wider sidewalk and all four tires on top of it at impact would not be expected to significantly impact the stability of the vehicle or outcome of the test. A narrower sidewalk would effectively raise the height of the vertical face of the concrete wall at impact, thus likely improving vehicle stability. Therefore the Type 732SW Bridge Rail can be used with both narrower and wider sidewalks than that tested without affecting crash performance.
6. The Type 732SW is not capable of meeting the 3-10 Occupant Risk criteria. This is because the initial impact between the tire and the sidewalk edge was significant enough to reduce the lateral flail space before impact with the bridge rail's vertical face. This reduction caused the theoretical occupant impact to occur sooner than is typical for a test on a barrier with a narrower sidewalk. The net result is that the lateral occupant ridedown acceleration occurred during the highest levels of vehicle deceleration, which is why the lateral ridedown acceleration was too high. A TRAP summary sheet with Test 3-10 analyzed with impact (t = 0) at the vertical face of the concrete wall is included in Figure 3-22 for reference.

6. Recommendations

The Type 732SW is recommended for use as a new bridge rail on moderate speed highways with pedestrian traffic under TL-2 conditions.

7. Implementation

The California Department of Transportation's Division of Engineering Services, Structure Design Office will be responsible for the preparation of Standard Plans and Specifications for the Type 732SW Bridge Rail.

8. Appendix

8.1. Test Vehicle Equipment

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

130MASH3P13-01 - 2006 Dodge RAM 1500 2WD Crew Cab Pickup: The gas tank was disconnected from the fuel supply line and drained. A 3-gallon (12 liter) 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.

TEST 130MASH3C13-02 - 2006 Kia Rio and TEST 110MASH2C14-01 - 2006 Kia Rio: The gas tank was not disconnected from the fuel supply line but was completely drained. The safety gas tank was not installed in this vehicle since it was towed, not self-powered. The stock fuel tank had gaseous CO_2 added in order to purge the gas vapors and minimize oxygen.

One pair of 12-volt, sealed lead acid batteries was mounted in each vehicle. The batteries powered the GMH Engineering DataBrick transient data recorders. A 12-volt deep-cycle gel cell battery operated the Electronic Control Box.

A 700 psi (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.

The remote brakes were controlled via a radio link transmitter. When the brakes were applied by remote control, the ignition was automatically rendered inoperable by removing power to the coil.

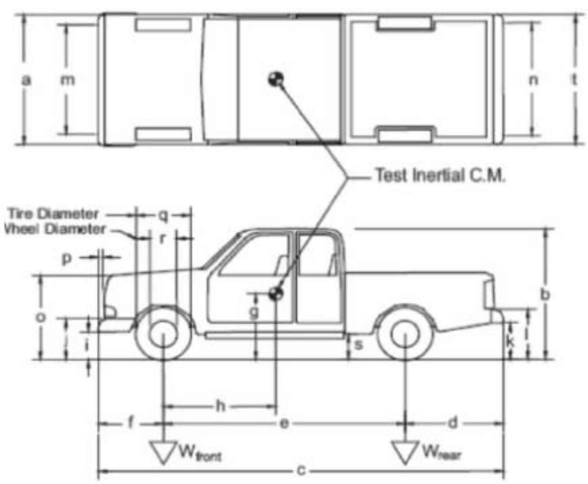
For test 130MASH3P13-01, an accelerator switch was located on the rear fender of the vehicle. The switch opened an electronic solenoid that released compressed CO_2 from a reservoir into a pneumatic ram that had been attached to the accelerator pedal. The CO_2 pressure for the accelerator ram was regulated to the same pressure of the remote braking system with a valve to adjust CO_2 flow rate. 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 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. A microswitch was mounted below the front bumper and connected to the ignition system. A trip plate on the ground near the impact point triggered the switch when the vehicle passed over it removing power from the engine coil.

For test 130MASH3C13-02 and 110MASH2C14-01, the vehicle speed was regulated by the speed of a tow vehicle. The tow vehicle pulled a tow cable through a series of sheaves arranged to produce a 2:1 mechanical advantage in test 130MASH3C13-02 and a 1:1 mechanical advantage in test 110MASH2c14-01. Vehicle speed control was attained through the use of the same speed control unit used in Test 130MASH3P13-01 but installed on the tow vehicle.

Table 8-1 – Test 130MASH3P-13 Vehicle Dimensions

Date:	4/10/2013	Test Number:	130MASH3P13-01	Model:	RAM 1500 Crew Cab SLT
Make:	Dodge	VIN:	1D7HA18N76J179068		
Tire Size:	265/70R17	Year:	2006	Odometer:	86816
Tire Inflation Pressure:					

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm (inches)

a	1980	(77.95)	b	1878	(73.94)
c	5791	(227.99)	d	1208	(47.56)
e	3575	(140.75)	f	1010	(39.76)
g	713.6	(28.09)	h	1547	(60.91)
i	260	(10.24)	j	645	(25.39)
k	525	(20.67)	l	742	(29.21)
m	1740	(68.5)	n	1700	(66.93)
o	1110	(43.7)	p	70	(2.76)
q	770	(30.31)	r	432	(17.01)
s	400	(15.75)	t	1943	(76.5)

Wheel Center Height Front:	362	(14.25)
Wheel Center Height Rear:	365	(14.37)
Wheel Well Clearance (F)	135	(5.31)
Wheel Well Clearance (R)	225	(8.86)
Frame Height (F):		
Frame Height (R):		
Engine Type:	V-8 gas	
Engine Size:	4.7L	
Transmission Type:		
Automatic or Manual:	Automatic	
FWD or RWD or 4WD:	RWD	

Mass Distribution - kg (lbs)

Left Front:	675.2	(1488.54)	Right Front:	633.6	(1396.83)
Left Rear:	481.8	(1062.17)	Right Rear:	505.1	(1113.54)

Weights

kg (lbs)	Curb		Test Inertial		Gross Static	
W_{front}	1288.1	(2839.73)	1308.8	(2885.36)	1308.8	(2885.36)
W_{rear}	962.9	(2122.8)	986.9	(2175.71)	986.9	(2175.71)
W_{total}	2251	(4962.52)	2295.7	(5061.07)	2295.7	(5061.07)

GVWR Ratings - kg (lbs)

Front:	1679	(3701.5)
Back:	1770	(3902.12)
Total:	3040	(6701.94)

Dummy Data

Type:

Mass:

Seat Position:

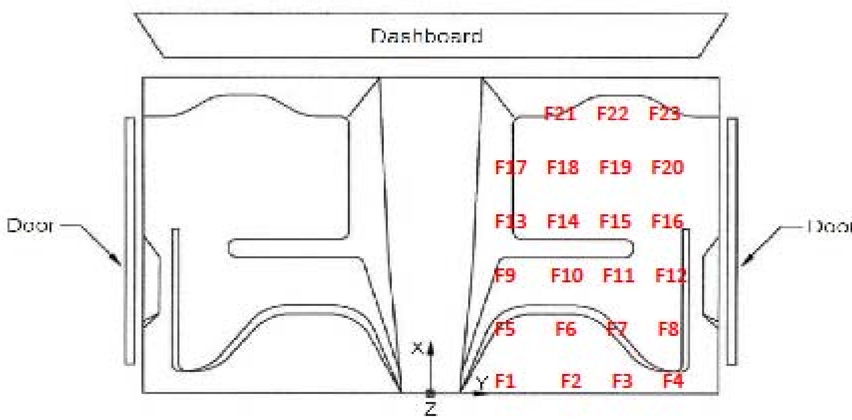
Note any damage prior to test: Small dent in center of rear bumper. Small dent in passenger side of rear bumper.

Table 8-2 – Occupant Compartment Deformation Measurement for Test 130MASH3P13-3

Vehicle Type	2270P	Test Number	130MASH3P13-01
Make	Dodge	Model	Ram
Year	2006	Color	Silver
VIN #	1D7HA18N76J179068		

Floorboard Measurements. Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
F1	1525 (60.04)	1172 (46.14)	249 (9.8)	1504 (59.21)	1156 (45.51)	252 (9.92)	-21 (-0.83)	-16 (-0.63)	3 (0.12)
F2	1525 (60.04)	1043 (41.06)	251 (9.88)	1505 (59.25)	1028 (40.47)	249 (9.8)	-20 (-0.79)	-15 (-0.59)	-2 (-0.08)
F3	1525 (60.04)	916 (36.06)	252 (9.92)	1504 (59.21)	901 (35.47)	245 (9.65)	-21 (-0.83)	-15 (-0.59)	-7 (-0.28)
F4	1525 (60.04)	790 (31.1)	253 (9.96)	1500 (59.06)	770 (30.31)	241 (9.49)	-25 (-0.98)	-20 (-0.79)	-12 (-0.47)
F5	1654 (65.12)	1172 (46.14)	276 (10.87)	1633 (64.29)	1153 (45.39)	279 (10.98)	-21 (-0.83)	-19 (-0.75)	3 (0.12)
F6	1654 (65.12)	1043 (41.06)	276 (10.87)	1633 (64.29)	1025 (40.35)	274 (10.79)	-21 (-0.83)	-18 (-0.71)	-2 (-0.08)
F7	1654 (65.12)	916 (36.06)	276 (10.87)	1634 (64.33)	896 (35.28)	269 (10.59)	-20 (-0.79)	-20 (-0.79)	-7 (-0.28)
F8	1654 (65.12)	790 (31.1)	277 (10.91)	1634 (64.33)	767 (30.2)	264 (10.39)	-20 (-0.79)	-23 (-0.91)	-13 (-0.51)
F9	1781 (70.12)	1172 (46.14)	279 (10.98)	1765 (69.49)	1149 (45.24)	281 (11.06)	-16 (-0.63)	-23 (-0.91)	2 (0.08)
F10	1781 (70.12)	1043 (41.06)	276 (10.87)	1765 (69.49)	1022 (40.24)	275 (10.83)	-16 (-0.63)	-21 (-0.83)	-1 (-0.04)
F11	1781 (70.12)	916 (36.06)	275 (10.83)	1765 (69.49)	897 (35.31)	270 (10.63)	-16 (-0.63)	-19 (-0.75)	-5 (-0.2)
F12	1781 (70.12)	790 (31.1)	276 (10.87)	1765 (69.49)	763 (30.04)	265 (10.43)	-16 (-0.63)	-27 (-1.06)	-11 (-0.43)
F13	1906 (75.04)	1172 (46.14)	281 (11.06)	1893 (74.53)	1127 (44.37)	283 (11.14)	-13 (-0.51)	-45 (-1.77)	2 (0.08)
F14	1906 (75.04)	1043 (41.06)	277 (10.91)	1896 (74.65)	1000 (39.37)	277 (10.91)	-10 (-0.39)	-43 (-1.69)	0 (0)
F15	1906 (75.04)	916 (36.06)	277 (10.91)	1894 (74.57)	875 (34.45)	275 (10.83)	-12 (-0.47)	-41 (-1.61)	-2 (-0.08)
F16	1906 (75.04)	790 (31.1)	198 (7.8)	1893 (74.53)	750 (29.53)	224 (8.82)	-13 (-0.51)	-40 (-1.57)	26 (1.02)
F17	2024 (79.69)	1172 (46.14)	226 (8.9)	2030 (79.92)	1125 (44.29)	222 (8.74)	6 (0.24)	-47 (-1.85)	-4 (-0.16)
F18	2024 (79.69)	1043 (41.06)	226 (8.9)	2025 (79.72)	1000 (39.37)	224 (8.82)	1 (0.04)	-43 (-1.69)	-2 (-0.08)
F19	2024 (79.69)	916 (36.06)	224 (8.82)	2015 (79.33)	875 (34.45)	225 (8.86)	-9 (-0.35)	-41 (-1.61)	1 (0.04)
F20	2024 (79.69)	790 (31.1)	100 (3.94)	1997 (78.62)	765 (30.12)	83 (3.27)	-27 (-1.06)	-25 (-0.98)	-17 (-0.67)
F21	2175 (85.63)	1172 (46.14)	100 (3.94)	2146 (84.49)	1118 (44.02)	89 (3.5)	-29 (-1.14)	-54 (-2.13)	-11 (-0.43)
F22	2207 (86.89)	1043 (41.06)	150 (5.91)	2187 (86.1)	1000 (39.37)	147 (5.79)	-20 (-0.79)	-43 (-1.69)	-3 (-0.12)
F23	2190 (86.22)	916 (36.06)	143 (5.63)	2172 (85.51)	878 (34.57)	134 (5.28)	-18 (-0.71)	-38 (-1.5)	-9 (-0.35)
F24	0	0	0	0	0	0	0	0	0
F25	0	0	0	0	0	0	0	0	0
F26	0	0	0	0	0	0	0	0	0
F27	0	0	0	0	0	0	0	0	0
F28	0	0	0	0	0	0	0	0	0
F29	0	0	0	0	0	0	0	0	0
F30	0	0	0	0	0	0	0	0	0



Vehicle Type	2270P	Test Number	130MASH3P13-01
Make	Dodge	Model	Ram
Year	2006	Color	Silver
VIN #	1D7HA18N76J179068		

Dashboard Measurements (Dimensions in mm)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
D1	1709 (67.28)	458 (18.03)	-381 (-15)	1704 (67.09)	436 (17.17)	-385 (-15.16	-5 (-0.2)	-22 (-0.87)	-4 (-0.16)
D2	1738 (68.43)	790 (31.1)	-385 (-15.16	1729 (68.07)	769 (30.28)	-384 (-15.12	-9 (-0.35)	-21 (-0.83)	1 (0.04)
D3	1739 (68.46)	916 (36.06)	-384 (-15.12	1733 (68.23)	897 (35.31)	-385 (-15.16	-6 (-0.24)	-19 (-0.75)	-1 (-0.04)
D4	1741 (68.54)	1043 (41.06)	-384 (-15.12	1743 (68.62)	1022 (40.24)	-385 (-15.16	2 (0.08)	-21 (-0.83)	-1 (-0.04)
D5	1749 (68.86)	1172 (46.14)	-380 (-14.96	1753 (69.02)	1150 (45.28)	-385 (-15.16	4 (0.16)	-22 (-0.87)	-5 (-0.2)
D6	1749 (68.86)	1172 (46.14)	-333 (-13.11	1741 (68.54)	1150 (45.28)	-337 (-13.27	-8 (-0.31)	-22 (-0.87)	-4 (-0.16)
D7	0	0	0	0	0	0	0	0	0
D8	0	0	0	0	0	0	0	0	0
D9	0	0	0	0	0	0	0	0	0
D10	0	0	0	0	0	0	0	0	0

Roof Measurements (Dimensions in mm)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
R1	1562 (61.5)	790 (31.1)	-945 (-37.2)	1553 (61.14	766 (30.16)	-944 (-37.17	-9 (-0.35)	-24 (-0.94)	1 (0.04)
R2	1435 (56.5)	790 (31.1)	-980 (-38.58	1424 (56.06)	764 (30.08)	-975 (-38.39	-11 (-0.43)	-26 (-1.02)	5 (0.2)
R3	1342 (52.83)	790 (31.1)	1008 (-39.69	1333 (52.48)	764 (30.08)	-997 (-39.25	-9 (-0.35)	-26 (-1.02)	11 (0.43)
R4	1226 (48.27)	790 (31.1)	1036 (-40.79	1217 (47.91)	764 (30.08)	1028 (-40.47	-9 (-0.35)	-26 (-1.02)	8 (0.31)
R5	1553 (61.14)	916 (36.06)	-940 (-37.01	1543 (60.75)	896 (35.28)	-934 (-36.77	-10 (-0.39)	-20 (-0.79)	6 (0.24)
R6	1216 (47.87)	916 (36.06)	-912 (-35.91	1202 (47.32)	895 (35.24)	-1021 (-40.2	-14 (-0.55)	-21 (-0.83)	-109 (-4.29)
R7	1503 (59.17)	1043 (41.06)	-914 (-35.98	1497 (58.94)	1033 (40.67)	-910 (-35.83	-6 (-0.24)	-10 (-0.39)	4 (0.16)
R8	1395 (54.92)	1043 (41.06)	-921 (-36.26	1387 (54.61)	1033 (40.67)	-915 (-36.02	-8 (-0.31)	-10 (-0.39)	6 (0.24)
R9	1295 (50.98)	1043 (41.06)	-931 (-36.65	1285 (50.59)	1035 (40.75)	-927 (-36.5)	-10 (-0.39)	-8 (-0.31)	4 (0.16)
R10	1185 (46.65)	1043 (41.06)	-942 (-37.09	1175 (46.26)	1034 (40.71)	-938 (-36.93	-10 (-0.39)	-9 (-0.35)	4 (0.16)
R11	1076 (42.36)	1043 (41.06)	-949 (-37.36	1065 (41.93)	1034 (40.71)	-947 (-37.28	-11 (-0.43)	-9 (-0.35)	2 (0.08)

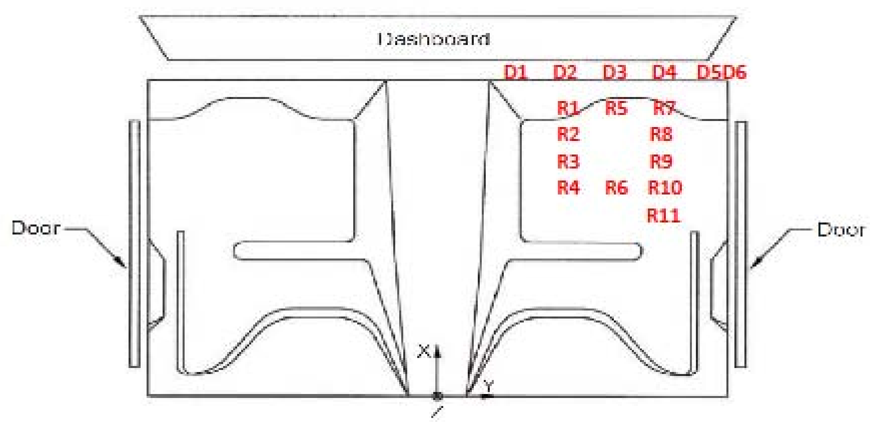
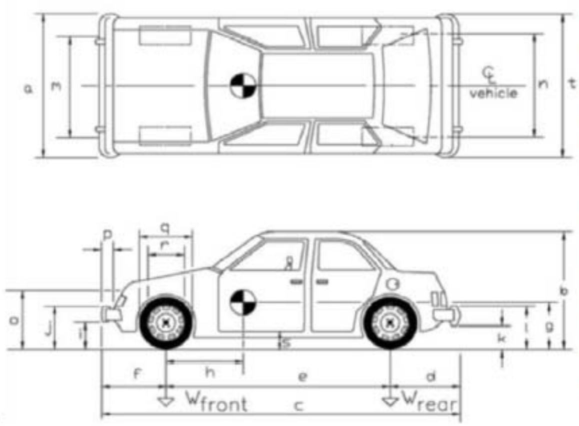


Table 8-3 – Test 130MASH3C-02 Vehicle Dimensions

Date:	7/9/2013	Test Number:	130MASH3C13-02	Model:	Rio
Make:	Kia	VIN:	KNADE123376186671		
Tire Size:	185/65R14	Year:	2006	Odometer:	127860

Tire Inflation Pressure: 32 psi

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm (inches)

a	1565	(61.61)	b	1482	(58.35)
c	4252	(167.4)	d	918	(36.14)
e	2505	(98.62)	f	836	(32.91)
g		(0)	h	937	(36.89)
i	196	(7.72)	j	548	(21.57)
k	303	(11.93)	l	633	(24.92)
m	144.5	(5.69)	n	145.5	(5.73)
o	718	(28.27)	p	20	(0.79)
q	595	(23.43)	r	356	(14.02)
s	309	(12.17)	t	1575	(62.01)

Wheel Center Height Front:	270	(10.63)
Wheel Center Height Rear:	280	(11.02)
Wheel Well Clearance (F)		
Wheel Well Clearance (R)		
Frame Height (F):		
Frame Height (R):		
Engine Type:	Gas, 4 cylinder	
Engine Size:		
Transmission Type:		
Automatic or Manual:	Manual	
FWD or RWD or 4WD:	FWD	

Mass Distribution

Left Front:	360.5	(794.75)	Right Front:	329.6	(726.63)
Left Rear:	455.36	(1003.88)	Right Rear:	475.54	(1048.37)

Weights

kg (lbs)	Curb		Test Inertial		Gross Static	
W_{front}	702.2	(1548.06)	690.1	(1521.38)	730.15	(1609.68)
W_{rear}	403.8	(890.21)	422.3	(931)	455.2	(1003.53)
W_{total}	1106	(2438.27)	1112.4	(2452.38)	1185.35	(2613.21)

GVWR Ratings

Front:

Back:

Total:

Dummy Data

Type: Hybrid III 50th Percentile Male

Mass: 78.3 kg (175 lb)

Seat Position: Passenger Front

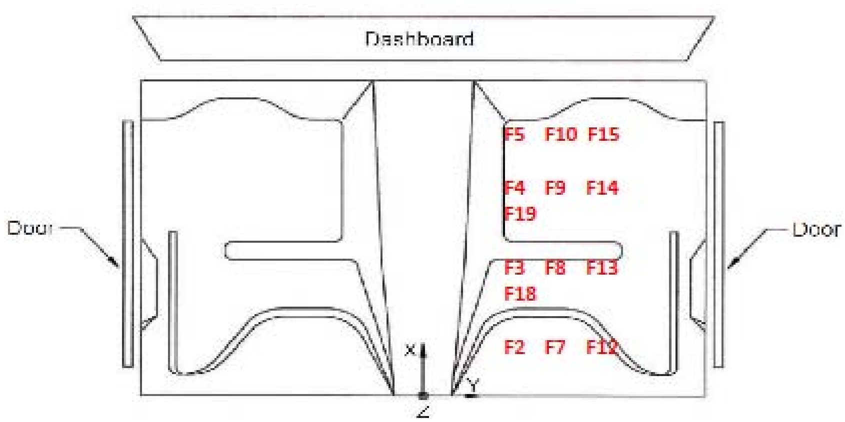
Note any damage prior to test:

Table 8-4 – Occupant Compartment Deformation Measurement for Test 130MASH3C13-02

Vehicle Type	1100C	**Test Number**	130MASH3C13-02
Make	Kia	**Model**	Rio
Year	2006	**Color**	Red
VIN #	KNADE123376186671		

Floorboard Measurements. Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
F1	854 (33.62)	412 (16.22)	177 (6.97)	859 (33.82)	409 (16.1)	174 (6.85)	5 (0.2)	-3 (-0.12)	-3 (-0.12)
F2	1009 (39.72	412 (16.22)	199 (7.83)	1010 (39.76	409 (16.1)	190 (7.48)	1 (0.04)	-3 (-0.12)	-9 (-0.35)
F3	1163 (45.79	412 (16.22)	190 (7.48)	1168 (45.98	408 (16.06)	180 (7.09)	5 (0.2)	-4 (-0.16)	-10 (-0.39)
F4	1318 (51.89	412 (16.22)	176 (6.93)	1311 (51.61	408 (16.06)	150 (5.91)	-7 (-0.28)	-4 (-0.16)	-26 (-1.02)
F5	1471 (57.91	412 (16.22)	89 (3.5)	1468 (57.8)	407 (16.02)	72 (2.83)	-3 (-0.12)	-5 (-0.2)	-17 (-0.67)
F6	854 (33.62)	569 (22.4)	181 (7.13)	857 (33.74)	563 (22.17)	176 (6.93)	3 (0.12)	-6 (-0.24)	-5 (-0.2)
F7	1009 (39.72	569 (22.4)	181 (7.13)	1009 (39.72	564 (22.2)	175 (6.89)	0 (0)	-5 (-0.2)	-6 (-0.24)
F8	1163 (45.79	569 (22.4)	181 (7.13)	1163 (45.79	565 (22.24)	172 (6.77)	0 (0)	-4 (-0.16)	-9 (-0.35)
F9	1337 (52.64	569 (22.4)	167 (6.57)	1334 (52.52	561 (22.09)	153 (6.02)	-3 (-0.12)	-8 (-0.31)	-14 (-0.55)
F10	1486 (58.5)	569 (22.4)	80 (3.15)	1480 (58.27	561 (22.09)	64 (2.52)	-6 (-0.24)	-8 (-0.31)	-16 (-0.63)
F11	854 (33.62)	718 (28.27)	182 (7.17)	857 (33.74)	714 (28.11)	176 (6.93)	3 (0.12)	-4 (-0.16)	-6 (-0.24)
F12	1009 (39.72	718 (28.27)	189 (7.44)	1009 (39.72	714 (28.11)	180 (7.09)	0 (0)	-4 (-0.16)	-9 (-0.35)
F13	1163 (45.79	718 (28.27)	184 (7.24)	1165 (45.87	714 (28.11)	175 (6.89)	2 (0.08)	-4 (-0.16)	-9 (-0.35)
F14	1369 (53.9)	718 (28.27)	150 (5.91)	1339 (52.72	715 (28.15)	137 (5.39)	-30 (-1.18)	-3 (-0.12)	-13 (-0.51)
F15	1479 (58.23	718 (28.27)	53 (2.09)	1468 (57.8)	721 (28.39)	35 (1.38)	-11 (-0.43)	3 (0.12)	-18 (-0.71)
F16	854 (33.62)	872 (34.33)	181 (7.13)	858 (33.78)	866 (34.09)	174 (6.85)	4 (0.16)	-6 (-0.24)	-7 (-0.28)
F17	1009 (39.72	872 (34.33)	181 (7.13)	1011 (39.8)	866 (34.09)	172 (6.77)	2 (0.08)	-6 (-0.24)	-9 (-0.35)
F18	1163 (45.79	872 (34.33)	181 (7.13)	1162 (45.75	866 (34.09)	171 (6.73)	-1 (-0.04)	-6 (-0.24)	-10 (-0.39)
F19	1394 (54.88	872 (34.33)	124 (4.88)	1350 (53.15	866 (34.09)	112 (4.41)	-44 (-1.73)	-6 (-0.24)	-12 (-0.47)
F20	0	0	0	0	0	0	0	0	0
F21	0	0	0	0	0	0	0	0	0
F22	0	0	0	0	0	0	0	0	0
F23	0	0	0	0	0	0	0	0	0
F24	0	0	0	0	0	0	0	0	0
F25	0	0	0	0	0	0	0	0	0
F26	0	0	0	0	0	0	0	0	0
F27	0	0	0	0	0	0	0	0	0
F28	0	0	0	0	0	0	0	0	0
F29	0	0	0	0	0	0	0	0	0
F30	0	0	0	0	0	0	0	0	0



Vehicle Type	1100C	Test Number	130MASH3C13-02
Make	Kia	Model	Rio
Year	2006	Color	Red
VIN #	KNADE123376186671		

Dashboard Measurements. Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
D1	994 (39.13)	227 (8.94)	-385 (-15.16	996 (39.21)	221 (8.7)	-389 (-15.31	2 (0.08)	-6 (-0.24)	-4 (-0.16)
D2	991 (39.02)	412 (16.22)	-386 (-15.2)	995 (39.17)	408 (16.06)	-392 (-15.43	4 (0.16)	-4 (-0.16)	-6 (-0.24)
D3	1056 (41.57	569 (22.4)	-383 (-15.08	1061 (41.77	561 (22.09)	-391 (-15.39	5 (0.2)	-8 (-0.31)	-8 (-0.31)
D4	1052 (41.42	719 (28.31)	-386 (-15.2)	1055 (41.54	712 (28.03)	-391 (-15.39	3 (0.12)	-7 (-0.28)	-5 (-0.2)
D5	1039 (40.91	850 (33.46)	-383 (-15.08	1037 (40.83	842 (33.15)	-391 (-15.39	-2 (-0.08)	-8 (-0.31)	-8 (-0.31)
D6	0	0	0	0	0	0	0	0	0
D7	0	0	0	0	0	0	0	0	0
D8	0	0	0	0	0	0	0	0	0
D9	0	0	0	0	0	0	0	0	0
D10	0	0	0	0	0	0	0	0	0

Roof Measurements. Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
R1	769 (30.28)	0 (0)	-920 (-36.22	763 (30.04)	-3 (-0.12)	-920 (-36.22	-6 (-0.24)	-3 (-0.12)	0 (0)
R2	757 (29.8)	227 (8.94)	-913 (-35.94	752 (29.61)	226 (8.9)	-925 (-36.42	-5 (-0.2)	-1 (-0.04)	-12 (-0.47)
R3	750 (29.53)	412 (16.22)	-919 (-36.18	738 (29.06)	411 (16.18)	-926 (-36.46	-12 (-0.47)	-1 (-0.04)	-7 (-0.28)
R4	734 (28.9)	567 (22.32)	-910 (-35.83	729 (28.7)	557 (21.93)	-921 (-36.26	-5 (-0.2)	-10 (-0.39)	-11 (-0.43)
R5	739 (29.09)	718 (28.27)	-901 (-35.47	734 (28.9)	707 (27.83)	-925 (-36.42	-5 (-0.2)	-11 (-0.43)	-24 (-0.94)
R6	530 (20.87)	712 (28.03)	-923 (-36.34	525 (20.67)	705 (27.76)	-924 (-36.38	-5 (-0.2)	-7 (-0.28)	-1 (-0.04)
R7	393 (15.47)	712 (28.03)	-948 (-37.32	385 (15.16)	704 (27.72)	-953 (-37.52	-8 (-0.31)	-8 (-0.31)	-5 (-0.2)
R8	241 (9.49)	712 (28.03)	-935 (-36.81	234 (9.21)	705 (27.76)	-943 (-37.13	-7 (-0.28)	-7 (-0.28)	-8 (-0.31)
R9	61 (2.4)	710 (27.95)	-940 (-37.01	56 (2.2)	695 (27.36)	-940 (-37.01	-5 (-0.2)	-15 (-0.59)	0 (0)
R10	723 (28.46)	-275 (-10.83	-897 (-35.31	716 (28.19)	-276 (-10.87	-899 (-35.39	-7 (-0.28)	-1 (-0.04)	-2 (-0.08)
R11	0	0	0	0	0	0	0	0	0

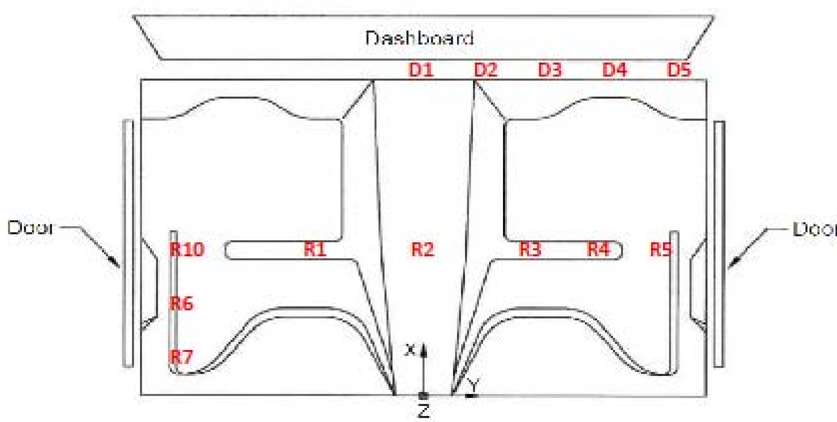
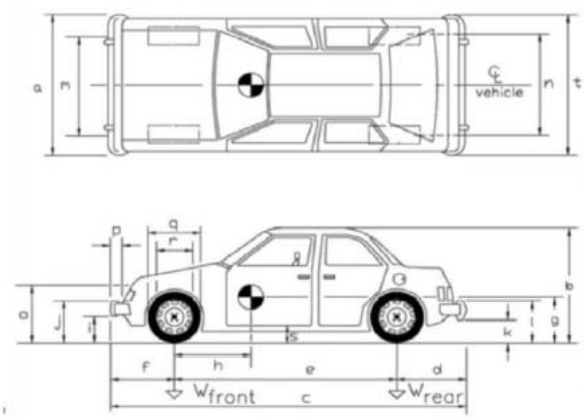


Table 8-5 – Test 110MASH2C14-01 Vehicle Dimensions

Date:	2/12/2014	Test Number:	110MASH2C14-01	Model:	Rio
Make:	Kia	VIN:	KNADE123166043121		
Tire Size:	185/65R14	Year:	2006	Odometer:	165524

Tire Inflation Pressure: 32 psi

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm (inches)

a	1687	(66.42)	b	1499	(59.02)
c	4248	(167.24)	d	921	(36.26)
e	2501	(98.46)	f	826	(32.52)
g		(0)	h	925.6	(36.44)
i	210	(8.27)	j	551	(21.69)
k	285	(11.22)	l	607	(23.9)
m	1484	(58.43)	n	1460	(57.48)
o	695	(27.36)	p	115	(4.53)
q	583	(22.95)	r	389	(15.31)
s	298	(11.73)	t	1681	(66.18)

Wheel Center Height Front:	275	(10.83)
Wheel Center Height Rear:	283	(11.14)
Wheel Well Clearance (F)	56	(2.2)
Wheel Well Clearance (R)	56	(2.2)

Frame Height (F): 165
Frame Height (R): 185
Engine Type: Gas, 4 cylinder
Engine Size: 1.6L

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

Mass Distribution

Left Front:	367.2	(809.52)	Right Front:	339.7	(748.9)
Left Rear:	209.05	(460.87)	Right Rear:	206.25	(454.7)

Weights

kg (lbs)	Curb		Test Inertial		Gross Static	
W_{front}	723.45	(1594.91)	706.9	(1558.42)	747.55	(1648.04)
W_{rear}	413.35	(911.27)	415.3	(915.56)	452.95	(998.57)
W_{total}	1136.8	(2506.17)	1122.2	(2473.99)	1200.5	(2646.6)

GVWR Ratings
Front:
Back:
Total:

Dummy Data
Type: Hybrid III 50th Percentile Male
Mass: 78.3 kg (175 lb)
Seat Position: Passenger front

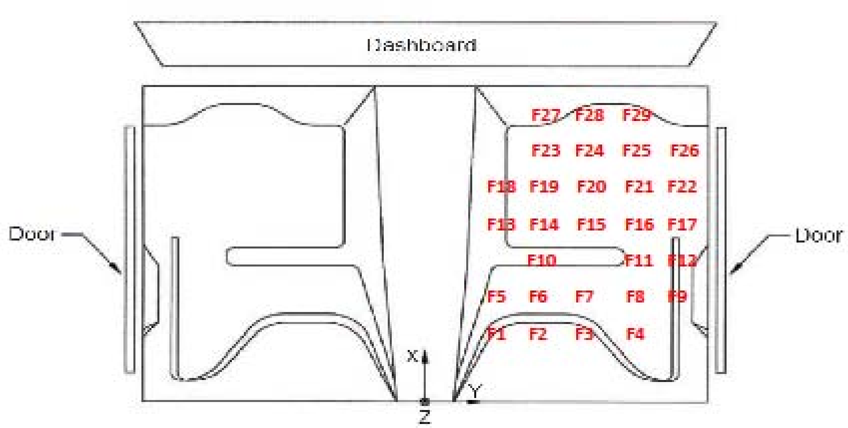
Note any damage prior to test:

Table 8-6 – Occupant Compartment Deformation Measurement for Test 110MASH2C14-01

Vehicle Type	1100C Passenger Car	Test Number	110MASH2C14-01
Make	Kia	Model	Rio
Year	2006	Color	White
VIN #	KNADE123166043121		

Floorboard Measurements. Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
F1	819 (32.24)	400 (15.75)	-178 (-7.01)	820 (32.28)	400 (15.75)	-178 (-7.01)	1 (0.04)	0 (0)	0 (0)
F2	819 (32.24)	502 (19.76)	-178 (-7.01)	820 (32.28)	504 (19.84)	-177 (-6.97)	1 (0.04)	2 (0.08)	1 (0.04)
F3	819 (32.24)	604 (23.78)	-178 (-7.01)	820 (32.28)	605 (23.82)	-176 (-6.93)	1 (0.04)	1 (0.04)	2 (0.08)
F4	819 (32.24)	706 (27.8)	-178 (-7.01)	820 (32.28)	706 (27.8)	-175 (-6.89)	1 (0.04)	0 (0)	3 (0.12)
F5	921 (36.26)	400 (15.75)	-196 (-7.72)	921 (36.26)	400 (15.75)	-191 (-7.52)	0 (0)	0 (0)	5 (0.2)
F6	921 (36.26)	502 (19.76)	-182 (-7.17)	921 (36.26)	504 (19.84)	-181 (-7.13)	0 (0)	2 (0.08)	1 (0.04)
F7	921 (36.26)	604 (23.78)	-177 (-6.97)	921 (36.26)	605 (23.82)	-175 (-6.89)	0 (0)	1 (0.04)	2 (0.08)
F8	921 (36.26)	706 (27.8)	-189 (-7.44)	921 (36.26)	707 (27.83)	-181 (-7.13)	0 (0)	1 (0.04)	8 (0.31)
F9	921 (36.26)	808 (31.81)	-187 (-7.36)	920 (36.22)	811 (31.93)	-185 (-7.28)	-1 (-0.04)	3 (0.12)	2 (0.08)
F10	1023 (40.28	502 (19.76)	-182 (-7.17)	1023 (40.28	504 (19.84)	-195 (-7.68)	0 (0)	2 (0.08)	-13 (-0.51)
F11	1023 (40.28	706 (27.8)	-191 (-7.52)	1023 (40.28	706 (27.8)	-180 (-7.09)	0 (0)	0 (0)	11 (0.43)
F12	1023 (40.28	808 (31.81)	-191 (-7.52)	1018 (40.08	808 (31.81)	-176 (-6.93)	-5 (-0.2)	0 (0)	15 (0.59)
F13	1125 (44.29	400 (15.75)	-195 (-7.68)	1125 (44.29	400 (15.75)	-189 (-7.44)	0 (0)	0 (0)	6 (0.24)
F14	1125 (44.29	502 (19.76)	-184 (-7.24)	1125 (44.29	504 (19.84)	-175 (-6.89)	0 (0)	2 (0.08)	9 (0.35)
F15	1125 (44.29	604 (23.78)	-179 (-7.05)	1125 (44.29	605 (23.82)	-178 (-7.01)	0 (0)	1 (0.04)	1 (0.04)
F16	1125 (44.29	706 (27.8)	-188 (-7.4)	1127 (44.37	705 (27.76)	-185 (-7.28)	2 (0.08)	-1 (-0.04)	3 (0.12)
F17	1125 (44.29	808 (31.81)	-189 (-7.44)	1116 (43.94	808 (31.81)	-186 (-7.32)	-9 (-0.35)	0 (0)	3 (0.12)
F18	1227 (48.31	400 (15.75)	-176 (-6.93)	1227 (48.31	402 (15.83)	-169 (-6.65)	0 (0)	2 (0.08)	7 (0.28)
F19	1227 (48.31	502 (19.76)	-181 (-7.13)	1227 (48.31	502 (19.76)	-175 (-6.89)	0 (0)	0 (0)	6 (0.24)
F20	1227 (48.31	604 (23.78)	-174 (-6.85)	1227 (48.31	605 (23.82)	-170 (-6.69)	0 (0)	1 (0.04)	4 (0.16)
F21	1227 (48.31	706 (27.8)	-180 (-7.09)	1228 (48.35	705 (27.76)	-175 (-6.89)	1 (0.04)	-1 (-0.04)	5 (0.2)
F22	1227 (48.31	808 (31.81)	-179 (-7.05)	1225 (48.23	808 (31.81)	-175 (-6.89)	-2 (-0.08)	0 (0)	4 (0.16)
F23	1365 (53.74	502 (19.76)	-152 (-5.98)	1364 (53.7)	504 (19.84)	-145 (-5.71)	-1 (-0.04)	2 (0.08)	7 (0.28)
F24	1365 (53.74	604 (23.78)	-142 (-5.59)	1366 (53.78	605 (23.82)	-135 (-5.31)	1 (0.04)	1 (0.04)	7 (0.28)
F25	1375 (54.13	706 (27.8)	-140 (-5.51)	1375 (54.13	705 (27.76)	-137 (-5.39)	0 (0)	-1 (-0.04)	3 (0.12)
F26	1364 (53.7)	808 (31.81)	-125 (-4.92)	1366 (53.78	813 (32.01)	-123 (-4.84)	2 (0.08)	5 (0.2)	2 (0.08)
F27	1491 (58.7)	502 (19.76)	-78 (-3.07)	1486 (58.5)	504 (19.84)	-70 (-2.76)	-5 (-0.2)	2 (0.08)	8 (0.31)
F28	1476 (58.11	604 (23.78)	-80 (-3.15)	1472 (57.95	605 (23.82)	-70 (-2.76)	-4 (-0.16)	1 (0.04)	10 (0.39)
F29	1451 (57.13	706 (27.8)	-70 (-2.76)	1449 (57.05	705 (27.76)	-63 (-2.48)	-2 (-0.08)	-1 (-0.04)	7 (0.28)
F30	0	0	0	0	0	0	0	0	0



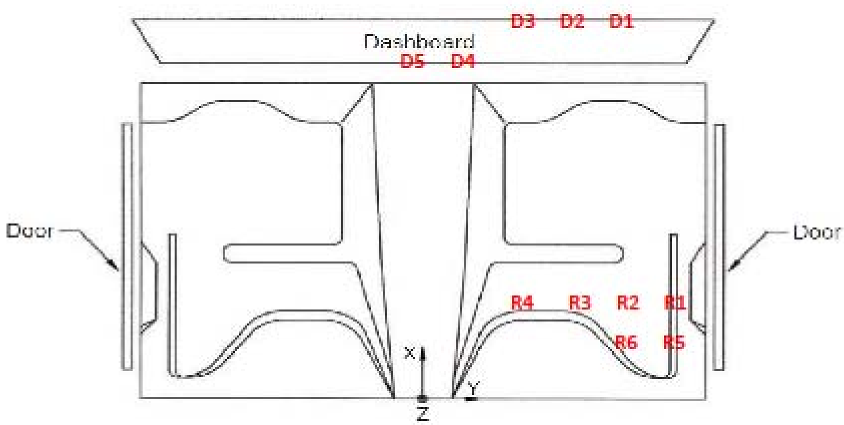
Vehicle Type	1100C Passenger Car	Test Number	110MASH2C14-01
Make	Kia	Model	Rio
Year	2006	Color	White
VIN #	KNADE123166043121		

Dashboard Measurements. Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
D1	1113 (43.82	706 (27.8)	529 (20.83)	1110 (43.7	705 (27.76)	531 (20.91)	-3 (-0.12)	-1 (-0.04)	2 (0.08)
D2	1117 (43.98	604 (23.78)	534 (21.02)	1114 (43.86	604 (23.78)	534 (21.02)	-3 (-0.12)	0 (0)	0 (0)
D3	1104 (43.46	502 (19.76)	539 (21.22)	1101 (43.35	504 (19.84)	539 (21.22)	-3 (-0.12)	2 (0.08)	0 (0)
D4	1050 (41.34	400 (15.75)	539 (21.22)	1047 (41.22	400 (15.75)	537 (21.14)	-3 (-0.12)	0 (0)	-2 (-0.08)
D5	1082 (42.6)	200 (7.87)	544 (21.42)	1079 (42.48	200 (7.87)	545 (21.46)	-3 (-0.12)	0 (0)	1 (0.04)
D6	0	0	0	0	0	0	0	0	0
D7	0	0	0	0	0	0	0	0	0
D8	0	0	0	0	0	0	0	0	0
D9	0	0	0	0	0	0	0	0	0
D10	0	0	0	0	0	0	0	0	0

Roof Measurements. Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
R1	730 (28.74)	706 (27.8)	896 (35.28)	730 (28.74)	703 (27.68)	897 (35.31)	0 (0)	-3 (-0.12)	1 (0.04)
R2	730 (28.74)	604 (23.78)	910 (35.83)	730 (28.74)	602 (23.7)	910 (35.83)	0 (0)	-2 (-0.08)	0 (0)
R3	730 (28.74)	502 (19.76)	919 (36.18)	730 (28.74)	502 (19.76)	921 (36.26)	0 (0)	0 (0)	2 (0.08)
R4	730 (28.74)	400 (15.75)	927 (36.5)	730 (28.74)	400 (15.75)	929 (36.57)	0 (0)	0 (0)	2 (0.08)
R5	603 (23.74)	706 (27.8)	884 (34.8)	603 (23.74)	703 (27.68)	892 (35.12)	0 (0)	-3 (-0.12)	8 (0.31)
R6	603 (23.74)	604 (23.78)	957 (37.68)	601 (23.66)	598 (23.54)	956 (37.64)	-2 (-0.08)	-6 (-0.24)	-1 (-0.04)
R7	476 (18.74)	706 (27.8)	903 (35.55)	473 (18.62)	702 (27.64)	908 (35.75)	-3 (-0.12)	-4 (-0.16)	5 (0.2)
R8	476 (18.74)	604 (23.78)	983 (38.7)	472 (18.58)	603 (23.74)	977 (38.46)	-4 (-0.16)	-1 (-0.04)	-6 (-0.24)
R9	476 (18.74)	502 (19.76)	989 (38.94)	473 (18.62)	502 (19.76)	986 (38.82)	-3 (-0.12)	0 (0)	-3 (-0.12)
R10	476 (18.74)	400 (15.75)	992 (39.06)	472 (18.58)	395 (15.55)	992 (39.06)	-4 (-0.16)	-5 (-0.2)	0 (0)



8.2. Test Vehicle Guidance System

A rail guidance system directed the vehicle into the barrier. The guidance rail, anchored at ~3.8 m intervals along its length was use to guide a mechanical arm, which was attached to the front right 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.

8.3. Photo – Instrumentation

Several high-speed video cameras recorded the impact during the tests. The high-speed video frame rates were set to 500 frames per second. The types of cameras and their locations are shown in Figure 8-1, Figure 8-2, and Figure 8-3, and Table 8-7, Table 8-8, and Table 8-9. The origin of the coordinates is at the intended point of impact. The camera location coordinates do not fall within the Lab's A2LA scope of accreditation.

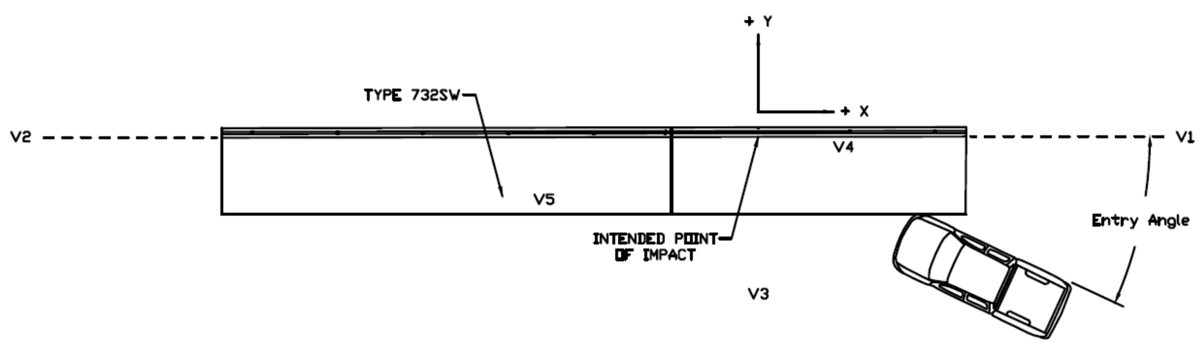


Figure 8-1 – Test 130MASH3P13-01 Camera Locations

Table 8-7 – Test 130MASH3P13-01 Camera Types and Locations

Camera Location	Camera Make/Model	Coordinates feet (m)		
		x	y	z
V1	Phantom V641	125.5 (38.24)	-1.5 (-0.47)	2.9 (0.89)
V2	Phantom V642	-190.1 (-57.95)	0 (0)	3.56 (1.09)
V3	Phantom V641	-6.2 (-1.90)	-71.6 (-21.8)	4.4 (1.34)
V4	Phantom Miro M110	7.1 (2.16)	-1.9 (-0.58)	30.8 (9.38)
V5	Phantom Miro M110	-29.6 (-9.02)	-12.7 (-3.86)	37.4 (11.39)

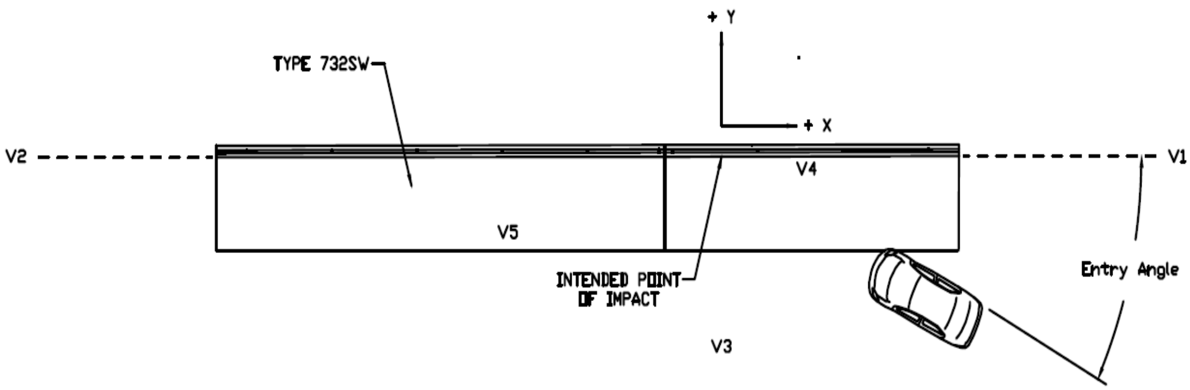


Figure 8-2 – Test 130MASH3C13-02 Camera Locations

Table 8-8 – Test 130MASH3C13-02 Types and Locations

Camera Location	Camera Make/Model	Coordinates (m)		
		x	y	z
V1	Phantom V641	133.0 (40.54)	-0.5 (-0.14)	3.9 (1.19)
V2	Phantom V642	-186.3 (-56.79)	-0.3 (-.09)	4.1 (1.244)
V3	Phantom V642	-0.4 (-0.114)	-76.9 (-23.44)	5.1 (1.56)
V4	Phantom Miro M110	10.6 (3.243)	-1.2 (-0.368)	31.1 (9.47)
V5	Phantom Miro M110	-19.8 (-6.05)	-9.1 (-2.77)	41.5 (12.65)

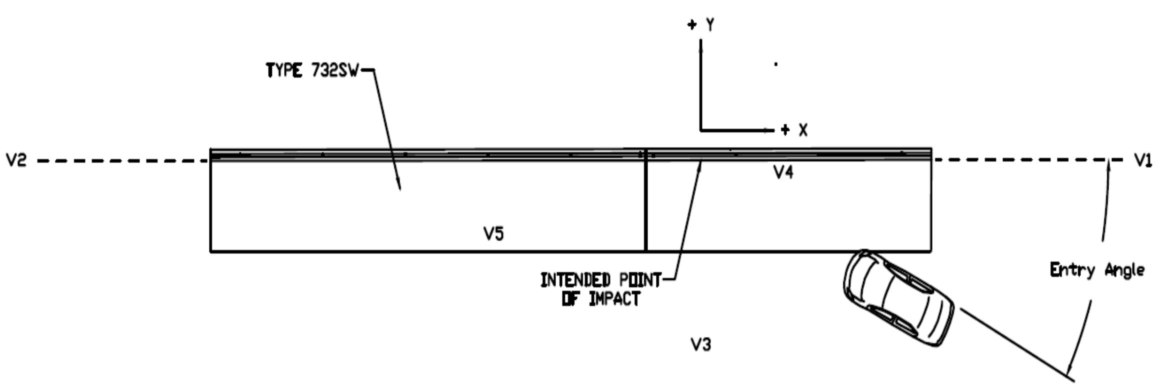


Figure 8-3 – Test 110MASH2C14-01 Camera Locations

Table 8-9 – Test 110MASH2C14-01 Camera Types and Locations

Camera Location	Camera Make/Model	Coordinates ft (m)		
		x	y	z
V1	Olympus iSpeed3	114.5 (34.91)	-2.6 (-0.79)	3.8 (1.15)
V2	Olympus iSpeed3	-183.8 (-56.02)	-0.8 (-0.25)	4.6 (1.40)
V3	Olympus iSpeed3	-4.2 (-1.29)	-94.2 (-28.71)	5.0 (1.52)
V4	Phantom Miro M110	0.92 (0.28)	15.9 (4.84)	31.2 (9.52)
V5	Phantom Miro M110	-6.2 (-1.90)	-18.6 (-5.66)	42.8 (13.04)

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

1. Butterfly targets were attached to the top and sides of the test vehicle. The targets were located on the vehicle at intervals of 500 mm and 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.

8.4. Electronic Instrumentation and Data

Transducer data were recorded on two separate GMH Engineering, Data Brick, Model II, digital transient data recorders (TDRs) that were mounted on the test vehicles. These transducers included two sets of accelerometers and one set 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 B18 (pre-processing) and TRAP version 2.3.2 (post-processing). Accelerometer specifications are shown in Table 8-5. The vehicle accelerometer sign convention used throughout this report is the same as described in MASH 09 and is show in Figure 8-3.

Table 8-10 – Accelerometer and Angular Rate Sensor Specifications

Type	Manufacturer	Model	Serial Number	Location	Range	Orientation	Test No.
Accelerometer	Endevco	7264-200	J16359	Vehicle's CG	200 G	Longitudinal (Primary)	130MASH3P13-01, 130MASH3C13-02, 110MASH2C14-01
Accelerometer	Endevco	7264-200	J16361	Vehicle's CG	200 G	Lateral (Primary)	130MASH3P13-01, 130MASH3C13-02, 110MASH2C14-01
Accelerometer	Endevco	7264-200	J16362	Vehicle's CG	200 G	Vertical (Primary)	130MASH3P13-01, 130MASH3C13-02, 110MASH2C14-01
Accelerometer	Endevco	7264-200	J16418	Vehicle's CG	200 G	Longitudinal (Secondary)	130MASH3P13-01, 130MASH3C13-02
Accelerometer	Endevco	7264-200	J16417	Vehicle's CG	200 G	Lateral (Secondary)	130MASH3P13-01, 130MASH3C13-02
Accelerometer	Endevco	7264-200	J16416	Vehicle's CG	200 G	Vertical (Secondary)	130MASH3P13-01, 130MASH3C13-02
Angular Rate Sensor	DTS, Inc.	ARS-1500	3395	Vehicle's CG	1500 deg/s	Roll (Primary)	130MASH3P13-01, 130MASH3C13-02, 110MASH2C14-01
Angular Rate Sensor	DTS, Inc.	ARS-1500	3348	Vehicle's CG	1500 deg/s	Pitch (Primary)	130MASH3P13-01, 130MASH3C13-02, 110MASH2C14-01
Angular Rate Sensor	DTS, Inc.	ARS-1500	3336	Vehicle's CG	1500 deg/s	Yaw (Primary)	130MASH3P13-01, 130MASH3C13-02, 110MASH2C14-01
Angular Rate Sensor	DTS, Inc.	ARS-1500	4018	Vehicle's CG	1500 deg/s	Roll (Secondary)	130MASH3P13-01, 130MASH3C13-02
Angular Rate Sensor	DTS, Inc.	ARS-1500	4019	Vehicle's CG	1500 deg/s	Pitch (Secondary)	130MASH3P13-01, 130MASH3C13-02
Angular Rate Sensor	DTS, Inc.	ARS-1500	3355	Vehicle's CG	1500 deg/s	Yaw (Secondary)	130MASH3P13-01, 130MASH3C13-02

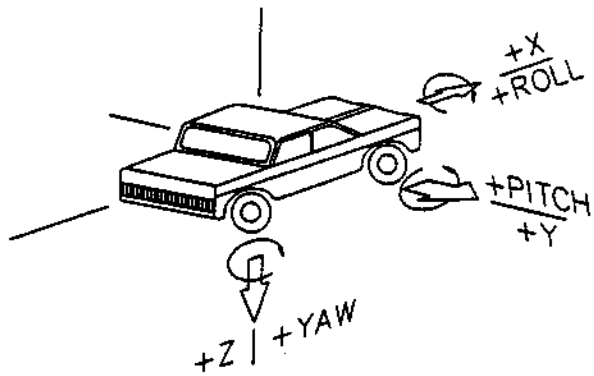


Figure 8-4 – Vehicle Accelerometer Sign Convention

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 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 tape switch on the front bumper of the vehicle closed at the instant of impact and triggered two events: 1) "event marker" was added to the recorded data, and 2) a flashbulb mounted on the top of the vehicle was activated. Two sets of tape switches, connected to a speed trap, were placed 4 m apart just upstream of the test article specifically to establish the impact speed of the test vehicle (This measurement is for reference only and in not a calibrated method of measuring speed). The layout for all of the tape switches and reflective tape is shown in Figure 8-5.

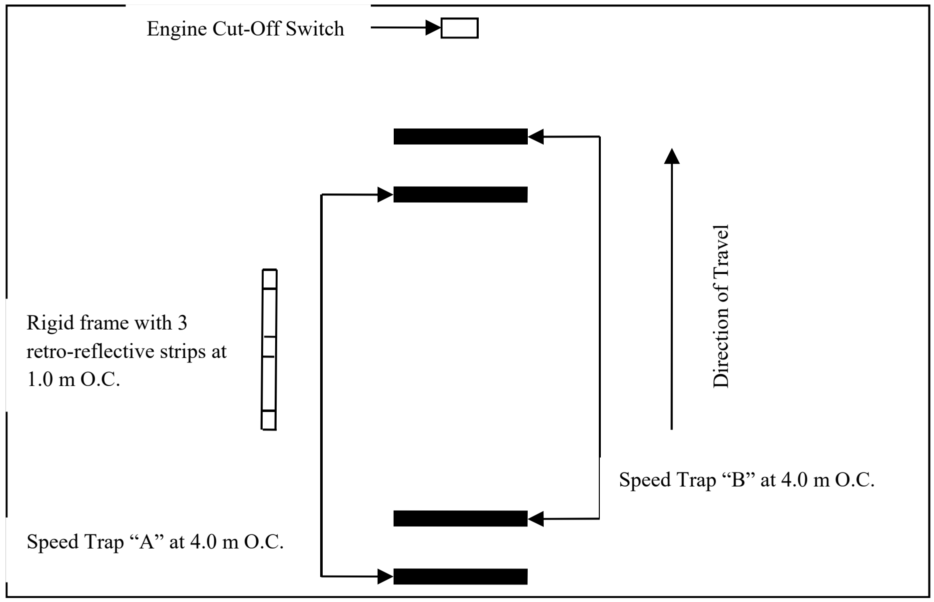


Figure 8-5 – Tape Switch Layout

The data curves are shown in Figure 8-6 through Figure 8-23 include the accelerometer and angular rate sensor records from the test vehicles. They also show the velocity and displacement curves for the longitudinal and lateral components. These plots are required to calculate the occupant impact velocity defined in MASH 09. All data were analyzed using TRAP.

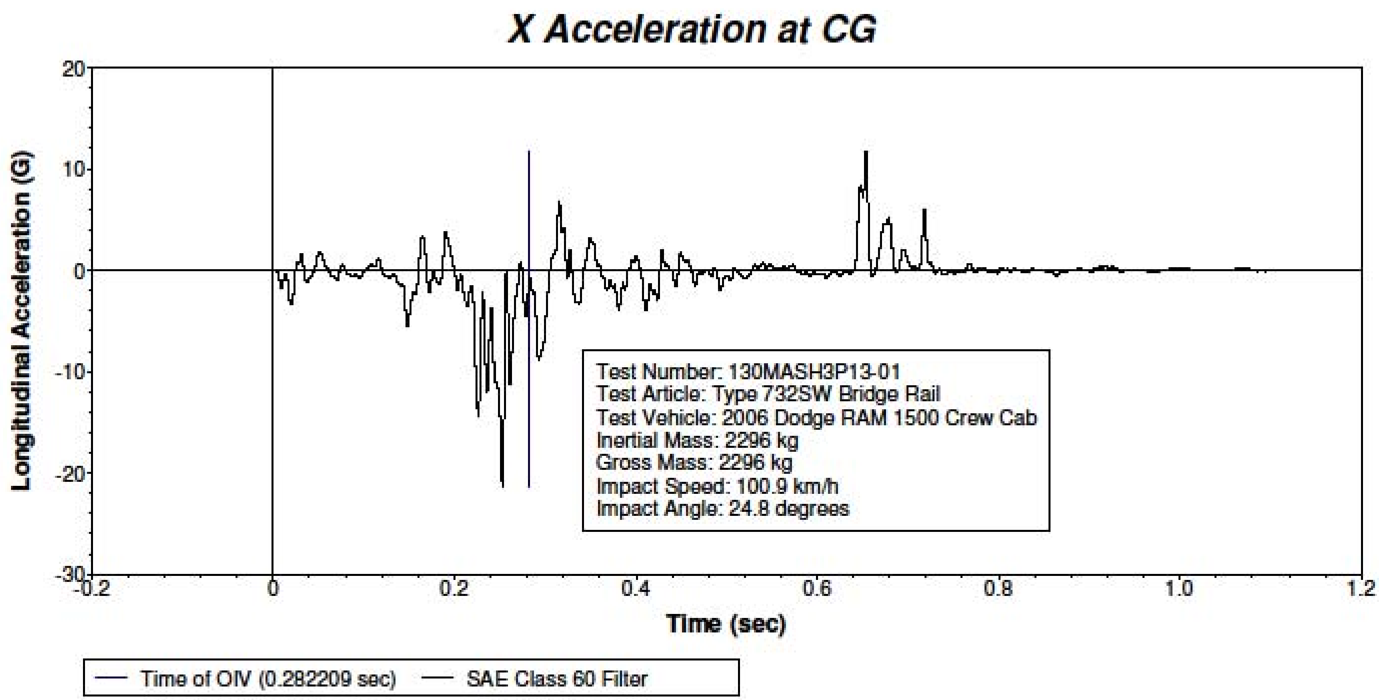


Figure 8-6 – Test 130MASH3P13-01 Vehicle Longitudinal Acceleration Vs Time

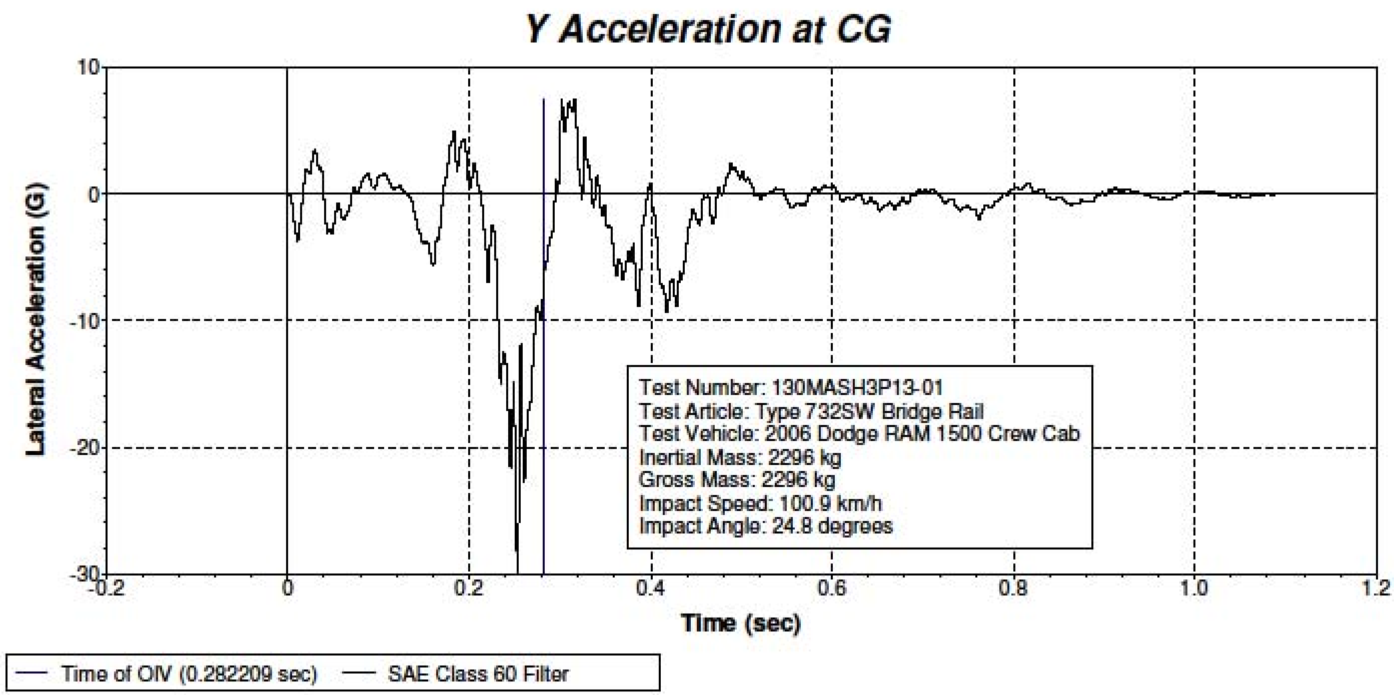


Figure 8-7 – Test 130MASH3P13-01 Vehicle Lateral Acceleration Vs Time

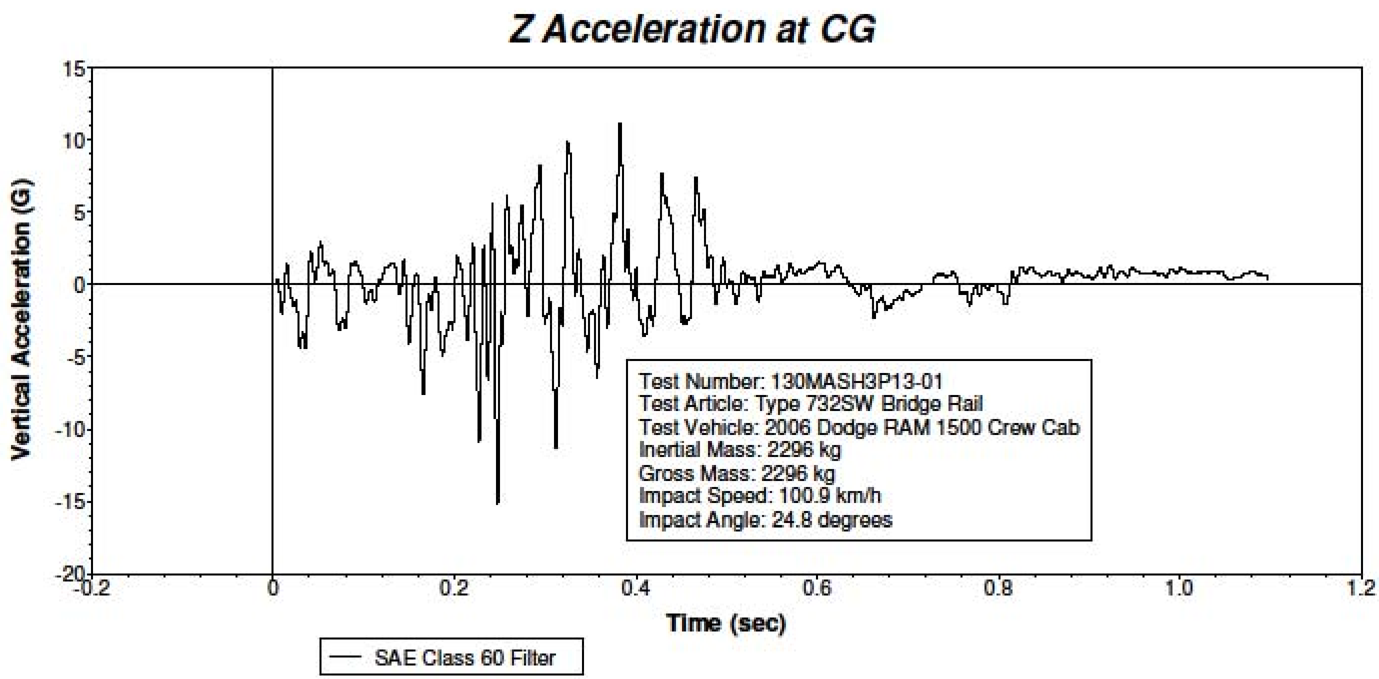


Figure 8-8 – Test 130MASH3P13-01 Vehicle Vertical Acceleration Vs. Time

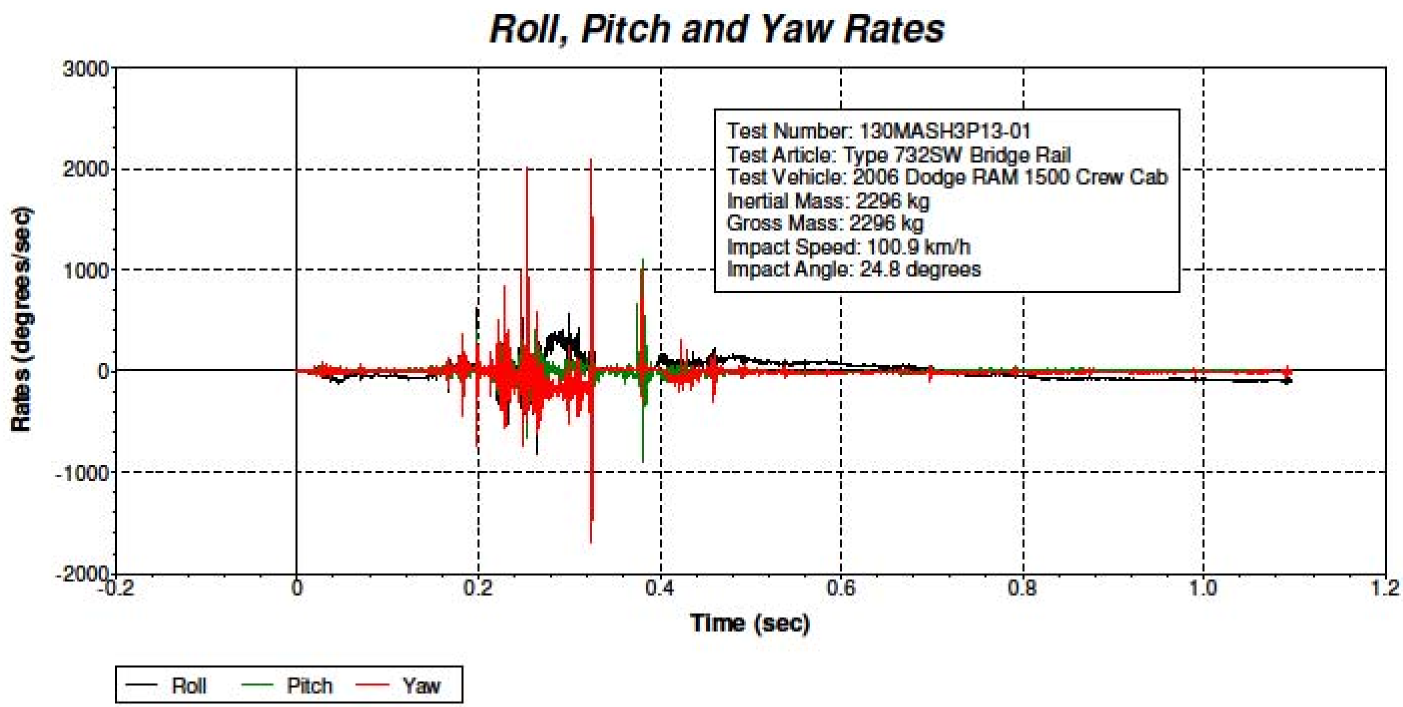


Figure 8-9 – Test 130MASH3P13-01 Vehicle Roll, Pitch, and Yaw Rate Vs Time

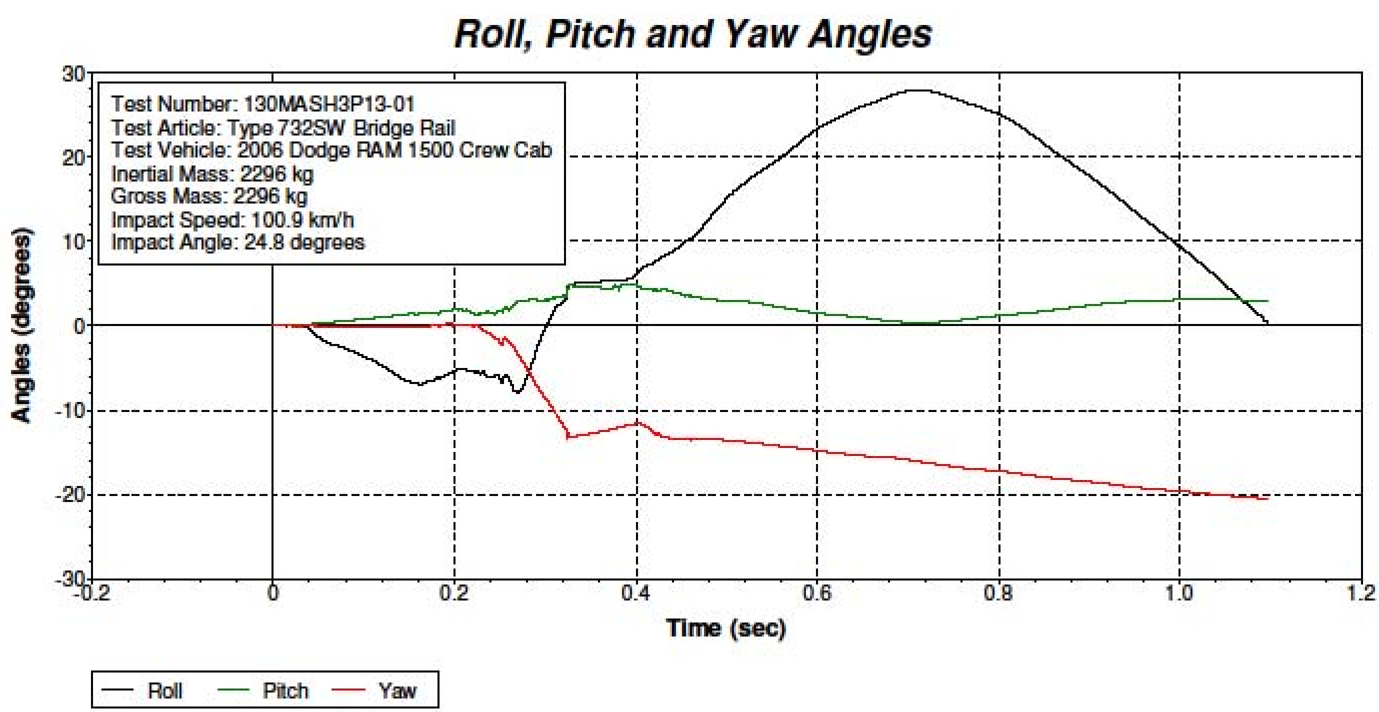


Figure 8-10 – Test 130MASH3P13-01 Vehicle Roll, Pitch, and Yaw Angle Vs Time

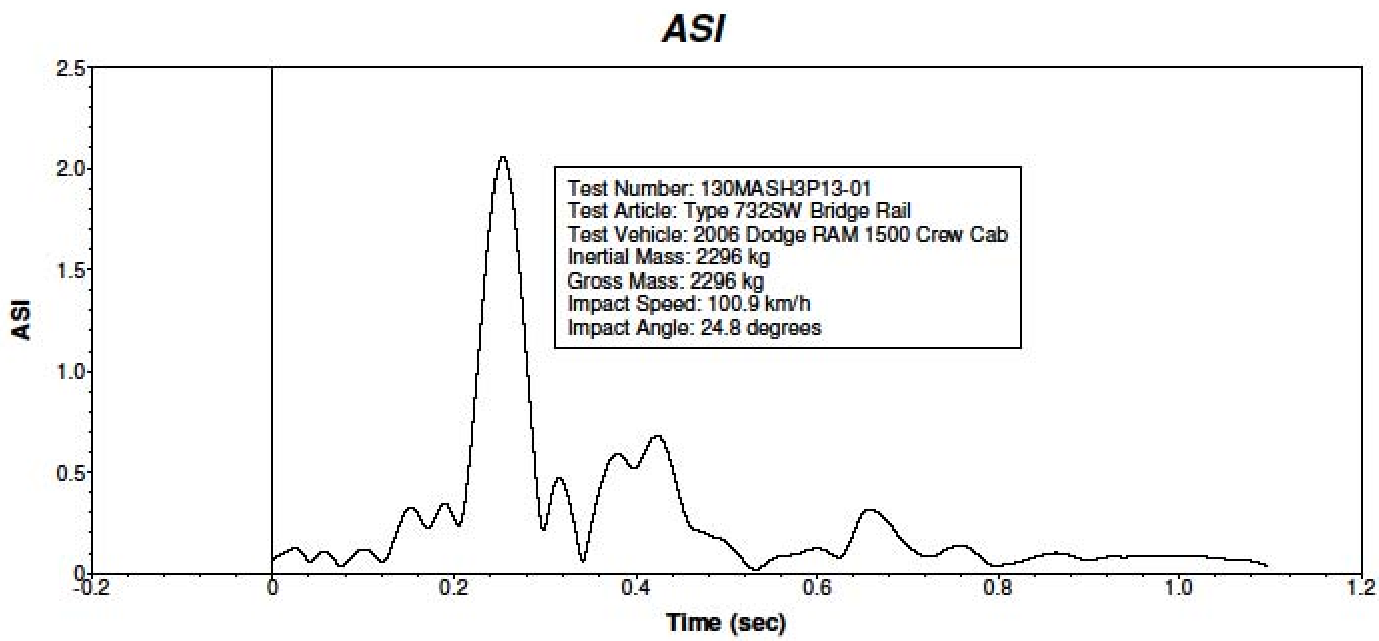


Figure 8-11 – Test 130MASH3P13-01 Vehicle Acceleration Severity Index (ASI) Vs Time

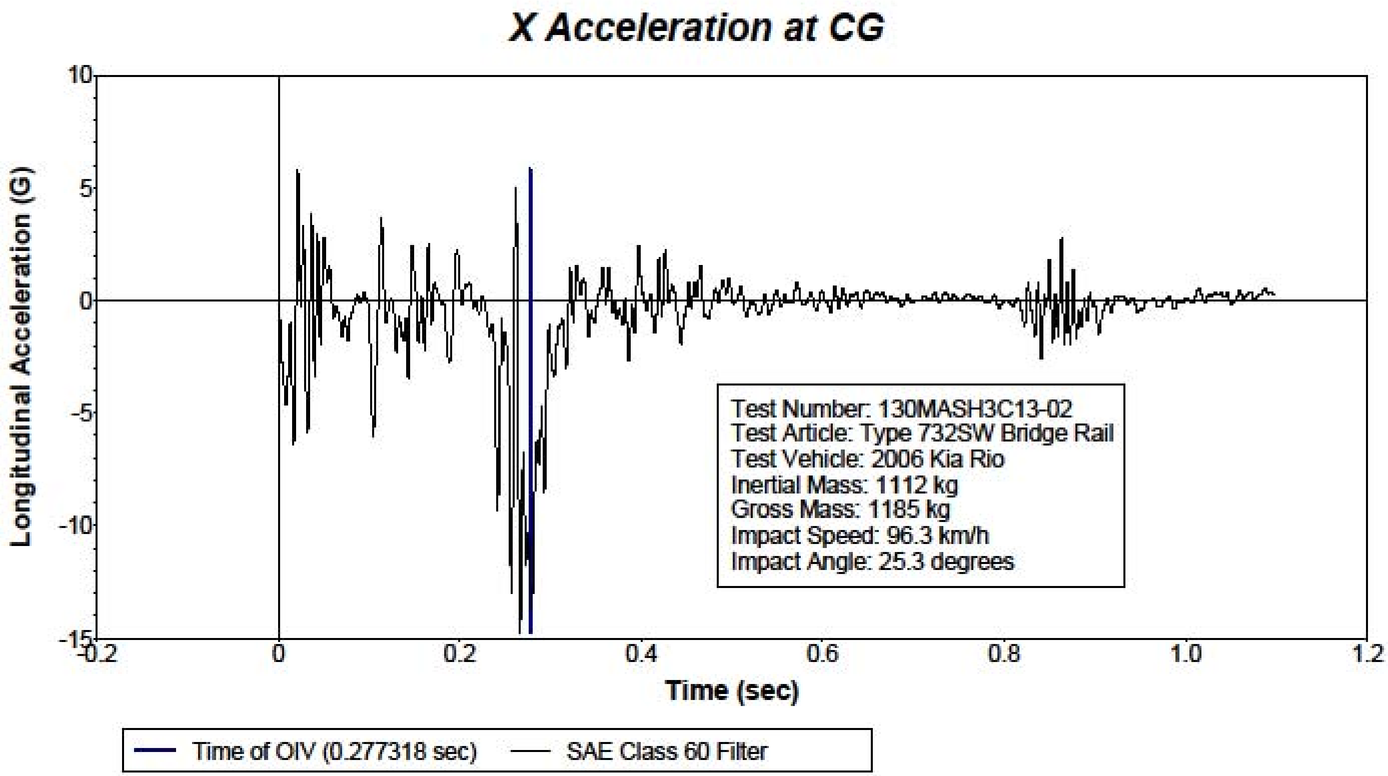


Figure 8-12 – Test 130MASH3C13-02 Vehicle Longitudinal Acceleration Vs Time

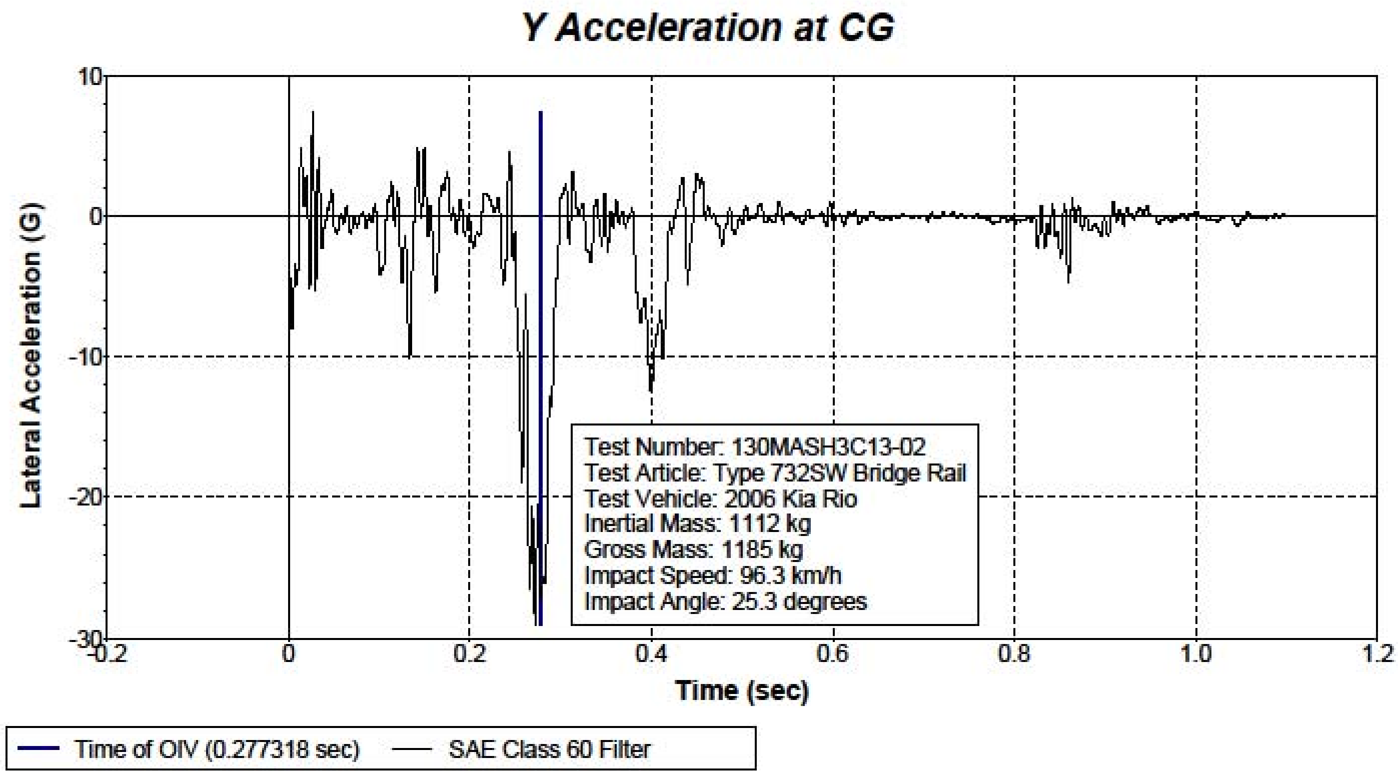


Figure 8-13 – Test 130MASH3C13-02 Vehicle Lateral Acceleration Vs Time

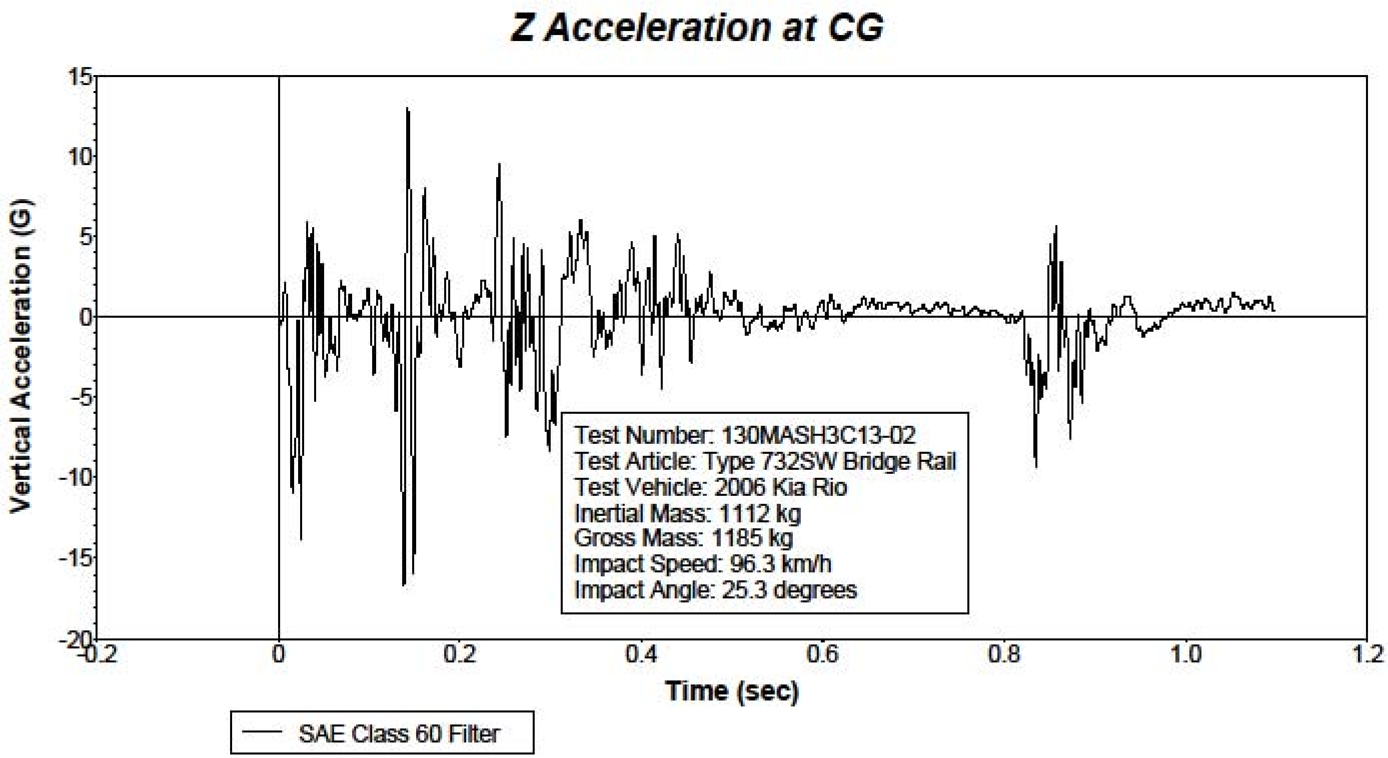


Figure 8-14 – Test 130MASH3C13-02 Vehicle Vertical Acceleration Vs Time

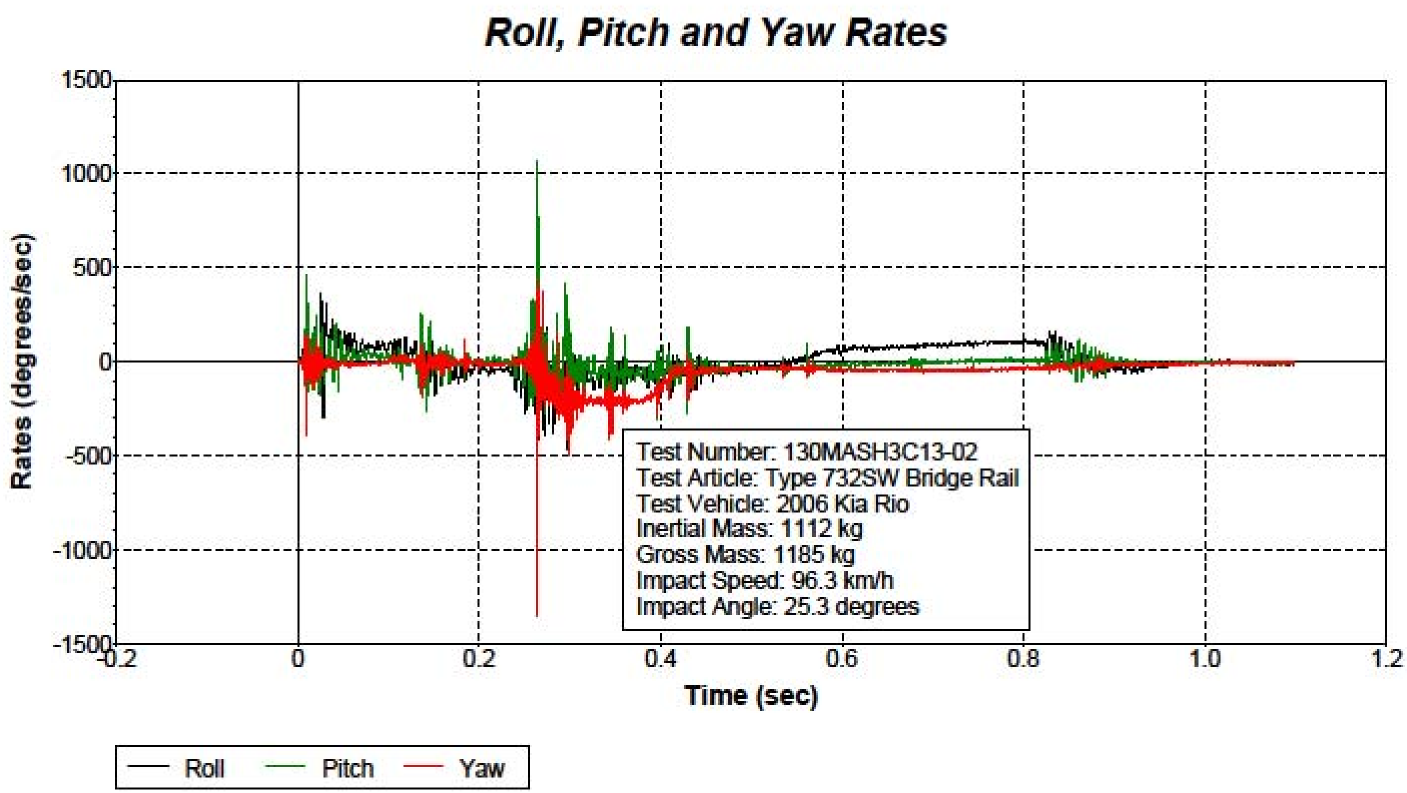


Figure 8-15 – Test 130MASH3C13-02 Vehicle Roll, Pitch, and Yaw Rate Vs Time

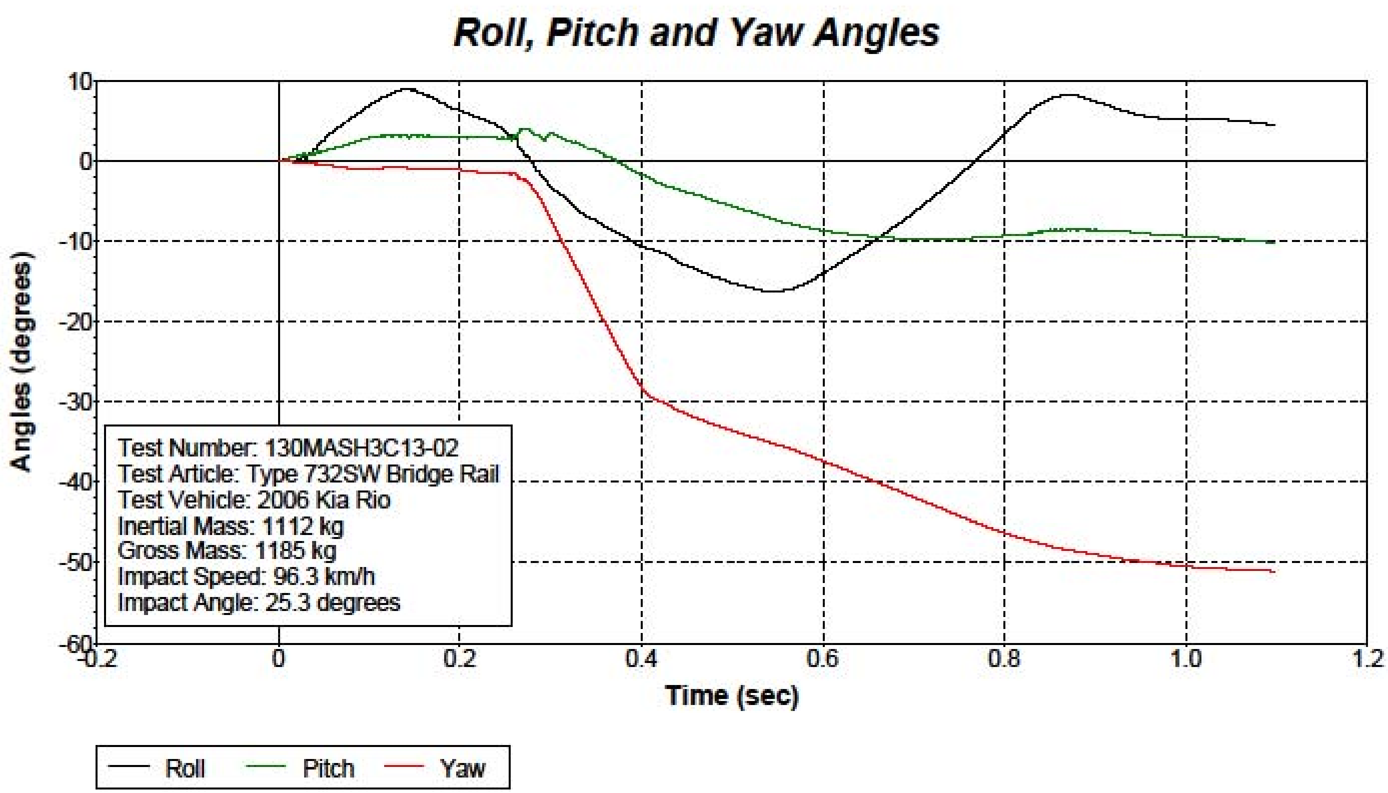


Figure 8-16 – Test 130MASH3C13-02 Vehicle Roll, Pitch, and Yaw Angle Vs Time

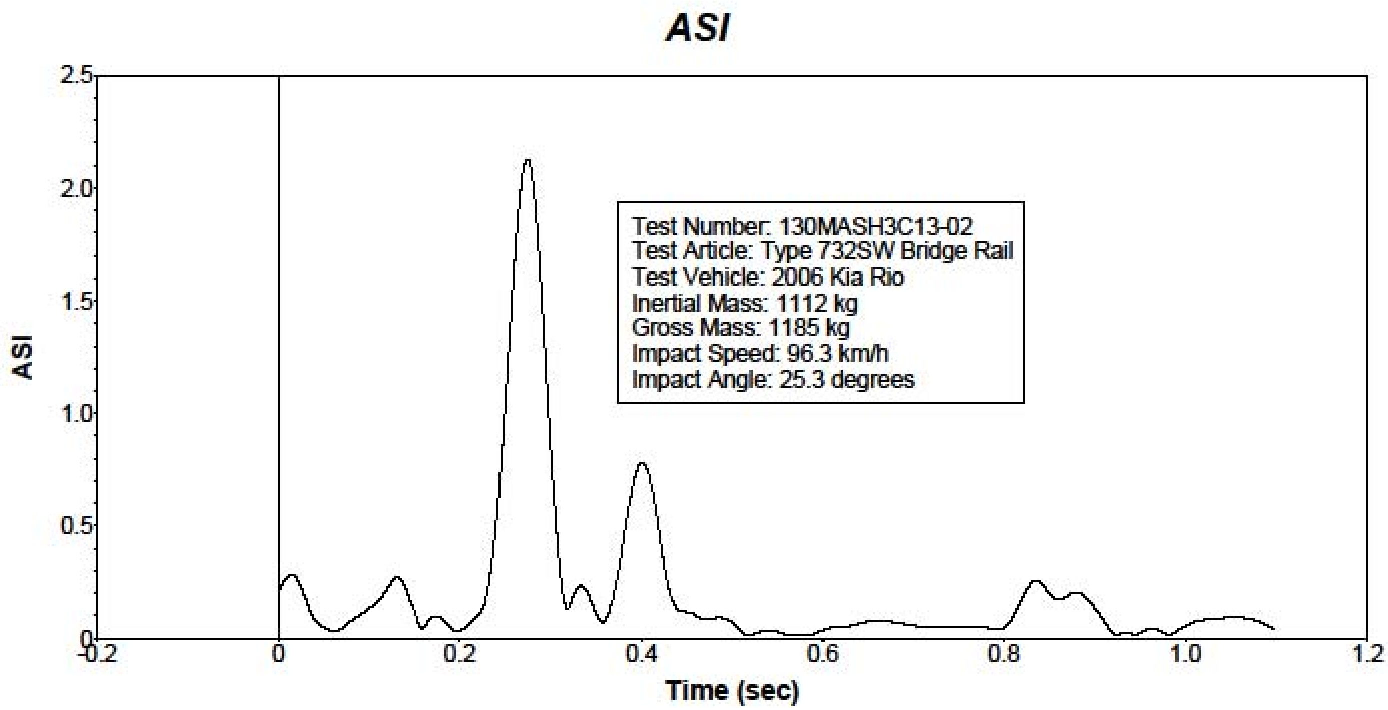


Figure 8-17 – Test 130MASH3C13-02 Vehicle Acceleration Severity Index (ASI) Vs Time

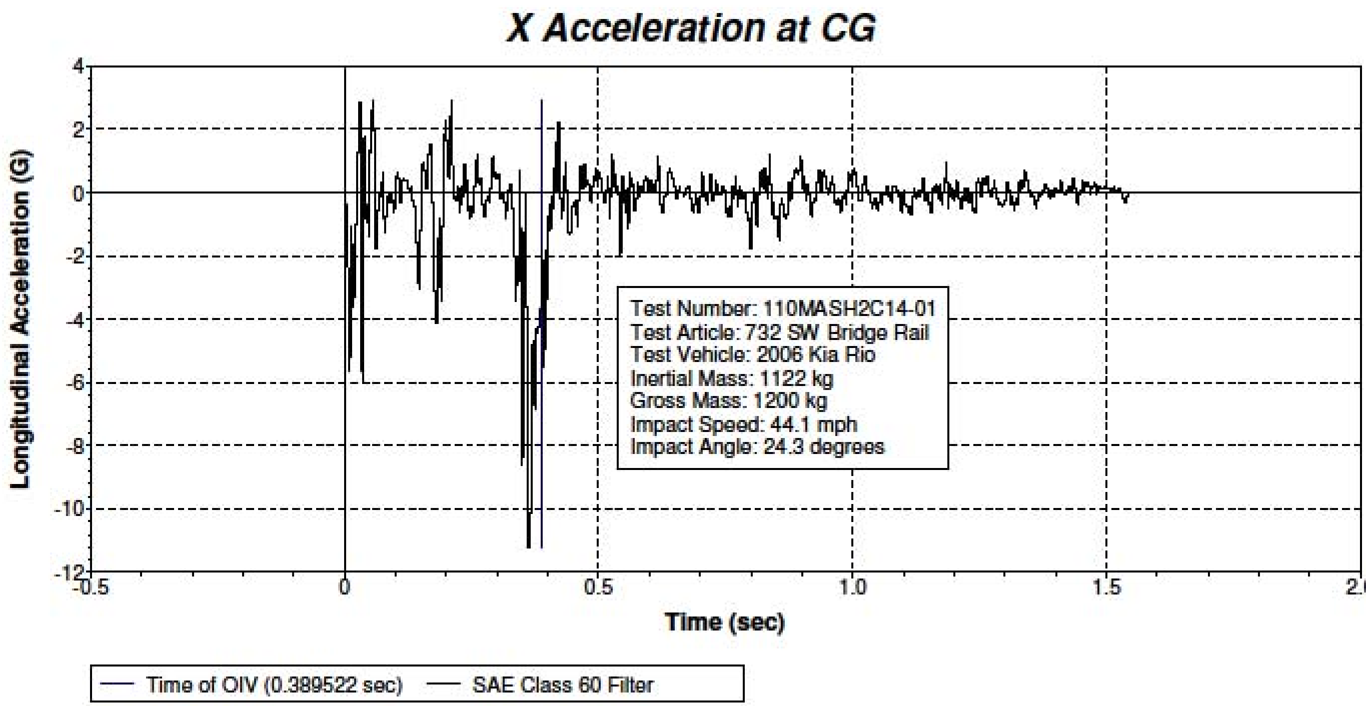


Figure 8-18 – Test 110MASH2C14-01 Vehicle Longitudinal Acceleration Vs Time

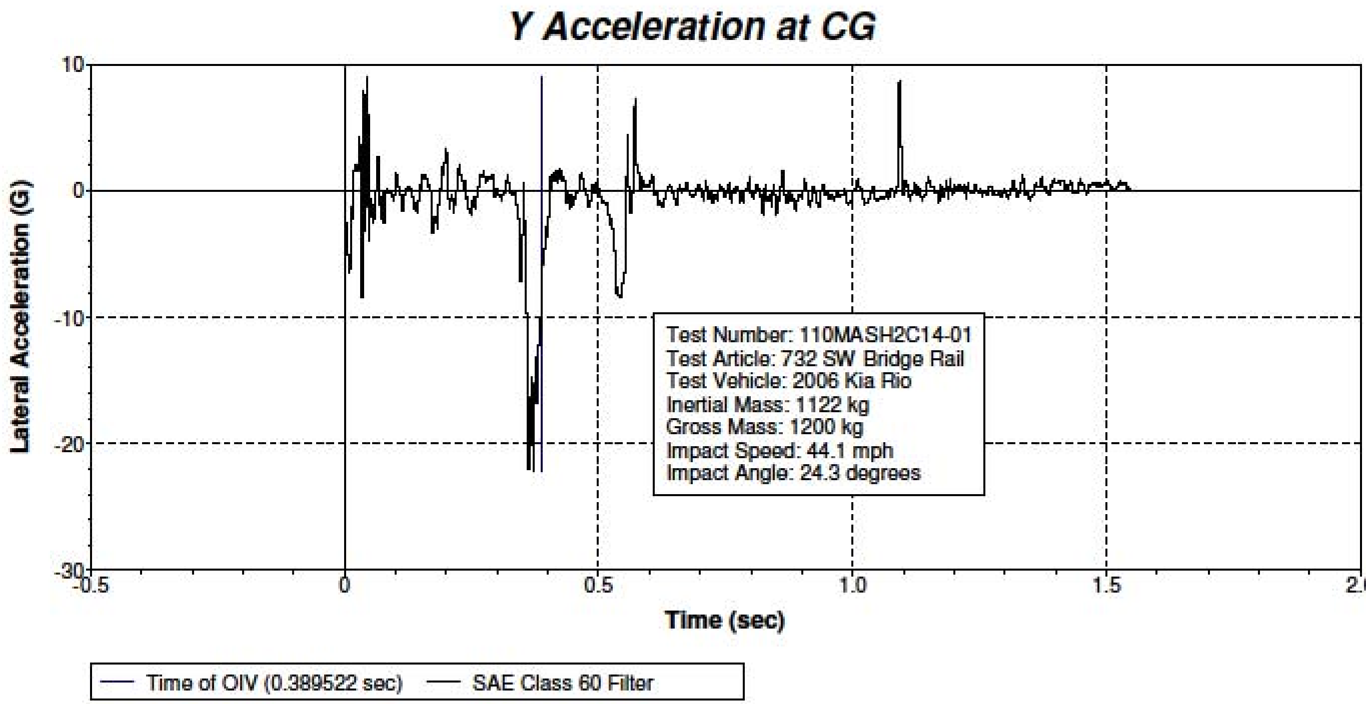


Figure 8-19 – Test 110MASH2C14-01 Vehicle Lateral Acceleration Vs Time

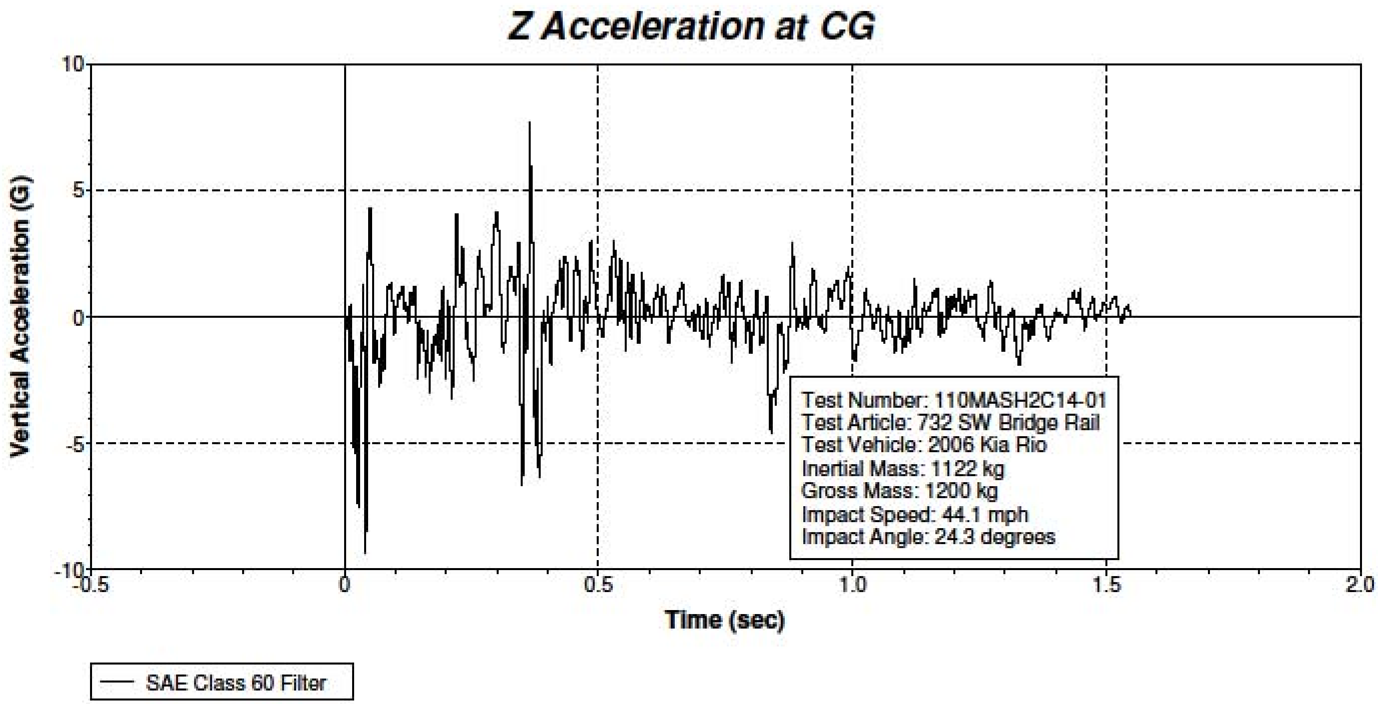


Figure 8-20 – Test 110MASH2C14-01 Vehicle Vertical Acceleration Vs Time

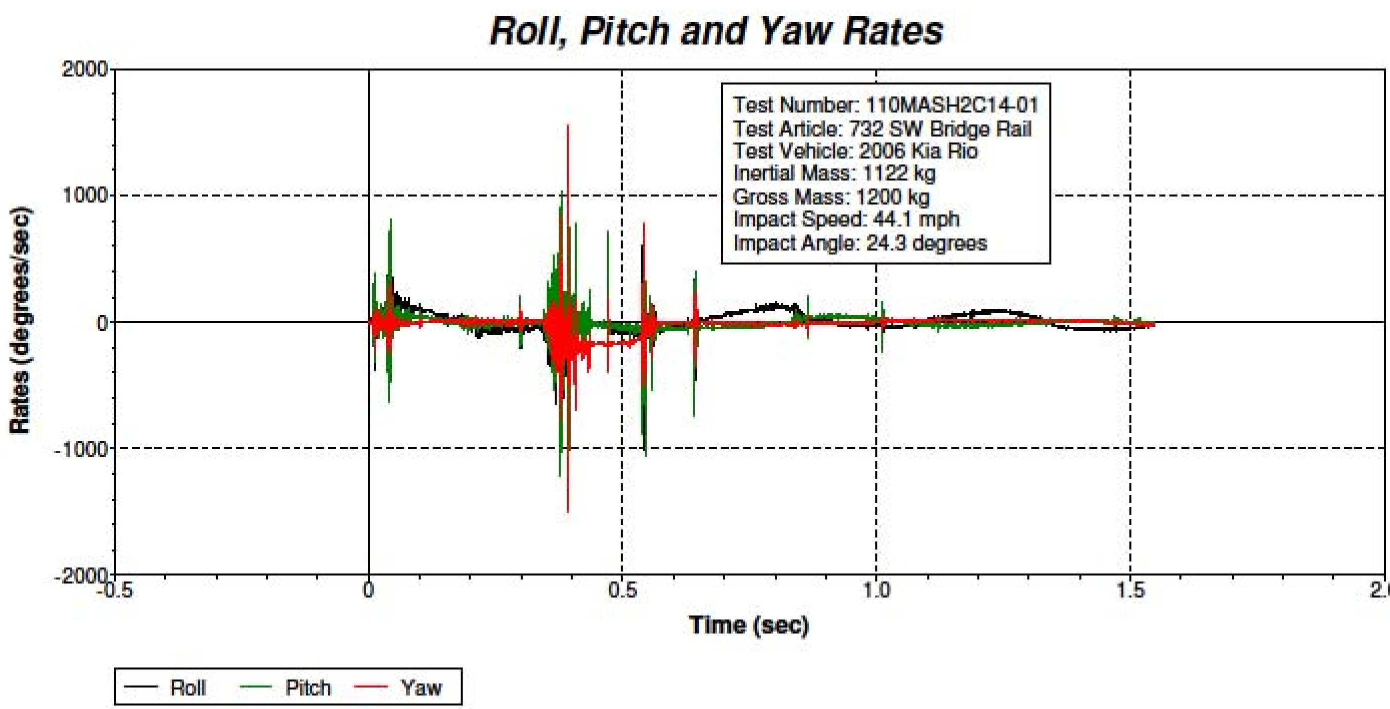


Figure 8-21 – Test 110MASH2C14-01 Vehicle Roll, Pitch, and Yaw Rate Vs Time

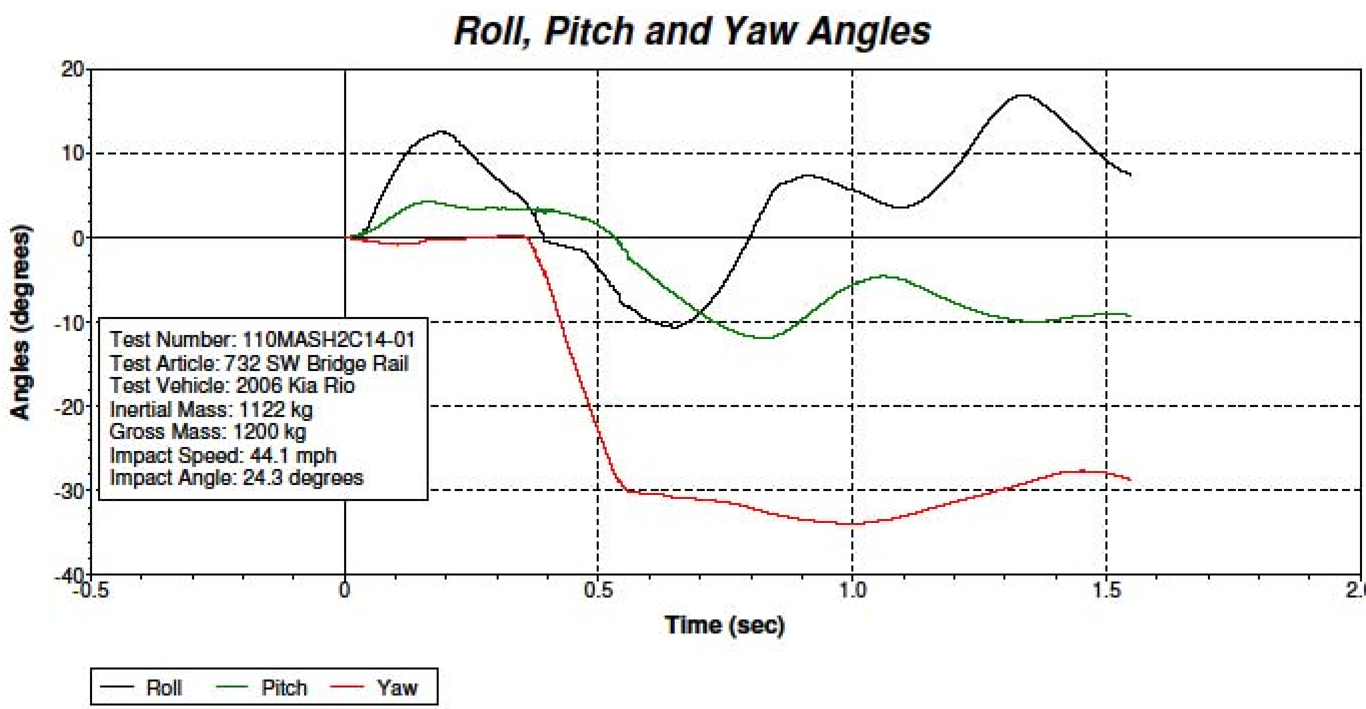


Figure 8-22 – Test 110MASH2C14-01 Vehicle Roll, Pitch, and Yaw Angle Vs Time

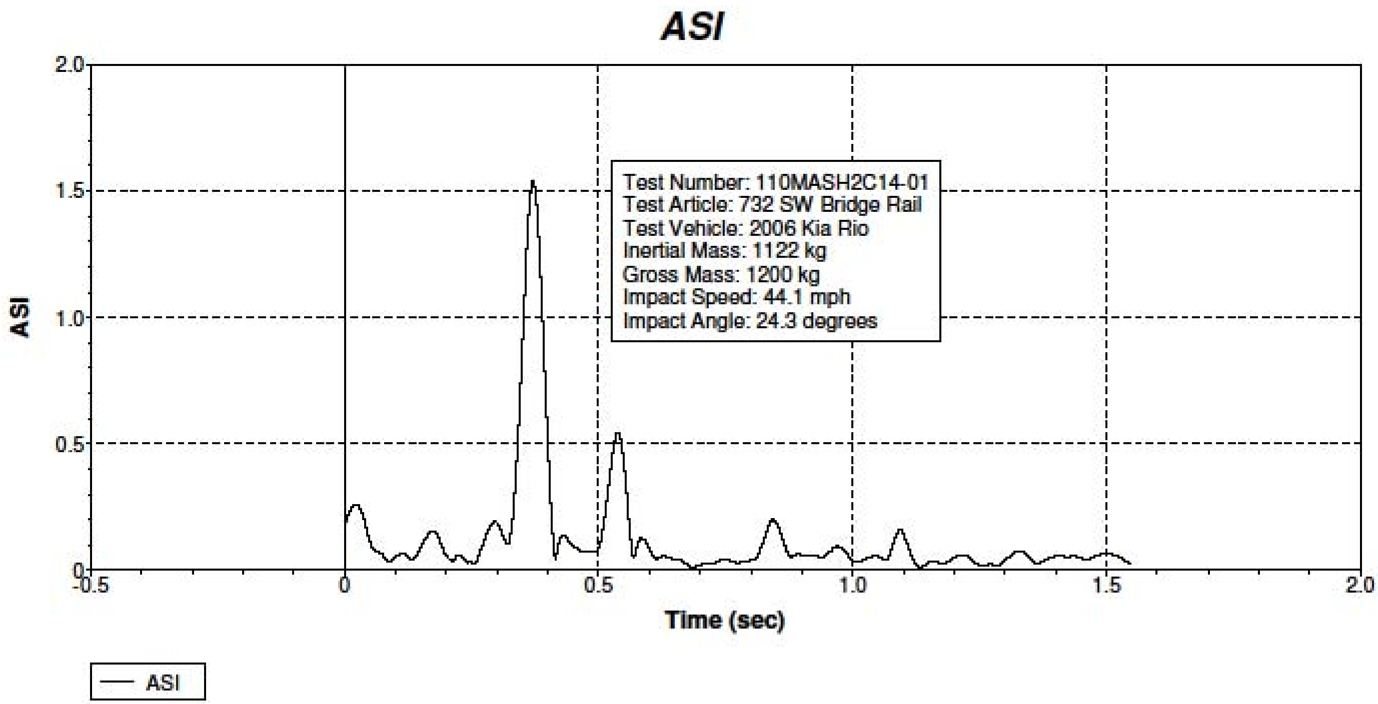


Figure 8-23 – Test 110MASH2C14-01 Vehicle Acceleration Severity Index (ASI) Vs Time

9. Appendix - Detail Drawings

The following details in Figure 8-28 to 8-32 are for the tested barrier only.

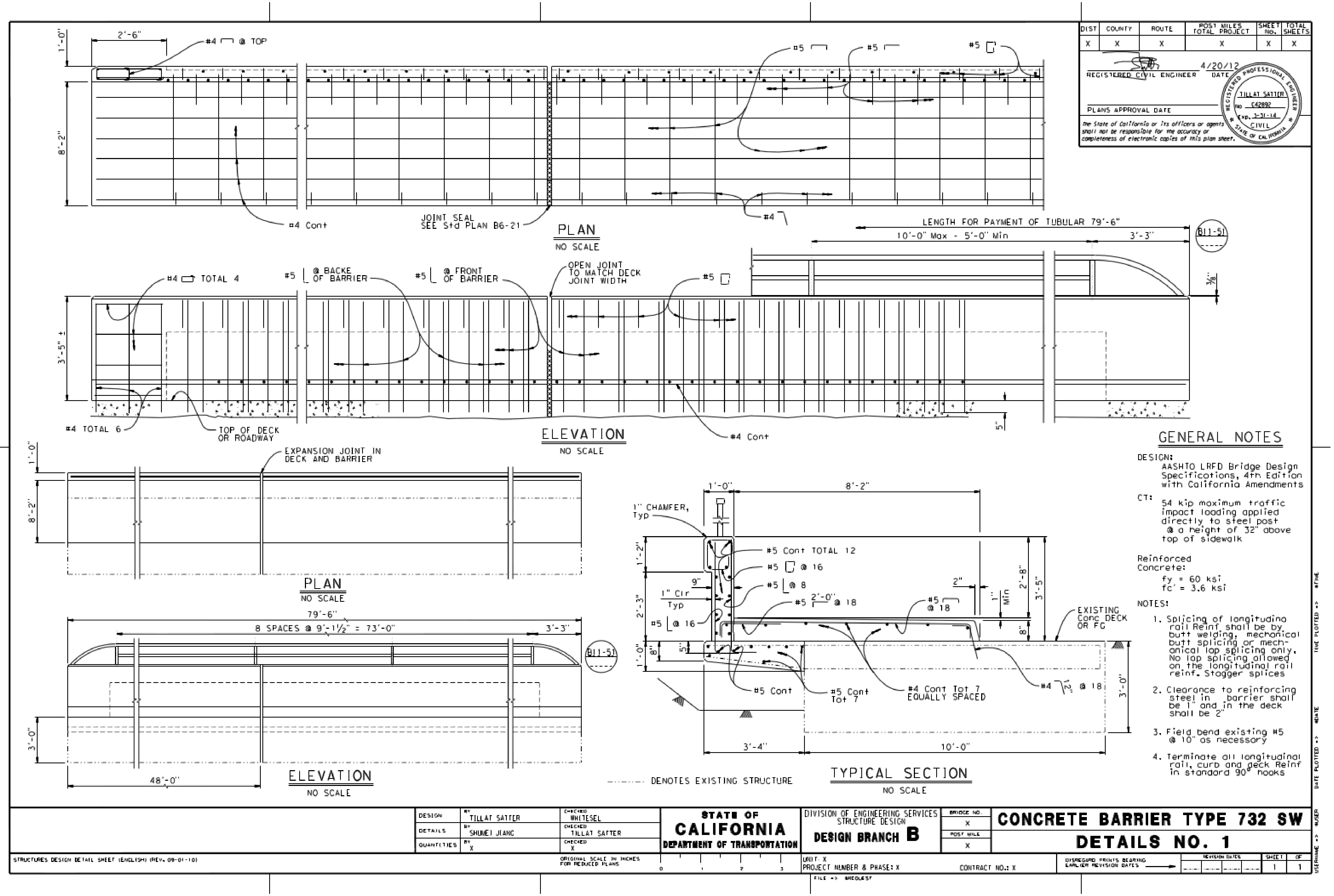


Figure 9-1 – Caltrans Type 732SW Bridge Rail Detail No. 1

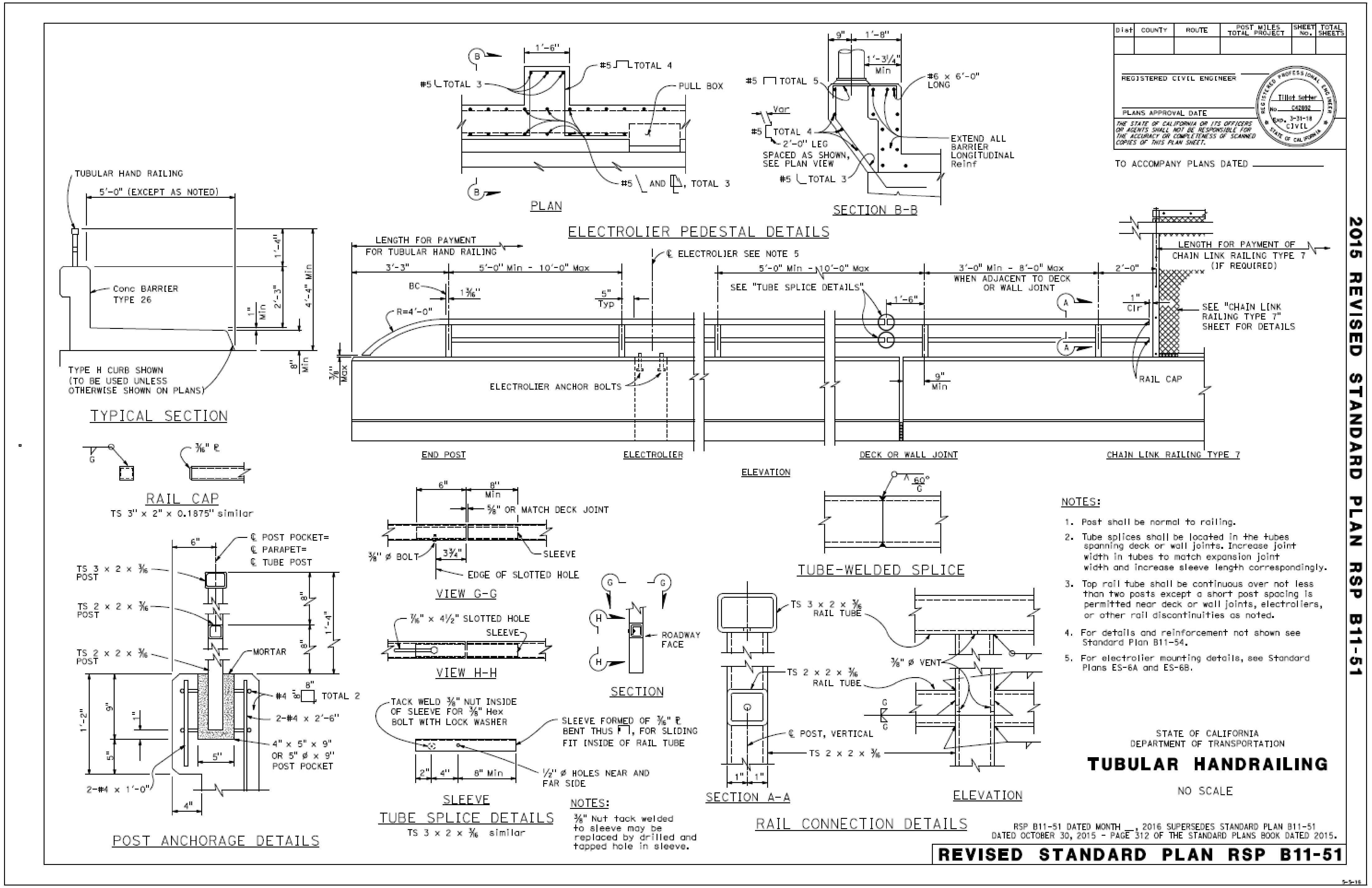


Figure 9-2 – Caltrans Type 732SW Bridge Rail Detail No. 2

10. Appendix - References

1. *Manual for Assessing Safety Hardware 2009 (MASH 09), American Association of State Highway and Transportation Officials, Washington, DC. 2009.*
2. *State of California Department of Public Works, Division of Highways Standard Plans. 1973.*
3. *NSC. Vehicle Damage Scale for Traffic Accident Investigators. National Safety Council. 444 Michigan Avenue, Chicago, Illinois, 60611. 1984.*
4. *SAE. Collision Deformation Classification. Recommended Practice J224a. Society of Automotive Engineers. New York, NY. 1972*

11. Appendix - Memo to File regarding 110MASH2C14-01 Lateral Accelerometer Trace

State of California
DEPARTMENT OF TRANSPORTATION

California State Transportation Agency

Memorandum

Serious drought.
Help Save Water!

To: File

Date: April 22, 2014
Rev. November 19, 2015

File: Type 732SW

From: **DEPARTMENT OF TRANSPORTATION**
Division of Research and Innovation - MS #5
Office of Safety Innovation and Cooperative Research

Subject: **Crash Test 110MASH2C14-01**

During the TL-2 test, 110MASH2C14-01, there were a couple of problems with the data acquisition system. The data acquisition system included a primary Databrick, tri-axial accelerometers, and angular rate sensors. It also included a secondary Databrick, tri-axial accelerometers, and angular rate sensors. On test day there was a delay that resulted in the data acquisition system being powered down. When the secondary Databrick was powered back up, the trigger cable was accidentally inserted into the wrong channel so the Databrick did not trigger and record data as it should have. Compounding this was a problem with the lateral accelerometer connected to the primary Databrick. It appears that there was a short in the connector from the accelerometer to the Databrick that resulted in noise in the lateral channel. The noise occurred late in the impact sequence and showed up as sustained spikes in the opposite direction of impact. Because the noise occurred late in the sequence, it was easily identifiable in the data and we were able to compare the data to an identical impact at TL-3 levels. The following filtering was done prior to running the data through TRAP.

The noise was filtered out by changing the affected data points above about 20g to zero. This is a conservative approach because the max ridedown acceleration occurred as a negative number. By changing the high positive values to 0, this resulted in a higher, more conservative ridedown acceleration. Looking at the third plot below, of the TL-3 small car test into the same barrier, backslap occurs at about 0.4 seconds and has a max acceleration of about -15 or -16g. The maximum acceleration during the TL-2 test should be less than the maximum acceleration during the TL-3 test. Since the MASH max occupant ridedown acceleration is 20g, even the TL-3 maximum acceleration of 16g would still be below the MASH maximum.

For these reasons, I believe that the lateral acceleration data obtained during the test is usable in the modified form described herein.

David A. Whitesel
Roadside Safety Research Group

"Provide a safe, sustainable, integrated and efficient transportation system to enhance California's economy and livability"

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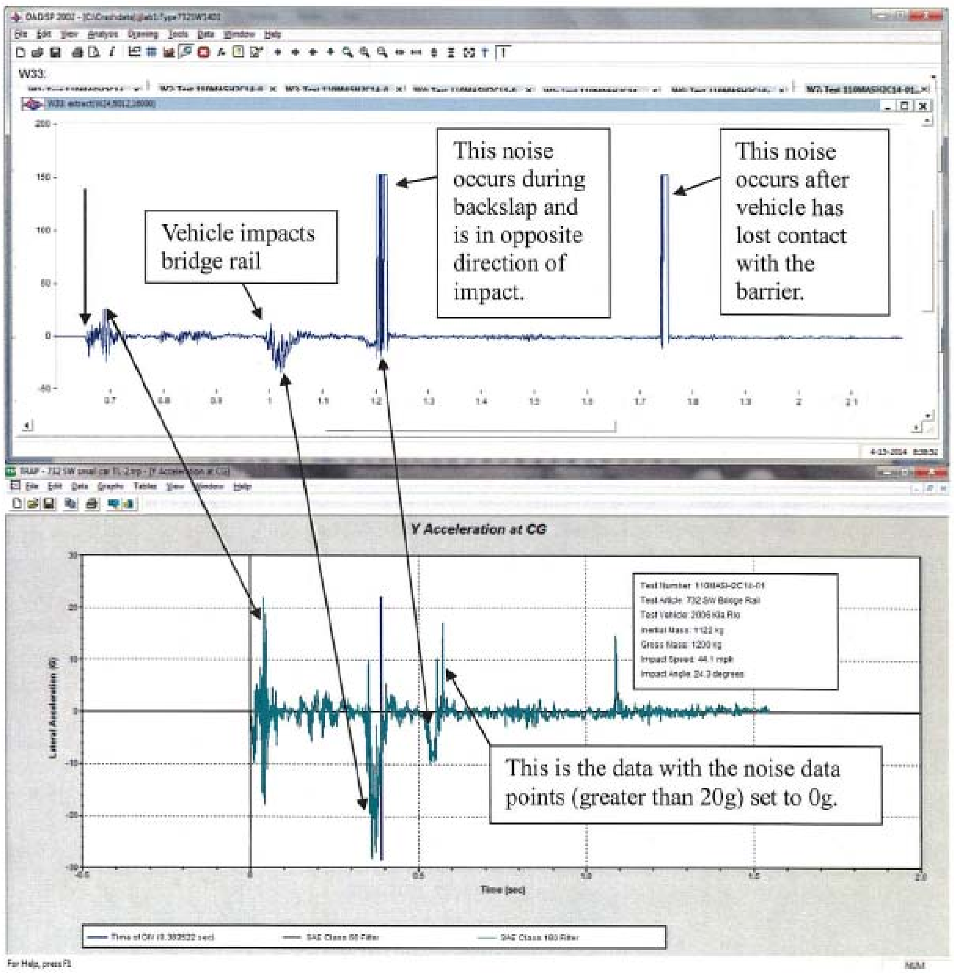

Upper plot: Original data with noise for 110MASH2C14-01

Lower plot: Data for 110MASH2C14-01 with noise removed (filtered)

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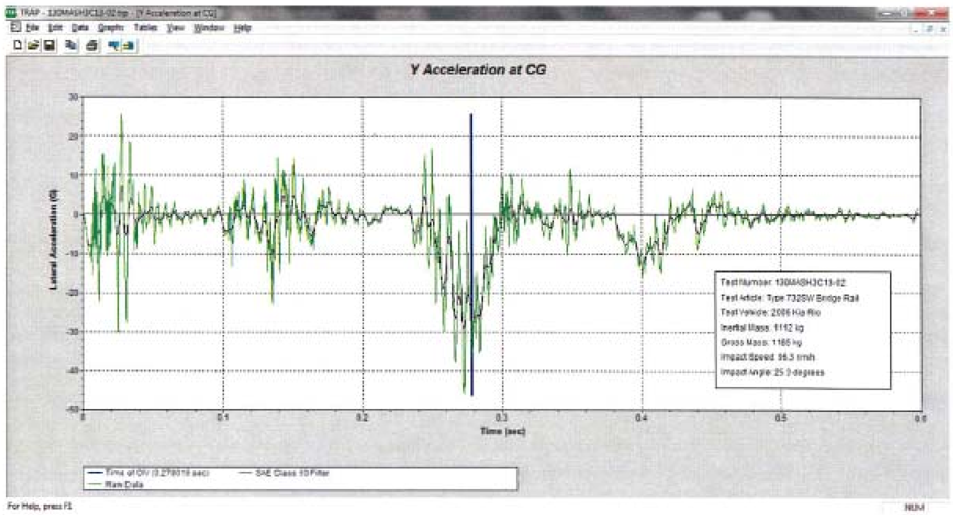

Data for 130MASH3C13-02
Same test conditions as plots on page 2 except at TL-3