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15. SUPPLEMENTARY NOTES

This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled “COMPLIANCE CRASH TESTING OF THE TYPE 60 MEDIAN BARRIER, Test 140MASH3C16-04”.

16. ABSTRACT

The California Department of Transportation has used Type 60 Median Barrier since it passed the National Cooperative Highway Research Program (NCHRP) Report 350 safety guidelines and became a Standard Plan in 1997. It is a single-slope concrete barrier that is 36 inches high with a face sloped 9.1 degrees from vertical.

The Manual for Assessing Safety Hardware (MASH09) TL-3 pickup test (Test 3-11) had been conducted successfully on the Texas single slope concrete barrier with a barrier face slope of 10.8 degrees, which is considered to perform similarly to the Type 60 with a barrier face slope of 9.1 degrees. However, no other single slope concrete barrier has been tested to MASH TL-3 with the small car (Test 3-10).

One crash test, MASH 3-10, was conducted on the Type 60 Median Barrier. The results were within the limits of MASH guidelines.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Barriers, Crash Test, Median Barrier, Vehicle Impact Test, Concrete, Median, Single-slope	No Restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161

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Unclassified	Unclassified	63	

DISCLAIMER STATEMENT

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. Information regarding the uncertainty of measurements for critical parameters is available upon request by the California Department of Transportation Roadside Safety Research Group.

COMPLIANCE CRASH TESTING OF THE TYPE 60 MEDIAN BARRIER

(TEST 140MASH3C16-04)

STATE OF CALIFORNIA

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

Supervised by... Robert Meline, P.E.

Principal Investigator .... John Jewell, P.E.

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

Research Performed by .... Roadside Safety Research Group

ACCREDITED

Testing Cert # 3046.01

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
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Test 140MASH3C16-04

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SI CONVERSION FACTORS

Metric (SI) to English System of Measurement

To Convert From	To	Multiply By
	ACCELERATION	
m/s^2	ft/s^2	3.281
	AREA	
m^2	ft^2	10.764
	ENERGY	
Joule (J)	$ft\text{-}lb_f$	0.7376
	FORCE	
Newton (N)	lb_f	0.2248
	LENGTH	
m	ft	3.281
m	in	39.37
cm	in	0.3937
mm	in	0.03937
	MASS	
kg	lb_m	2.205
	PRESSURE OR STRESS	
kPa	psi	0.1450
	VELOCITY	
km/h	mph	0.6214
m/s	ft/s	3.281
km/h	ft/s	0.9113

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1. Introduction

1.1. Problem

The California Department of Transportation (Caltrans) has used Type 60 Median Barrier (Type 60) for decades as a single slope concrete median barrier in Test Level 3 (TL-3) applications. It was tested in the mid 1990's by Caltrans and meets TL-3 crash test requirements of National Cooperative Highway Research Committee Report 350 guidelines (Report 350). However, it had not been tested to all of the requirements of the newest set of crash test guidelines called Manual for Assessing Safety Hardware 2009 (MASH). The Caltrans Division of Traffic Operations and the Highway Safety Features New Products Committee, a committee comprise of representatives from several Divisions within Caltrans, recognizes that compliance crash testing of the Type 60 with the small car to MASH Test Level 3 criteria is a high priority.

1.2. Objective

The objective of this research project is to verify that the Type 60 Median Barrier will meet the evaluation criteria of MASH Test 3-10 for longitudinal barriers.

1.3. Background

Caltrans has used Type 60 Median Barrier since it became a Standard Plan in 1997. Caltrans also adopted the same shape for the Type 70 series concrete bridge rails. The MASH TL-3 pickup test (Test 3-11) had been conducted successfully on the Texas SSTR (Single Slope Traffic Rail) concrete barrier with a barrier face slope of 10.8 degrees, which is considered to perform similarly to the Type 60 with a barrier face slope of 9.1 degrees[1]. MASH Test 3-11 was conducted and passed on another single slope concrete barrier tested by Texas Transportation Institute (TTI) in 2009. It is not directly comparable to a rigid barrier as it was embedded in soil and had a dynamic deflection of about 6 inches. However, no single slope concrete barrier had been tested to MASH TL-3 with the small car (Test 3-10).

1.4. Literature Search

An extensive literature search was conducted related to any references to Test 3-10 on single slope barriers. Also, TTI and FHWA were contacted to follow up on informational leads. The Texas SSTR testing results were not submitted to FHWA for eligibility but TTI provided their test results to aid in our research. Several FHWA Eligibility Letters were reviewed for MASH 2009 Test 3-10 crash tests on single slope concrete barriers. No 3-10 tests were found. FHWA eligibility letters for single slope barriers, B-225 and B-249, specifically waive Test 3-10 based on results of prior F Shape barrier testing. The results of the search concluded that Test 3-10 had not been conducted by the roadside safety community on a single slope barrier.

[1] FHWA website Q/A: https://safety.fhwa.dot.gov/roadway_dept/countermeasures/faqs/qa_bttabr.cfm#brrs4.
"The Texas Constant-Slope Barrier is 1070 mm (42 in) high and has a constant-slope face that makes an angle of 10.8 degrees with respect to the vertical. California developed a Single Slope profile that makes an angle of 9.1 degrees with respect to the vertical. The crash tests indicate that the performance of the Texas Constant-Slope Barrier is comparable to that of the Jersey-shape and the performance of the California Single-Slope Barrier is comparable to that of the F-shape."

1.5. Scope

One full-scale crash test will be performed and evaluated in accordance with MASH 2009 Test Level 3 guidelines. The purpose of Test 3-10 is to determine if the barrier would successfully and safely redirect a small car and meet MASH 2009 requirements.

2. Test Article Details

2.1. Barrier Design

The barrier design has been used by Caltrans since it became a standard in 1997. It is a slip-formed, single-slope, concrete barrier, which is anchored at the ends. The barrier is 36 inches high with a face sloped 9.1 degrees from vertical. Due to frequent road width constraints, Caltrans prefers the narrower base provided by the steeper face, when compared to the 10.8 degree Texas Single Slope Concrete Median Barrier. The 1999 Standard Plans, which were used to construct the test article, are shown in the Appendix (Figure 8-1 and Figure 8-2).

2.2. Construction

A section of Type 60 concrete barrier, 46 m (150 ft.) in length, was constructed in 2006 at the Caltrans Dynamic Test Facility for a previous tort response project. The section of Type 60 was still in place when it was decided to run MASH Test 3-10, so it was utilized for this project. Construction photos are shown below.

Figure 2-1 Asphalt and Aggregate Base Removed for End Anchorage Footing

Figure 2-2 Footing Depth

Figure 2-3 Beginning of Slip-forming

Figure 2-4 Slip-forming the Barrier

Figure 2-5 Slip-forming Nearly Complete

Figure 2-6 Placing Rebar for the End Anchorage

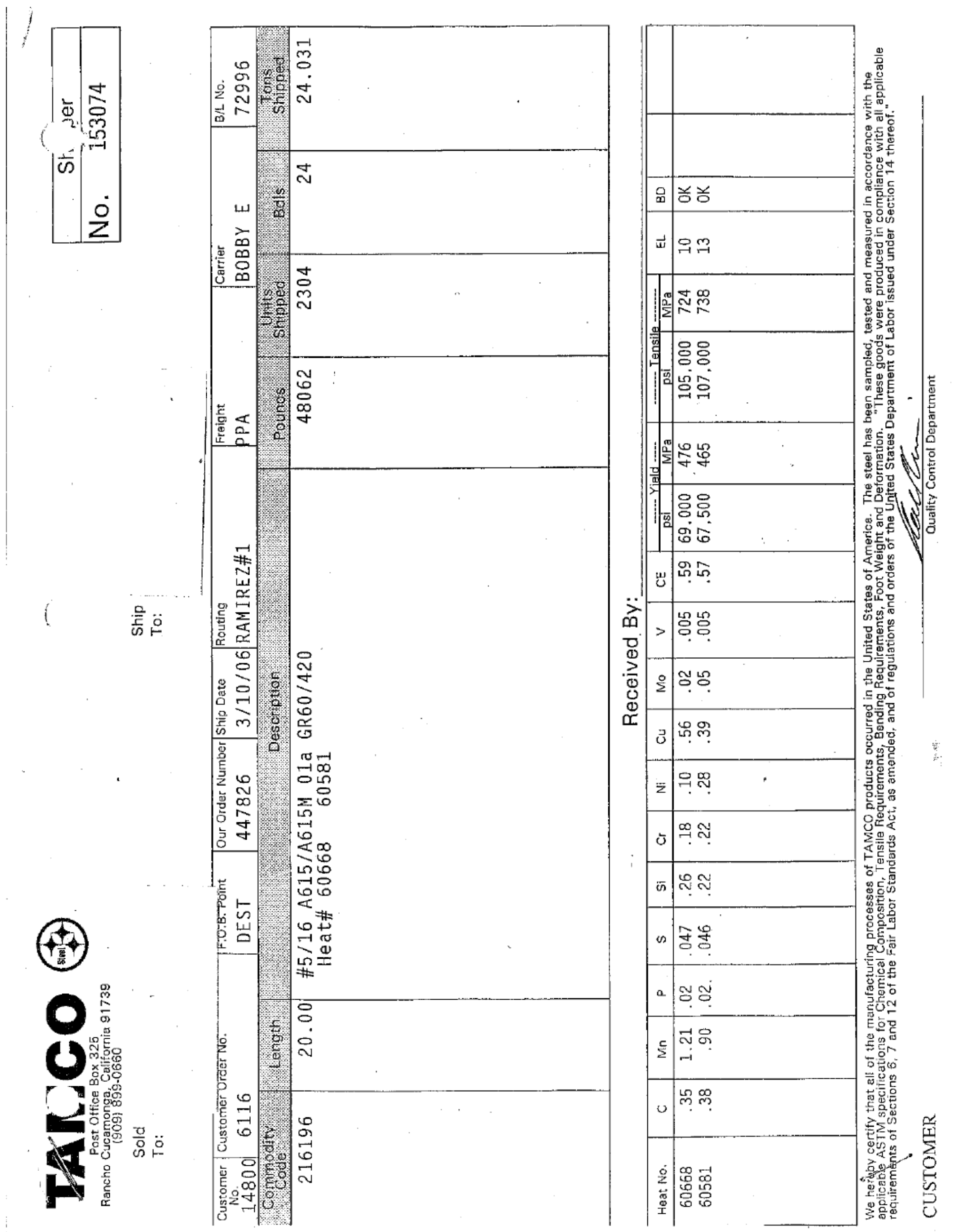
Figure 2-7 Formwork and Steel in Place for End Anchorage

Figure 2-8 End Anchorage Pour Complete

Figure 2-9 Completed Test Article: Concrete Barrier Type 60

The completed test article is 46 m (150 feet) long with a nominal height of 910 mm (36 inches). The actual test article height at the area of impact was approximately 965 mm (38 inches). The nominal width at the top and the base were 320 mm (12.6 in) and 610 mm (24 in), respectively. The nominal slope of the barrier face was 9.1 degrees. As constructed, the barrier face slope was shallower at approximately the upper two feet and steeper at the bottom foot due to concrete slump during slip forming. The average slope of the barrier face at the area of impact was measured to be approximately 7.9 degrees[2]. The measured face slope is not within the scope of our accreditation. The ends were anchored per the End Anchorage detail in Figure 8-2. The concrete was sampled and cast into standard 6" x 12" cylinders for testing. A615 Grade 60 rebar with a tested yield strength of approximately 70 ksi was used for reinforcement, see Figure 2-10. The average compressive strength of two cylinders at 28 days was 4,440 psi. The reported rebar strength and concrete strength fall outside the lab's scope of accreditation.

[2] The effect of the actual average face slope being steeper than the theoretical results in conservative Occupant Risk Factors and Occupant Compartment Deformation for Test 3-10.



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60581	.38	.90	.02	.046	.22	.22	.28	.39	.05	.005	.57	67,500	465	107,000	738	13	OK

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Figure 2-10 Rebar Tensile Strength

3. Test Requirements and Evaluation Criteria

3.1. Crash Test Matrix

MASH Test Level 3 for longitudinal barriers consists of two crash tests as follows:

1. A 1,100 kg (2,420 lbs.) small car at 100 km/hr. and a 25° impact angle (MASH 2009 Test No. 3-10).
2. A 2,270 kg (5,000 lbs.) pickup truck at 100 km/hr. and a 25° impact angle (MASH 2009 Test No. 3-11).

The pickup truck test (Test 3-11) was successfully conducted on another single slope concrete barrier, the TxDOT Single Slope Traffic Rail (Reference #3), which should perform similarly to the Type 60 because they are both single-slope concrete barriers of similar slope. The TxDOT barrier has a slope of 10.8° from vertical while the Type 60 has a slope of 9.1° from vertical. Thus, the 3-11 test will not be conducted as part of this research project. The objective of this project is to verify that the Type 60 meets the evaluation criteria of MASH Test 3-10.

3.2. Evaluation Criteria

The evaluation criteria are those set forth in MASH 2009 Test 3-10 for longitudinal barriers: A, D, F, H, I. Evaluation Criteria are explained later in Table 5-2.

4. Test Conditions

4.1. Test Facilities

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

4.2. Test Vehicle

The vehicle was a 2007 Kia Rio in good condition. The test vehicle complied with all MASH 2009 requirements for 1100C vehicles except age. That said, the vehicle body style was similar to the newer 2010 Kia Rio that would have met the age requirement. The critical properties defined in MASH Table 4-1 of the 2007 Kia Rio were compared to those of a 2010 Kia Rio for a test conducted by another crash test research facility. Both met the requirements of MASH and were similar to each other. See Table 4-1 below.

The MASH 2009 1100C test for the Type 60 Median Barrier was assigned test identification number 140MASH3C16-04. The vehicle was free of major body damage and not missing any structural parts. It was not modified in any way and had no standard equipment missing. The inertial mass of 1119 kg was within the recommended mass limits of MASH 2009. To achieve the desired impact speed, the vehicle was towed. A speed control device was installed in the tow vehicle, which limited the acceleration of the vehicle once the target impact speed was reached. The steering was accomplished by means of a guidance rail anchored to the ground and a guide arm attached to the vehicle wheel hub. Remote braking was possible at any time during the test via radio control. The vehicle was released from the guidance rail a short distance before impact. Photos of the test vehicle are shown in Figure 4-1 to Figure 4-8. See Appendix 7.1 and 7.4 for more information on vehicle equipment and instrumentation.

Table 4-1 Vehicle Properties Comparison

MASH 1100C			
Property	MASH 1100C (Small Car)	Model Year 2007 (RSRG Measured)*	Model Year 2010 (TTI Measured)**
MASS, lb.		Actual Weight	Actual Weight
Test Inertial	2420 ± 55	2466	2426
Max. Ballast	175		
DIMENSIONS, inches		From Spec Sheet	
Wheelbase	98 ± 5	98.5	98.75
Front Overhang	35 ± 4	32.99	33.00
Overall Length	169 ± 8	167.48	165.75
Overall Width	65 ± 3	65.91	66.38
Hood Height	24 ± 4***	28.62	31.50***
Track Width[a]	56 ± 2	57.44	57.44
CENTER OF MASS LOCATION,[b] inches			
Aft of Front Axle	39 ± 4	36.5	35.98
Above Ground	N/A	N/A	N/A
LOCATION OF ENGINE	Front	Front	Front
LOCATION OF DRIVE AXLE	Front	Front	Front

a Average of front and rear axles. b For "test inertial" mass.

* From RSRG Test 140MASH3C16-04
**From TTI Report TR No. 9-1002-12-12
***Subject to update as part of 2015 ILC. TTI measurement was taken before 2015 ILC while there was still a great deal of ambiguity about how hood height is defined.

Figure 4-1 Test Vehicle Front

Figure 4-2 Test Vehicle Front Left

Figure 4-3 Test Vehicle Driver's Side

Figure 4-4 Test Vehicle Rear Left

Figure 4-5 Test Vehicle Rear

Figure 4-6 Test Vehicle Relative to Barrier

4.3. Data Acquisition System

The test was documented through the use of still cameras, video cameras, high-definition high-speed digital video cameras, and GMH Engineering Data Brick III data acquisition systems to record accelerations and rotational rate changes. The impact phase of the crash test was recorded with five high-definition high-speed digital video cameras, a normal-speed DVC format video camera, digital SLR cameras and three action cameras mounted inside the test vehicle set to record video. The test vehicle and barrier were photographed before and after impact with the DVC format camera and a digital SLR camera.

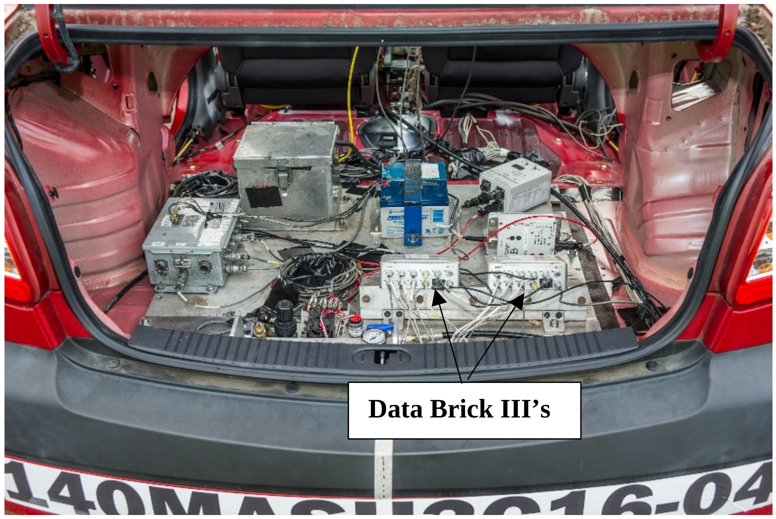

Figure 4-7 Data Brick III's

Figure 4-8 Test Vehicle Dummy and Instrumentation

Two sets of orthogonal accelerometers were mounted at the center of gravity of the test vehicles (as per MASH 2009 specifications). The rate gyro transducers (angular rate sensors) were also placed at the center of gravity of the test vehicles to measure roll, pitch, and yaw rates. The data was analyzed in Test Risk Assessment Program version 2.3.10 (TRAP) to determine the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation. See Appendix 7.4 for more information on vehicle instrumentation.

5. Crash Test Results

5.1. Test 140MASH3C16-04 Impact Description and Results

The point of impact was approximately 6.25 meters from the upstream barrier end. The impact angle of 25° was set with a Total Station. The intended impact speed was 100 kph.

Figure 5-1 Test Article Impact Area with Checkered Tape at Impact Point

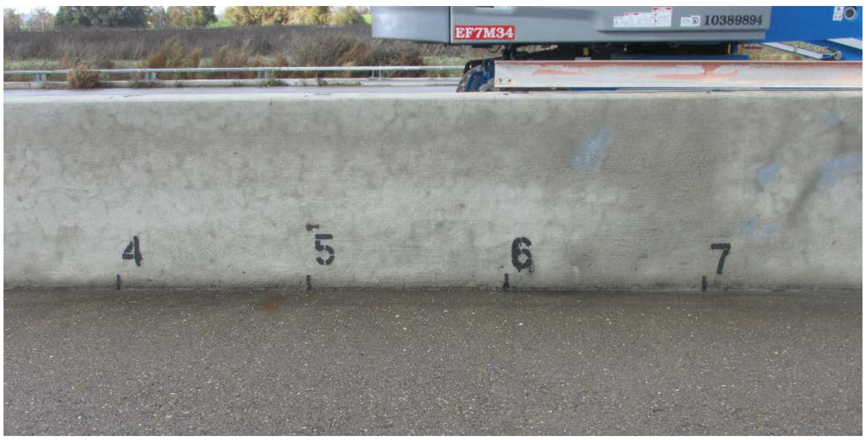

Figure 5-2 Type 60 Barrier Point of Impact (I-beam on barrier was removed prior to test)

Figure 5-3 Barrier Face Downstream of Impact (I-beam on barrier was removed prior to test)

5.2. Test Description

The vehicle was towed up to the intended target speed of 100 km/hr. The vehicle impacted the Type 60 barrier at approximately 6.25 meters from the upstream end at a speed of 61.2 mph (98.5 kph) and angle of 25.7°. The vehicle impacted on the driver's side; the front corner of the hood and front panel contacted the barrier and crumpled. The vehicle began to redirect and slide along the face of the barrier. The buckling of the front panel appears to cause the driver door to separate from the vehicle (as if it were opening and then quickly closing) at approximately 0.04 seconds to 0.05 seconds after impact. The buckling forces on the driver's side of the vehicle appear to cause the driver's side-window to spider-crack and shatter at approximately 0.066 seconds after impact. The dummy's head subsequently hit the glass fragments at approximately 0.076 seconds after impact. The vehicle continued to redirect and became parallel to the rail at approximately 0.168 seconds after impact. At approximately 0.276 seconds after impact, the rear of the vehicle lost contact with the barrier. There were approximately 3 meters of contact with the barrier. The exit speed and angle were measured to be 39.6 mph (63.8 kph) and 8.6°, respectively. The brakes were applied approximately 1.0 seconds after the initial impact and while the vehicle was moving away from the barrier. The braking action caused the car to yaw back toward the barrier, resulting in a secondary impact with the barrier. The vehicle came to a stop with the front end of the vehicle facing the barrier, approximately 2.7 feet (0.82 m) from the face of the barrier and approximately 139 feet (42.4 m) downstream from the initial point of impact.

5.3. Barrier Damage

There was no significant damage to the barrier. The only damage was extremely minor surface scrapes and gouges (see Figure 5-6, Figure 5-7, and Figure 5-8). The red contact marks are from the front left tire. The green contact marks are from the rear left tire. The barrier did not move.

Figure 5-4 Downstream Impact View

Figure 5-5 Upstream Impact View

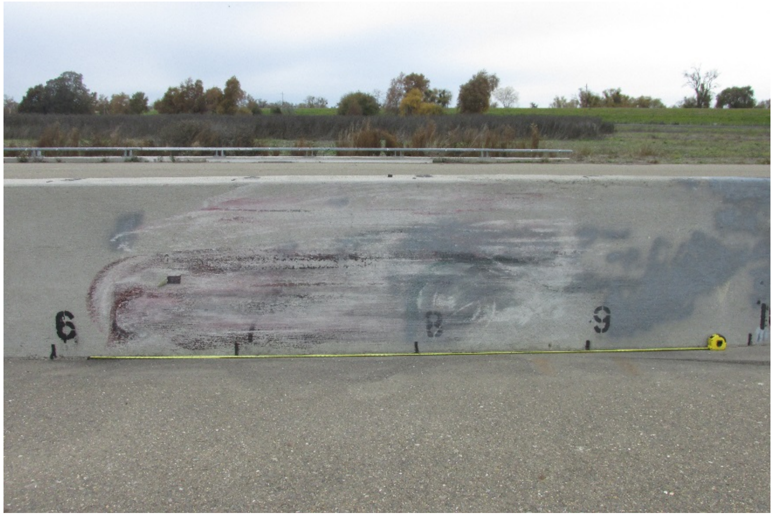

Figure 5-6 Vehicle Marks on Type 60 Barrier

Figure 5-7 Type 60 Barrier Post Test Upstream of Impact

Figure 5-8 Type 60 Barrier Post-Test Downstream of Impact

5.4. Vehicle Damage

The front left corner and driver's side of the test vehicle sustained most of the damage from the initial impact while the front and front left corner sustained additional damage from the secondary impact. The entire length of the passenger side of the vehicle made contact with the barrier. Nearly the entire front bumper was torn off. The driver's side headlight was completely shattered and/or torn off the vehicle. As mentioned previously, the driver's side front window was shattered and broken out. The bumper, hood, left doors, and front and rear fenders were severely damaged. The airbags did not deploy because the vehicle was towed and there was no power to the airbag system. The maximum amount of passenger compartment deformation measured by known points was 2.1 inches (53 mm), which occurred at the floorboard. However, the maximum floorboard deformation occurred between known points and is estimated to be 2.6 inches (66 mm). See Figure 5-14 140MASH3C16-04 Kia Rio Floorboard Crease with Maximum Deformation. The maximum amount of deformation for the roof and dashboard were 0.5 inches (13 mm) and 1.6 inches (41 mm), respectively. These values are below the maximum MASH 2009 limits. See Table 7-7 and Table 7-8 for complete interior deformation measurements. The Vehicle Damage Scale (VDS) and Collision Deformation Classification (CDC) reported under vehicle damage on the test data summary sheet do not include the secondary impact.

Figure 5-9 140MASH3C16-04 Kia Rio Damage (Right Side)

Figure 5-10 140MASH3C16-04 Kia Rio Damage (Rear Left)

Figure 5-11 140MASH3C16-04 Kia Rio Driver Side Damage

Figure 5-12 140MASH3C16-04 Kia Rio Damage (Front)

Figure 5-13 140MASH3C16-04 Kia Rio Interior Post Test

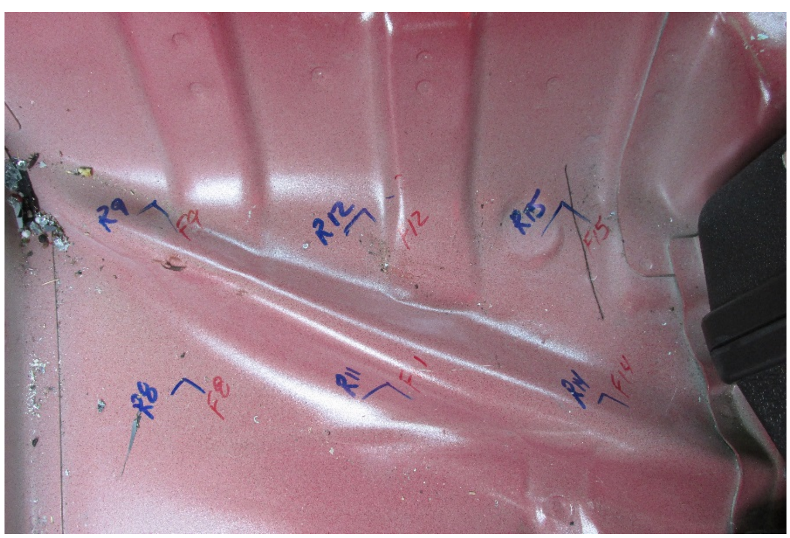

Figure 5-14 140MASH3C16-04 Kia Rio Floorboard Crease with Maximum Deformation

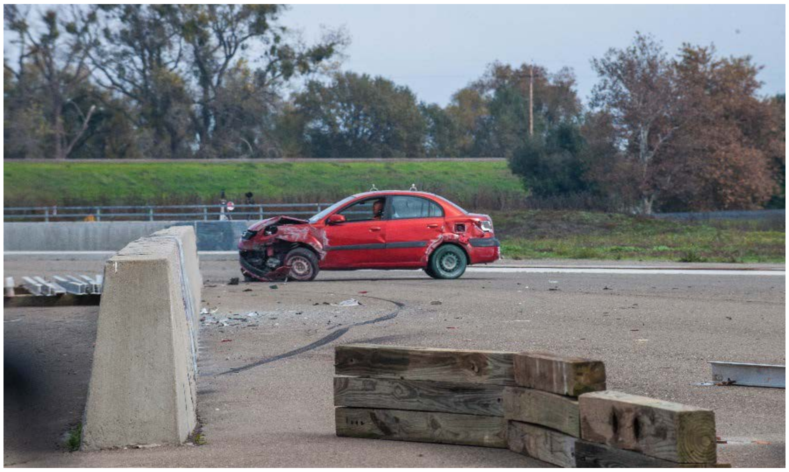

Figure 5-15 Trajectory after Impact

Figure 5-16 Vehicle in Yaw

Figure 5-17 Vehicle Resting Location

Table 5-1 Test 140MASH3C16-04 Data Summary Sheet


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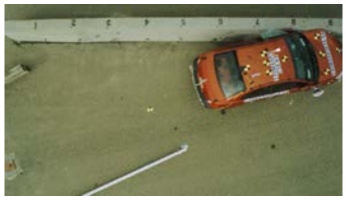
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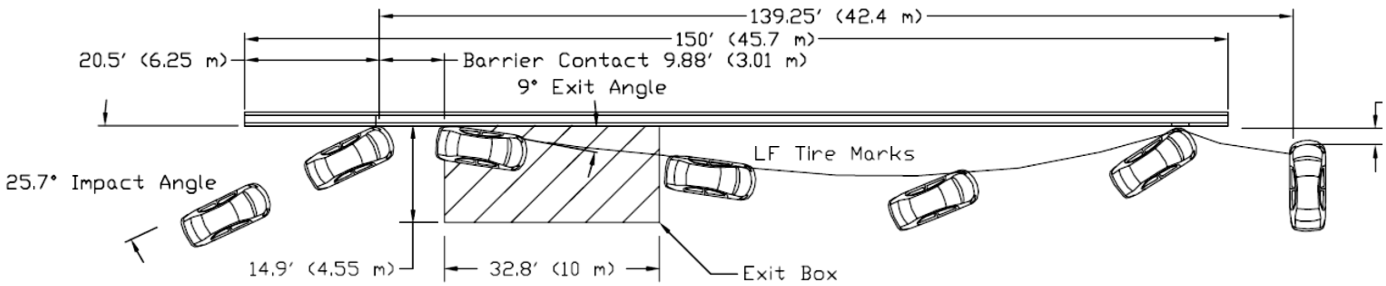

Test Agency .... California, Department of Transportation
Test Number 140MASH3C16-04
Date 11/30/2016
Test Article .... CA Type 60 Median Barrier
Total Length .... 150 ft (40 m)
Key Elements – Barrier
- Description .... CA Type 60 Median Barrier
- Base Width .... 24 in (610 mm)
- Height .... 36 in (910 mm)

Test Vehicle
- Type/Designation 1100C
- Make and Model .... 2007 Kia Rio
- Curb .... 2497 lb (1133 kg)
- Test Inertial .... 2466 lb (1119 kg)
- Gross Static .... 2640 lb (1197 kg)

Impact Conditions
- Speed .... 61.2 mph (98.5 kph)
- Angle .... 25.7°
- Location/Orientation .... 21 ft (6.25 m) downstream of end anchor
- Impact Severity .... 58.1 kip-ft (78.8 kJ)

Exit Conditions
- Speed .... 44 mph (71 kph)
- Angle .... 9 °

Post-impact Trajectory
- Vehicle Stability .... Satisfactory
- Stopping Distance (from point of impact) Approx., 139 ft (43 m) downstream and 2.7 ft (0.6 m) laterally in front

Vehicle Snagging .... None
Vehicle Pocketing .... None
Occupant Impact Velocity[1]
- Longitudinal .... 25.6 ft/s (7.8 m/s)
- Lateral .... -31.2 ft/s (-9.5 m/s)

Occupant Ridedown Deceleration (10 msec avg.)[1]
- Longitudinal .... -4.8 G
- Lateral .... 10.8 G

THIV[1] .... 40.0 ft/s (12.2 m/s)
PHD[1] .... 11.6 G
Maximum Roll, Pitch, Yaw[1] .... 12.0°, -4.2°, 4.8°
Test Article Damage .... Minor scrapes
Test Article Deflections
- Permanent Set .... 0.0 in (0 mm)
- Dynamic .... 0.0 in (0 mm)
- Working Width .... 0.0 in (0 mm)

Vehicle Damage .... Moderate
- VDS 11-FL-3, LD-1, 9-LP-1, 7-LBQ-3
- CDC 10LYMK2, 09LBEK2
- Maximum Deformation .... Approx. 2.6 in (66 mm) at floorboard[2]

[1] Reported from the instrumentation mounted closest to the vehicle C.G. (labeled Secondary), except for Roll and Yaw because portions of those channels did not record correctly. Roll and Yaw from the other set of instrumentation (labeled Primary) were used in TRAP calculations.
[2] Estimated because the maximum deformation did not occur at a defined pre-marked point. Maximum recorded deformation was 2.5 inches (64 mm) at floorboard.

5.5. Discussion of Test Results

5.5.1. General Evaluation Methods

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

The structural adequacy and occupant risk associated with the Type 60 Median Barrier were evaluated using evaluation criteria found in Tables 2.2 (Recommended Test Matrices for longitudinal barriers) and 5.1 (Safety Evaluation Guidelines) of MASH 2009. The post-impact vehicular response was evaluated using section 5.4 of MASH 2009.

5.5.2. Structural Adequacy

The structural adequacy of the Type 60 Median Barrier was acceptable

Refer to Table 5-2 for the assessment summary of the safety evaluation criteria for the Type 60 Median Barrier.

5.5.3. Occupant Risk

The occupant risk was acceptable. The maximum interior dashboard, roof, and floorboard measured deformations were 1.6 inches (41 mm), 0.5 inches (13 mm), and 2.5 inches (63 mm), respectively. As mentioned previously, the maximum floorboard measurement was estimated to be 2.6 inches because the point of greatest deformation did not appear to occur at a predefined point. There was no occupant compartment intrusion or potential for it. The occupant compartment was not compromised. The dummy head protruded slightly beyond the plane of the driver's side window when it was broken but did not show potential for striking any portion of the barrier. The yaw, pitch, and roll of the vehicle were within acceptable limits.

Refer to Table 5-2 for the assessment summary of the safety evaluation criteria for the Type 60 Median Barrier.

5.5.4. Vehicle Trajectory

The vehicle trajectory was acceptable. The exit trajectory was within the exit box. The yaw, pitch, and roll of the vehicle were below the maximum limits.

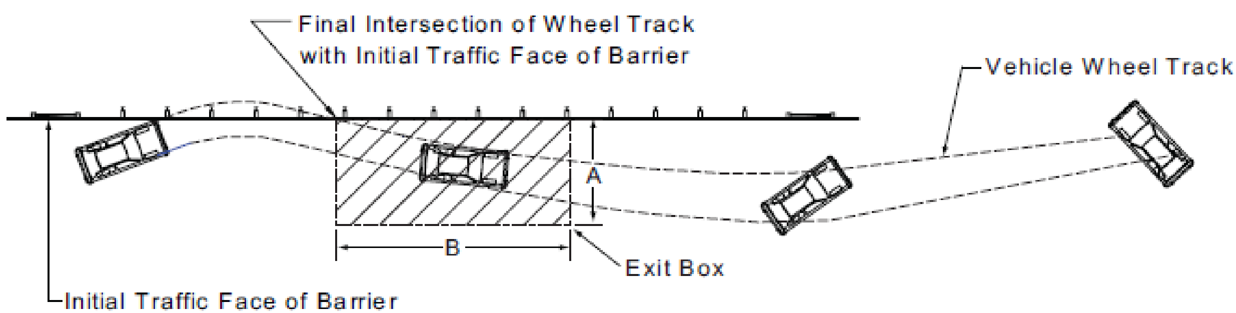

Figure 5-18. Exit Box for Longitudinal Barriers

Refer to Table 5-2 for the assessment summary of the safety evaluation criteria for the Type 60 Median Barrier.

Table 5-2. 140MASH3C16-04 Assessment Summary

<table>
<tr><th>Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td>Structural Adequacy
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation, although controlled lateral deflection of the test article is acceptable.</td><td>The vehicle was contained and redirected smoothly.</td><td>PASS</td></tr>
<tr><td>Occupant Risk
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or personnel in a work zone.

Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E.</td><td>The barrier did not detach any elements, fragments, and/or other debris</td><td>PASS</td></tr>
<tr><td>Occupant Risk
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>The vehicle remained upright during and after the collision.</td><td>PASS</td></tr>
<tr><td>Occupant Risk
H. Occupant Impact Velocities (OIV) (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
</table></td><td>Longitudinal OIV = 25.6 ft/s (7.8 m/s)

Lateral OIV = -31.2 ft/s (-9.5 m/s)</td><td>PASS</td></tr>
<tr><td>Occupant Risk
I. The occupant ridedown acceleration (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (G)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 G</td><td>20.49 G</td></tr>
</table></td><td>Longitudinal ORA = -4.8 G

Lateral ORA = 10.8 G</td><td>PASS</td></tr>
<tr><td>Vehicle Trajectory
It is preferable that the vehicle be smoothly redirected, and this is typically indicated when the vehicle leaves the barrier within the "exit box". The concept of the exit box is defined by the initial traffic face of the barrier and a line parallel to the initial traffic face of the barrier, at a distance A plus the width of the vehicle plus 16 percent of the length of the vehicle, starting at the final intersection (break) of the wheel track with the initial traffic face of the barrier for a distance of B. All wheel tracks of the vehicle should not cross the parallel line within the distance B.</td><td>A = 14.9ft (4.55 m)
B = 32.8 ft (10 m)</td><td>PASS</td></tr>
</table>

6. Conclusions

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

1. The Type 60 Median Barrier can successfully redirect an 1100-kg small car impacting at 100 km/h and 25°.
2. The Type 60 Median Barrier meets the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware 2009* (MASH 2009) criteria for Test 3-10 for longitudinal barriers.

7. Appendix

7.1. Test Vehicle Equipment

Test 140MASH3C16-04: The vehicle used for this test was a 2007 Kia Rio. Since the vehicle was towed and not self-powered, the fuel in the gas tank was pumped out and gaseous CO_2 added in order to purge the gas vapors and eliminate oxygen. One pair of 12-volt wet cell batteries was mounted in the vehicle. The batteries powered the GMH DataBrick 3 transient data recorders. A 12-volt deep-cycle gel cell battery powered the Electronic Control Box.

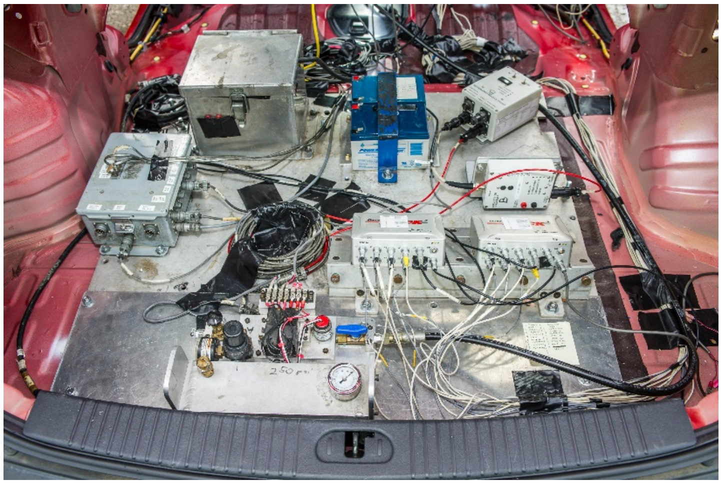

Figure 7-1 Instrumentation Board Mounting Location

Figure 7-2 Back Seat Removed

A 4800 kPA CO_2 system, actuated by a solenoid valve, controlled remote braking after the impact and emergency braking if necessary. Part of this system was a pneumatic ram which was attached to the brake pedal. The operating pressure for the ram was adjusted through a pressure regulator during a series of trial runs prior to the actual test. Adjustments were made to ensure the shortest stopping distance without locking up the wheels. When activated, the brakes could be applied in less than 100 milliseconds.

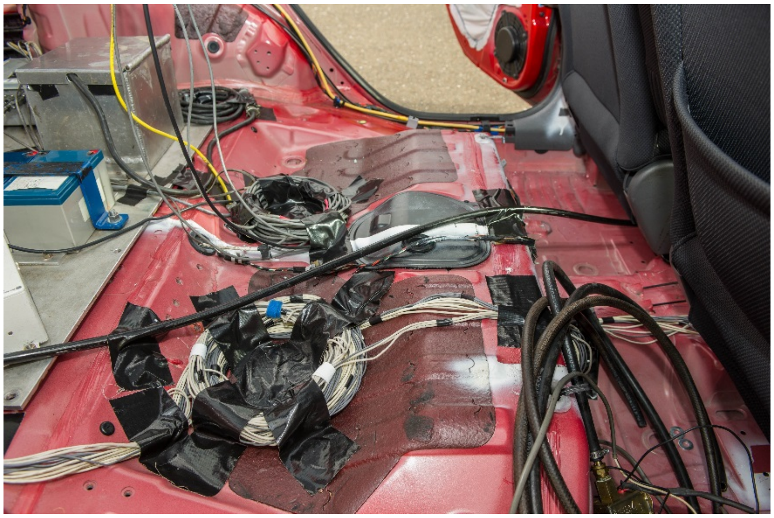

Figure 7-3 Rear of Instrumentation Panel

Figure 7-4 Brake Pedal Actuator

A speed control device was connected in-line with the ignition module signal to the coil on the tow vehicle. It was used to regulate the speed based on the signal from the vehicle transmission speed sensor. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap comprised of two tape switches (set at a specific distance apart) and a digital timer.

7.2. Test Vehicle Guidance System

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

Figure 7-5 Rail Guidance System Set-Up

Figure 7-6 Rail Guidance System

7.3. Photo - Instrumentation

Several high-speed video cameras recorded the impact during the test. The high-speed video frame rates were set to 500 frames per second. The types of cameras and their locations are shown in Figure 7-7 and Table 7-1. The origin of the coordinates is at the intended point of impact.

Figure 7-7 High-Speed Video Camera Locations (Not to Scale)

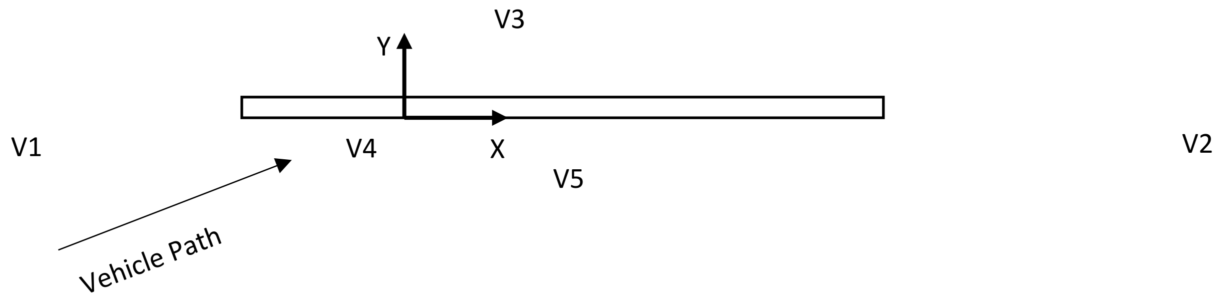

Table 7-1. 140MASH3C16-04 Camera Types and Location Coordinates

Camera Location	Camera Make/Model	Camera Serial No.	Lens	Lens Serial No.	Coordinates		
					x	y	z
V1 Upstream	Olympus iSpeed3	1400022	35 mm	259936	-89.58’	-1.0’	4.2’
V2 Downstream	Olympus iSpeed3	1400014	135 mm	309666	305.75’	1.92’	6.6’
V3 Across	Olympus iSpeed3	1400012	20 mm	182398	19.67’	88.92’	5.6’
V4 Upstream Tower	Vision Research Miro 110	13235	20 mm	447169	-6.75’	-6.42	28’
V5 Downstream Tower	Vision Research Miro 110	13234	14 mm	217706	25.67’	-11.83’	41’

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

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

7.4. Electronic Instrumentation and Data

Transducer data were recorded on two separate GMH Engineering, Data Brick, Model III, digital transient data recorders (TDRs) that were mounted in the test vehicle. These transducers included two sets of accelerometers and two sets of angular rate sensors at the center of gravity. The TDR data were reduced using a desktop personal computer. DADiSP 2002 version 6.0 NI NK B14 was used for pre-processing. TRAP was used for the post-processing. Accelerometer and angular rate sensor specifications are shown in Table 7-2. Accelerometer and Angular Rate Sensor Specifications

Table 7-2. Accelerometer and Angular Rate Sensor Specifications

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

A rigid stand with three retro-reflective 90° polarizing tape strips spaced 1000 mm apart was placed on the ground near the test article and alongside the path of the test vehicle. The strips were measured immediately before the test to account for any thermal expansion. The test vehicle had an onboard optical sensor that produced sequential impulses or "event blips" as the vehicle passed the reflective tape strips. The event blips were recorded concurrently with the accelerometer signals on the TDR, serving as "event markers". The impact velocity of the vehicle could be determined from these sensor impulses, the data record time, and the known distance between the tape strips. A pressure sensitive tape switch on the front bumper of the vehicle closed at the instant of impact and triggered two events: 1) "event marker" was added to the recorded data, and 2) a flashbulb mounted on the top of the vehicle was activated. One set of pressure activated tape switches, connected to a speed trap, was placed 4 m apart just upstream of the test article to check the impact speed of the test vehicle (not a reported measurement). The layout for all of the pressure sensitive tape switches and reflective tape is shown in Figure 7-8.

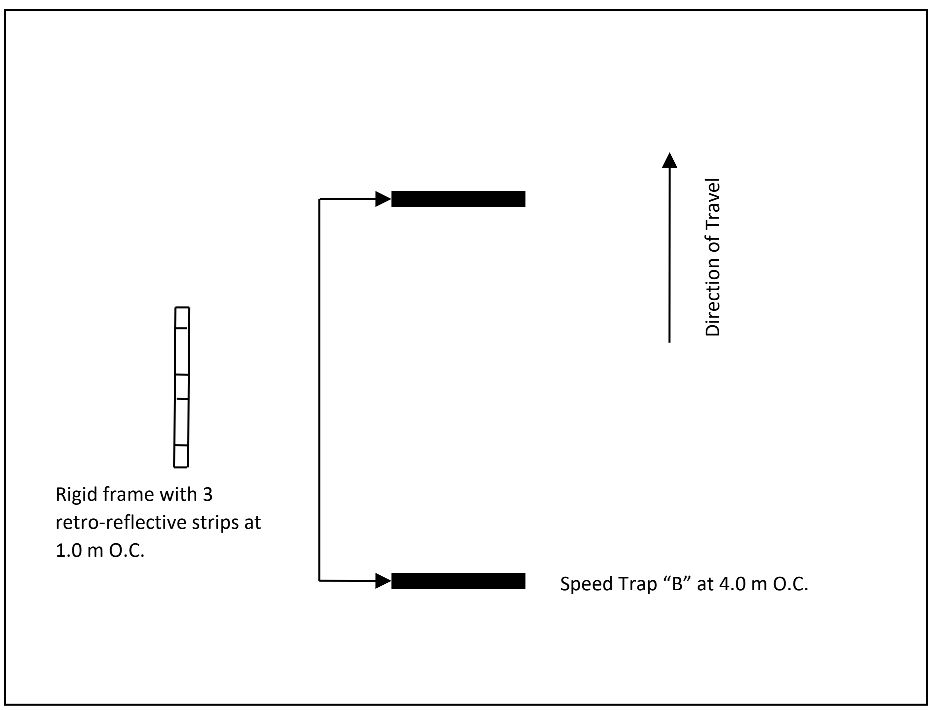

Figure 7-8 Speed Trap Tape Layout

7.5. Vehicle Measurements

Table 7-3. Exterior Vehicle Measurements

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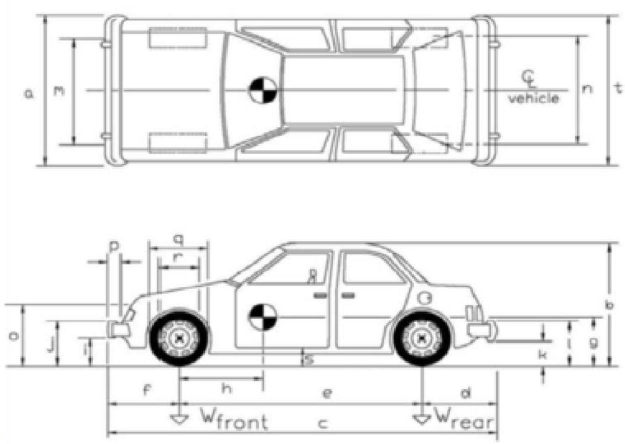
Attachment 5.4.5 --- 1100C and 1500A Small Car Parameters

Date:	11/1/2016	Test Number:	140MASH3C16-04	Model:	Kio
Make:	Kia	VIN:	KNADE123376242513		
Tire Size:	18565R14	Year:	2007	Odometer:	145564
Tire Inflation Pressure:	32 psi	Tape Measure Used:	Tape #1	CLE:	

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm (inches)

	mm	(in)		mm	(in)
a	1674	(65.91)	b	1472	(57.95)
c	4254	(167.48)	d	915	(36.02)
e	2502	(98.5)	f	838	(32.99)
g	N/A	#VALUE!	h	927	(36.5)
i	185	(7.28)	j	563	(22.17)
k	283	(11.14)	l	613	(24.13)
m	1472	(57.95)	n	1446	(56.93)
o	727	(28.62)	p	25	(0.98)
q	572	(22.52)	r	384	(15.12)
s	190	(7.48)	t	1682	(66.22)

Wheel Center Height Front:	275	(10.83)
Wheel Center Height Rear:	282	(11.1)
Wheel Well Clearance (F)	125	(4.92)
Wheel Well Clearance (R)	130	(5.12)
Frame Height (F):	172	(6.77)
Frame Height (R):	190	(7.48)
Engine Type:	4 Cylinder	
Engine Size:	1.6 Liter	

Transmission Type:

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

Mass Distribution

Left Front:	356.5	(785.93)	Scale:	red	Right Front:	347.6	(766.31)	Scale:	green
Left Rear:	204.45	(450.73)	Scale:	yellow	Right Rear:	210.25	(463.51)	Scale:	blue

Weights

kg (lbs)	Curb		Test Inertial		Gross Static	
W_{front}	710.2	(1565.7)	704.1	(1552.25)	744.9	(1642.2)
W_{rear}	422.6	(931.66)	414.7	(914.24)	452.4	(997.35)
W_{total}	1132.8	(2497.35)	1118.8	(2466.49)	1197.3	(2639.55)

GVWR Ratings

Front:	870	(1918)
Back:	850	(1874)
Total:	1650	(3638)

Dummy Data

Type:	Hybrid III 50th Male Dummy
Mass:	78.5 kg
Seat Position:	Driver

Note any damage prior to test: Small dent/scratch on hood.

Christopher Caldwell reviewed calculations on 8/20/2014

Table 7-4. CG Calculation: Curb Weight

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Last Revised by John Jewell

Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #1: Curb Weight

Make:	Kia	Test Number:	140MASH3C16-04
Model:	Rio LX	Date:	10/25/2016
Year:	2007	Temperature:	70°F
VIN:	KNADE123376242513		
Fuel in Tank:	1/4 Tank		
Fuel Removed:	None		
Staff:	John Williams		
	Chris Caldwell		

W1 = Left Front (LF) = 361.7 kg
Scale Used: Green

W2 = Right Front (RF) = 348.5 kg
Scale Used: Red

W3 = Left Rear (LR) = 214.95 kg
Scale Used: Yellow

W4 = Right Rear (RR) = 207.65 kg
Scale Used: Blue

Total Weight:
Wtotal (measured) = 1132.8 kg
Wtotal (calculated) = 1132.8 kg

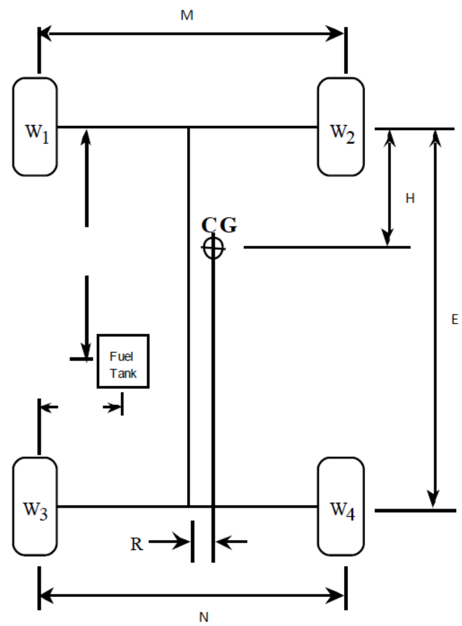
Distance between front wheels:
M = 1472 mm

Distance between rear wheels:
N = 1446 mm

Distance from front to rear wheels:
E = 2502 mm

Distance from front wheels back to CG:
H = 933 mm

Distance from vehicle centerline to CG:
R = -13 mm



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

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

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

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

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

140MASH3C16-04 CG Data Calculation Worksheet.xlsx

Curb WorkSheet

Table 7-5. CG Calculation: Test Inertial Weight

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Roadside Safety Research Group
A2LA Certificate No. 3046.01

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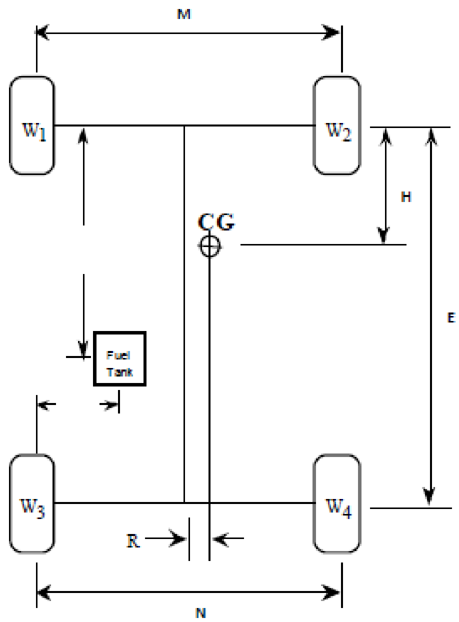
Last Revised by John Jewell

Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #2: Test Inertial Weight

Make:	Kia	Test Number:	140MASH3C16-04
Model:	Rio 4 door LX	Date:	Nov. 9th and 10th, 2016
Year:	2007	Temperature:	75
VIN:	KNADE123376242513		
Fuel in Tank:	none		
Fuel Removed:	approx. 3 gal.		
Staff:	Vue H.,Chris C., John W., Jean V.		
	Jean V. recorded data, performed the calculation		



W1 = Left Front (LF) = 356.5 kg
Scale Used: red

W2 = Right Front (RF) = 347.6 kg
Scale Used: green

W3 = Left Rear (LR) = 204.45 kg
Scale Used: yellow

W4 = Right Rear (RR) = 210.25 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 1118.4 kg

Wtotal (calculated) = 1118.8 kg

Distance between front wheels:
M = 1472 mm

Distance between rear wheels:
N = 1446 mm

Distance from front to rear wheels:
E = 2502 mm

Distance from front wheels back to CG:
H = 927 mm

Distance from vehicle centerline to CG:
R = -2 mm

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

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

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

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

Test Inertial Weight Conditions: (vehicle condition, items removed, items added, environmental conditions, etc.)
Initial weight recorded as 1150kg; MASH max. is 1125kg. So removed rear dash panel, rear speakers and seat-belts along with back doors panel's, pumped out the gas. Also removed the glove box, front door panels and speakers.

140MASH3C16-04 CG Data Calculation Worksheet.xlsx

Test Inertial WorkSheet

Table 7-6. CG Calculation: Gross Static Weight

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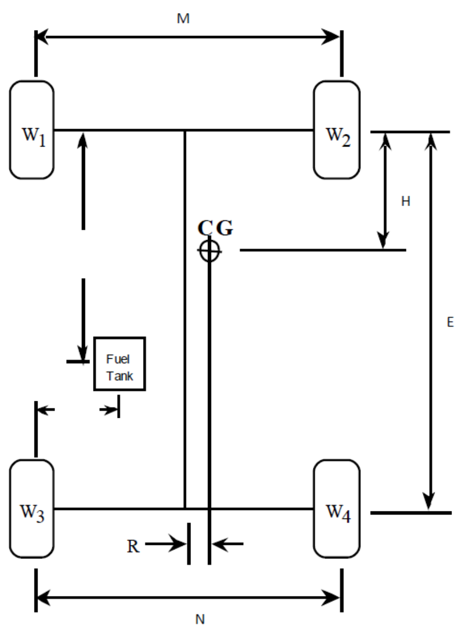
Attachment 5.4.2 --- CG Data Calculation Worksheet

CG Calculation Worksheet #3: Gross Static Weight

Make:	Kia	Test Number:	140MASH3C16-04
Model:	Rio 4 door LX	Date:	Nov. 10th, 2016
Year:	2007	Temperature:	75
VIN:	KNADE123376242513		
Fuel in Tank:	none		
Fuel Removed:	approx. 3 gal.		
Staff:	Vue H.,Chris C., John W., Jean V.		
	Jean V. recorded data,		
	performed the calculation		



W1 = Left Front (LF) = 389.7 kg
Scale Used: red

W2 = Right Front (RF) = 355.2 kg
Scale Used: green

W3 = Left Rear (LR) = 228.4 kg
Scale Used: yellow

W4 = Right Rear (RR) = 224 kg
Scale Used: blue

Total Weight:
Wtotal (measured) = 1196.3 kg

Wtotal (calculated) = 1197.3 kg

Distance between front wheels:
M = 1472 mm

Distance between rear wheels:
N = 1446 mm

Distance from front to rear wheels:
E = 2502 mm

Distance from front wheels back to CG:
H = 945 mm

Distance from vehicle centerline to CG:
R = -24 mm

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

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

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

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

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

140MASH3C16-04 CG Data Calculation Worksheet.xlsx	Gross Static WorkSheet

7.6. Vehicle Interior Deformation Measurements

Table 7-7. Interior Floorboard Pre, Post, and Deformation Measurements

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Attachment 5.5 --- Interior Vehicle Measurement Report

Vehicle Type	1100C	Test Number	140MASH3C16-04
Make	Kia	Model	Rio LX
Year	2007	Color	Red
VIN #	KNADE123376242513		

Floorboard Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
F7	620 (24.4)	-350 (-13.8)	-173 (-6.8)	612 (24.1)	-342 (-13.5)	-163 (-6.4)	-8 (-0.3)	8 (0.3)	10 (0.4)
F8	620 (24.4)	-250 (-9.8)	-177 (-7)	616 (24.3)	-242 (-9.5)	-165 (-6.5)	-4 (-0.2)	8 (0.3)	12 (0.5)
F9	620 (24.4)	-150 (-5.9)	-170 (-6.7)	623 (24.5)	-159 (-6.3)	-152 (-6)	3 (0.1)	-9 (-0.4)	18 (0.7)
F10	520 (20.5)	-350 (-13.8)	-178 (-7)	512 (20.2)	-344 (-13.5)	-159 (-6.3)	-8 (-0.3)	6 (0.2)	19 (0.7)
F11	520 (20.5)	-250 (-9.8)	-189 (-7.4)	515 (20.3)	-249 (-9.8)	-147 (-5.8)	-5 (-0.2)	1 (0)	42 (1.7)
F12	520 (20.5)	-150 (-5.9)	-181 (-7.1)	522 (20.6)	-163 (-6.4)	-157 (-6.2)	2 (0.1)	-13 (-0.5)	24 (0.9)
F13	420 (16.5)	-350 (-13.8)	-183 (-7.2)	412 (16.2)	-345 (-13.6)	-160 (-6.3)	-8 (-0.3)	5 (0.2)	23 (0.9)
F14	419 (16.5)	-250 (-9.8)	-197 (-7.8)	417 (16.4)	-260 (-10.2)	-144 (-5.7)	-2 (-0.1)	-10 (-0.4)	53 (2.1)
F15	417 (16.4)	-150 (-5.9)	-188 (-7.4)	423 (16.7)	-164 (-6.5)	-165 (-6.5)	6 (0.2)	-14 (-0.6)	23 (0.9)
F16	870 (34.3)	-553 (-21.8)	-182 (-7.2)	859 (33.8)	-545 (-21.5)	-190 (-7.5)	-11 (-0.4)	8 (0.3)	-8 (-0.3)
F17	870 (34.3)	-450 (-17.7)	-175 (-6.9)	856 (33.7)	-442 (-17.4)	-189 (-7.4)	-14 (-0.6)	8 (0.3)	-14 (-0.6)
F18	870 (34.3)	-347 (-13.7)	-173 (-6.8)	853 (33.6)	-349 (-13.7)	-186 (-7.3)	-17 (-0.7)	-2 (-0.1)	-13 (-0.5)
F19	870 (34.3)	-249 (-9.8)	-180 (-7.1)	862 (33.9)	-247 (-9.7)	-175 (-6.9)	-8 (-0.3)	2 (0.1)	5 (0.2)
F20	870 (34.3)	-150 (-5.9)	-167 (-6.6)	870 (34.3)	-147 (-5.8)	-168 (-6.6)	0 (0)	3 (0.1)	-1 (0)
F21	972 (38.3)	-551 (-21.7)	-193 (-7.6)	959 (37.8)	-538 (-21.2)	-204 (-8)	-13 (-0.5)	13 (0.5)	-11 (-0.4)
F22	972 (38.3)	-450 (-17.7)	-174 (-6.9)	957 (37.7)	-439 (-17.3)	-187 (-7.4)	-15 (-0.6)	11 (0.4)	-13 (-0.5)
F23	972 (38.3)	-348 (-13.7)	-174 (-6.9)	954 (37.6)	-338 (-13.3)	-184 (-7.2)	-18 (-0.7)	10 (0.4)	-10 (-0.4)
F24	972 (38.3)	-247 (-9.7)	-187 (-7.4)	961 (37.8)	-254 (-10)	-185 (-7.3)	-11 (-0.4)	-7 (-0.3)	2 (0.1)
F25	972 (38.3)	-146 (-5.7)	-179 (-7)	970 (38.2)	-152 (-6)	-172 (-6.8)	-2 (-0.1)	-6 (-0.2)	7 (0.3)
F26	1070 (42.1)	-553 (-21.8)	-193 (-7.6)	1059 (41.7)	-536 (-21.1)	-204 (-8)	-11 (-0.4)	17 (0.7)	-11 (-0.4)
F27	1070 (42.1)	-450 (-17.7)	-174 (-6.9)	1057 (41.6)	-435 (-17.1)	-185 (-7.3)	-13 (-0.5)	15 (0.6)	-11 (-0.4)
F28	1070 (42.1)	-348 (-13.7)	-173 (-6.8)	1055 (41.5)	-334 (-13.1)	-182 (-7.2)	-15 (-0.6)	14 (0.6)	-9 (-0.4)
F29	1070 (42.1)	-245 (-9.6)	-189 (-7.4)	1059 (41.7)	-255 (-10)	-159 (-6.3)	-11 (-0.4)	-10 (-0.4)	30 (1.2)
F30	1070 (42.1)	-144 (-5.7)	-176 (-6.9)	1069 (42.1)	-157 (-6.2)	-168 (-6.6)	-1 (0)	-13 (-0.5)	8 (0.3)
F31	1175 (46.3)	-554 (-21.8)	-184 (-7.2)	1161 (45.7)	-535 (-21.1)	-190 (-7.5)	-14 (-0.6)	19 (0.7)	-6 (-0.2)
F32	1175 (46.3)	-450 (-17.7)	-174 (-6.9)	1157 (45.6)	-431 (-17)	-185 (-7.3)	-18 (-0.7)	19 (0.7)	-11 (-0.4)
F33	1175 (46.3)	-348 (-13.7)	-174 (-6.9)	1156 (45.5)	-329 (-13)	-177 (-7)	-19 (-0.7)	19 (0.7)	-3 (-0.1)
F34	1175 (46.3)	-246 (-9.7)	-180 (-7.1)	1154 (45.4)	-255 (-10)	-140 (-5.5)	-21 (-0.8)	-9 (-0.4)	40 (1.6)
F35	1175 (46.3)	-145 (-5.7)	-174 (-6.9)	1171 (46.1)	-163 (-6.4)	-157 (-6.2)	-4 (-0.2)	-18 (-0.7)	17 (0.7)
F36	1225 (48.2)	-554 (-21.8)	-152 (-6)	1288 (50.7)	-535 (-21.1)	-161 (-6.3)	63 (2.5)	19 (0.7)	-9 (-0.4)
F37	1224 (48.2)	-450 (-17.7)	-173 (-6.8)	1259 (49.6)	-429 (-16.9)	-180 (-7.1)	35 (1.4)	21 (0.8)	-7 (-0.3)
F38	1220 (48)	-350 (-13.8)	-171 (-6.7)	1257 (49.5)	-330 (-13)	-172 (-6.8)	37 (1.5)	20 (0.8)	-1 (0)
F39	1219 (48)	-244 (-9.6)	-174 (-6.9)	1247 (49.1)	-224 (-8.8)	-156 (-6.1)	28 (1.1)	20 (0.8)	18 (0.7)
F40	1217 (47.9)	-142 (-5.6)	-165 (-6.5)	1258 (49.5)	-157 (-6.2)	-114 (-4.5)	41 (1.6)	-15 (-0.6)	51 (2)
F41	1327 (52.2)	-452 (-17.8)	-137 (-5.4)	1341 (52.8)	-434 (-17.1)	-137 (-5.4)	14 (0.6)	18 (0.7)	0 (0)
F42	1323 (52.1)	-348 (-13.7)	-139 (-5.5)	1349 (53.1)	-327 (-12.9)	-131 (-5.2)	26 (1)	21 (0.8)	8 (0.3)
F43	1319 (51.9)	-242 (-9.5)	-135 (-5.3)	CNBM	CNBM	CNBM	CNBM	CNBM	CNBM
F44	1317 (51.9)	-143 (-5.6)	-140 (-5.5)	1359 (53.5)	-117 (-4.6)	-147 (-5.8)	42 (1.7)	26 (1)	-7 (-0.3)
F45	1351 (53.2)	-555 (-21.9)	-80 (-3.1)	1361 (53.6)	-521 (-20.5)	-79 (-3.1)	10 (0.4)	34 (1.3)	1 (0)
F46	1426 (56.1)	-450 (-17.7)	-80 (-3.1)	1445 (56.9)	-435 (-17.1)	-66 (-2.6)	19 (0.7)	15 (0.6)	14 (0.6)
F47	1426 (56.1)	-348 (-13.7)	-80 (-3.1)	1446 (56.9)	-328 (-12.9)	-65 (-2.6)	20 (0.8)	20 (0.8)	15 (0.6)
F48	1417 (55.8)	-242 (-9.5)	-78 (-3.1)	CNBM	CNBM	CNBM	CNBM	CNBM	CNBM
F49	1418 (55.8)	-140 (-5.5)	-85 (-3.3)	1462 (57.6)	-119 (-4.7)	-84 (-3.3)	44 (1.7)	21 (0.8)	1 (0)

NOTE: CNBM stands for "Could Not Be Measured" due to loss of the measured mark.

Table 7-8. Interior Dashboard and Roof Pre, Post, and Deformation Measurements

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Attachment 5.5 --- Interior Vehicle Measurement Report

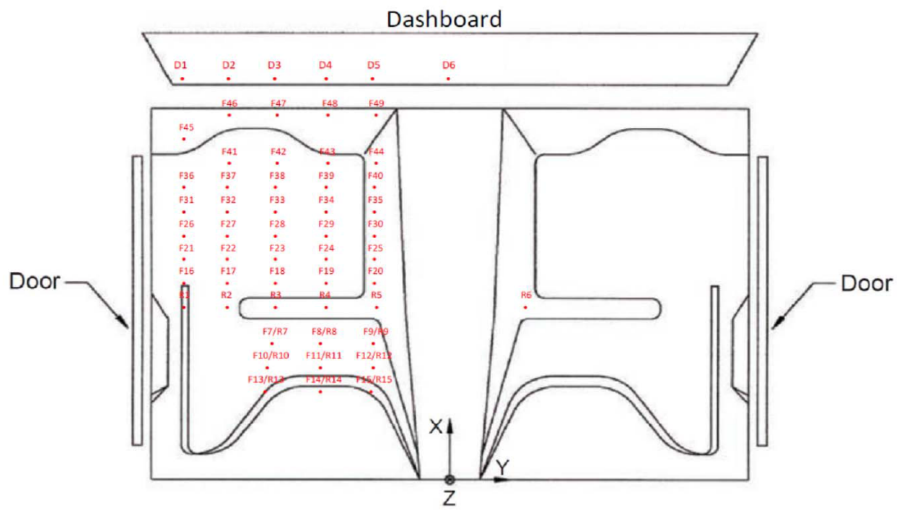
Vehicle Type	1100C	Test Number	140MASH3C16-04
Make	Kia	Model	Rio LX
Year	2007	Color	Red
VIN #	KNADE123376242513		

Dashboard Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
D1	1058 (41.7)	-550 (-21.7)	522 (20.6)	1099 (43.3)	-545 (-21.5)	538 (21.2)	41 (1.6)	5 (0.2)	16 (0.6)
D2	1044 (41.1)	-448 (-17.6)	569 (22.4)	1041 (41)	-441 (-17.4)	566 (22.3)	-3 (-0.1)	7 (0.3)	-3 (-0.1)
D3	1008 (39.7)	-345 (-13.6)	615 (24.2)	1008 (39.7)	-340 (-13.4)	615 (24.2)	0 (0)	5 (0.2)	0 (0)
D4	980 (38.6)	-249 (-9.8)	592 (23.3)	1031 (40.6)	-233 (-9.2)	597 (23.5)	51 (2)	16 (0.6)	5 (0.2)
D5	1040 (40.9)	-148 (-5.8)	540 (21.3)	1092 (43)	-143 (-5.6)	546 (21.5)	52 (2)	5 (0.2)	6 (0.2)
D6	1106 (43.5)	0 (0)	560 (22)	1086 (42.8)	2 (0.1)	549 (21.6)	-20 (-0.8)	2 (0.1)	-11 (-0.4)

Roof Measurements - Dimensions in mm (inches)

Point	Pre-Impact			Post-Impact			Difference		
	X	Y	Z	X	Y	Z	ΔX	ΔY	ΔZ
R1	717 (28.2)	-551 (-21.7)	838 (33)	730 (28.7)	-539 (-21.2)	837 (33)	13 (0.5)	12 (0.5)	-1 (0)
R2	720 (28.3)	-450 (-17.7)	920 (36.2)	724 (28.5)	-446 (-17.6)	917 (36.1)	4 (0.2)	4 (0.2)	-3 (-0.1)
R3	720 (28.3)	-350 (-13.8)	929 (36.6)	722 (28.4)	-347 (-13.7)	926 (36.5)	2 (0.1)	3 (0.1)	-3 (-0.1)
R4	720 (28.3)	-250 (-9.8)	939 (37)	721 (28.4)	-245 (-9.6)	937 (36.9)	1 (0)	5 (0.2)	-2 (-0.1)
R5	720 (28.3)	-150 (-5.9)	945 (37.2)	721 (28.4)	-146 (-5.7)	943 (37.1)	1 (0)	4 (0.2)	-2 (-0.1)
R6	720 (28.3)	148 (5.8)	945 (37.2)	720 (28.3)	149 (5.9)	945 (37.2)	0 (0)	1 (0)	0 (0)
R7	620 (24.4)	-350 (-13.8)	962 (37.9)	622 (24.5)	-346 (-13.6)	963 (37.9)	2 (0.1)	4 (0.2)	1 (0)
R8	620 (24.4)	-250 (-9.8)	971 (38.2)	619 (24.4)	-246 (-9.7)	972 (38.3)	-1 (0)	4 (0.2)	1 (0)
R9	620 (24.4)	-150 (-5.9)	978 (38.5)	620 (24.4)	-144 (-5.7)	981 (38.6)	0 (0)	6 (0.2)	3 (0.1)
R10	520 (20.5)	-350 (-13.8)	973 (38.3)	519 (20.4)	-346 (-13.6)	976 (38.4)	-1 (0)	4 (0.2)	3 (0.1)
R11	520 (20.5)	-250 (-9.8)	982 (38.7)	520 (20.5)	-240 (-9.4)	986 (38.8)	0 (0)	10 (0.4)	4 (0.2)
R12	520 (20.5)	-150 (-5.9)	986 (38.8)	523 (20.6)	-141 (-5.6)	989 (38.9)	3 (0.1)	9 (0.4)	3 (0.1)
R13	420 (16.5)	-350 (-13.8)	1000 (39.4)	419 (16.5)	-344 (-13.5)	1004 (39.5)	-1 (0)	6 (0.2)	4 (0.2)
R14	419 (16.5)	-250 (-9.8)	1009 (39.7)	419 (16.5)	-240 (-9.4)	1014 (39.9)	0 (0)	10 (0.4)	5 (0.2)
R15	417 (16.4)	-150 (-5.9)	1016 (40)	420 (16.5)	-140 (-5.5)	1020 (40.2)	3 (0.1)	10 (0.4)	4 (0.2)



NOTE: CNBM stands for "Could Not Be Measured" due to loss of the measured mark.

7.7. Data Plots

The TRAP data plots are shown in Figure 7-9 through Figure 7-18. The plots included are the accelerations, angular rate sensor rates, angular rate sensor degrees, Acceleration Severity Index (ASI), and TRAP test summary sheets. All data were analyzed using TRAP. As noted on the Test Data Summary Sheet, the data was analyzed using the "Secondary" Acceleration records and a hybrid of the "Primary" and "Secondary" Angular Rate Sensor (ARS) records. The reasons for this are: 1) The "Secondary" channels were closer to the vehicle CG and 2) Some of the ARS Channels did not record properly so the ARS channels that recorded properly were combined to provide a complete set of ARS data[3]. The plots of data used for the TRAP analysis are shown on the following pages preceding the TRAP summary with the "Primary" Acceleration plots shown thereafter for reference.

[3] Roll and Yaw were used from the "Primary" Set. Pitch was used from the "Secondary" Set. Both "Primary" and "Secondary" were within the recommended distance from the vehicle C.G.

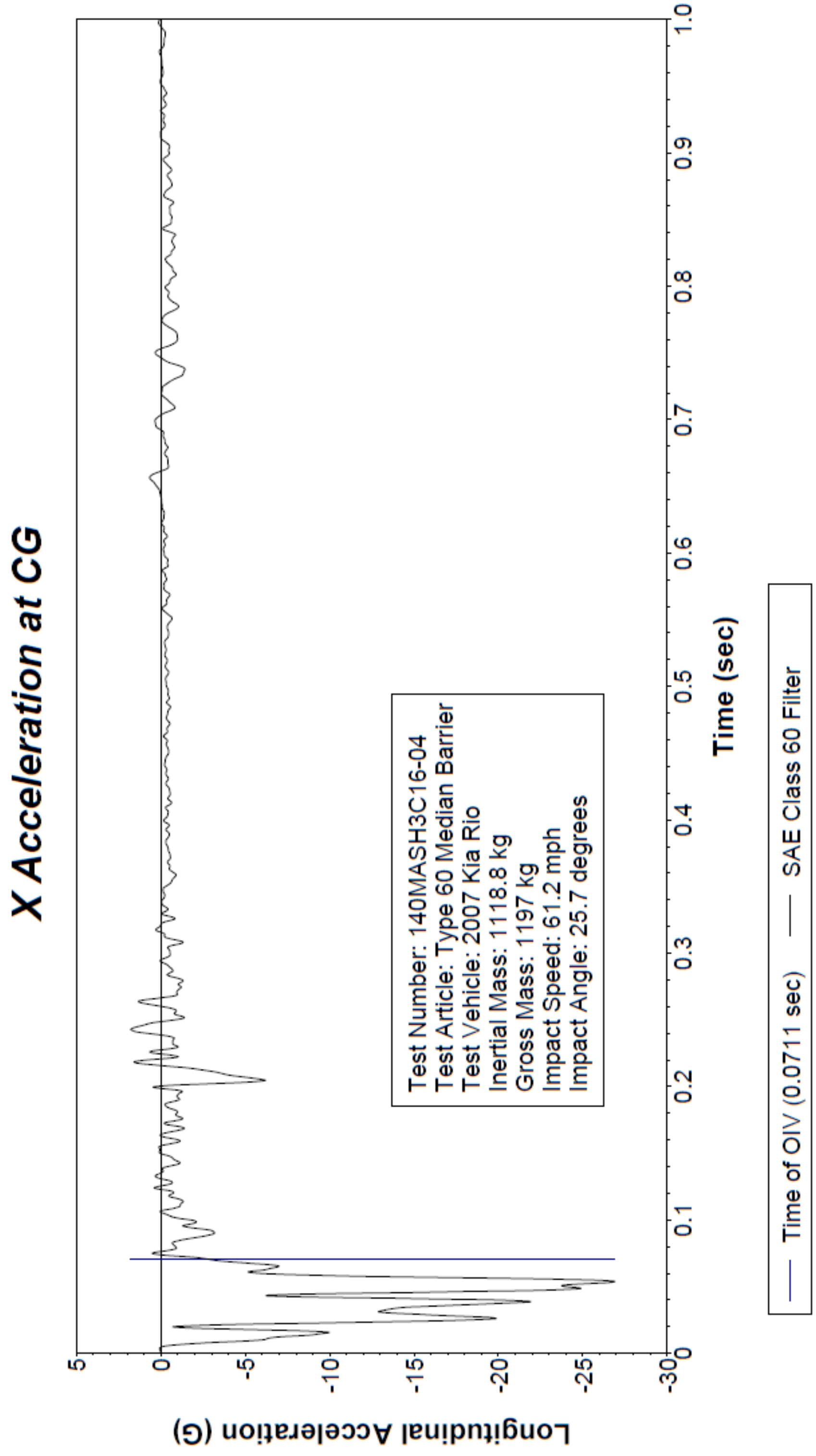


Figure 7-9 Longitudinal Acceleration at CG - Secondary

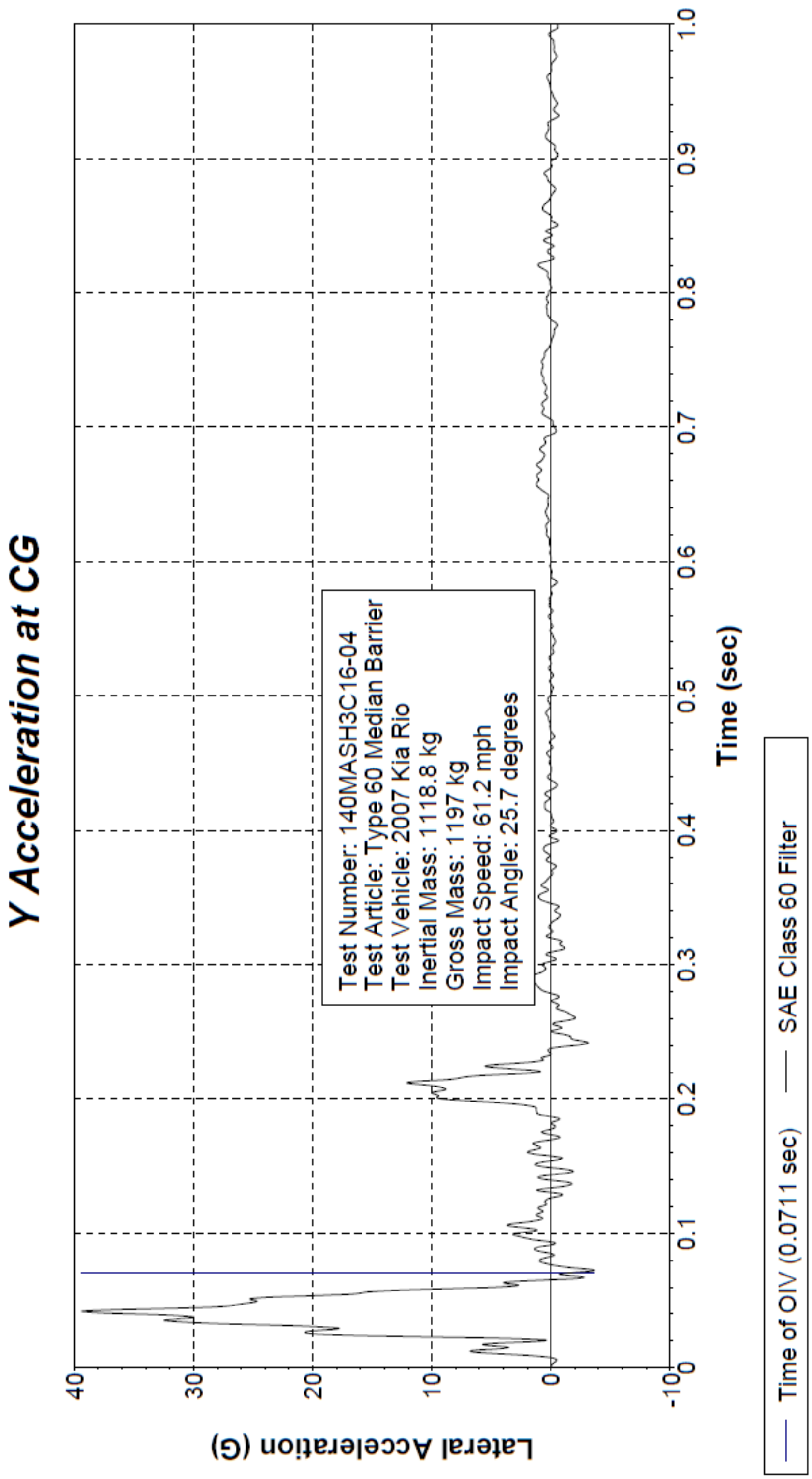


Figure 7-10 Lateral Acceleration at CG – Secondary

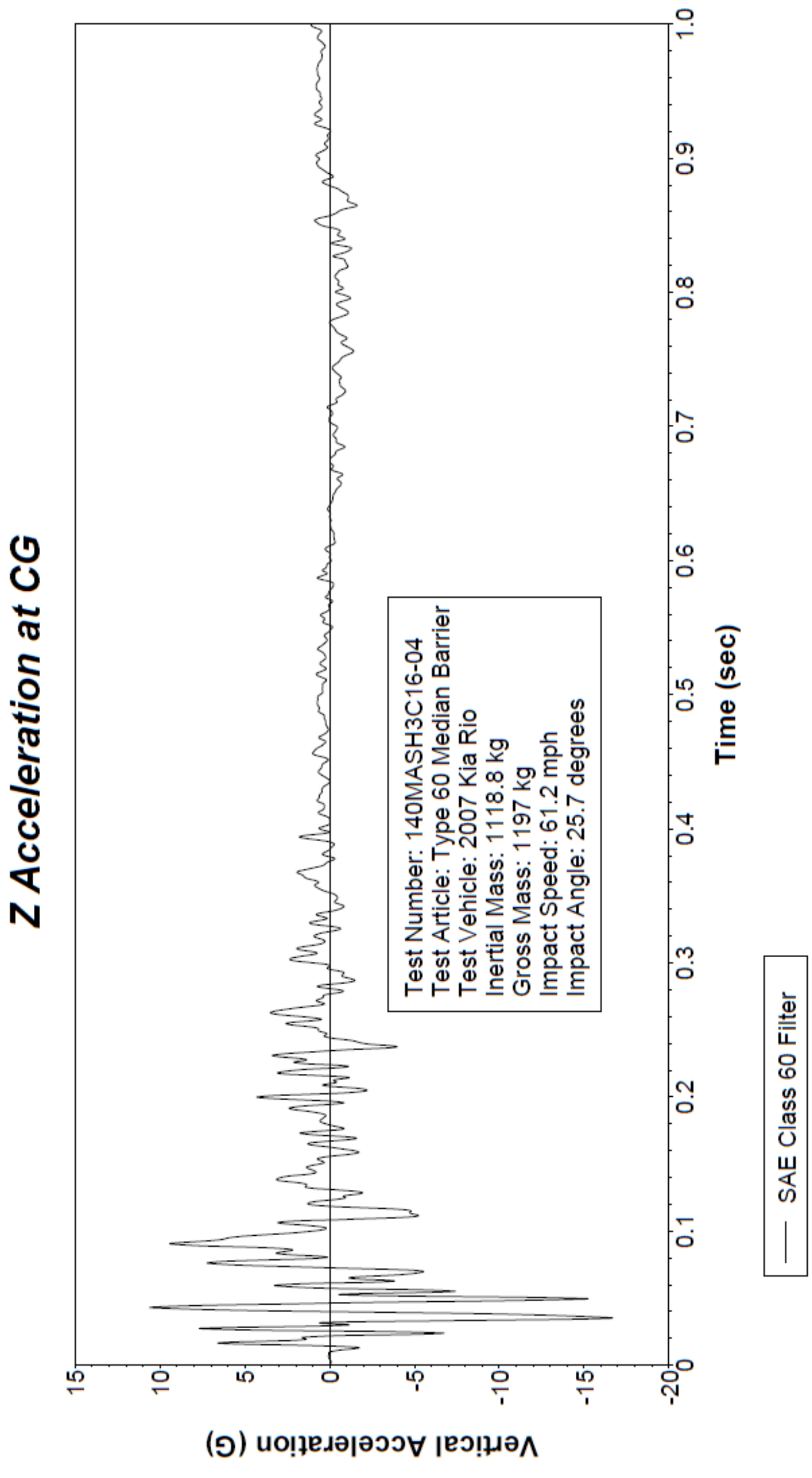


Figure 7-11 Vertical Acceleration at CG – Secondary

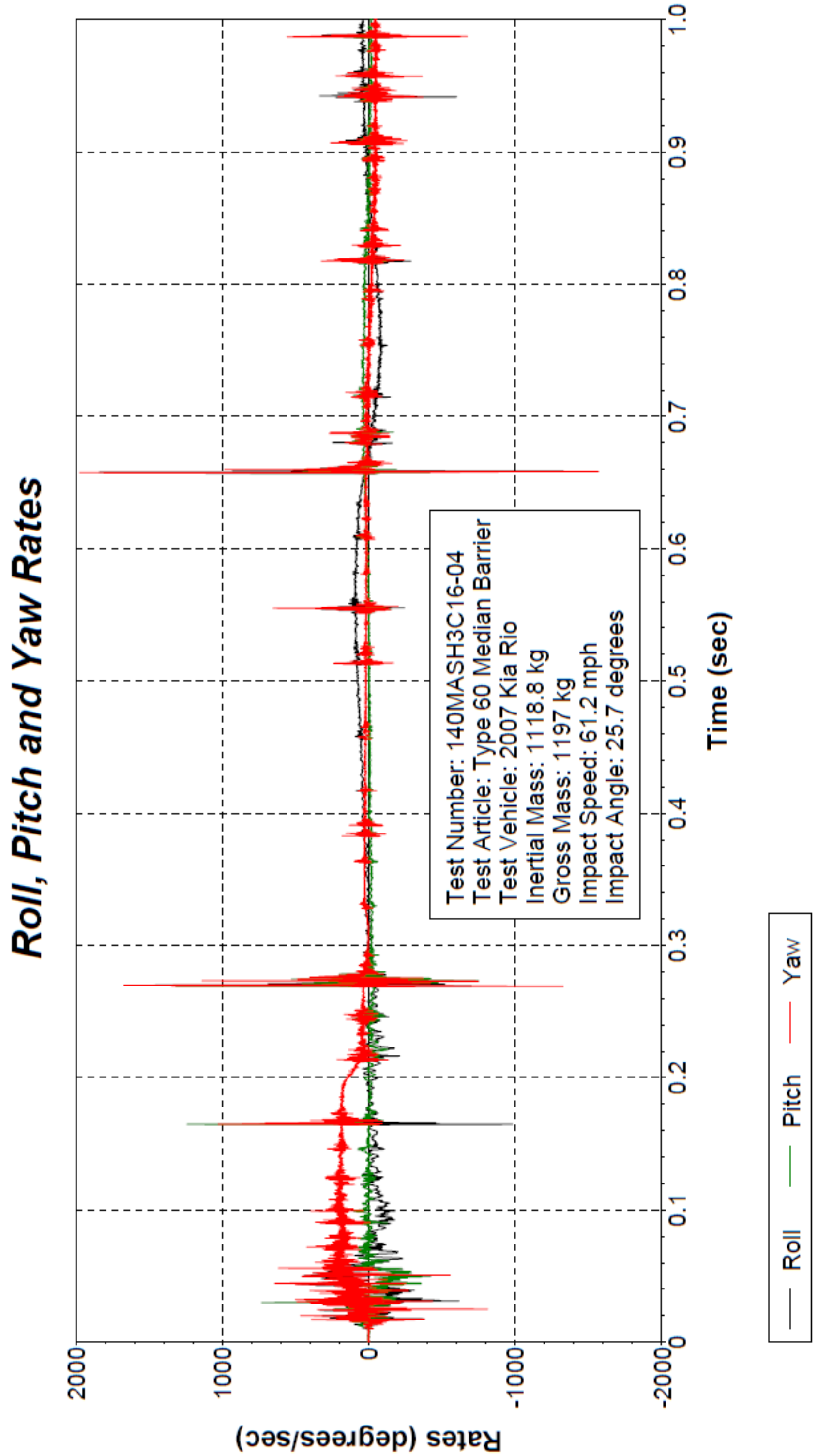


Figure 7-12 Roll, Pitch, and Yaw Rates at CG – Combined

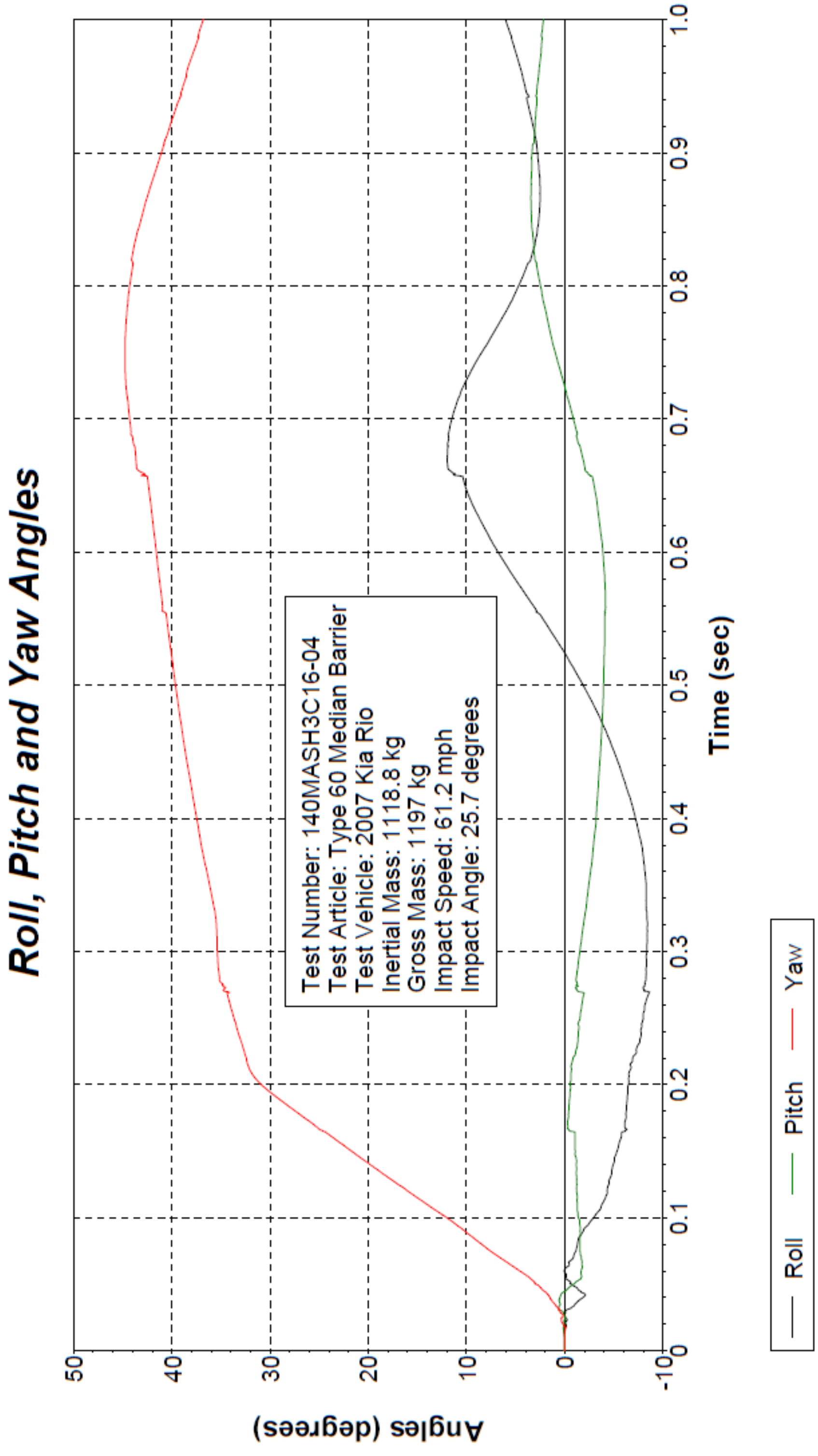


Figure 7-13 Roll, Pitch, and Yaw Angles at CG - Combined

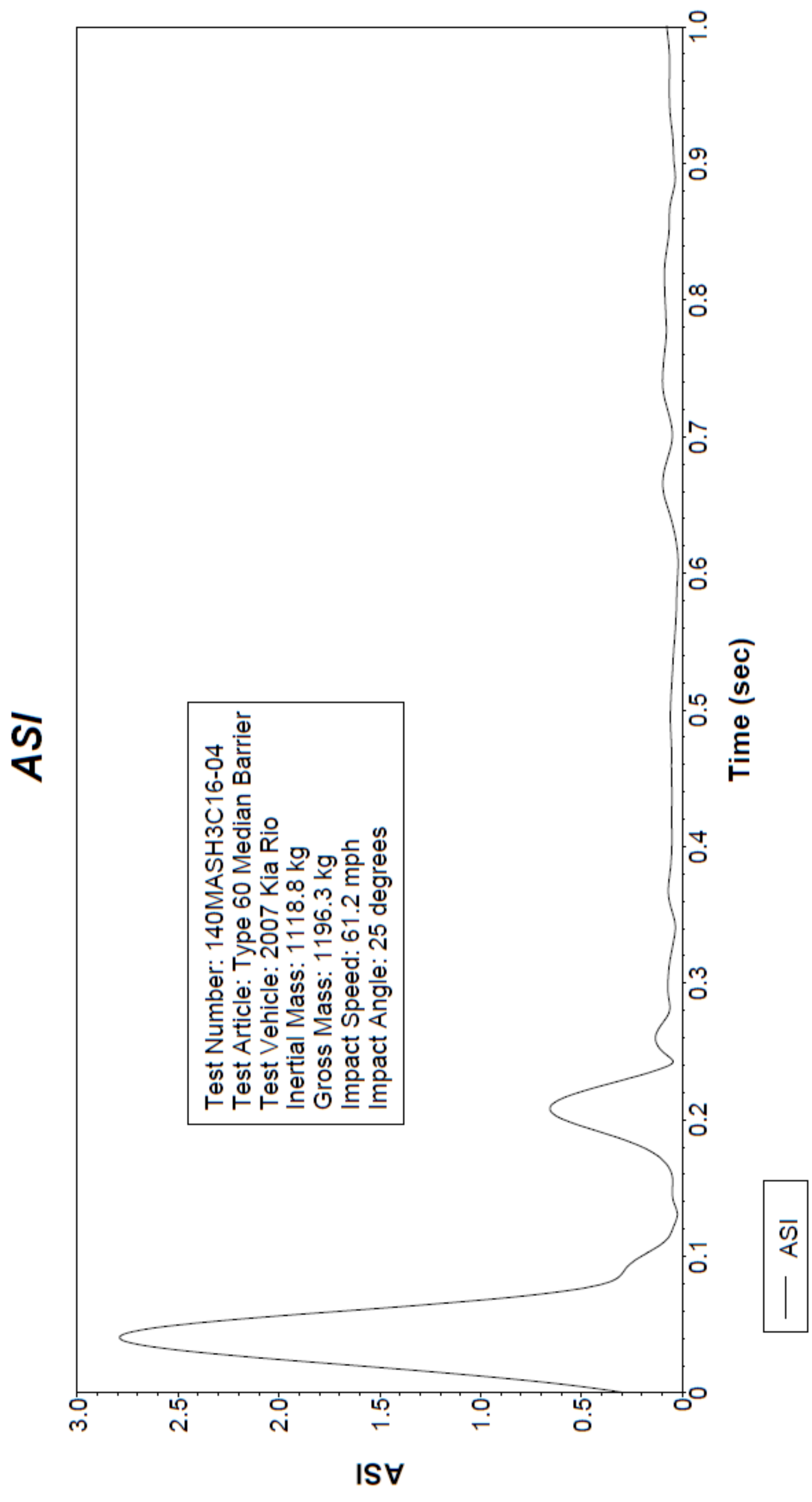


Figure 7-14 Acceleration Severity Index (ASI) - Combined

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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:   140MASH3C16-04
   Test Date:     11/30/2016
   Test Article:  Type 60 Median Barrier

Test Vehicle
   Description:            2007 Kia Rio
   Test Inertial Mass:     1119 kg
   Gross Static Mass:      1197 kg

Impact Conditions
   Speed:   61.2   mph
   Angle:   25.7   degrees

Occupant Risk Factors
   Impact Velocity (m/s)       at 0.0711 seconds on left side of interior
      x-direction    7.8
      y-direction    -9.5

   THIV (km/hr):     44.0      at 0.0692  seconds on left side of interior
   THIV (m/s):       12.2

   Ridedown Accelerations (g's)
      x-direction    -4.8      (0.2019 -  0.2119 seconds)
      y-direction    10.8      (0.2036 -  0.2136 seconds)

   PHD (g's):        11.6      (0.2035 -  0.2135 seconds)

   ASI:              2.79      (0.0407 -  0.0907 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
   x-direction       -14.5     (0.0130 -  0.0630 seconds)
   y-direction       19.2      (0.0103 -  0.0603 seconds)
   z-direction       -3.1      (0.0225 -  0.0725 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
   Roll           12.0      (0.6686 seconds)
   Pitch             -4.2      (0.5589 seconds)
   Yaw            44.8      (0.7551 seconds)
```

Figure 7-15 TRAP Summary Sheet - Combined

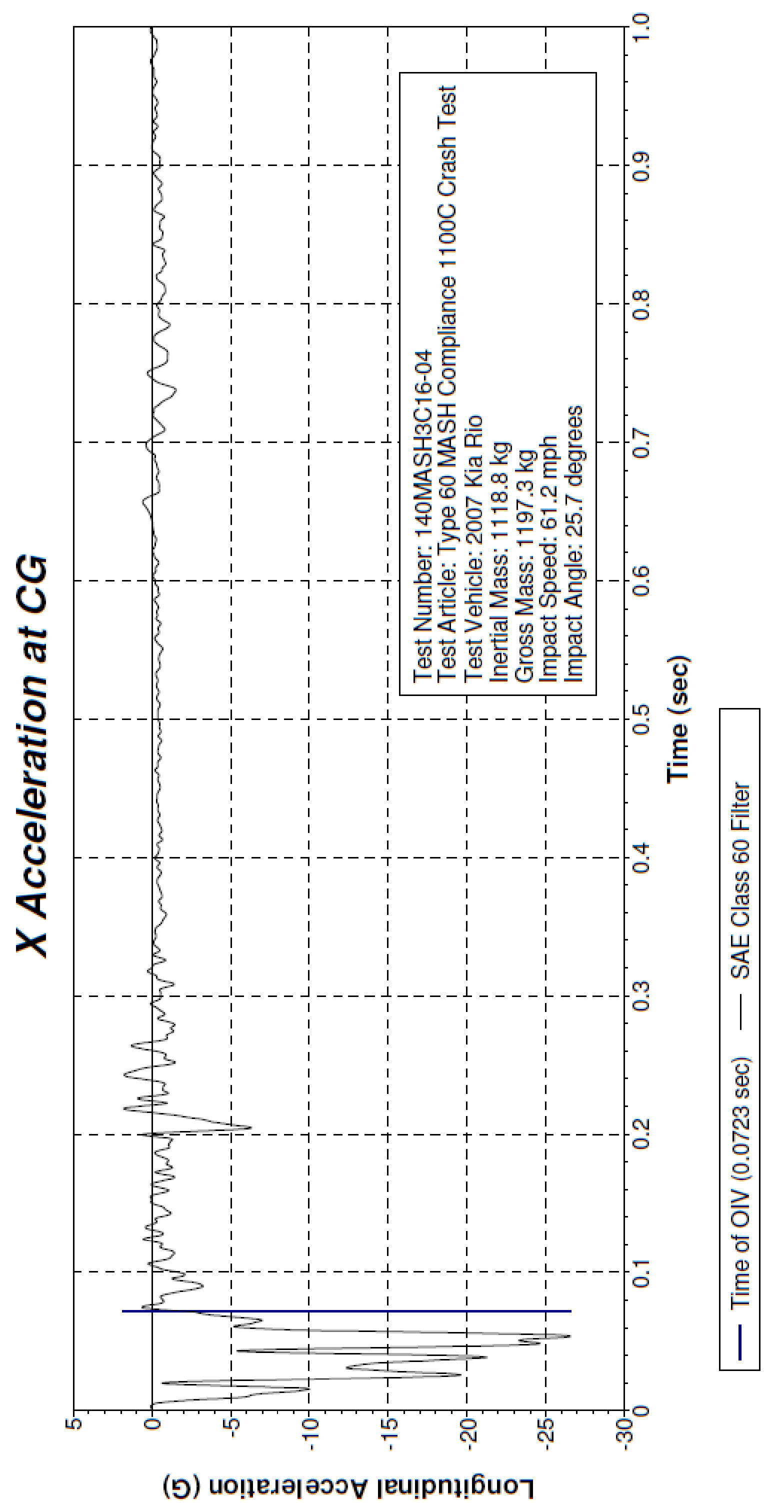

Figure 7-16 Longitudinal Acceleration at CG - Primary

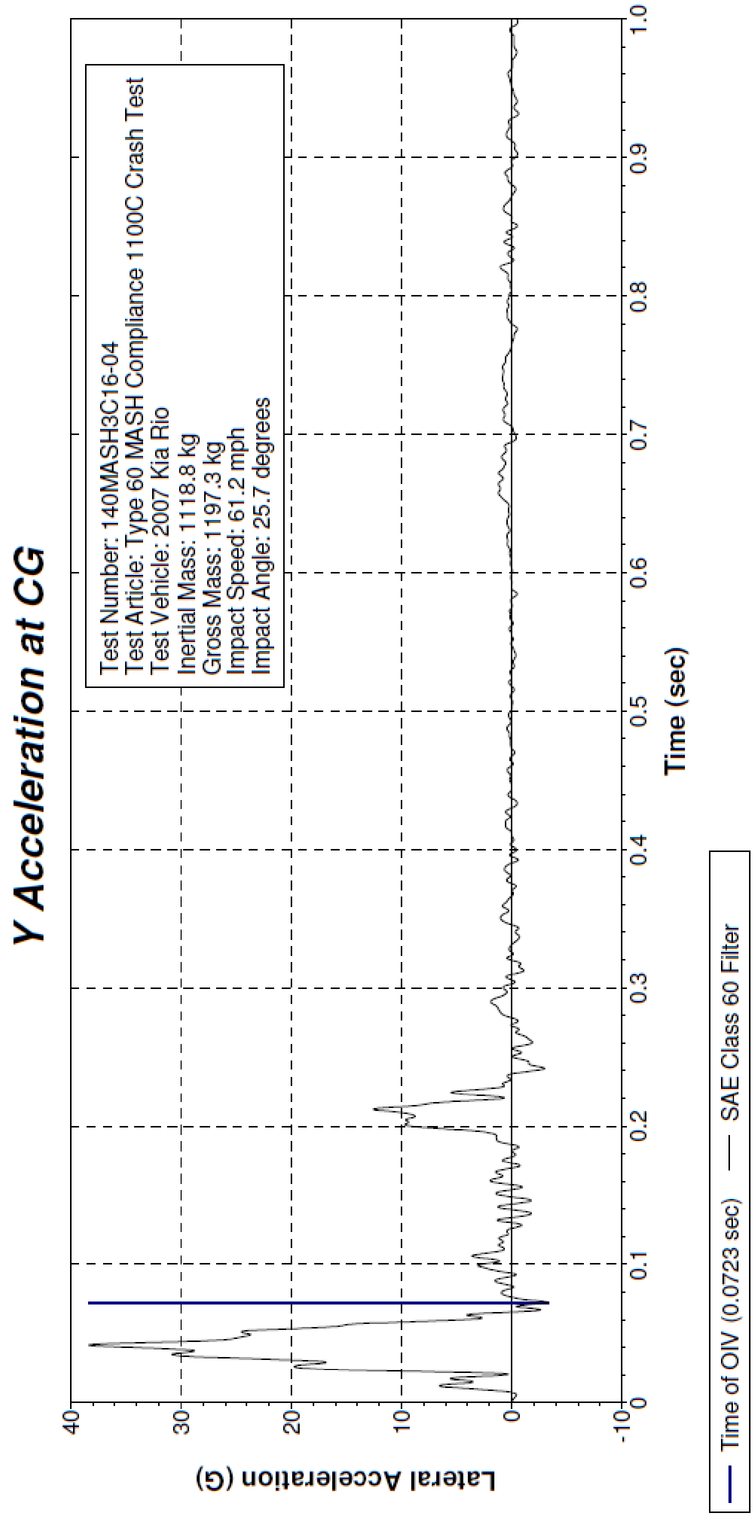

Figure 7-17 Lateral Acceleration at CG - Primary

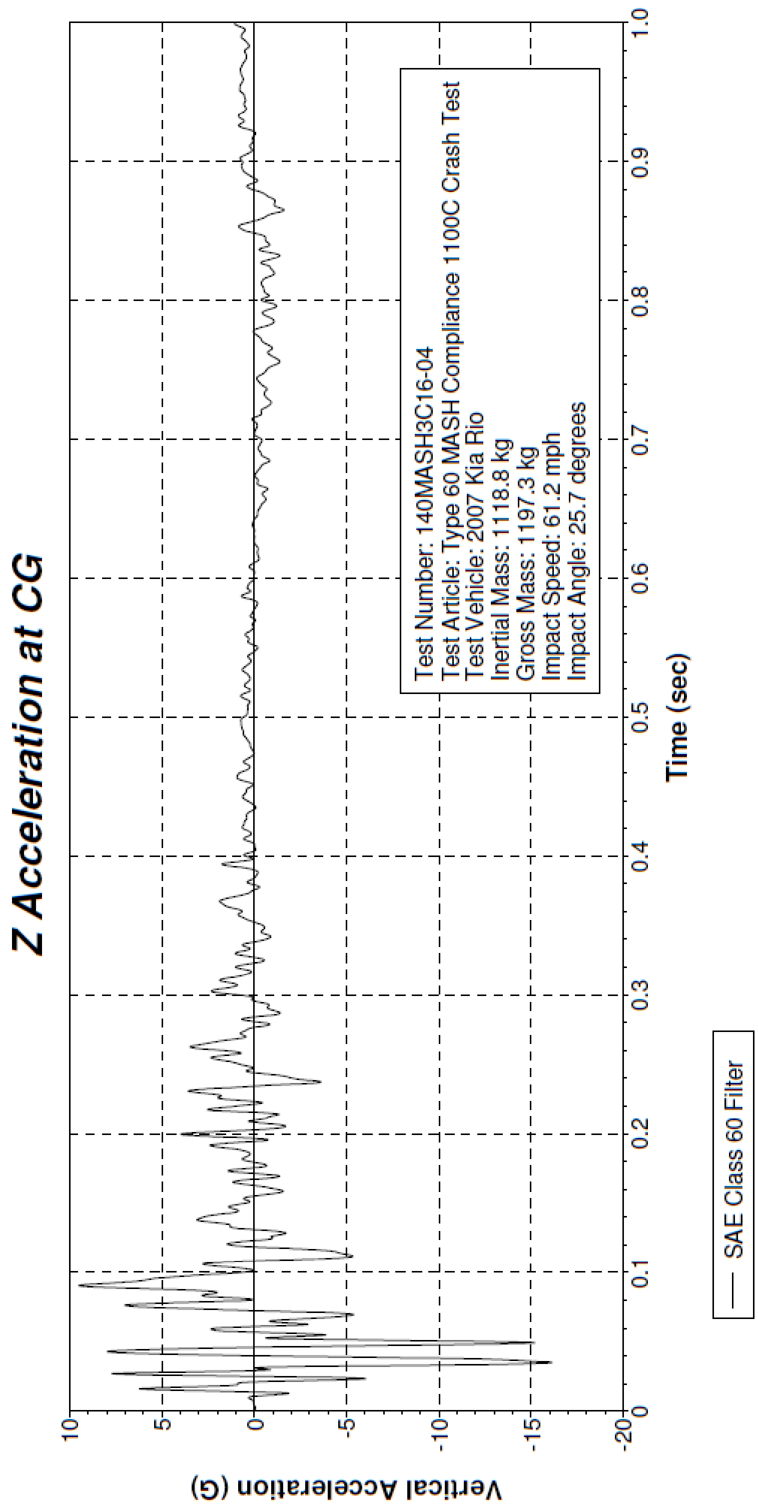

Figure 7-18 Vertical Acceleration at CG – Primary

8. Detail Drawings

The following details in Figure 8-1 and Figure 8-2 are Type 60 Median Barrier Standard Plans.

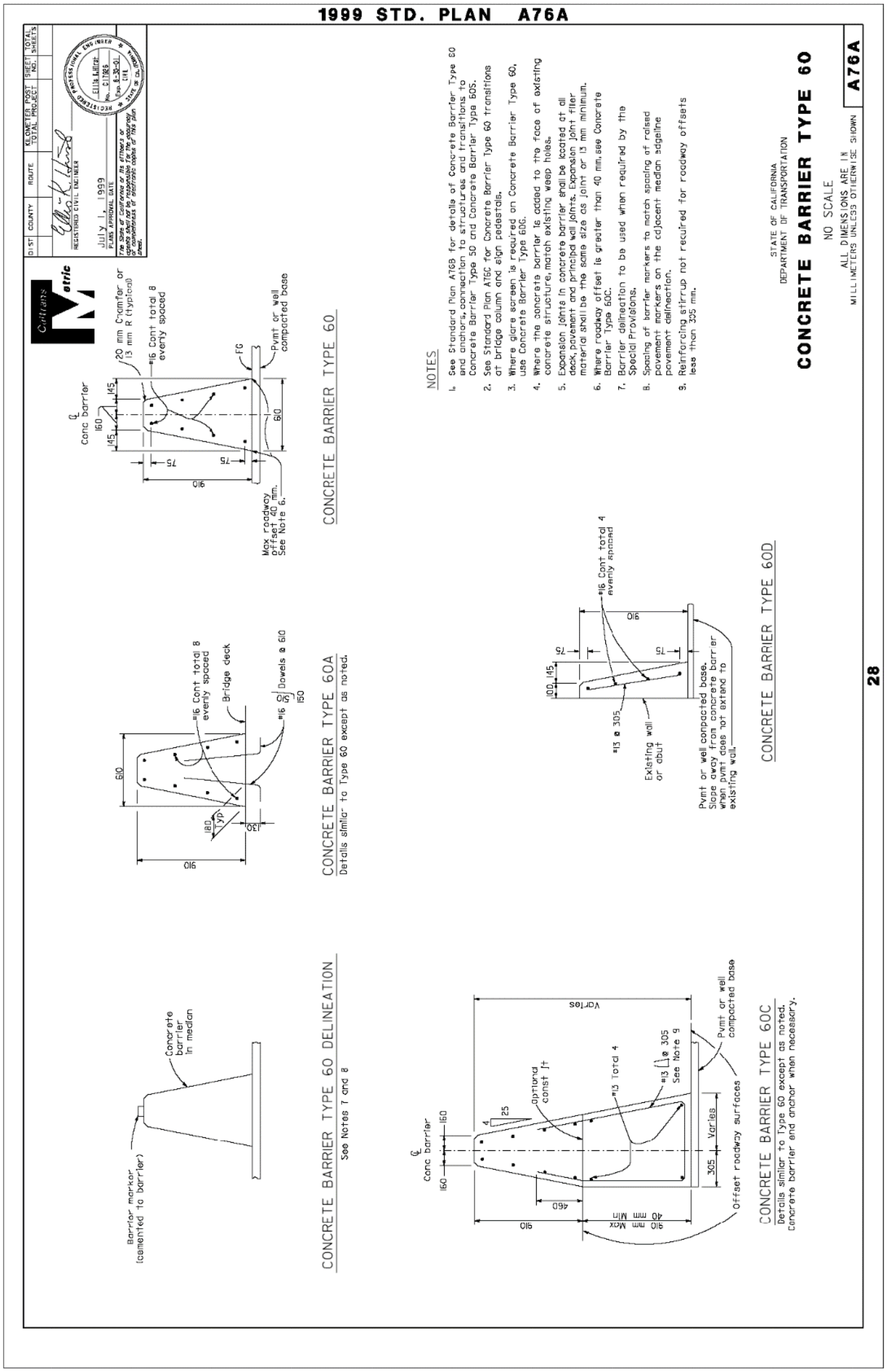

Figure 8-1. Standard Plan for Type 60 Barrier

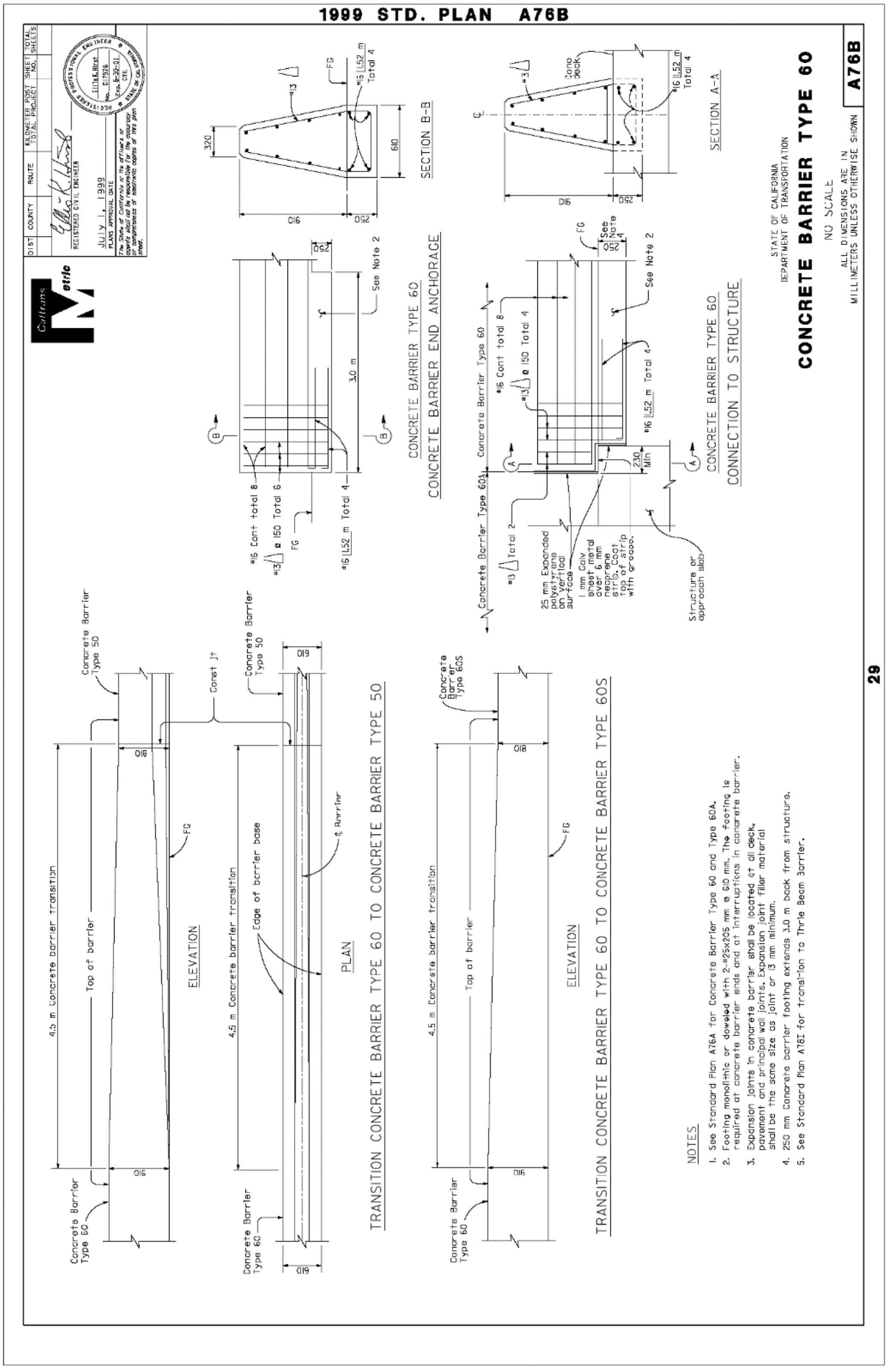

Figure 8-2. Standard Plan for Type 60 Barrier (End Anchorage)

9. References

1. *Manual for Assessing Safety Hardware 2009 (MASH 09).* American Association of State Highway and Transportation Officials. Washington, DC. 2009.
2. *(Caltrans) Standard Plans 1997.* State of California Department of Transportation. Sacramento. 1997.
3. William F. Williams, Roger P. Bligh, and Wanda L. Menges. MASH TEST 3-11 OF THE TXDOT SINGLE SLOPE BRIDGE RAIL (TYPE SSTR) ON PAN-FORMED BRIDGE DECK. Texas Transportation Institute. Austin. 2011.
4. William F. Williams, R. P. *MASH TL-3 CRASH TESTING AND EVALUATION OF THE TxDOT T631 BRIDGE RAIL.* Texas Transportation Institute. Austin. 2016.
5. *Vehicle Damage Scale for Traffic Crash Investigators.* Texas Department of Public Safety. Austin. 2006.
6. *Collision Deformation Classification SAE Recommended Practice J224 MAR80.* Society of Automotive Engineers. New York, NY. 1980
7. *Test Risk Assessment Program.* Texas Transportation Institute. Austin. 2013.

10. Document Revision History

Date	Description