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Test Report Date: October 2018

MASH TEST 4-12 ON KEYED-IN SINGLE-SLOPE BARRIER WITH 40-FT SEGMENT LENGTH

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16. Abstract

The objective of this research was to determine the impact performance of a single slope barrier restrained by keying it 1-inch into asphalt pavement. The barrier was constructed with a 40-ft long segment unconnected to the adjacent barrier segment. The objective of this test was to determine if the 40-ft long keyed-in barrier segment could successfully contain and redirect an impacting vehicle. The barrier was evaluated by performing American Association of State Highway and Transportation Officials (AASHTO), *Manual for Assessing Safety Hardware* (*MASH*) Test 4-12 with a single-unit truck. *MASH* Test 4-12 involves a 10000S vehicle impacting the barrier at a target impact speed and angle of 56 mi/h and 15°, respectively.

This report provides details of the keyed-in single slope barrier with the 40-ft segment, detailed documentation of the crash test results, and an assessment of the performance of the barrier for *MASH* Test 4-12 evaluation criteria. Based on the results of the test, the keyed-in single-slope barrier with the unconnected 40-ft segment performed acceptably for *MASH* Test 4-12.

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TABLE OF CONTENTS

Page

Disclaimer ii
List of Figures x
List of Tables xi
Chapter 1. Introduction 1
1.1 Background 1
1.2 Objective 1
Chapter 2. System Details 3
2.1. Test Article and Installation Details 3
Chapter 3. Test Requirements and Evaluation Criteria 7
3.1. Crash Test Performed / Matrix 7
3.2. Evaluation Criteria 7
Chapter 4. Test Conditions 9
4.1. Test Facility 9
4.2 Vehicle Tow and Guidance System 9
4.3 Data Acquisition Systems 9
4.3.1 Vehicle Instrumentation and Data Processing 9
4.3.3 Photographic Instrumentation Data Processing 10
Chapter 5. *MASH* Test 4-12 (Crash Test No. 610221-01-1) 13
5.1 Test Designation and Actual Impact Conditions 13
5.2 Weather Conditions 13
5.3 Test Vehicle 13
5.4 Test Description 14
5.5 Damage to Test Installation 14
5.6 Vehicle Damage 16
5.7 Occupant Risk Factors 17
Chapter 6. Summary and Conclusions 21
6.1. Assessment of Test Results 21
6.2 Conclusions 21
6.3 Implementation 21
References 25
Appendix A. Details of the Keyed-In Single Slope Barrier 27
Appenidx B. *MASH* Test 4-12 (Crash Test No. 610221-01-1) 29
B1 Vehicle Properties and Information 29
B2 Sequential Photographs 31
B3 Vehicle Angular Displacements 34
B4 Vehicle Accelerations 35

LIST OF FIGURES

Page

Figure 2.1. Details of the Keyed-In Single Slope Barrier. 4
Figure 2.2. Keyed-In Single Slope Barrier prior to Testing. 5
Figure 5.1. Keyed-In Single Slope Barrier/Test Vehicle Geometrics for Test No. 610221-01-1. 13
Figure 5.2. Test Vehicle before Test No. 610221-01-1. 14
Figure 5.3. Keyed-In Single Slope Barrier after Test No. 610221-01-1. 15
Figure 5.4. Keyed-In Single Slope Barrier Asphalt after Test No. 610221-01-1. 16
Figure 5.5. Test Vehicle after Test No. 610221-01-1. 17
Figure 5.6. Interior of Test Vehicle for Test No. 610221-01-1. 17
Figure 5.7. Summary of Results for *MASH* Test 4-12 on Keyed-In Single Slope Barrier. 19
Figure B.1. Sequential Photographs for Test No. 610221-01-1 (Overhead and Frontal Views). 31
Figure B.2. Sequential Photographs for Test No. 610221-01-1 (Rear View). 33
Figure B.3. Vehicle Angular Displacements for Test No. 610221-01-1. 34
Figure B.4. Vehicle Longitudinal Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located at Center of Gravity). 35
Figure B.5. Vehicle Lateral Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located at Center of Gravity). 36
Figure B.6. Vehicle Vertical Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located at Center of Gravity). 37
Figure B.7. Vehicle Longitudinal Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located Rear of Center of Gravity). 38
Figure B.8. Vehicle Lateral Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located Rear of Center of Gravity). 39
Figure B.9. Vehicle Vertical Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located Rear of Center of Gravity) 40

LIST OF TABLES

Page

Table 3.1. Test Conditions and Evaluation Criteria Specified for *MASH* Test 4-12 for Longitudinal Barriers. 7
Table 3.2. Evaluation Criteria Required for *MASH* Test 4-12 for Longitudinal Barriers.......... 8
Table 5.1. Events during Test No. 610221-01-1.......... 14
Table 5.2. Occupant Risk Factors for Test No. 610221-01-1. 18
Table 6.1. Performance Evaluation Summary for *MASH* Test 4-12 on Keyed-In Single Slope Barrier. 23
Table B.1. Vehicle Properties for Test No. 610221-01-1. 29

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSTIONS 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 yards	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 1000L 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
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSTIONS 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	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 (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

Chapter 1. INTRODUCTION

1.1 BACKGROUND

The Pooled Fund Program stated a desire for a design of a single slope barrier restrained by keying into asphalt pavement, but with a shorter segment length than the recently tested Texas Department of Transportation's (TxDOT) single slope barrier design, which had a segment length of 75 ft (*1*).

Texas A&M Transportation Institute (TTI) previously tested a 42-inch tall single slope barrier keyed 1-inch deep into a 1-inch thick layer of asphalt pavement on the traffic and field sides of the barrier. An American Association of State Highway and Transportation Officials (AASHTO), *Manual for Assessing Safety Hardware* (*MASH*) Test 4-12 with a single-unit truck was performed on this barrier. The vehicle impacted a 75 ft long segment of the barrier and successfully contained and redirected the test vehicle (*1*, *2*). The test installation of this system was still available at the TTI Proving Ground and the Pooled Fund stated a desire to use the same installation, but test a 40-ft segment length of the barrier using *MASH* Test 4-12 evaluation criteria.

1.2 OBJECTIVE

The objective of this research was to use an existing installation of the 42-inch tall, single slope barrier keyed into asphalt, and determine the impact performance of the barrier with a segment length of 40 feet. The performance of the barrier was evaluated by performing *MASH* Test 4-12 with a single-unit truck. This test involves a 10000S vehicle impacting the barrier at a target impact speed and impact angle of 56 mi/h and 15°, respectively.

This report provides details of the keyed-in single slope barrier with a 40-ft segment length, detailed documentation of the crash test results, and an assessment of the performance of the barrier for *MASH* Test 4-12 evaluation criteria.

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Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of four collinear single slope reinforced concrete barrier segments, 42 inches tall, 8 inches wide at top, and sloping symmetrically on both sides to 24 inches wide at bottom. The total test installation length was 120 ft. The first barrier segment, which was impacted in the test, was 40 ft long. All barrier segments were sitting on unreinforced jointed-concrete pavement and keyed into a 1-inch thick asphalt overlay that was 9 ft wide on each side of the barrier. Adjacent barrier segments were not connected to each other.

Figure 2.1 presents overall information on the keyed-in single slope barrier, and Figure 2.2 provides photographs of the installation. Appendix A provides further details of the barrier.

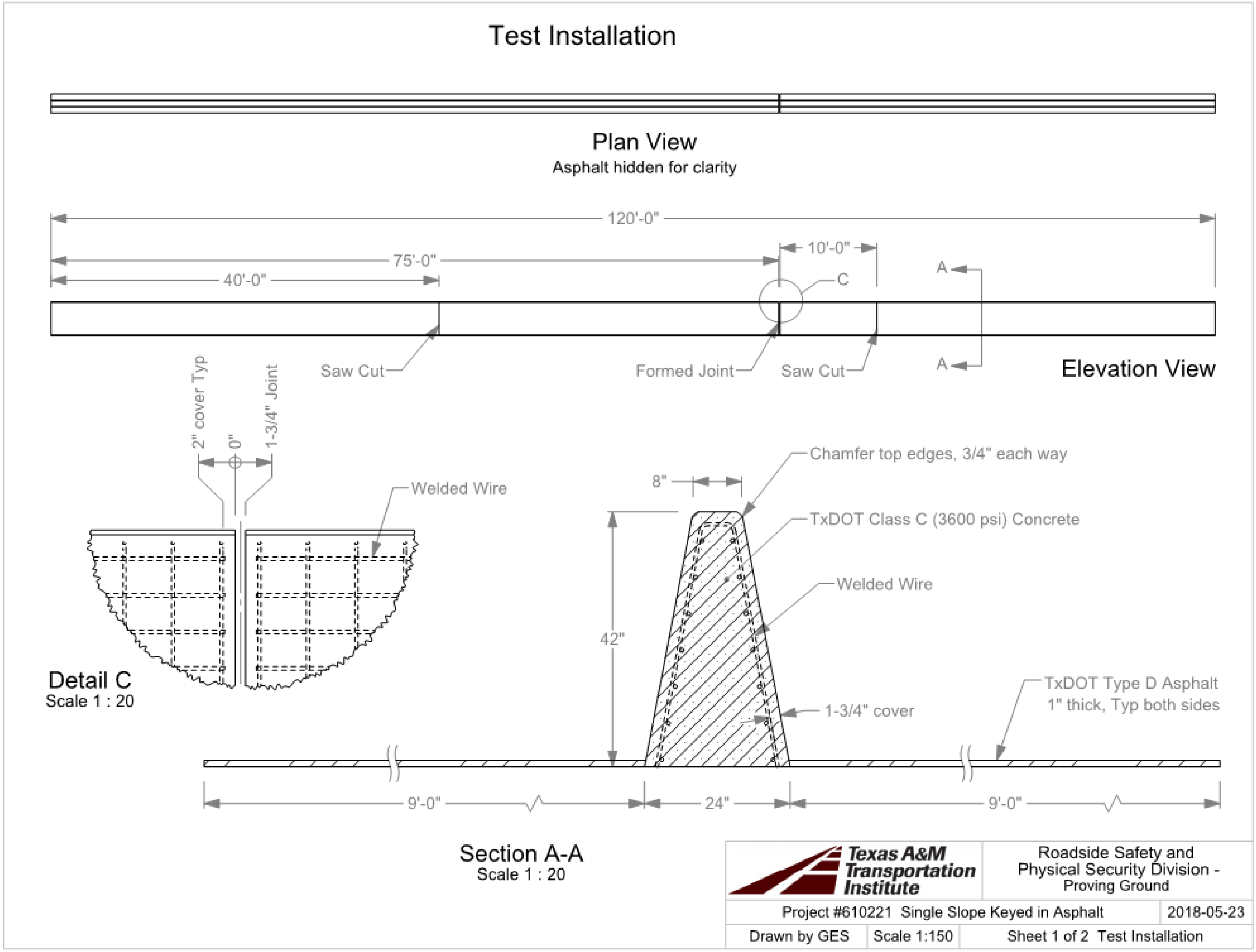

Figure 2.1. Details of the Keyed-In Single Slope Barrier.

Figure 2.2. Keyed-In Single Slope Barrier prior to Testing.

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Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST PERFORMED / MATRIX

Table 3.1 shows the test conditions and evaluation criteria for *MASH* Test 4-12. *MASH* Test 4-12 involves a 10000S vehicle weighing 22,046 lb (±660 lb) impacting the critical impact point (CIP) of the barrier at a speed of 56 mi/h (±2.5 mi/h) and an angle of 15° (±1.5°). To maximize the toppling potential and the lateral load into the 40-ft barrier segment, the target CIP was determined to be 5 ft upstream of the middle of the 40-ft segment (25 ft upstream of the joint). Information provided in *MASH* Section 2.2.1, Section 2.3.2, and Figure 2-1 were also used in determining the CIP. The crash test and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 4 presents brief descriptions of these procedures.

Table 3.1. Test Conditions and Evaluation Criteria Specified for *MASH* Test 4-12 for Longitudinal Barriers.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	4-12	10000S	56 mi/h	15°	A, D, G

3.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2A and 5-1 of *MASH* were used to evaluate the crash test reported herein. The test conditions and evaluation criteria required for *MASH* Test 4-12 are listed in Table 3.1, and the substance of the evaluation criteria in Table 3.2. An evaluation of the crash test results is presented in detail under the section Assessment of Test Results.

Table 3.2. Evaluation Criteria Required for *MASH* Test 4-12 for Longitudinal Barriers.

Evaluation Factors	Evaluation Criteria
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 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 5.2.2 and Appendix E of MASH.*
	G. It is preferable, although not essential, that the vehicle remain upright during and after the collision.

Chapter 4. TEST CONDITIONS

4.1. TEST FACILITY

The full-scale crash test reported herein was performed at Texas A&M Transportation Institute (TTI) Proving Ground, an International Standards Organization (ISO)/International Electrotechnical Commission (IEC) 17025-accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing Certificate 2821.01. The full-scale crash test was performed according to TTI Proving Ground quality procedures, and according to the *MASH* guidelines and standards.

The test facilities of the TTI Proving Ground are located on the Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 miles northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and evaluation of roadside safety hardware and perimeter protective devices. The site selected for construction and testing of the keyed-in single slope barrier was an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement, but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE SYSTEM

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site (no sooner than 2 s after impact), after which the brakes were activated to bring the test vehicle to a safe and controlled stop.

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems, Inc. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid state units designed for crash test service. The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 values per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark as well as initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units is returned to the manufacturer annually for complete recalibration and all instrumentation used in the vehicle conforms to all specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO® 2901, precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the data acquisition system receive a calibration via a Genisco Rate-of-Turn table. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are also made any time data are suspect. Acceleration data is measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k=2).

TRAP uses the data from the TDAS Pro to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals, then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact. Rate of rotation data is measured with an expanded uncertainty of ±0.7 percent at a confidence factor of 95 percent (k=2).

4.3.3 Photographic Instrumentation Data Processing

Photographic coverage of the test included three digital high-speed cameras:

- One overhead with a field of view perpendicular to the ground and directly over the impact point;
- One placed behind the installation at an angle; and
- A third placed to have a field of view parallel to and aligned with the installation at the downstream end.

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the keyed-in single slope barrier. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

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Chapter 5. *MASH* TEST 4-12 (CRASH TEST NO. 610221-01-1)

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-12 involves a 10000S vehicle weighing 22,046 lb ±660 lb impacting the CIP of the barrier at an impact speed of 56 mi/h ±2.5 mi/h and an angle of 15° ±1.5°. The target CIP for *MASH* Test 4-12 on the keyed-in single slope barrier was 5 ft upstream of the middle of the 40-ft long barrier segment (25 ft upstream of the joint) ±1 ft.

The 2013 International 4300 single-unit truck used in the test weighed 22,210 lb, and the actual impact speed and angle were 56.2 mi/h and 14.6°, respectively. The actual impact point was 24.2 ft upstream of the first joint. Minimum target impact severity (IS) was 142 kip-ft, and actual IS was 149 kip-ft.

5.2 WEATHER CONDITIONS

The test was performed on the morning of June 8, 2018. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 176 degrees (vehicle was traveling in a northerly direction); temperature: 89°F; relative humidity: 72 percent.

5.3 TEST VEHICLE

Figures 5.1 and 5.2 show the 2013 International 4300 single-unit truck used for the crash test. The vehicle's test inertia weight was 22,210 lb, and its gross static weight was 22,210 lb. The height to the lower edge of the vehicle bumper was 18.5 inches, and height to the upper edge of the bumper was 33.5 inches. The height to the ballast's center of gravity was 62.5 inches. Table B.1 in Appendix B1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 5.1. Keyed-In Single Slope Barrier/Test Vehicle Geometrics for Test No. 610221-01-1.

Figure 5.2. Test Vehicle before Test No. 610221-01-1.

5.4 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 56.2 mi/h when it contacted the keyed-in single slope barrier 24.2 ft upstream of the first joint, at an impact angle of 14.6°. Table 5.1 lists events that occurred during Test No. 610221-01-1. Figures B.1 and B.2 in Appendix B2 present sequential photographs during the test.

Table 5.1. Events during Test No. 610221-01-1.

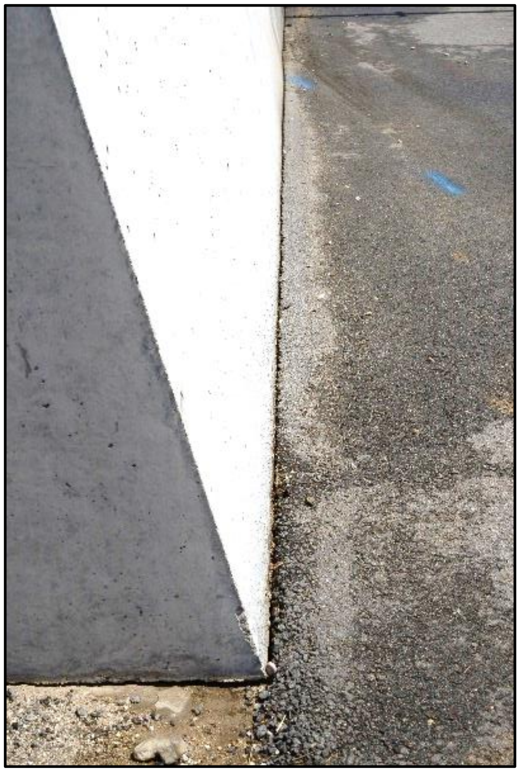
TIME (s)	EVENTS
0.000	Vehicle contacts barrier
0.046	Vehicle begins to redirect
0.104	Front right tire lifts off of pavement
0.197	Right rear tires come off of pavement
0.245	Vehicle parallel with barrier
0.248	Rear left corner of box impacts barrier
0.484	Vehicle lost contact with barrier while traveling at 52.8 mi/h
0.827	Front right tire lands back on pavement
1.311	All tires land back on pavement

5.5 DAMAGE TO TEST INSTALLATION

Figure 5.3 shows the damage to the barrier. The traffic face of the barrier was gouged 1.25 inches at impact. The downstream end of the 40-ft long impact segment was leaning toward the field side 0.75 inch at the top. Working width was 59.8 inches at a height of 112.4 inches. Maximum dynamic deflection during the test was 5.8 inches, and maximum permanent deflection was 0.75 inch.

Figure 5.4 shows the damage to the asphalt at the base of the barrier. The base of the barrier was pushed back toward the protected side leaving a ½-inch gap from the face of the barrier to the start of the asphalt. A single crack in the asphalt began on the back side of the barrier at the upstream end. The crack propagated through the asphalt to 28 inches back from the impact zone.

Figure 5.3. Keyed-In Single Slope Barrier after Test No. 610221-01-1.



Impact Side

Field Side

Field Side

Figure 5.4. Keyed-In Single Slope Barrier Asphalt after Test No. 610221-01-1.

5.6 VEHICLE DAMAGE

Figure 5. shows the damage sustained by the vehicle. The front bumper, hood, left front tire and rim, left battery box, left lower edge of cargo box, and left rear outer tire and rim were damaged. Maximum exterior crush to the vehicle was 18.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 4.0 inches in the left side kick panel area. Figure 5. shows the interior of the vehicle.

Figure 5.5. Test Vehicle after Test No. 610221-01-1.

Before Test **After Test**

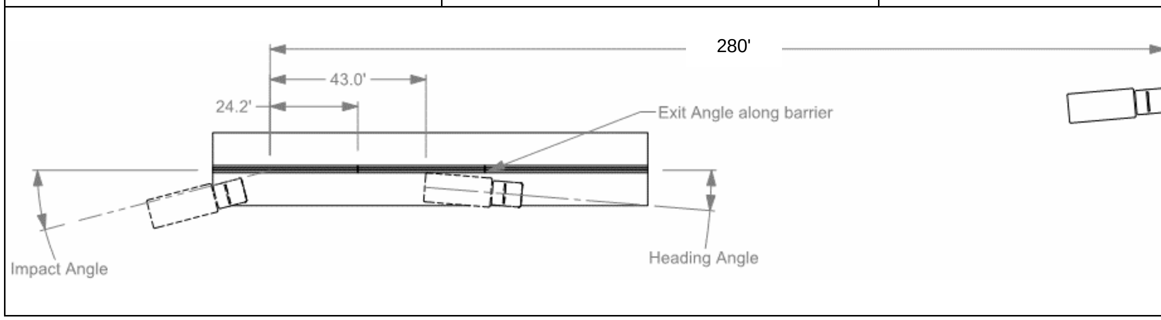
Figure 5.6. Interior of Test Vehicle for Test No. 610221-01-1.

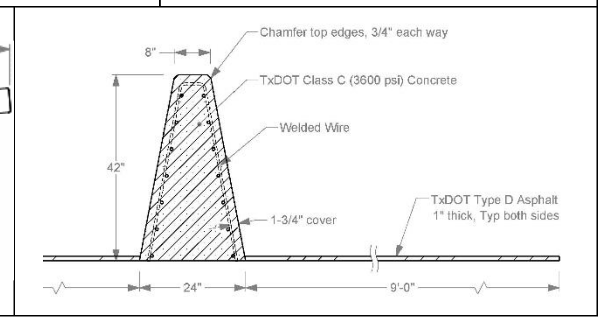
5.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for informational purposes only, and are shown in Table 5.2. Figure 5. summarizes these data and other pertinent information from the test. Figure B.3 in Appendix B3 shows the vehicle angular displacements, and Figures B.4 through B.9 in Appendix B4 show acceleration versus time traces.

Table 5.2. Occupant Risk Factors for Test No. 610221-01-1.

Occupant Risk Factors			
Occupant Impact Velocity (OIV)			at 0.1746 s on left side of interior
	x-direction	6.2 ft/s	
	y-direction	13.1 ft/s	
THIV (km/hr):		16.6	at 0.1692 s on left side of interior
THIV (m/s):		4.6	
Ridedown Accelerations (g)			
	x-direction	3.4	(0.2497 - 0.2597 s)
	y-direction	15.8	(0.2514 - 0.2614 s)
PHD (g):		15.9	(0.2513 - 0.2613 s)
ASI:		0.74	(0.2992 - 0.3492 s)
Max. 50msec Moving Avg. Accelerations (g's)			
x-direction		-1.7	(0.0075 - 0.0575 s)
y-direction		6.6	(0.2690 - 0.3190 s)
z-direction		-4.3	(0.0223 - 0.0723 s)
Max Roll, Pitch, and Yaw Angles (degrees)			
Roll		32	(0.7790 s)
Pitch		12	(0.8002 s)
Yaw		27	(1.2069 s)





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 4-12
TTI Test No.	610221-01-1
Test Date	2018-06-08

Test Article

Type	Longitudinal Barrier
Name	Keyed-In Single Slope Barrier
Installation Length	120 ft
Material or Key Elements	42 inches tall, 8 inches wide at top, sloping on both sides to 24 inches wide at bottom keyed 1 inch into asphalt
Soil Type and Condition	Asphalt Pavement, Damp

Test Vehicle

Type/Designation	10000S
Make and Model	2013 International 4300
Curb	13,250 lb
Test Inertial	22,210 lb
Dummy	No dummy
Gross Static	22,210 lb

Impact Conditions

Speed	56.2 mi/h
Angle	14.6°
Location/Orientation	24.2 ft upstream of joint
Impact Severity	149 kip-ft

Exit Conditions

Speed	52.8 mi/h
Exit Heading Angle	0.6°
Exit Trajectory Angle	4.6°

Occupant Risk Values

Longitudinal OIV	6.2 ft/s
Lateral OIV	13.1 ft/s
Longitudinal Ridedown	3.4 g
Lateral Ridedown	15.8 g
THIV	16.6 km/h
PHD	15.9 g
ASI	0.74
Max. 0.050-s Average	
Longitudinal	−1.7 g
Lateral	6.6 g
Vertical	−4.3 g

Post-Impact Trajectory

Stopping Distance	280 ft downstream 25 ft twd field side

Vehicle Stability

Maximum Yaw Angle	27°
Maximum Pitch Angle	12°
Maximum Roll Angle	32°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	5.8 inches
Permanent	0.75 inch
Working Width (Cargo Box)	59.8 inches
Height of Working Width	112.4 inches

Vehicle Damage

VDS	NA
CDC	11FLEW5
Max. Exterior Deformation	18.0 inches
OCDI	NA
Max. Occupant Compartment Deformation	4.0 inches

Figure 5.7. Summary of Results for *MASH* Test 4-12 on Keyed-In Single Slope Barrier.

Chapter 6. SUMMARY AND CONCLUSIONS

6.1. ASSESSMENT OF TEST RESULTS

The crash test reported herein was performed in accordance with evaluation criteria for *MASH* Test 4-12. A 10000S vehicle impacted the keyed-in single slope barrier with 40-ft segment at an impact speed and impact angle of 56.2 mi/h and 14.6°, respectively. An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 4-12 for longitudinal barriers is provided in Table 6.1.

6.2 CONCLUSIONS

The keyed-in single slope barrier with a 40-ft segment performed acceptably for *MASH* Test 4-12 criteria for longitudinal barriers.

6.3 IMPLEMENTATION[*]

For *MASH* TL- 4, in addition to the Test 4-12 with the single unit truck, *MASH* also requires longitudinal barriers to be evaluated with the pickup truck (Test 4-11) and the small car (Test 4-10). Both of these tests were not considered critical and were thus not performed. Under this project, the keyed-in single slope barrier with a 40-ft segment length was primarily being evaluated for its potential to contain and redirect the *MASH* single unit truck. There were concerns that under the impact from this vehicle, the barrier segment might topple or have enough lateral rotation or movement that results in the barrier being unable to contain and redirect the vehicle. The results of the crash test showed that the barrier was successful in containing and redirecting the vehicle in a very stable manner, and with minimal deflection or rotation. Testing with the small car and the pickup truck is not expected to impart greater lateral load into the barrier segment compared to the single unit truck. Thus, there are no concerns for these vehicles to topple or breach the barrier. Furthermore, in past testing, the single slope barrier has been successfully crash tested with the small car and the pickup truck vehicles under *MASH* Test 4-10 and 4-11 conditions, respectively (*3, 4*). Based on these facts, it was determined that Tests 4-10 and 4-11 of *MASH* are not critical and therefore not needed.

The 40-ft barrier segment in this project was tested keyed into 1-inch of asphalt. Using greater thicknesses of asphalt or restraining the barrier by keying it into concrete are also considered acceptable alternatives. Increasing pavement thickness and/or using concrete material increase the lateral restraint capacity of the keyed-in barrier system. These changes are not expected to negatively affect the performance of the barrier. It should, however, be noted that for *MASH* TL-4, the barrier should have a minimum 36-inch height. For this reason, the key-in design or the extent of overlays should not reduce the effective height of the barrier below 36 inches.

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[*] The opinions/interpretations in this section of the report are outside the scope of TTI Proving Ground's A2LA Accreditation.

The 1-inch asphalt layer that keyed in the test installation barrier was constructed on an existing concrete pavement. In a field installation, having the underlying concrete pavement is not a requirement. Any base material such as asphalt, road base, soil, etc. that is well compacted and stable enough to construct and compact a 1-inch think asphalt pad for keying in the barrier is expected to result in similar barrier performance.

It is sometimes desired to have drainage slots along the base of the barrier. Presence of drainage slots decreases the total length of the barrier that is keyed into asphalt, thus reducing the lateral restraint provided by the asphalt key-in. If drainage slots are desired, the length of the barrier segment should be increased so that at least 40 ft length is keyed in. As an example, if it is desired to have drainage slots that are 2 ft long, spaced 10 ft on centers, the length of the barrier segment should be increased to 50 ft so that at least 40 ft of the barrier is restrained by the asphalt.

Table 6.1. Performance Evaluation Summary for *MASH* Test 4-12 on Keyed-In Single Slope Barrier.

Test Agency: Texas A&M Transportation Institute | Test No.: 610221-01-1 | Test Date: 2018-06-08

***MASH* Test 4-12 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The keyed-in single slope barrier contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 5.8 inches.	Pass
<u>Occupant Risk</u> *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.*	No detached elements, fragments, or other debris were present to penetrate or show potential to penetrate the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 4.0 inches in the left kick panel area.	
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The 10000S vehicle remained upright during and after the collision event. Maximum roll angle was 32°.	Pass

REFERENCES

1. Bligh, R.P., Menges, W.L., and Kuhn, D.L. (2017). "*MASH* Test 4-12 of the TxDOT 42-inch Single Slope Concrete Barrier (SSCB) in 1-inch Asphalt." Texas A&M Transportation Institute, College Station, Texas.

2. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition.* 2016, American Association of State Highway and Transportation Officials: Washington, D.C.

3. Whitesel, D., Jewell, J., and Meline, R. (2018). "Compliance Crash Testing of the Type 60 Median Barrier, Test 140MASH3C16-04." Roadside Safety Research Group, California Department of the Transportation, Sacramento, California.

4. Sheikh, N.M., Bligh, R. P., and Menges, W.L. (2009). "Development and Testing of a Concrete Barrier Design for Use in Front of Slope or on MSE Wall." Report 405160-13-1, Texas A&M Transportation Institute, College Station, Texas.

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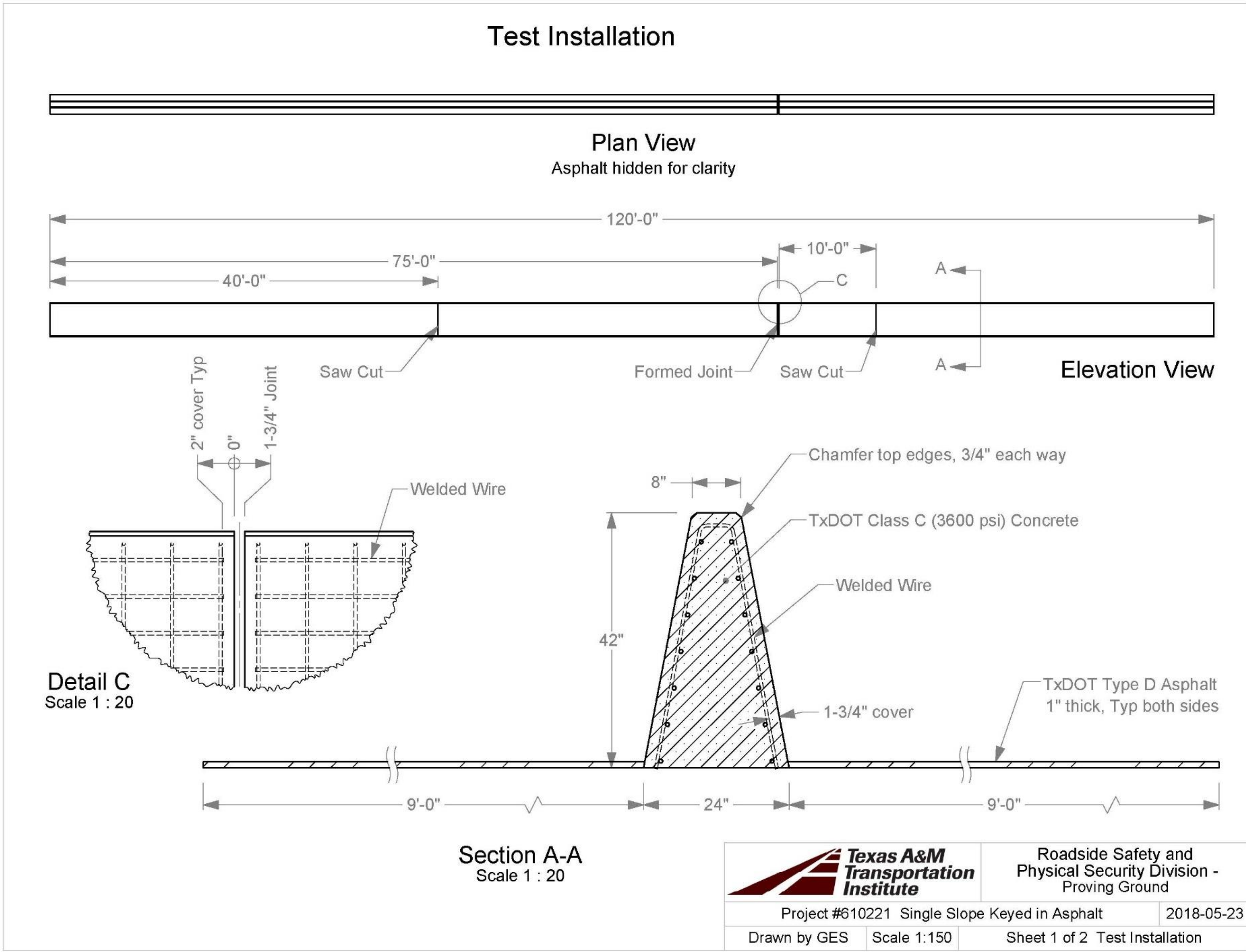
APPENDIX A. DETAILS OF THE KEYED-IN SINGLE SLOPE BARRIER



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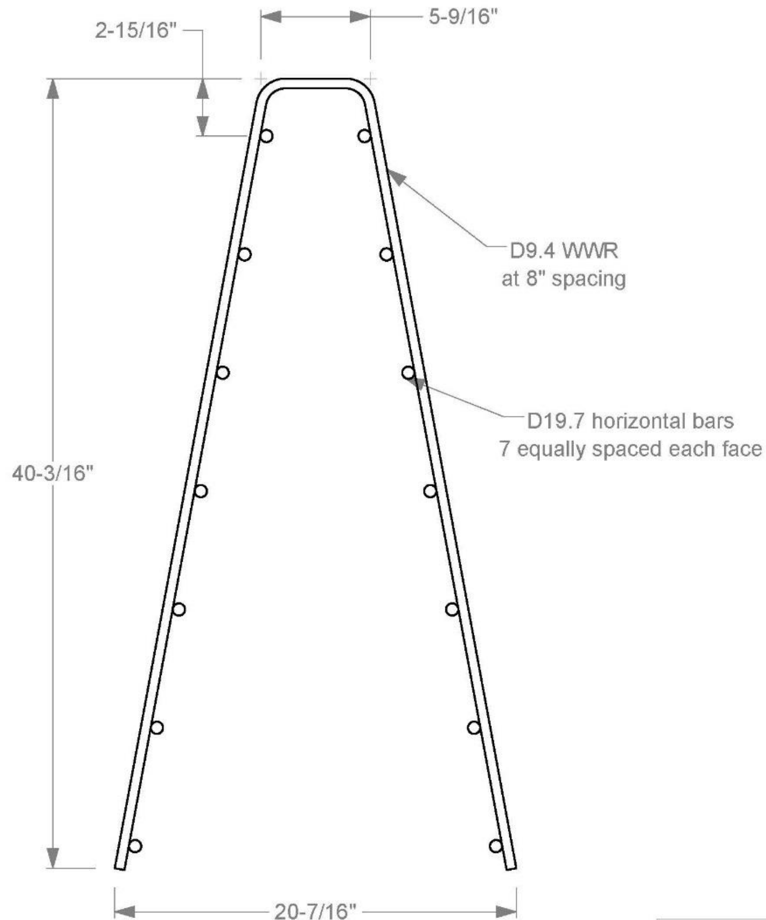
Welded Wire



Welded Wire
Grade 70

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #610221 Single Slope Keyed in Asphalt		2018-05-23
Drawn by GES	Scale 1:8	Sheet 2 of 2 Welded Wire

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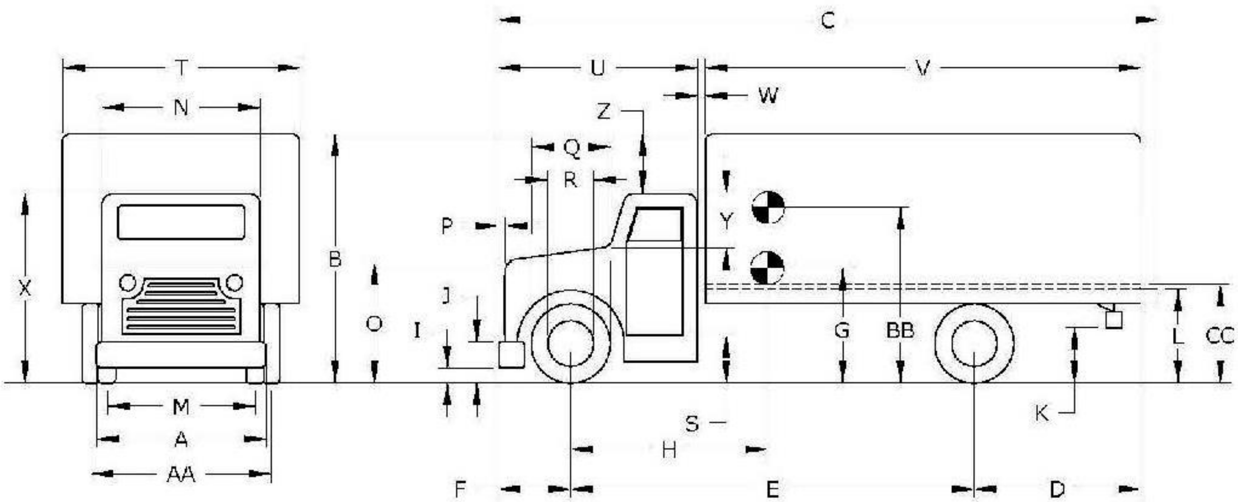
APPENIDX B. *MASH* TEST 4-12 (CRASH TEST NO. 610221-01-1)

B1 VEHICLE PROPERTIES AND INFORMATION

Table B.1. Vehicle Properties for Test No. 610221-01-1.

Date:	2018-06-08	Test No.:	610221-01-1	VIN No.:	1HTMMAAND7H156262
Year:	2013	Make:	International	Model:	4300
Odometer:	82887	Tire Size Front:	275/80 R22.5	Tire Size Rear:	275/80 R22.5



Vehicle Geometry: inches

A	Front Bumper Width:	92.00	K	Rear Bumper Bottom:		U	Cab Length:	103.50
B	Overall Height:	134.00	L	Rear Frame Top:	37.75	V	Trailer/Box Length:	214.00
C	Overall Length:	319.75	M	Front Track Width:	79.50	W	Gap Width:	2.50
D	Rear Overhang:	76.00	N	Roof Width:	72.00	X	Overall Front Height:	97.00
E	Wheel Base:	204.75	O	Hood Height:	59.00	Y	Roof-Hood Distance:	22.00
F	Front Overhang:	39.00	P	Bumper Extension:	4.00	Z	Roof-Box Height Difference:	36.00
G	C.G. Height:		Q	Front Tire Width:	40.00	AA	Rear Track Width:	73.00
H	C.G. Horizontal Dist. w/Ballast:	126.29	R	Front Wheel Width:	23.25	BB	Ballast Center of Mass:	62.50
I	Front Bumper Bottom:	18.50	S	Bottom Door Height:	37.50	CC	Cargo Bed Height:	51.00
J	Front Bumper Top:	33.50	T	Overall Width:	96.00			

Allowable Range: C = 394 inches max.; E = 240 inches max.; CC = 51 ±2 inches; BB = 63 ±2 inches above ground;

Wheel Center Height Front	18.75	Wheel Well Clearance (Front)	8.50	Bottom Frame Height (Front)	26.00
Wheel Center Height Rear	18.75	Wheel Well Clearance (Rear)	7.50	Bottom Frame Height (Rear)	27.50

Table B1. Vehicle Properties for Test No. 610221-01-1 (Continued).

Date:	2018-06-08	Test No.:	610221-01-1	VIN No.:	1HTMMAAND7H156262
Year:	2013	Make:	International	Model:	4300

WEIGHTS
lb

	CURB	TEST INERTIAL
$W_{front\ axle}$	7,150	8,510
$W_{rear\ axle}$	6,100	13,700
W_{TOTAL}	13,250	22210

Allowable Range for CURB = 13,200 ±2200 lb | Allowable Range for TIM = 22,046 ±660 lb

Ballast: 8,960 lb **(as-needed)** **(See *MASH* Section 4.2.1.2 for recommended ballasting)**

Mass Distribution
lb

LF:	RF:	LR:	RR:
4370	4140	6780	6920

Engine Type: DT
Engine Size: 466

Transmission Type:
☑ Auto or ☐ Manual
☐ FWD ☑ RWD ☐ 4WD

Accelerometer Locations inches

	x[1]	y	z[2]
Front:	126.25	0.00	50.00
Center:	226.25	0.00	50.00
Rear:			

Describe any damage to the vehicle prior to test:

Other notes to include ballast type, dimensions, mass, location, center of mass, and method of attachment:

2 BLOCKS H 30" W 60" L 30"

TIED DOWN WITH 4 5/16 CABLES PER BLOCK

CENTERED IN MIDDEL OF BLOCK

[1] Referenced to the front axle
[2] Above ground

B2 SEQUENTIAL PHOTOGRAPHS

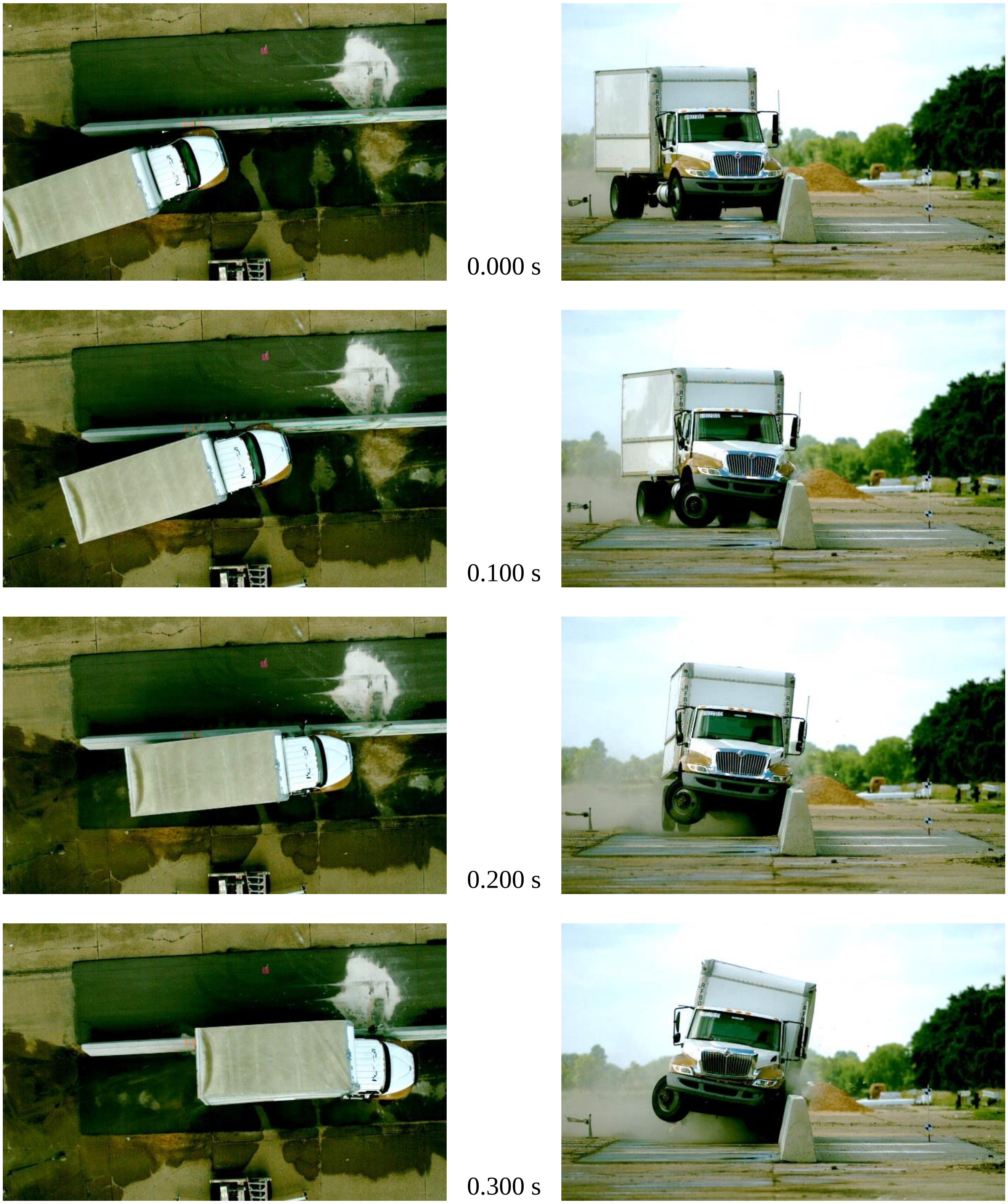
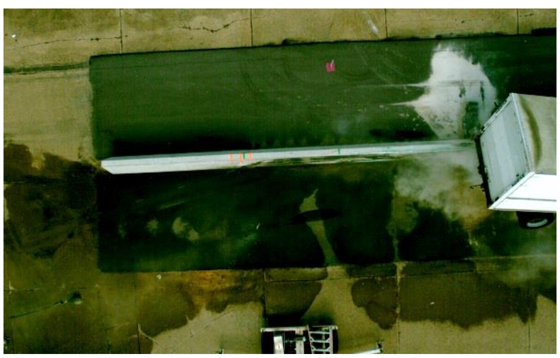


Figure B.1. Sequential Photographs for Test No. 610221-01-1 (Overhead and Frontal Views).

0.400 s

0.500 s



0.600 s

0.700 s

Figure B.1. Sequential Photographs for Test No. 610221-01-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

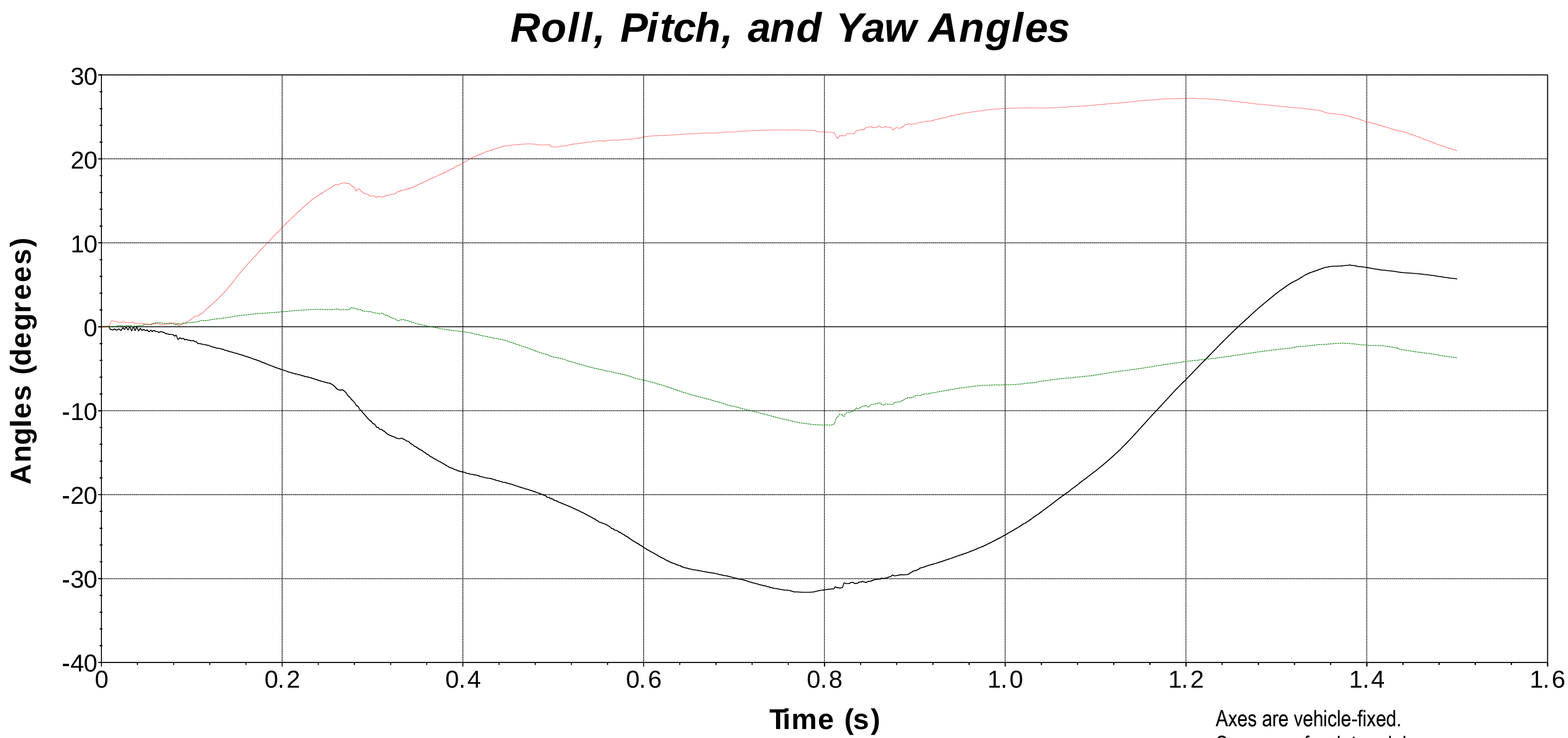
0.400 s

0.500 s

0.600 s

0.700 s

Figure B.2. Sequential Photographs for Test No. 610221-01-1 (Rear View).



Test Number: 610221-01-1
Test Standard Test Number: MASH Test 4-12
Test Article: Keyed-In Single Slope Barrier
Test Vehicle: 2013 International 4300 Single Unit Truck
Inertial Mass: 22,210 lb
Gross Mass: 22,210 lb
Impact Speed: 56.2 mi/h
Impact Angle: 14.6°

Axes are vehicle-fixed.
Sequence for determining orientation:

1. Yaw.
2. Pitch.
3. Roll.

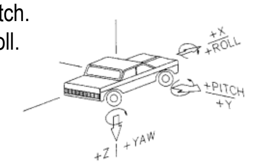


Figure B.3. Vehicle Angular Displacements for Test No. 610221-01-1.

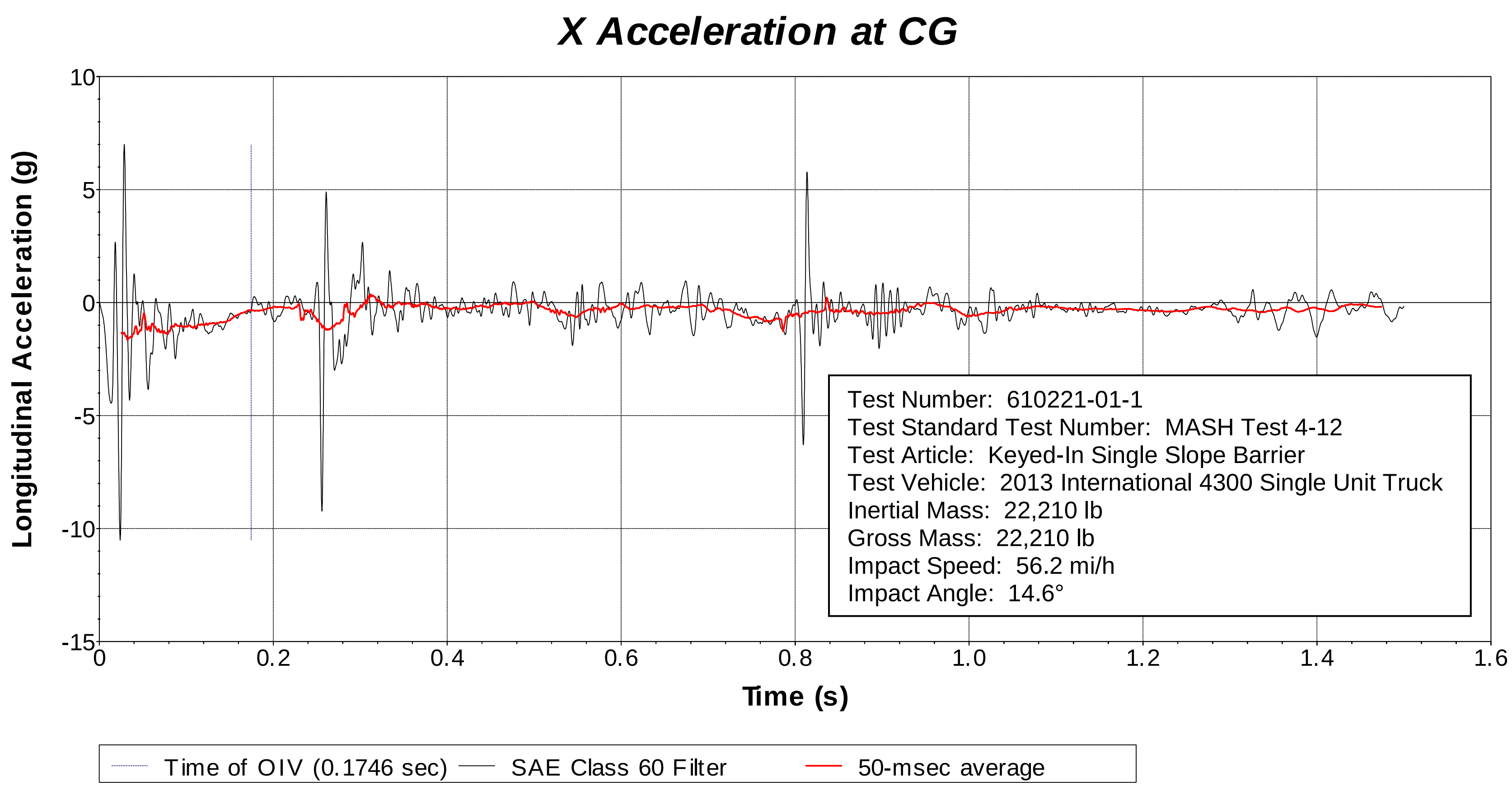


Figure B.4. Vehicle Longitudinal Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located at Center of Gravity).

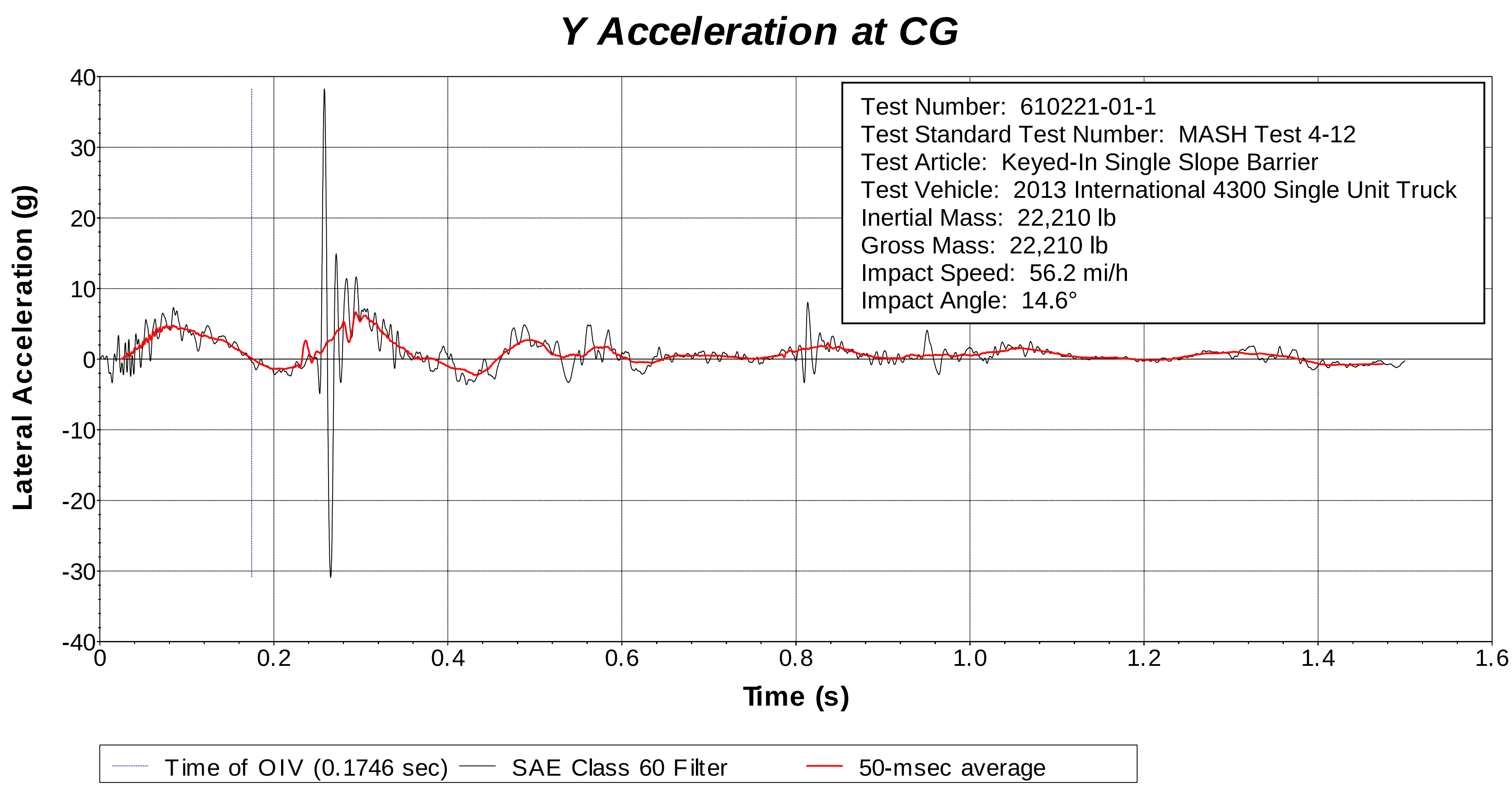


Figure B.5. Vehicle Lateral Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located at Center of Gravity).

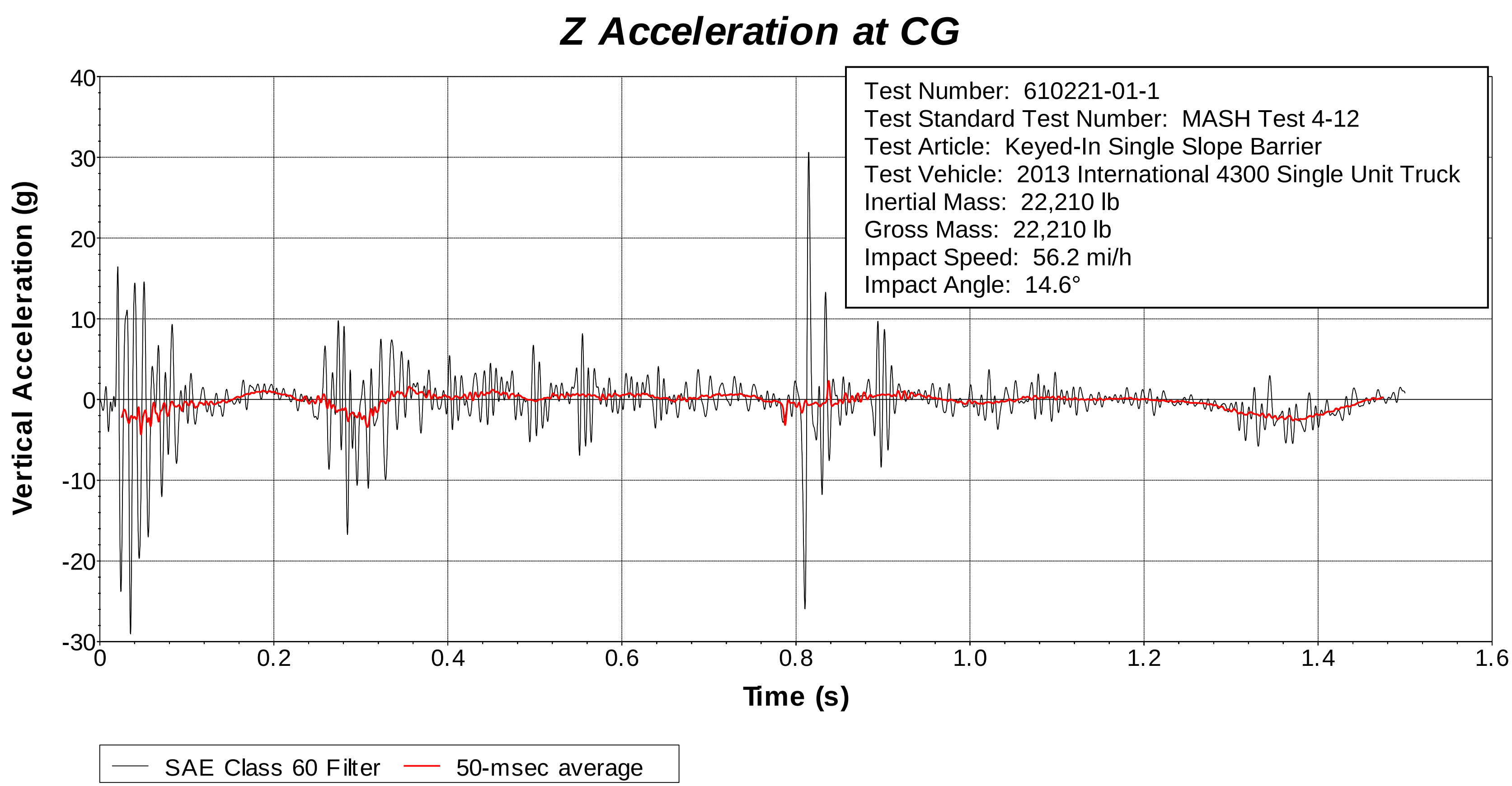


Figure B.6. Vehicle Vertical Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located at Center of Gravity).

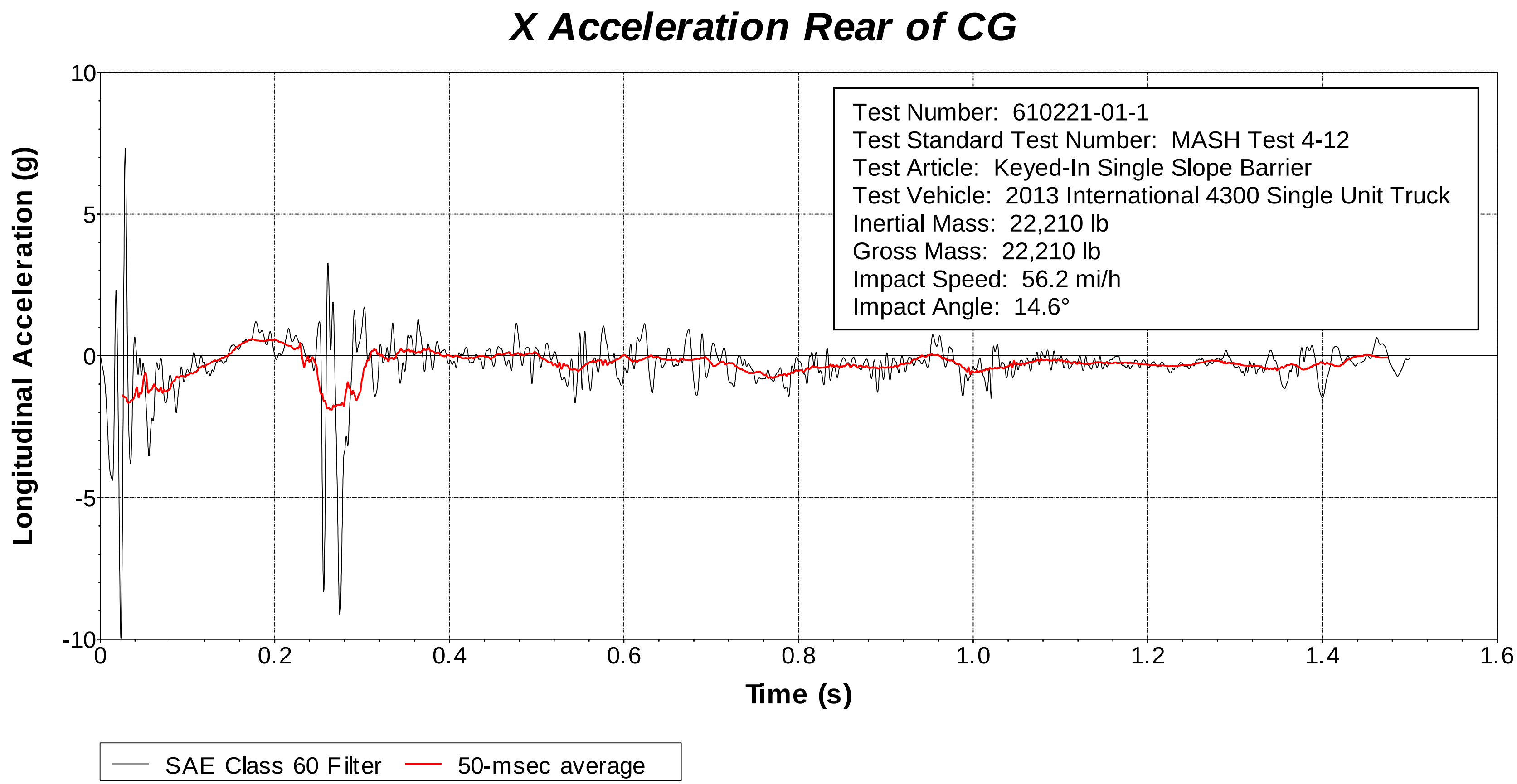


Figure B.7. Vehicle Longitudinal Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located Rear of Center of Gravity).

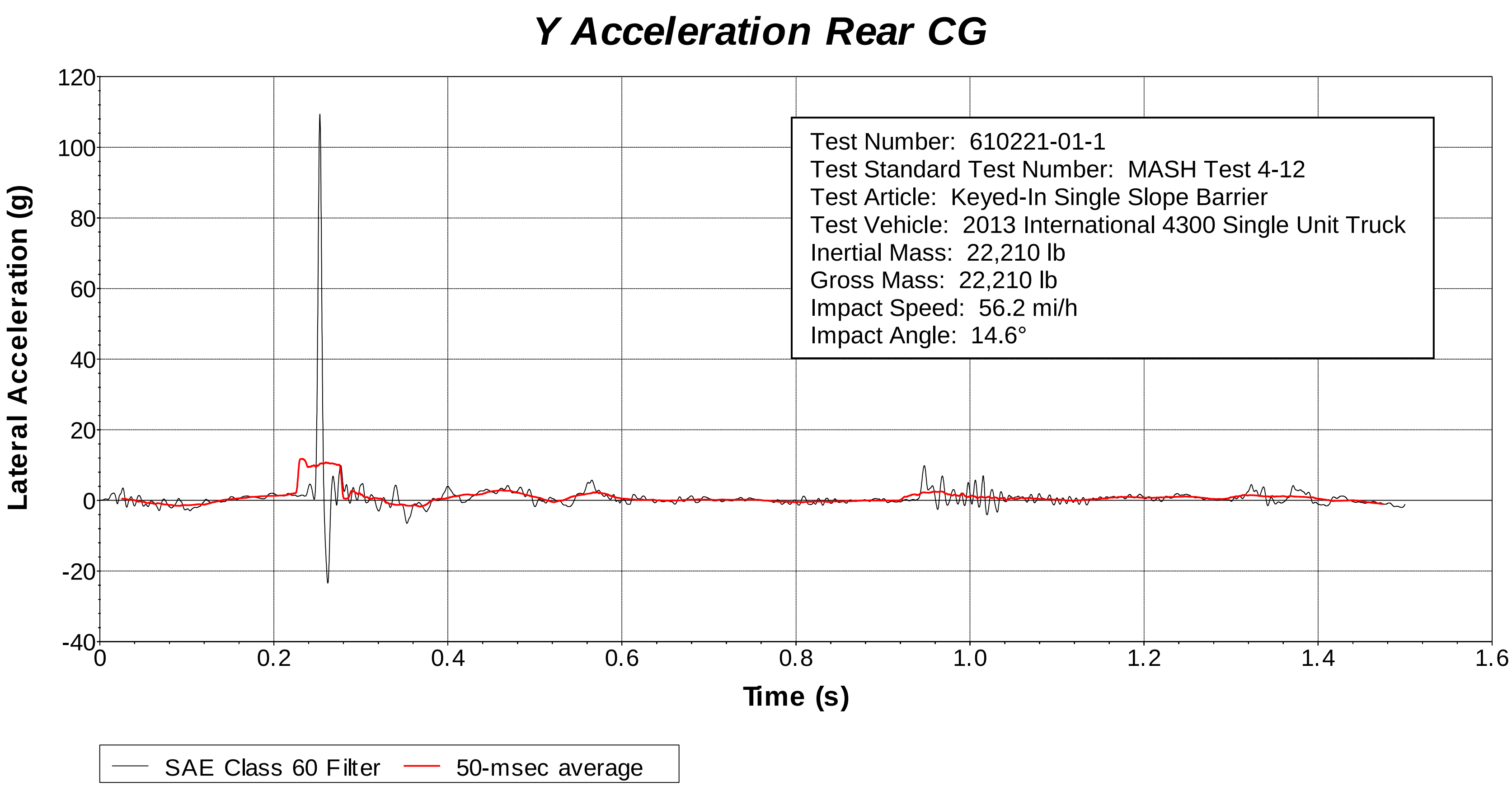


Figure B.8. Vehicle Lateral Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located Rear of Center of Gravity).

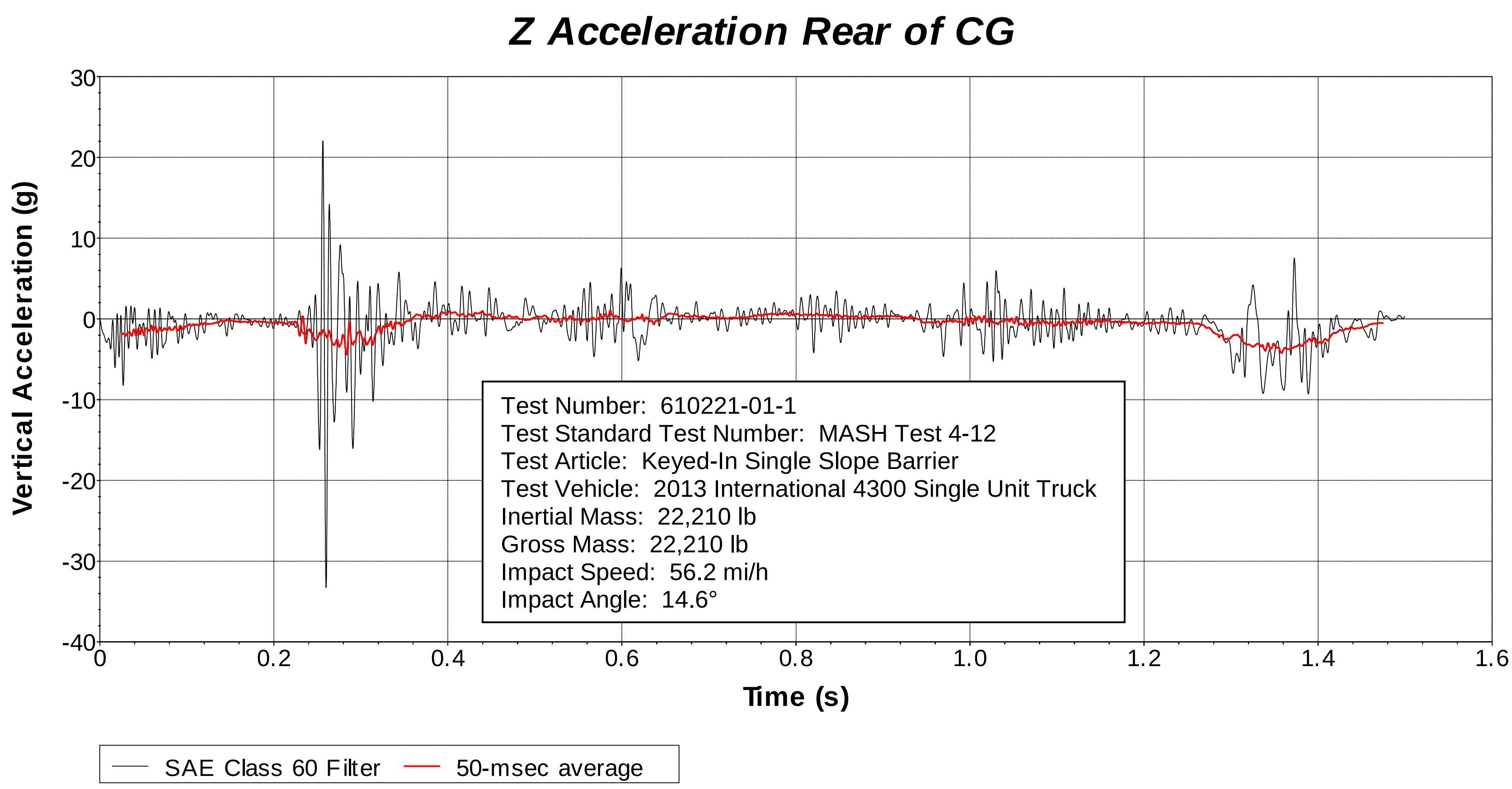


Figure B.9. Vehicle Vertical Accelerometer Trace for Test No. 610221-01-1 (Accelerometer Located Rear of Center of Gravity)