Appendix E: Full-Scale Crash Testing Report

DRAFT TEST REPORT

CRASH TEST EVALUATION OF LONGITUDINAL BARRIERS ON CURVED-SUPER ELEVATED ROAD SECTIONS (NCHRP PROJECT 22-29A)

Authors:
Dhafer Marzougui, Christopher Story,
and Cing Dao (Steve) Kan,

Center for Collision Safety and Analysis (CCSA)
The George Mason University

Kenneth S. Opiela
Consultant

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16. Abstract

This report documents three full-scale crash tests that were conducted at the Federal Highway Administration (FHWA) Federal Outdoor Impact Laboratory (FOIL). These tests were conducted to evaluate the safety performance of longitudinal barriers placed on curved, superelevated roadway sections (CSRS) in support of efforts under NCHRP Project 22-29A "Evaluating the Performance of Longitudinal Barriers on Curved Superelevated Roadway Sections." The barriers were tested for Test Level-3 requirements and protocols as provided in Manual for Assessing Safety Hardware (MASH 2009) from AASHTO. The objective of this project is to evaluate the safety performance of longitudinal barrier on a curved, superelevated roadway. The crash test results are expected to provide validation for a series of simulations that is documented in the NCHRP project report. Other factors, such as economics, aesthetics, maintenance needs, or environmental effect, are not considered in this evaluation.

G4(1S) W-beam longitudinal barriers were constructed for each test with 55.2 m (181.25 ft) of W-beam guardrail set in 21A strong soil on an asphalt pad that was 12.2 m (140 ft) x 7.3m (24 ft) with 4.9 m (16 ft) of roadway with a 6% superelevation reflecting a 254 m (833 ft) radius of road curvature. A 2.4 m (8 ft) shoulder with a 2% decline from the roadway surface was included. The rail for Tests 16004 and 16010 was set 1.2 m (4 ft) on the shoulder away from the edge of the roadway. For Tests 16015 the rail was set on the shoulder 2.4m (8') away from the edge of the roadway.

The longitudinal barrier in Test 16004 was impacted with a 2315.0 kg (5103.7 lb) pickup truck traveling at 100 km/h (62 mph) for the Test 3-11 impact condition. In Test 16010, the barrier was impacted by a 2283.0 kg (5033.2 lb) pickup truck and Test 16015 was impacted by a 2268.5 kg (5001.2 lb) pickup truck.

The design of the longitudinal barriers, the set-up for the curved, superelevated roadway, details of the vehicles used in the test, results of the three tests, and assessment of the barrier performance are included in this report.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised March 2002)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

This document reports the result of a crash test as follows:

Test Type	Full-scale crash test: Vehicle impacting barrier
What is Tested	G4(1S) longitudinal barrier installed on a curved-superelevated road section
Purpose/Objective	Determine the safety performance of longitudinal barriers on curved-superelevated road sections at MASH Test Level-3 (TL 3-11)
Impacting Item/Vehicle	Chevrolet Silverado 1500 (2270P) pickup trucks – Three test vehicles: Test 1604: 2315.0 kg (5103.7 lb), Test 1610: 2283.0 kg (5033.2 lb), and Test 1615: 2268.5 kg (5001.2 lb): 3-2009
Impact Speed & Conditions	Release speed: 102 km/hr (63.5 mi/hr), impact angle: 25-deg, on curved-superelevated asphalt surface.
Test Procedures & Standards Information	ASSHTO Designation: *Manual for Assessing Safety Hardware,* MASH 2009
Test Criteria	MSAH Test Level-3 (3-11) Impact Condition/Rating
Test Number	FOIL Test No. 16004, 16010, 16015
Test Date	Test 16004: April 4th, 2016, Test 16010: June 15th, 2016, and Test 16015: August 8th, 2016
Test Location	Federal Outdoor Impact Laboratory (FOIL) Turner-Fairbank Highway Research Center Federal Highway Administration (FHWA) U.S. Department of Transportation 6300 Georgetown Pike, McLean, VA 22101-2296
Conducted by	Center for Collision Safety and Analysis (CCSA) George Mason University 4087 University Dr., Fairfax, VA 22030
Report Authors	Dhafer Marzougui, Christopher Story, Cing Dao (Steve) Kan, and Kenneth S. Opiela,
Test Results Summary	Test 16004: Pass, Test 16010: Fail, Test 16015: Pass

1 Introduction

1.1 Background

This project was undertaken to support National Cooperative Highway Research Program (NCHRP) Project 22-29A entitled "Evaluating the Performance of Longitudinal Barriers on Curved, Superelevated Roadway Sections (CSRS)." Curves on high-speed roadways are usually superelevated (i.e., banked) to make it roadway easier for drivers to navigate the curve. Typically, standard longitudinal barriers are used (when needed) for CSRS situations, but very little research has been undertaken to evaluate the safety performance. Since vehicle road departures on curves can occur at higher impact angles, vehicles can have different trajectories than on level surfaces, and barriers can be interfaced differently, there have been concerns about safety performance that have not been analyzed. The concerns relate to a greater potential for occupant risk, or that curvature could increase the impact loading that could potentially exceed the structural capacity of a barrier and result in vehicle penetration or override of the barrier. The NCHRP project undertook hundreds of crash simulations to isolate the effects of the various features of CSRS for impact with typical longitudinal barriers. These test are intended to provide validations for the simulations. Test objectives, testing specifications, test results, and evaluation of the results for the tests were performed in accordance with the requirements of the Manual for Assessing Safety Hardware (MASH).

1.2 Objective

The objectives of this research are to evaluate the crash performance of standard longitudinal barriers installed on curved, superelevated, roadway sections (CSRS) to analyze the effects of the curvature and superelevation parameters and the barrier placement details used by the states on barrier safety performance. For this effort, MASH Test 3-11 is used as the benchmark for safety performance. The tests provide physical evidence on barrier performance that will be used qualitatively and quantitatively determine whether safety performance is acceptable. The ultimate objective of the NCHRP research is to provide guidance for barrier design, selection, placement, and maintenance relative to CSRS geometrics and conditions to assure safety.

1.3 Scope

The specifications for these tests are documented in AASHTO's, "Manual for Assessing Safety Hardware" that was adopted in 2009. This standard is referred to as MASH (2009) or MASH hereafter in this report.

The G4(1S) W-beam guardrail was selected as the longitudinal barrier that would be tested (other longitudinal barriers were also analyzed in the research). The testing would be conducted on a surface representing a CSRS, unlike the level, tangent surfaces normally used for testing. The tests are conducted at the FOIL. Tests are set-up and conducted for MASH Test Level 3 with Test 3-11 impact conditions and criteria. Three tests of W-beam barrier impacted with similar Chevrolet Silverado vehicles that weighed 2315 kg (5107 lb), 2283 kg (5033 lb), and 2268 kg (5001 lb) were conducted. The tests were set-up for the vehicle to be traveling at 62 km/h (100 mph) at impact. This required pre-testing to determine an appropriate launch speed prior to the inclined roadway section to impact at the desired speed. The full-scale crash tests were conducted on April 4th, 2016, June 15th, 2016, and August 8th, 2016.

E-2

2 System Details

2.1 Test Article and Installation Details

Longitudinal barriers on curved superelevated roadways were initially evaluated using crash simulation software LS-DYNA [2] to analyze design and placement effect on safety performance. The barriers that were tested were constructed with 55.2 m (181.3 ft) of G4(1S) W-beam guardrail with 2-Type-T anchor assembly end terminations set in 21A strong soil on the CSRS test bed.

The CSRS test bed was an asphalt pad that was 12.2 m (140 ft) x 7.3 m (24 ft) with 4.9 m (16 ft) of roadway with a 6% superelevation and 254 m (833 ft) radius road curvature. The test bed included a 2.4 m (8 ft) shoulder with a 2% decline from the roadway (Figure 1). The guardrail in Tests 16004 and 16010 was set just beyond the 1.2 m (4 ft) representing the shoulder along the edge of the roadway. In Test 16015 the guardrail was set 2.4 m (8 ft) from the edge of the roadway on the shoulder.

Since the roadway and shoulder areas were laid in a single asphalt paving operation, a process to replicate driving posts in the side slope was formulated. It involved auguring 29 holes using a bobcat for each post location. The holes were augured to be 0.9 m (3 ft) wide and 1.5 m (5 ft) deep. Then each hole had AASHTO defined strong soil added to it in 152 mm (6 in) lifts and compacted to MASH specifications. The individual guardrail posts were installed with a hydraulic hammer.

The test article (shown in Figure 2) consisted of a G4(1S) W-beam guardrail with 25 standard steel posts and block outs with 2 Type-T anchor assembly end terminations (shown in Figure 3) for a total of 29 posts. The spacing of each post was 1.9 m (6 ft 3 in) for a total length of 53.3 m (175 ft). The height of the G4(1S) W-beam rail 737 mm (29 in). The posts were embedded in VDOT (Virginia Department of Transportation) 21A soil, which conforms to the MASH standard for strong soil.

Photos in Figure 4 (Test 16004), Figure 5 (Test 16010), and Figure 6 (Test 16015) show multiple views of the installed test articles. The setup was identical for all three tests except for the lateral barrier placement.

The design configuration of the CSRS test bed was developed by iterative computer simulation runs using finite element models of the barrier and impacting vehicle. Models of the test vehicle had been developed by the CCSA Team under joint efforts between the FHWA and NHTSA. The model of the barrier was created by replicating the geometry of each component, defining the connection details, and inputting information to characterize the materials used in the barrier. The impact performance of the barrier was evaluated in impact simulations in which the forces and resulting outcomes (e.g., deformations, fracture, slippage) of each element was analyzed for each time step for the entire duration of the impact event (about 1 second). The software used for these simulations allowed the output of various metrics to evaluate the barrier performance, including deformation, force levels, stress and strain, and dynamic measures (e.g., trajectory, yaw, pitch, and roll). Based on the simulation results, performance envelopes were generated of longitudinal barriers on CSRS.
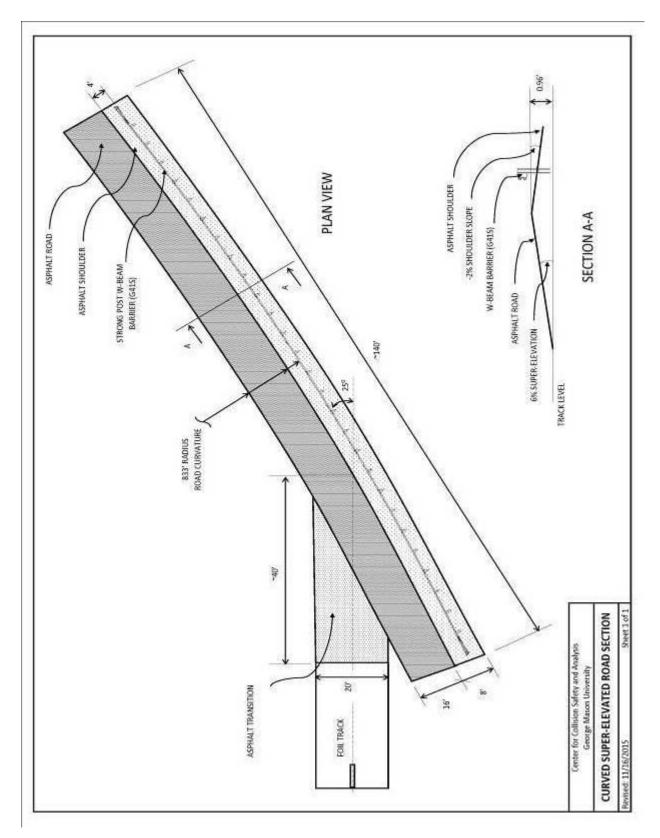
Figure 1: CSRS Test Bed used for Test 16004, 16010, and 16015
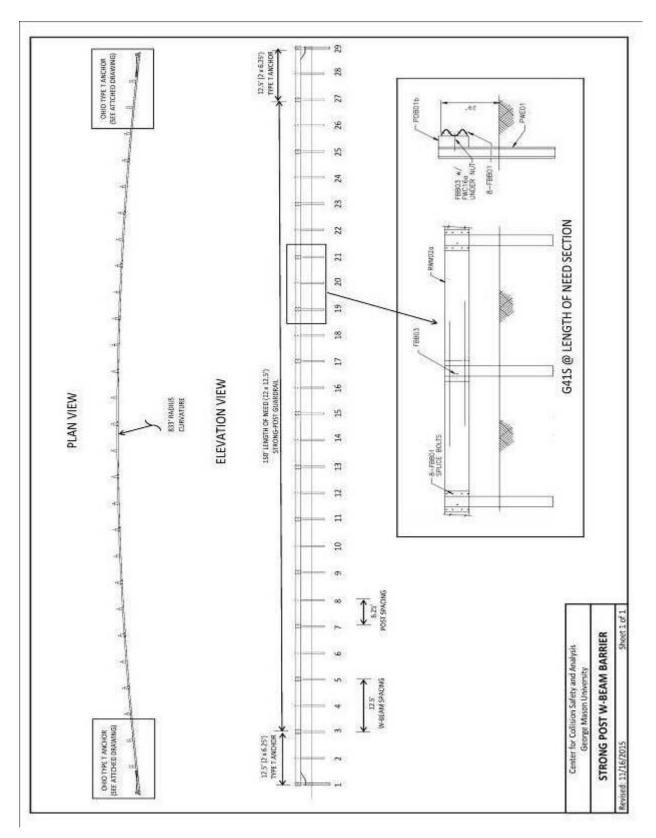
Figure 2: Drawing of G4(1S) Barrier Used for Tests 16004, 16010, and 16015
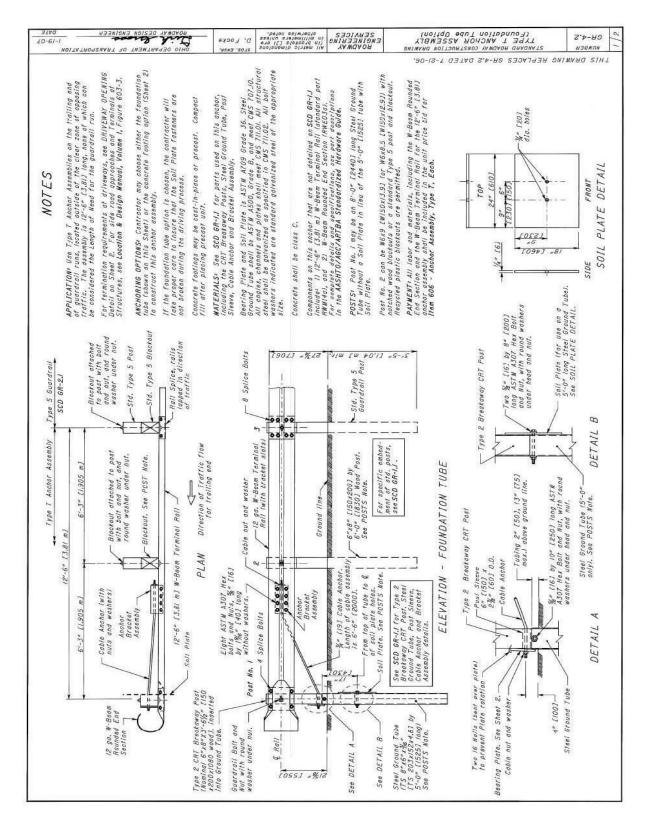
Figure 3: Drawing of End Termination user for Tests 16004, 16010, and 16015

(A)

(B)

(C)

(D)

(E)

(F)

Figure 4: Test Article and Construction for Test 16004

(A)

(B)

(C)

(D)

(E)

(F)
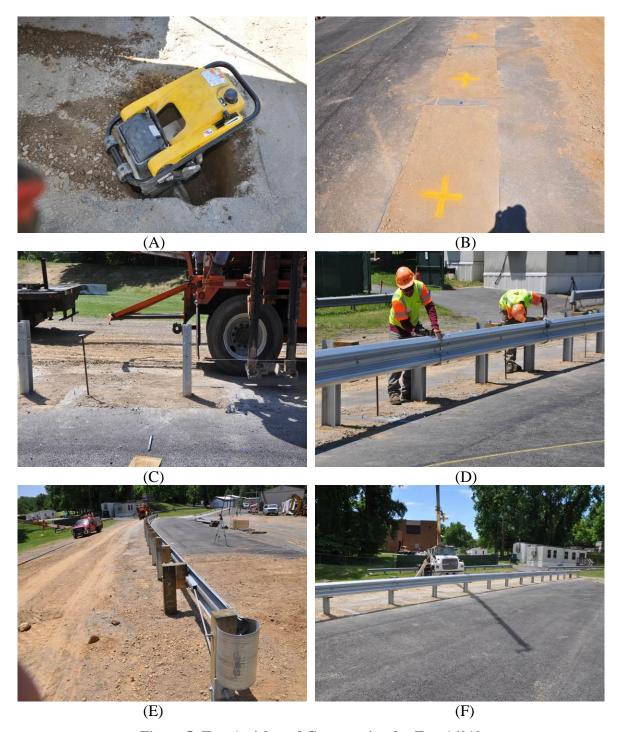
Figure 5: Test Article and Construction for Test 16010

(A)

(B)

(C)

(D)

(E)

(F)

Figure 6: Test Article and Construction for Test 16015

2.2   Test Article and Installation Details

Standard guardrail, posts, block-out, and related barrier hardware was procured from commercial vendors responsible for certifying that they meet AASHTO standards. Details of the different components of the system and their material specifications are included in the Appendixes of this test report.

2.3   Soil Conditions

Soil strength was determined by the specification required in MASH-2009 Chapter 3 and Appendix B that must be verified before the test is conducted. Prior to the full-scale crash testing, dynamic pendulum and static pull testing was conducted in accordance to MASH recommendations to ensure that the soil used in the tests comply with the MASH criteria. The tests consisted of impacting (dynamics) or pulling (static) a W6x15 post that is 1.8 m (6 ft) in length and embedded 101.6 cm (40 in) in standard strong soil. The post was impact/pulled at a height of 635 mm (25 in) and the load was measured to verify the minimum soil resistance. The minimum dynamic load required for post deflections between 125 mm (5 in) and 635 mm (25 in) is 33 kN (7.5 kips) force. They soil type and compaction procedure was then used for all G4(1S) installation. Static pull tests were conducted the day of the crash test and compared to the previously conducted static pull tests to ensure that it is of similar strength (higher than 90% the initial test). These posts were compacted the same day as the test article installation and using the same soil material. Soil compaction measurements are other details are included in the Appendixes of this test report.

3   Test Requirements and Evaluation Criteria

3.1   Crash Test Matrix

Table 1 lists the three tests conducted on longitudinal barriers installed on CSRS. The barrier in all three tests was a G4(1S) system with a top rail height of 737 mm (29 in). Standard G4(1S) steel posts and blockouts were used for the barrier. The spacing of each post was 1.9 m (6'3") for a total length of 53.3m (175'). All three tests were performed in accordance with the MASH Test 3-11 condition for longitudinal barriers, with a 2270P vehicle at an impact speed 100 km/hr (62 mph) and 25-deg angle.

Table 1: Summary of Tests Concocted

Test Number	Test Designation	Road Curvature	Super-Elevation	Shoulder Width	Impact Location
16004	MASH 3-11	254 m (833 ft)	6%	1.2 m (4 ft)	0.75 m (2.5 ft) upstream from post 11
16010	MASH 3-11	254 m (833 ft)	6%	1.2 m (4 ft)	0.3 m (1 ft) downstream from post 11
16015	MASH 3-11	254 m (833 ft)	6%	2.4 m (8 ft)	0.3 m (1 ft) downstream from post 11

The road section profile used in the three tests was 12.2 m (140 ft) x 7.3 m (24 ft) x 4.9 m (16 ft) surface with a 254 m (833 ft) radius curvature and 6% supereleevation. The only difference between the tests is the barrier lateral placement (i.e. shoulder width) and the impact location. A shoulder width of 1.2 m (4 ft) was used for the first two tests (Test 16004 and Test 16010) and a

shoulder width of 2.4 (8 ft) was used for the third test (Test 16015). The impact location for test 16004 was about 0.75 m (2.5 ft) upstream from post 11. This was about 1 m (3.5 ft) off from the computed critical location in accordance to MASH and for this reason this test had to be repeated. The impact location for the other two tests, Test 16010 and Test 16015, was close to the computed critical location, 0.3 m (1 ft) downstream from post 11.

3.2 Evaluation Criteria

The recommended evaluation criteria used followed the MASH 2009 criteria for longitudinal barriers at the Test Level 3 (TL3) impact condition. The evaluations are comprised of three factors: (1) Structural Adequacy, (2) Occupant Risk, and (3) Post-impact Vehicular Response as outlined in Table 2.

Table 2: MASH Evaluation Criteria [1]

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.		
Occupant Risk	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.		
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.		
	H. Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:		
	Occupant Impact Velocity Limits		
	Component	Preferred	Maximum
	Longitudinal and Lateral	30 ft./s (9.1 m/s)	40 ft./s (12.2 m/s)
	I. The Occupant Ridedown Acceleration (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:		
	Occupant Ridedown Acceleration Limits (G)		
	Component	Preferred	Maximum
	Longitudinal and Lateral	15.0 g's	20.49 g's
Vehicle Trajectory	For redirective devices the vehicle shall exit within the prescribed box.		

4 Test Conditions

4.1 Test Facility

The Federal Outdoor Impact Laboratory (FOIL) is located at the Turner-Fairbank Highway Research Center of FHWA at McLean, Virginia. The FOIL is a full-scale outdoor crash test facility, primarily designed to test the impacts of vehicles with roadside safety hardware. It is also capable of testing various anti-ram security barriers and vehicle-to-vehicle impacts with the second vehicle stationary. The facility is also equipped with a impact pendulum for dynamic testing of materials, components, and sub-systems.

Figure 7 shows an aerial view of the FOIL. The FOIL facility consists of six main areas: (1) propulsion system building, (2) test control center trailer, (3) vehicle preparation garage, (4) track, (5) runway, and (6) pendulum area. Additionally, several storage trailers are located at different areas of the facility.

Figure 7 : Overhead View of the FOIL Crash Test Facility

4.2 Vehicle Tow and Guidance System

The test vehicle is pulled into the barrier using the FOIL track rail towing system. The towing system is a specially designed aluminum track rail for outdoor applications. The vehicle propulsion system (Figure 8) is capable of accelerating test vehicles of various sizes and types up to speeds commonly found on U.S. highways. The FOIL propulsion system is powered hydraulically with a capacity of more than 10,000 N•m (13,560 lb•ft) of torque. The vehicles are accelerated on a 67 m (220 ft) concrete runway with a 110 m (360 ft) runoff area. Typical vehicle weights, and the corresponding maximum speed, include the following:

- Passenger vehicles, including pickup trucks, weighing up to 2,000 kg (4,400 lb) can be accelerated up to speeds in excess of 100 km/h (62 mph).
- Single-unit trucks (that is, non-articulated trucks larger than pickup trucks) weighing up to 8,000 kg (17,600 lb) can be accelerated up to speeds in excess of 80 km/h (50 mph).

Figure 8 : Vehicle Propulsion System

The test vehicle is accelerated up to the desired speed using a cable driven tow trolley. The tow trolley travels the length of the runway in a ground level track system. A cable with sufficient slack to form a loop connects the test vehicle to the tow trolley. The two ends of this cable terminate at the attachment to the test vehicle's front axle near the tires; the center of cable loops over the front surface of the tow trolley. Prior to the test vehicle's collision into the test article, the test vehicle disengages from the tow trolley. With the test vehicle disengaged, the vehicle rolls freely until it collides with the test article. The propulsion system is computer controlled.

4.3   Data Acquisition Systems and Sensors

Data Acquisition System

The TDAS PRO® digital data-acquisition system is used to record the analog accelerometer signals from accelerometers attached to the test vehicle. The TDAS PRO® system is a self-contained data system that supplies each sensor with a user-specified excitation voltage. The signals from each sensor are digitally sampled at a user-specified sample rate, conditioned, and stored in the system's memory for download to a computer. The signals from the accelerometers are digitally sampled at 10,000 hertz (Hz) and pre-filtered with a low-pass hardware filter at 3,000 Hz. The TDAS PRO® system consist of TDAS PRO® racks, TDAS PRO® sensor input modules (SIM's), wireless interfaces, and the battery power source. A sample rack with SIM's and sample TDAS PRO system installation is shown in Figure 9. The data acquisition system is mounted on the test vehicle; it is a self-contained, capable of withstanding high shock loads, with power supplied by a battery located onboard.
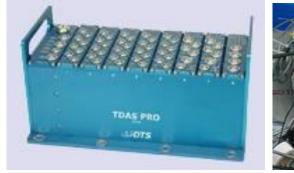
Figure 9 : FOIL Data Acquisition System

Over 40 accelerometers are available at the FOIL. These accelerometers are used to measure vehicle or barrier accelerations during the impact. The most commonly used accelerometer at FOIL is the ENDEVCO Model 7265AM3, mounted on specially fabricated aluminum blocks (Figure 10). The ENDEVCO Model 7265AM3 is a low mass, undamped piezoresistive accelerometer designed with a miniature receptacle to allow for detachment of the cable assembly. This accelerometer is designed specifically for the automotive crash testing industry and meets SAEJ211 specifications.

Figure 10 : Typical Accelerometers and Mounting Blocks

Tri-axial accelerometers are available for installation on test vehicles. A tri-axial accelerometer measures the X, Y, & Z axis acceleration components. Typically, accelerometers are installed on the vehicle's center of gravity and on other locations of interest. For example, in many truck tests, specifically for anti-ram barriers, another accelerometer may be installed on the instrumentation tray near the end of truck-bed. Often, redundant accelerometers are placed at the same location in case the primary accelerometer fails during the impact. Information about the accelerometer locations are included in the Appendixes of this report.

The accelerometers generate a continuous analog signal. This continuous signal is captured by the data acquisition system as a series of digital pulses. The digital pulses (digital data) are acquired, or sampled, at a rate specified by the test personnel. The magnitude, or amplitude, of each digital pulse acquired corresponds to magnitude of the analog signal at the time the signal is sampled. These digital pulses are conditioned, or pre-filtered, and then stored in the solid state memory of the data acquisition system.

Different types of load-cells are available at FOIL for measuring the impact force. A typical load cell is shown in Figure 11. The capacity of these load cells vary from 10 to 1000 kN (2 to 200 kips). The load cells at FOIL are made by Interface. Some of the characteristics of these load cells include: proprietary Interface temperature compensated strain gages, performance to 0.04% accuracy, eccentric load compensated, low deflection, less than 0.0009% per °F (0.0015% per °C) temperatures effect on output, shunt calibration, barometric compensation, ability to measure tension and compression, and compact size.

Two rate gyro models are available at FOIL for measuring vehicle rotational motion during the crash tests (the DTS 6DXPRO). The newer 6DXPRO model, developed by Diversified Technical Systems, is the one more typically selected for the tests and is shown in Figure 12. This sensor features three linear accelerometers and three angular rate sensors conveniently packaged in a compact, high-shock enclosure for a 6 degree-of-freedom measurement system. This system is used with TDAS Pro data acquisition system. The data measured is in deg/sec which is converted to angular displacements (in deg) by integrating the signal. This gives the Roll (about x), Pitch (about y), and Yaw (about z) vehicle rotations. The ARS 06 rate gyro has a

range of ± 11,500 degree/sec. They require a 10 Volt excitation source. The Temperature operation range is -20 to +50 ℃ (-4 to +122 ℉).

Figure 11: Sample Load Cell

Figure 12: Sample Angular Rate Sensor

String pots are available at foil for measuring displacements during impact. They are also known as displacement transducers, draw wire transducers, string encoders, cable extension transducers, and yo-yo pots. Most string pots at FOIL are made by the Space Age Control. The most common model used at FOIL is the 162-3405 (Figure 13). This model is noted for its small size, rugged performance, accuracy, flexible mounting, and easy installation. Some of the features of this string pot include: all-environment operation, 42.5-inch (1080-mm) maximum travel, analog signal using precision conductive plastic/hybrid potentiometers, accutrak threaded drum for enhanced repeatability, bearing-mounted rotating components, direct-connect sensor-to-drum technology, zero backlash, and no torsion springs or clutches.

Pressure sensitive tape switches are used at FOIL as triggers. A typical pressure sensitive tape switch is shown in Figure 14. Tape switches are contact switches actuated by an imposed load, such as contact by the test vehicle. The switches are flexible and can be attached to curved surfaces, such as the bumper of a test vehicle, using tape. When attached to the bumper of the test vehicle or the impact surface of the test article, the switches are used to sense the instant of vehicle contact as it collides into the test article. At impact, two contacts inside the switch close sending a time zero signal to the various data acquisition systems and digital cameras to capture the pre and post collision data. This signal is also used to trigger other control functions associated with data capture.

Figure 13: Sample String Pot

Figure 14: Sample Tape Switch

Speed Traps

Two different speed measuring methods are used in full scale vehicle crash tests to measure pre-impact speed. The first velocity measurement system is a stand-alone unit. The test vehicle is mounted with a speed wand. The speed wand is positioned such that it passes through a laser speed trap just prior to impacting the test article. The laser speed trap consists of two laser diodes mounted 0.5 m (1.6 ft) apart. The laser beams are focused on phototransistor detectors that turn on when a laser beam is detected. In the absence of light they turn off. The pulse is

sent to a meter box where it is converted to velocity in both kilometers-per-hour and miles-per-hour.

The second speed trap consists of two sets of four pressure-actuated contact switches fastened to the runway in 0.5-m intervals. Each switch is spaced 0.5 m (1.6 ft) apart. One set of contact switches will be positioned just prior to releasing the vehicle from the tow system and the second set of contact switches will be positioned just prior to impacting the test article. As the vehicle passes over the contact switches, electronic pulses will be recorded on an off-board data acquisition module. The signal will then be analyzed to measure the pre-impact velocity. The test vehicle speed can be determined from the fixed distance of travel, 0.5 m (1.6 ft), and the measured time between the two pulses. In addition, motion analysis will be conducted using the high speed digital movies after the test to estimate the pre-impact velocity.

4.4   High Speed Digital Imaging

High-resolution high-speed digital cameras, digital camcorders, and a digital still camera are available to film the tests. The high-speed cameras are developed by "NAC Image Technology Corporation". They are capable of resolution of 1280x1024 and recording rates of up to 1000 frames per second (fps). Typical frame rate of 500 fps is used for the high-speed imaging. In some tests, higher or lower rates are used depending on the need of the test. The high-speed digital cameras are positioned to get overhead, left, right, rear and isometric views of the crash event. Figure 15 shows one of NAC cameras. Locations of the cameras and other information related to the high-speed recording is included in the Appendixes to this report.

Figure 15 : Typical High Speed Digital Camera

4.5   Test Data Collection and Compilation

Test data is collected automatically by a computerized data acquisition system. The computers for the data acquisition system and all other test control functions are located in the test control center trailer. The data acquisition computer is connected wirelessly to the TDAS PRO digital data acquisition system which is installed on the test vehicle and/or test article. The data acquisition system is armed by the test operator just before the start of the test. When the system is armed, the data recording begins and continues on a circular buffer. Upon the impact of the test vehicle with the test article, a contact switch triggers the data acquisition system to set the time zero for the event (on the circular buffer). From this point on, the TDAS PRO stores a pre-specified amount of pre-impact and post-impact test data. The detail requirements of the data acquisition are set up in the software prior to test (e.g., sampling frequency, pre and post-impact duration for the test data collection, filtering method, etc.). The data acquisition system automatically collects the required test data and stores the data in a flash memory. The test data is downloaded immediately after the test. After each test, the test technician/operator compiles and copies the automatically generated data files for further review and reporting. Test data is readily available after the test and can be plotted or viewed in various formats.

5 Crash Test 16004

5.1 Test Designation and Impact Conditions

This crash test was performed using specifications set forth in MASH for Test 3-11. This test consisted of a 2009 Chevrolet Silverado 2270 kg (5000 lb) impacting a G4(1S) W-beam guardrail barrier with two type-T anchor assembly end terminations set on the CSRS Test Bed with the representation of a 1.2 m (4 ft) shoulder which had a 2% decline from the edge of the roadway. The G4(1S) W-beam guardrail barrier was placed just beyond the edge of the shoulder (i.e., the point where the roadway and the shoulder meet). The barrier was installed along the curvature of the roadway/shoulder. The setup is shown in Figure 16. The vehicle speed in this test was 62 km/h (100 mph). Additional test details and sequential photos can be viewed in Appendix E.1

5.2 Test Vehicle

The vehicles used in the test was a 2009 Chevrolet Silverado pick-up truck that were equipped with eight-cylinder gasoline engines. The pick-up trucks also had 4 full doors and were rear wheel drive (2WD). Pictures of the vehicle are shown in Figure 17. The exact curb mass of the vehicle in was 2308 kg (5088.3 lb) and its measured test inertial mass was 2315 kg (5107.3 lb). The height of the lower edge of the vehicle front bumper 54.2 cm (21.3 in); the upper edge of the front bumper was 66.3 cm (26.1 in) and the hood height was 114.2 cm (45 in). Additional dimensions of the vehicle are given in the Appendix E.1 of this test report.

5.3 Test Description

The 2270P vehicle began impacting the G4(1S) W-beam guardrail barrier at post 11 as shown in the sequential overhead photos in Appendix E.1. The impact was approximately 19.1m (62.5 ft) downstream from the beginning of the barrier installation and 34.3 m (112.5 ft) upstream from the end of the barrier installation. When the barrier was impacted, some snagging occurred and the vehicle was redirected.

5.4 Test Article and Component Damage

There was significant damage to the impacted area of the G4(1S) W-beam guardrail barrier. The damage to the barrier was contained between post 10 and post 16. There was considerable flattening of the W-beam guardrail with tearing. Also, there was significant twisting of the posts and broken blockouts. The damage to the barrier is shown in Figure 18.

5.5 Test Vehicle Damage

The 2009 Chevrolet Silverado had significant damage. The majority of the damage came on the right hand side of the vehicle due to being the impacted side. There was major denting to the passenger side of the vehicle. The front passenger side tire became detached during the impact and passenger rear tire was flat after impact. The front and rear bumper had considerable damage to the passenger side but the driver's side received minimal to no damage. The tires on the driver's side remained undamaged during the impact. The vehicle damage is shown in Figure 19.

(a)

(b)

(c)

(d)
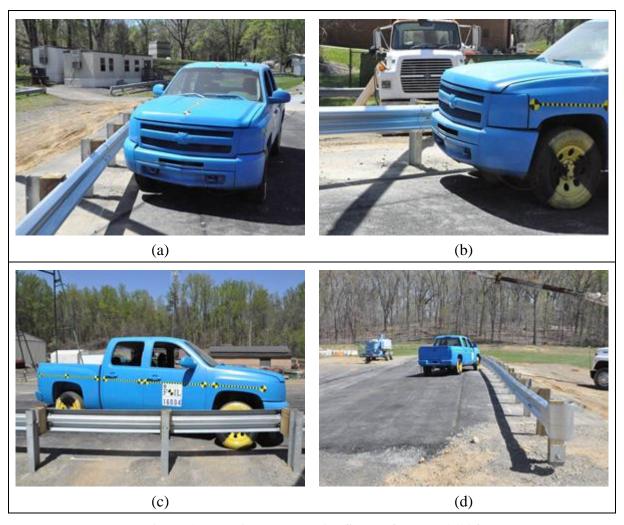
Figure 16 : Vehicle and Barrier Set-Up for Test 16004

(a)

(b)

Figure 17 : Test Vehicle for Test 16004

(a)

(b)

(c)

(d)

Figure 18 : Damage to Test Article for Test 16004

(a)

(b)

Figure 19 : Damage to Test Vehicle for Test 16004

5.6 Test Summary and MASH Evaluation Metrics

Table 3 shows the MASH evaluation results for Test 16004. The table indicates that the barrier meets all MASH criteria. The vehicle was redirected although it experienced a high degree of yaw, pitch and roll, but came to rest on its wheels.

Figure 20 provides a summary of Test 16004 that includes all pertinent information about the set-up and outcomes of the test. It is noted that the test vehicle was within the mass tolerance range (+/-50kg) for testing requirements. The impact speed and angle were also within tolerance limits. Data from the tri-axial accelerometers and rate transducers mounted at the CG of the vehicle are graphed and included the Appendix E.1. These show the filtered pulses recorded during the impact point that provide the basis for computing the various crash test metrics.

Table 3: MASH Evaluation for Test 16004

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.			Pass
Occupant Risk	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.			Pass
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.			Pass
	H. Occupant Impact Velocity (OIV) should satisfy the following limits:			Pass
	Occupant Impact Velocity Limits			OIV_x= 4.9 m/s
	Componen	Preferred	Maximum	
	Longitudinal and Lateral	30 ft/s (9.1 m/s)	40 ft/s (12.2 m/s)	OIV_y= 4.5 m/s
	I. The Occupant Ridedown Acceleration should satisfy the following limits:			Pass
	Occupant Ridedown Acceleration Limits (G)			ORA_x= -7.5 g
	Component	Preferred	Maximum	
	Longitudinal and Lateral	15.0 g's	20.49 g's	ORA_y= -7.7 g
Vehicle Trajectory	For redirective devices the vehicle shall exit within the prescribed box.			Pass
Overall				Pass

Figure 20 : Summary Results for Test 16004

General Information
- CCSA/GMU - FHWA/FOIL
- Test Number: MASH 3-11
- FOIL Test Number: 16004
- Test Date: 04/01/2016

Test Article
- G41S W-beam Guardrail on a Superelevated Curved Roadway (737 mm, 29 in Rail Height)
- Installation Length: 533m(175ft)
- Material or Key Elements: G4(1S) Steel W-beam with type- T end terminations

Soil Type and Condition:
- Type of Soil: AASHTO M147-65 – Grade B
- Soil Strength: VDOT 21A - Dry

Test Vehicle
- Type/Designation: 2270P
- Make and Model: Chevrolet Silverado
- Curb: 2308 kg (5008.3 lb)
- Test Inertial: 2315 kg (5103.7 lb)
- Gross Static: 2315 kg (5103.7 lb)

Impact Conditions
- Speed: 100 km/hr (62 mph)
- Angle: 25 degrees
- Location/Orientation: 0.75 m (2.5 ft) upstream from post 11

Exit Conditions
- Speed: 69 km/hr (43 mph)
- Angle: 9 degrees
- Exit Box Criterion: Inside Box

Post-Impact Trajectory
- Vehicle Stability: Upright
- Stopping Distance: 52.4 m (173 ft)
- Vehicle Snagging: No
- Vehicle Pocketing: No

Occupant Risk Values
- Longitudinal OIV: 4.9 m/s (16.1 ft/s)
- Lateral OIV: 4.5 m/s (14.8 ft/s)
- Longitudinal RA: -7.5 g
- Lateral RA: -7.7 g

Vehicle Stability
- Maximum Yaw Angle: -23.9 degrees
- Maximum Pitch Angle: -36.5 degrees
- Maximum Roll Angle: 25.4 degrees

Test Article Damage
- Moderate damage

Test Article Deflections
- Dynamic: 0.95 m (3.1 ft)
- Permanent: 0.85 ft (2.8 ft)
- Vehicle Penetration: 1.10 m (3.6 ft)

Vehicle Damage
- VDS: NA
- CDC: NA
- Max Interior Deformation: 69 mm (2.7 in)

6 Crash Test 16010

6.1 Test Designation and Impact Conditions

This crash test was performed using specifications set forth in MASH for Test 3-11. This test consisted of a 2009 Chevrolet Silverado 2270 kg (5000 lb) impacting a G4(1S) W-beam guardrail barrier with two type-T anchor assembly end terminations set on the CSRS Test Bed with the representation of a 1.2 m (4 ft) shoulder which had a 2% decline from the edge of the roadway. The G4(1S) W-beam guardrail barrier was placed just beyond the edge of the shoulder (i.e., the point where the roadway and the shoulder meet). The barrier was installed along the curvature of the roadway/shoulder. The setup is shown in Figure 21. The vehicle speed in this test was 62 km/h (100 mph). Additional test details and sequential photos can be viewed in Appendix E.2

6.2 Test Vehicle

The vehicles used in the test was a 2009 Chevrolet Silverado pick-up truck that were equipped with eight-cylinder gasoline engines. The pick-up trucks also had 4 full doors and were rear wheel drive (2WD). Pictures of the vehicle are shown in Figure 22. The exact curb mass of the vehicle in was 2313 kg (5099.3 lb) and its measured test inertial mass was 2283 kg (5033.2 lb). The height of the lower edge of the vehicle front bumper 55.9 cm (22 in); the upper edge of the front bumper was 68 cm (26.8 in) and the hood height was 114.1 cm (44.9 in). Additional dimensions of the vehicle are given in the Appendix E.2 of this test report.

6.3 Test Description

The 2270P vehicle began impacting the G4(1S) W-beam guardrail barrier between post 11 and post 12 as shown in the sequential overhead photos in Appendix E.2. The impact was approximately 20 m (65.6 ft) downstream from the beginning of the barrier installation and 33.4 m (109.4 ft) upstream from the end of the barrier installation. When the barrier was impacted it was flattened out and allowed for vehicle override. The vehicle came to rest on the opposite side of the barrier.

6.4 Test Article and Component Damage

There was significant damage to the impacted area of the G4(1S) W-beam guardrail barrier. The damage to the barrier was contained between post 10 and post 16. There was considerable flattening of the W-beam guardrail with tearing. Also, there was significant twisting of the posts and broken blockouts. The damage to the barrier is shown in Figure 23.

6.5 Test Vehicle Damage

The 2009 Chevrolet Silverado had significant damage. During the initial impact the majority of the damage came on the right hand side of the vehicle due to being the impacted side. As in the previous test the front passenger side tire became detached during the impact but the other 3 tires remained intact and were undamaged. When the vehicle went to the opposite side of the barrier it rolled onto its roof causing damage to the roof. The vehicle had significant damage the cab, suspension parts, truck bed, and broken windshield. The vehicle damage is shown in Figure 24.

(a)

(b)

(c)

(d)
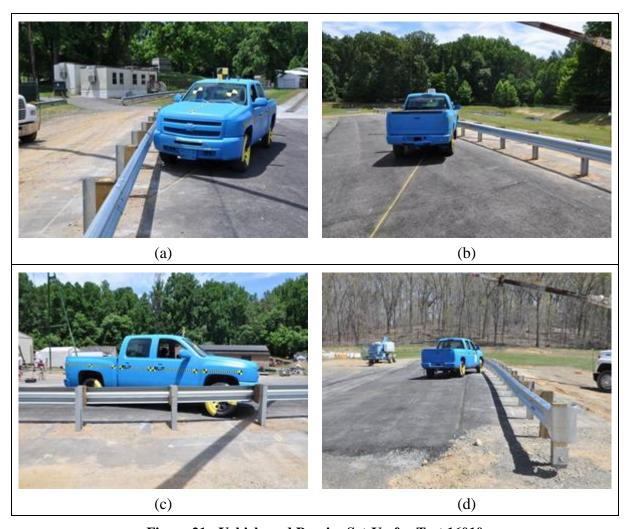
Figure 21 : Vehicle and Barrier Set-Up for Test 16010

(a)

(b)

Figure 22 : Test Vehicle for Test 16010

(a)

(b)

(c)

(d)

Figure 23 : Damage to Test Article for Test 16010

(a)

(b)

Figure 24 : Damage to Test Vehicle for Test 16010

6.6 Test Summary and MASH Evaluation Metrics

Table 4 shows the MASH evaluation results for Test 16010. The table indicates that the barrier does not meet MASH as the vehicle overrode the barrier and rolled over.

Figure 25 provides a summary of Test 16010 that includes all pertinent information about the set-up and outcomes of the test. It is noted that the test vehicle was within the mass tolerance range (+/-50kg) for testing requirements. The impact speed and angle were also within tolerance limits. Data from the tri-axial accelerometers and rate transducers mounted at the CG of the vehicle are graphed and included the Appendix E.2. These show the filtered pulses recorded during the impact point that provide the basis for computing the various crash test metrics.

Table 4: MASH Evaluation for Test 16010

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.		Fail
Occupant Risk	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.		Pass
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.		Pass
	H. Occupant Impact Velocity (OIV) should satisfy the following limits:		Pass

	Occupant Impact Velocity Limits			OIV$_x$= 4.8 m/s
	Componen	Preferred	Maximum	OIV$_y$= 3.8 m/s
	Longitudinal and Lateral	30 ft/s (9.1 m/s)	40 ft/s (12.2 m/s)	

	I. The Occupant Ridedown Acceleration should satisfy the following limits:		Pass

	Occupant Ridedown Acceleration Limits (G)			ORA$_x$= -6.1 g
	Component	Preferred	Maximum	ORA$_y$= -6.0 g
	Longitudinal and Lateral	15.0 g's	20.49 g's	

Vehicle Trajectory	For redirective devices the vehicle shall exit within the prescribed box.	Fail
Overall		Fail

General Information
- CCSA/GMU - FHWA/FOIL
- Test Number: MASH 3-11
- FOIL Test Number: 16010
- Test Date: 06/15/2016

Test Article
- G41S W-beam Guardrail on a Superelevated Curved Roadway (737 mm, 29 in Rail Height)
- Installation Length: 53.3m(175ft)
- Material or Key Elements: G4(1S) Steel W-beam with type- T end terminations

Soil Type and Condition:
- Type of Soil: AASHTO M147-65 – Grade B
- Soil Strength: VDOT 21A - Dry

Test Vehicle
- Type/Designation: 2270P
- Make and Model: Chevrolet Silverado
- Curb: 2313 kg (5099.3 lb)
- Test Inertial: 2283 kg (5133.2 lb)
- Gross Static: 2283 kg (5133.2 lb)

Impact Conditions
- Speed: 100 km/hr (62 mph)
- Angle: 25 degrees
- Location/Orientation: 0.3 m (1 ft) downstream from post 11

Exit Conditions
- Speed: 79 km/hr (49 mph)
- Angle: -20 degrees
- Exit Box Criterion: Outside Box

Post-Impact Trajectory
- Vehicle Stability: Vehicle Rolled
- Stopping Distance: 41.2 m (135 ft)
- Vehicle Snagging: No
- Vehicle Pocketing: No

Occupant Risk Values
- Longitudinal OIV: 4.8 m/s (15.7 ft/s)
- Lateral OIV: 3.8 m/s (12.5 ft/s)
- Longitudinal RA: -6.1 g
- Lateral RA: -6.0 g

Vehicle Stability
- Maximum Yaw Angle: -51.4 degrees
- Maximum Pitch Angle: -50.0 degrees
- Maximum Roll Angle: -168.5 degrees

Test Article Damage
- Moderate Damage

Test Article Deflections
- Dynamic: 0.76 m (2.5 ft)
- Permanent: 0.67 ft (2.2 ft)
- Vehicle Penetration: NA

Vehicle Damage
- VDS: NA
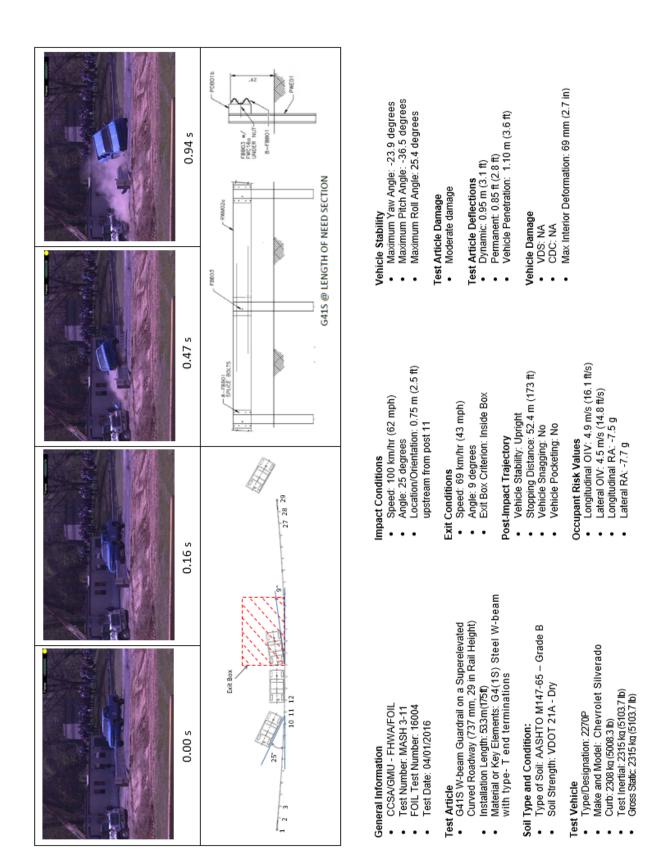- CDC: NA
- Max Interior Deformation: 158 mm (6.2 in)

Figure 25 : Summary Results for Test 16010

7 Crash Test 16015

7.1 Test Designation and Impact Conditions

This crash test was performed using specifications set forth in MASH for Test 3-11. This test consisted of a 2009 Chevrolet Silverado 2270 kg (5000 lb) impacting a G4(1S) W-beam guardrail barrier with two type-T anchor assembly end terminations set on the CSRS Test Bed with the representation of a 2.4 m (8 ft) shoulder which had a 2% decline from the edge of the roadway. The G4(1S) W-beam guardrail barrier was placed just beyond the edge of the shoulder (i.e., the point where the roadway and the shoulder meet). The barrier was installed along the curvature of the roadway/shoulder. The setup is shown in Figure 26. The vehicle speed in this test was 62 km/h (100 mph). Additional test details and sequential photos can be viewed in Appendix E.3.

7.2 Test Vehicle

The vehicles used in the test was a 2009 Chevrolet Silverado pick-up truck that were equipped with eight-cylinder gasoline engines. The pick-up trucks also had 4 full doors and were rear wheel drive (2WD). Pictures of the vehicle are shown in Figure 27. The exact curb mass of the vehicle in was 2257 kg (4975.3 lb) and its measured test inertial mass was 2268.5 kg (5001.2 lb). The height of the lower edge of the vehicle front bumper 56.9 cm (22.4 in); the upper edge of the front bumper was 69 cm (27.7 in) and the hood height was 115.1 cm (45.3 in). Additional dimensions of the vehicle are given in the Appendix E.3 of this test report.

7.3 Test Description

The 2270P vehicle began impacting the G4(1S) W-beam guardrail barrier between post 12 and post 13 as shown in the sequential overhead photos in Appendix E.3. The impact was approximately 24.8 m (81.3 ft) downstream from the beginning of the barrier installation and 28.6 m (93.7 ft) upstream from the end of the barrier installation. When the vehicle impacted the barrier, the barrier crushed allowing the vehicle to redirect. The vehicle came to rest upright on the impacted side of the barrier.

7.4 Test Article and Component Damage

There was significant damage to the impacted area of the G4(1S) W-beam guardrail barrier. The damage to the barrier was contained between post 12 and post 18. There was considerable flattening of the W-beam guardrail with tearing. Also, there was significant twisting of the posts and broken blockouts. The damage to the barrier is shown in Figure 28.

7.5 Test Vehicle Damage

The 2009 Chevrolet Silverado had significant damage. The majority of the damage came on the right hand side of the vehicle due to being the impacted side. There was major denting to the passenger side of the vehicle. The front passenger side tire became detached during the impact due to broken suspension parts and passenger rear tire was flat after impact. The front and rear bumper had considerable damage to the passenger side but the driver's side received minimal damage. The tires on the driver's side remained undamaged during the impact. The vehicle damage is shown in Figure 29.

(a)

(b)

(c)

(d)
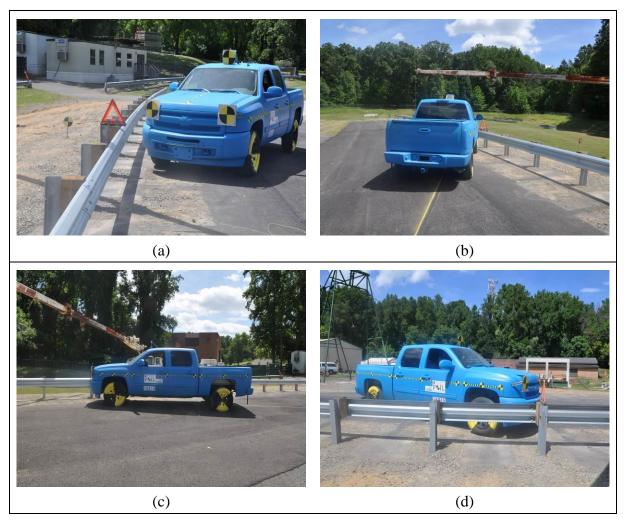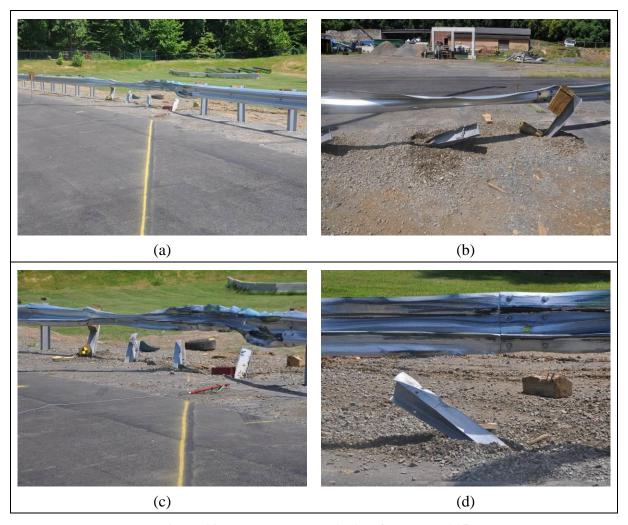
Figure 26 : Vehicle and Barrier Set-Up for Test 16015

(a)

(b)
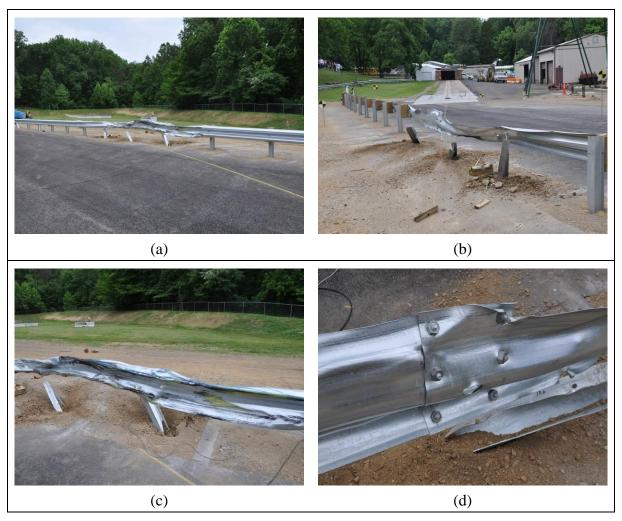
Figure 27 : Test Vehicle for Test 16015

Figure 28 : Damage to Test Article for Test 16015

Figure 29 : Damage to Test Vehicle for Test 16015

7.6 Test Summary and MASH Evaluation Metrics

Table 5 shows the MASH evaluation results for Test 16015. The table indicates that the barrier meets all MASH criteria. The vehicle was redirected although it experienced a moderate degree of yaw, pitch and roll, but came to rest on its wheels.

Figure 30 provides a summary of Test 16015 that includes all pertinent information about the set-up and outcomes of the test. It is noted that the test vehicle was within the mass tolerance range (+/-50kg) for testing requirements. The impact speed and angle were also within tolerance limits. Data from the tri-axial accelerometers and rate transducers mounted at the CG of the vehicle are graphed and included the Appendix E.3. These show the filtered pulses recorded during the impact point that provide the basis for computing the various crash test metrics.

Table 5: MASH Evaluation for Test 16015

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.	Pass
Occupant Risk	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Pass
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	Pass
	H. Occupant Impact Velocity (OIV) should satisfy the following limits:	Pass

Occupant Impact Velocity Limits			
Component	Preferred	Maximum	OIV_x= 4.7 m/s
Longitudinal and Lateral	30 ft/s (9.1 m/s)	40 ft/s (12.2 m/s)	OIV_y= 4.2 m/s

	I. The Occupant Ridedown Acceleration should satisfy the following limits:	Pass

Occupant Ridedown Acceleration Limits (G)			
Component	Preferred	Maximum	ORA_x= -5.9 g
Longitudinal and Lateral	15.0 g's	20.49 g's	ORA_y= -6.7 g

Vehicle Trajectory	For redirective devices the vehicle shall exit within the prescribed box.	Pass
Overall		Pass

General Information
- CCSA/GMU - FHWA/FOIL
- Test Number: MASH 3-11
- FOIL Test Number: 16015
- Test Date: 08/08/2016

Test Article
- G41S W-beam Guardrail on a Superelevated Curved Roadway (737 mm, 29 in Rail Height)
- Installation Length: 53.3 m (175 ft)
- Material or Key Elements: G4(1S) Steel W-beam with type- T end terminations

Soil Type and Condition:
- Type of Soil: AASHTO M147-65 – Grade B
- Soil Strength: VDOT 21A - Dry

Test Vehicle
- Type/Designation: 2270P
- Make and Model: Chevrolet Silverado
- Curb: 2257 kg (4975.8 lb)
- Test Inertial: 2268.5 kg (5001.2 lb)
- Gross Static: 2268.5 kg (5001.2 lb)

Impact Conditions
- Speed: 100 km/hr (62 mph)
- Angle: 25 degrees
- Location/Orientation: 0.3 m (1 ft) downstream from post 12

Exit Conditions
- Speed: 67 km/hr (42 mph)
- Angle: 12 degrees
- Exit Box Criterion: Inside Box

Post-Impact Trajectory
- Vehicle Stability: Upright
- Stopping Distance: 47 m (154 ft)
- Vehicle Snagging: No
- Vehicle Pocketing: No

Occupant Risk Values
- Longitudinal OIV: 4.7 m/s (15.4 ft/s)
- Lateral OIV: 4.2 m/s (13.8 ft/s)
- Longitudinal RA: -5.9 g
- Lateral RA: -5.1 g

Vehicle Stability
- Maximum Yaw Angle: -31.6 degrees
- Maximum Pitch Angle: -34.5 degrees
- Maximum Roll Angle: 51.3 degrees

Test Article Damage
- Moderate damage

Test Article Deflections
- Dynamic: 0.91 m (3.0 ft)
- Permanent: 0.76 ft (2.5 ft)
- Vehicle Penetration: 1.05 m (3.4 ft)

Vehicle Damage
- VDS: NA
- CDC: NA
- Max Interior Deformation: 7 mm (0.27in)

Figure 30 : Summary Results for Test 16015

8 Conclusions and Recommendations

The three full-scale crash tests were conducted at the Federal Outdoor Impact Laboratory (FOIL) located at the Federal Highway Administration's (FHWA) Turner-Fairbank Highway Research Center in McLean Virginia. The tests were conducted according to MASH requirements for Test 3-11 involving 2270P vehicles. The evaluation criteria appropriate for longitudinal barriers were used as the performance benchmark. An inclined surface was constructed to represent a CSRS section with the features of a 254 m (833 ft) radius curve with 6% superelevation. An asphalt shoulder was installed with a 2-degree declination from the edge of the roadway. The test bed was set-up to all barrier placements for shoulder widths of 4 and 8 ft. The barrier was placed just at the edge of the shoulder. An appropriate length of G4(1S) longitudinal barrier with end treatments was installed by a certified barrier contractor for each test. The two shoulder widths required that the positioning of the posts consider the prescribed critical impact points determined to be the most critical. The tests involved launching the vehicle at a speed that allowed it to be at the MASH impact speed when the barrier was reached after traversing the inclined roadway surface and the down sloping shoulder.

These results reflected outcomes predicted in the simulations. The first test was expected to result in a failure due to excessive vehicle roll (and possibly vaulting). In the first test, the vehicle did not impact the barrier at the expected critical impact point just beyond the post due to less "drift" than anticipated in traversing the inclined surface. The vehicle followed the rail and was redirected because the early impact with the post kept the rail in an upright position allowing better capture of the vehicle. The other two tests impacted the barrier at the computed critical location using the procedure included in MASH. These two tests confirmed the simulations results where it was predicted that the vehicle would vault the barrier and not meet MASH with a 1.22m (4 ft) shoulder and would get redirected and meet the MASH criteria with a 2.44 m (8 ft) shoulder (for the tested curvature, superelevation, and shoulder angle).

9 References

1. American Association of State Highway and Transportation Officials, Manual for Assessment of Safety Hardware, published by the American Associations of State Highway & Transportation Officials, Washington, DC, 2009.
2. American Association of State Highway and Transportation Officials, A Policy on Geometric Design for Highways and Streets, AASHTO, Washington, D. C., 2011
3. American Association of State Highway and Transportation Officials, Roadside Design Guide, published by the American Associations of State Highway & Transportation Officials, Washington, DC, 2011.

APPENDIX E.1
Test 16004 Additional Information

GENERAL	
TEST NO.	16004
DATE	04/14/2016
TIME	1:00 PM
WEATHER	Sunny
TEST CONFIGURATION	Chevrolet Silverado into Super Elevated Curved Roadway with G41S W-Beam Guardrail @ 4 feet from Peak
SPEED (KM/H)	100 KM\H
PURPOSE	Evaluate the Performance of Longitudinal Barriers on Curved, Superelevated Roadway Sections

COMMENTS

Release Point Speed Trap: Front Tire- 103.2km/h (63.7 mph) Rear Tire- 102.4 km/h (63.6 mph)

Pre Impact Speed Trap: Front Tire-102.4 km/h (63.6 mph) Rear Tire-102.3 km/h (63.6 mph)

Test Vehicle Parameters for Test 16004 (1 of 2)

Veh No: _____ **Test No:** 16004 **Date:** 04/14/16

		Measured Curb mass (Kg)	
Make:	Chevrolet	**LF:**	668.5
Model:	Silverado 1500	**RF:**	701.5
Year:	2009	**LR:**	490.5
Color:	White to Blue	**RR:**	447.5
Engine:	5.3		
Vin No.:	2GCEC13J1113609		

Location of Vehicle CG (cm)   **Measured Test Inertial Mass (Kg)**

X-Axis (from LF to LR):	154.2	**LF:**	663.5
Y-Axis (From LF to RF):	86.0	**RF:**	676.0
Z-Axis (From Ground):	75.9	**LR:**	509.0
		RR:	466.5

Location of CG Accelerometer (cm)

X-Axis (from LF to LR):	155.3
Y-Axis (From LF to RF):	85.1
Z-Axis (From Ground):	69.4

	Items Removed	Mass (Kg)	Added	Mass (Kg)
1	Oil	5.0	Instrument Tray	25.5
2	Transmission Fluid	4.5	Battery	16.5
3	Antifreeze	8.5	Data Acquisition	5.5
4	Battery	19.0	Brake System	6.0
5	Center Seat	12.5	Data Wireless	1.0
6	Spare Tire	24.0	Instrumentation Cage	26.0
7				
8				
9				
10				
11				
12				

Total Mass Removed (Kg) = 73.5   **Total Mass Added (Kg) =** 80.5

Measured Curb Mass =	2308.0
Removed Total =	73.5
Stripped Vehicle Mass =	2234.5
Added Mass =	80.5
Calculated Test Inertial Mass =	2315.0
Measured Test Inertial Mass =	2315.0

MASH Page #'s: 9-12, 80
*All weights are in Kg

Test Vehicle Parameters for Test 16004 (1 of 2)

TEST NO.: 16004		**DATE:** 4/14/2016		**ODOMETER:** 217534	
MAKE: Chevrolet		**MODEL:** Silverado 1500		**YEAR:** 2009	
VIN NO.: 2GCEC13J191113609		**TIRE SIZE:** P245/70R17			

TIRE INFLATION PRESSURE: 35

MASS DISTRIBUTION (KG):

LF 663.5		**RF** 676.0	
LR 509.0		**RR** 466.5	

Door Lower Edge Height (cm)   39.5

GEOMETRTY - (CM)

A	199.1	D	186.4	G	155.3	K	66.3	N	172.9	Q	47.0
B	97.0	E	117.0	H	69.4	L	14.2	O	171.0	S	74.4
C	366.0	F	580.0	J	114.2	M	54.2	P	76.5		

Wheel Center Heights (cm):   Front: 36.6   Rear: 36.4

Wheel Well Clearance (cm):   Front: 16.4   Rear: 26.9

Frame Height (cm):   Front: 42.5   Rear: 64.7

WEIGHTS (kg)	**GVWR Ratings**	**Curb**	**Test Inertial**	**Gross Static**
W_{front}	1,656.0	1,370.0	1,339.5	1,339.5
W_{rear}	1,792.0	938.0	975.5	975.5
W_{total}	3,085.0	2,308.0	2,315.0	2,315.0

DUMMY DATA: Type: NA   Mass (kg): NA   Seat Position: NA

DAMAGE TO VEHICLE PRIOR TO TEST: Dent on driver side of bed and roof

Performed by : Christopher R.Story   *MASH Page #'s: 80*

E-35
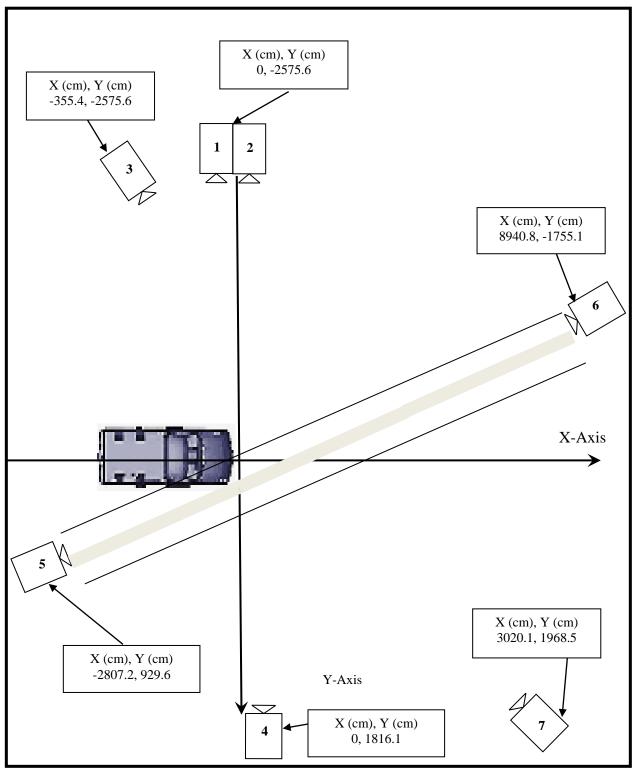
Camera Configuration and Placement for Test 16004

NO.	CAMERA	LENS	LENS (MM)	LENS (ZOOM	RESOLUTION (PIXELS)	SPEED (FPS)	LOCATION
1	K3	Nikon	24-85	85	1280 X 1024	500	Left Perp Close
2	K3	Nikon	18-35	35	1280 X 1024	500	Left Perp
3	K3R	Nikon	50	50	1280 X 1024	500	Left Front Iso
4	GX-1	Nikon	25-85	60	1280 X 1024	500	Right Perp
5	GX-1	Nikon	85	85	1280 X 1024	500	Right Front Iso
6	K3R	Nikon	35-105	105	1280 X 1024	500	Left Rear Iso
7	GX-1	Nikon	50	50	1280 X 1024	500	Right Rear Iso
8	K3R	Nikon	14	14	1280 X 1024	500	Overhead

MASH Page #'s: 101

High Speed Camera Parameters for Test 16004

X (cm), Y (cm)
0, -2575.6

X (cm), Y (cm)
-355.4, -2575.6

X (cm), Y (cm)
8940.8, -1755.1

X (cm), Y (cm)
3020.1, 1968.5

X (cm), Y (cm)
-2807.2, 929.6

X (cm), Y (cm)
0, 1816.1

X-Axis

Y-Axis

1 2

3

4

5

6

7

*Overhead Camera place over impact point (0.0, 0.0 cm) _1164.3_ cm high
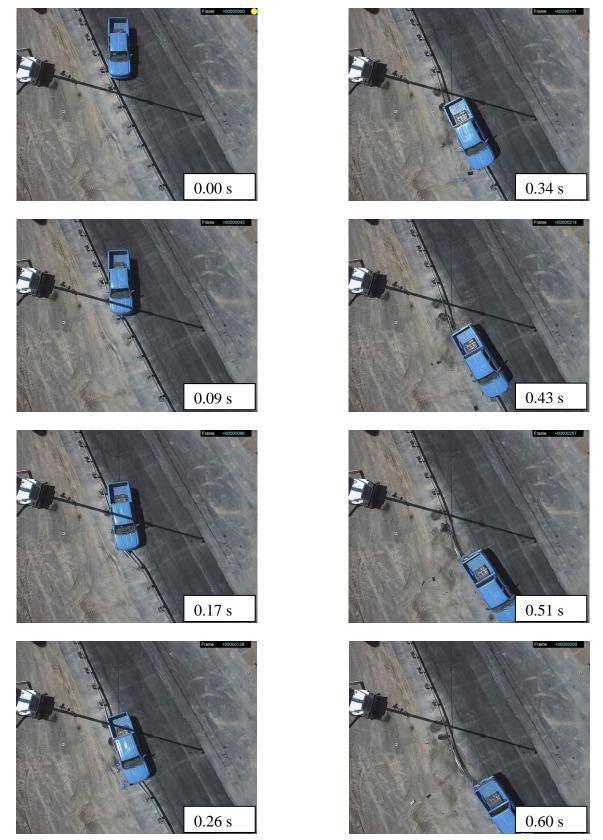
Sequential Photographs for Test 16004 (Overhead View)

0.00 s

0.34 s

0.09 s

0.43 s

0.17 s

0.51 s

0.26 s

0.60 s

Sequential Photographs for Test 16004 (Left Rear Iso View)

0.00 s

0.63 s

0.16 s

0.79 s

0.31 s

0.94 s

0.47 s

1.10 s

Sequential Photographs for Test 16004 (Right Front Iso View)

0.00 s

0.63 s

0.16 s

0.79 s

0.31 s

0.94 s

0.47 s

1.10 s

Sequential Photographs for Test 16004 (Right Rear Iso View)

0.00 s

0.34 s

0.09 s

0.43 s

0.17 s

0.51 s

0.26 s

0.60 s
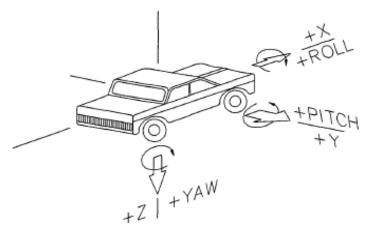
Vehicle Accelerometer Locations and Data Axis for Test 16004

CH.	LOCATION	X (cm) From frt. axle	Y (cm) From lft frt. hub	Z (cm) From ground	SERIAL NO.	Cal STATUS	UNIT (Meas.)	AXIS
1	Center of Gravity	154.2	86.0	75.9	6DX0013 ACC1	Calibrated	Gs	X
2	Center of Gravity	154.2	86.0	75.9	6DX0013 ACC2	Calibrated	Gs	Y
3	Center of Gravity	154.2	86.0	75.9	6DX0013 ACC3	Calibrated	Gs	Z
4	Center of Gravity	154.2	86.0	75.9	6DX0013 ARS1	Calibrated	Deg\Sec	ROLL
5	Center of Gravity	154.2	86.0	75.9	6DX0013 ARS2	Calibrated	Deg\Sec	PITCH
6	Center of Gravity	154.2	86.0	75.9	6DX0013 ARS3	Calibrated	Deg\Sec	YAW
7	Center of Gravity Redundant	154.2	86.0	75.9	6DX0014 ACC1	Calibrated	Gs	X
8	Center of Gravity Redundant	154.2	86.0	75.9	6DX0014 ACC2	Calibrated	Gs	Y
9	Center of Gravity Redundant	154.2	86.0	75.9	6DX0014 ACC3	Calibrated	Gs	Z
10	Center of Gravity Redundant	154.2	86.0	75.9	6DX0014 ARS1	Calibrated	Deg\Sec	ROLL
11	Center of Gravity Redundant	154.2	86.0	75.9	6DX0014 ARS2	Calibrated	Deg\Sec	PITCH
12	Center of Gravity Redundant	154.2	86.0	75.9	6DX0014 ARS3	Calibrated	Deg\Sec	YAW
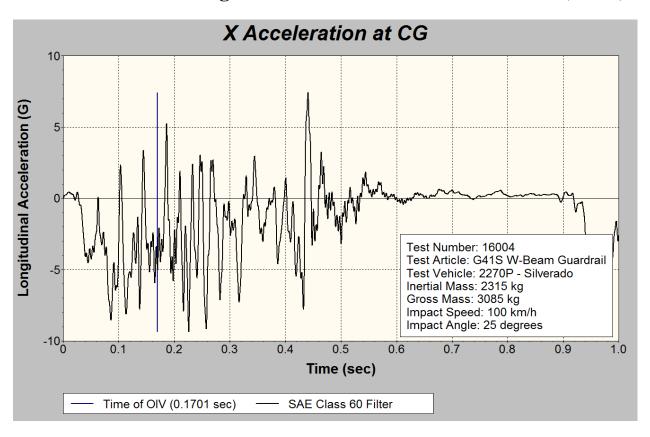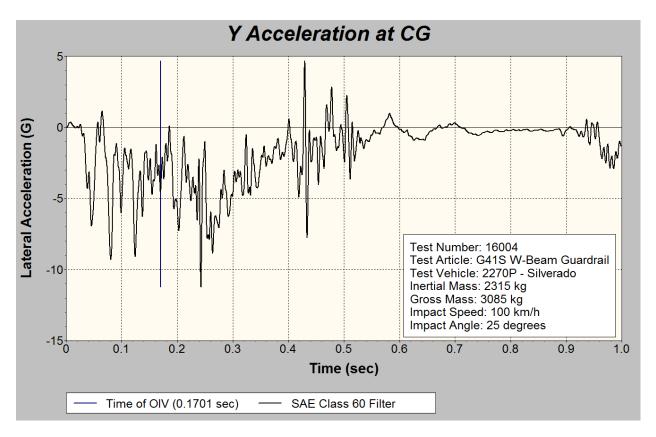
MASH Page #'s: 88, 89

For each accelerometer, the X-axis is referenced from the center of the right front tire (X=0), the Y-axis from the centerline of the test vehicle (Y=0), and the Z-axis from ground level (Z=0).

X Acceleration at CG

Test Number: 16004
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 2315 kg
Gross Mass: 3085 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

Time of OIV (0.1701 sec) — SAE Class 60 Filter

Y Acceleration at CG

Test Number: 16004
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 2315 kg
Gross Mass: 3085 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

Time of OIV (0.1701 sec) — SAE Class 60 Filter
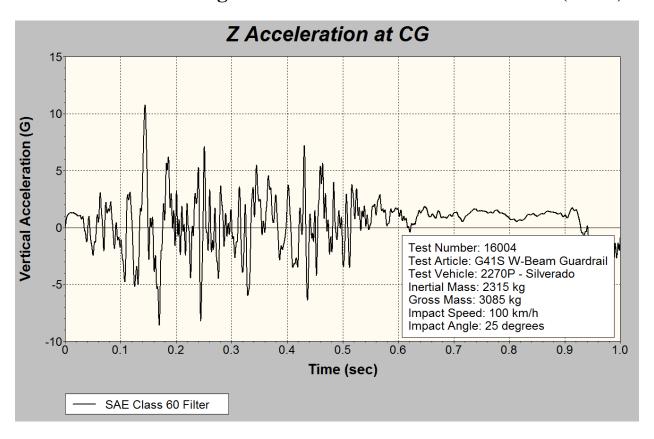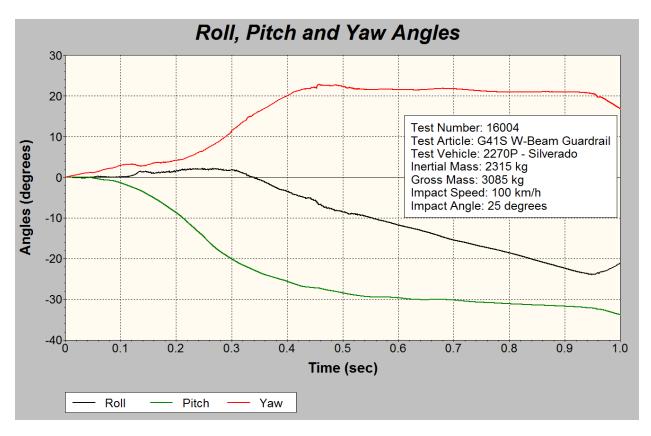
Acceleration and Angular Rotations at CG for Test 16004 (2 of 2)
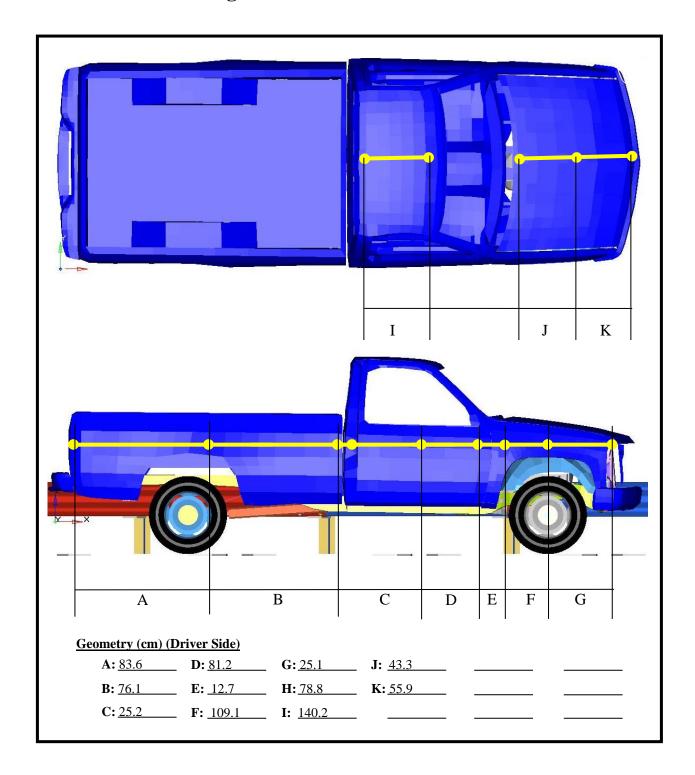
Z Acceleration at CG

Test Number: 16004
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 2315 kg
Gross Mass: 3085 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

— SAE Class 60 Filter

Roll, Pitch and Yaw Angles

Test Number: 16004
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 2315 kg
Gross Mass: 3085 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

— Roll   — Pitch   — Yaw

Data and Results for Test 16004

General Information
       Test Agency: FOIL
       Test Number: 16004
       Test Date: 04/14/2016
       Test Article: G41S W-Beam Guardrail
Test Vehicle
       Description: 2270P - Silverado
       Test Inertial Mass: 2315 kg
       Gross Static Mass: 3085 kg
Impact Conditions
       Speed: 100.0 km/h
       Angle: 25.0   degrees
Occupant Risk Factors
       Impact Velocity (m/s)   at 0.1701 seconds
                x-direction   4.9
                y-direction   4.5
       THIV (km/hr):   24.7   at 0.1721 seconds
       THIV (m/s):   6.9
Ridedown Accelerations (g's)
                x-direction   -7.5   (0.9691 - 0.9791 seconds)
                y-direction   -7.7   (0.2571 - 0.2671 seconds)
       PHD (g's):   10.1   (0.2536 - 0.2636 seconds)
       ASI: 0.71   (0.2518 - 0.3018 seconds)
Max. 50msec Moving Avg. Accelerations (g's)
       x-direction   -5.7   (0.9402 - 0.9902 seconds)
       y-direction   -6.0   (0.2517 - 0.3017 seconds)
       z-direction   -3.6   (0.9490 - 0.9990 seconds)
Max Roll, Pitch, and Yaw Angles (degrees)
       Roll   -23.9   (0.9487 seconds)
       Pitch   -36.5   (1.2232 seconds)
       Yaw   25.4   (9.9888 seconds)
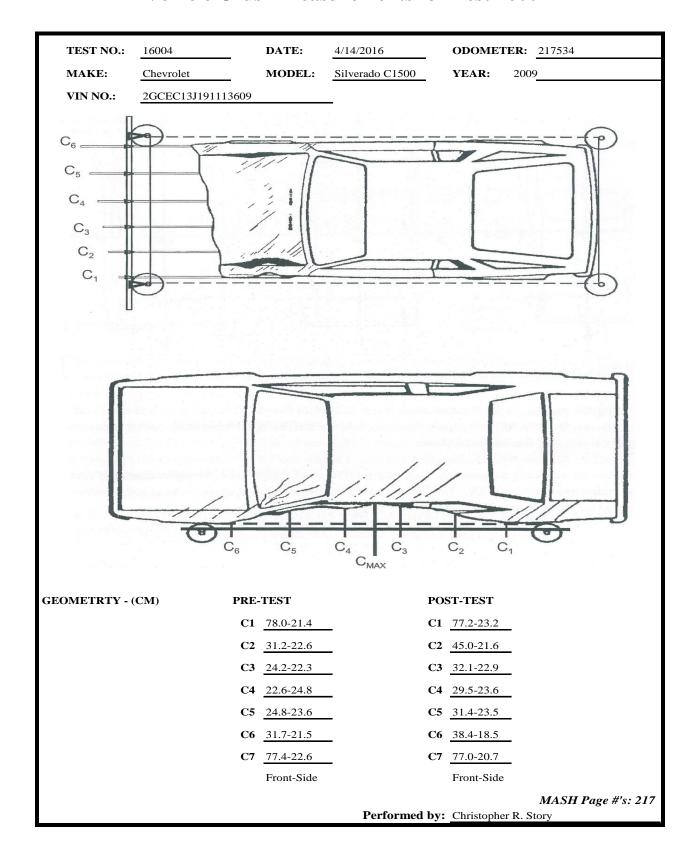
Target Locations for Test 16004

Geometry (cm) (Driver Side)

A: 83.6	**D:** 81.2	**G:** 25.1	**J:** 43.3		
B: 76.1	**E:** 12.7	**H:** 78.8	**K:** 55.9		
C: 25.2	**F:** 109.1	**I:** 140.2			

Vehicle Crush Measurements for Test 16004

TEST NO.:	16004	**DATE:**	4/14/2016	**ODOMETER:**	217534
MAKE:	Chevrolet	**MODEL:**	Silverado C1500	**YEAR:**	2009
VIN NO.:	2GCEC13J191113609				

GEOMETRTY - (CM)	PRE-TEST		POST-TEST	
	C1	78.0-21.4	**C1**	77.2-23.2
	C2	31.2-22.6	**C2**	45.0-21.6
	C3	24.2-22.3	**C3**	32.1-22.9
	C4	22.6-24.8	**C4**	29.5-23.6
	C5	24.8-23.6	**C5**	31.4-23.5
	C6	31.7-21.5	**C6**	38.4-18.5
	C7	77.4-22.6	**C7**	77.0-20.7
		Front-Side		Front-Side

MASH Page #'s: 217

Performed by: Christopher R. Story

E-47

Interior Crush Measurements for Test 16004

Vehicle Interior Crush Measurements
16004

		Pretest				Post Test			DEL	DEL	DEL
Point	X	Y	Z		X	Y	Z		X	Y	Z
1	167.5	35.9	0		167.2	36.9	0		.3	-1.0	0
2	168.3	42.2	0		168.2	42.3	0		.1	-.1	0
3	168.3	57.6	0.4		167.6	56.7	0.2		.7	.9	.2
4	162.2	44.3	4.5		162.2	41.2	4.9		0	3.1	-.4
5	162.1	53.8	4.6		161.8	48.5	5.6		-.7	5.3	-1.0
6	162.2	58.8	4.5		161.9	56.5	5.5		.3	2.3	-1.0
7	148.3	39.0	10.5		147.7	40.2	10.5		.6	-1.2	0
8	147.7	59.2	10.4		147.6	56.1	10.4		.1	3.1	0
9	148.2	63.1	10.3		147.0	63.2	9.9		1.2	-.1	.4
10	137.5	66.2	10.4		137.1	62.5	9.8		.4	3.7	.6
11	110.0	25.6	-104.8		110.0	25.4	-105.1		0	.2	.3
12	109.3	28.2	-105.0		111.2	34.1	-104.9		-1.9	-5.9	-.1
13	106.5	47.1	-105.1		107.0	54.0	-105.4		-.5	-6.9	.3
14	99.1	18.3	-111.5		98.7	19.1	-111.4		.4	-.8	-.1
15	96.4	30.8	-111.5		96.5	36.7	-111.5		-.1	-5.9	0
16	94.2	43.0	-111.4		92.2	47.3	-111.3		2.0	-4.3	-.1
17	81.4	17.7	-113.6		81.7	17.2	-113.5		-.3	.5	-.1
18	79.1	26.4	-113.5		78.1	30.3	-113.7		1	-3.9	.2
19	78.2	34.7	-113.1		77.5	39.7	-113.1		.7	-5.0	0
20	62.8	26.1	-144.0		62.5	32.0	-144.4		.3	-5.9	.4
21	127.3	31.9	-52.0		128.0	37.5	-52.7		-.7	-5.6	.7
22	128.1	43.1	-54.1		129.7	43.9	-54.2		-1.6	-.8	.1
23	129.3	55.4	-47.0		129.7	53.8	-49.7		-.4	1.6	2.7
24	132.1	37.1	-33.4		131.7	37.2	-33.7		.4	-.1	.3
25	132.5	61.0	-35.0		131.9	59.2	-34.4		-.6	1.8	-.6

APPENDIX E.2
Test 16010 Additional Information

GENERAL	
TEST NO.	16010
DATE	06/15/2016
TIME	1:00 PM
WEATHER	Cloudy
TEST CONFIGURATION	Chevrolet Silverado into Super Elevated Curved Roadway with G41S W-Beam Guardrail @ 4 Feet from peak
SPEED (KM/H)	100 KM\H
PURPOSE	Evaluate the Performance of Longitudinal Barriers on Curved, Superelevated Roadway Sections

COMMENTS

Release Point Speed Trap: Front Tire- 102.3 km/h (63.6 mph) Rear Tire- 102.1 km/h (63.5 mph)

End of Track Speed Trap: Front Tire-103.1 km/h (64.0 mph) Rear Tire-102.8 km/h (63.9 mph)

Laser Speed Trap: 63.9 km/h (102.9)

Test Vehicle Parameters for Test 16010 (1 of 2)

Veh No:		Test No: 16010		Date: 06/16/16

Make: Chevrolet

Model: Silverado 1500

Year: 2009

Color: White to Blue

Engine: 4.8

Vin No.: 2GCEC13C891113639

Measured Curb mass (Kg)

LF: 679.0

RF: 668.0

LR: 477.5

RR: 488.5

Location of Vehicle CG (cm)

X-Axis (from LF to LR): 156.5

Y-Axis (From LF to RF): 85.7

Z-Axis (From Ground): 82.8

Measured Test Inertial Mass (Kg)

LF: 659.0

RF: 647.0

LR: 488.5

RR: 488.5

Location of CG Accelerometer (cm)

X-Axis (from LF to LR): 157.1

Y-Axis (From LF to RF): 84.2

Z-Axis (From Ground): 68.8

	Items Removed	Mass (Kg)	Added	Mass (Kg)
1	Oil	4.0	Instrument Tray	25.5
2	Transmission Fluid	3.0	Battery	16.5
3	Antifreeze	8.0	Data Acquisition	5.5
4	Battery	17.0	Brake System	6.0
5	Center Seat	12.0	Data Wireless	1.0
6	Spare Tire	30.0	Instrumentation Cage	26.0
7	Carpet Flooring	4.5		
8	Gas	32.0		
9				
10				
11				
12				

Total Mass Removed (Kg) = 110.5

Total Mass Added (Kg) = 80.5

Measured Curb Mass = 2313.0

Removed Total = 110.5

Stripped Vehicle Mass = 2202.5

Added Mass = 80.5

Calculated Test Inertial Mass = 2283.0

Measured Test Inertial Mass = 2283.0

MASH Page #'s: 9-12, 80

*All weights are in Kg

TEST NO.: 16010		**DATE:** 6/15/2016		**ODOMETER:** 175210	
MAKE: Chevrolet		**MODEL:** Silverado 1500		**YEAR:** 2009	
VIN NO.: 2GCEC13C891113639			**TIRE SIZE:** P245/70R17		

TIRE INFLATION PRESSURE: 35

MASS DISTRIBUTION (KG):

LF 659.0		**RF** 647.0	
LR 488.5		**RR** 488.5	

Door Lower Edge Height (cm)   39.9

GEOMETRTY - (CM)

A	190.5	D	185.4	G	156.5	K	68.0	N	172.5	Q	46.9
B	97.3	E	119.8	H	82.8	L	11.9	O	170.3	S	71.4
C	366.0	F	583.1	J	114.1	M	55.9	P	76.9		

Wheel Center Heights (cm):   Front: 36.2   Rear: 36.4

Wheel Well Clearance (cm):   Front: 16.2   Rear: 25.4

Frame Height (cm):   Front: 43.0   60.8   64.7

WEIGHTS (kg)	GVWR Ratings	Curb	Test Inertial	Gross Static
W_{front}	1,656.0	1,347.0	1,306.0	1,306.0
W_{rear}	1,792.0	966.0	977.0	977.0
W_{total}	3,085.0	2,313.0	2,283.0	2,283.0

DUMMY DATA: Type: NA   Mass (kg): NA   Seat Position: NA

DAMAGE TO VEHICLE PRIOR TO TEST: No damage

Performed by : Christopher R.Story   *MASH Page #'s: 80*
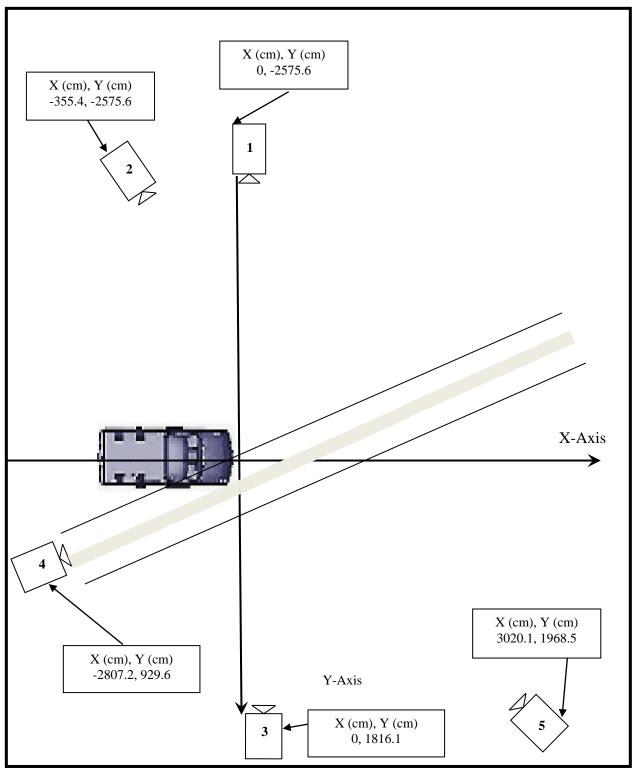
Camera Configuration and Placement for Test 16010

NO.	CAMERA	LENS	LENS (MM)	LENS (ZOOM	RESOLUTION (PIXELS)	SPEED (FPS)	LOCATION
1	K3	Nikon	24-85	85	1280 X 1024	500	Left Perp Close
2	K3R	Nikon	50	50	1280 X 1024	500	Left Front Iso
3	GX-1	Nikon	25-85	60	1280 X 1024	500	Right Perp
4	GX-1	Nikon	85	85	1280 X 1024	500	Right Front Iso
5	GX-1	Nikon	50	50	1280 X 1024	500	Right Rear Iso
6	K3R	Nikon	14	14	1280 X 1024	500	Overhead

MASH Page #'s: 101

High Speed Camera Parameters for Test 16010

X (cm), Y (cm)
0, -2575.6

X (cm), Y (cm)
-355.4, -2575.6

1

2

X-Axis

4

X (cm), Y (cm)
-2807.2, 929.6

X (cm), Y (cm)
3020.1, 1968.5

Y-Axis

3

X (cm), Y (cm)
0, 1816.1

5

*Overhead Camera place over impact point (0.0, 0.0 cm) __1164.3__ cm high

MASH Page #'s: 101
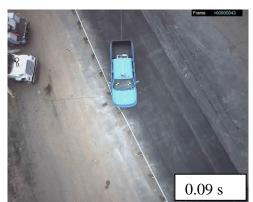
Sequential Photographs for Test 16010 (Overhead View)
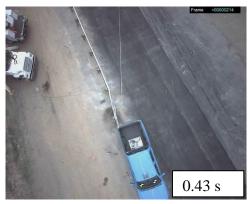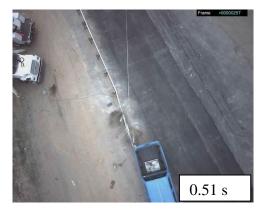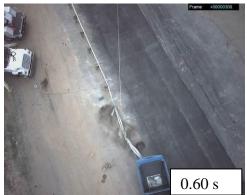
0.00 s

0.34 s

0.09 s

0.43 s

0.17 s

0.51 s

0.26 s

0.60 s

Sequential Photographs for Test 16010 (Right Front Iso View)

0.00 s

1.37 s

0.34 s

1.71 s

0.69 s

2.06 s

1.03 s

2.40 s

Sequential Photographs for Test 16010 (Right Rear Iso View)

0.00 s

0.63 s

0.16 s

0.79 s

0.31 s

0.94 s

0.47 s

1.10 s

Sequential Photographs for Test 16010 (Right Front Iso View)

0.00 s

0.34 s

0.09 s

0.43 s

0.17 s

0.51 s

0.26 s

0.60 s
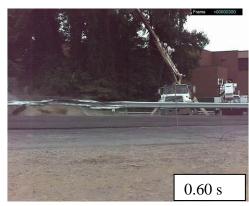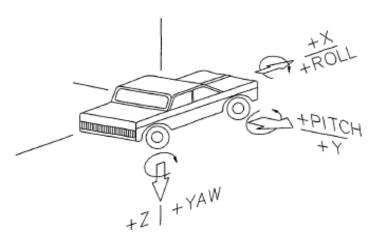
Vehicle Accelerometer Locations and Data Axis for Test 16010

CH.	LOCATION	X (cm) From frt. axle	Y (cm) From lft frt. hub	Z (cm) From ground	SERIAL NO.	Cal STATUS	UNIT (Meas.)	AXIS
1	Center of Gravity	156.5	85.7	82.8	6DX0013 ACC1	Calibrated	Gs	X
2	Center of Gravity	156.5	85.7	82.8	6DX0013 ACC2	Calibrated	Gs	Y
3	Center of Gravity	156.5	85.7	82.8	6DX0013 ACC3	Calibrated	Gs	Z
4	Center of Gravity	156.5	85.7	82.8	6DX0013 ARS1	Calibrated	Deg\Sec	ROLL
5	Center of Gravity	156.5	85.7	82.8	6DX0013 ARS2	Calibrated	Deg\Sec	PITCH
6	Center of Gravity	156.5	85.7	82.8	6DX0013 ARS3	Calibrated	Deg\Sec	YAW
7	Center of Gravity Redundant	156.5	85.7	82.8	6DX0014 ACC1	Calibrated	Gs	X
8	Center of Gravity Redundant	156.5	85.7	82.8	6DX0014 ACC2	Calibrated	Gs	Y
9	Center of Gravity Redundant	156.5	85.7	82.8	6DX0014 ACC3	Calibrated	Gs	Z
10	Center of Gravity Redundant	156.5	85.7	82.8	6DX0014 ARS1	Calibrated	Deg\Sec	ROLL
11	Center of Gravity Redundant	156.5	85.7	82.8	6DX0014 ARS2	Calibrated	Deg\Sec	PITCH
12	Center of Gravity Redundant	156.5	85.7	82.8	6DX0014 ARS3	Calibrated	Deg\Sec	YAW

MASH Page #'s: 88, 89

For each accelerometer, the X-axis is referenced from the center of the right front tire (X=0), the Y-axis from the centerline of the test vehicle (Y=0), and the Z-axis from ground level (Z=0).

Accelerations and Angular Rotations at CG for Test 16010 (1 of 2)

X Acceleration at CG

Test Number: 16010
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 3085 kg
Gross Mass: 2283 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

— Time of OIV (0.21 sec)   — SAE Class 60 Filter

Y Acceleration at CG

Test Number: 16010
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 3085 kg
Gross Mass: 2283 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

— Time of OIV (0.21 sec)   — SAE Class 60 Filter

Acceleration and Angular Rotations at CG for Test 16010 (2 of 2)

Z Acceleration at CG

Test Number: 16010
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 3085 kg
Gross Mass: 2283 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

— SAE Class 60 Filter

Roll, Pitch and Yaw Angles

Test Number: 16010
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 3085 kg
Gross Mass: 2283 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

— Roll — Pitch — Yaw

Data and Results for Test 16010

General Information
    Test Agency: FOIL
    Test Number: 16010
    Test Date: Times New Roman
    Test Article: G41S W-Beam Guardrail
Test Vehicle
    Description: 2270P - Silverado
    Test Inertial Mass: 3085 kg
    Gross Static Mass: 2283 kg
Impact Conditions
    Speed: 100.0 km/h
    Angle: 25.0   degrees
Occupant Risk Factors
    Impact Velocity (m/s)   at 0.2100 seconds
            x-direction   4.8
            y-direction   3.8
    THIV (km/hr):   22.7   at 0.2149 seconds
    THIV (m/s):   6.3
    Ridedown Accelerations (g's)
            x-direction   -6.1   (0.2730 - 0.2830 seconds)
            y-direction   -6.0   (0.2153 - 0.2253 seconds)
    PHD (g's):   8.0   (0.2339 - 0.2439 seconds)
    ASI: 0.56   (0.1288 - 0.1788 seconds)
Max. 50msec Moving Avg. Accelerations (g's)
    x-direction   -5.1   (0.1249 - 0.1749 seconds)
    y-direction   -3.7   (0.1952 - 0.2452 seconds)
    z-direction   3.5   (3.5260 - 3.5760 seconds)
Max Roll, Pitch, and Yaw Angles (degrees)
    Roll   -51.4   (2.3602 seconds)
    Pitch   -50.0   (4.1601 seconds)
    Yaw   -168.5 (3.8266 seconds)
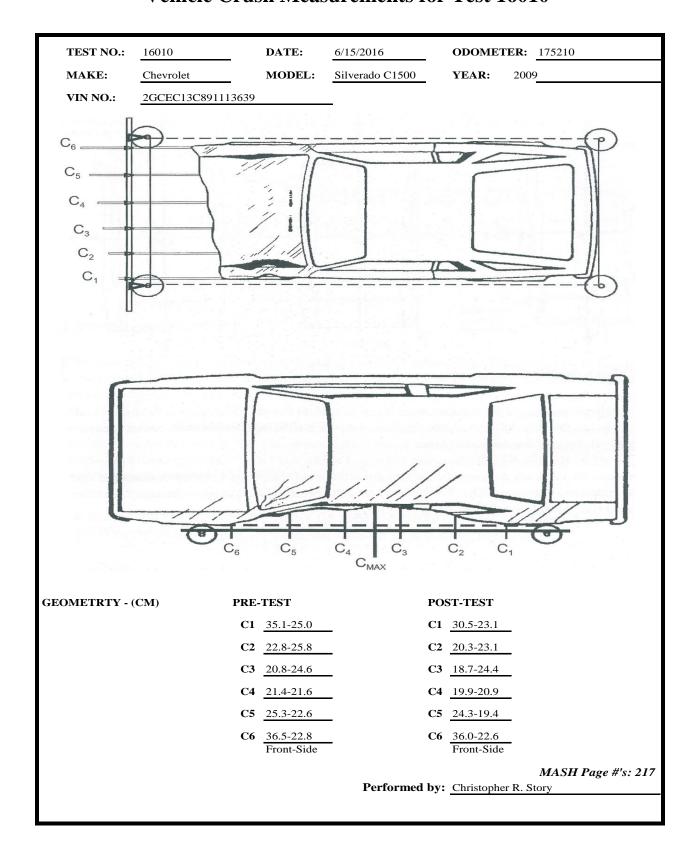
CCSA

Target Locations for Test 16010

I   J   K

A   B   C   D   E   F   G

Geometry (cm) (Driver Side)

A: 83.6	**D:** 81.2	**G:** 25.1	**J:** 43.3		
B: 76.1	**E:** 12.7	**H:** 78.8	**K:** 55.9		
C: 25.2	**F:** 109.1	**I:** 140.2			

Vehicle Crush Measurements for Test 16010

TEST NO.:	16010	**DATE:**	6/15/2016	**ODOMETER:**	175210
MAKE:	Chevrolet	**MODEL:**	Silverado C1500	**YEAR:**	2009
VIN NO.:	2GCEC13C891113639				

GEOMETRTY - (CM)	PRE-TEST	POST-TEST
C1	35.1-25.0	**C1** 30.5-23.1
C2	22.8-25.8	**C2** 20.3-23.1
C3	20.8-24.6	**C3** 18.7-24.4
C4	21.4-21.6	**C4** 19.9-20.9
C5	25.3-22.6	**C5** 24.3-19.4
C6	36.5-22.8 Front-Side	**C6** 36.0-22.6 Front-Side

MASH Page #'s: 217

Performed by: Christopher R. Story

E-63

Interior Crush Measurements for Test 16010

Vehicle Interior Crush Measurements
16010

Point		Pretest				Post Test			DEL X	DEL Y	DEL Z
	X	Y	Z		X	Y	Z				
1	161.3	35.6	0		161.3	34.2	0		0	1.4	0
2	161.2	43.1	0		161.1	41.7	0		.1	1.4	0
3	161.0	55.2	0.3		160.9	54.3	-.2		.1	.9	.5
4	155.4	36.3	3.8		155.1	36.2	3.8		.3	.1	0
5	155.2	44.6	4.0		155.0	43.3	2.8		.2	1.3	1.2
6	156.0	55.2	3.5		155.9	54.6	3.2		.1	.6	.3
7	141.3	38.4	9.1		140.9	37.1	8.5		.4	1.3	.6
8	141.7	51.6	9.1		141.2	50.6	8.9		.5	1.0	.2
9	134.0	32.7	9.3		132.6	31.9	9.2		1.4	.8	.1
10	125.1	57.7	9.6		123.5	57.5	9.3		1.6	.2	.3
11	97.5	12.7	114.1		94.9	11.5	98.3		2.6	1.2	15.8
12	98.4	23.8	114.8		94.7	22.2	99.4		3.7	1.6	15.4
13	98.2	40.4	114.2		93.9	38.4	101.0		4.3	2.0	13.2
14	90.0	11.7	119.9		87.9	10.4	104.8		2.1	1.3	15.2
15	89.3	26.3	119.9		85.0	25.6	106.0		4.3	.7	13.9
16	84.9	37.0	120.1		82.9	35.4	105.6		2.0	1.6	14.5
17	75.4	9.8	121.4		73.4	9.2	108.1		2.0	.6	13.3
18	70.9	18.3	122.5		68.7	17.8	109.8		2.2	.5	12.7
19	67.0	25.5	123.5		65.0	22.7	110.8		2.0	3.2	13.7
20	52.7	21.3	123.0		51.2	20.3	112.1		1.5	1.0	10.9
21	120.2	23.4	56.8		119.8	22.8	51.4		.4	.6	5.2
22	120.3	34.9	57.9		120.2	34.7	52.3		.1	.2	5.6
23	120.8	47.5	64.1		120.6	47.1	52.6		.2	.4	11.5

APPENDIX E.3
Test 16015 Additional Information

GENERAL	
TEST NO.	16015
DATE	08/18/2016
TIME	1:00 PM
WEATHER	Sunny
TEST CONFIGURATION	Chevrolet Silverado into Super Elevated Curved Roadway with G41S W-Beam Guardrail @ 8 feet from peak
SPEED (KM/H)	100 km/h
PURPOSE	Evaluate the Performance of Longitudinal Barriers on Curved, Superelevated Roadway Sections

COMMENTS

Release Point Speed Trap: Front Tire-102.2 km/h (63.5 mph) Rear Tire-102.2 km/h (63.5 mph)

End of Track Speed Trap: Front Tire-103.6 km/h (64.4 mph) Rear Tire-102.2 km/h (63.5 mph)

Test Vehicle Parameters for Test 16015 (1 of 2)

Veh No: _____ **Test No:** 16015 **Date:** 08/18/16

Make:	Chevrolet	**Measured Curb mass (Kg)**
Model:	Silverado 1500	**LF:** 668.0
Year:	2009	**RF:** 681.5
Color:	Gold to Blue	**LR:** 456.5
Engine:	4.8 8 Cylinder	**RR:** 451.0
Vin No.:	3GCEC13C49G118389	

Location of Vehicle CG (cm)   **Measured Test Inertial Mass (Kg)**

X-Axis (from LF to LR):	154.8	**LF:**	653.5
Y-Axis (From LF to RF):	85.9	**RF:**	651.5
Z-Axis (From Ground):	72.9	**LR:**	484.5
		RR:	479.0

Location of CG Accelerometer (cm)

X-Axis (from LF to LR):	154.9
Y-Axis (From LF to RF):	85.7
Z-Axis (From Ground):	68.6

	Items Removed	Mass (Kg)	Added	Mass (Kg)
1	Oil	5.0	Instrument Tray	25.5
2	Transmission Fluid	3.0	Battery	16.0
3	Antifreeze	6.5	Data Acquisition	5.5
4	Battery	17.0	Brake System	5.5
5	Center Seat	12.5	Data Wireless	0.5
6	Gas	14.5	Instrumentation Cage	26.0
7	Carpet Flooring	9.0		
8				
9				
10				
11				
12				

Total Mass Removed (Kg) = 67.5   **Total Mass Added (Kg) =** 79.0

Measured Curb Mass =	2257.0
Removed Total =	67.5
Stripped Vehicle Mass =	2189.5
Added Mass =	79.0
Calculated Test Inertial Mass =	2268.5
Measured Test Inertial Mass =	2268.5

MASH Page #'s: 9-12, 80

Performed by : Christopher R Story

*All weights are in Kg

Test Vehicle Parameters for Test 16015 (1 of 2)

TEST NO.:	16015	**DATE:**	8/18/2016	**ODOMETER:**	140949
MAKE:	Chevrolet	**MODEL:**	Silverado 1500	**YEAR:**	2009
VIN NO.:	3GCEC13C49G118389		**TIRE SIZE:** 245/70R17		

TIRE INFLATION PRESSURE: 35

MASS DISTRIBUTION (KG):

	LF	653.5	RF	651.5
	LR	484.5	RR	479.0

Door Lower Edge Height (cm)   42

GEOMETRTY - (CM)

A	199.4	D	185.1	G	154.8	K	69.0	N	172.5	Q	46.4
B	95.5	E	116.2	H	72.9	L	13.0	O	170.0	S	72.5
C	364.5	F	576.2	J	115.1	M	56.9	P	74.9		

Wheel Center Heights (cm):   Front: 35.1   Rear: 36.2

Wheel Well Clearance (cm):   Front: 17.8   Rear: 23.3

Frame Height (cm):   Front: 44.8   Rear: 61.6

WEIGHTS (kg)	**GVWR Ratings**	**Curb**	**Test Inertial**	**Gross Static**
W_{front}	1,656.0	1,349.5	1,305.0	1,305.0
W_{rear}	1,792.0	907.5	963.5	963.5
W_{total}	3,085.0	2,257.0	2,268.5	2,268.5

DUMMY DATA: Type: NA   Mass (kg): NA   Seat Position: NA

DAMAGE TO VEHICLE PRIOR TO TEST: Damage to left bed rails

Performed by :   Christopher R.Story   *MASH Page #'s: 80*
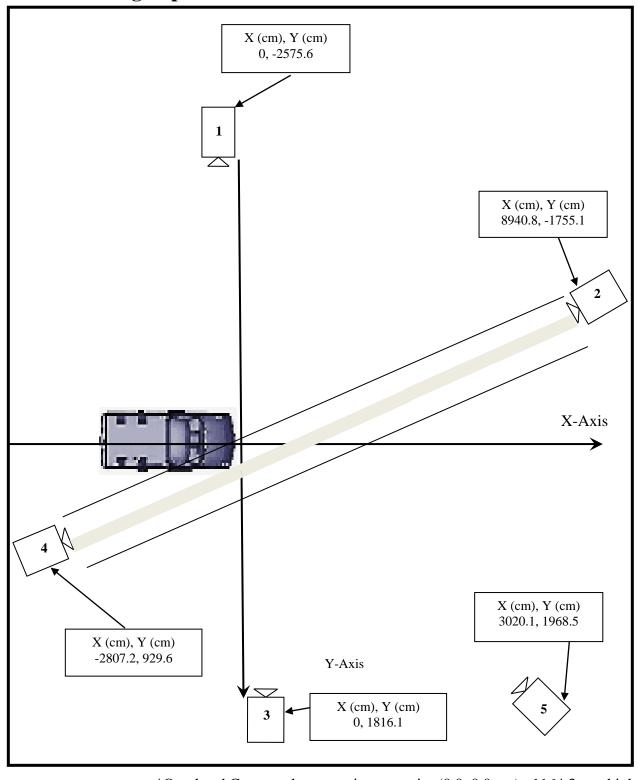
Camera Configuration and Placement for Test 16015

NO.	CAMERA	LENS	LENS (MM)	LENS (ZOOM	RESOLUTION (PIXELS)	SPEED (FPS)	LOCATION
1	K3R	Nikon	24-85	40	1280 X 1024	500	Left Perp
2	K3	Nikon	50	50	1280 X 1024	500	Left Rear Iso
3	GX-1	Nikon	25-85	60	1280 X 1024	500	Right Perp
4	GX-1	Nikon	85	85	1280 X 1024	500	Right Front Iso
5	GX-1	Nikon	50	50	1280 X 1024	500	Right Rear Iso
6	K3R	Nikon	14	14	1280 X 1024	500	Overhead

MASH Page #'s: 101

High Speed Camera Parameters for Test 16015

X (cm), Y (cm)
0, -2575.6

1

X (cm), Y (cm)
8940.8, -1755.1

2

X-Axis

4

X (cm), Y (cm)
-2807.2, 929.6

X (cm), Y (cm)
3020.1, 1968.5

Y-Axis

3

X (cm), Y (cm)
0, 1816.1

5

*Overhead Camera place over impact point (0.0, 0.0 cm) 1164.3 cm high

MASH Page #'s: 101

Sequential Photographs for Test 16015 (Overhead View)

0.00 s

0.43 s

0.11 s

0.54 s

0.22 s

0.65 s

0.33 s

0.76 s

Sequential Photographs for Test 16015 (Left Rear Iso View)

0.00 s

0.63 s

0.16 s

0.79 s

0.31 s

0.94 s

0.47 s

1.10 s

Sequential Photographs for Test 16015 (Right Front Iso View)

0.00 s

0.63 s

0.16 s

0.79 s

0.31 s

0.94 s

0.47 s

1.10 s

Sequential Photographs for Test 16015 (Right Rear Iso View)

0.00 s

0.43 s

0.11 s

0.54 s

0.22 s

0.65 s

0.33 s

0.76 s
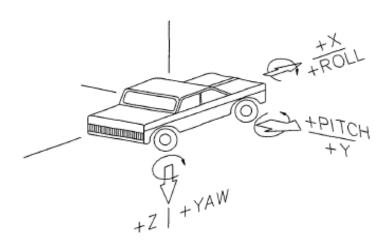
Vehicle Accelerometer Locations and Data Axis for Test 16015

CH.	LOCATION	X (cm) From frt. axle	Y (cm) From lft frt. hub	Z (cm) From ground	SERIAL NO.	Cal STATUS	UNIT (Meas.)	AXIS
1	Center of Gravity	154.9	85.7	68.6	6DX0013 ACC1	Calibrated	Gs	X
2	Center of Gravity	154.9	85.7	68.6	6DX0013 ACC2	Calibrated	Gs	Y
3	Center of Gravity	154.9	85.7	68.6	6DX0013 ACC3	Calibrated	Gs	Z
4	Center of Gravity	154.9	85.7	68.6	6DX0013 ARS1	Calibrated	Deg\Sec	ROLL
5	Center of Gravity	154.9	85.7	68.6	6DX0013 ARS2	Calibrated	Deg\Sec	PITCH
6	Center of Gravity	154.9	85.7	68.6	6DX0013 ARS3	Calibrated	Deg\Sec	YAW
7	Center of Gravity Redundant	154.9	80.0	68.6	6DX0014 ACC1	Calibrated	Gs	X
8	Center of Gravity Redundant	154.9	80.0	68.6	6DX0014 ACC2	Calibrated	Gs	Y
9	Center of Gravity Redundant	154.9	80.0	68.6	6DX0014 ACC3	Calibrated	Gs	Z
10	Center of Gravity Redundant	154.9	80.0	68.6	6DX0014 ARS1	Calibrated	Deg\Sec	ROLL
11	Center of Gravity Redundant	154.9	80.0	68.6	6DX0014 ARS2	Calibrated	Deg\Sec	PITCH
12	Center of Gravity Redundant	154.9	80.0	68.6	6DX0014 ARS3	Calibrated	Deg\Sec	YAW

MASH Page #'s: 88, 89

For each accelerometer, the X-axis is referenced from the center of the right front tire (X=0), the Y-axis from the centerline of the test vehicle (Y=0), and the Z-axis from ground level (Z=0).

Accelerations and Angular Rotations at CG for Test 16015 (1 of 2)

X Acceleration at CG

Test Number: 16015
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 2268 kg
Gross Mass: 3085 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

— Time of OIV (0.2728 sec)   — SAE Class 60 Filter

Y Acceleration at CG

Test Number: 16015
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 2268 kg
Gross Mass: 3085 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

— Time of OIV (0.2728 sec)   — SAE Class 60 Filter

Acceleration and Angular Rotations at CG for Test 16015 (2 of 2)

Z Acceleration at CG

Test Number: 16015
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 2268 kg
Gross Mass: 3085 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

— SAE Class 60 Filter

Roll, Pitch and Yaw Angles

Test Number: 16015
Test Article: G41S W-Beam Guardrail
Test Vehicle: 2270P - Silverado
Inertial Mass: 2268 kg
Gross Mass: 3085 kg
Impact Speed: 100 km/h
Impact Angle: 25 degrees

— Roll — Pitch — Yaw

Data and Results for Test 16015

General Information
       Test Agency: FOIL
       Test Number: 16015
       Test Date: 08/18/2016
       Test Article: G41S W-Beam Guardrail
Test Vehicle
       Description: 2270P - Silverado
       Test Inertial Mass: 2268 kg
       Gross Static Mass: 3085 kg
Impact Conditions
       Speed: 100.0 km/h
       Angle: 25.0   degrees
Occupant Risk Factors
       Impact Velocity (m/s)   at 0.2728 seconds
             x-direction   4.7
             y-direction   4.2
       THIV (km/hr):   24.3   at 0.2780 seconds
       THIV (m/s):   6.8
       Ridedown Accelerations (g's)
             x-direction   -5.9   (0.3182 - 0.3282 seconds)
             y-direction   -6.7   (0.2804 - 0.2904 seconds)
       PHD (g's):   8.8   (0.2805 - 0.2905 seconds)
       ASI: 0.60   (0.2014 - 0.2514 seconds)
Max. 50msec Moving Avg. Accelerations (g's)
       x-direction   -4.9   (0.2012 - 0.2512 seconds)
       y-direction   -5.1   (0.3687 - 0.4187 seconds)
       z-direction   1.9   (0.5016 - 0.5516 seconds)
Max Roll, Pitch, and Yaw Angles (degrees)
       Roll   -31.6   (0.9998 seconds)
       Pitch   -34.5   (0.8023 seconds)
       Yaw   51.3   (0.9998 seconds)
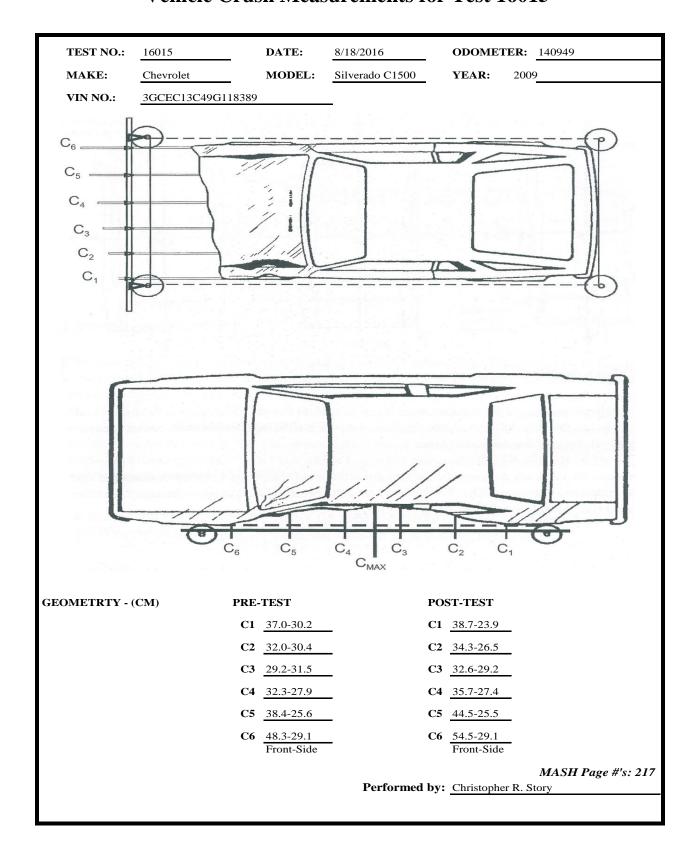
Target Locations for Test 16015

Geometry (cm) (Driver Side)

A: 80.2	**D:** 94.5	**G:** 42.3	**J:** 50.3		
B: 80.2	**E:** 21.2	**H:** 40.2	**K:** 48.4		
C: 20.9	**F:** 109.9	**I:** 121.8			

Vehicle Crush Measurements for Test 16015

TEST NO.:	16015	**DATE:**	8/18/2016	**ODOMETER:**	140949
MAKE:	Chevrolet	**MODEL:**	Silverado C1500	**YEAR:**	2009
VIN NO.:	3GCEC13C49G118389				

GEOMETRTY - (CM)	**PRE-TEST**	**POST-TEST**
	C1 37.0-30.2	**C1** 38.7-23.9
	C2 32.0-30.4	**C2** 34.3-26.5
	C3 29.2-31.5	**C3** 32.6-29.2
	C4 32.3-27.9	**C4** 35.7-27.4
	C5 38.4-25.6	**C5** 44.5-25.5
	C6 48.3-29.1 Front-Side	**C6** 54.5-29.1 Front-Side

MASH Page #'s: 217

Performed by: Christopher R. Story

Interior Crush Measurements for Test 16015

		Pretest				Post Test				DEL X	DEL Y	DEL Z
Point	X	Y	Z		X	Y	Z					

Vehicle Interior Crush Measurements
16015

Point	X	Y	Z		X	Y	Z		DEL X	DEL Y	DEL Z
1	170.2	30.7	5.2		170.2	30.6	5.2		0.0	0.1	0.0
2	170.0	46.6	5.1		170.0	46.4	5.1		0.0	0.2	0.0
3	170.2	60.4	6.2		169.8	60.3	5.9		0.4	0.1	0.3
4	163.6	33.4	9.3		163.3	33.2	9.3		0.3	0.2	0.0
5	164.3	44.6	11.0		164.0	44.1	11.0		0.3	0.5	0.0
6	163.4	60.4	11.2		163.3	60.3	11.2		0.1	0.1	0.0
7	148.3	32.8	15.4		148.1	32.4	15.4		0.2	0.4	0.0
8	148.3	47.9	15.7		147.9	47.7	15.6		0.4	0.2	0.1
9	145.4	59.5	15.6		144.8	59.2	15.5		0.6	0.3	0.1
10	131.4	66.7	16.4		130.7	66.4	16.3		0.7	0.3	0.1
11	108.2	16.1	-108.4		108.1	16.1	-108.3		0.1	0.0	0.1
12	108.9	28.9	-107.5		108.9	28.8	-107.5		0.0	0.1	0.0
13	107.1	37.4	-107.2		107.0	37.4	-106.9		0.1	0.0	0.3
14	92.3	15.9	-114.3		91.9	15.7	-114.2		0.4	0.2	0.1
15	85.0	32.7	-114.0		84.6	32.4	-113.9		0.4	0.3	0.1
16	79.8	44.5	-113.7		79.6	44.2	-113.5		0.2	0.3	0.2
17	73.0	16.4	-115.4		72.3	16.4	-115.2		0.7	0.0	0.2
18	66.6	29.1	-115.1		66.3	29.0	-115.0		0.3	0.1	0.1
19	63.0	41.7	-114.7		62.7	41.7	-114.4		0.3	0.0	0.3
20	56.2	22.0	-115.8		55.7	21.9	-115.5		0.5	0.1	0.3
21	130.0	29.1	-50.4		129.7	29.0	-50.1		0.3	0.1	0.3
22	130.8	52.7	-51.9		130.7	52.4	-51.6		0.1	0.3	0.3
23	134.0	33.4	-35.6		133.6	33.2	-35.6		0.4	0.2	0.0
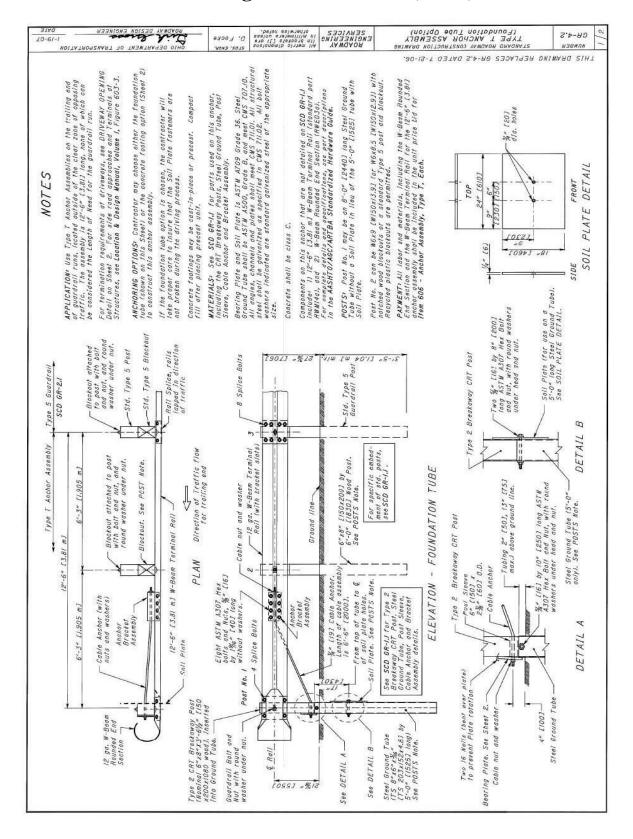
Appendix E.4
Drawings for Test Article (1 of 7)

Strong-post W-beam Guardrail – SGR04c – (2 x 187.5 ft long sections)

QTY	Description	Hardware Guide
30	W-beam rail	RWM02a
60	Wide flange steel post	PWE01
60	Timber post blockout	PDB01b
60	Guardrail-post bolt and nut	FBB03
240	Splice bolt and nut	FBB01
60	Round washer	FWC16a

Drawings for Test Article (2 of 7)

NOTES

APPLICATION: Use Type T Anchor Assemblies on the trailing end of guardrail runs, located outside of the clear zone of opposing traffic. The assembly is 12'-6" [3.81] long, none of which can be considered the Length of Need for the guardrail run.

For termination requirements at driveways, see DRIVEWAY OPENING Detail on Sheet 2. For side road approaches and Terminals at Structures, see Location & Design Manual, Volume I, Figure 603-3.

ANCHORING OPTIONS: Contractor may choose either the foundation tube (shown on this Sheet) or the concrete footing option (Sheet 2) to construct this anchor assembly.

If the foundation tube option is chosen, the contractor will take proper care to insure that the Soil Plate fasteners are not broken during the driving process.

Concrete footings may be cast-in-place or precast. Compact fill after placing precast unit.

MATERIALS: See SCD GR-1.1 for parts used on this anchor, including the CRT Breakaway Posts, Steel Ground Tube, Post Sleeve, Cable Anchor and Bracket Assembly.

Bearing Plate and Soil Plate is ASTM A709 Grade 36. Steel Ground Tube shall be ASTM A500, Grade B, and meet CMS 707.10. All angles, channels and plates shall meet CMS 711.01. All structural steel shall be galvanized as specified in CMS 711.02. All bolt washers indicated are standard galvanized steel of the appropriate size.

Concrete shall be class C.

Components on this anchor that are not detailed on SCD GR-1.1 includes 1) 12'-6" [3.81 m] W-Beam Terminal Rail (standard part RWM14a), and 2) W-Beam Rounded End Section (RWE03a). For complete details and specifications, see part descriptions in the AASHTO/AGC/ARTBA Standardized Hardware Guide.

POSTS: Post No. 1 may be an 8'-0" [2440] long Steel Ground Tube without a Soil Plate in lieu of the 5'-0" [1525] tube with Soil Plate.

Post No. 2 can be W6x9 [W150x13.9] or W6x8.5 [W150x12.9] with notched wood blockouts or a standard Type 5 post and blockout. Recycled plastic blockouts are permitted.

PAYMENT: All labor and materials, including the W-Beam Rounded End Section and the W-Beam Terminal Rail for the 12'-6" [3.81] anchor assembly shall be included in the unit price bid for Item 606 - Anchor Assembly, Type T, Each.

SOIL PLATE DETAIL

TOP
24" [610]
6" [150]
9" [230]
¾" [20] dia. holes
FRONT
9" [6]
18" [460]
¼" [6]
SIDE

PLAN

Type 5 Guardrail
SCD GR-2.1
Type T Anchor Assembly
12'-6" [3.81 m]
6'-3" [1.905 m]
6'-3" [1.905 m]
Blockout attached to post with bolt and nut, and round washer under nut.
Std. Type 5 Post
Std. Type 5 Blockout
Rail Splice, rails lapped in direction of traffic
Direction of Traffic flow for trailing end
Blockout attached to post with bolt and nut, and round washer under nut.
Blockout. See PCST Note.
Cable Anchor (with nuts and washers)
Anchor Bracket Assembly
Soil Plate
12 ga. W-Beam Rounded End Section
Type 2 CRT Breakaway Post (Nominal 6"x8"x3'-6½" [150 x200x1080 wood]. Inserted into Ground Tube.
Guardrail Bolt and Nut with round washer under nut.
Steel Ground Tube (TS 8"x6"x3⁄16 [TS 203x152x4.8] by 5'-0" [1525] long) See POSTS Note.

ELEVATION - FOUNDATION TUBE

3'-5" [1.04 m] min.
27⅛" [705]
8 Splice Bolts
Std. Type 5 Guardrail Post
12 ga. W-Beam Terminal Rail (with bracket slots)
Cable nut and washer
Ground line
6"x8" [150x200] by 6'-0" [1830] Wood Post. See POSTS Note.
For specific embedment of std. posts, see SCD GR-1.1.
Anchor Bracket Assembly
Eight ASTM A307 Hex bolts and Nuts, ⅝" [16] by 1⅜" [40] long without washers.
4 Splice Bolts
Post No. 1
¾" [19] Cable Anchor. Length of cable assembly is 6'-6" [2000].
From top of tube to ₵ of soil plate holes. See POSTS Note.
Soil Plate. See Sheet 2.
See SCD GR-1.1 for Type 2 Breakaway CRT Post, Steel Ground Tube, Post Sleeve, Cable Anchor and Bracket Assembly details.
See DETAIL A
See DETAIL B
₵ Rail
17" [430]
21⅝" [550]
Steel Ground Tube (TS 8"x6"x3⁄16 [TS 203x152x4.8] by 5'-0" [1525] long) See POSTS Note.
Bearing Plate. See Sheet 2.
Cable nut and washer
4" [100]
Steel Ground Tube

DETAIL A

Type 2 Breakaway CRT Post
Post Sleeve 6" [150] x 2⅜" [60] O.D.
Cable Anchor
Tubing 2" [50], 13" [75] long.
⅝" [16] by 10" [250] long ASTM A307 Hex Bolt and Nut, with round washers under head and nut.
Two 16 Nails (bent over plate) to prevent plate rotation
Steel Ground Tube

DETAIL B

Type 2 Breakaway CRT Post
Two ⅝" [16] by 8" [200] long ASTM A307 Hex Bolt and Nut, with round washers under head and nut.
Soil Plate (for use on a 5'-0" long Steel Ground Tube. See SOIL PLATE DETAIL.

1905

1905

4130

24x30 SPLICE BOLT
SLOT (TYP)

20x65 POST BOLT
SLOT (TYP)

108

108

216

52

(-6 , +30)

312
(±2)

DESIGNATOR	BASE METAL THICKNESS
RWM02a	2.67
RWM02b	3.43

THE CROSS-SECTIONAL
DIMENSIONS FOR THIS
PART ARE THE SAME
AS PART RWM02a (SHT
3 of 4).

1994

2-SPACE W-BEAM GUARDRAIL

RWM02a-b

SHEET NO.	REF. NO.
1 of 4	RE-3-73

NOTE: 1. ALL FILLETS SHALL HAVE A MINIMUM RADIUS OF 2
2. IF THE BOLT EXTENDS MORE THAN 6 FROM THE NUT THE BOLT SHOULD BE TRIMMED BACK.

8 5.5

45°

16

24 (+1.5,−0.5)

16

28

35

35 R

M16x2 THREAD PITCH

T

L

DESIGNATOR	L	T (MIN)
FBB01	35	30
FBB02	50	45
FBB03	255	100
FBB04	460	100
FBB05	640	100

25 D x 1.5 DEEP RECESS BOTH SIDES

M16x2 MODIFIED HEAVY HEX NUT

17.5

32

1976

GUARDRAIL BOLT AND RECESSED NUT

FBB01-05

SHEET NO.	REF. NO.
1 of 2	

CCSA

DESIGNATOR	A MIN	B MAX	C MIN	ANSI SIZE
FWC06a	6.65	18.80	1.20	6
FWC08a	8.90	25.40	1.60	8
FWC10a	10.85	28.00	2.00	10
FWC12a	13.30	34.00	2.50	12
FWC14a	15.25	39.00	2.50	14
FWC16a	17.25	44.00	3.00	16
FWC20a	21.80	50.00	3.50	20
FWC24a	25.60	56.00	4.00	24
FWC30a	32.40	72.00	4.50	30
FWC36a	38.30	90.00	5.00	36

PLAIN ROUND WASHER

FWC06a-36a

SHEET NO.	REF. NO.
1 of 2	F-13-73

6
[150]

3
[75]

7-7/8
[200]

PLAN (a)

6
[150]

1-3/4
[45]

7-7/8
[200]

3/8 [10]

3/4 [18]

4-1/2
[115]

PLAN (b)

14
[360]

7
[180]

SIDE

3/4 [20] D HOLE

3/4 [20] D HOLE

(a)

(b)

FRONT

1994

W-BEAM TIMBER BLOCKOUT

PDB01a-b

SHEET NO.	DATE:
1 of 2	6/30/2005

CCSA

Appendix E.5
Material Specification for Test Article (1 of 11)

Gregory

Gregory Industries, Inc.
4100 13th Street, SW • Canton, Ohio 44710
330-477-4800 • Fax 330-477-0626 • www.gregorycorp.com
HIGHWAY • COIL • FENCE • STRUT • ROLL FORM • GALVANIZING • METAL PROCESSING

INVOICE   NO.: 254950
DATE: 11/09/15

Page 1

ACCOUNT NO.: GRE016

BILL TO:

GREGORY HIGHWAY PRODUCTS INC.
4100 13TH ST. S.W.
CANTON, OH 44710

SHIP TO:

FEDERAL OUTDOOR IMPACT LABORATORY
ATTN:CRIS STORY PH: 202-493-3323
6300 GEORGETOWN PIKE
MC LEAN, VA 22101

CUST. PO : NCHRP 22-49 PROJECT
PROJECT : NCHRP 22-29 TESTING
SO NO   : 188414

SHIP DATE   : 11/09/15
BILL OF LADING : 88792
SHIP VIA   : GREENLINES

NO.	ORDERED	BALANCE DUE	SHIPPED	PART NUMBER/DESCRIPTION		UNIT PRICE	UOM	AMOUNT
1	64.0	0.0	64.0	609	5 1/2IN X 7 1/2IN X 14IN S4S ROUTED WOOD BLOCK .60 CC	0.00	EA	0.00
2	30.0	0.0	30.0	1PG4HDW	12FT6IN WB T2 WITH 8 SPL BOLT & NUT	0.00	EA	0.00
3	30.0	0.0	30.0	1PG4	12GA 12FT 6IN WB T2 HS AT 6FT 3IN		EA	
4	240.0	0.0	240.0	1000G	5/8IN DBL REC GR NUT		EA	
5	240.0	0.0	240.0	1001G	5/8IN X 1 1/4IN SPL BOLT		EA	
6	64.0	0.0	64.0	500-0600HDGHDW	6INWF AT 8.5 X 6FT0IN GR POST W/HDW	0.00	EA	0.00
7	64.0	0.0	64.0	500-0600HDG	6INWF AT 8.5 X 6FT0IN GR POST 2HS AT 7IN F/B		EA	
8	64.0	0.0	64.0	1000G	5/8IN DBL REC GR NUT		EA	
9	64.0	0.0	64.0	1019G	5/8IN F844 FLAT WASHER HDG 1 3/4IN OD X 11/16IN ID X		EA	
10	64.0	0.0	64.0	1010G	5/8IN X 10IN GR P BOLT		EA	
11	4.0	0.0	4.0	OHTYT-NEW	OHIO TY-T ANCHOR	0.00	EA	0.00
12	4.0	0.0	4.0	14PG4	12GA 12FT 6IN WB T2 EP		EA	
13	4.0	0.0	4.0	3000PG4	12GA SINGLE BUFFER		EA	
14	4.0	0.0	4.0	3012G	6FT 6IN CABLE ASSEM		EA	
15	4.0	0.0	4.0	3013HDG	BEARING PLATE 5/8IN X 8IN X 8IN		EA	
16	4.0	0.0	4.0	3014HDG	TUBE SLEEVE 3/16INX6INX8INX5FT0IN		EA	
17	4.0	0.0	4.0	3017HDG	CABLE ANCHOR BOX		EA	
18	4.0	0.0	4.0	3022HDG	SOIL PLATE 1/4IN X 18IN X 24IN		EA	
19	4.0	0.0	4.0	3028HDG	PIPE SLEEVE 2IN X 5 1/2IN		EA	
20	4.0	0.0	4.0	500-0600HDG	6INWF AT 8.5 X 6FT0IN GR POST 2HS AT 7IN F/B		EA	
21	4.0	0.0	4.0	609	5 1/2IN X 7 1/2IN X 14IN S4S ROUTED WOOD BLOCK .60 CC		EA	
22	4.0	0.0	4.0	613	5.5IN X 7.5IN X 42.75IN S4S WOOD BREAK-AWAY POST BCT		EA	
23	24.0	0.0	24.0	1000G	5/8IN DBL REC GR NUT		EA	
24	16.0	0.0	16.0	1001G	5/8IN X 1 1/4IN SPL BOLT		EA	
25	32.0	0.0	32.0	1004G	5/8IN X 1 1/2IN H-H BOLT A307		EA	
26	44.0	0.0	44.0	1005G	5/8IN HX NUT		EA	
27	8.0	0.0	8.0	1007G	5/8IN X 7 1/2 IN H-H BOLT		EA	
28	4.0	0.0	4.0	1009G	5/8IN X 9 1/2IN H-H BOLT		EA	

*** Continued on Page 2 ***

E-88

Gregory

Gregory Industries, Inc.
4100 13th Street, SW • Canton, Ohio 44710
330-477-4800 • Fax 330-477-0626 • www.gregorycorp.com
HIGHWAY • COIL • FENCE • STRUT • ROLL FORM • GALVANIZING • METAL PROCESSING

INVOICE   NO.: 254950
DATE: 11/09/15

Continued from Page 1

ACCOUNT NO.: GRE016

BILL TO:

GREGORY HIGHWAY PRODUCTS INC.
4100 13TH ST. S.W.
CANTON, OH 44710

SHIP TO:

FEDERAL OUTDOOR IMPACT LABORATORY
ATTN:CRIS STORY PH: 202-493-3323
6300 GEORGETOWN PIKE
MC LEAN, VA 22101

NO.	ORDERED	BALANCE DUE	SHIPPED	PART NUMBER/DESCRIPTION	UNIT PRICE	UOM	AMOUNT
29	8.0	0.0	8.0	1011G 1IN HVY HEX DH NUT HDG		EA	
30	8.0	0.0	8.0	1012G 1IN F844 FLAT WASHER		EA	
31	40.0	0.0	40.0	1019G 5/8IN F844 FLAT WASHER HDG 1 3/4IN OD X 11/16IN ID X		EA	
32	8.0	0.0	8.0	1010G 5/8IN X 10IN GR P BOLT		EA	

SUB TOTAL   0.00

Payment Terms: COD

AMOUNT DUE   0.00

REMITTANCE ADDRESS:
4100 13TH ST. SW
CANTON, OH 44710

Complete - Page 2 of 2

CCSA

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer:
FEDERAL OUTDOOR IMPACT LABORATORY
ATTN: CHRIS STORY PH: 202-493-3323
6300 GEORGETOWN PIKE
MC LEAN, VA 22101

Test Report
Ship Date: 11/9/2015
Customer P.O.: NCHRP 22-49 PROJECT
Shipped to: FEDERAL OUTDOOR IMPACT LABORATORY
PROJECT: MCHRP 22-29 TESTING
GHP Order No: 188414

HT # code	Lot #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quanity	Class	Type	Description
T84868		0.19	0.8	0.011	0.01	0.01	70000	43000	35.2	4		2	5/8IN X 8IN X 8IN BRG. PL.
541318		0.21	0.81	0.014	0.004	0.02	72260	57090	33.2	4		2	3/16IN X 6IN X 5FT0IN TUBE SLEEVE
A70556		0.2	0.71	0.014	0.001	0.02	82800	56700	25.9	4		2	CABLE AB
A77093		0.08	0.87	0.011	0.003	0.02	61200	50960	31	4		2	1/4IN X 18IN X 24IN SOIL PLATE
C86373		0.22	0.79	0.008	0.01	0.019	69900	55700	26	4		2	2IN X 5 1/2IN PIPE SLEEVE

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Missouri Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: _____
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

James P. Deinke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 10 day of November, 2015

_____
Notary Public, State of Ohio

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer:
FEDERAL OUTDOOR IMPACT LABORATORY
ATTN: CHRIS STORY PH: 202-493-3323
6300 GEORGETOWN PIKE
MC LEAN, VA 22101

Test Report
Ship Date: 11/9/2015
Customer P.O.: NCHRP 22-49 PROJECT
Shipped to: FEDERAL OUTDOOR IMPACT LABORATORY
PROJECT: MCHRP 22-29 TESTING
GHP Order No: 186414

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quanity	Class	Type	Description
7800285	0.18	0.74	0.006	0.004	0.07				328			5/8IN DBL. REC. GR NUT
20358710	0.14	0.33	0.008	0.001	0.07				256			5/8IN X 1 1/4IN SPL. BOLT
NF14202603	0.17	0.45	0.008	0.022	0.17				32			5/8IN X 1 1/2IN H-H BOLT
10361250	0.09	0.48	0.007	0.01	0.09				44			5/8IN FINISHED HX NUT
NF14203568	0.13	0.51	0.008	0.032	0.17				8			5/8IN X 7 1/2IN H-H BOLT
NF14102002	0.11	0.56	0.01	0.02	0.19				4			5/8IN X 9 1/2IN H-H BOLT
NF14101422	0.13	0.56	0.008	0.031	0.19				72			5/8IN X 10IN GR P BOLT
20274080	0.39	0.82	0.008	0.004	0.21				8			1IN HVY. HX NUT H2
831D08840	0.05	1.54	0.012	0.003	0.116				8			1IN F844 FLAT WASH.
C72256	0.21	0.48	0.009	0.002	0.03				104			5/8IN F844 FLAT WASH.

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Missouri Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By:
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

STATE OF OHIO, COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 10 day of November, 2015

Notary Public, State of Ohio

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer: FEDERAL OUTDOOR IMPACT LABORATORY
ATTN: CHRIS STORY PH: 202-493-3323
6300 GEORGETOWN PIKE
MC LEAN, VA 22101

Test Report
Ship Date: 11/9/2015
Customer P.O.: NCHRP 22-49 PROJECT
Shipped to: FEDERAL OUTDOOR IMPACT LABORATORY
Project: NCHRP 22-29 TESTING
GHP Order No.: 188414

HT # code	Heat #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
8837	9512090	0.22	0.76	0.01	0.008	0.01	76079	55580	20.47	4	A	2	12GA 12FT6IN WB T2 EP
8918	468639	0.22	0.74	0.01	0.004	0.02	81937	61922	24.51	30	A	2	12GA 12FT6IN/6FT3IN WB T2

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with New Mexico Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: _____
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF Ohio, COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 10 day of November, 2015

_____
Notary Public, State of Ohio

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

NOTARIAL SEAL · STATE OF OHIO

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer: FEDERAL OUTDOOR IMPACT LABORATORY
ATTN: CHRIS STORY PH: 202-493-3323
6300 GEORGETOWN PIKE
MC LEAN, VA 22101

Test Report
Ship Date: 11/9/2015
Customer P.O.: NCHRP 22-49 PROJECT
Shipped to: FEDERAL OUTDOOR IMPACT LABORATORY
PROJECT: MCHRP 22-29 TESTING
GHP Order No: 188414

HT # code	Lot #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quanity	Class	Type	Description
18018	5S44	0.13	0.66	0.022	0.032	0.21	69000	47000	23.9	68		2	6IN WF AT 8.5 X 6FT 0IN GR POST

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Missouri Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By:
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 10 day of November, 2015.

Notary Public, State of Ohio

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Test Report

Ship Date: 11/9/2015

Customer: FEDERAL OUTDOOR IMPACT LAB(
ATTN: CHRIS STORY PH: 202-493-3
6300 GEORGETOWN PIKE
MC LEAN, VA 22101

Customer P.O.: NCHRP 22-49 PROJECT
Shipped to: FEDERAL OUTDOOR IMPACT LABORATORY
Project:: NCHRP 22-29 TESTING
GHP Order No.: 188414

QTY	P/N	PRODUCT DESCRIPTION	CHARGE NO.	RETENTION
68	609	6IN x 8IN x 14IN O.D. RB S4S .60 CCA-C	45109, 45223	0.6
4	613	7 1/2IN X 5 1/2IN X 42 3/4IN BCT WOOD POST	44707, 44583, 44584, 44742	0.6

Gregory Highway Products, Inc. Certifies that all treated wood products referenced above have been distributed by Gregory Highway Products, Inc. in strict accordance with all applicable:

1. American Wood Preserver's Association "A.W.P.A" standards and guidelines as defined in A.W.P.A. standards C1 and C2.
2. A.A.S.H.T.O.: M-133 Requirements of wood preservation
3. A.A.S.H.T.O.: M-168 Requirements for physical characteristics of wood

Each charge of product is sampled, and laboratory tested for CCA penetration and retention per The American Wood Preserver's Association "AWPA"

By:

Andrew Artar
Vice President of Sales and Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 10 day of November, 2015.

Notary Public, State of Ohio

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

ASSEMBLY
SPECIALTY PRODUCTS INC.

PH 216.676.5600
FX 216.676.6761
www.assemblyspecialty.com

ISO 9001:2008

14700 Brookpark Rd
Cleveland, OH 44135-5166
customerservice@assemblyspecialty.com

Certificate of Conformance

Date: October 21, 2015

To: Gregory Industries, Inc.
Gregory Galv. & Metal Processing
4100 13th St. SW
Canton, OH 44710

We certify that our system and procedures for the control of quality assures that all items furnished on the order will meet applicable tests, requirements and inspection requirements as required by the purchase order and applicable specifications and drawings.

PURCHASE ORDER #: 32974

DATE SHIPPED: 100/20/2015

ASPI SALES ORDER #: 108841

MANUFACTURER: ASSEMBLY SPECIALTY PRODUCTS, INC.

QTY	Gregory Ind. P/N	ASPI P/N	DESCRIPTION
250	3012G	C-2028	Wire Rope Assembly

Attachments:

ASPI LOT(S): 63409, 63277, 63590,

ASPI REEL(S) 10036, 10050, 10066, 10068, 10069

LOT: 63409	**Galvanized Threaded Stud Assembly**
Eaton Steel	Heat: M59475 (Hercules, Gerdau) [swage sleeve]
	Heat: M59477 (Hercules, Gerdau) [swage sleeve]
	Heat: M60026 (Hercules, Gerdau) [swage sleeve]
Keystone Threaded	Heat: 10379580 (Taubensee, Charter) [threaded rod]
Art Galvanizing Works	Galvanizing certificate [swage sleeve & threaded rod assembly]

Attachments continued on next page:

REMARKS: NOMINAL BREAKING STRENGTH: 46,000 lbs

WIRE ROPE MANUFACTURED IN ACCORDANCE WITH AASHTO DESIGNATION: M30-02 and ASTM A741 TYPE 2, CLASS A

FITTINGS GALVANIZED IN ACCORDANCE WITH ASTM A-153 CLASS C.

STEEL USED TO MANUFACTURE THESE ITEMS WAS MELTED AND MANUFACTURED IN THE U.S.A

ALL MANUFACTURING PROCESSES SUPPLIED OR PERFORMED BY ASSEMBLY SPECIALTY PRODUCTS, INC. TOOK PLACE IN THE U.S.A.

Signature: _____
Certification and Compliance Manager

CCSA

ASSEMBLY
SPECIALTY PRODUCTS INC.

PH 216.676.5600
FX 216.676.6761
www.assemblyspecialty.com

ISO 9001:2008

14700 Brookpark Rd
Cleveland, OH 44135-5166
customerservice@assemblyspecialty.com

Attachments (continued):

LOT: 63277 Galvanized Threaded Stud Assembly

Eaton Steel Heat: M59475 (Hercules, Gerdau) [swage sleeve]

Heat: M59477 (Hercules, Gerdau) [swage sleeve]

Heat: M60026 (Hercules, Gerdau) [swage sleeve]

Keystone Threaded Heat: 10375400 (Taubensee, Charter) [threaded rod]

Heat: 10379580 (Taubensee, Charter) [threaded rod]

Art Galvanizing Works Galvanizing certificate [swage sleeve & threaded rod assembly]

LOT: 63590 Galvanized Threaded Stud Assembly

Eaton Steel Heat: M59477 (Hercules, Gerdau) [swage sleeve]

Heat: M60026 (Hercules, Gerdau) [swage sleeve]

Keystone Threaded Heat: 10379580 (Taubensee, Charter) [threaded rod]

Art Galvanizing Works Galvanizing certificate [swage sleeve & threaded rod assembly]

Wirerope Works: Certificate#: AA30229; Reel#: 5202976 [ASPI Reel 10035, **10036**, 10037, 10038]

.054" Heat: 53135588/02 Gerdau

Heat: 10357110 Charter

.040" Heat: 20347130 Charter

061: Heat: 10246830 Charter

. Heat: 53127002/06 Gerdau

.046" Heat: 53132132/05 Gerdau

Wirerope Works: Certificate#: AA30234; Reel#: 5202977 [ASPI Reel 10049, 10050, 10051, 10052]

.054" Heat: 53135588/02 Gerdau

Heat: 10357110 Charter

.040" Heat: 20347130 Charter

Heat: 10284590 Charter

Heat: 53132649/02 Gerdau

061: Heat: 53127002/04 Gerdau

.046". Heat: 53132132/05 Gerdau

Heat: 10364280 Charter

Wirerope Works: Certificate#: AA30240; Reel#: 5204561 [ASPI Reel **10066**, 10067, **10068**, **10069**]

.054" Heat: 53135588/02 Gerdau

.040" Heat: 10284590 Charter

061: Heat: 53127002/04 Gerdau

.046". Heat: 10384530 Charter

CCSA

Form T.L.-32 4-17-80

VIRGINIA DEPARTMENT OF HIGHWAYS

MATERIALS DIVISION

REPORT ON SAMPLE OF SOIL

Report No. _____

Sample of soil tested for conformity with specifications for use in

Route No. _____
Project No. _____
F.H.W.A. No. _____
_____ County

Sample No. _____ ,Va.   Date: 11/6/2015

_____ ,Va. _____

Mat'l -   Type 21 A

Submitted by _____ at _____ Va.

For _____ District Engineer _____ Va

MECHANICAL ANALYSIS OF TOTAL				150.5	MECHANICAL ANALYSIS OF SOIL			1	HYDROMETER ANALYSIS OF SAND AND SOIL	
Sieve Sizes	Grams Retained	Per Cent Retained	%	Per Cent Passing	Sieve Sizes	Grams Retained	Per Cent Retained	%	Per Cent Passing	*Passing The No. 10 Sieve	Total Sample
+2 1/2	0	0.0	%	100.0				%		**Coarse Sand** 2.0 to 0.25 mm ____ % ____	
-2 1/2 + 2	0	0.0	%	100.0				%			
-2 + 1 1/2	0	0.0	%	100.0				%		**Fine Sand** 0.25 to 0.05mm ____ % ____	
-1 1/2 + 1	61.1	0.8	%	100.0				%			
-1 + 3/4	312	4.1	%	99.2				%		**Silt** 0.05 to 0.005mm ____ % ____	
-3/4 + 3/8	2280.9	29.9	%	95.1				%			
-3/8 + 4	1089.7	14.3	%	65.2				%		**Clay** 0.005 to 0.001mm ____ % ____	
-4 + 10	1209.8	15.9	%	50.9				%			
-10 + 20			%	35.0	-10 + 20	52.7	27.0	%	100	**Field Moisture =** ____ %	
-20 + 40			%	25.6	-20 + 40	32.5	16.6	%	73.0		
-40 + 60			%	19.7	-40 + 60	24.6	12.6	%	56.4	**Soil Classification**	
-60 + 80			%	15.3	-60 + 80	13.9	7.1	%	43.8		
-80 + 100			%	12.8	-80 + 100	5.5	2.8	%	36.7	**AASHTO** _____	
-100 + 200			%	11.9	-100 + 200	20.3	10.4	%	33.9	**Physical Characteristics of Soil**	
-200			%	8.2	-200		0.0	%	23.5		
Total	7615.7		%		Total	195.2		%		**LIQUID LIMIT** 16.3 %	
Total Wet	7967.9		%					%			

4953.5 2662.2   **LIQUID LIMIT**

Dish No. __401__   No.of Blows __24__

Dish & Wet Soil __47.7__ Dish & Dry Soil __42.8__

Dish & Dry Soil __42.8__ Dish __12.8__

Wt. Of Water __4.9__ Dry Soil __30.0__

% Moisture = Weight (Mass) of Water X 100

    Dry Soil __16.33__

    L.L. = __16.26__

PLASTIC LIMIT

Dish No. _____

Dish & Wet Soil _____

   0   Dish & Dry Soil __0__

Dish & Dry Soil

   0   Dish __0__

Wt. Of Water

   0   Dry Soil __0__

P.L. = Weight (Mass) of Water X 100

    Dry Soil

PLASTIC LIMIT #DIV/0! %

PLASTICITY INDEX #DIV/0! %

Optimum Moisture Content

Total Soil _____ %

-4 portion _____ %

Maximum Density (Unit Mass)

Total Soil _____ lbs/cu.ft

-4 portion _____ lbs/cu.ft

Sampled from property of _____

Location _____
Depth _____
Representing _____

% Moisture __4.6__
% Density _____
CBR Value _____
% Swell after soaking _____
Monitor # _____

CBR DATA

_____ = _____

Remarks _____

Reported as _____ Code No. _____ By _____

By _____ Insp. Test Cost. _____ (State/District) Materials Engineer

Date _____ Debit Memo No. _____ Report No. _____

Loudoun Quarries

	Corrected	Uncorrected	
Maximum Dry Density	153.9	147.2	Percent > 3/4	9.1
Optimum Moisture	5.3	5.6	Percent < 200	7.6
Specific Gravity	3		Project No.	Various Projects

Moisture %	2.8	5.3	7.6	8
Dry Density	142.9	154	146	

SOIL MOISTURE RELATIONSHIP

Test Specification : ASTM 1557 - 91 Procedure C modified
Classification : (USCS GW-GM) (ASSHTO A-1-a)
Material :   Base Material 21 A

Date: 10/9/2015
Location: Loudoun Quarries